AN ABSTRACT OF THE THESIS OF

Shweta Keshari for the degree of
Master of Science in
Civil Engineering presented
on December 3, 2009.
Title: Effect of Constituent Materials and Curing Methods on the Abrasion Resistance and Durability of High Performance Concrete for Pre-Cast Pre-Stressed Bridge Deck Slabs.

Abstract approved:

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This thesis is the consequence of a research effort undertaken by the School of Civil and Construction Engineering at Oregon State University and funded by the Oregon Department of Transportation (ODOT) and the Federal Highway Administration (FHWA). The principal objective of the effort was to reduce the life cycle cost of bridges by developing one or more materials systems for precast and pre-stressed bridge deck components that improve the studded tire wear (abrasion) resistance and durability of bridge decks.

Degradation of the concrete bridge decks due to abrasion caused by the studded tires and accelerated corrosion of the reinforcing steel in the concrete often triggers costly, premature rehabilitation or replacement of these bridges. High performance concrete (HPC) can provide improved abrasion resistance, but is more costly than ordinary concrete and can exhibit early age cracking when used for cast-in-place concrete members, which can accelerate corrosion of embedded reinforcing steel. However, several studies have suggested that HPC developed for precast members offers a viable alternative to cast-in-place concrete deck slabs due in part to improved control of the curing process.

The scope of this research was to develop one or more mixture designs for HPC that improve the durability and abrasion resistance of the bridge decks through careful selection and proper proportioning of the constituent materials and improved control of the curing process. The materials investigated in this research included silica fume, slag, and fly ash as partial replacement of Type I and Type III portland cement mixed with crushed aggregate and river gravel. Phase I of the study included development of 15 mixture designs incorporating various combinations of the materials. Mixtures were cast under controlled laboratory conditions and cured using a variety of methods. The results of tests conducted on the cured samples indicated that the mixture with silica fume and slag had greater strength than the mixture with silica fume and fly ash mixture, and that mixtures with crushed rock provided better abrasion resistance than those with river gravel. Results from the chloride ion penetration test for permeability indicated that mixtures cured in saturated lime water for 28 days exhibited reduced permeability in comparison to mixtures which were steam cured followed by ambient curing.

Following phase I, a pilot study was undertaken to identify the best curing method to apply during production at precast yards to assist high early strength gain so that the concrete member can be removed from the casting bed in a matter of several hours as well as to facilitate high ultimate strength, improved abrasion resistance, and low permeability. The pilot study indicated the best curing method to be steam curing followed by application of a curing compound.

Phase II of the research study included seven mix designs and focused on various levels of supplementary cementitious materials. It adopted the curing method suggested by the pilot study. Results from phase II indicated that slag was better in enhancing durability of the concrete than fly ash. Increasing the proportion of silica fume did not improve the properties of high performance concrete significantly.

Some other interesting results indicated that compressive strength was inversely proportional to wear rate and chloride ion penetration. Wear rate was directly proportional to chloride ion penetration. There was no relationship between durability factor (freeze-thaw test) and compressive strength or chloride ion penetration.

Two mixtures were identified as having significantly improved abrasion and permeability characteristics over the control mixture (ODOT bridge deck mixture). Both included slag and silica fume as supplementary cementitious materials as a partial replacement of portland cement and one did not contain an air entraining admixture.

Effect of Constituent Materials and Curing Methods on the Abrasion Resistance and Durability of High Performance Concrete for Pre-Cast Pre-Stressed Bridge Deck Slabs

by

Shweta Keshari

A THESIS

submitted to

Oregon State University

in partial fulfillment of

the requirements for the

degree of

Master of Science

Presented December 3, 2009

Commencement June 2010

Master of Science thesis of Shweta Keshari presented on December 3, 2009.

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Shweta Keshari, Author

ACKNOWLEDGEMENTS

Firstly, I would like to thank God for all His blessings and my parents, Dr. G.C. Keshari and Mrs. Rita Lal for bringing me to life and teaching me to take baby steps towards success with patience and perseverance. I would like to thank my husband, Subrat Sahu for his unflinching faith on me and his ever-enthusiastic encouragement to go one more step farther in pursuit of excellence in professional as well as personal life. I would like to take this opportunity to express my gratitude to my in-laws, my younger brothers, Siddharth and Saurav, my friend Nirjharini Sahoo, and my all other friends and relatives. Without their love and support, I would not have reached so far in life.

Now standing at the doorstep of reaching a career milestone and setting the next one, as I reflect on my past in quest for the defining moment which transformed my career and my life, it is my introduction to and my association with Dr Todd V. Scholz that stands out conspicuously. I would like to quote Dan Rather who says “The dream begins with a teacher who believes in you, who tugs and pushes and leads you to the next plateau.” I had also read somewhere “A good teacher is like a candle; it consumes itself to light the way for others.” I have held these sayings dear to my heart; these sayings have been so true in my life and Dr. Todd is the physical embodiment of the “teacher” these sayings refer to. I take this opportunity to express my heart-felt gratitude to Dr. Todd who has been my mentor, my advisor, and my source of inspiration.

I would also like to thank my professors Dr. John A. Gambatese, Dr. David N. Sillars, Dr. Jason Ideker for their allowing me to grow under their tutelage. I would like to thank Dr. Ping-Hung Hsieh for his consent to be my minor advisor and Dr. John Sessions for his consent to be the Graduate Council Representative of my thesis defense committee.

I thank the Oregon Department of Transportation and the Federal Highway Administration and their technical advisory board for funding this project.

I would also like to thank Mr. James Batti and Mr. Manfred Dittrich for their help and support in the research laboratory.

I take this opportunity express my gratitude to all my friends at the Oregon State University for being there in my life and making my life lively. I specially thank Indu Peruri, Pratheeksha Premraj, and Suraj Darra for their unconditional support, love and affection.

Finally, I would like to thank God again for everything in life

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1 INTRODUCTION

Studded tires have been attributed to pervasive pavement wear in the winter dominated United States and other countries since their introduction in 1960s. Studded tires cause considerable wear to concrete surfaces, even when the concrete is of good quality. The ruts caused by the studs lead to the reduced pavement life and increasing pavement life cycle cost. The design life expectancy based on a limiting wheel path rut depth of 19 mm, at which the pavement would require rehabilitation, for asphalt and portland cement concrete (PCC) pavements is 14 years and 25 years respectively. The time to reach a 19 mm rut for an asphalt pavement exposed to studded tires at 35,000 ADT is about 7 years and for PCC pavements exposed to studded tires at 120,000 ADT, the estimated time to reach a 19 mm rut is less than 10 years. The pavement wear rate has been increasing alarmingly with the increased adoption of studded tire use among the populace exposed to snowy driving conditions. The studded tires do provide increased traction and safety in winter driving conditions; but the ruts, after attaining the critical depth, present themselves as a safety hazard by causing increase in splash and spray, and hydroplaning during rainy driving conditions. The rehabilitation of highways with ruts attaining critical depth becomes imperative to ensure driving safety. The estimated annual cost for increased pavement wear attributed to use of studded tire in the state of Oregon has increased from $1.1 million in 1974 to $42 million in 1994, and this trend continues [1]. At present, the debate to ban the use of studded tires at the cost of safety during long winter driving conditions in states like Oregon has not reached any conclusion. The researchers in industry and academia have only one option at present; and that is to explore the possibilities of concretes of higher strength for pavement construction.

1.1 Background

Degradation of the concrete decks from wear and corrosion (due to permeable mixture) due to the studded automobile tires require costly, and often premature, replacement or rehabilitation of many of ODOT's bridges. The damage caused by studded tires is due to the dynamic impact of the small tungsten carbide tips of the studs, of which there are approximately 100 in each tire [2]. Efforts have been made to study the properties of existing concrete as related to studded tire wear and develop more wear-resistant types of concretes. Although the reported research results show promise, no affordable concrete has yet been developed that will provide the same service life of the pavements exposed to studded tires as compared to pavements made of existing concrete and exposed to un-studded rubber tires.

Polymer cement concrete and polymer-fly ash concrete provide better resistance to wear at the cost of skid resistance. Steel fiber concrete provides better wear resistance, but abraded loose steel fibers can cause additional scour of the concrete pavement, and the exposed fibers can adversely affect the tire wear [2]. High Performance Concrete (HPC) is intended to meet the design engineer's minimum requirements for compressive strength and to enhance the long-term properties of the concrete such as durability, abrasion resistance, low permeability to protect against corrosive-ion attack on reinforcing steel, and cracking resistance. It is well known that adding approximately 7% silica fume to the concrete significantly increases the strength and reduces the permeability of the concrete. However, real-life experiences reveal that this improvement often comes with an increased propensity for early-age cracking in the cast-in-place (CIP) bridge decks that essentially negates the benefits of lower permeability and high strength. In fact, ODOT has changed its bridge deck concrete specifications to limit the strength of the concrete in order to reduce the level of cracking seen in the field. Precast components allow bridge elements to be manufactured under controlled factory conditions, which should provide a higher level of quality. Also, prefabricated components can be assembled more quickly at a bridge site without the need to wait for fresh concrete to reach threshold strengths before continuing construction activities. Precast deck panels could allow HPC designed for abrasion resistance to be used for bridge decks while maintaining production controls to minimize cracking.

This study strives to develop one or more materials systems for precast and pre-stressed bridge deck components that improve the studded tire wear (abrasion) resistance and durability of bridge decks.

1.2 Purpose

The overall purpose of this project was to develop one or more materials systems for precast and pre-stressed bridge deck components that would reduce the life-cycle cost of bridges by improving the studded tire wear (abrasion) resistance and the durability of bridge decks. Specifically, the experiment objectives are to:

- Develop a hardened concrete mixture that is more resistant to abrasion than a conventional ODOT bridge deck mixture.
- Develop a hardened concrete mixture that is more resistant to chloride ion penetration than a conventional ODOT bridge deck mixture.

1.3 Scope

The scope of the project was to conduct an extensive literature review to investigate past research on HPC with emphasis on abrasion and corrosion resistance followed by a laboratory study to develop such a mixture for Oregon in phase I of the research study through investigation of factors including 1) varying combinations of supplementary cementitious materials (i.e., silica fume plus slag versus silica fume plus fly ash); and 2) two different coarse aggregate types (i.e., crushed versus natural aggregate). Mixtures were tested following water curing and steam curing. Different curing types were investigated in a pilot study to obtain the best curing method that could be adopted in the field and at the same time give results similar to that obtained by water curing. All the samples were tested for various response variables (i.e., compressive strength test, abrasion test, rapid chloride penetration test RCPT test and freeze and thaw test). Phase II focused more on various levels of silica fume and their effect on the properties of HPC . All the mixtures were tested for the same response variables in the phase II except for freeze-thaw test.

2 LITERATURE REVIEW

The contents and findings of the literature review has been obtained from various sources including reports from NCHRP projects 12-65 and 12-69 (mentioned above), the Transportation Research Information Services (TRIS) database, the National Technical Information Service (NTIS) database, the International Transport Research Documentation (ITRD) database, Transportation Research Board (TRB) journals, American Concrete Institute (ACI) publications, Portland Cement Association (PCA) publications, American Concrete Pavement Association (ACPA) publications, and reports from other states (e.g., California, Nevada, Texas, Nebraska, Ohio, Maryland, and New York) that have investigated abrasion-resistant concrete and/or use of precast concrete panels for concrete pavement rehabilitation. The experiences gained from the ODOT, Region 4 Mill Creek project is also included as part of the literature review.

2.1 High Performance Concrete

An extensive amount of research has been undertaken to develop high performance concrete (HPC), as well as sustainable concrete. According to ACI, "HPC is defined as a concrete meeting special combination of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing, and curing practices" [3]. It is a concrete consisting of special properties designed depending on the requirements of the structure. A normal strength concrete having properties such as high durability and low permeability can be called a HPC. These requirements may involve enhancements of the following:

- Ease of placement and completion without segregation
- Long-term mechanical properties
- Early-age strength
- Toughness
- Volume stability
- Long life in severe environments

2.2 Characteristics of HPC

The structural and construction requirements of the structure must be met by the concrete to be used. Both early age and long-term strength are critical characteristics for HPC. Specified design strengths of 8,000 psi or more for 28 day strength are defined as high strength concrete. This designation was made in 2002, by the ACI Committee on High Strength Concrete [3]. HPC must be designed to provide long service life in severe environments [3]. Accordingly, the concrete must be able to provide protection against abrasion, weathering action, and chemical attack. A high early strength mixture is used for fast track paving. "An example of a fast track concrete mixture used for a bonded concrete highway overlay would be 380 kg of type III cement, 42 kg of type C fly ash, 6 ½% air, a water reducer and a w/c ratio of 0.4" [4]. The NCHRP-12-65 report was reviewed and the compressive strength specified for the precast concrete deck panels at 28 days was kept as 6200 psi to 6500 psi. [3]. Also, the Minnesota Department of Transportation (Mn/DOT) has specified a minimum compressive strength of 6500 psi for the inverted-t precast section (deck slab) [4]. HPC also requires a high modulus of elasticity greater than 6,500,000psi (44816 MPa).

It should have high durability capable of withstanding corrosion of embedded steel and other severe service environments. The other structural characteristics include high abrasion resistance, volume stability and toughness and impact resistance. The concrete must be able to withstand the effects of various agents such as heating and cooling, wetting and drying, freezing and thawing etc. This again differs depending on where the structure is being constructed and the environmental factors affecting it. HPC must be capable of inhibiting bacterial and mold growth. It also needs to be resistant to frost and chemical attack.

The concrete mixture must be constructible i.e. it should be workable, pump-able and easily consolidated within the confines of any steel or fiber reinforcements. To achieve these properties a mid-range concrete should have a 6 to 8 inch slump. A flowing concrete should have a slump greater than 8 inches without segregation. It should also posses reduced pumping pressures and easy finishing characteristics. HPC should have normal setting time, accelerated strength gain and low temperature freeze protection to be placeable in cold weather. It should have normal slump retention and control of hydration to be placeable in hot weather. In order to achieve controlled hydration it should have extended setting time as required by the project conditions.

2.3 Constituent materials

High performance concrete constitutes various materials like cement, supplementary cementitious materials, both fine and coarse aggregates and admixtures which reduces the water requirement considerably. This section mainly furnishes a detailed overview of ingredients of concrete.

2.3.1 Cement

The rate of early strength development depends on cement composition and other factors such as cement fineness, use of supplementary cementitious materials, curing temperatures, admixtures, w/c ratio and curing conditions. “For high strength concrete, cement should produce approximately minimum 7-day mortar cube strength of approximately 4350 psi (30 MPa)” [4].

Portland cement is manufactured to conform to ASTM C 150- 07 specifications which designates five types: I (and IA), II (and IIA), III (and IIIA), IV, and V.

2.3.1.1 Type I Cement

Type I cement or normal portland cement is general purpose cement which is suitable for most of the construction practices except for that where some special properties are needed. It is used in pavements, bridges, reinforced concrete buildings, culverts, reservoirs, water pipes, etc.

2.3.1.2 Type II Cement

This is used where moderate sulfate resistance is required or for structures exposed to seawater. This is also used where moderate heat of hydration is required as in mass concrete, dams, large piers, heavy retaining walls and abutments. Type IIA is an air entraining cement used when the air entrainment is desired for the same uses as Type II cement. Some cement are specified as Type I/Type II, indicating that the cement meets the requirements of the indicated types and is being offered as suitable for use when either type is desired.

2.3.1.3 Type III Cement

This is used when high early strength is desired as in early removal of forms for cast-in-place concrete, precast concrete, and slip formed concrete. It is beneficial in cold weather conditions because of its faster rate of hydration, and hence faster rate of strength gain. Type IIIA is an air entraining cement used when air entrainment is desired for the same uses as Type III cement.

2.3.1.4 Type IV cement

This is used when low heat of hydration is desired in massive structures such as large gravity dams, where the temperature rise resulting from heat generated during curing is a critical factor. It develops strength at a slower rate than Type I cement.

2.3.1.5 Type V cement

Type V is sulfate-resisting cement used only in concrete exposed to severe sulfate attack as with soils or ground water having high sulfate content. It develops strength at a slower rate than Type I cement.

2.3.2 Blended cements

There are five classes of blended cements specified under ASTM specification C 595-05[5]:

- Portland blast furnace slag cement (Type IS)
- Portland- pozzolan cement (Type IP and Type P)
- Pozzolan-modified portland cement (Type I (PM))
- Slag cement (Type S)
- Slag-modified portland (Type I (SM))

Slag cement develops strength very slowly. Portland pozzolan cement includes four types (IP, IP-A, P and P-A) of which P and P-A are used when high early strength is not required. All the other blended cements can be used for general construction purposes.

2.3.3 Supplementary Cementitious Materials

Various cementitious materials such as fly ash, silica fume, slag, calcined clay, calcined shale, etc. have been used in HPC to produce high strength. The following paragraphs describe these materials in more detail.

2.3.3.1 Fly Ash

Fly ash is the fine material that results from the combustion of pulverized coal in a coal-fired power plant. Fly ashes are classified in ASTM C 618-05 [7] as either Class F or Class C. Class F fly ash has pozzolanic properties. Class C fly ash has pozzolanic and cementitious properties. The Class C fly ash content of concrete generally ranges from 15 to 40 percent by mass of the cementitious materials, and Class F fly ash content ranges from 15 to 25 percent by mass of cementitious material [4]. Class C fly ash has more calcium content than Class F fly ash. Class F ashes generally improve sulphate resistance more efficiently than Class C ashes [8]. Fly ash reduces permeability and chloride diffusivity and hence increases resistivity to chloride ion attack, making it a beneficial material in concrete that is exposed to chlorides (e.g., bridge decks) [9]. Fly ash also binds up the alkalis in the concrete and, thereby, reduces the potential for alkali silica reactivity. The addition of fly ash to concrete enhances the strength gain at later ages, making it beneficial when high-strength concrete is specified at ages of 56 or 90 days.

Nasser and Lai [10] found that 20% replacement of cement with Class C fly ash containing 4 to 6% air content improves the resistance to freezing and thawing. However, it was found to decrease when 35-50% of Class C fly ash was used in concrete containing 6% air. For high strength concrete, use of Class C fly ash can lead to higher 28 day and 91 day compressive strengths and higher 7-day and 28-day flexural strengths at lower cementitious contents as compared with concrete containing no fly ash [11]. According to Naik et al [12], concrete incorporating Class C fly ash offers more abrasion resistance than Class F fly ash concrete with 35% cement replacement. In another study [13], it was found that concrete abrasion resistance was not greatly influenced by inclusion of Class C fly ash with 40% of total cementitious materials. A slight decrease in the abrasion resistance of high volume fly ash concrete, especially at fly ash content above 50%, was noted as compared to the reference mixture without fly ash. Rafat Siddique [14] in his study concluded that Class F fly ash can be suitably used with 50% of cement replacement in concrete for use in pre-cast elements and reinforced cement concrete construction.

In summary, fly ash produces the following properties in concrete as compared to a similar mixture containing no fly ash: (1) equal or greater flexural and compressive strengths; (2) equal or better workability and cohesiveness; (3) equal or greater resistance to abrasion; and (4) improved long term durability to provide serviceability and performance throughout the life of the structure [11]. It also improves workability, decreases bleeding, reduces heat evolution, decreases permeability, has minimal effect on modulus of elasticity, and has variable effects on creep and shrinkage.

Fly ash may be used as a partial replacement for or an addition to portland cement. Its performance however depends upon the quality and performance of the other constituents of the mixture. In a mix design a minimum quantity of Portland cement is required to maintain early strength, setting times etc. Fly ash can be used in addition to improve the workability, strength, and durability of the concrete mixture.

2.3.3.2 Silica Fume

Silica fume, also known as condensed silica fume or microsilica, is a very fine pozzolanic material produced as a by-product in the production of silicon or ferro-silicon alloys. The silica fume content of concrete generally ranges from 5 to 10 percent of the total cementitious materials content [4]. It should conform to the requirements in ASTM C 1240-05[15]. Silica fume increases the durability of concrete by reducing the permeability, thereby slowing the rate of penetration of aggressive chemicals such as deicing salts. The use of silica fume can result in rapid chloride permeability values of less than 500 coulombs when tested in accordance with ASTM C 1202-10 (Rapid Chloride test) whereas a maximum value of 1000 coulombs is often specified *[2]*. Whiting and Detwiler (1998) observed that increasing the silica fume content up to approximately 6% of the total cementitious materials reduced the chloride diffusivity. However, above approximately 6%, a much greater addition of silica fume was needed to effect the same change [16]. Silica fume can make a significant contribution to early-age strength of concrete and affects the interfacial transition zone by making it dense, reducing pore size and its percentage in concrete. Silica fume increases the water demand of the concrete. The use of fly ash and slag counteracts the water demand created by the silica fume. The use of silica fume is particularly beneficial in achieving high early strengths and ultimate compressive strengths in precast, prestressed concrete beams. One pound of silica fume produces about the same amount of heat as a pound of portland cement, and yields much greater compressive strength**.** Use of silica fume often allows a reduction in the total amount of cementitious materials. The abrasion resistance of HPC incorporating silica fume is high. This makes silica-fume concrete particularly useful for spillways and stilling basins, and for concrete pavements or concrete pavement overlays subjected to heavy or abrasive traffic [17].

In summary, when used in concrete, silica fume increases durability, abrasion resistance and reduces bleeding [17]. It is much more reactive than portland cement, Class F fly ash, Class C fly ash, and slag cement, particularly at its early stages because of its higher silicon dioxide content and its very small particle size. However, as the particles are small, the water demand increases. So, silica fume should be used in combination with a water reducing admixture or a superplasticizer. Also, as bleed water is reduced due to adding silica fume, care should be taken to avoid plastic shrinkage cracks.

2.3.3.3 Blast Furnace Slag

Ground granulated blast-furnace slag (GGBFS), also called slag, is made by rapidly quenching molten blast-furnace slag and grinding the resulting material into a fine powder. GGBFS is classified by ASTM C 989-05[18] according to its level of reactivity. Depending on the desired properties, the amount of GGBFS can be as high as 70 percent or more of the total cementitious materials content**.** The literature suggests that typical replacement of cement by slag is between 30-45% [4]. In addition, slag has cementitious properties which can be a major factor in increasing strength. Slag also reduces the water demand by 1 to 10%, which makes it possible to reduce the water-cement ratio (w/c) to a lower value [4]. The use of GGBFS lowers concrete permeability, thereby reducing the rate of chloride ion diffusion. For alkali-silica reaction, GGBFS consumes some of the alkalis produced from the portland cement leaving them unavailable for reaction with the aggregates. Proper proportioning of slag cement can eliminate the need to use low alkali or sulfate-resistant portland cements. High early strength can be obtained when slag is used in conjunction with silica fume. This has been utilized in the columns of several office towers in Toronto having 70 and 85 MPa specified strengths.

In summary the performance of concrete, in terms of its placeability, physical properties, and its durability, can be enhanced by the use of slag-blended cements or through addition of ground granulated blast-furnace slag. Properly proportioned and cured slag concretes will control alkali–silica reactions, impart sulphate resistance, and greatly reduce chloride ion penetration and heat of hydration.

2.3.4 Aggregates

Good aggregates should be selected to ensure proper consolidation of the concrete mix so as to prevent segregation when the mix is subjected to vibration. The compressive strength of very high strength concretes is highly dependent on the type of aggregate used. The best workability can be achieved when larger aggregates are used. However, smaller aggregates provide more bonding area between mortar and aggregate resulting in higher compressive strengths [19]. According to the Washington Department of Transportation (WSDOT), smaller coarse aggregates are being used in concrete to increase freeze-thaw resistance and achieve higher compressive strength [9]. In addition, according to Laplante et al, coarse aggregate is the most important factor affecting the concrete abrasion resistance [20]. For high strength concrete according to ACI 211.4R, fine aggregates with a fineness modulus in the range of 2.5 to 3.2 are preferable for high-strength concrete (for 70 MPa or greater). Also, they should be at least 25% siliceous to be abrasion resistant [9].

HPC has specific aggregate size, shape, surface texture, mineralogy, and cleanliness requirements [17]. According to Aitcin and Mehta [21], the mineralogy and the strength of the coarse aggregate control the ultimate strength of the concrete. Krauss and Rogalla

(1996) suggested that aggregates with a low modulus of elasticity, low coefficient of thermal expansion, and high thermal conductivity result in reduced shrinkage and thermal stresses [22]. Higher strengths can also sometimes be achieved through the use of crushed stone aggregate rather than the rounded-gravel aggregate [4]. In general, equi-dimensional, rough textured and harder aggregates are preferred to give high strength.

2.3.5 Admixtures

Concrete admixtures are used to improve the behavior of concrete under a variety of conditions and are of two main types: chemical and mineral. As indicated previously, mineral admixtures make mixtures more economical, reduce permeability, increase strength, and influence other concrete properties. Fly ash, silica fume, slag and other cementitious materials are common types of mineral admixtures. Chemical admixtures reduce the cost of construction, modify properties of hardened concrete, and improve the quality of concrete during mixing, transporting, placement, and curing [4]. They fall into the following categories:

- Air entrainers
- High range water reducers (superplasticizers)
- Set retarders
- Set accelerators
- Specialty admixtures: which include corrosion inhibitors, shrinkage control, alkali-silica reactivity inhibitors, and coloring

According to Kerkhoff, air-entrainers give hardened mortars and concretes freeze-thaw resistance. Also, air entrainment improves workability and reduces bleeding [16]. Water reducers produce an increase in the workability of mortars and concretes at constant water-to-cement ratio. Set-retarders retard the initial rate of reactions between cement and water. The use of a plasticizer is mandatory in high strength concrete to ensure adequate workability while achieving a low water-to-cementitious materials ratio. Retarding admixtures may also be used for this purpose. The effectiveness of each admixture may vary depending on its concentration in the concrete and various other constituents of the concrete. It is also important to be sure that admixtures are compatible when used in combination. According to De Almedia [23], silica fume should be used in concrete along with a superplasticizer to maintain the abrasion resistance. Without a superplasticizer, the mineral admixtures will require more water resulting in a decrease in abrasion resistance. In summary, the materials that have been used in HPC and their desired properties are listed in the Table 1 [4].

Table 1: Materials Used in HPC Mixtures [4]

Material	Desired property
Portland cement	Cementing material/Durability
Blended cement	Cementing material/Durability/High strength
Fly ash/Slag/Silica Fume	Cementing material/Durability/High strength
Calcined clay/Metakaolin	Cementing material/Durability/High strength
Calcined shale	Cementing material/Durability/High strength
Superplasticizers	Flowability
High-range water reducers	Reduced water to-cement ratio
Hydration control admixture	Control setting
Retarders	Control setting
Accelerators	Accelerate setting
Corrosion Inhibitors	Control Steel corrosion
Water reducers	Reduce cement and water content
Shrinkage reducers	Reduce shrinkage
ASR inhibitors	Control alkali-silica Activity
Optimally graded aggregates	Improve workability
Polymer/latex modifiers	Durability

2.4 Mix Designs

Mixture proportions for HPC are influenced by many factors, including specified performance properties, locally available materials, local experience, personal preferences, and cost. The main goal is to produce concrete with high strength and low permeability. There is no standard mix to produce a high-strength concrete. Trial mixes are needed to obtain the optimum use of each locally available constituent material. WSDOT lists the following as general guidelines for developing HPC mix designs [9]

1. Include 5 to 6% air entrainment for freeze-thaw durability, to prevent chloride penetration, and to increase resistance to scaling.
2. Keep the w/c ratio below 0.35 to increase durability and strength.

3. Include fly ash or other mineral admixtures to improve freeze-thaw durability and resist chloride ion penetration.
4. Use Type III cement to improve early age compressive strength
5. Add superplasticizers to reduce w/c ratio to increase the strength for a given mix design.

2.4.1 Washington DOT study

WSDOT studied the performance characteristics of the five mix designs summarized in Table 2. Freeze-thaw durability, scaling resistance, abrasion resistance, chloride ion penetration, compressive strength, elasticity, shrinkage, and creep of the mixtures were evaluated according to the criteria shown in Table 3 [9].

Table 2: Mix Designs Used for the WSDOT Study [2]

Characteristics	A			B			C			D			E		
Load	4000 psi@28days Compressive Strength			650 psi @Flexural Strength			650 psi @14 days Flexural Strength			4000 psi @ 28 days Compressive Strength			650 psi @3 days Flexural Strength		
Construction Type	Cast in place			Slipform Concrete Pavement			Slipform Concrete Pavement			-			3 day/night paving		
Placement	Pour or Pump			Dump Truck and Chute			Dump Truck and Chute			-			-		
Materials	**Type**	**Weights per Cubic Yard (saturated, surface-dry)**		**Type**	**Weights per Cubic Yard (saturated, surface-dry)**		**Type**	**Weights per Cubic Yard (saturated, surface-dry)**		**Type**	**Weights per Cubic Yard (saturated, surface-dry)**		**Type**	**Weights per Cubic Yard (saturated, surface-dry)**	
		lbs	**Yield, ft^3**		**lbs**	**Yield, ft^3**		**lbs**	**Yield, ft^3**		**lbs**	**Yield, ft^3**		**lbs**	**Yield, ft^3**
Cement	Type I-II	565	2.87	Type III	708	3.60	Type I-II	452	2.30	Type I-II	611	3.108	Type I-II ASTM C 150 lbs	658	3.35
Fly ash	Class F	141	1.00	-	-	-	Class F	113	0.79	-	-	-	-	-	-
Sand	Class 2	947	5.88	R-101 WSDOT Class 1	1108	6.58	Coarse Sand Fine Sand	711 472	4.30 2.86	-	1165	7.235	ASTM C 33 lbs	1261	7.77
Aggregates	¾" (AASHTO # 67 / # 57)	2002	11.88	R-101 WSDOT Agg. #5 R-101 WSDOT Agg. #4	1170 780	6.87 4.58	Agg. 1½" Agg. ¾" Agg. 3/8"	689 1177 98	4.09 7.01 0.58	Agg. ¾"	1843	10.98	Agg.3/4" ASTM C 33 # 67, lbs Agg. 1½" ASTM C 33 # 4, lbs	1016 838	5.96 4.92
Water	250	4.01	-		251	4.02	-	215	3.45	-	270	4.327	-	231	3.70
Total Air, %	5.0+/-1.5	1.35	-		5.0 +/- 1.5	1.35	-	6.0 +/- 1.5	1.62	-	5	1.35	-	5.5	1.50
		Total	27.00	Total	27.00			Total	27.00		Total	27.00		Total	27.00
Water reducing agent	WRA POZZ 80, ounces	35.3	-	200N WRA, ounces	28.32	-	WRDA 64/Type A, ounces	22.60	-	WRA POZZ 82 meets ASTM C260, ounces per yard	5	-	WRDA-64 ASTM C 494 Type A, ounces	29.61	-

Table 3: Evaluation Criteria for the WSDOT Study. Adapted from [9]

Performance Characteristic[2]	Standard test Method	FHWA HPC performance grade[3] 1	2	3	4
Freeze-thaw durability[4] (x=relative dynamic modulus of elasticity after 300 cycles	AASHTO T 161 ASTM C 666 Proc. A	60%≤x<80%	80%≤x		
Scaling resistance[5] (x=visual rating of the surface after 50 cycles)	ASTM C 672	x=4,5	x=2,3	x=0,1	
Abrasion resistance[6] (x=avg. Depth of wear in mm)	ASTM C 944	2.0> x≥1.0	1.0> x≥0.5	0.5>x	
Chloride penetration[7] (x=coulombs)	AASHTO T 277 ASTM C 1202	3000≥x>2000	2000≥x>800	800≥x	
Strength (x=compressive strength)	AASHTO T 2 ASTM C 39	41≤x<55 Mpa (6≤x<8 ksi)	55≤x<69 MPa (8≤x<10 ksi)	69≤x<97 MPa (10≤x<14 ksi)	x≥97 MPa (x≥14 ksi)
Elasticity[10] (x=modulus of elasticity)	ASTM C 469	28≤x<40 Gpa (≤x<6x10^6 psi)	40≤x<50 Gpa (6≤x<7.5x10^6 psi)	x≥50 Gpa (x≥7.5x10^6 psi)	
Shrinkage[8] (x=microstrain)	ASTM C 157	800>x≥600	600>x≥400	400>x	
Creep[9] (x=microstrain/pressure unit)	ASTM C 512	75≥x>60/Mpa (0.52x>0.41/psi)	60≥x>45/MPa (0.41≥x0.31/psi)	45≥x>30/MPa (0.31≥x0.21/psi)	30 MPa≥x (0.21 psi≥x)

[1]This table does not represent a comprehensive list of all characteristics that good concrete should exhibit. It does list characteristics that can quantifiably be divided into different performance groups.
[2]All tests to be performed on concrete samples moist or submersion cured for 56 days. See Table 2 for additional information and exceptions.
[3]A given HPC mix design is specified by a grade for each desired performance characteristic. For example, a concrete may perform at Grade 4 in strength and elasticity, Grade 3 in shrinkage and scaling resistance, and Grade 2 in all other categories.
[4]Based on SHRP C/FR-91, p. 3.52.
[5]Based on SHRP S-360.
[6]Based on SHRP C/FR-91-103.
[7]Based on *PCA Engineering Properties of Commercially Available High-Strength Concretes.*
[8]Based on SHRP C/FR-91-103, p. 3.25.
[9]Based on SHRP C/FR-91-103, p. 3.30.
[10]Based on SHRP C/FR-91-103, p. 3.17.

Summary

The study concluded that the all of the mixes satisfied different HPC performance grades for freeze-thaw durability. Mix designs A through D met HPC performance grade 2 (Table 2) and the mix design E met HPC performance grade 1 (Table 2). Including 5 to 6% air entrainment and maintaining a w/c ratio of 0.35 was found to increase the freeze-thaw durability. Adding fly ash also increased freeze-thaw durability. Based on the testing results, it was concluded that low chloride permeability could be achieved by using a low w/c ratio and including fly ash.

2.4.2 Montana study

A study was conducted in Montana to come up with the optimum HPC mix design for bridge decks using locally available raw materials. Fourteen mix designs were considered [22]. Table 4 summarizes the mix designs while Table 5 summarizes the percent of Portland cement that was replaced by the indicated supplementary cementitious materials.

Table 4: HPC Mix Designs used in the Montana Study [22]

Material per cubic yard	Mixture ID													
	A	B	C	D	E	F	G	H	J	K	L	M	N	O
Cement or blend (lbs.)	562	684	526	526	526	720	649*	649*	575†	629†	654‡	685	526	526
Water (lbs.)	266	266	266	266	266	252	252	252	252	252	252	252	252	252
Fly Ash - Class C (lbs.)	138	0	138	63	0	0	0	0	0	0	0	0	0	125
Fly Ash - Class F (lbs.)	0	0	0	0	54	0	0	0	54	0	0	0	0	0
Silica Fume (lbs.)	0	25	25	25	25	0	38	0	28	38	20	25	35	35
Slag (lbs.)	0	0	0	80	80	0	0	0	0	0	0	0	133	0
HR Metakaolin (lbs.)	0	0	0	0	0	0	0	45	0	0	0	0	0	0
Fine Aggregate (lbs.)	1284	1284	1284	1284	1284	1300	1300	1300	1300	1300	1300	1296	1296	1296
Coarse Aggregate (lbs.)	1572	1572	1572	1572	1572	1593	1593	1593	1593	1593	1593	1573	1573	1573
AEA (fl. oz./cwt.)	2.5	1.8	2.6	2.6	2.2	1.5	1.8	2.9	2.3	2.0	1.8	1.9	2.4	4.2
MRWR (fl. oz./cwt.)	2.4	2.0	2.5	2.5	1.7	4.0	7.0	2.6	2.5	2.6	2.5	2.5	2.5	2.5
HRWR (fl. oz./cwt.)	4.4	4.3	3.7	6.1	7.1	8.0	6.4	11.7	16.3	11.8	17.1	14.1	20.2	18.4

* = Class C fly ash blend, † =Slag blended cement, ‡ = Calcined clay blended cement

Table 5: Percentage Replacement of Cement with the Supplementary Cementitious Materials (SCM) Used in the Mix Designs for the Montana Study [22]

Material/Property		Mixture ID													
		A	B	C	D	E	F	G	H	J	K	L	M	N	O
Replacement of cement	Fly Ash (Class C) Blend							92.5	92.5						
	Slag Blend									84.5	92.5				
	Calcined-Clay Blend											96			
	Fly Ash (Class C)	22		22	10										20
	Fly Ash (Class F)					10				10					
	Slag				12	12								20	
	Silica Fume		5	5	5	5		7.5		5.5	7.5	4	5	7	7
	HR Metakaolin								7.5						
SCM equivalent replacement of cement	Fly Ash - Class C	22		22	10			18.6	18.6						
	Fly Ash - Class F					10				10	17.1				
	Slag				12	12				15.6					
	Silica Fume		5	5	5	5		7.5		5.5	7.5	4			
	HR Metakaolin								7.5						
	Calcined Clay											19.8			
Basis w/cm (for cement-only mixture)		0.37	0.37	0.37	0.37	0.37	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Aggregate Source		YR	YR	YR	YR	YR	YR	YR	YR	YR	YR	YR	WM	WM	WM

YR=Yellowstone River
WM = Western Montana

For the specific set of raw materials evaluated, the combinations of supplementary cementitious materials that produced the best results were 5% silica fume alone (Mixtures B and M), 7% silica fume and 20% slag (Mixture N), the slag-blended cement with 10% Class F fly ash and 5.5% silica fume (Mixture J), and the calcined clay-blend with 4% silica fume (Mixture L). The combination of the slag-blended cement, Class F fly ash, and silica fume also gave excellent performance across all tests, standing out particularly for low drying shrinkage, and would be expected to be the best option to mitigate alkali-silica reactivity.

2.4.3 Strategic Highway Research Program Study

A four year study was conducted by the researchers at North Carolina State University, University of Arkansas, and University of Michigan to evaluate the mechanical behavior of HPC. The goal of this study was to significantly improve the criteria for highway applications pertaining to HPC. The study was broken down into three categories of Very Early Strength Concrete (VES), High Early Strength Concrete (HES) and Very High Strength Concrete (VHS) [24].

The authors of the study defined various categories of HPC according to the criteria listed in Table 6. They also developed a matrix of potential applications for each of the categories of HPC as shown in Table 7.

Table 6: Criteria Used to Categorize the HPC Mixtures Used in the Strategic Highway Research Program Study [24]

Category of HPC	Minimum Compressive Strength	Maximum Water/ Cement Ratio	Minimum Frost Durability Factor
Very early strength (VES)			
Option A (with Type III cement)	2,000 psi (14 MPa) in 6 hours	0.40	80%
Option B (with PBC-XT cement)	2,500 psi (17.5 MPa) in 4 hours	0.29	80%
High early strength (HES) (with Type III cement)	5,000 psi (35 MPa) in 24 hours	0.35	80%
Very high strength (VHS) (with Type I cement)	10,000 psi (70 MPa) in 28 days	0.35	80%

Table 7: Potential Applications for the HPC Mixtures Used in the Strategic Highway Research Program Study [24]

Potential Applications	Concrete Type			
	VES (A)	VES (B)	HES	VHS
New pavement	X		X	
Full-depth pavement patch	X	X	X	
Pavement overlay	X	X	X	
New bridge deck			X	X
Full bridge deck replacement			X	X
Bridge deck overlay	X	X	X	
Bridge girders			X	X
Precast elements		X	X	X
Prestressed piles		X	X	X
Columns and piers			X	X

Twenty one HPC mixtures incorporating the aggregates listed in Table 8 were studied in detail. For each category of HPC (Table 6), four mixtures were developed and evaluated for compressive strength. Tables 9 through 13 provide the strength test results. Fly ash and silica fume were utilized in the very high strength (VHS) mixtures (Tables 12 and 13).

Table 8: Aggregate Sources Used in the Strategic Highway Research Program Study [24]

Type	Symbol	Source
Marine marl	MM	Castle Hayne, N.C.
Crushed granite	CG	Garner, N.C.
Dense crushed limestone	DL	West Fork, Ark.
Washed rounded gravel	RG	Memphis, Tenn.
Sand		Lillington, N.C.
Sand		Memphis, Tenn.
Sand		Van Buren, Ark.

Table 9: Mixture Proportions of VES (A) Concrete with Four Different Aggregate Types [24]

Coarse aggregate type: Source of sand:	CG Lillington	MM Lillington	RG Memphis	DL Van Buren
Cement (Type III), pcy	870	870	870	870
Coarse aggregate, pcy	1,720	1,570	1,650	1,680
Sand, pcy	820	800	760	920
HRWR (melamine based), oz/cwt	5.0	5.0	10	4.0
Calcium nitrite (DCI), gcy	6.0	6.0	6.0	6.0
AEA, oz/cwt	3.0	2.5	4.0	2.5
Water, pcy	350	350	350	340
W/C	0.40	0.40	0.40	0.39
Slump, in.	5	7	6	5.75
Air, %	6.5	6.4	7.5	4.40
Strength at 6 hr, psi (insulated)	2,090	2,000	2,360	3,090
Concrete temperature at placement, ^{o}F	71	75	79	78

Note: 1 MPa = 145 psi

Table 10: Mixture Proportions of VES (B) Concrete with Four Different Aggregate Types [24]

Aggregate type: Source of sand:	CG Lillington	MM Lillington	RG Memphis	DL Van Buren
Cement (Pyrament), pcy	850	850	850	855
Coarse aggregate, pcy	1,510	1,500	1,510	1,680
Sand, pcy	1,410	1,460	1,400	1,560
HRWR (Melamine Based), oz/cwt	0	0	0	0
Calcium nitrite (DCI), gcy	0	0	0	0
AEA, oz/cwt	0	0	0	0
Water, pcy	195	145	183	200
W/C	0.23	0.17	0.22	0.23
Slump, in.	6.5	4	3.5	7.0
Air, %	6.0	7.0	3.7	7.6
Strength at 4 hr, psi (insulated)	2,510	2,270	3,060	2,890
Concrete temperature at placement, ^{O}F	72	72	75	77

Note: 1 MPa = 145 psi

Table 11: Mixture Proportions of HES Concrete with Four Different Aggregate Types [24]

Aggregate type: Source of sand:	CG Lillington	MM Lillington	RG Memphis	DL Van Buren
Cement (Type III), pcy	870	870	870	870
Coarse aggregate, pcy	1,720	1,570	1,650	1,680
Sand, pcy	960	980	900	1,030
HRWR (Naphthalene Based), oz/cwt	26	26	26	16
Calcium nitrite (DCI), gcy	4.0	4.0	4.0	4.0
AEA, oz/cwt	9	1.0	1.0	4.0
Water, pcy	280	280	300	300
W/C	0.32	0.32	0.34	0.34
Slump, in.	1.0	6.75	7.0	3.5
Air, %	5.3	5.6	6.6	5.4
Strength at 1 day, psi	5,410	5,610	5,690	5,300
Concrete temperature at placement, ^{O}F	80	73	84	78

Note: 1 MPa = 145 psi

Table 12: Mixture Proportions of VHS Concrete with Fly Ash [24]

Aggregate type: Source of sand: Type of fly ash:	CG Lillington F	MM Lillington F	RG Memphis F	DL Van Buren C
Cement (Type I), pcy	830	830	830	830
Fly ash, pcy	200	200	200	200
Coarse aggregate, pcy	1,720	1,570	1,650	1,680
Sand, pcy	937	900	860	1,020
HRWR (Naphthalene Based), oz/cwt	26	20	20	18
Retarder, oz/cwt	3.0	3.0	3.0	3.0
AEA, oz/cwt	3.5	1.3	1.2	2.5
Water, pcy	240	240	240	240
W/(C+FA)	0.23	0.23	0.23	0.23
Slump, in.	3.5	10	7.0	3.75
Air, %	5.5	8.0	2.0	4.8
Strength at 28 days, psi	12,200	7,620	8,970	9,833
Concrete temperature at placement, ^{o}F	80	72	69	76

Note: 1 MPa = 145 psi
W/(C+FA) = ratio of weight of water to combined weight of cement and fly ash

Table 13: Mixture Proportions of VHS Concrete with Silica Fume [24]

Aggregate type: Source of sand:	CG Lillington	MM Lillington	RG Memphis	DL Van Buren
Cement (Type I), pcy	760	760	760	770
Silica fume, pcy	35	35	35	35
Coarse aggregate, pcy	1,720	1,570	1,650	1,680
Sand, pcy	1,206	1,140	1,150	1,250
HRWR (naphthalene based), oz/cwt	14	12	14	17
Retarder, oz/cwt	2.0	2.0	3.0	3.0
AEA, oz/cwt	0.9	0.6	0.9	1.5
Water, pcy	230	240	240	230
W/(C+SF)	0.29	0.30	0.30	0.29
Slump, in.	2.75	4.25	3.0	2.75
Air, %	5.0	5.6	7.3	5.1
Strength at 28 days, psi	11,780	8,460	9,120	10,010
Concrete temperature at placement, ^{o}F	80	77	80	75

Note: 1 MPa = 145 psi
W/(C+SF) = ratio of weight of water to combined weight of cement and silica fume

Seven out of the 21 mixtures failed to reach the desired compressive within a time limit. However, 6 out of these 7 HPC mixtures contained the weaker aggregates, those being marine marl and rounded gravel. High quality aggregates, high quality cement, and air entraining agents were required to produce HPC.

2.4.4 Structural Engineering Research Center Study

A study was conducted by the members of Structural Engineering Research Centre at Chennai [25], to observe the properties of HPC when the cement was partially replaced by ground granulated blast furnace slag (GGBFS) versus a control mixture design. It was concluded from this study that the addition of GGBFS, as a partial replacement of cement, causes a reduction in the compressive strength at early ages but at the later ages HPCs with GGBFS had nearly the same strength as that of HPC without GGBFS. The use of GGBFS in HPCs to replace cement by 70% helped to reduce the cement content of HPCs from about 530 kg/m^3 to 160 kg/m^3. Due to this replacement, there was no significant effect on the 28-day and 90-day compressive strengths and an improvement in the durability properties of the HPC was observed. Also, HPCs containing GGBFS displayed higher impermeability than the HPC without GGBFS and considerable imperviousness to chloride ions was obtained.

Four experimental mixture designs--HPC-20S, HPC-30S, HPC- 50S, and HPC- 70S— were developed by replacing 20%, 30%, 50% and 70% of the mass of cement by GGBFS, respectively, for this study. Grade 53 portland cement, river sand and crushed granite aggregates were used in the concretes mixes. The mixture designs used for this study are shown in Table 14.

Table 14: Mix Proportions of the HPCs [25]

Composition	**Mix Designation**					
	HPC-0S	HPC-20S	HPC-30S	HPC-50S	HPC-70S	Conventional Concrete
CRM %	0	20	30	50	70	-
w/b	0.3	0.3	0.3	0.3	0.3	0.5
w/c	0.3	0.375	0.429	0.6	1.0	0.5
Cement, kg/m^3	535	428	375	267	160	315
GGBFS, kg/m^3	0	107	160	268	375	-
Total Aggregate, kg/m^3	1765	1765	1765	1765	1765	1840
Water, l/m^3	160	160	160	160	160	160
Super plasticizer, ml/m^3	1235	1235	1235	1235	1235	-

CRM: Cement replacement material (by mass of cement of control mix HPC-0S) w/b: Water-binder ratio

2.5 Construction Practices

Use of supplementary cementitious materials and other admixtures in concrete mixtures necessitates special consideration with regard to construction practices. Several considerations identified in the literature include [26]:

- **Flash set and temperature**: Retarding admixtures can be added to combat the early setting problems in concrete. Since HPC has low water-to-cement ratios compared with normal weight concrete, the concrete placement temperature can be limited to 65 degrees Fahrenheit in some projects.
- **Finishability and slump**: HPC is typically placed at relatively high slumps, from 8 to 10 inches, because of the superplasticizer required for workability. HPC with silica fume can be sticky and can lead to tears and pulls during finishing. Screeding operations must begin as soon as possible after placement.
- **Lack of bleed water**: Superplasticizers must be added to distribute the limited water in HPC mixtures as they have low w/c ratios. Silica fume concrete, with its lack of bleed water and susceptibility to surface crusting from evaporation, should not be placed in high-wind and low-humidity conditions.
- **Plastic shrinkage and mandatory curing**: Curing is critical in HPC projects. Because autogenous shrinkage begins with cement hydration and even before the concrete begins to set, effective curing must start early. Curing specifications require that moisture loss be minimized by the use of evaporation retarders, continuous misting or fogging, and moist curing for 7 days. Curing must begin immediately after finishing, and continue for as long as possible to avoid plastic shrinkage cracking.
- **Abrasion resistance:** Abrasion of concrete occurs due to rubbing, scraping, skidding, or sliding of objects on its surface.

2.6 Abrasion Resistance Concrete

For many applications, abrasion resistance is one of the important characteristics of high performance concrete. The primary factors affecting the abrasion resistance of concrete are compressive strength, aggregate properties, finishing methods, use of toppings, and curing [12]. Abrasion of concrete occurs due to rubbing, scraping, skidding or sliding of objects on its surface. Concrete mixtures that are subjected to abrasion must have concrete mixture designs that have high abrasion resistance [13]. Abrasion resistance is closely related to the compressive strength of concrete. Strong concrete has more resistance to abrasion than that of weak concrete [27]. It has been shown that by carefully selecting aggregates, it is possible to achieve the same abrasion resistance on high strength concrete (on the order of 100-120 MPa) as on granite [28]. Since compressive strength depends on water-to-cementing materials ratio and curing, a low water-to-cementing materials ratio and adequate curing are necessary for abrasion resistance. According to Liu [29], concrete of the lowest practical water-cement ratio and the hardest available aggregates should be used for new constructions or repair of hydraulic structures where abrasion is of major concern.

2.6.1 Case Study I

Laplante, Aitcin and Vezina [20] studied 12 HPC mixtures summarized in Table 15 and concluded that coarse aggregate is the most important factor affecting concrete abrasion resistance (mixtures C3 and C4 performed exceedingly well) and inclusion of silica fume in the concrete mixture increased the abrasion resistance of concrete. Also, the abrasion resistance of the concrete was strongly influenced by the abrasion resistance of its constituent mortar and coarse aggregate. A very low water-to-cement ratio of about 0.30 can make the concrete as highly abrasion resistant as that of high performance rocks like trap rock and fine-grained granite. The abrasion resistance was established according to ASTM C779-82.

Table 15: Mix Proportions Used for Case Study I [20]

A1, A2, A3 and A4 are air entrained concretes.
B1, B2, B3 and B4 are non-air entrained concretes.
C1, C2, C3 and C4 are non-air entrained concretes.
T represents Type of material
C represents composition of the materials.

Materials	A1		A2		A3		A4		B1		B2		B3		B4		C1		C2		C3		C4	
	T*	C**	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Water (kg/m^3)	-	170	-	170	-	170	-	170	-	135	-	140	-	145	-	150	-	140	-	140	-	140	-	140
Cement (kg/m^3) Cement Type	I	350	I	350	I	350	I	350	III	505	III	425	III	390	III	350	III	430	III	430	III	430	III	430
Silica Fume (kg/m^3)	-	-	-	-	-	27	-	27	-	40	-	35	-	31	-	28	-	35	-	35	-	35	-	35
Coarse Aggregate*** (kg/m^3)	GG	1000	L	970	GG	1010	L	995	G	1010	G	1000	G	1020	G	1010	L	1010	DL	1015	TR	990	G	1000
Fine Aggregate (kg/m^3)	-	785	-	785	-	775	-	785	-	800	-	860	-	890	-	900	-	850	-	860	-	880	-	860
Super plasticizer (l/m^3)	-	-	-	-	-	1. 2	-	1. 2	-	15.4	-	9	-	7.2	-	5	-	10.6	-	11	-	12	-	9
Slump (mm)	-	75	-	80	-	80	-	90	-	150	-	185	-	180	-	95	-	190	-	190	-	150	-	185
Air content (%)	-	8. 0	-	8. 0	-	6.4	-	6.4	-	2.3	-	2.2	-	1.9	-	2.1	-	1.9	-	1.5	-	Not measured	-	2.2
W/C	-	0.48	-	0.48	-	0.48	-	0.48	-	0.27	-	0.32	-	0.36	-	0.41	-	0.32	-	0.32	-	0.32	-	0.32

*T = type
**C = Content
***GG = Granite gravel; L = limestone; G = granite; DL= dolomitic limestone; TR = trap rock

2.6.2 Case Study II

In the UK, a study was conducted by Atis in which a control mixture was designed to have a 45 MPa target compressive strength [30]. The mixture design was based on the principle of minimizing the porosity. In the control mix, normal portland cement, sand, and gravel were proportioned at a ratio of 1:1.5:3 by mass, respectively. The water-to-cement ratio was 0.55 for better flow. Fly ash concrete mixtures were made for comparison reasons, using two cement substitute levels at 50% and 70% by mass. The mix proportions for 1m^3 were as shown in Table 16.

Table 16: Mix Proportions for 1 m^3 of Concrete [30]

Parameter	Mixture Designation				
	M0	M1	M2	M3	M4
Cement(kg/m^3)	400	120	120	200	200
Fly ash(kg/m^3)	-	280	280	200	200
Sand(kg/m^3)	600	600	600	600	600
Gravel(kg/m^3)	1200	1200	1200	1200	1200
Water(kg/m^3)	220	112	116	132	120
Optimal W/ (FA+C)	-	0.29	0.29	0.30	0.30
Actual W/(FA+C)	0.55	0.28	0.29	0.33	0.30
Super plasticizer (L)	-	5.6	-	5.6	-
FA/(C+FA)(%)	0	70	70	50	50

M1 and M2 were the concrete mixtures having 70% fly ash as cement replacement. M3 and M4 were the concrete mixtures having 50% fly ash replacement. Also M1 and M3 contain a super-plasticizer, and M2 and M4 were concrete mixtures having zero slump for application in roller compacted concrete. Generally, an increase in compressive strength and a decrease in porosity yielded a higher abrasion resistance. Additionally, a constant compressive strength and an increase in porosity yielded a decrease in abrasion resistance.

2.6.3 Case Study III

Another study [12] observed the effect of fly ash on the abrasion resistance of concrete. Class C fly ash was used in the mix proportions which are summarized in Table 17. Concrete mixtures having 50% cement replacement with fly ash attained sufficient strength required for structural applications. All the concrete mixtures used in this study showed excellent abrasion resistance when tested in accordance with ASTM C-944.

Table 17: Mix Proportions Using ASTM Class C Fly Ash [12]

Mixture Number	**C-3** (reference mixture containing no fly ash)	**P4-7** (50% cement replacement)	**P4-8** (70% cement replacement)
Specified Design Strength	41	-	-
Cement (kg/m^3)	375	180	110
Fly Ash (kg/m^3)	0	226	316
Water (kg/m^3)	135	136	155
w/c ratio	0.36	0.33	0.36
Sand (kg/m^3)	687	655	606
25-mm aggregates (kg/m^3)	1182	1139	1145
Slump (mm)	120	114	120
Air Content (%)	6.3	7.0	6.4
Superplasticizer (l/m^3)	2.9	2.7	2.6
Air Entraining Admixture (ml/m^3)	270	886	380
Air Temperature (deg-Celsius)	21.1	-	-
Concrete Temperature (deg-Celsius)	23	26	25
Fresh Concrete Density (kg/m^3)	2393	2328	2365
Hardened Concrete Density (kg/m^3)	2486	2342	2326

2.6.4 Case Study IV

Holland and Gutschow studied the high strength concrete incorporating silica fume used for the repairs on the Kinzua Dam stilling basin and Los Angeles River projects [31]**.** The mix design for the Kinzua project is shown in Table 18. The researchers concluded that the concrete at the Kinzua Dam performed as intended. They could not come to any conclusion on the Los Angeles River project as it was too soon at the time of their study. However, they mentioned the following observations pertinent to the placement of the silica-fume concrete: (1) slump control can be very sensitive in hot weather because of the effective life of some high-range water-reducing admixtures; (2) Pozzolans enhance the workability of silica-fume concretes; (3) silica fume concrete is more plastic and cohesive than conventional concrete and less susceptible to aggregate segregation and bleeding; (4) plastic shrinkage appears more likely than with conventional concrete; and (5) the occurrence of reflection cracking was minimal.

Table 18: Mixture Proportions and Properties of Fresh Concrete Used for the Kinzua Dam Stilling Basin Repair [31]

Constituent	**Unit Weight**	
	lb/yd^3	kg/m^3
Cement, Type I/II	650	386
Silica fume slurry	263	156
Water	134	80
Silica fume	118	70
Admixtures	11	6
Coarse aggregate	1637	971
Fine aggregate	1388	824
Water	85	40
Properties		
w/b ratio	0.28	
Silica fume content by cement mass	18%	
Average air content	3.2%	
Average slump	250 mm	
Average unit weight	152.6 lb/ft^3 (2444 kg/m^3)	

2.6.5 Case Study V

Horszczaruk [32] examined nine types of high strength concrete. The abrasion resistance of HSC with regard to compression strength, modulus of elasticity, fiber material, and dimensions was studied. The mixes were made with portland cement (CEM I 42.5 R, CEM I 52.5 R) and blast furnace cement (CEM IIIA 42.5), and basalt aggregate with added superplasticizers and silica fume. A few of the mixes contained fibers and two of the mixtures were modified with latex. The mix designs are summarized in Table 19.

Table 19: Mixture Proportioning [32]

Type of mix	Mixture Designations								
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**
Type of cement	CEM I 52.5R	CEM I 42.5R	CEM III/A 42.5N	CEM III/A 42.5N	CEM III/A 42.5N	CEM I 52.5R	CEM I 52.5R	CEM I 52.5R	CEM I 52.5 R
Cement (kg/m^3)	470	470	470	470	470	450	450	450	450
Water (l/m^3)	135	135	135	135	135	135	135	22.5	22.5
Latex (l/m^3)	-	-	-	-	-	-	-	112.5	-
Silica fume (kg/m^3)	47	47	47	47	47	45	45	45	45
w/cm ratio	0.26	0.26	0.26	0.26	0.26	0.27	0.27	0.27	0.27
Superplasticizer (% mass of cement)	2	1	1.5	1.5	1.5	1	1	1.5	2
Sand (kg/m^3)	1007	1007	1007	1007	1007	630	630	630	630
Maximum diameter of basalt (mm)	8	8	8	8	8	16	16	16	16
Basalt (kg/m^3)	1006	1006	1006	1006	1006	1279	1279	1279	1279
Steel fibers (kg/m^3)	-	-	-	70*	70**	70*	70**	70**	-
PVC fibers (kg/m^3)	-	-	-	-	-	-	-	-	1.8

*Steel fibers ME30/50.

** Steel fibers ME50/1.00.

Out of the three HSC mixes (C3, C4 and C5) made with blast furnace cement, the C5 concrete showed the highest abrasive resistance. The 28-day compressive strength of C5 was 25% higher than the strength of the other two concretes. The abrasive resistance of HSC reinforced with fiber and latex additive were compared with that of the non-reinforced concrete C1. The latex additive did not increase the abrasion resistance of concrete. The HSC with added PVC fiber improved the abrasive resistance of concrete.

2.6.6 Case Study VI

In a study by Fernandez and Malhotra [33], the abrasion resistance of concrete incorporating ground-granulated blast-furnace slag (GGBFS) obtained from a source in Ontario was studied. Nine air-entrained concrete mixtures involving 18 batches were prepared. Type I portland cement, GGBFS, lime stone, natural sand, and a sulphonated hydrocarbon-type air-entraining admixture was used for these mixtures. The mixture designs used for this study are summarized in Table 20. The strength development characteristics of the slag concrete showed that the GGBFS could be used satisfactorily as a partial replacement of the portland cement in concrete. However, the abrasion resistance of the concrete containing slag was inferior to that of the concrete made with portland cement alone.

Table 20: Mixture Proportions for the GGBFS Study [33]

Mix series	Mixture number	Water/ (cement + slag) by weight	% Slag as replacement of cement	Quantities, kg/m^3					Air Entraining Admixture ml/m^3
				Water	Cement	Slag	CA	FA	
I	1	0.70	0	142	202	-	1175		
	2	0.70	25	138	148	50	1148		
	3	0.70	50	141	100	100	1171		
II	4	0.55	0	143	259	-	1139	759	128
	5	0.55	25	142	196	65	1119		
	6	0.55	50	144	131	131	1121		
III	7	0.45	0	151	336	-	1103		
	8	0.45	25	149	248	82	1134	666	199
	9	0.45	50	150	166	166	1137	667	222

2.7 Implementation of HPC

Several State DOTs are becoming attracted to the benefits of using HPC. It has been used extensively in states such as Ohio, Nebraska, New Mexico, Maryland, and Texas. Georgia Department of Transportation (GDOT) viewed HPC as a concrete having significant applications providing longer spans and shallower beams for pre-stressed concrete beams for highway bridges in Georgia. The deck concrete was specified to have a compressive strength of 7,000 psi (50 MPa) at 56 days and a maximum chloride permeability of 2,000 coulombs at 56 days [34].

Fifteen HPC bridge decks have been placed in Minnesota since 1997. Few of them, though with a specified compressive strength of 4,300 psi (29.6 MPa) at 28 days, have faced the problem of cracking due to improper curing [35].

The need to potentially extend the service life of bridges and pavements, while reducing maintenance and replacement costs influenced Nebraska Department of Roads to adopt HPC in 1995, when they designed their first bridge incorporating HPC. Their project aimed at obtaining a specified concrete strength of 8,000 psi (55 MPa) at 56-days, while the required design strength was 4,000 psi (28 MPa) [36].

HPC bridge projects in other states, and the results of various HPC research projects, convinced the Texas Department of Transportation (TxDOT) to modify their specification and add supplementary cementitious materials (SCM) to make concrete more durable. Class S (HPC) concrete for the bridge deck specified by the TxDOT has a minimum compressive strength requirement of 4,000 psi (28 MPa) at 28 days and a maximum w/cm ratio of 0.44, and also a provision requiring replacement of 30% of the cement with Class F fly ash. In Lubbock District of Texas, HPC was recommended to replace two deteriorated concrete bridges because of the significant use of deicing chemicals related to the 70 annual freeze-thaw cycles [35].

Due to several stringent constraints, California Department of Transportation (Caltrans) opted for high performance precast concrete for pre-stressed, post-tensioned, spliced bulb-tee girders to be built across the Sacramento River in Northern California. They used a concrete mix with water to cementitious materials ratio of 0.33 and a high-range water reducing admixture. The average 10-day and 35-day strengths were approximately 10,000 psi (69 MPa) and 11,000 psi (75 MPa), respectively; the highest compressive strength concrete used by Caltrans [38].

With more and more new projects coming, the trend has changed over the past decade. Not only states, but small counties also aim at decreasing the life-cycle costs associated with bridges. According to 'Bridge Views, June 2000', Prince George's County, Maryland aimed at making 12 bridges in the next three years would like to design more durable bridges with extended longevity and decreased long-term maintenance and repair costs at the expense of higher initial costs [39].

The purpose of building the Rio Puerco Bridge located on Old Route 66 west of Albuquerque in 2000 was to establish the viability of HPC in New Mexico. They used cement, silica fume, and Class F fly ash as cementitious materials. A 3-day steam curing period was done to achieve concrete strength of 7,500 psi and 10,340 psi (51.7 and 71.3MPa) at release and 56 days, respectively. Although there was a 10% increase in the overall construction cost of bridge, it was expected to be much cheaper in long run with respect to life cycle costs [40].

In 1997, the Ohio Department of Transportation installed their first HPC precast, pre-stressed concrete bridge as part of the Federal Highway Administration Showcase program. This bridge superstructure consisted of adjacent box girders. Availability of 10,000 psi (69 MPa) compressive strength HPC enabled the span of the Ohio B42-48 section [42 in. deep by 48 in. wide (1.07 m by 1.22 m)] to be extended to 116 ft (35.4 m). In Hamilton County, over 20 HPC bridges have been built in the last ten years. Their mix design must have a w/cm ratio less than 0.40, maximum slump of 6 in. (150 mm), minimum compressive strength of 4,500 psi (31 MPa) at 28 days, and 2 lb/y3 (1.2 kg/m3) of polypropylene fibers not less than 3/4 in. (19 mm) long to minimize plastic shrinkage cracking. It also requires 7% silica fume by weight of cement, either as a replacement or as an ad

dition [41].

2.8 Benefits of Pre-cast Bridge Deck Slab

Improving and developing HPC would not be a good solution until we go for pre-cast elements because HPC requires excellent quality control which is more difficult when cast in-situ. Charles in his report on 'Application of Precast Decks and other Elements to Bridge Structures' stated

> *Benefits of using precast elements in bridge construction include the high level of quality control that can be achieved in plant cast production compared to field cast operations and speed of construction afforded by the assembly of precast elements at the site rather than the time consuming on site forming and casting required in cast-in-place construction.* [42].

Other benefits of pre-cast components according to Ralls. et al. are stated as follows: [43]

- Use of Pre-cast elements can significantly compress the construction project timeline and reduce traffic disruption.
- Fabricating the elements off-site, in a safe environment reduces the amount of time workers are exposed to these potentially dangerous situations.
- The use of prefabricated elements gives contractors more options and can often reduce the impact bridge construction has on its surroundings.
- Plant operations are often standardized therefore ensures quality control.
- Same elements can be used for different projects and this repeatability often results in large economic benefits as well.

All these benefits of pre-cast elements formed the basis to make a decision to develop HPC for pre-cast panels studied in this research.

2.9 Grand Summary

HPC has been successfully used in several projects. The characteristics of HPC depend on the characteristics of its constituent materials. Therefore, the mix design should be done carefully to achieve the desirable properties of HPC required for a specified project. In general, Portland cement (Type I or III) used with supplementary cementitious materials such as silica fume or fly ash, along with appropriate admixtures and superplasticizers, can provide a very good HPC mixture. The relative proportions of these can be determined by testing various trial mixes to achieve the required compressive strength. A cost-benefit analysis also needs to be done so as to finalize the choice of supplementary cementitious materials and other materials used to produce a good quality HPC mix. From the case studies, it can be concluded that concrete incorporating silica fume offers high abrasion resistance. This makes silica fume concrete particularly useful for spillways and stilling basins, and for concrete pavements or concrete pavement overlays subjected to heavy or abrasive traffic. Thus, HSC containing silica fume with a low water cement ratio and hard aggregates can offer high abrasion resistance. Pre-cast panels would have lower life cycle cost and require minimal repairs. Also, use of prefabricated, precast elements can significantly provide safer and better construction option apart from better quality control and.

3 EXPERIMENT DESIGN

The whole project was divided in to four phases namely Phase I, Pilot Study, Phase II and Field Study. Phase I, pilot study and phase II, being purely experimental and limited to laboratory testing, are covered in this thesis while the field testing will be conducted at a future date to provide some input to develop models to predict the life cycle cost of the bridge deck slab. Based on the extensive literature review, factors affecting HPC and abrasion resistant concrete were identified (see Chapter 2). Curing of concrete also plays an important role in the durability characteristics of HPC concrete; therefore this factor was also studied in detail in pilot study.

3.1 Phase I

Preliminary tests were conducted to determine the optimum water-to-binder (w/b) ratio for all the concrete mixtures under investigation during phase I of the project. Findings from the literature review indicated that HPC mixtures are predominately manufactured with w/b ratios in the range of 0.20 to 0.45 [4]; hence, w/b ratios of 0.30, 0.35 and 0.40 were utilized to determine the optimum w/b ratio for phase I. Based on the results obtained from compressive strength and flexural strength tests, a w/b ratio of 0.3 was selected 3.1.4.2

Having selected the w/b ratio for the concrete mixtures, the primary factors that were investigated during phase I included: 1) combination of supplementary cementitious materials (i.e., silica fume plus slag versus silica fume plus fly ash); 2) coarse aggregate type (i.e., crushed versus natural aggregate); and 3) methods for curing the concrete mixtures. These factors (treatments) are discussed in more detail in the following sections.

3.1.1 Experimental Matrix

Table 21 below is a 2×2×3 (two by two by three) matrix summarizing the experiment design for phase I. It identifies the tests conducted on the hardened concrete mixtures as well as the number of specimens per test for each mixture investigated. Details of the tests are provided below in Section 3.2.1.

The first group in the matrix was the control mixture (ODOT Class 4350, 2002 Standard Specifications) [44] which was a normal-weight concrete consisting of natural aggregate (gravel) for the coarse aggregate fraction, cement, sand, and water, plus an air-entraining agent. The control mixture was divided into three different sub-categories, each pertaining to three different curing regimes, all of which are described in detail under Section 3.1.1.1.

The experimental mixtures (A, B, C, and D) contained, in addition to cement, sand, water and an air-entraining agent, different combinations of supplementary cementitious materials (SCMs), as described in detail in Section 3.1.1.1. Two of these contained natural aggregate (gravel), while the other two contained crushed rock, as the coarse aggregate fraction.

Table 21 indicates that the concrete mixtures were tested at differing periods; that is, freeze and thaw at 14 days, compressive strength at 28 and 90 days, and chloride ion penetration resistance and abrasion resistance at 90 days. At 14 days, the concrete has still not attained its maturity and is really susceptible to wetting and drying. Concrete samples subjected to very severe conditions during the freeze-thaw test conducted in the laboratory might be considered as a reasonable measure of field performance. Compressive strength test conducted at 28 days is a standard test. It is believed that if concrete attains characteristic strength at 28 days, then it has attained 90% of the total strength and has passed the compressive strength requirement. Compressive strength at 90 days was conducted to obtain a relationship between compressive strength, abrasion resistance, and chloride ion penetration resistance of the concrete. Three samples were tested for each test for each concrete mixture to obtain variance and standard error.

Table 21: Phase I experimental matrix

			Curing Regime / Test Period	Number of Specimens for:				Subtotal Number of Specimens
				Compressive Strength (ASTM C 39; AASHTO T 22)	Chloride Ion Penetration Resistance (ASTM C 1202; AASHTO T 277)	Abrasion Resistance (ASTM C 779)	Freeze-Thaw Resistance (ASTM C 666; AASHTO T 161)	
	Gravel	ODOT Class 4350	Water: 14-day	---	---	---	3	3
			28-day	3	---	---	---	3
			90-day	3	3	3	---	9
			Steam[a]: 14-day	---	---	---	3	3
			28-day	3	---	---	---	3
			90-day	3	3	3	---	9
			Steam[b]: 14-day	---	---	---	3	3
			28-day	3	---	---	---	3
			90-day	3	3	3	---	9
Silica Fume and Slag	Gravel	Experimental Mix A	Water: 14-day	---	---	---	3	3
			28-day	3	---	---	---	3
			90-day	3	3	3	---	9
			Steam[a]: 14-day	---	---	---	3	3
			28-day	3	---	---	---	3
			90-day	3	3	3	---	9
			Steam[b]: 14-day	---	---	---	3	3
			28-day	3	---	---	---	3
			90-day	3	3	3	---	9
	Crushed Rock	Experimental Mix B	Water: 14-day	---	---	---	3	3
			28-day	3	---	---	---	3
			90-day	3	3	3	---	9
			Steam[a]: 14-day	---	---	---	3	3
			28-day	3	---	---	---	3
			90-day	3	3	3	---	9
			Steam[b]: 14-day	---	---	---	3	3
			28-day	3	---	---	---	3
			90-day	3	3	3	---	9
Silica Fume and Fly Ash	Gravel	Experimental Mix C	Water: 14-day	---	---	---	3	3
			28-day	3	---	---	---	3
			90-day	3	3	3	---	9
			Steam[a]: 14-day	---	---	---	3	3
			28-day	3	---	---	---	3
			90-day	3	3	3	---	9
			Steam[b]: 14-day	---	---	---	3	3
			28-day	3	---	---	---	3
			90-day	3	3	3	---	9
	Crushed Rock	Experimental Mix D	Water: 14-day	---	---	---	3	3
			28-day	3	---	---	---	3
			90-day	3	3	3	---	9
			Steam[a]: 14-day	---	---	---	3	3
			28-day	3	---	---	---	3
			90-day	3	3	3	---	9
			Steam[b]: 14-day	---	---	---	3	3
			28-day	3	---	---	---	3
			90-day	3	3	3	---	9

NOTES:

[a]Steam cure + water cure to 14 days + ambient cure to 90 days

[b]Steam cure + ambient cure to 90 days

3.1.2 Treatments

Three different treatments were studied in phase I; namely; aggregates, supplementary cementitious material, and curing method. Each treatment is described in the following sections.

3.1.2.1 Aggregates

Oregon is a state with numerous rivers and naturally occurring gravels are found in abundance. The precast industry in Oregon uses river gravel as coarse aggregate in their precast slabs and members due to abundance and cheap availability of river gravel. But the literature review suggests that abrasion of the concrete is directly proportional to the hardness of the aggregate used in the mixture. It was found in the literature review that use of crushed aggregate like basalt increased the abrasion resistance of concrete several-fold [20]. Therefore in this research, it was decided to compare the abrasion resistance obtained by the use of conventional river gravel as coarse aggregate in the HPC concrete to that obtained by the use of crushed rock. It was reasoned that if the use of more costly crushed rock significantly increased the abrasion resistance of the concrete, it may be more economical from a life cycle standpoint to use crushed rock rather than river gravel. Hence, the two treatments regarding aggregate type included river gravel versus a crushed rock. They are identified in experiment matrix as Experimental Mixtures ‘A’ versus ‘B’ and ‘C’ versus ‘D’.

3.1.2.2 Cementitious Materials

According to the literature review, silica fume reduces the permeability of concrete, thus improving the protection of steel imbedded in the concrete against corrosion. It also increases the early age compressive strength and abrasion resistance of the concrete apart from improving fresh properties like reduced bleeding. To satisfy the requirement of the early age strength (1 day) of pre-cast concrete, it was important to incorporate silica fume. Therefore, it became mandatory to include silica fume in the experimental mixtures. Silica fume content in phase I was set at 4%. In addition, fly ash and slag both play an important role in improving durability of HPC by reducing permeability and by increasing abrasion resistance and freeze-thaw resistance. Slag also helps in mitigating the effect of alkali silica reactivity and sulfate attack. Slag has cementitious properties while fly ash is pozzalanic in nature. Nevertheless, there remains a need to study the effect of supplementary cementitious materials on the abrasion of concrete caused by use of studded tires. Class F fly ash is cheaper than slag. Therefore, efforts were taken in phase I of this research study to separately investigate the effects of combinations of silica fume and slag versus combinations of silica fume and fly ash. They are identified in the experiment matrix as Experimental Mixtures ‘A’ versus ‘C’ and ‘B’ versus ‘D’.

3.1.2.3 Curing

Curing plays an important role in improving the durability of concrete structures by preventing the internal water of the concrete from evaporating and thus enhancing or aiding the hydration process of the cement in concrete. There are various ways of curing concrete structures, among which water curing is the most effective method. Since manufacturers of pre-cast concrete members (e.g., bridge girders) require high early strength for high production purposes, the manufacturers raise the concrete temperature through steam curing, thereby aiding the cement hydration process. Though by steam curing one can easily attain a compressive strength of nearly 4,500 psi at 1 day, ultimate strength is either the same or less than that obtained by water curing for 28 days.

Therefore in this research study, efforts were taken to compare between three different curing regimes: 1) water curing at 23±2°C (73±3°F) for 28 days and beyond up to 90 days, as required, 2) steam curing A (steam curing followed by water curing for 14 days followed by ambient curing up to 28 days and beyond up to 90 days, as required), and 3) steam curing B (steam curing followed by ambient curing up to 90 days).

3.1.3 Response Variables

All the concrete mixtures were tested for four different properties of hardened concrete. These are categorized under primary and secondary response variables according to research interest.

3.1.3.1 Primary Response Variables

The main aim of the project was to develop a mixture design for HPC with improved abrasion resistance and chloride ion penetration resistance and thereby increasing the durability of the concrete. Therefore, abrasion resistance and chloride ion penetration resistance properties of the concrete mixtures were the primary investigation factors, or the primary response variables.

3.1.3.1.1 Abrasion

According to American Concrete Institute 2009, abrasion resistance of concrete can be defined as "ability of a surface to resist being worn away by rubbing and friction" [45]. Abrasion, a mechanical property of concrete is basically a surface phenomenon. The paste at the surface of newly-placed concrete abrades away pretty quickly and exposes the aggregate, which further gets damaged due to impact and abrasion. Abrasion causes surface wear which aggravates various problems like chloride ion diffusivity and corrosion of embedded steel bars subsequently leading to failure of structures. Abrasion of different concrete structures takes place due to different factors such as abrasion of dam spillways due to water borne particles, abrasion of floors due to production operations and rubbing by foot, and abrasion of pavements and bridge deck slabs due to vehicular traffic, particularly by vehicles equipped with studded tires. Some of the factors that affect abrasion are w/c ratio, compressive strength, finishing technique, curing, types of aggregates, etc.

This research was mainly focused on abrasion of the concrete bridge deck slab caused by studded tire and aimed at improving it. When vehicles travel on bridges and highways, the tires of vehicles cause the wear of the concrete surface due to friction between the bridge surface and tire. Abrasion of concrete is more prominent in the late fall and winter months in areas that allow studded tires on vehicles. In order to reduce abrasion of concrete, efforts were taken to develop high performance concrete which is abrasion resistant.

3.1.3.1.2 Chloride Ion Permeability

Permeability is a general word which refers to the amount of water or other substances (e.g., ions, gas, and liquids) that can penetrate a concrete. This research was mainly concerned with chloride ion permeability. Generally, chlorides are introduced into the deck slabs through deicing salts and sea water. Porous concrete allows water containing chloride ions to enter into the concrete and corrode the embedded steel reinforcement, thereby increasing the chance of concrete failure and, hence, considerably reducing the service life of the concrete structure. In other words, the higher the permeability of the concrete, the less durable it tends to be. Permeability of concrete is affected by the size and arrangement of pores, and the interfacial transition zone of concrete, paste quality, aggregate gradation. Permeability of concrete can be improved by the use supplementary cementitious materials like silica fume, fly ash and slag.

3.1.3.2 Secondary Response Variables

3.1.3.2.1 Freeze Thaw Resistance

Freeze-thaw resistance is defined as the ability of concrete to withstand cycles of freezing and thawing. When the concrete is exposed to alternate cycles of freezing and thawing, water inside the concrete pores alternatively expand and contract creating hydraulic pressures which ultimately leads to detorioration of concrete. Some of the factors that affect freeze-thaw are air entrainment, void spacing factor, aggregate durability, and properties of the paste. Freeze and thaw is a severe at high altitude exposed to alternate freezing and thawing. Freeze and thaw resistance of a concrete can be enhanced by use of air entrainment.

3.1.3.2.2 Compressive strength

Compressive strength can be defined as, “The maximum resistance that a concrete specimen will sustain when loaded axially in compression in a testing machine at a specified rate” [45]. It is the basic and most important parameter for quality control of concrete. Historically, high strength was considered as a sign of better concrete. In today’s world, higher strength concrete does not necessarily equate to a highly durable concrete. Still, some factors such as abrasion resistance and chloride ion permeability are directly proportional to compressive strength. Compressive strength still plays an important role in practical applications where durability is a significant concern.

3.1.4 Mixture Designs

3.1.4.1 Overview

A total of five mixture designs were developed in accordance with ACI 211.1-91 – R 2002. [46] The first mixture design, named the 'Control Mix', was developed to meet the requirements of the ODOT 2002 Standard Specifications [44] and acted as the basis for comparison with the mixture designs for the experimental mixtures. These were developed in an attempt to exceed the performance of the Control Mix in terms of abrasion and chloride ion penetration resistance. The mixture designs are described in detail in the following two sections.

3.1.4.2 Mixture Designs for Control Mixture

The required criteria of minimum compressive and flexural strength, air content, cement content, water-to-cement ratio (w/c ratio), etc. for the Control Mix were set according to the ODOT 2002 Standard Specifications for an ODOT Class 4350 concrete mixture for bridge deck panels [44]. Several trials were required to determine the optimum w/c ratio that would provide the highest compressive strength and satisfy the requirement for flexure strength.

The final concrete mixture design for control mix was developed after several trials. The nominal maximum size of aggregate for the Control Mix was kept at 3/4 inch, slump was targeted at 4 inches, and the entrained air content for severe condition of exposure was determined to be 6%. Several trials were required to determine the optimum dose of air entraining agent to achieve 6% air content. Type I cement and sand with a fineness modulus of 3.0 were used in the mixture. Once the optimum dose of air entraining agent was determined, three mixtures with water-to-cement ratios of 0.30, 0.35, and 0.40 were cast, cured, and tested for fresh and hardened concrete properties. Tests conducted on the fresh concrete included determination of unit weight, air content, slump, density and the temperature of the concrete. Tests conducted on the hardened concrete included determination of compressive strength and flexural strength. Based on the results obtained from the laboratory tests and the requirements of the ODOT specifications, the mixture design with a w/c ratio of 0.30 was selected for the final mixture design for the Control Mix. A summary of results is given in Table 22. A detail of the mixture design is given in appendix A. The details of the tests performed are presented in the appendix B.

Table 22: Summary of flexural tests and compressive tests for Control mixture

Materials	Mixture A	Mixture B	Mixture C
w/c ratio	**0.3**	0.35	0.40
Cement	900	771	675
Coarse aggregate	1648	1648	1648
Fine aggregate	970	1070	1145
Water	270	270	270
Compressive Strength at 28 days,	5970	5240	3500
Flexure Strength at 28 days, psi	670	510	510

3.1.4.3 Mixture Designs for Experimental Mixtures

The mixture design for experimental mixtures was selected on the basis of high compressive strength through an extensive literature review. The mixture design was similar to that used by the Morse Brothers, Inc. (now Knife River). The basic mixture design was same for all four experimental mixtures except that slight modifications were made to the base mixture design to account for different specific gravities of the two coarse aggregates used. A spreadsheet for mixture design is given in appendix A. All mixtures were comprised of 4% silica fume and 30% slag or fly ash for their respective mixture design. The ratio of the percentage of fine aggregate to coarse aggregate was kept at 40:60. ‘Experiment mixture A’ was similar to that used by Morse Brothers and contained 30% slag, natural sand, and river gravel. ‘Experiment mixture B’ constituted crushed rock instead of gravel along with 30% slag and natural sand. Similarly, ‘Experiment mixtures C and D’ contained 30% fly ash instead of slag, along with gravel and crushed rock, respectively. A summary of all the mixture designs used in phase I of the research project is given in Table 23.

Table 23: Summary of mixture designs for phase I

Mix Design	Units	Control	Exp A	Exp B	Exp C	Exp D
Max. size of aggregate used	-	3/4 in.	3/4 in.	3/4 in.	3/4 in.	3/4 in.
Max. w/b ratio	-	0.30	0.30	0.30	0.30	0.30
Total cementitious content	lb	900	800	800	800	800
Cement	lb	900	528	528	528	528
Fly ash	lb	0	0	0	240	240
GGBFS (slag)	lb	0	240	240	0	0
Micro silica (silica fume)	lb	0	32	32	32	32
Water	lb	270	240	240	240	240
3/4-1/2 in.	lb	1,648	613	1,786	613	1,786
1/2 - 4# in.	lb		1,173		1,173	
Sand	lb	929	1,048	1048	1,234	1,234
Aggregate to binder ratio	ratio	2.86	3.54	3.54	3.78	3.78
Fine aggregate (%) to coarse aggregate ratio (%)	ratio	36:64	40:60	40:60	40:60	40:60
Fly ash/GGBFS as a percentage of total cementitious material	%	0 %	30%	30%	30%	30%
Micro silica as a percentage of total cementitious material	%	0%	4%	4%	4%	4%
Air entraining agent dose (ml)	ml	1,,037	149	325	108	325
High-range water-reducer dose	ml	0	1,359	1,561	1,350	1,561

Table 24 gives the details of nomenclature used for each individual mixture design used in phase I of the research study. The first group starting with a "C" indicated the Control Mixture followed by characters indicating the three different curing regimes. The mixture which underwent 'Water Curing' was abbreviated as 'CW'; the mixture that was subjected to 'Steam Curing A' was abbreviated as 'CSA'; and the mixture subjected to 'Steam Curing B' was abbreviated as 'CSB'. Similarly, 'Experimental mixture A' with 'Water Curing' was abbreviated as 'EAW', with 'Steam Curing A' as 'EASA', and with 'Steam curing B' as 'EASB'; and 'Experimental mix B' with 'Water Curing' was abbreviated as ‘EBW’, with ‘Steam Curing A’ as ‘EBSA’, and with ‘Steam curing B’ as ‘EBSB’. Finally, ‘Experimental mix C’ with ‘Water Curing’ was abbreviated as ‘ECW’, with ‘Steam Curing A’ as ‘ECSA’, and with ‘steam curing B’ as ‘ECSB’; and ‘Experimental mix D’ with ‘Water Curing’ was abbreviated as ‘EDW’, with ‘Steam curing A’ as ‘EDSA’, and with ‘Steam curing B’ as ‘EDSB’

Table 24: Nomenclature for mixture designs used for identification

Mixture ID	Mixture Description
CW	Control Mix - water curing
CSA	Control Mix - steam curing + water cure to 14 days + ambient cure to 90 days (Steam Curing
CSB	Control Mix - steam curing + ambient cure to 90 days (Steam Curing B)
EAW	Experimental Mix A - water curing
EASA	Experimental Mix A - steam curing + water cure to 14 days + ambient cure to 90 days (Steam Curing A)
EASB	Experimental Mix A - steam curing + ambient cure to 90 days (Steam Curing B)
EBW	Experimental Mix B - water curing
EBSA	Experimental Mix B - steam curing + water cure to 14 days + ambient cure to 90 days (Steam Curing A)
EBSB	Experimental Mix B - steam curing + ambient cure to 90 days (Steam Curing B)
ECW	Experimental Mix C - water curing
ECSA	Experimental Mix C - steam curing + water cure to 14 days + ambient cure to 90 days (Steam Curing A)
ECSB	Experimental Mix C - steam curing + ambient cure to 90 days (Steam Curing B)
EDW	Experimental Mix D - water curing
EDSA	Experimental Mix D - steam curing + water cure to 14 days + ambient cure to 90 days (Steam Curing A)
EDSB	Experimental Mix D - steam curing + ambient cure to 90 days (Steam Curing B)

3.2 Pilot Study

Based on the results obtained from phase I, it was found out that water curing for 28 days was the best method of curing (which was also evident from the literature review), while the steam curing followed by the ambient curing provided the worst results in terms of compressive strength, abrasion resistance, and chloride ion permeability (Section 5 for details). However, it is really impracticable to apply water curing in the precast industry because it will hamper the production process by reducing productivity and may result in more costly products. For these reasons, it became important to conduct a pilot study to establish the best rapid-curing method that would give similar results similar to 28-day water curing.

3.2.1 Experimental Matrix

Table 25 presents a summary of nine curing methods (i.e., nine different treatments) and the number of samples of each mixture that was tested for compressive strength at different intervals. As shown in the experimental matrix, each mixture was tested for compressive strength at 1-day, 3-day, 7-day, 14-day and 28-day to capture strength development over time. To reduce variability, a sufficient amount of the concrete was mixed to provide enough samples for up to three treatment conditions.

Table 25: Experimental matrix for the pilot study

Mixture ID	Curing Method (Treatment)	Compressive Strength (Response Variable) at				
		1 day	3 days	7 days	14 days	28 days
1	Water curing up to 28 days	3	3	3	3	3
2	14 Days water curing + ambient curing	x	x	x	x	3
3	7 Days water curing + ambient curing	x	x	x	3	3
4	14 Days water curing + curing compound + ambient	x	x	x	x	3
5	7 Days water curing + curing compound + ambient	x	x	x	3	3
6	1 Day water curing + curing compound + ambient	x	3	3	3	3
7	3 Days water curing + curing compound + ambient	x	x	3	3	3
8	3 Days water curing + ambient curing	x	x	3	3	3
9	1 Day water curing + ambient curing	x	3	3	3	3
10	Steam curing + ambient curing	3	3	3	3	3
11	Steam curing + curing compound + ambient curing	3	3	3	3	3

3.2.2 Treatments

In the pilot study, curing method was the only treatment investigated. ODOT was interested in shortening the duration of field curing; therefore investigation was done for 14 days water curing, 7 days water curing and 3 days water curing to capture the optimal curing length to be followed at field. Since the pilot study was aimed at studying different curing types, 12 different treatments (in terms of 12 different curing methods) were applied to only one mixture composition. The details of the mixture composition are provided under section 3.2.4.

3.2.3 Response Variables

All of the samples prepared for the pilot study was tested for only one response variable; that is, compressive strength. Because compressive strength of the concrete is directly proportional to abrasion resistance, this test was identified as an indirect measure of abrasion resistance. Hence, it was reasoned that compressive strength would be an adequate way to determine the best curing method to carry forward into phase II of the project.

3.2.4 Mixture Designs

As alluded to earlier, only one mixture design was utilized for the pilot study. It incorporated 66% cement, 10% silica fume, and 24% slag for the cementitious ingredients, river gravel for the coarse aggregate and natural sand for the fine aggregate.

3.3 Phase II

The principal objective of phase II was to improve upon the most promising mixture design developed in phase I. The results from phase I indicated that the HPC mixtures were more durable than the Control Mixture (Section 5). Due to a change in the ODOT Standard Specifications 2008 [47] for bridge deck mixtures, it became necessary to modify the direction of the research to include a new 'control mixture' which constituted an HPC mixture with 66% cement, 4% silica fume, and 30% fly ash. Use of crushed rock showed significant improvement in abrasion resistance and compressive strength, but barely satisfied the maximum chloride ion permeability requirement of 1000 coulombs set by the new (2008) specification. Locally available river gravel, instead of crushed rock, was used to develop a mixture that would satisfy the objectives of the research without the added expense of the crushed rock. Also, since the chloride ion penetration resistance requirement was so stringent, ODOT requested that the amount of silica fume be varied to observe its effect on chloride ion penetration resistance and abrasion resistance. This gave rise to phase II of the study.

3.3.1 Experimental Matrix

Table 26 summarizes the experiment matrix for phase II of the study. Mixtures A, B, C, D, and E were the primary mixtures investigated. The tests conducted on the mixtures, along with the number of sample per test per mixture, is also shown in the experiment matrix. Two more experiment mixtures (S and T) with higher cement contents were also investigated to determine if it was possible to get a highly durable mixture with increased cement content at low to moderate silica fume content. Mixture S was non-air entrained concrete while others were air entrained concrete

Table 26: Phase II experimental matrix

Mixture ID	**Material Proportion**				**Number of Specimens for**				
					Compressive Strength			**Abrasion Resistance**	**Chloride Ion Perm.**
	Cement	Slag	Fly Ash	Silica Fume	1-day	28-day	56-day	56-day	56-day
Control	66%	-	30%	4%	3	3	3	3	3
Mix A	66%	27%	-	7%	3	3	3	3	3
Mix B	66%	24%	-	10%	3	3	3	3	3
Mix C	66%	-	27%	7%	3	3	3	3	3
Mix D	66%	-	24%	10%	3	3	3	3	3
Mix E	66%	30%	-	4%	3	3	3	3	3
Mix S	58%	35%	-	7%	-	3	3	3	3
Mix T	58%	38%	-	4%	3	3	3	3	3

3.3.2 Treatments

Only two independent treatments were investigated in phase II. The first treatment was level of silica fume used. Since the new control mixture already contained 4% silica fume, the other two levels included 7 and 10%. The second treatment was type of supplementary cementitious material, either fly ash or slag. The method of curing was based on the results obtained from the pilot study (Section 3.2). All the specimens were steam cured after initial set, de-molded and applied with a curing compound coating and were left in ambient environment for curing until tested.

3.3.2.1 Supplementary Cementitious Materials

Phase I aimed at comparing the effect of different supplementary cementitious materials, fly ash and silica fume versus slag and silica fume, on the abrasion resistance and durability of HPC. Phase II took it one step further by varying the proportions of the supplementary cementitious materials Section 3.1.1.1.2 provided a brief discussion regarding the use of these materials in concrete mixtures.

3.3.2.2 Levels of Silica fume

According to the literature review, an improvement in HPC durability through reduced permeability can be achieved with increased silica fume content. To investigate whether or not increased silica fume content significantly increases the durability of HPC, different percentages of silica fume were used in the mixtures. The base for comparison was 4% of silica fume. The other two percentage of silica fume were 7% and 10% as a replacement of cement. The intermediate quantity (i.e., 7%) was chosen since findings from the literature review suggested that this level of silica fume enhances the durability properties of concrete. But when the level of silica fume is increased beyond 7%, a very high amount of silica fume is required to attain the same properties. Therefore, a level of 10% was chosen as the maximum quantity to be used in the HPC.

3.3.3 Response Variables

3.3.3.1 Primary Response Variables

All the concrete mixtures developed in the phase II were tested for abrasion resistance and chloride ion permeability resistance as primary response variables. Section 3.1.2.1 provided an overview of these tests.

3.3.3.2 Secondary Response Variables

Since the worst mixture in phase I satisfied the freeze-thaw durability requirement of the ODOT Standard Specifications, it was reasoned that all of the concrete mixtures in phase II would be more durable and would easily satisfy the specified freeze-thaw requirements. Hence, ODOT recommended the elimination of freeze- thaw testing in phase II. However, compressive strength was retained as a secondary response variable. An overview of this test was provided in Section 3.1.2.2.

3.3.4 Mixture Designs

3.3.4.1 Overview

A new 'control mixture' was designed based on the new ODOT specification (ODOT 2008), details of which are provided in 3.3.4.2. Also, the mixture designs for the experimental mixtures were developed based on the different treatments identified in Section 3.3.2.

3.3.4.2 Mix Designs for Control Mixture

Table 02001-1 in Section 02001.30 of the 2008 ODOT Standard Specifications [46] provides the details of HPC mixtures used for structural concrete deck slabs. It specifies a compressive strength of 4000 psi, a maximum w/c ratio of 0.40, and constituents and criteria as follows:

> *High performance concrete (HPC) mix designs shall either contain cementitious material with 66% portland cement, 30% Fly ash, and 4% Silica fume; or have trial batches performed to demonstrate that the alternate mix design provides a maximum of 1,000 coulombs at 90 days when tested according to AASTHO T 277.*

Additional criteria indicate a maximum slump of 10 inch for pre-cast pre-stressed concrete, use of a high-range water-reducing admixture (Table 02001-3), an air content of 6% (+2%/-1%) for concrete exposed to severe condition, and a nominal maximum aggregate size of 3/4 inch (Table 02001-2). Details of the mixture design are given in Table 27.

3.3.4.3 Mix Designs for Experimental Mixtures

A summary of the mixture designs for the experimental mixtures is given in Table 27. As indicated, the mixture designs have different levels of silica fume, and either slag or fly ash, also at different levels. Mixtures A, B and E contained slag while the control mixture and mixtures C and D contained fly ash. Mixtures B and D contained 10% silica fume and 24% slag or fly ash, respectively. Similarly, mixtures A and C contained 7% silica fume and 27% slag or fly ash, respectively. The control mixture and mixture E contained

4% silica fume and 30% slag or fly ash, respectively. Mixtures S and T contained higher cement contents relative to the other mixtures. Though the percentage of cement in mixtures S and T was less than that of the other mixtures (i.e., 58% instead of 66%); mixtures S and T had 7% and 4% silica fume, respectively. Also, mixture S did not contain an air entraining agent, whereas mixture T did to obtain 6% air. All mixtures, except mixtures S and T, were designed with a w/b ratio of 0.30; mixture S had a w/b ratio of 0.26, and mixture T had a w/b ratio of 0.27.

Table 27: Summary of mixture designs for phase II*

Mix ID	Control	Mix A	Mix B	Mix C	Mix D	Mix E	Mix S	Mix T
Cement-Type III	541	541	541	541	541	541	604	604
Fly Ash	246	0	0	221	197	0	0	0
Slag	0	221	197	0	0	246	365	396
Silica Fume	33	57	82	57	82	33	74	42
Water	245	245	245	245	245	245	269	279
Coarse Aggregate-3/4-1/2	661	661	661	661	661	661	620	624
Sand	928	957	950	925	921	963	1065	1062
w/c ratio	0.30	0.30	0.30	0.30	0.30	0.30	0.26	0.27

*Quantities in lb/ft3

4 MATERIALS AND METHODS

Once the mixture designs were developed, the required materials were procured from different sources. The materials were then mixed, cast, and tested as per set standards. This section provides brief descriptions of the materials and tests utilized for this study.

4.1 Materials Descriptions

Once the mixture designs were developed, the required materials were procured from different sources. The materials were then mixed, cast, and tested as per set standards. This section provides brief descriptions of the materials and tests utilized for this study.

4.1.1 Aggregates

4.1.1.1 Coarse Aggregate

The nominal maximum size of ¾ inch was selected for aggregates in the experimental mixture design. Unwashed gravel with some crushed particles, obtained from Knife River in Corvallis pit, was used as the coarse rock for the control mixtures tested in phase I and in the pilot study. A fully crushed, hard basalt rock obtained from Knife River's quarry, Watters was also used as coarse aggregate in phase I. This aggregate was very dense, dark black in color, and angular in structure. Washed, rounded gravel with some crushed particles used for the experimental mixtures in all phases were divided into two gradation sizes, namely, ¾ in. to ½ in. and ½ in. to #4. All coarse aggregates were densely graded between the ¾ inch to #4 sizes.

4.1.1.2 Fine Aggregate

Unwashed sand was used for control mixture in phase I, while washed sand was used for all of the experimental mixtures in phase I, pilot study and phase II. The source of the sand was the Knife River Corvallis pit. The sand had fineness modulus of 3.0.

Physical analyses of both coarse and fine aggregates were done according to ASTM C-33 [47]. The results of these tests are shown in the Table 28.

Table 28: Physical Properties of Coarse and Fine Aggregate

	Gravel for Control mixture	Gravel for Experimental mixture		Crushed rock	Sand for Control mixture	Pre-stressed sand
	-	3/4 - 1/2 in.	1/2 in. -# 4	3/4 -1/2 in.	-	-
Specific gravity (SSD)	2.6	2.58	2.58	2.77	2.55	2.54
Specific gravity (Dry)	2.5	2.52	2.5	2.71	2.46	2.46
% water absorption	2.5	2.7	3.02	2.0	3.8	3.42
Fineness Modulus	-	-	-	-	3.0	3.0
% Passing						
For coarse aggregate						
1 in.		100.00%		100	-	-
¾ in.		88.36%		96.7%	-	-
½ in.		15.54%		66.4%	-	-
3/8 in.		5.03%		36.5%	-	-
#4		0.62%		1.2%	-	-
For fine aggregate						
#4	-	-	-	-	96.54	96.54
#8	-	-	-	-	77.41	77.41
#16	-	-	-	-	63.07	63.07
#30	-	-	-	-	49.91	49.91
#40	-	-	-	-	36.38	36.38
#50	-	-	-	-	18.25	18.25
#100	-	-	-	-	2.6	2.6
#200	-	-	-	-	0.84	0.84

4.1.2 Cement

Cement used for the mixtures design in phase I was Type I cement. Tests certificates for Type I cement were not available. Cement used for pilot study and phase II was of Type III and met the requirements of ASTM C-150 [48]. The cement was supplied by Ash Grove Cement Company, Durkee, Oregon. Test results of physical and chemical analyses of cement are summarized in Table 29.

Table 29: Physical and chemical analyses of ASH GROVE type III cement

Tests	ASH GROVE type III cement
Chemical Properties	
Silicon dioxide (SiO_2), %	21
Aluminum oxide ($A1_20_3$), %	3.4
Ferric oxide (Fe_20_3) , %	2.9
Calcium oxide (CaO), %	63.1
Magnesium oxide (MgO), %	1.7
Sulfur trioxide (SO_3), %	2.9
Loss on ignition, %	1.46
Sodium oxide (Na_20), %	0.21
Potassium oxide (K_20), %	0.48
Total equivalent alkali content, %	0.53
Tricalcium silicate, %	62
Dicalcium silicate, %	14
Tricalcium aluminate, %	3
Tetracalcium aluminoferrite, %	9
Insoluble residue, %	0.48
Physical Properties	
Fineness, m^2/Kg	549
Specific Gravity	3.15
Autoclave expansion	0.00%
Time of setting, minutes	
Initial	93
Final	169
Compressive strength, psi	
1 day	3318
3 days	4826
7 days	5943

4.1.3 Slag

NewCem slag was used in the research project and was supplied by Lafarge North America Company from their Seattle Cement Plant. It met all the requirements of ASTM C 989 [18]. Detailed physical and chemical test results of the slag are given in the Table 30.

Table 30: Physical and chemical analysis of NewCem slag

Tests	NewCem Slag
Chemical Properties	
Sulfide sulfur (S), %	0.77
Sulfate Ion (SO_3), %	2.72
Physical Properties	
Fineness, m^2/kg	421
Specific Gravity	2.89
Air Content, %	5.3
Compressive strength, psi	
7 day	4,300
28 days	6,365
Slag Activity Index	
7 day	94
28 days	122

4.1.4 Fly ash

There are two types of fly ash, namely, Class F fly ash and Class C fly ash. Class F fly ash was used in this research study due to the abundant availability of this material in Oregon at the time the study began. This fly ash was supplied by CTL Thompson Materials Engineers, Inc. from their Centralia plant. It met the requirements of ASTM C618-05 [7]. Test results of physical and chemical analyses of fly ash are given in Table 31.

Table 31: Physical and Chemical Analyses of Class F Fly Ash

Tests	Class F fly ash
Chemical Properties	
Chemical Properties	
Silicon dioxide (SiO_2), %	55.3
Aluminum oxide (Al_20_3), %	16.7
Ferric oxide (Fe_20_3) ' %	5.8
Calcium oxide (CaO), %	9.9
Sulfur trioxide _SO_3), %	0.5
Loss on ignition, %	0.1
Sodium oxide (Na_20),%	1.86
Potassium oxide (K_20), %	0.9
Total Silica, Aluminum, Iron, %	77.8
Physical Properties	
Fineness, retained on #325 sieve, %	22.4
Specific Gravity	2.56
Autoclave expansion, %	0.05
Moisture content, %	0
Slag Activity Index	
Ratio to control@ 7 day	81.1
Ratio to control@ 28 day	89.6
Water requirement, % of control	92.6
Drying shrinkage, increase @ 28 days, %	0

4.1.5 Silica Fume

Silica fume used in the research project was in the form of dry compacted powder. It was manufactured by Masters Builders and was given by Knife River. The specific gravity of the silica fume used was 2.2. Silica fume used in the project satisfied all the requirements of ASTM C 1240. [15]

4.1.6 Admixtures:

Glenium 3400 NV was used as a high-range water-reducing admixture in the research study. Glenium 3400 NV admixture met the requirements of ASTM C 494/C 494M – 99. [49] As per material data sheet of Glenium 3400 NV, 8 to 12 fl Oz per 100 lbs of cement is required for HPC with a slump of around 10”. Actual quantity of admixture required for each mixture design was based on trial and error. Benefits of Glenium 3400 NV are enumerated as follows: [50]

- Can be used in a wide variety of concrete mixtures as a Type A or Type F admixture
- Extremely high early strength development
- Improved finish ability and surface appearance
- May reduce/eliminate need for vibration and heat curing
- Improves overall production cost efficiencies
- Increases productivity

Air entraining agent used in this project was MBAE 90. It met the requirements of ASTM C 260 [51]. Typical dosage of MBAE 90 is 1/4 to 4 fl Oz per 100 lbs of cement [52]. Actual quantity was determined through trial and error.

4.1.7 Curing Compound

Curing compound used in this project was 1300 Clear which is a water-based, wax based concrete curing compound. It was supplied by W. R. Meadows. It was white in color. It satisfied all the requirements set by the ODOT [46]. Curing compound was applied as per manufacturer's data sheet.

4.2 Laboratory Concrete Mixing Method

Mixing of concrete in the laboratory was done in accordance with ASTM C 192 [53] during the phase I of study. Since, silica fume content in the pilot study and phase II was much higher, longer mixing times was required for homogeneous mixing of the silica fume. For this purpose, it was proposed to follow the mixing procedure recommended by the Silica Fume Association. Figure 1 provides a flow chart of the mixing process for the concrete with supplementary cementitious materials utilized in this study. Flow chart is based on the guidelines and recommendations from the Silica Fume Association. [54] All mixing was performed in a concrete mixer with a 2.5 cubic feet capacity.

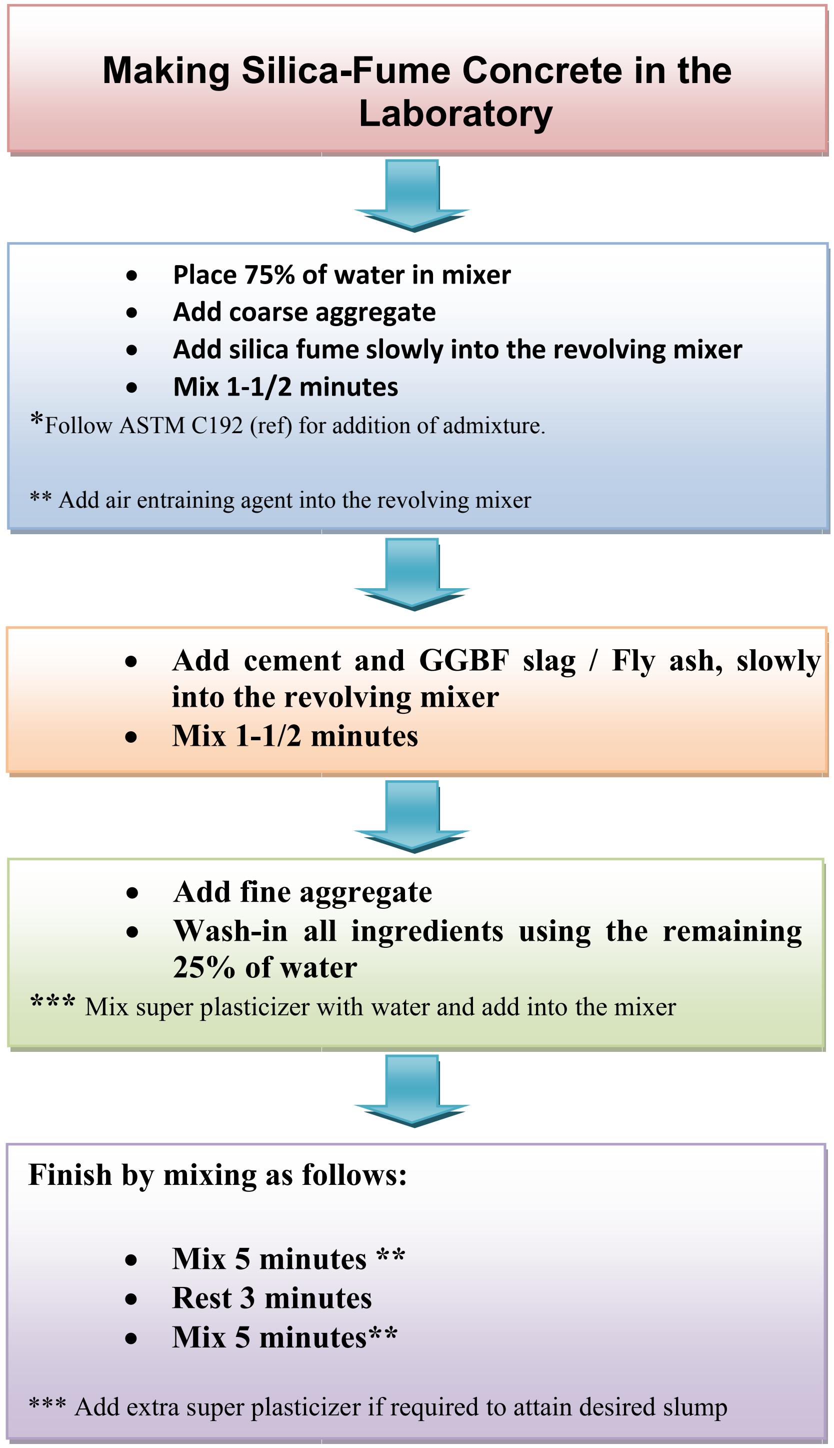


Figure 1: Flow chart for mixing procedure [54]

4.3 Casting

All specimens were cast according to ASTM C 192 [53]. All concrete cylinders were cast in 4”x8” plastic molds while the slabs were cast in 12”x12”x3” steel molds. The freeze and thaw beams were cast in 11”x3”x3” steel molds. Once the specimens were cast, they were cured according to the predetermined curing method.

4.4 Curing

The method of steam curing was investigated for use to simulate the curing method followed by the precast industry. In general, steam curing is used when it is essential to achieve high early strength. In a study of curing methods on concrete containing 10 percent silica fume, it was found that the steam curing gave the concrete higher early-age compressive strength compared to air curing and moist curing methods [55]. Additionally, it was found that the use of steam curing decreases the permeability of silica fume concrete as compared to the other methods [55]. Different phases of the research study adopted different curing methods, all of which are described in Section 3.

Water curing involved soaking of specimens in lime-saturated water at 23±2°C (73±3°F) for a specified duration of time [53]. Steam curing involved soaking the specimens at ambient temperature until initial setting, followed by increasing the temperature to 140°F in two hours, and again soaking the specimen at 140°F for up to 8 hours, followed by decreasing the temperature to ambient temperature in approximately two hours.

Figure 2 displays two production steam curing regimes and one laboratory curing regime. The production steam curing regimes were as carried out by Knife River (Harrisburg, Oregon) and Central Pre-Mixture (Spokane, Washington), whereas the laboratory curing regime was as described by Dr. Hooton [56]. Given that the production steam curing regimes and the laboratory curing regime were similar with regard to durations and temperature ramping rates, and that Knife River would be fabricating the bridge deck panels for the purposes of this project, the laboratory curing method which closely resembled that used by Knife River was used for the research.

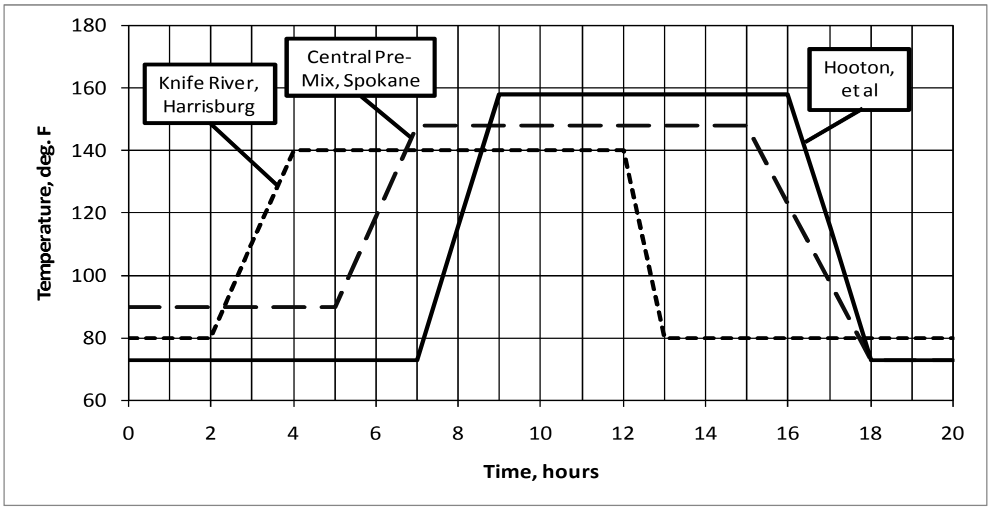


Figure 2: Contractor and laboratory steam curing regimes

Another curing method involved application of curing compound. Curing compound was sprayed using a manual sprayer after the specimens were stripped out from the molds at a coverage rate of approximately 200 sq. ft. /gal [57].

4.5 Test Methods

4.5.1 Fresh Properties of Concrete

Several tests were conducted on the newly mixed concrete to determine the properties of the fresh concrete. This section briefly describes these tests.

4.5.1.1 Slump

Slump is the measure of workability of concrete. Workability is a measure of how easy or difficult it is to place, consolidate, and finish concrete. These tests were conducted in accordance with ASTM C 143 [58]

4.5.1.2 Density

The unit weight (density) of concrete varies with the density of the aggregate, the amount of entrapped or entrained air, water content, and the density and content of the cementitious materials. Unit weight of the freshly mixed concrete was determined using the procedure described in ASTM C138. [59]

4.5.1.3 Air content

Air content can have significant impact on the strength, with higher contents resulting in lower strengths. Therefore, careful measures were taken to ensure the mixtures were fabricated with the design entrained air contents. Air contents in the fresh concrete were determined using ASTM C138. [59]

4.5.1.4 Temperature

ASTM C1064/C1064M-08 [60] was used for determining the temperature of freshly mixed concrete in this study.

4.5.2 Hardened Properties of Concrete

Hardened properties of concrete were monitored very carefully and tests were conducted for primary and secondary variables of interest. This section briefly describes the tests conducted on the hardened concrete test specimens.

4.5.2.1 Abrasion Resistance

The abrasion resistance tests were conducted on square test specimens that were 12”x12” in plan and 3 inch thick as per ASTM C 779/C 779M – 00 [61] at 90-day and 56 day for phase I and II respectively. The revolving disk method was used with a minor modification to the disks. Quarter inch tungsten carbide studs with a Rockwell hardness of A92 were used to develop a more aggressive abrasive environment. There were three revolving disks; each equipped with 12 detachable tungsten carbide studs arranged in concentric circles on the disks (see Figure 3). These hard studs were sharpened and pointed at the bottom. A total of 36 studs were used. They were replaced by another set only after they got abraded or studs broke off while the test was running during the phase I of the study. During phase II, the studs were replaced after every third sample tested.

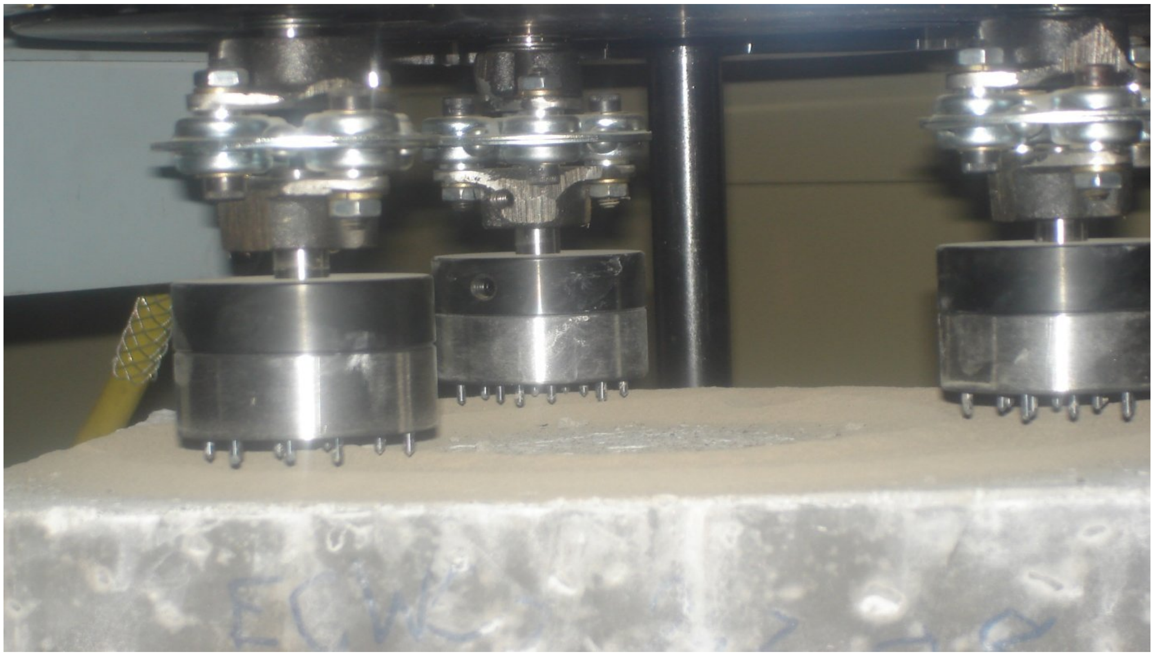


Figure 3: Revolving disks with studs

Testing Procedure: Three samples were tested per experimental mixture at 90-day in phase I and 56-day in phase II. Prior to start of actual experiments, the test specimens were preconditioned to remove the surface irregularities and the curing compound, if any, by running the abrasion testing machine for 5 minutes. Following this, measurements were made using a micrometer depth gage (figure 4) to an accuracy of 0.001 inch to establish the 'initial reading at zero minutes of abrasion'. Each test was run for 30 minutes after which the specimen surfaces were cleaned to remove all the dust and loose particles and measurements were taken again. In order to ensure that the micrometer bridge was placed at the same position every time while taking the readings, 24 holes were made on a flat aluminum plate at a diameter of 7.9 inch (200mm) as shown in figure 5.

Depth of wear was calculated by subtracting the initial reading from the reading taken at 30 minutes and slope or wear rate was obtained by dividing the depth of wear by the corresponding duration of wear. A concrete specimen showing the depth of wear after the test is given in figure 6. The same procedure was repeated again to get measurements at 60 minutes.

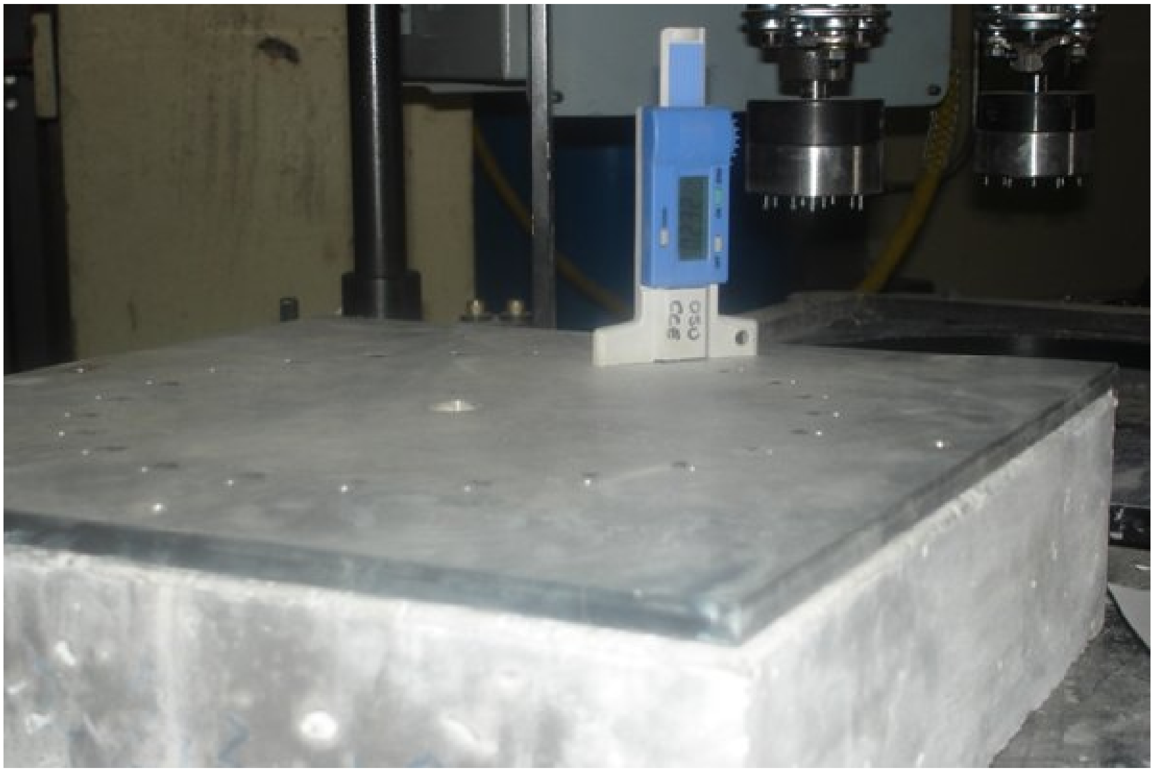


Figure 4: Measurement of depth of wear using micrometer

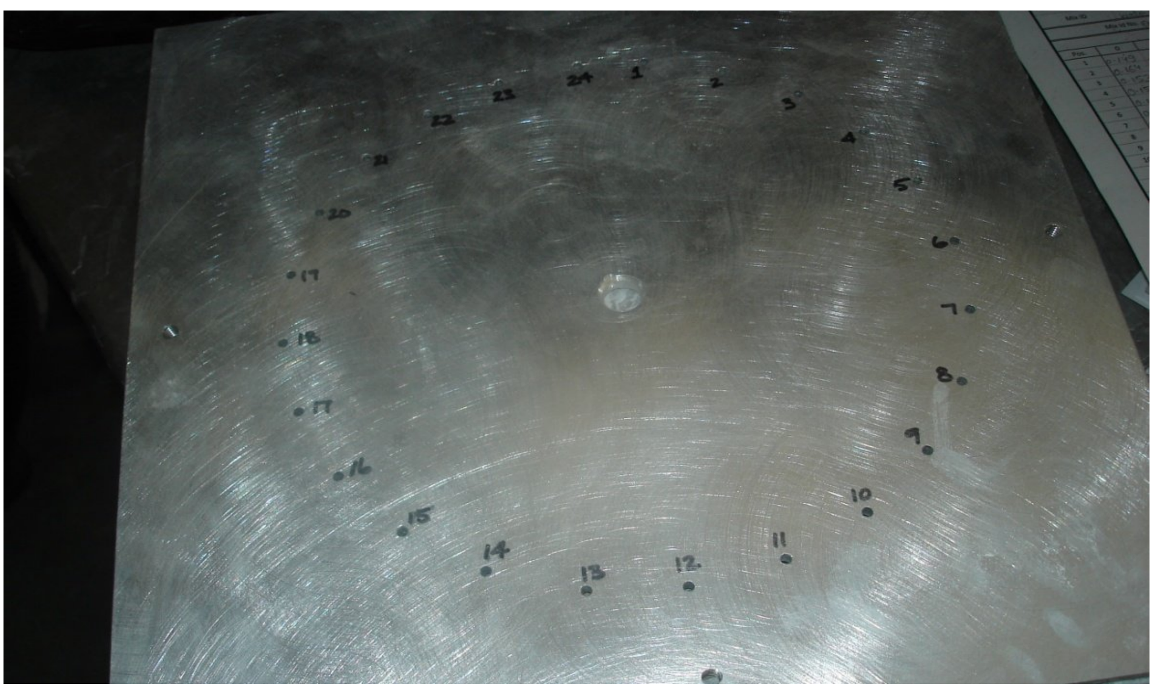


Figure 5: Arrangement of slots on aluminum plate

Figure 6: Abraded surface after test showing depth of abrasion

4.5.3 Permeability

The rapid chloride permeability test (RCPT) was performed in accordance with ASTM C 1202-97 [62] at 90-day and 56-day for phase I and II respectively. The test specimens consisted of 2 inch thick slices obtained from a cylinder of 4 inch diameter and 8 inch height, typically used for compressive strength.

Test Procedure: Four samples were tested per mixture design. Test specimens were coated with a rapid setting epoxy sealant on side surfaces to ensure impermeability from the side surfaces. Pre-conditioning of samples was done by vacuum saturation of the specimens for 4 hours followed by a soaking period of 18 +/-2 hours as shown figure 7. Top and bottom surfaces of the specimen were connected to one cell filled with 300 ml of a 3% Sodium Chloride (NaCl) solution and another cell filled with a 0.3N Sodium Hydroxide (NaOH) solution. The positive terminal of the power supply was connected to the NaOH cell while the negative terminal was connected to the NaCl cell. A voltage of 60V was applied across the cells and the voltage across a shunt resistor was measured to obtain the current passing through the specimen using the Ohm's Law. Each test lasted for 6 hours. A picture of chloride permeability specimen cell showing all the parts are shown in figure 8. An arrangement for the test setup is shown in figure 9.

Reading was taken every 30 minutes and based on trapezoidal rule; charge passed through the specimen was calculated using formula 1.

$$Q = 900 * (I_0 + 2I_{30} + 2I_{60} + \ldots\ldots\ldots\ldots + 2I_{300} + 2I_{330} + I_{360}) \quad (1)$$

Where:

Q = charge passed (coulombs),

I_0 = current (amperes) immediately after voltage is applied, and

I_t = current (amperes) at t min after voltage is applied.

Figure 7: Setup for conditioning the specimen

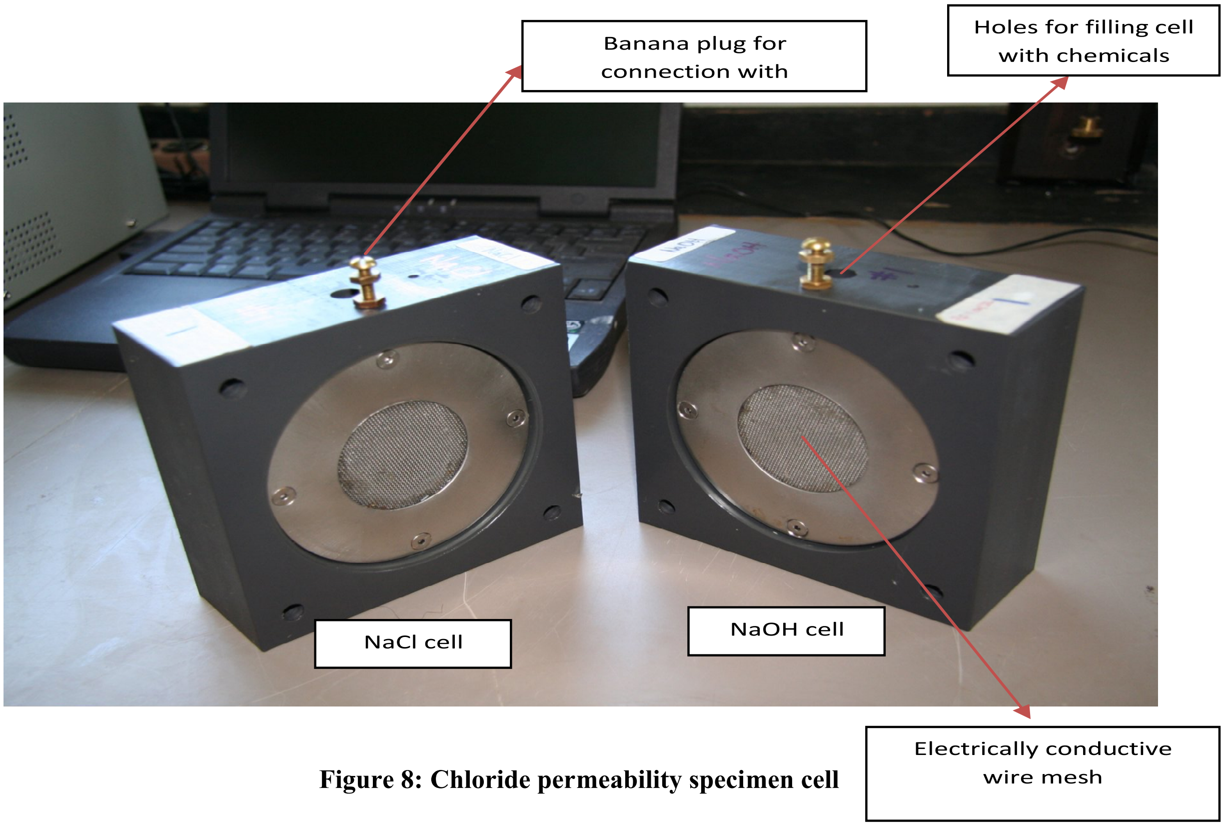


Figure 8: Chloride permeability specimen cell

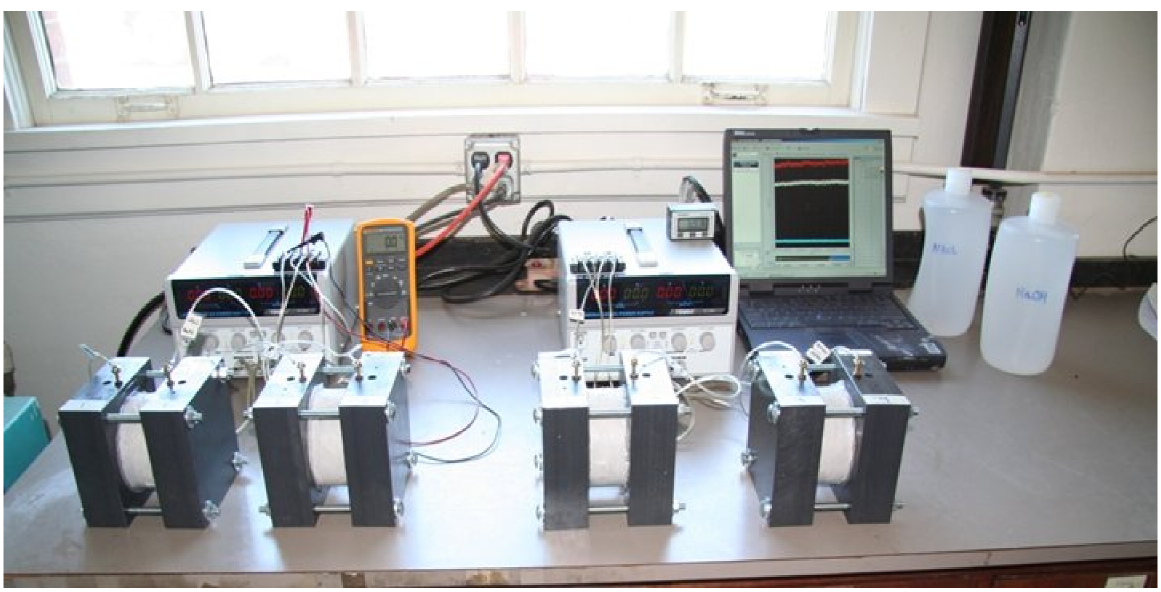


Figure 9: Setup for the rapid chloride penetration Test

4.5.4 Strength

The compressive tests were conducted on 4”x8” cylinders in accordance with ASTM C 39/C 39M – 01 [63] at the specified times as described in Section 3.

Test Procedure: Three samples were tested for each experimental mixture design. The machine used for measuring compressive strength test had a capacity of 400,000 lb. Before strength testing, the diameter and length of specimens were measured, and then the density in air and the density in water were determined. The specimens were tested in moist condition one at a time by placing it on the device. The top and bottom of the specimen were aligned with the alignment mark. Neoprene pads were used in place of capping compound. Load was applied at a constant loading rate of 20 to 50 psi/second. Maximum load at which failure took place was recorded. Compressive strength (to nearest to 10 psi) was calculated by dividing the maximum load taken by the specimen during the test by the average cross-sectional area calculated using the measurement.

4.5.5 Freeze-Thaw Resistance

Freeze and thaw tests were conducted on a prism of 3”x3”x11” at 14 days in accordance with ASTM C 666 – 97 [64], but with minor modifications.

Test Procedure: Prior to the testing, length, breadth, width and weight of the specimens were measured and the initial fundamental frequency at zero cycles of freeze and thaw were determined. The minor modification involved wrapping of the specimen in a felt having a thickness neither less than 1/32 in. (1 mm) nor more than 1/8 in. (3 mm). The specimens covered with felts were then immersed in cold water maintained at a temperature of 4^0C. After immersion for 1 minute, specimens were taken out from the cold water to allow excess water to drain out, and then specimens were vacuum sealed in plastic vacuum bags and placed in the freeze and thaw chamber. The temperature of the chamber and core of concrete were recorded using a Lab View Program on a computer. One cycle of freeze and thaw cycle constituted lowering the core temperature of the concrete from 40^0F to 0^0F and again raising the temperature from 0^0F to 40^0F. The duration of one cycle of freeze and thaw was determined to be 3 hours and 56 minutes. Initially, samples were tested at intervals not exceeding 10 cycles and then those were tested at intervals not exceeding 36 cycles up to 300 cycles. After each interval, samples were taken out, tested for transverse frequency, measured for weight, again wrapped as described earlier, vacuum sealed, and returned to the chamber for the next set of freeze and thaw cycles. The samples in the chamber were rotated in a particular set pattern so that each sample got equal exposures from all side. 10 to 15 shows the complete process of vacuum sealing of specimen. Figure 16 shows testing method for fundamental frequency.

Figure 10: Specimen wrapped in felt

Figure 11: Wrapped specimen submerged in water

Figure 12: Ready for vacuum seal process

Figure 13: Wet specimen inside vacuum seal bag

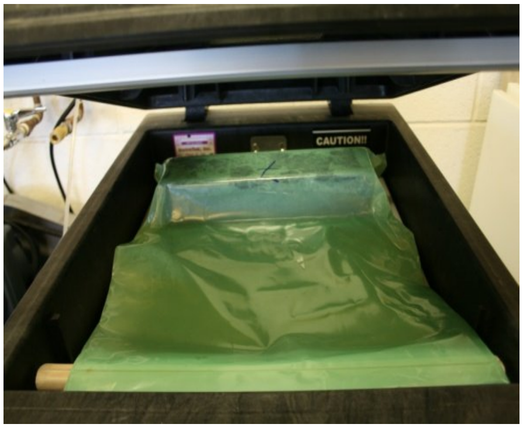


Figure 14: Vacuum seal process complete

Figure 15: Ready to be kept in freeze-thaw chamber

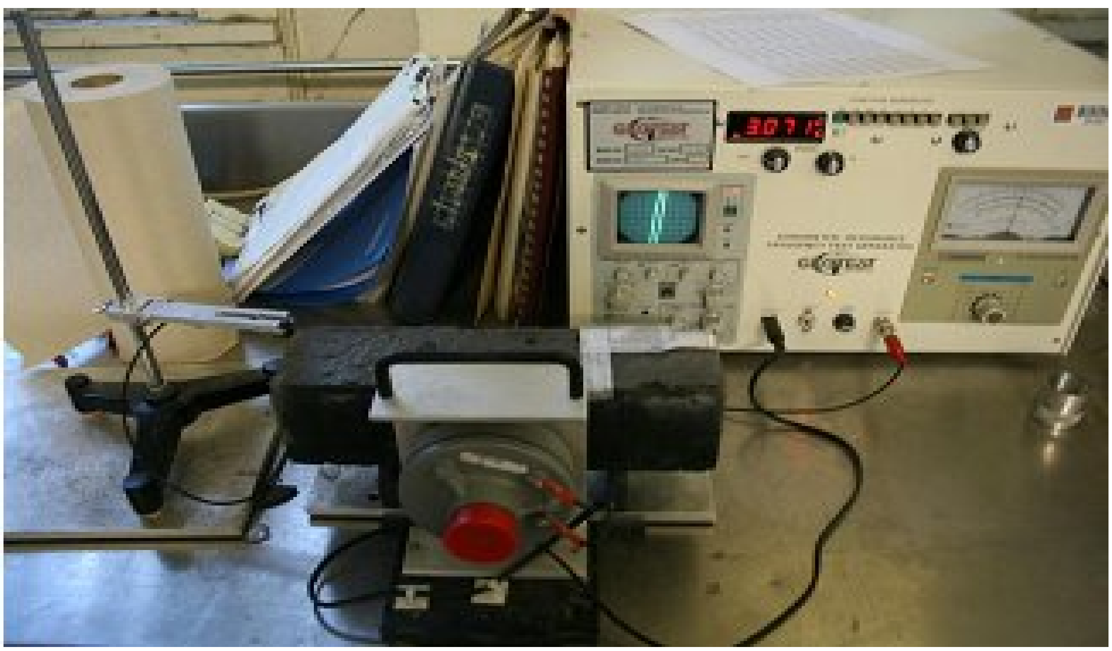


Figure 16: Fundamental transverse frequency measurement of sample using dynamic testing apparatus

5 EXPERIMENT TEST RESULTS

The tests results of all the phases of research are presented in this section. The test results were analyzed to determine if the desirable characteristics of HPC for the experimental (HPC) mixtures were significantly better than that of the control mixture, or not. The results for the compressive strength and the chloride-ion penetration were compared using the two-sample student t-tests. The research question for the chloride-ion penetration resistance test was to determine if the true mean charge passed through the control mixture was greater than that passed through the experimental mixtures and the research question for the compressive strength test was to determine if the true mean compressive strength of the control mixture was greater than that of the experimental mixtures. The t-tests were designed accordingly so that the rejection of the null hypothesis would answer the research question with specified certainty level.

Hypothesis Testing for Compressive Strength

a. μ_E - μ_C = the difference between true mean compressive strengths of experimental mixtures (μ_E) and the control mixture (μ_C) as determined by ASTM C 39/C 39M – 01.
b. Null hypothesis, H_0: $\mu_E - \mu_C = 0$ (i.e., no difference in true mean compressive strengths).
c. Alternate hypothesis, H_a: $\mu_E - \mu_C > 0$ (i.e., the true mean compressive strengths of experimental mixtures is significantly higher than that of the control mixture).

Test statistic (t-test):

$$t = \frac{\overline{X}_E - \overline{X}_C - 0}{\sqrt{\frac{s_C^2}{n_C} + \frac{s_E^2}{n_E}}}$$

Where:

$\overline{X}_C$ = mean compressive strength determined during testing for the control mixture

$\overline{X}_E$ = mean compressive strength determined during testing the experimental mixtures

s_C^2 , s_E^2 = estimate of the population variance

n_C, n_E = sample sizes for the control and experimental mixtures, respectively

d. **Significance level:** The significance level used in the research study was 5% or 0.05.

e. **Critical region:** Reject the null hypothesis (H_0) in favor of the alternate hypothesis (H_a) if $t > t_{critical}$

f. **Interpretation**: if $t > t_{critical}$, then the sample data provided strong evidence to suggest that the mean compressive strengths of the experimental mixtures is significantly higher than that of the control mixture.

Hypothesis Testing for Chloride Ion Penetration Resistance

a. $\mu_C - \mu_E$ = the difference between true mean charge passed (coulombs) during the test period through the control mixture (μ_C) and experimental mixtures (μ_E) as determined by ASTM C 1202-97.

b. Null hypothesis, H_0: $\mu_C - \mu_E = 0$ (i.e., no difference in true mean charge passed).

c. Alternate hypothesis, H_a: $\mu_C - \mu_E > 0$ (i.e., the true mean charge passed through the control mixture is greater than that passed through the experimental mixtures).

Test statistic (t-test):

$$t = \frac{\overline{X}_C - \overline{X}_E - 0}{\sqrt{\frac{s_C^2}{n_C} + \frac{s_E^2}{n_E}}}$$

Where:

$\overline{X}_C$ = mean charge passed through the control mixture during testing

$\overline{X}_E$ = the mean charge passed through the experimental mixtures during testing

s_C^2, s_E^2 = estimate of the population variance

n_C, n_E = sample sizes for the control and experimental mixtures, respectively

d. **Significance level:** The significance level used in the research study was 5% or 0.05.

e. **Critical region:** Reject the null hypothesis (H_0) in favor of the alternate hypothesis (H_a) if $t > t_{critical}$

f. **Interpretation**: if $t > t_{critical}$, then the sample data provided strong evidence to suggest that the charge passed through the control mixture is greater than that passed through the experimental mixtures (i.e., strongly suggesting that the experimental mixtures are more resistant to chloride ion penetration than the control mixture.

It should be noted that other response variables such as abrasion resistance and freeze-thaw resistance can be compared in similar fashion.

The results of the comparison have been presented in pictorial form in terms of bar chart and confidence interval at the confidence level of 95%.

Confidence Interval (CI) is defined as:

$$\bar{Y} \pm t_{(\alpha/2, N-1)} s / \sqrt{N}$$

Where:

$\bar{Y}$ is the sample mean,

s is the sample standard deviation,

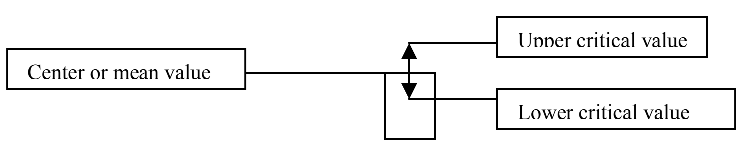
N is the sample size,

α is the desired significance level,

$t_{(\alpha/2, N-1)}$ is the upper critical value of the t- distribution with N - 1 degrees of freedom. Note that the confidence coefficient is 1 - α [64]

Using sample average and sample standard deviation, upper and lower 95% confidence levels were calculated and plotted in the bar graph centered along the mean of the sample.

<u>Interpretation of 95% confidence interval</u>



If the 95 % confidence interval for two mixtures overlaps, then it can be interpreted that there is no significant difference between the two mixtures; whereas if the 95% confidence intervals do not overlap, then it can be inferred that the two mixtures are significantly different from each other. Also, if the 95% confidence intervals do not overlap and one (say, for mixture A) is higher than the other (say, mixture B), it can be interpreted that A is significantly higher than B.

For example: Figure 17 shows 95% confidence interval for the chloride ion penetration in terms of charge passed for concrete at 56-day. Since, 95% CI for mixture C and mixture Con overlaps; it is interpreted that the mixture C and the mixture Con are not significantly different from each other in terms of charge passed through the sample. In other words, it means we fail to reject the null hypothesis. Since, 95% CI for the mixture C and mixture A do not overlap and the CI for mixture C is strictly above that of mixture A, it can be interpreted that mixture C is significantly different from mixture A; and we can even say, there is strong evidence that mean charge passed through mixture C is significantly greater than that passed through mixture A, which in turn means that the mixture A has a significantly higher resistance to chloride ion penetration than the mixture C at 95% confidence level. In this case, it represents that we reject the null hypothesis. Details of t-test results obtained from S-plus software is given in appendix F.

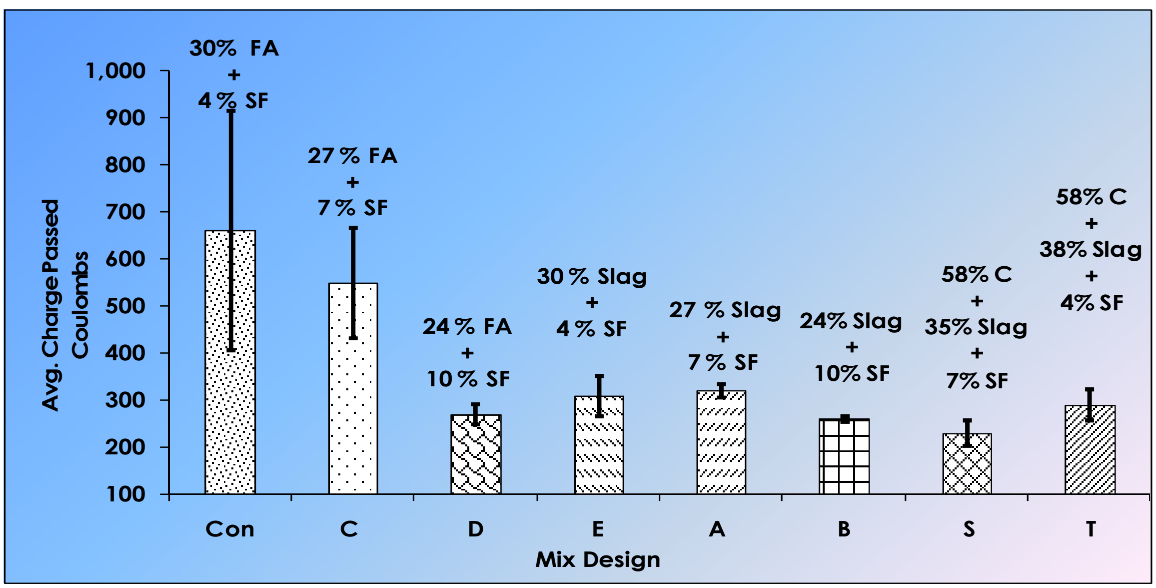


Figure 17: Example for interpretation of confidence interval

It should be noted that other response variables such as compressive strength and freeze-thaw resistance can be compared in the similar fashion.

Multiple Sample Comparison

Multiple sample comparisons for compressive strength and chloride ion penetration were conducted using ANOVA test for the entire mixture designs for all the phases of the study. The null hypothesis was that there is no difference between all the mixture designs being compared and the alternate hypothesis was that at least one of them is different. The ANOVA tests were conducted using Stat-Graphics software and the results for the compressive strength and the chloride ion penetration test are presented in the Appendix-G.

5.1 Phase I

During the phase I of the study, comparisons were made with regards to the types of supplementary cementitious materials (SCM), types of aggregates and the types of curing methods. The methods have been described in detail in the Section 3. The tests results and their analyses are presented in this section.

5.1.1 Fresh Properties of Concrete

The fresh properties of concrete mainly include slump, temperature, density and air content. In this research, focus was on developing an air entrained concrete that could sustain severe conditions of exposure. The air content had to be maintained at 6 +/- 2 %. Slump and temperature affect the hardened properties of concrete such as strength and abrasion. The slump also affects the placement method. Therefore, freshly mixed concrete for 15 mixture designs were tested for the above mentioned properties. A summary of test results for phase I is presented in Table 32. The results obtained were within the specified limit of ODOT's standard specification. Specified slump for the control mixture was 4" while for the experimental mixtures were around 10" [44].

Table 32: Tests results for fresh properties of concrete in phase I

Mixture Id	Mixture Description	Slump, in.	Temperature, ^0C	Air Content, %
CW	Control-Water Curing	4	25	5
CSA	Control- Steam Curing A	5	17	7
CSB	Control-Steam Curing B	6	16	6
EAW	Exp A-Water Curing (Slag + Gravel + Silica Fume)	9	18	8
EASA	Exp A-Steam Curing A (Slag + Gravel + Silica Fume)	10	17	8
EASB	Exp A-Steam Curing B (Slag + Gravel + Silica Fume)	10	18.5	8
EBW	Exp B-Water Curing (Slag + Crushed rock + Silica Fume)	9	16.5	6
EBSA	Exp B-Steam Curing A (Slag + Crushed rock + Silica Fume)	9	17	8
EBSB	Exp B-Steam Curing B (Slag + Crushed rock + Silica Fume)	9	18	8
ECW	Exp C-Water Curing (Fly ash + Gravel + Silica Fume)	10	17	8
ECSA	Exp C-Steam Curing A (Fly ash + Gravel + Silica Fume)	10	17.5	7
ECSB	Exp C-Steam Curing B (Fly ash + Gravel + Silica Fume)	10.5	17.5	8
EDW	Exp D-water Curing (Fly ash + Crushed Rock + Silica Fume)	10.5	10	8
EDSA	Exp D-Steam Curing A (Fly ash + Crushed Rock + Silica Fume)	9.5	16	8
EDSB	Exp D-Steam Curing-B (Fly ash + Crushed Rock + Silica Fume)	10.5	17.5	8

5.1.2 Hardened Concrete Properties

A summary of tests results of relevant hardened properties of concrete is given in Table 33. The summary is an average of three samples per mixture design for all the tests except for chloride ion test (average of four) and freeze and thaw test (which has only one sample). Details are presented in appendix C.

Table 33: Summary of tests results for hardened properties of concrete in phase I

		Abrasion test		RCPT test	Compressive strength		Freeze and Thaw test
Mixture Id	Mixture Description	Wear Depth, inches	Wear Rate, in./hour	Charge passed, Coulombs	At 28 days, psi	At 90 days, psi	Durability Factor %
CW	Control-Water Curing	0.036	0.072	1709	6520	7650	91
CSA	Control- Steam Curing A	0.072	0.145	4254	3880	3810	94
CSB	Control-Steam Curing B	0.100	0.200	4419	2980	2790	96
EAW	Exp A-Water Curing (Slag + Gravel + Silica Fume)	0.062	0.124	1124	7190	8000	95
EASA	Exp A-Steam Curing A (Slag + Gravel + Silica Fume)	0.050	0.100	2112	5880	5360	95
EASB	Exp A-Steam Curing B (Slag + Gravel + Silica Fume)	0.072	0.144	1922	4570	4210	97
EBW	Exp B-Water Curing (Slag + Crushed rock + Silica Fume)	0.025	0.051	1048	9450	11010	93
EBSA	Exp B-Steam Curing A (Slag + Crushed rock + Silica Fume)	0.047	0.094	1984	7820	7510	95
EBSB	Exp B-Steam Curing B (Slag + Crushed rock + Silica Fume)	0.0382	0.076	2313	6550	6180	97
ECW	Exp C-Water Curing (Fly ash + Gravel + Silica Fume)	0.0773	0.155	956	4450	5300	90
ECSA	Exp C-Steam Curing A (Fly ash + Gravel + Silica Fume)	0.0729	0.146	3031	3630	3250	91
ECSB	Exp C-Steam Curing B (Fly ash + Gravel + Silica Fume)	0.1987	0.397	5638	2200	1750	94
EDW	Exp D-water Curing (Fly ash + Crushed Rock + Silica Fume)	0.0394	0.079	687	6530	8410	93
EDSA	Exp D-Steam Curing A (Fly ash + Crushed Rock + Silica Fume)	0.0734	0.147	3567	4320	4200	94
EDSB	Exp D-Steam Curing-B (Fly ash + Crushed Rock + Silica Fume)	0.0766	0.153	4246	3020	2990	95

5.1.2.1 Abrasion Resistance

Figure 18 presents the bar graph of wear rate versus different mixtures design. From the graph, it can be inferred that the mixtures containing crushed rock, silica fume and slag (Exp-B) had significantly higher abrasion resistance than the control mixtures.

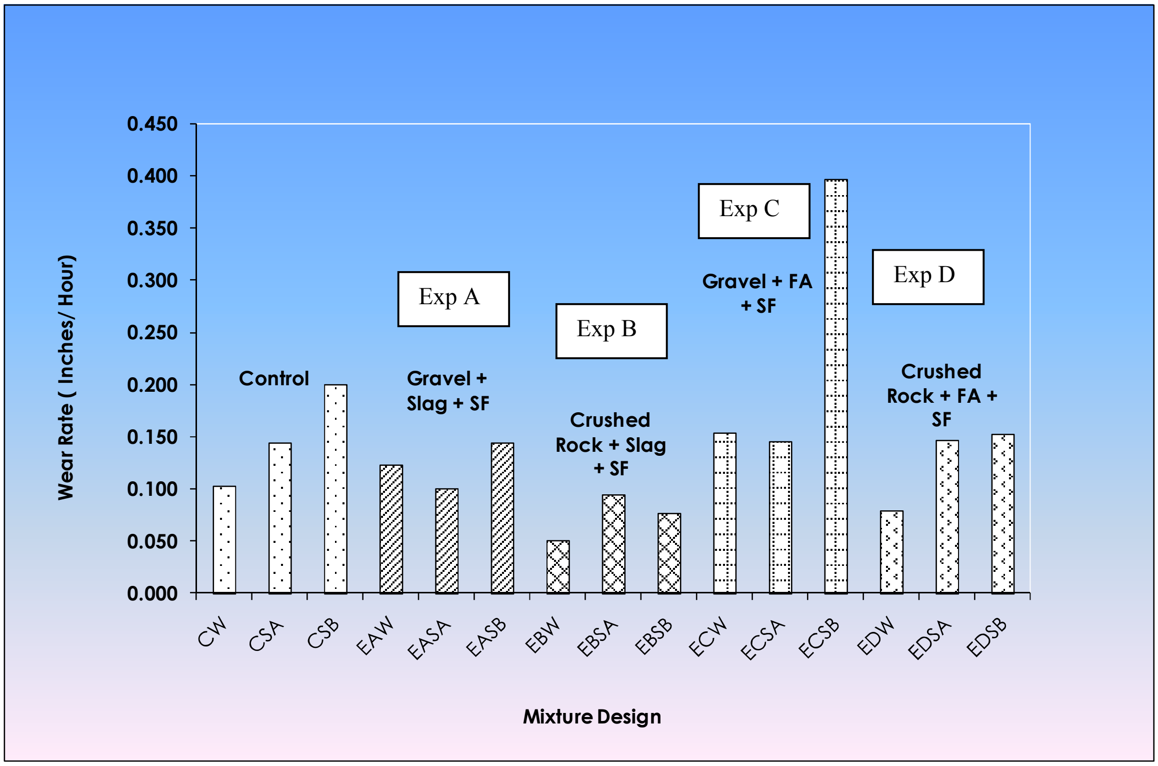


Figure 18: Abrasion in terms of wear rate at 30 minutes for Phase I

The mixture with slag and crushed rock with water curing (mixture EBW) had 29% higher abrasion resistance than the control mixture CW. Mixtures having slag and crushed rock and with steam curing A (mixture EBSA) had 34% higher abrasion resistance than the control mixture with steam curing A (mixture CSA) and mixtures having slag and crushed rock and with steam curing B (mixture EBSB) had 62% higher abrasion resistance than the control mixture with steam curing B (CSB). The possible reason behind this could be the combined effects of using slag and crushed rock used in this mixture design. Slag has higher CaO percentage than fly ash and thus might contribute to the paste property. Previous studies suggest that crushed and hard rock like basalt improves the abrasion resistance in comparison to river gravel [20]. The results reveal that the mixtures containing slag outperformed the mixtures containing fly ash. It is evident from the bar graph that the slag mixtures containing either gravel or crushed rock (Exp A or Exp B) had higher abrasion resistance than that of fly ash. The effect of aggregates is not clearly evident from the graph; though it seems that mixtures which had crushed rock and were cured using either water curing regime or steam curing B regime (EBW, EDW, EBSB, and EDSB) had higher abrasion resistance than the mixtures containing gravel (EAW, ECW, EASB, and ECSB). There was no difference between the crushed rock and gravel mixtures cured using steam curing A regime (EASA, ECSA and EBSA, EBSB). So, there is inconclusive but suggestive evidence that the use of crushed rock increased the abrasion resistance of the concrete. Based on the overall performance, the mixture EBW seemed to be the best mixture having a better performance in terms of abrasion resistance.

5.1.2.2 Permeability (Rapid Chloride-ion Penetration Test)

Permeability of concrete is measured in terms of coulombs of charge passed through the concrete. Charge passing through the concrete is also a measure of amount of chloride ion passing through the concrete. The less the charge passing through the concrete surface, the less permeable it is considered. From Figure 19, it appears that the mixtures CW, EAW, EBW, ECW, and EDW (all water cured) had significantly lower permeability than the other mixtures. Therefore, it can be concluded that there is a general trend of increase in permeability with the type of curing: lower for water curing and higher for steam curing A and steam curing B. The results also reveal that the water curing significantly reduced the permeability of the concrete. Possible reason for this could be that the water curing ensures proper hydration of the cementitious materials. Effect of fly ash, slag, gravel or crushed rock is not clearly evident from the results. The mixtures EDW and ECW have relatively lower chloride ion permeability than the mixtures EBW and EAW. This fact can be used to infer that fly ash mixtures decrease the permeability of the concrete, and thereby increase the durability of the concrete more than the slag mixtures only if they were water cured. All the experimental mixtures had better resistance to rapid chloride ion penetration than the control mixtures except for mixtures ESCB, EDSA and EDSB, possibly because of worst combination of treatments. There was suggestive but inconclusive evidence that experimental mixture designs have better chloride ion penetration resistance than the control mixture.

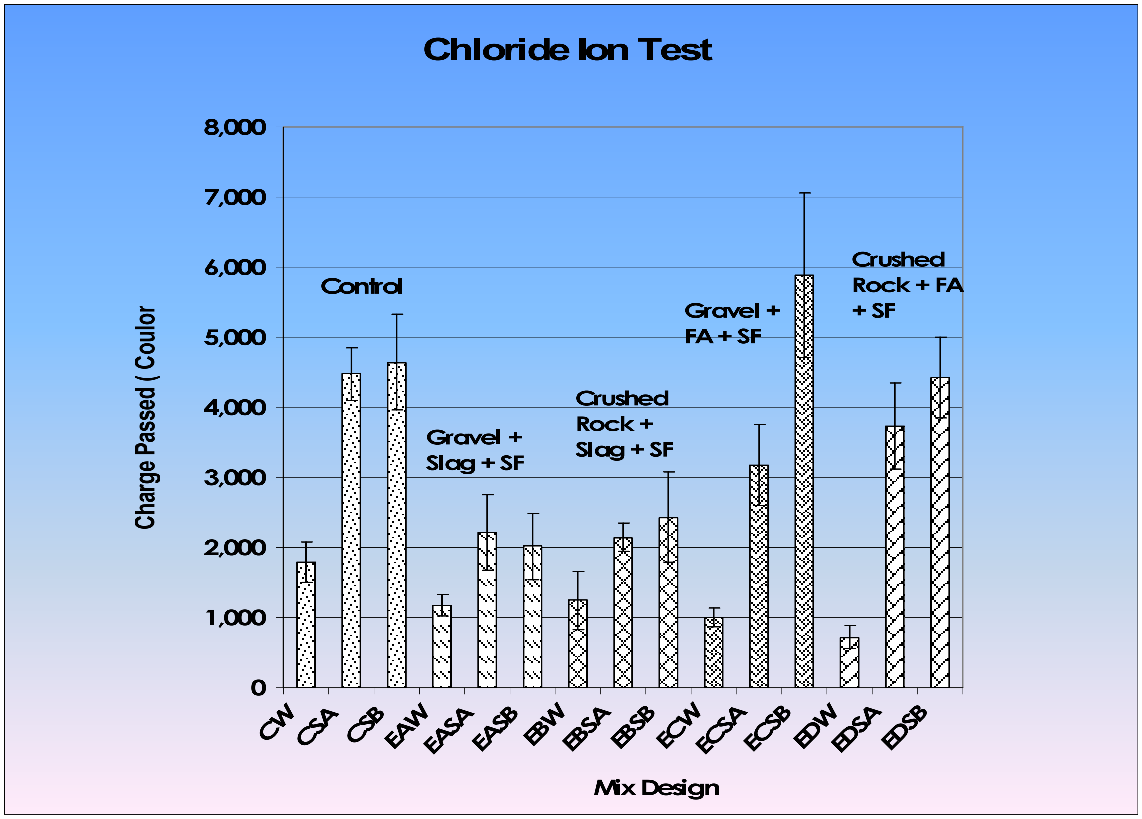


Figure 19: Average charge passed for different concrete mixtures in phase I

5.1.2.3 Compressive Strength

Figures 20 and 21 shows the average compressive strength of the mixtures following 28 and 90 days of curing respectively. Taken together, it can be seen that the compressive strength of different concrete mixtures varied from 2000 psi to 12000 psi. The compressive strength of slag mixtures is significantly higher than that of fly ash mixtures. The effect of type of coarse aggregate used is also evident from the graph. From both the graph, it is evident that the use of crushed rock increased the strength of the concrete manifolds both at 28 days and 90 days. Also, there was a clear trend in decrease in the compressive strength among the three curing regimes, with water curing providing the greatest strength followed by the steam curing A regime.

Though the difference in effect of steam curing regime A and the steam curing regime B on the compressive strength is insignificant; the effect of water curing is highly significant. By comparing compressive strengths at 28 and 90 days, it can be observed that the strength of the concrete increased by approximately 15% from 28 to 90 days under water curing, while steam curing A and B did not have a considerable effect on the rate of strength gain. Overall, the compressive strength of experimental mixtures (other than Exp C) was significantly higher than that of the control mixture.

Comparison of the individual mixtures illustrated that the mixture with slag and crushed rock (EBW, EBSA and EBSB) had a significantly higher strength than the control mixture (CW, CSA and CSB). Though there was suggestive, but inconclusive evidence that the mixture with slag and gravel that underwent water curing (EAW) had higher compressive strength than the water-cured control mixture (CW), the compressive strengths of the mixtures with slag and gravel that underwent steam curing A and B (EASA and EASB) were significantly higher than those of control mixture as well as the mixtures cured with either steam curing A or B (CSA and CSB). Mixture C (containing fly ash, silica fume and gravel) appeared to be worst mixture with very low compressive strength.

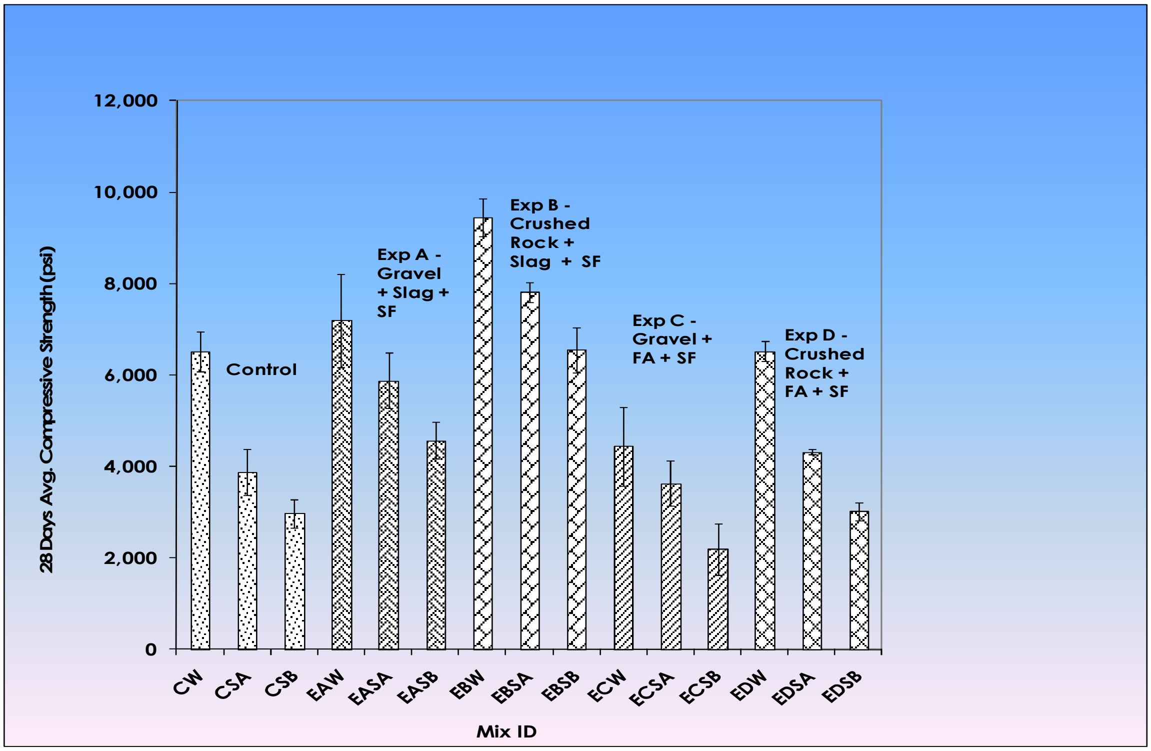


Figure 20: Average compressive strength at 28 days

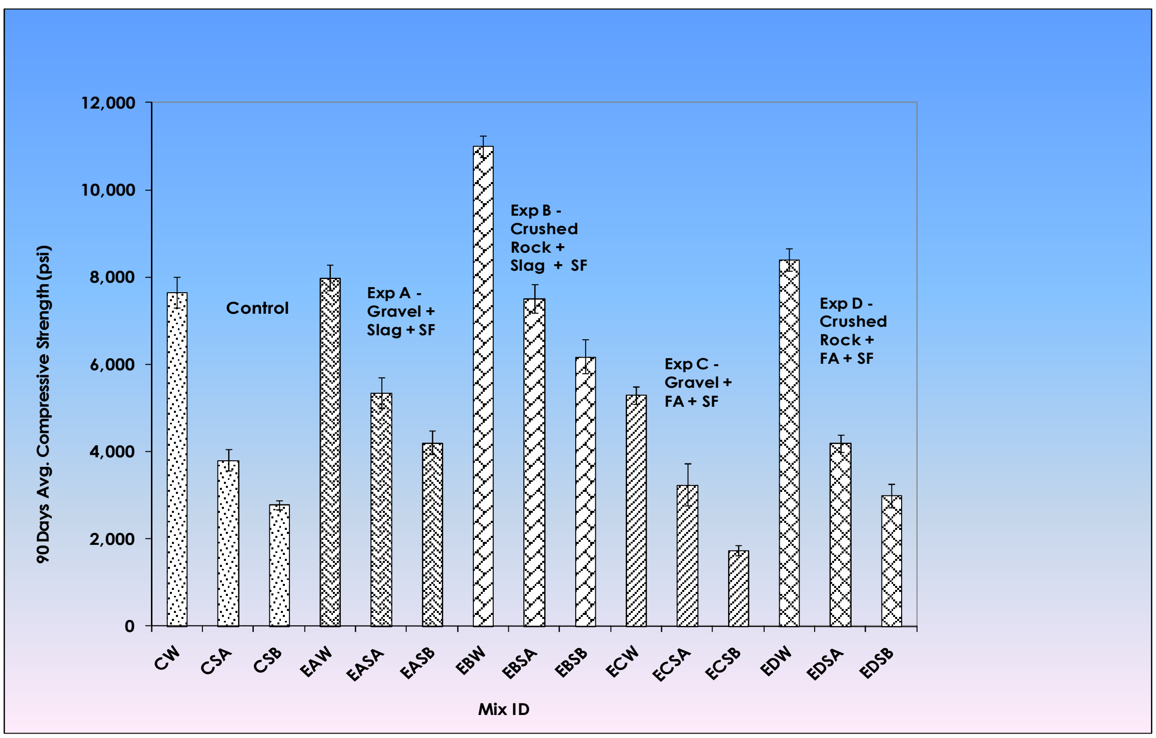


Figure 21: Average compressive strength at 90 days

5.1.2.4 Freeze-Thaw Resistance

Figure 22 is a bar graph of the durability factors for the various mixture designs. From the figure, it can be seen that the steam curing B method resulted in greater durability for the concrete in comparison to the water curing and steam curing A methods.

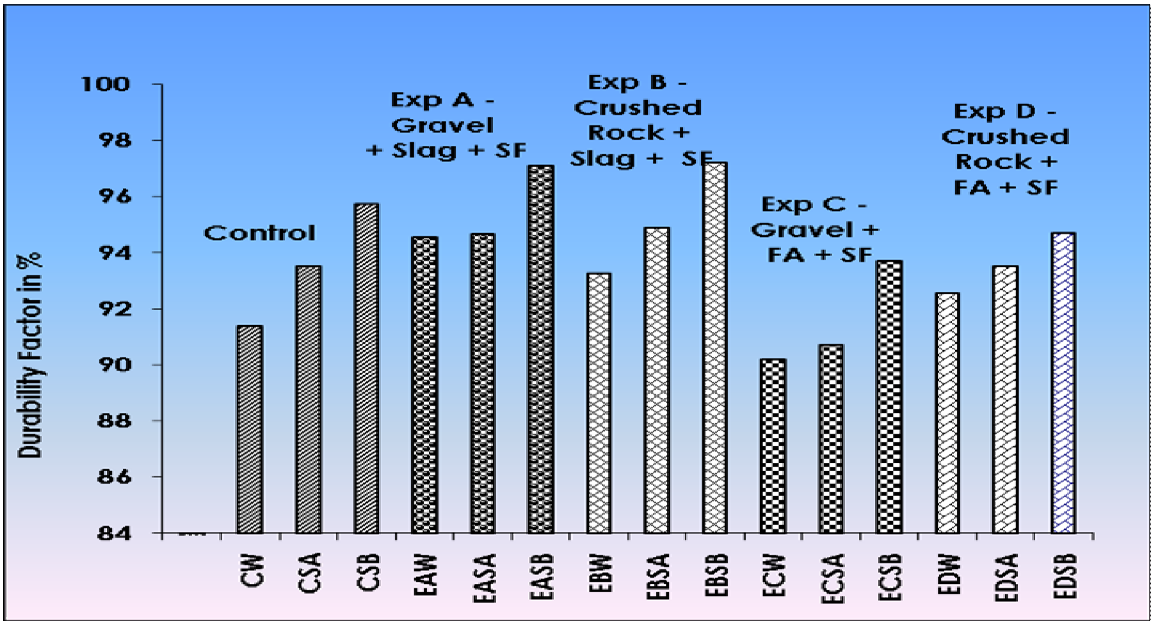


Figure 22: Durability Factor of Concrete

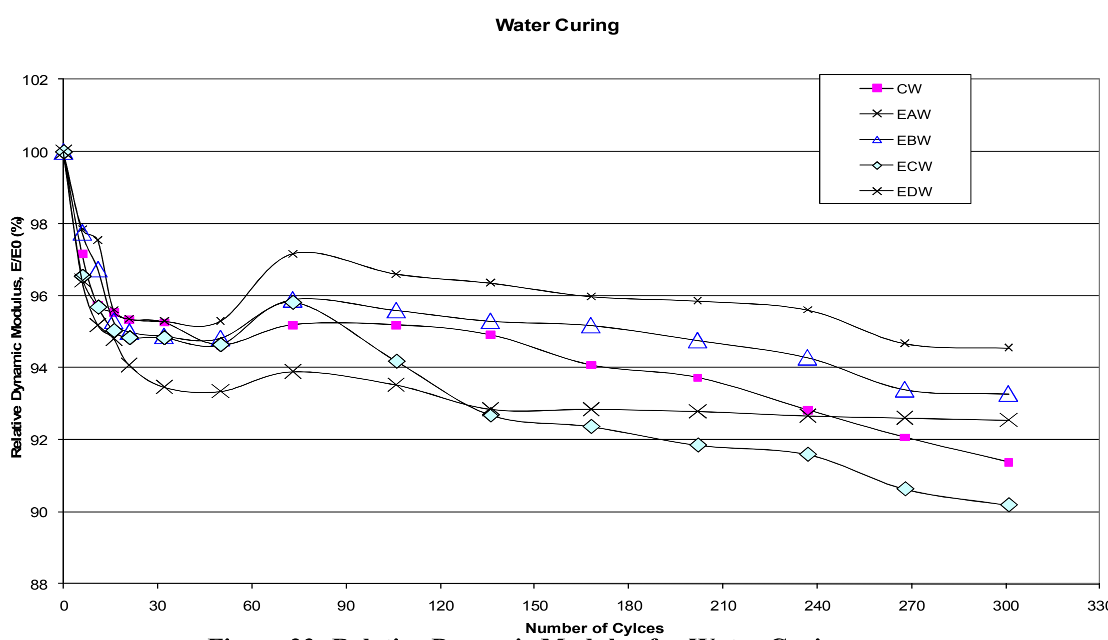


Figure 23: Relative Dynamic Modulus for Water Curing

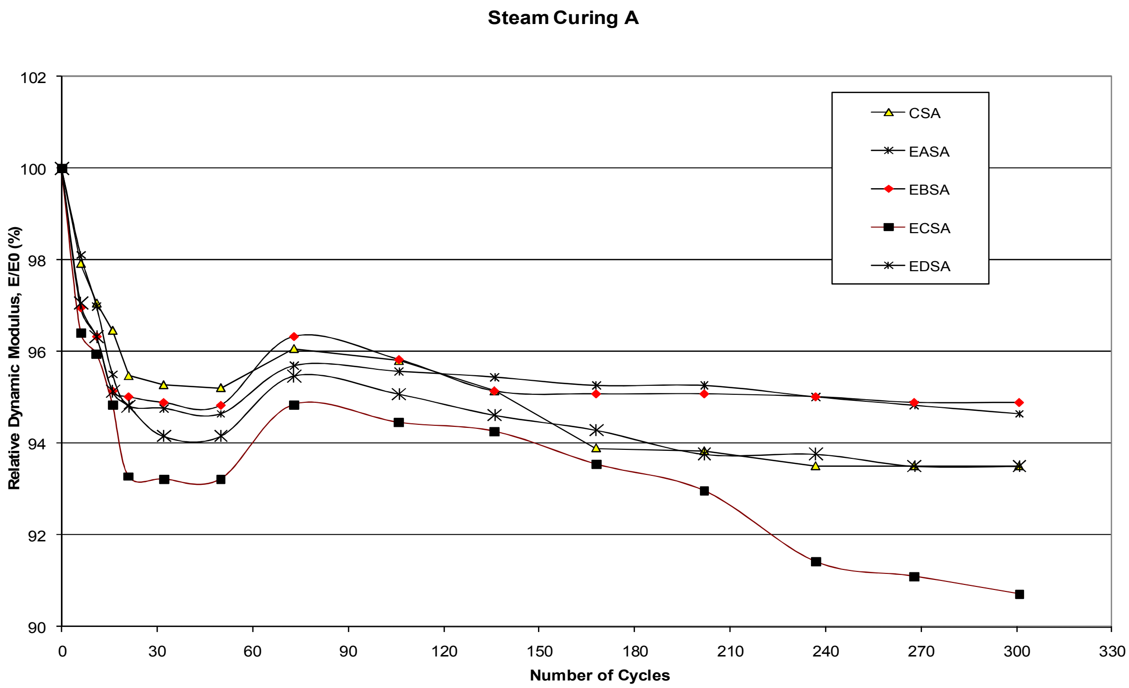


Figure 24: Relative Dynamic Modulus for Steam Curing A

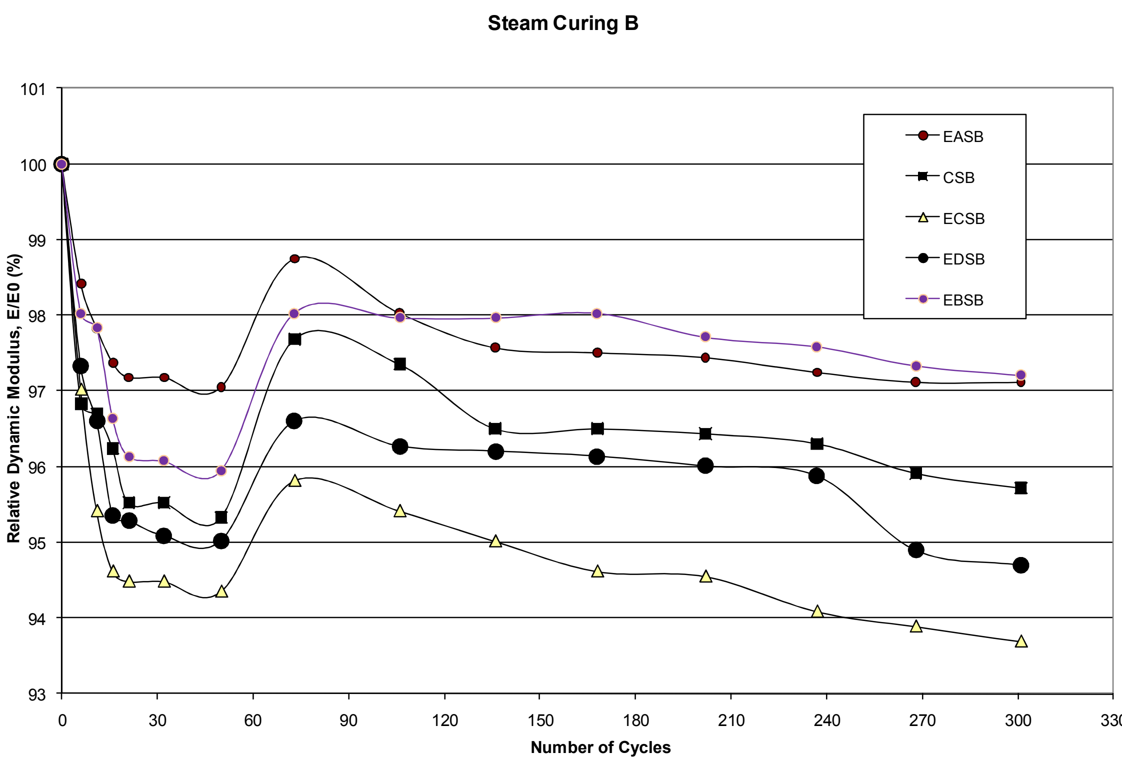


Figure 25: Relative Dynamic Modulus for Steam Curing B

Figures 23, 24, 25 present detail results of the freeze-thaw tests in terms of relative dynamic modulus versus number of cycles, with the last being 300 cycles. Since there was only one specimen per mixture design, the 95% confidence interval could not be established. From figure 23, it can be inferred that the mixtures with slag (EAW and EBW) performed better than all other mixtures (i.e., these mixtures were damaged less than the other mixtures). It can also be seen that the control mixture performed better, for the most part, than the mixtures with fly ash.

From figure 24 and 25, the slag mixture with steam curing A (EASA and EBSA) and with steam curing B (EASB and EBSB) outperformed other mixes. Therefore, it can be inferred that the slag mixtures were better than fly ash mixtures in terms of durability but the effect of aggregate type was not evident much. Unlike other tests, steam curing showed better results in term of durability test than water curing. The reason behind steam curing outperforming other curing method in terms of durability would be formation of small air voids in the concrete mixtures due to improper hydration which enhanced freeze thaw resistance.

Photographs of the specimens were taken following the freeze-thaw test. Examples of degradation are shown in figures 26-29. Though, there was not much decrease in the durability of control mixture, evidence of surface degradation was prominently visible. From figures 26 and 27 it can be seen that the control mixture suffered significant degradation with complete surface scaling leading to aggregate exposure (figure 27) and breaking of the concrete (figure 26). Some of the aggregates (gravel) were also susceptible to freeze-thaw. EASB, one of the best mixtures, was highly resistant to freeze-thaw as evidenced by lack of surface scaling (Figure 28).

Overall, all of the mixtures had durability factors greater than 90%. This suggests that all of the mixtures were highly resistant to freeze-thaw action.

Figure 26: Surface scaling clearly evident for edge during freeze and thaw cycle for control

Figure 27: Broken control mixture specimen

Figure 28: Surface scaling not evident in EASB

Figure 29: Surface scaling evident in ECW

5.2 Pilot Study

The primary purpose of conducting a pilot study was to identify and develop a curing regime which would provide high early strength and at the same time higher compressive strength comparable to that obtained when samples are water cured for 28 days. The findings from Phase I confirmed that the water curing is the best method of curing, but it would be quite difficult to carry out in the field due to the constraints of cost and construction issues. Therefore, it became imperative to search for an alternative technique which would emulate the water curing. Efforts were made to develop 12 curing methods combining different curing techniques and different curing periods. Twelve concrete mixtures were cast for the pilot study to study the effect of different curing types on the compressive strength of concrete. Results for compressive strength and fresh properties of concrete are in the following section.

5.2.1 Freshly-Mixture Concrete Properties

All 12 concrete mixtures had an identical mixture design (see Section 3.2.4). Air contents for some of the mixtures were different but within the specified limit set by the new (2008) ODOT specification. Slump of the concrete mixtures were within the acceptance limit. Temperature of the concrete varied according to the ambient temperature on the day of casting. A summary of fresh properties of concrete is given in Table 34.

Table 34: Test results for fresh properties of concrete for pilot study

Mix ID	Slump, in.	Air content, %	Temperature, °F
Mix 1	9	6.5	58
Mix 2	9	6.5	58
Mix 3	9	6.5	58
Mix 4	9	6.5	58
Mix 5	9.75	7.5	66
Mix 6	9.75	7.5	66
Mix 7	9.75	7.5	66
Mix 8	8.5	7.2	64
Mix 9	10	7.5	58
Mix 10	10	7.5	58
Mix 11	8.5	6.6	61
Mix 12	8.5	7.2	64

5.2.2 Hardened Concrete Properties

Since the previous studies suggested that the abrasion resistance of concrete is directly proportional to its compressive strength, the pilot study focused on the compressive strength at various stages of curing. A summary of the average compressive strength at various stages of curing after 1 day, 3 days, 7 days, 14 days and 28 days for all mixtures are given in Table 35. Detailed results are presented in appendix D.

Table 35: Average compressive strength at different specified duration of curing for pilot study

Mixture ture Id.	Mixtureture Description	Test on hardened concrete				
		Compressive strength, psi				
		1 day	3 days	7 days	14 days	28 days
1	Water curing up to 28 days	4870	8070	9800	10450	11260
2	14 Days water curing + ambient curing	x	x	x	x	11690
3	7 Days water curing + ambient curing	x	x	x	10460	11190
4	14 Days water curing + curing compound + ambient curing	x	x	x	x	11520
5	7 Days water curing + curing compound + ambient curing	x	x	x	9170	10130
6	1 Days water curing + curing compound + ambient curing	x	6750	7660	9340	9110
7	3 Days water curing + curing compound + ambient curing	x	x	8920	9350	9940
8	3 Days water curing + ambient curing	x	x	9990	10220	11000
9	1 Days water curing + ambient curing	x	4420	5590	6410	6170
10	Steam curing + ambient curing	5390	6570	7210	7160	6860
11	Steam curing + curing compound + ambient curing	8870	9810	10480	10550	10930

5.2.2.1 Comparison between Water Curing and Steam Curing

From figure 30, it can be interpreted that the mixture 10 (concrete specimen subjected to steam curing followed by ambient curing) had significantly lower compressive strength than both mixture 1 (concrete specimen subjected to water curing) and mixture 11 (concrete specimen subjected to steam curing followed by application of curing compound and left for ambient curing). Mixture 1 and mixture 11 had almost 60% higher compressive strength than mixture 10. Again, there was no significant difference in the compressive strengths of mixture 1 and mixture 11 at 28 days of curing. Application of curing compound to prevent evaporation of internal water from concrete greatly improved the compressive strength by increasing the strength gain by approximately 60% over the ambient cured sample. The possible reason behind this is that the application of curing compound makes an impervious layer over the concrete surface which prevents the internal water from evaporating and thus aiding the hydration process.

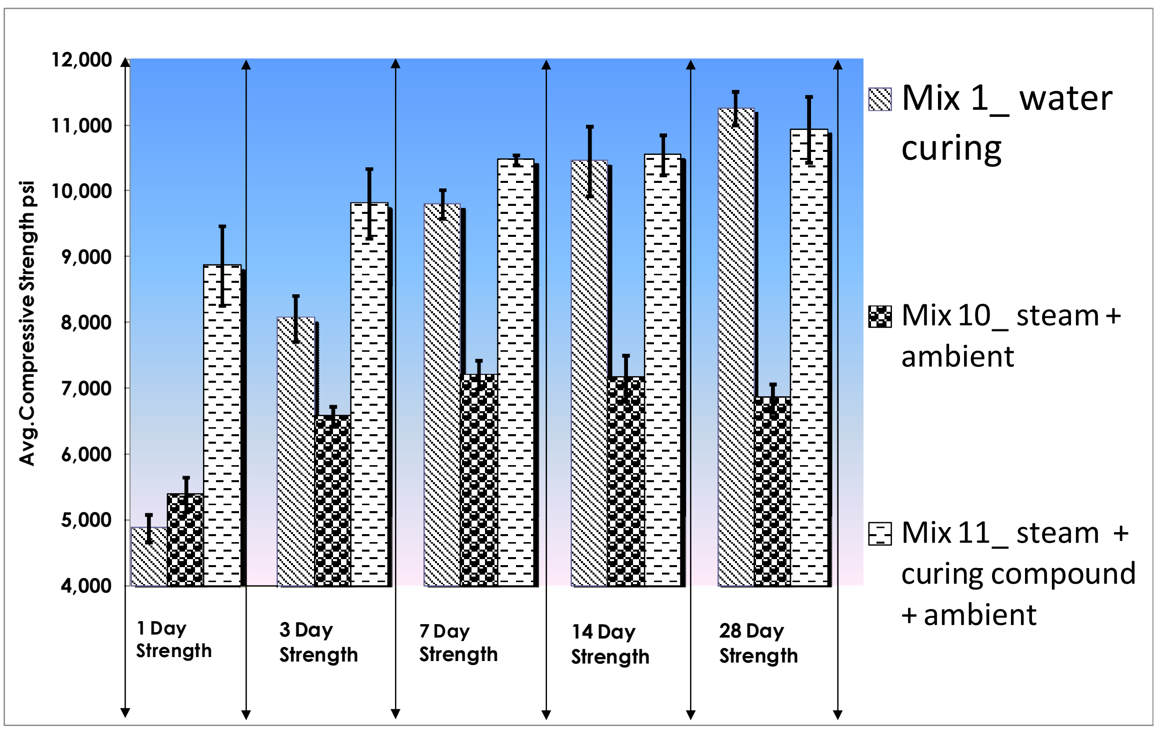


Figure 30: Comparison of compressive strength between steam and water curing with 95% CI

5.2.2.2 Comparison between Compressive Strengths at Day 1 and Day 28 of Water Curing

From figure 31, it is clearly evident that the gain in compressive strength of the concrete subjected to water curing was significantly higher (at a 95% confidence level) than that subjected to water curing for one day and then left in the ambient condition. It is also evident from the figure that the gain in compressive strength of the concrete subjected to water curing was significantly higher than that subjected to water curing for one day and then left in the ambient condition after applying the curing compound. The effect of curing compound is clearly evident from the graph; the samples which were cured in ambient temperature after applying curing compound had significantly higher compressive strength than the samples which were cured in ambient temperature without curing compound.

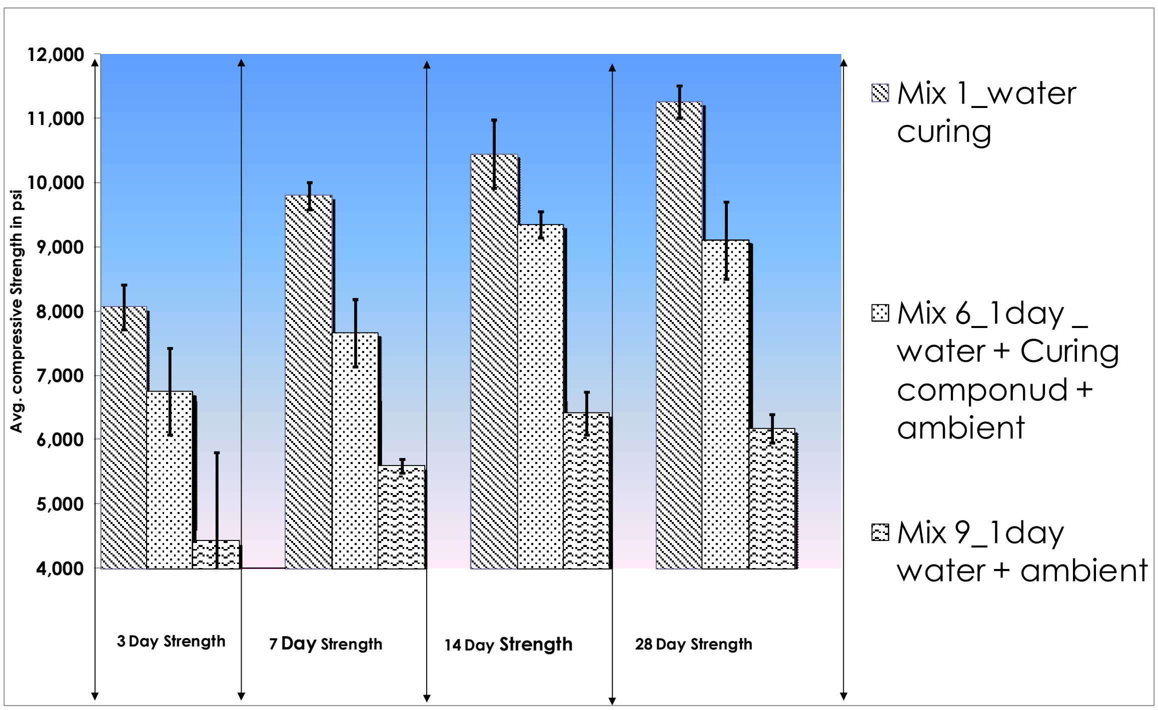


Figure 31: Compressive strength for different curing types with 95% CI

5.2.2.3 Comparison between Compressive Strengths at Day 3 and Day 28 of Water Curing

Figure 32 shows that the curing compound does not have any effect on the strength gain process of concrete if the concrete sample is water cured for 3 days and then coated with curing compound. The samples which were water cured for 3 days followed by ambient curing had similar compressive strength compared to those subjected to normal water curing for 28 days.

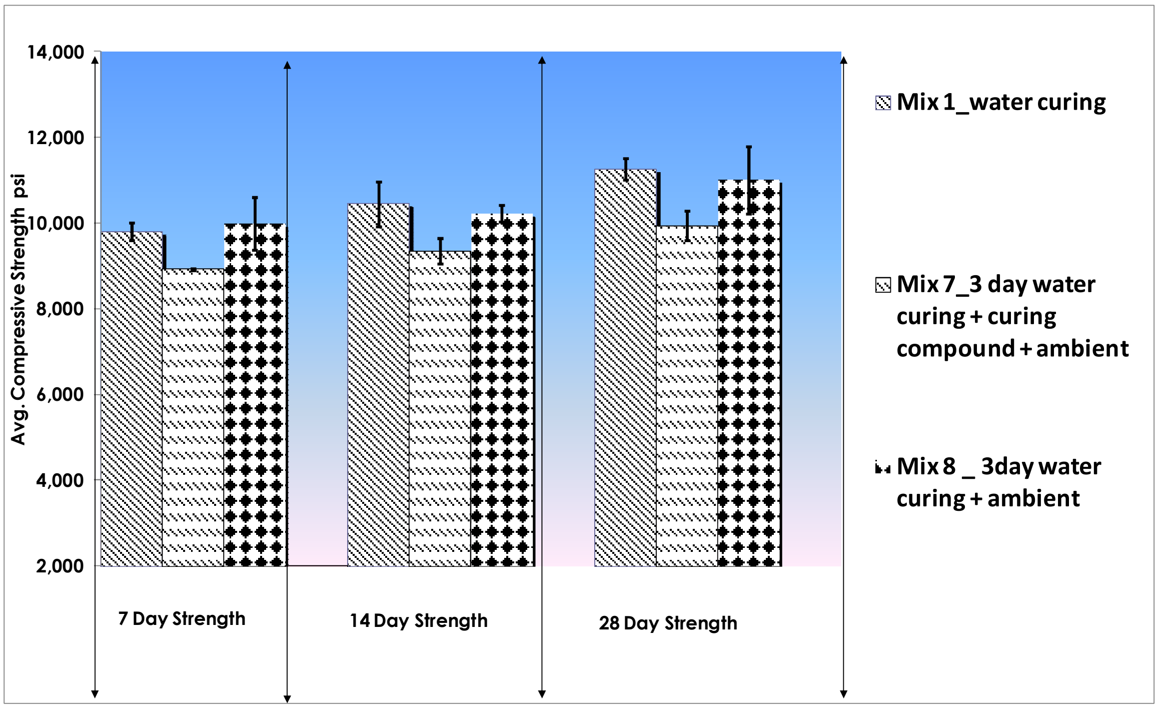
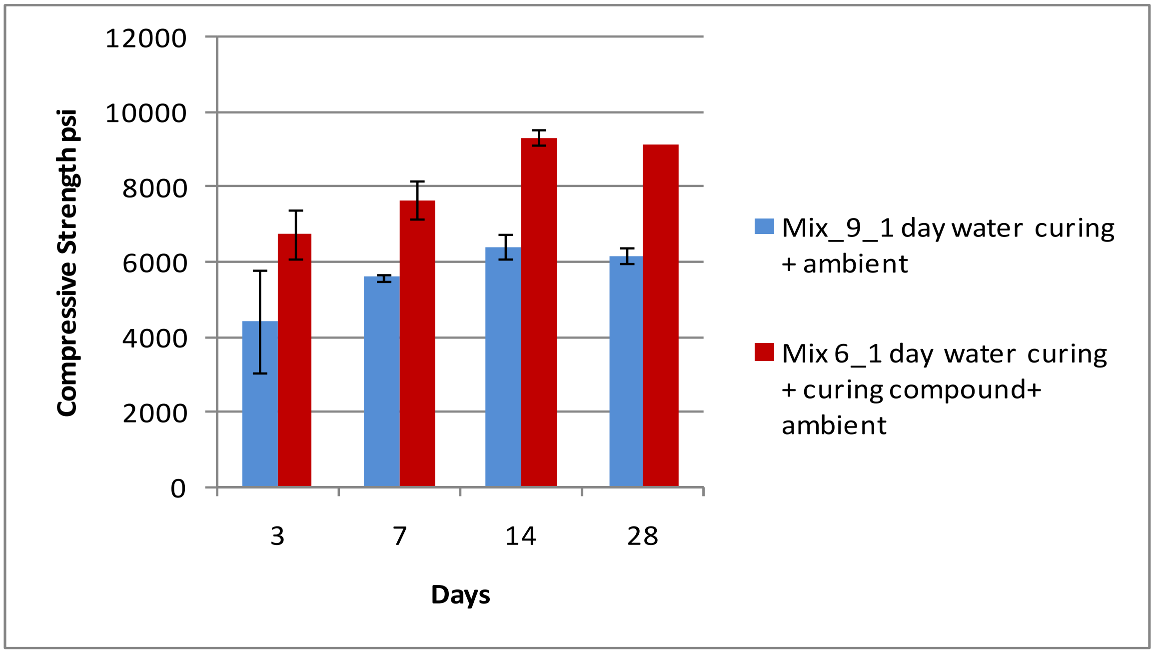


Figure 32: Effect of different duration of water curing

5.2.2.4 Effect of Curing Compound

Figure 33 shows that the application of curing compound after 1 day of water curing followed by ambient curing increased the compressive strength by 47% compared to water curing followed by ambient curing without application of curing compound. The effect of application of curing compound on samples after three days of normal water curing was insignificant, which shows that the curing compound coating is effective in ensuring proper hydration of cement only when it is applied sooner (e.g., after 1 day of the water curing).



. Figure 33: Effect of curing compound for 1 day water curing

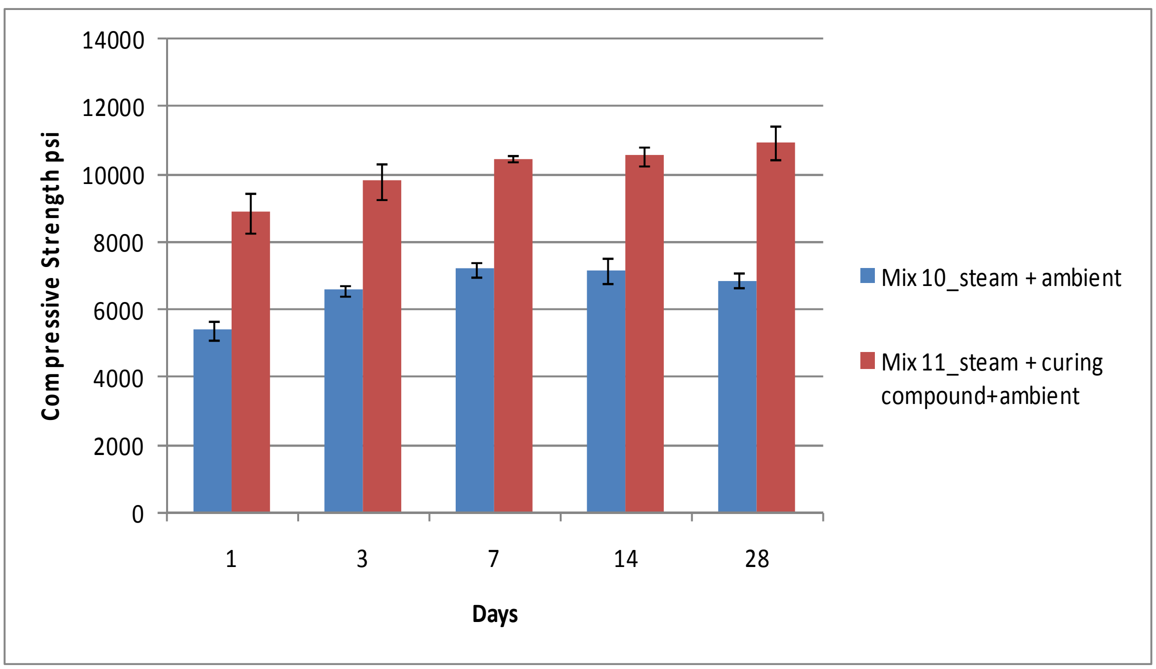


Figure 34: Effect of curing compound for steam curing

5.2.2.5 Effect of Length of Curing Period

Figure 35 shows how the gain in compressive strength takes place over time for different curing types. It can be interpreted that all the mixtures except 6 and 9 continued to gain strength up to at least 28 days. The rate of strength gain leveled off after 14 days for mixtures 6 and 9, both of which were cured in water for 1 day followed by application of curing and then left in ambient conditions.

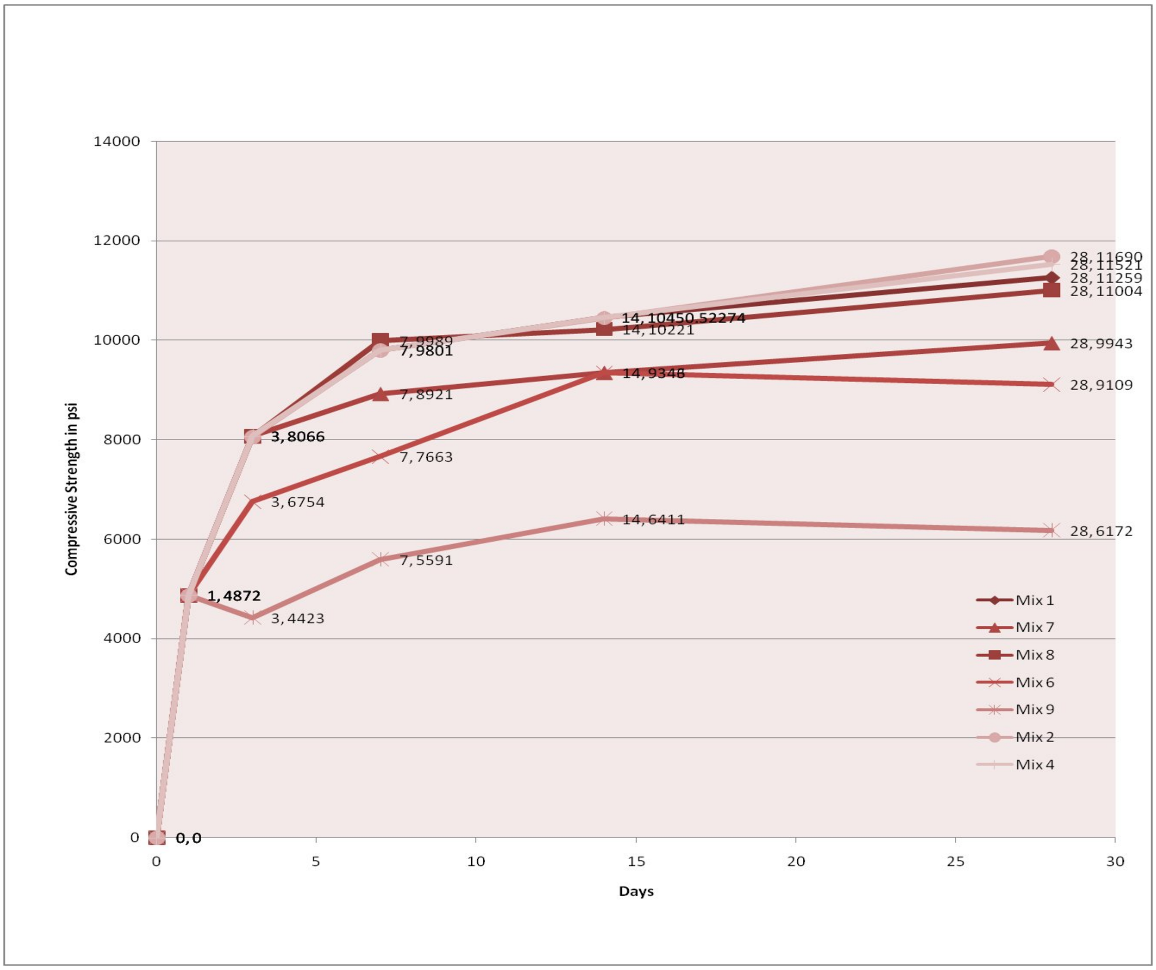


Figure 35: Compressive strength gain over time

Note: Nomenclature shown in the graph pertains to:

- **1**-Water Curing till 28 days
- **2**-14 Days water curing + ambient curing
- **3**-7 Days water curing + ambient curing
- **4**-14 Days water curing + curing compound + ambient curing
- **5**-7 Days water curing + curing compound + ambient curing
- **6**-1Days water curing + curing compound + ambient curing
- **7**-3Days water curing + curing compound + ambient curing
- **8**-3 Days water curing + ambient curing

5.3 Phase II

Phase II was undertaken to capitalize on the findings from phase I and the pilot study that showed the most promise in developing a highly abrasion resistant and durable concrete mixture. . Also, there was not a very significant increase in the abrasion resistance with the use of crushed rock. Therefore, it was decided to develop a sustainable mixture design with locally available material. Efforts were made to investigate and develop a concrete mixture design using locally available gravel as aggregates and attain similar abrasion resistance and chloride ion permeability as that obtained by using crushed rock as aggregates. Results of all the tests conducted on the different concrete mixture designs are given in the following sections.

5.3.1 Freshly-Mixed Concrete Properties

A summary of tests conducted on the freshly mixed concrete are given in Table 36. All the results were within the specified limits. Mixture S was designed for non air-entrained concrete, therefore the air content of the mixture was only 2%.

Table 36: Tests results for fresh properties of concrete for phase II

Mixture ID	Temperature, ^{0}C	Slump, inch	Air, %
Control	19	8.5	7.5
Mix A	19	10	6.5
Mix B	22	8.5	7.5
Mix C	15	9.5	7.8
Mix D	19	10	6.9
Mix E	18	9.5	5
Mix S	16	10	2
Mix T	26	10	7

5.3.2 Hardened Concrete Properties

A summary of all the tests results conducted on hardened properties of concrete are given in Table 37. Tests on hardened properties of concrete included compressive strength, abrasion resistance, and chloride-ion penetration resistance (as mentioned previously, freeze-thaw tests were not conducted during phase II due to the satisfactory performance of the HPC mixtures during phase I). Detailed analyses of all the tests are given in following sections. Details of tests results are presented in appendix E.

Table 37: Summary of tests conducted on the hardened concrete mixtures in phase II (Average results of three samples)

Mixture ID	Compressive Strength, psi			Abrasion Wear Rate, inch/hr		Chloride Ion Charge Passed, Coulombs
	1 day	28 days	56 days	56 days		56 days
				30 min	60 min	
Control	6610	7860	7520	0.1120	0.070	660
Mix A	7680	9540	9260	0.1480	0.100	320
Mix B	7700	9700	9990	0.1210	0.083	260
Mix C	5230	5760	5750	0.2270	0.103	550
Mix D	7270	8820	9070	0.1130	0.071	270
Mix E	8200	10680	10170	0.0820	0.048	310
Mix S	-	13600	13900	0.0200	0.016	230
Mix T	8870	10440	11060	0.0750	0.032	290

5.3.2.1 Abrasion Resistance

As seen in Table 37, the average wear rate at 30 minutes of abrasion was much higher than the average wear rate at 60 minutes. A possible explanation for this difference could be that the abrasion of concrete is primarily a surface phenomenon. According to Mehta, hardened cement mortar paste does not possess a high resistance to attrition and the weak surface layer consists of very fine particles called laitance [66]. Though efforts were made to remove the laitance during the first five minutes of the abrasion test, the layer of fine particles might have been thicker than expected and, therefore, might not have been completely removed during the first 5 minutes of running the abrasion test. Once this top layer had been removed, the aggregate surfaces were exposed which were relatively harder and therefore abrasion rate was less in the second 30 minutes duration of the test.

Though the average wear rate after 60 minutes of abrasion was significantly lower than that after 30 minutes, both the graphs (Figures 36 and 37) show the same trend of wear rate for the different mixture designs. From Figures 36 and 37, it can be seen that mixtures E and S had significantly lower wear rates than the control mixture. One of the possible reasons behind this could be the lower air content and higher strength of the mixtures. Also, it appears that mixtures E and A, with the slag as supplementary cementitious material, had significantly lower wear rates than the control mixture and mixture C, in which the supplementary cementitious material was fly ash. This shows that the mixtures containing slag provided better abrasion resistance than those containing fly ash. This can be validated from the results obtained in phase I.

Though, mixtures B and D had different supplementary cementitious materials, but the same percentage of silica fume, they were not much different from each other in terms of wear rate. This possibly could be due to the high amount of silica fume (i.e., 10%) which played a major role in the strength gain and subsequently abrasion resistance, negating the effect of the other supplementary cementitious materials.

In looking at the charts, it appears that the mixtures with 7% silica fume (aside from Mixture S, of course) had lower abrasion resistance than the mixtures with 4% and 10% silica fume. Mixtures with 4% silica fume showed improved wear resistance relative to the control mixture and the mixture with 10% silica fume had about the same wear resistance as the control mixture. The mixtures with 7% actually resulted in a decrease in wear resistance relative to the control mixtures and those containing lower or higher percentages of silica fume. In general, reducing the fly ash or slag content with an associated increase in silica fume content actually reduced the wear resistance relative to the control mixture. At the lower (4%) silica fume content, the mixture with slag performed slightly better than the mixture with fly ash, and for all silica fume contents, the mixtures with slag were about equal to or better than the mixtures with fly ash in terms of wear resistance. Although mixture S was clearly the best performer, it might be due to the 2% air content, but the added cement content probably contributed as well. The cement content of all the mixture except for mixture S and mixture T was 541 lb/yd^3. Cement content for mixture S and mixture T was 600 lb/yd^3.

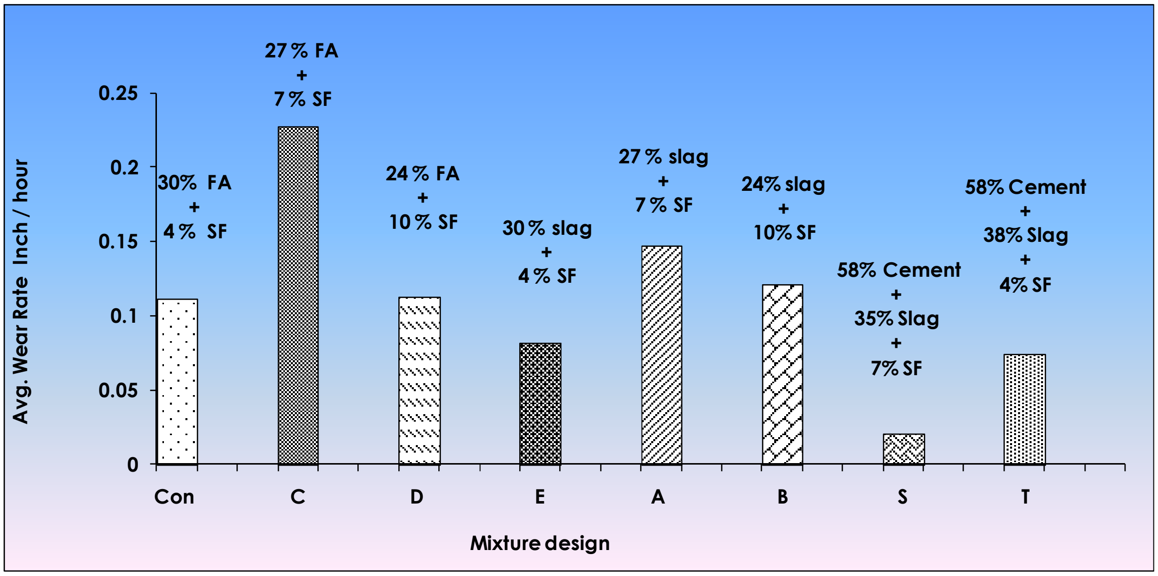


Figure 36: Average wear rate at 30 minutes for phase II

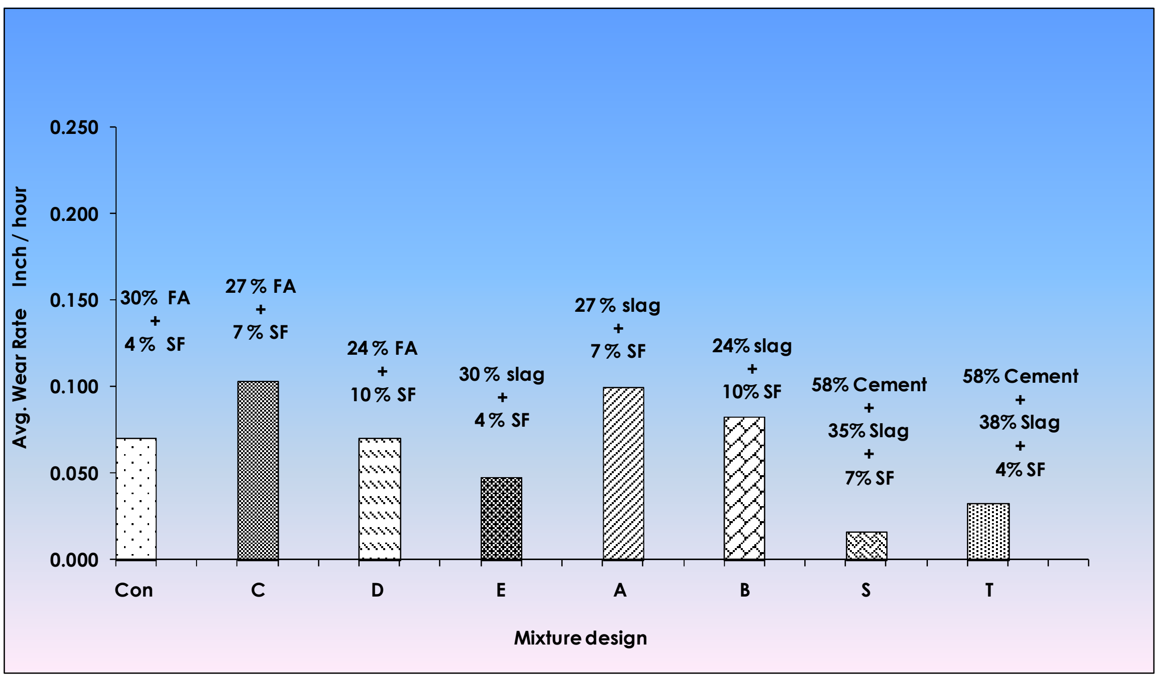


Figure 37: Average wear rate at 60 minutes

5.3.2.2 Permeability

Figure 38 presents the results of the chloride ion permeability tests in graphical format. From the figure, it can be seen that the charge passed by all of the samples were well below the threshold level of 1000 coulombs set by the ODOT standard specifications. In fact, most of the mixtures passed fewer than 350 coulombs of charge. Further, there was a general trend of decrease in permeability with an increase in silica fume content. Mixtures B and D, both having 10% silica fume, passed significantly fewer coulombs of charge passed (indicating lower permeability) than those containing lower percentages of silica fume. Mixtures A and C were not significantly different from the control mixture and mixture E (Figure 38).

This validates the statement given in the literature review that up to 6% silica fume enhances this property of concrete but requires much higher percentages above 6% to reap the same benefit. The addition of 7% silica fume did not improve chloride ion penetration resistance considerably. Mixtures A and E had lower permeability than the control mixture and mixture C. Therefore, it can be inferred that, similar to the findings from phase I, the inclusion of slag was more effective in suppressing chloride ion permeability than inclusion of fly ash. This could be because of better compatibility between slag, cement, and silica fume and a higher rate of hydration of the cementitious materials. Formation of C-S-H gel in ample quantity might have led to greater concrete density and, hence, lower permeability. Overall, all of the experimental mixtures were better than the control mixture in regards to improving impermeability.

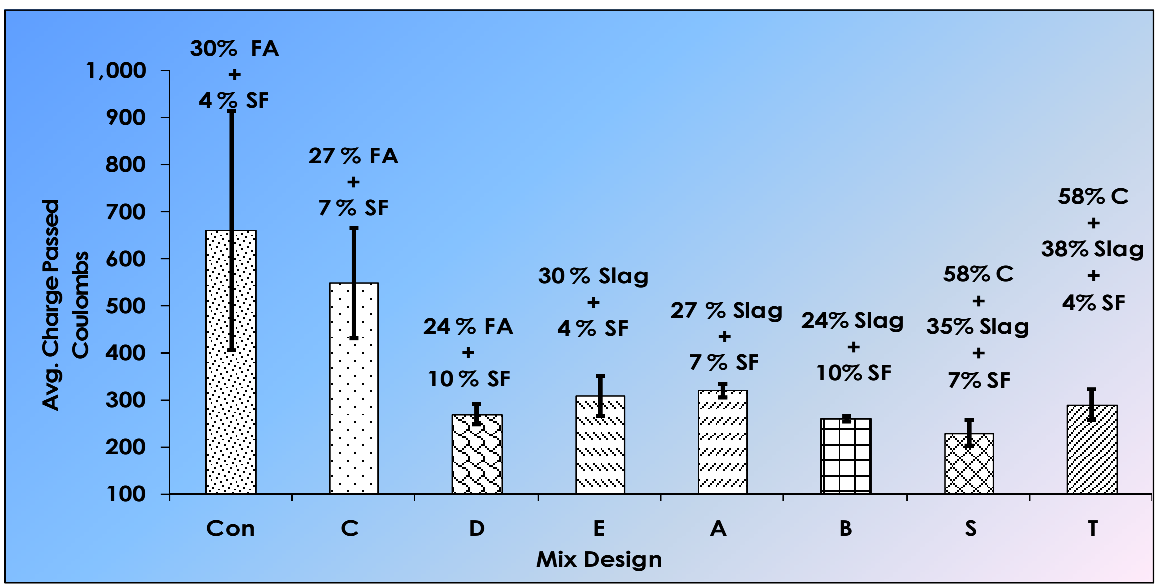


Figure 38: Chloride ion permeability test at 56days

5.3.2.3 Strength

Due to industry requirements of high early age strength for releasing tension and de-molding purposes, all of the specimens were tested for compressive strength at 1 day. Figure 39 presents these results graphically. From the figure, it can be seen that all of the mixtures had 1-day compressive strengths greater than 4000 psi and the experimental mixtures (except mixture C) had significantly higher compressive strengths than the control mixture. In addition, it can be seen that the experimental mixtures (again, with the exception of mixture C) had compressive strengths well in excess of 5000 psi, which is a minimum target 1-day strength for the purposes of de-molding structural concrete elements.

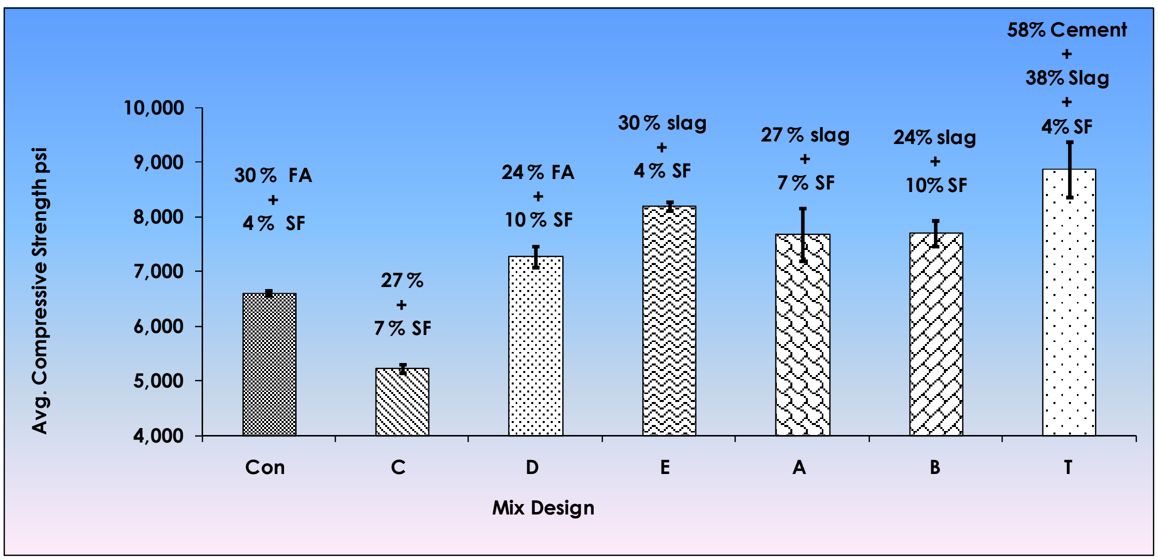


Figure 39: Average compressive strength at 1 day

Figures 40 and 41 present the compressive strengths of the mixtures following 28 and 56 days of curing, respectively. In comparing figure 38 (1-day strengths) with figure 39 (28-day strengths), in can be seen that, on average, there was approximately a 21% increase in the strength from 1 day to 28 days. The lowest increase was 10% for mixture C and the highest increase was 30% for mixture E. However, in comparing figure 40 with figure 41, it can be seen that there was hardly any increase in the compressive strength from 28 days to 56 days.

All of the experimental mixtures had significantly higher compressive strengths than the control mixture. Mixtures E, A, and B had significantly higher compressive strengths than the control mixture, and mixtures C and D. This showed that the concrete mixtures containing slag resulted in higher compressive strengths than those containing fly ash. This possibly could be due to the higher rate of hydration of slag and, subsequently, reduced porosity in the interfacial transition zone. Mixture D had a relatively higher compressive strength than the control mixture. Mixtures S and E had higher compressive strengths than all the other mixtures, probably because of the lower air content in mixtures S and E. According to Mehta, high strength concrete suffers a considerable strength loss with increasing amount of entrained air [66]. Also, mixture S had a higher cement content relative to all of the other mixtures (except mixture T), likely resulting in the very high strength.

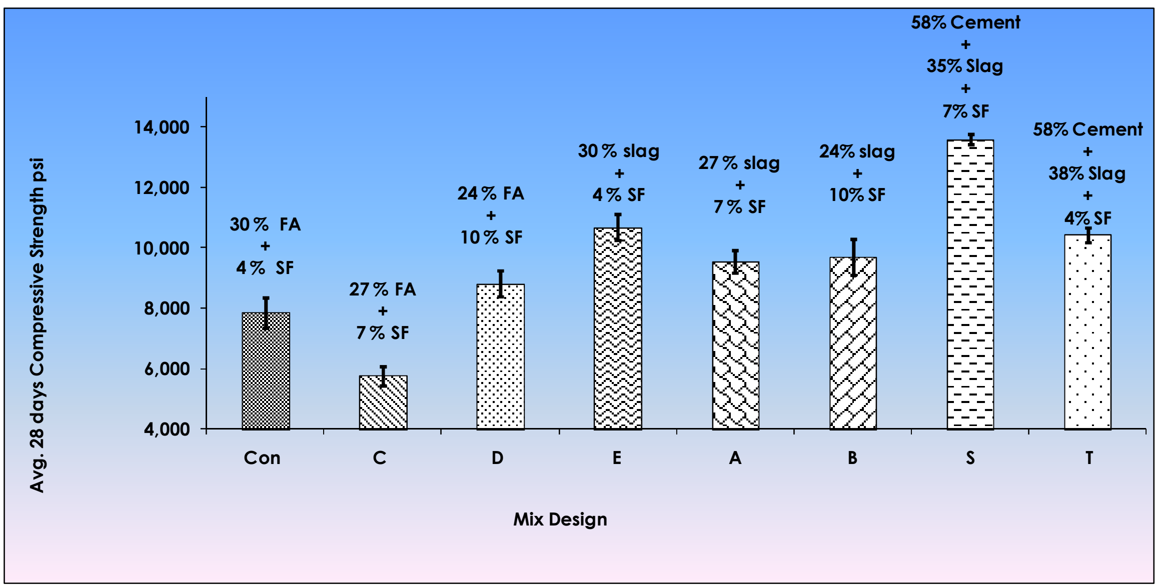


Figure 40: Average compressive strength at 28 days for phase II

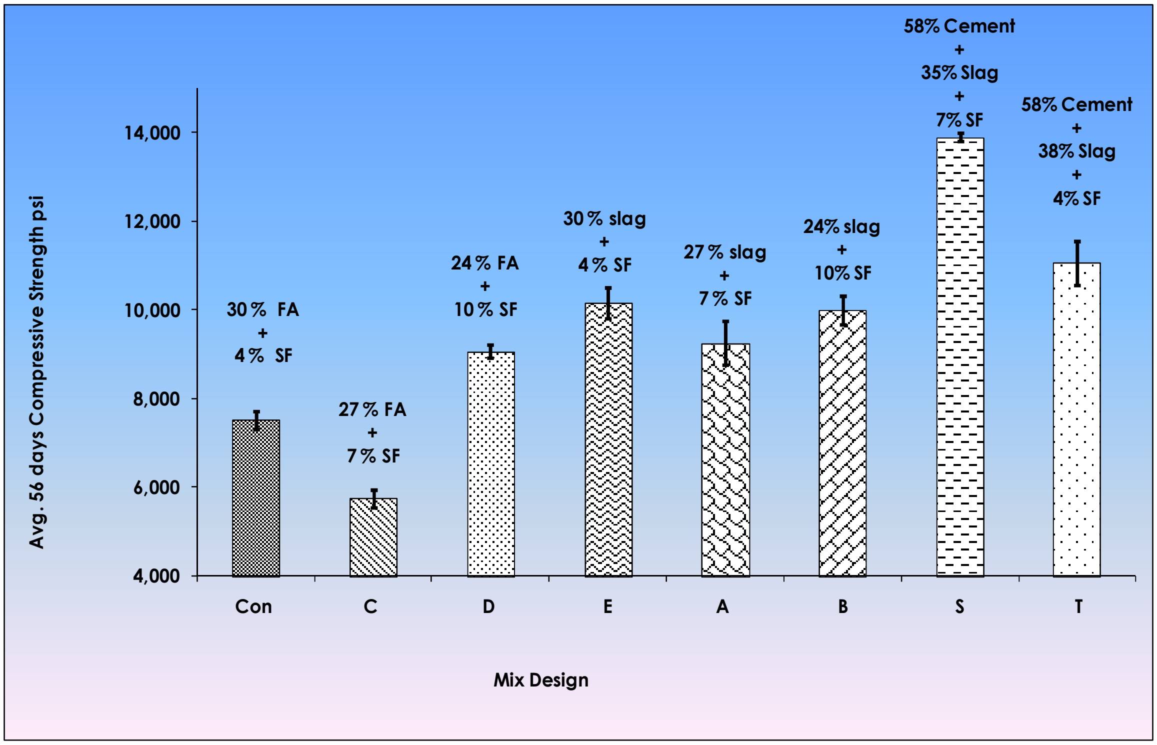


Figure 41: Average compressive strength at 56 days for phase II

Most of the failures took place along the aggregate phase. Type II and Type III failures were prevalent in all of the cylinders as illustrated in figure 42 and figure 43.

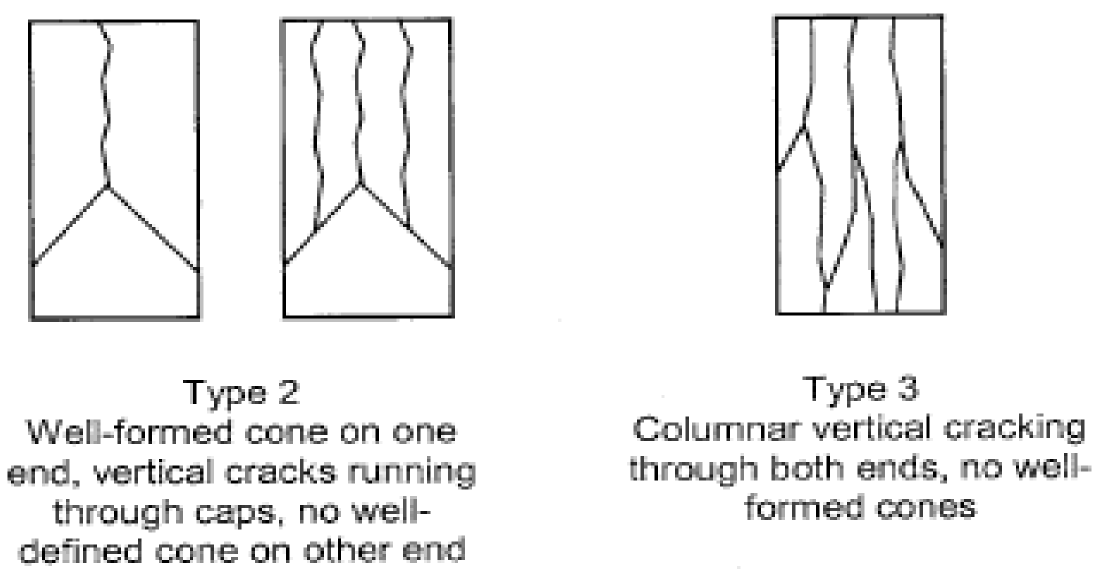


Figure 42: Type 2 and type 3 failure [adopted from ASTM C 39]

Figure 43: Type 3 failure

6 DISCUSSION OF RESULTS

The primary aim of this study was to investigate and develop at least one concrete mixture design which was significantly better, in terms of abrasion resistance and durability, than the bridge deck mixture presently being used by ODOT. Based on the analysis of the tests results from the different phases of the research study, a cumulative summary discussing the results and common findings of all the phases are described in this chapter.

6.1 Summary of Findings

6.1.1 Types of SCM

From phase I of study, it was found that there was strong evidence to support that the use of slag as an SCM significantly increased the compressive strength and freeze-thaw resistance of the concrete. Slag also improved the abrasion resistance and resistance to chloride ion penetration of the concrete more than fly ash. This could possibly be because of the fact that slag is hydraulic in nature while fly ash is a pozzolanic. Slag being hydraulic in nature reacts in the presence of water and an activator (NaOH or CaOH) supplied by portland cement, hydrates and sets in a manner similar to portland cement, while class F fly ash (which is low in CaO) reacts with calcium hydroxide released by the hydration of portland cement to form compounds possessing cementing properties (a relatively slow process occurring later in the overall hydration process) [4]. For phase II of the study, it was evident that mixtures containing slag as a constituent material had significantly higher compressive strength, higher abrasion resistance, and lower permeability than the mixtures containing fly ash as a constituent material. Based on the overall results presented herein, it can be stated that mixtures containing slag were significantly better than mixtures containing fly ash with regard to enhancing durability of the concrete.

6.1.2 Types of Aggregate

There was suggestive, but inconclusive, evidence that crushed rock increased the abrasion resistance, freeze-thaw resistance, and reduced the permeability of the concrete, but there was strong evidence to support that it significantly improved compressive strength. Abrasion resistance is directly proportional to the compressive strength of the concrete [4]. Based on this theory, abrasion resistance should have been higher for concrete having higher compressive strength. Though concrete containing crushed rock had significantly higher compressive strength, its abrasion resistance was comparatively low relative to the mixtures with river gravel. Low abrasion resistance obtained may have been due to the testing techniques used during phase I and minor errors introduced during testing.

Wear rate in the first 30 minutes was significantly higher than that in the next 30 minutes. This clearly indicated that when the aggregate particles were exposed, the wear rate decreased. In other words, exposure of the aggregate improved the wear resistance of concrete.

6.1.3 Curing Methods

Water curing method provides significantly improved compressive strength, abrasion resistance and resistance to chloride ion penetration but is not very effective in improving freeze-thaw resistance. Improved properties can be attributed to pore size reduction due to proper and continuous early stage hydration. It was confirmed from the phase I that water curing is the best method of curing and modification in steam curing method is required to provide the same level of durability as provided by the water curing. In order to expedite the production process at the pre-cast yard, to reduce the labor cost and at the same time to obtain a durable bridge deck slab, ODOT personals suggested to conduct a pilot study to investigate different curing methods and come up with a solution that would be the best alternative to the water curing. Some of the important findings of pilot study were:

- Steam curing accelerates the early strength gain which is a requirement for de-molding at the pre-cast yard.
- Effect of curing compound is only significant when water curing duration is short (one or two days). Samples cured in air after steam curing had the worst results. According to Andersson and Petersson, "concrete cured in water for 2 or 5 days had much lower penetration depth of water and air permeability than concrete cured with a membrane

curing compound cured under a plastic sheet, or cured in air." This validates the results obtained in the pilot study [67].

- Water curing period of 3 days or more in lime saturated water maintained at a temperature of 23+/-2^{0}C gives compressive strength similar to that obtained by water curing samples for 28 days. Possible reason behind this could be related to maturity phenomenon of concrete. Zhang et.al stated that for a w/c ratio of 0.4 and less, approximate age required to produce maturity at which capillaries would become discontinuous is 3 days [68].
- Application of curing compound after steam curing allows continued gain in strength through 28 days. This would be due to the fact that curing compound forms a membrane coating on the surface which prevents loss of water from the surface of the concrete without the ingress of external water into the concrete [68].

From the results obtained in the pilot study, steam curing followed by application of curing compound on the concrete slab appeared to be the best alternative to normal water curing technique.

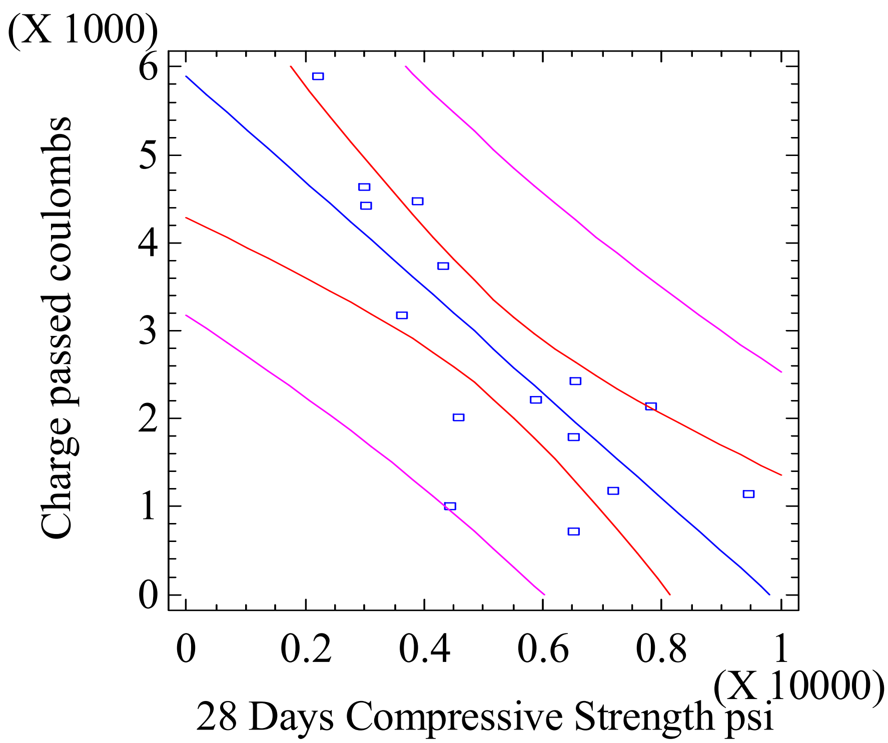
6.1.4 Level of Silica Fume

With the moderate increase in the amount of silica fume (i.e., from 4 to 7%), there was no significant increase in the abrasion resistance or compressive strength of the concrete. But with a substantial increase in the percentage of silica fume used (i.e., from 4 to 10%), there was an increase in the abrasion resistance, compressive strength, and resistance to chloride ion penetration of the HPC. This is likely because the concrete became denser due to the higher volume of silica fume. Though the permeability of the control mixture was below the threshold value of 1000 coulombs specified by ODOT, the variance in the values of permeability was very high.

6.1.5 Relation between Different Response Variables

Figure 44 depicts a linear regression (central line) with the charge passed in coulombs (chloride ion permeability) as the dependent variable and the compressive strength as an independent variable. The curved lines adjacent to the regression line indicate the 95% confidence interval about the regressed line while the outer lines represent prediction limit. As indicated, 61% of the variability in the charge passed is explained by the model.

It also indicates that permeability of the mixture is negatively correlated to the compressive strength. There is a strong evidence to support a statistically significant relationship between the two response variables of interest (p-value<0.01).

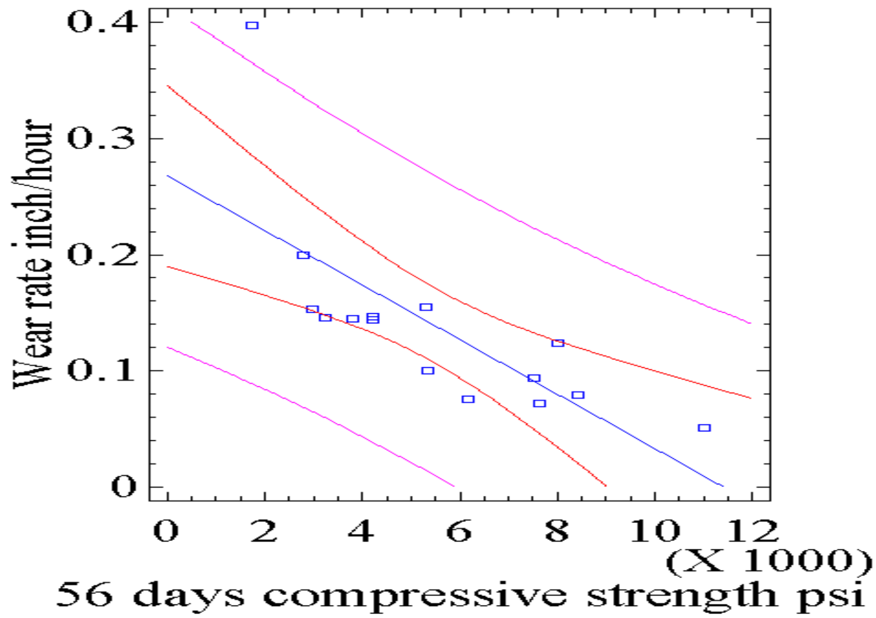


Charge passed = 5894.43 - 0.600816* 28-Day Compressive Strength; R^2=0.61

Figure 44: Relationship between compressive strength and permeability of the concrete

From the figure 44, it can be interpreted that the permeability of the concrete (charge coulombs passed) decreases as the compressive strength of the concrete increases. It means that the higher the compressive strength, the lower the permeability, hence the higher the durability of the concrete.

Figure 45 depicts linear regression with a wear rate as the dependent variable and compressive strength as an independent variable. 54% variability in the wear rate is explained by the model. Wear rate of the sample is negatively correlated to the compressive strength. There is a strong evidence to support statistically significant relationship between the two response variables of interest at 95% CI (p-value<0.01).

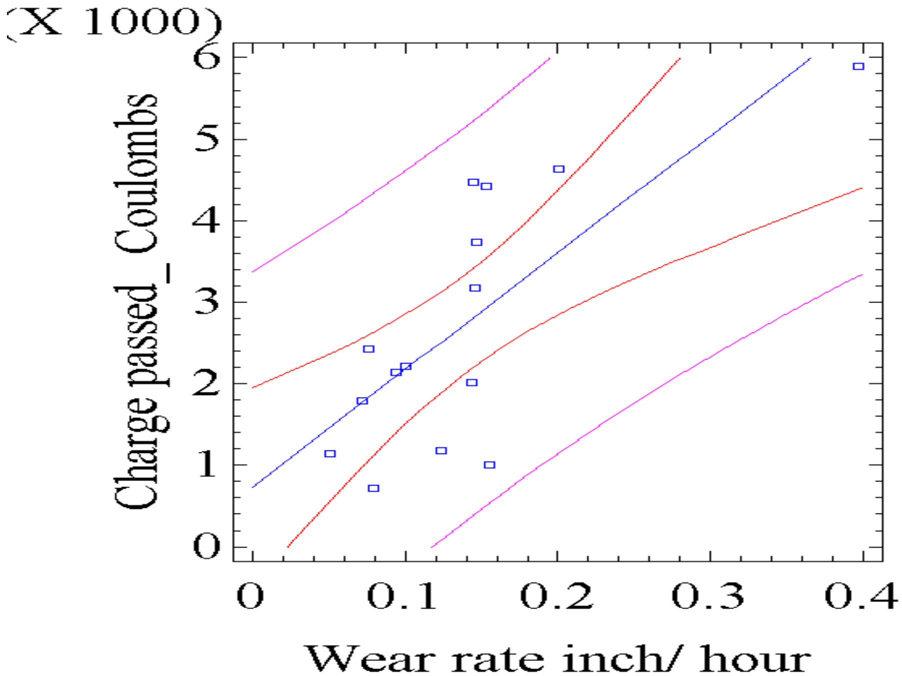


Wear rate = 0.267495 - 0.0000234097* 56 day Compressive Strength; R^2=0.54

Figure 45: Relationship between compressive strength and wear rate of the concrete

From figure 45, it can be seen that as the compressive strength of the concrete increases, the wear rate (expressed in inches/hour) decreases. It means that the higher the compressive strength, the better the abrasion resistance. This validates the statement that the abrasion resistance is directly proportional to the compressive strength of the concrete [4].

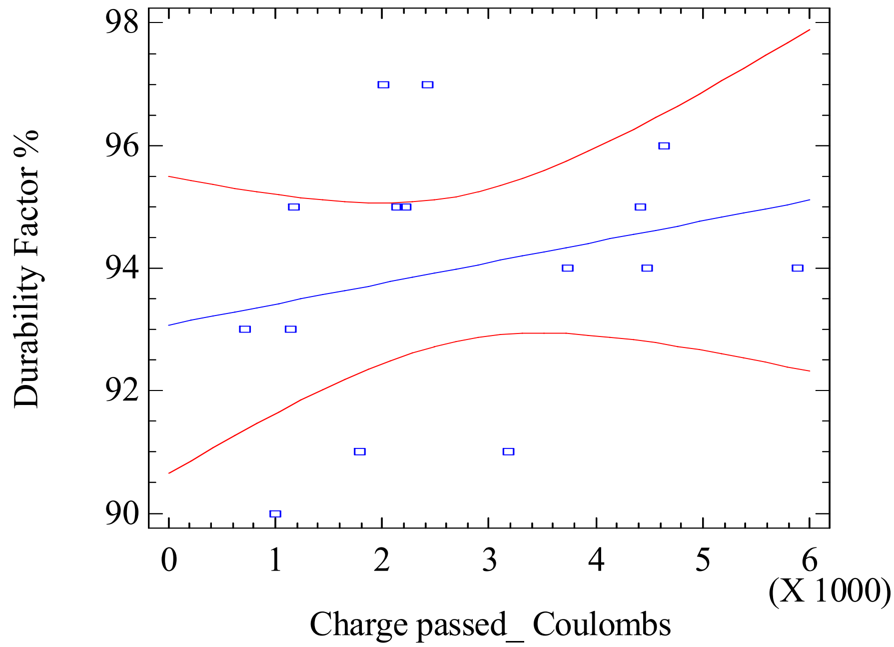
Figure 46 depicts a positive correlation between wear rate and permeability of the concrete (the lines are as explained previously). Therefore, with an increase in the permeability of the concrete, the abrasion (wear rate) of the concrete also increases. As indicated, 56% of the variability is explained by the model. Correlation coefficient of 0.75 indicates moderately strong relationship between the two variables.



Charge passed = 734.202 + 14375.9*wear rate; R^2=0.56;Correlation coefficient=0.75

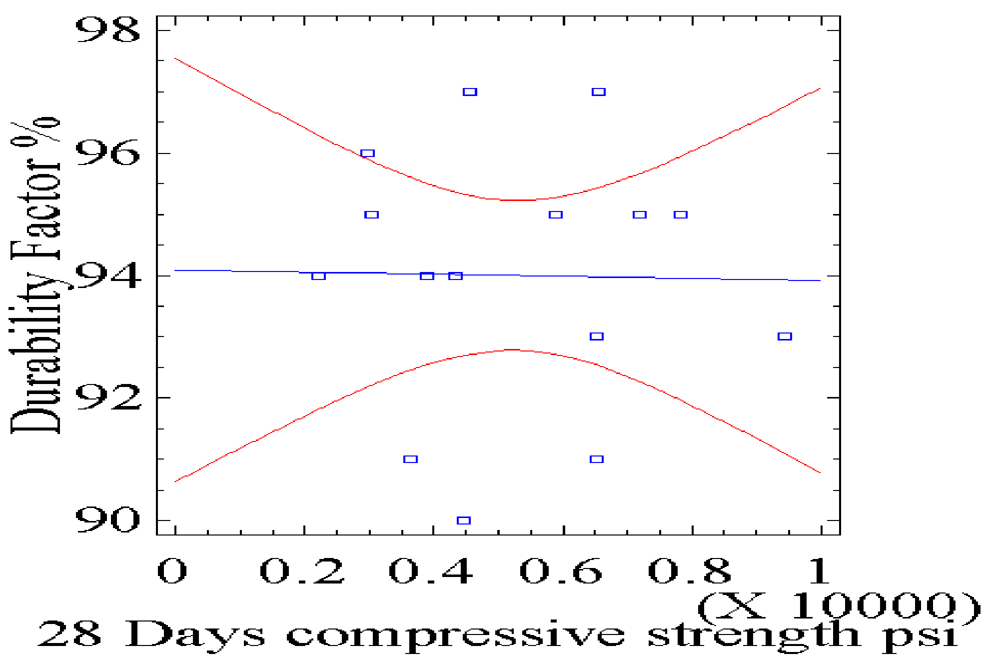
Figure 46: Relationship between wear rate and permeability of the concrete

Figure 47 depicts a weak correlation between the permeability and the durability factor (freeze-thaw) as indicated by a correlation coefficient of only 0.25. There is no correlation between the compressive strength and the durability factor of the concrete (correlation coefficient equal to 0.06) (figure 48). Only 6% of the variability in the freeze-thaw resistance is explained by the model containing chloride ion permeability as the independent variable. This suggests that the freeze-thaw resistance of concrete tested in this study was not dependent on the compressive strength. The freeze-thaw or frost resistance of the concrete is more dependent on air content, w/c ratio, and degree of saturation. Higher strength of the concrete does not relate to higher frost resistance but higher air content can sometimes translate into lower strength [66]. Since, no significant relationship was established between compressive strength and durability factor, freeze-thaw resistance of the HPC could not be predicted by just knowing the compressive strength.



Durability Factor % = 93.0755 + 0.00033859*Charge passed; R^2=.06; Correlation coefficient=0.25

Figure 47: Relationship between durability factor and permeability of the concrete



Durability Factor % = 94.0889 - 0.0000168806* Compressive Strength; R^2=.02; Correlation coefficient=0.016

Figure 48: Relationship between compressive strength and durability factor

6.2 Selection of Best Mixture Design

In phase I of the research, mixture EBW (i.e., the mixture containing slag, silica fume, crushed rock, and cured in water) was identified as the best mixture. Mixture EBW had an average wear rate of 0.051 inches/hour which translates to very good abrasion resistance (relative to the other mixtures), but the charge passed was above 1000 coulombs. Though it had a very high wear resistance, it did not satisfy the requirements of chloride ion permeability set by the ODOT 2008 specifications [46].

6.2.1 Durability Comparison

In phase II of the research, a comparison was made to assess the relative durability characteristics of the mixtures more critically. A comparison of all of the mixtures used in phase II was prepared by plotting the abrasion resistance on one axis and the RCPT values on the other axis to identify and select the best possible mixture design as shown in Figure 47. The thick bars depict the wear rate of the concrete with associated scale on the left side Y-axis, while the thin bars depict charge passed in coulombs with associated scale on the right side Y-axis. The 95% CI for the wear rate is black in color, while that for the charge passed is blue in color.

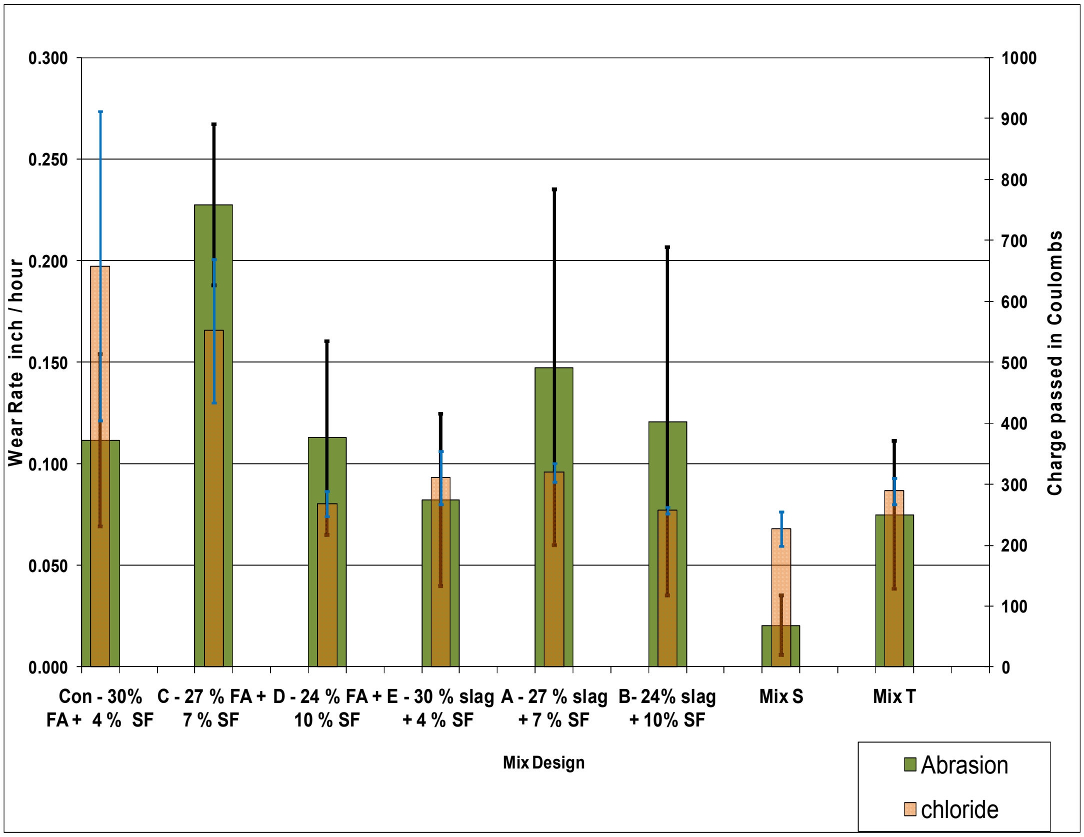


Figure 49: Durability comparison of HPC

From figure 49, it can be seen that mixtures E, S, and T performed significantly better than the others in terms of resistance to chloride ion penetration and abrasion resistance. Comparing the best mixtures from phases I and II, it was found that the use of crushed rock significantly improved abrasion resistance.

Mixture S was the most durable HPC but it had no entrained air. There is a lot of debate going on regarding eliminating the air content from the HPC. According to Stefan, HPC with low water/binder ratio (w/b), however, can be very durable without air entraining, even after very severe freeze/thaw exposure in the presence of deicing salt. One key factor is that the water in the hardened cement paste of saturated HPC cannot freeze at winter temperatures [69]. Findings from the literature review suggested that the entrainment of air in the concrete is a complicated process and that it is quite difficult to maintain a consistent air content throughout the mixing, casting, and placing processes. According to Beatrix, certain high strength concretes do not need as much air as conventional strength concretes to be frost resistant due to the reduced porosity and less freezable water within the high strength concrete. Beatrix, in his paper, suggested that two important requirements for a good air void system are spacing factor and specific surface [70]. But Hewlett in his book "LEA'S Chemistry of Cement and Concrete" stated that air entrainment is required if freeze-thaw damage has to be avoided even at a w/c ratio of 0.30. He also found that surface scaling cannot be prevented by air entrainment but a spacing factor of 200 microns provided the same protection [71]. Also, mixture S had higher cement content which could be one of the possible reasons for high durability.

Based on the overall results, mixture E, which had entrained air, provided the next best performance in terms of abrasion resistance and impermeability. Hence, mixtures E and S are proposed for the purposes of conducting the field study.

6.3 Validation of Abrasion Tests Results by Alaska ODOT.

Three samples each for all the concrete mixture designs investigated in phase II and one sample of the aggregate (river gravel) were sent to Alaska Department of Transportation & Public Facilities (Alaska DOT&PF) to conduct independent tests for abrasion resistance of the concrete and aggregate. The Prall test was conducted on concrete, while Nordic abrasion test was conducted on aggregate. The Prall test, generally conducted for the asphalt pavements, originated in the USA and is being used by the Swedish asphalt laboratories to predict pavement wear due to studded tires. The test method adopted by Alaska DOT&PF is described in the data sheet provided by the Alaska DOT&PF materials engineer as follows:

> "*The sample to be tested is placed into a small chamber. The chamber is then shaken up and down (950 rpm) together with a number of steel balls for 15 minutes. The steel balls wear the sample surface by bouncing between the chamber walls, ceiling and the test sample. Water is circulated continuously at 5°C, which rinses the worn pavement particles out of the chamber. The Prall value is defined as the volume loss of the material.*

Interpretation of Prall test result is provided in the Table 38.

Table 38: Interpretation from Prall Test

Class	Prall-value, cm^3	Wear resistance
1	< 20	Very good
2	20 – 29	Good
3	30 – 39	Satisfactory
4	40 –50	Less satisfactory
5	> 50	Poor

Tests results obtained from Alaska DOT&PF were plotted on a bar chart with 95% CI as shown in figure 48. Both the Prall test conducted by Alaska DOT&PF and the abrasion test conducted by OSU showed that mixture S outperformed the other mixtures, the former indicating a Prall wear rate of 20 cm^3. Also, as indicated in the figure, mixtures S, E, T, and Q outperformed the control mixture. The Prall tests conducted by the Alaska DOT&PF substantiate the results obtained at Oregon State University (OSU) and validate the claim that the mixtures E and S were the best mixture designs.

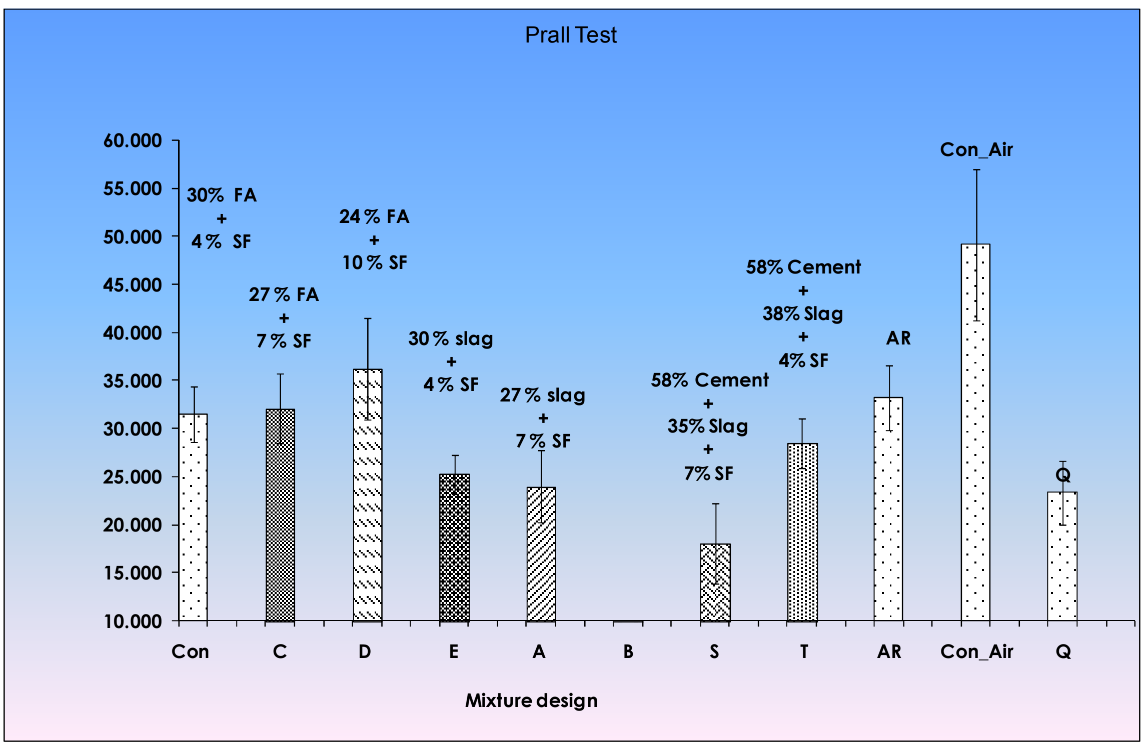


Figure 50: Prall test for abrasion of concrete

The Nordic abrasion test conducted by Alaska DOT&PF on the 3/4”×5/8” aggregate sample suggested that the aggregates play an important role in imparting studded tire wear resistance to the concrete. If the aggregates are hard and durable, then the pavement is also wear resistant. A Nordic Abrasion of 7.5 and less is considered to be good. The river gravel had a Nordic Abrasion of 13. It gives an insight to conduct tests using different type of aggregate to truly understand its effect on abrasion resistance of concrete.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Results from phase I indicated that combination of slag and silica fume significantly improved the durability properties of HPC in comparison to control mixture. Between slag and fly ash, slag provided much better durability than the fly ash. The phase I laboratory study also established that the water curing was the best method of curing; steam curing deteriorated the durability characteristics of the concrete. Steam cured followed by water curing for 14 days was better than steam curing followed by ambient curing in terms of improving the properties of concrete in comparison. Unlike other tests, steam curing improved the freeze thaw resistance of HPC better than water curing. There was suggestive, but inconclusive evidence that the crushed rock increased the abrasion resistance, freeze-thaw resistance, and reduced the permeability of the concrete. The crushed rock did not seem to have an effect on the chloride ion permeability and freeze-thaw resistance but further investigation is required to ascertain this. Mixtures having crushed rock had highest compressive strength. Considering the fact that most of the compressive failures were along the aggregate phase, further research is required to study the true effect of aggregates on the durability characteristics of the concrete. The mixture containing slag crushed rock, silica fume and cured with water curing (i.e., mixture EBW) was found to be highly abrasion resistant, but failed to satisfy the requirements of chloride ion permeability threshold values.

The findings from the Phase I of the research confirmed that the water curing is the best method of curing, but it would be quite difficult to carry out in the field due to the constraints of cost and construction issues. The pilot study identified a curing regime which would provide high early strength and at the same time higher compressive strength comparable to that obtained when samples are water cured for 28 days. It was concluded from the pilot study that the steam curing followed by application of curing compound on the concrete slab was the best alternative to the water curing technique. This will increase the speed of production at the pre-cast yard, and also ensure high durability of the concrete.

The phase II of the research validated the result from phase I that slag indeed improved the properties of HPC better than fly ash. Increasing the proportion of silica fume in the mixture design improved the durability characteristics of the concrete but, beyond a certain percentage level, only a marginal improvement in the durability characteristic was realized. In this study, 4% of silica fume combined with slag produced the best result. From this study, it was concluded that mixture S and mixture E were the best in terms of performance characteristics. Mixture S was a non-air entrained concrete containing 58% cement (604 lb/cy), 35% slag (565 lb/cy), and 7% silica fume (74 lb/cy). Mixture E was air-entrained concrete containing 66% cement (541 lb/cy), 4% silica fume (33 lb/cy) and 30% slag (246 lb/cy).

Based on the two phases of the laboratory study, it was concluded that slag significantly improved the durability characteristics of the HPC and was better than fly ash in terms enhancing durability characteristics. Linear regression analyses revealed that permeability and abrasion resistance are inversely proportional to the compressive strength of the concrete. However, the regression analysis did not reveal any relationship between the compressive strength and the freeze-thaw resistance of the concrete. Further investigation is required to ascertain this fact.

7.2 Recommendations

This research effort revealed that the aggregate had a significant effect on the abrasion resistance characteristic of the concrete; hence, it would be worthwhile to conduct further studies using different aggregates types and from different sources. It is also recommended to investigate if smaller nominal maximum aggregate sizes than those used in this study would improve the durability characteristics of the concrete.

The abrasion of concrete is a surface phenomenon, so further investigation should be made to explore the possibilities of improving the surface properties of the concrete. Previous studies report that concrete made from calcium aluminate cement has improved abrasion resistance; hence, it would be beneficial to conduct further investigations using different combinations of SCMs together with calcium aluminate cement to study the combined effects on studded tire wear resistance.

Apart from investigating the abrasion resistance and resistance to chloride ion penetration properties of the concrete, other durability factors like alkali silica reactivity and sulphate attack should also be investigated for HPC mixtures. Further investigation is also recommended to study the durability and strength characteristics of HPC without air entrainment admixtures.

One of the limitations of the research study was that all the tests for different response variables were conducted on different samples in laboratory conditions which precluded the confounding effects of and the interaction between the different response variables. This approach does simplify the study, but might not represent the reality exactly. This makes it difficult to correlate between the laboratory results and the field results. Therefore, a field study is essential to validate laboratory results in real life situations. If a field study is not possible due to any constraints (e.g., cost, project availability, etc.), a laboratory study utilizing a simulated environment can give improved insights into the durability characteristics of the concrete, but it cannot substitute for a field study. A field study can also provide cost and performance data essential for conducting life cycle cost analyses. To this end, it is recommended that a field study be conducted to validate the findings of this research and to gather requisite information for conducting cost analyses.

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9 APPENDICES

9.1 *Appendix A*

Mixture Designs

Concrete Mix Design – Control Mixture (ODOT Class 5000 – 3/4 inch)

1. **Required Strength**

- Specified strength: f'_c = 5,000 psi
- New mix design – standard deviation of strength unknown
- Required strength, f'_{cr} (02001.43 option a):
    - $f'_{cr} = f'_c \times 1.20$ = 5,000 x 1.20 = 6,000 psi

2. **Select w/c Ratio:**

- Historical records unavailable
- Trial batches based on Table 9-3 [4] and Morse Bros. Mix Design No. MB 031-50N17000
- Air-entrained: w/c = 0.30, 0.35, and 0.40
- Check w/c limits based on exposure conditions: Tables 9-1 and 9-2

3. **Air Content**

- Maximum aggregate size for coarse aggregate = 3/4 in.
- Target slump = 4 in.
- Table 9-5 [4]
- Target air content: 5%

4. **Target Slump**

- Morse Bros. mix design: 4 in.

5. **Water Content**

- Maximum coarse aggregate size: 3/4 in.
- Desired slump: 4 in.
- Aggregate shape: Crushed with some fractured faces
- Table 9-5 [4]
- Water Content: 305 - 35 = 270 pounds per cubic yard
- Note: Water content reduced by 35 lb for gravel with some crushed faces

6. **Cement Content**

- Based on the w/c ratio and the water content
- Minimums for:
    - Severe freeze-thaw, deicer, and sulfate exposure
    - Placing concrete under water
    - Flatwork
- Cement content:

- For w/c = 0.30: 900 pounds per cubic yard
- For w/c = 0.35: 771 pounds per cubic yard
- For w/c = 0.40: 675 pounds per cubic yard

- Minimum required for flatwork (Table 9-7): 540 lb/cy → okay

7. Bulk Volume of Coarse Aggregate

- Maximum coarse aggregate size: 3/4 in.
- Fineness modulus of sand: 3.05
- Dry rodded unit weight of coarse aggregate: 101.7 pcf
- Table 9.4: 0.60 [4]
- Weight of CA: 0.60 x 101.7 lb/ft^3 x 27 ft^3/yd^3 = 1648 lb/yd^3

8. Admixture Requirements

- Air entraining agent: WR Grace/Daravair-1000

9. Fine Aggregate Content:

- Volumes of other ingredient:
  - Water: 270 lb / (1 x 62.4 lb/ft^3) = 4.327 ft^3
  - Cement:
    - For w/c = 0.30: 900 lb / (3.15 x 62.4 lb/ft^3) = 4.579 ft^3
    - For w/c = 0.35: 771 lb / (3.15 x 62.4 lb/ft^3) = 3.922 ft^3
    - For w/c = 0.40: 675 lb / (3.15 x 62.4 lb/ft^3) = 3.434 ft^3
  - Air: (5 / 100) x 27 ft^3) = 1.35 ft^3
  - Coarse Aggregate: 1,648 lb / (2.532 x 62.4 lb/ft^3) = 10.430 ft^3
  - Totals:
    - For w/c = 0.30: 20.686 ft^3
    - For w/c = 0.35: 20.029 ft^3
    - For w/c = 0.40: 19.541 ft^3
- **FA Content:**
  - For w/c = 0.30: 6.413 ft^3 x 2.461 x 62.4 lb/ft^3 = 970 lb
  - For w/c = 0.35: 6.971 ft^3 x 2.461 x 62.4 lb/ft^3 = 1,070 lb
  - For w/c = 0.40: 7.459 ft^3 x 2.461 x 62.4 lb/ft^3 = 1,145 lb

10. Adjustment for Moisture:

- Aggregates are dry → no adjustment necessary

Appendix Table 1: Summary of batch weights for one cubic yard of concrete:

Ingredient	Batch Weight for One Cubic Yard, lb		
w/c ratio →	0.30	0.35	0.40
Water (to be added)	270	270	270
Cement	900	771	675
Coarse aggregate (dry)	1,648	1,648	1,648
Fine aggregate (dry)	970	1,070	1,145
Total			

Appendix Table 2: HPC mixture design spreadsheet

Fraction		Proportion	Sp.Gr	W/A (%)	DRY	Volume	Moisture content	Adjustment for Moisture	Batch Weight (Wet)
			SSD		lb/Cubic yard			lb/cubic Yard	lb/cubic Yard
Cement		-	3.150		528.000	2.686			528.000
Flyash			2.520		0.000	0.000			0.000
Slag			2.890		240.000	1.331			240.000
Microsilica			2.200		32.000	0.233			32.000
Water		-	1.000		240.000	3.846		131.731	108.269
Coarse Aggregate-3/4-1/2		35.79%	2.510	2.42%	613.000	3.914	2.6%	1.103	614.103
Coarse Aggregate-1/2-#4		64.21%	2.500	2.61%	1100.000	7.051	3.39%	8.580	1108.580
Sand			2.460	3.50%	1012.000	6.593	15.56%	122.047	1134.047
W/c Ratio		-	-	-	0.30				
Extra water added		-	-	-	-				-18.900
Total water		-	1	-	221.1				89.369
so modified w/c ratio		-	-	-	0.276375				
Air Entraining Dose, MBAE 90 (ml)		-	-	-	148.5				
BASF?/ Glen. 3400NV	ml				1359.045				
Air %		-	-	-	-	1.35			
Slump	inch.	-	-	-	-				
Totals		-	-	-	3765.000	27.004	-	-	3765.000

9.2 APPENDIX B

Tests Results- Determining Optimum Water to Cement Ratio – Control Mixture

Compressive Strength

Appendix Table 3: Compressive strength for control mixture (w/c ratio=0.3)

No: ....

Date of Casting:...18 Dec 07..

......Control Mix, w/c ratio= 0.30

Temperature of water:----62.4oF------------

Time of Testing: 9.00 am

Testing date	Dia ,(in.)	Length (in.)	Area , (in.2)	Weight in air, (kg)	Weight in water, (kg)	Density in air , (lb/ in.3)	Density in water , (lb/ in.3)	Max. Load , (lbf)	Compressive Strength , (psi)	Avg. Strength , (psi)	STDEV	Co.of Variation	Type of Fracture	Remarks
15-Jan-08	4	8	12.560	3.8455	2.1736	0.0844	0.0477	69900	5565.286624	5966.8	286.4	4.8	Shear	-
	4.024	8	12.711	3.8612	2.1859	0.0837	0.0474	75200	5916.055502				Shear	Pulling out of aggregate, Mortar Faliure, breaking of weathered rock
	4.039	8	12.806	3.9129	2.2335	0.0842	0.0481	80000	6247.016081				conical	Pulling out of aggregate, Mortar Faliure, breaking of weathered rock
	4.045	8	12.844	3.8606	2.1892	0.0828	0.0470	80000	6228.497269				Shear	-
	4.024	8	12.711	3.8524	2.1843	0.0835	0.0474	72500	5703.643935				Shear	Pulling out of aggregate, Mortar Faliure, breaking of weathered rock
	4.024	8	12.711	3.9141	2.229	0.0849	0.0483	78050	6140.267712				columnar	Pulling out of aggregate, Mortar Faliure, breaking of weathered rock

Appendix Table 4: Compressive strength for control mixture (w/c ratio=0.35)

Lab Identification No: ....

Date of Casting:...20 Dec 07..

Concrete Grade: ......Control Mix, w/c ratio= 0.35

Temperature of water:----62.4oF------------

Time of Testing: 4.00 pm

Specim. No.	Age	Testing date	Dia ,(in.)	Length (in.)	Area , (in.2)	Weight in air, (kg)	Weight in water, (kg)	Density in air , (lb/ in.3)	Density in water , (lb/ in.3)	Max. Load , (lbf)	Compressive Strength , (psi)	Avg. Strength , (psi)	Stdev	Co.of Variation	Type of Fracture	Remarks
C1	28	17-Jan-08	4.033	8	12.768	3.9418	2.2662	0.0851	0.0489	65950	5165.218515	5244.56	307.3584	5.86052	Shear	Pulling out of aggregate, Mortar Failure, breaking of weathered rock
C2			4.036	8	12.787	3.9529	2.2762	0.0852	0.0491	69300	5419.525483				Shear	Pulling out of aggregate, Mortar Failure, breaking of weathered rock
C3			4.021	8	12.692	3.9114	2.2353	0.0849	0.0485	65300	5144.881524				Shear	Pulling out of aggregate, Mortar Failure, breaking of weathered rock
C4			4.032	8	12.762	3.9101	2.235	0.0844	0.0483	60800	4764.231713				Shear	Pulling out of aggregate, Mortar Failure, breaking of weathered rock
C5			4.027	8	12.730	3.9066	2.2343	0.0846	0.0484	65500	5145.272542				Shear	Pulling out of aggregate, Mortar Failure, breaking of weathered rock
C6			4.022	8	12.699	3.9296	2.2567	0.0853	0.0490	63800	5024.199656				Shear	Pulling out of aggregate, Mortar Failure, breaking of weathered rock
C7			4.03	8	12.749	3.9178	2.2445	0.0847	0.0485	72400	5678.829336				Columnar	Pulling out of aggregate, Mortar Failure, breaking of weathered rock
C8			4.025	8	12.717	3.9298	2.2502	0.0852	0.0488	71400	5614.315128				Shear	Pulling out of aggregate, Mortar Failure, breaking of weathered rock

Appendix Table 5: Compressive strength for control mixture (w/c ratio=0.40)

Lab Identification No: ....

Date of Casting:...21Dec 07..

Concrete Grade: ......Control Mix, w/c ratio= 0.40

Temperature of water:----62.4oF------------

Time of Testing: 12.00 Noon

Specim. No.	Age	Testing date	Dia ,(in.)	Length (in.)	Area , (in.2)	Weight in air, (kg)	Weight in water, (kg)	Density in air , (lb/ in.3)	Density in water , (lb/ in.3)	Max. Load , (lbf)	Compressive Strength , (psi)	Avg. Strength , (psi)	STDEV	Co.of Variation	Type of Fracture	Remarks
C1	28	18-Jan-08	4.022	8	12.699	3.8304	2.154	0.0831	0.0467	55900	4402.0809	3499.432	503.7275	14.39455	Columnar	Pulling out of aggregate, Mortar Faliure, breaking of weathered rock
C2			4.035	8	12.781	3.7817	2.1067	0.0815	0.0454	37300	2918.4489				Shear	
C3			4.042	8	12.825	3.8309	2.1544	0.0823	0.0463	50950	3972.6647				Shear	Pulling out of aggregate, Mortar Faliure, breaking of weathered rock
C4			4.03	8	12.749	3.8186	2.1379	0.0825	0.0462	45450	3564.9557				Shear	
C5			4.033	8	12.768	3.7666	2.0905	0.0813	0.0451	40400	3164.1369				Shear	Pulling out of aggregate, Mortar Faliure, breaking of weathered rock
C6			4.024	8	12.711	3.765	2.0911	0.0816	0.0453	43000	3382.8509				Shear	Pulling out of large aggregate, Mortar Faliure, breaking of
C7			4.05	8	12.876	3.7566	2.0838	0.0804	0.0446	38500	2990.0677				Shear	
C8			4.03	8	12.749	3.7712	2.0951	0.0815	0.0453	45900	3600.2523				Shear	

Flexure Strength

Appendix Table 6: Flexural strength for control mixture (w/c ratio=0.30)

Lab Identification No: .... **Date of Casting:** 18-Dec-07

Concrete Grade: Control Mix, w/c ratio= 0.30 **Time of Testing: 9.00 am** **Temperature of Water:** ...55.9°F......

Specim. No.	Age	Testing date	Weight in Air (Kg)	Weight in Water (Kg)	Average width of the specimen to the nearest 0.05 in.(1mm) at the fracture , b=	Average depth of specimen to the nearest 0.05 in.(1mm) at the fracture, d=	Span length (in.), L=	Avg. dist. between line of fracture & the nearest support measured on the tension surface of the beam , a=	Max. applied load (lbf) , P=	Modulus of Rupture (psi), R=	Avg. Modulus of Rupture (psi)	Stdev	Remarks: Curing history and apparent moisture condition of the specimen at the time of testing	Remarks: If specimen were capped,ground or if leather shims were used	Remarks: Whether sawed or moulded & defects in specimen	Remarks: Any other remark
C1	**28**	15 Jan 08	28.88	16.273	6	**6**	18	8	7460	621.666667	671.67	54.14	**Moist**	Leather shims	None	Two Days after testing Date
C2			28.84	16.332	6	**6**	18	8	**8750**	729.166667			**Moist**	None	None	
C3			29.14	16.582	6	**6**	18	8	7970	664.166667			**Moist**	Leather shims	None	Two Days after testing Date

Appendix Table 7: Flexural strength for control mixture (w/c ratio=0.35)

Lab Identification No: .... **Date of Casting:** 20-Dec-07

Concrete Grade: Control Mix, w/c ratio= 0.35 **Time of Testing: 4.00 pm** **Temperature of Water:** ...55.9°F......

Specim. No.	Age	Testing date	Weight in Air (Kg)	Weight in Water (Kg)	Average width of the specimen to the nearest 0.05 in.(1mm) at the fracture , b=	Average depth of specimen to the nearest 0.05 in.(1mm) at the fracture, d=	Span length (in.), L=	Avg. dist. between line of fracture & the nearest support measured on the tension surface of the beam , a=	Max. applied load (lbf) , P=	Modulus of Rupture (psi), R=	Avg. Modulus of Rupture (psi)		Remarks: Curing history and apparent moisture condition of the specimen at the time of testing	Remarks: If specimen were capped,ground or if leather shims were used	Remarks: Whether sawed or moulded & defects in specimen	Remarks: Any other remark
C1	**28**	17 Jan 08	29.48	16.717	6	**6**	18	8.25	6840	570.000	514.21	48.84	**Moist**	Leather shims	None	
C2			29.28	16.71	6	**6**	18	5.5	**6460**	493.472			**Moist**	Leather shims	None	DIST BETWEEN FRACTURE LESS THAN MIDDLE THIRD, SO FORMULA 2 USED
C3			29.66	16.826	6	**6**	18	8	5750	479.167			**Moist**	Leather shims	None	

Appendix Table 8: Flexural strength for control mixture (w/c ratio=0.40)

Lab Identification No: ....

Date of Casting: 21-Dec-07

Concrete Grade: Control Mix, w/c ratio= 0.40

Time of Testing: 12.00 Noon

Temperature of Water: ...55.9°F......

Specim. No.	Age	Testing date	Weight in Air (Kg)	Weight in Water (Kg)	Average width of the specimen to the nearest 0.05 in.(1mm) at the fracture , b=	Average depth of specimen to the nearest 0.05 in.(1mm) at the fracture, d=	Span length (in.), L=	Avg. dist. between line of fracture & the nearest support measured on the tension surface of the beam , a=	Max. applied load (lbf) , P=	Modulus of Rupture (psi), R=	Avg. Modulus of Rupture (psi)		Remarks: Curing history and apparent moisture condition of the specimen at the time of testing	Remarks: If specimen were capped,ground or if leather shims were used	Remarks: Whether sawed or moulded & defects in specimen	Remarks: Any other remark
C1	28	18 Jan 08	28.38	15.75	6	**6**	18	8.5	5640	470.000	510.21	54.14	**Moist**	Leather shims	None	
C2			28.36	15.661	6	**6**	18	7.5	5930	494.167			**Moist**	Leather shims	None	
C3			28.34	15.663	6	6	18	7.5	7080	590.000			**Moist**	Leather shims	None	
C4			28.34	15.679	6	**6**	18	7	5840	486.667			**Moist**	Leather shims	None	

9.3 APPENDIX C

Tests Results- Phase I

Chloride Ion Test

Appendix Table 9: Control Mixture

Date of Casting		1-Mar-08		Date of Testing		12-Jun-08		Time of Testing		12.20 pm			
Mix Id	Control Mix_Water Curing, CW			Mix Type		Control Mix		Curing Period		103 days			
Resistance		Cell 1	1.01	ohm	Cell 2	0.99	ohm	Cell 3	1.00 ohm		Cell 4	1.01 ohm	
		Cell 1			Cell 2			Cell 3			Cell 4		
Time	Temperature	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp
12.20 pm	69.3	60	0.0598	0.059	60	0.0663	0.067	60	0.0723	0.0723	60	0.0718	0.071
12.50 pm	69.3	60	0.0600	0.059	60	0.0642	0.065	60	0.0739	0.0739	60	0.0685	0.068
1.20 pm	69.3	60	0.0618	0.061	60	0.0680	0.069	60	0.0766	0.0766	60	0.0704	0.070
1.50 pm	69.4	60	0.0607	0.060	60	0.0715	0.072	60	0.0795	0.0795	60	0.0740	0.073
2.20 pm	69.4	60	0.0645	0.064	60	0.0746	0.075	60	0.0826	0.0826	60	0.0771	0.076
2.50 pm	69.6	60	0.0658	0.065	60	0.0775	0.078	60	0.0855	0.0855	60	0.0829	0.082
3.20 pm	69.6	60	0.0685	0.068	60	0.0808	0.082	60	0.0887	0.0887	60	0.0844	0.084
3.50 pm	69.6	60	0.0723	0.072	60	0.0828	0.084	60	0.0909	0.0909	60	0.0852	0.084
4.20 pm	69.6	60	0.0718	0.071	60	0.0850	0.086	60	0.0935	0.0935	60	0.0881	0.087
4.50 pm	69.4	60	0.0740	0.073	60	0.0864	0.087	60	0.0960	0.0960	60	0.0907	0.090
5.20 pm	69.6	60	0.0753	0.075	60	0.0880	0.089	60	0.0984	0.0984	60	0.0928	0.092
5.50 pm	70.0	60	0.0720	0.071	60	0.0891	0.090	60	0.1006	0.1006	60	0.0936	0.093
6.20 pm	69.6	60	0.0730	0.072	60	0.0896	0.091	60	0.1022	0.1022	60	0.1004	0.099
Total Charge Passed		Q1=	1449.089	Coulombs	Q2 =	1719.727	Coulombs	Q2 =	1896.21	Coulombs	Q2 =	1771.129	Coulombs
Average Charge Passed, Coulombs									1709.0				

Appendix Table 10: EAW

Date of Casting		24-Mar-08		Date of Testing		28-Jun-08		Time of Testing		10.21am			
Mix Id	Exp A_Water Curing, EAW			Mix Type		Slag+Gravel		Curing Period		95 days			
Resistance		Cell 1	1.01	ohm	Cell 2	0.99	ohm	Cell 3	1.00 ohm		Cell 4	1.01 ohm	
		Cell 1			Cell 2			Cell 3			Cell 4		
Time	Temperature	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp
10.21 am	77.5	60	0.0409	0.040	60	0.0407	0.041	60	0.0440	0.044	60	0.0466	0.046
10.52 am	77.5	60	0.0406	0.040	60	0.0409	0.041	60	0.0495	0.0495	60	0.0472	0.047
11.21 am	77.5	60	0.0451	0.045	60	0.0430	0.043	60	0.0525	0.0525	60	0.0469	0.046
11.51 am	77.7	60	0.0470	0.047	60	0.0450	0.045	60	0.055	0.055	60	0.0461	0.046
12.21 pm	77.7	60	0.0500	0.050	60	0.0481	0.049	60	0.0571	0.0571	60	0.0492	0.049
12.51 pm	77.7	60	0.0510	0.050	60	0.0490	0.049	60	0.0590	0.059	60	0.0496	0.049
1.21 pm	77.7	60	0.0520	0.051	60	0.0492	0.050	60	0.0611	0.0611	60	0.0505	0.050
1.51 pm	78.1	60	0.0530	0.052	60	0.0510	0.052	60	0.0620	0.062	60	0.0512	0.051
2.21 pm	78.1	60	0.0550	0.054	60	0.0516	0.052	60	0.0644	0.0644	60	0.052	0.051
2.53 pm	78.3	60	0.0522	0.052	60	0.0517	0.052	60	0.0647	0.0647	60	0.0514	0.051
3.21 pm	78.3	60	0.0532	0.053	60	0.0526	0.053	60	0.0653	0.0653	60	0.0549	0.054
3.51 pm	78.3	60	0.0552	0.055	60	0.0533	0.054	60	0.0662	0.0662	60	0.0558	0.055
4.21 pm	78.3	60	0.0541	0.054	60	0.0547	0.055	60	0.0665	0.0665	60	0.0564	0.056
Total Charge Passed		Q1=	1072.515	Coulombs	Q2 =	1060.182	Coulombs	Q2 =	1281.69	Coulombs	Q2 =	1080.535	Coulombs
Average Charge Passed, Coulombs									1123.73				

Appendix Table 11: EASA

Date of Casting		25-Mar-08		Date of Testing		29-Jun-08		Time of Testing		12.20 pm			
Mix Id	Exp A_Steam Curing A, EASA			Mix Type		Slag+Gravel		Curing Period		95 days			
Resistance		Cell 1	1.01	ohm	Cell 2	0.99	ohm	Cell 3	1.00 ohm		Cell 4	1.01 ohm	
Time	Temperature	Cell 1			Cell 2			Cell 3			Cell 4		
		Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp
7.33 am	79.5	60	0.0719	0.071	60	0.0721	0.073	60	0.0882	0.0882	60	0.0729	0.072
8.03 am	79.7	60	0.0712	0.070	60	0.0761	0.077	60	0.0948	0.0948	60	0.0686	0.068
8.33 am	79.9	60	0.0795	0.079	60	0.0779	0.079	60	0.1023	0.1023	60	0.0718	0.071
9.03 am	79.9	60	0.0827	0.082	60	0.0810	0.082	60	0.109	0.109	60	0.0751	0.074
9.33 pm	79.9	60	0.0840	0.083	60	0.0902	0.091	60	0.1148	0.1148	60	0.0807	0.080
10.03 pm	79.9	60	0.0873	0.086	60	0.0908	0.092	60	0.1202	0.1202	60	0.0819	0.081
10.33 am	79.9	60	0.0932	0.092	60	0.1005	0.102	60	0.125	0.125	60	0.0881	0.087
11.03 am	79.9	60	0.0919	0.091	60	0.1035	0.105	60	0.1295	0.1295	60	0.0915	0.091
11.33 am	79.9	60	0.0980	0.097	60	0.1060	0.107	60	0.1332	0.1332	60	0.0884	0.088
12.03 pm	79.9	60	0.0979	0.097	60	0.1045	0.106	60	0.1366	0.1366	60	0.0926	0.092
12.33 pm	79.9	60	0.1028	0.102	60	0.1027	0.104	60	0.1395	0.1395	60	0.0991	0.098
1.03 pm	79.7	60	0.1019	0.101	60	0.1115	0.113	60	0.1418	0.1418	60	0.1014	0.100
1.33 pm	79.9	60	0.1039	0.103	60	0.1073	0.108	60	0.1438	0.1438	60	0.1025	0.101
Total Charge Passed		Q1=	1921.723	Coulombs	Q2 =	2062.545	Coulombs	Q2 =	2632.86	Coulombs	Q2 =	1830.119	Coulombs
	Average Charge Passed, Coulombs								**2111.81**				

Appendix Table 12: EASB

Date of Casting		25-Mar-08		Date of Testing		29-Jun-08		Time of Testing		2.37 pm			
Mix Id	Exp A_Steam Curing B, EASB			Mix Type		Slag+Gravel		Curing Period		95 days			
Resistance		Cell 1	1.01	ohm	Cell 2	0.99	ohm	Cell 3	1.00 ohm		Cell 4	1.01 ohm	
Time	Temperature	Cell 1			Cell 2			Cell 3			Cell 4		
		Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp
2.37 pm	80.2	60	0.0631	0.062	60	0.0744	0.075	60	0.0716	0.0716	60	0.0668	0.066
3.07 pm	80.4	60	0.0601	0.060	60	0.0720	0.073	60	0.0823	0.0823	60	0.0622	0.062
3.37 pm	80.4	60	0.0701	0.069	60	0.0774	0.078	60	0.0895	0.0895	60	0.0636	0.063
4.07 pm	80.4	60	0.0744	0.074	60	0.0817	0.083	60	0.0958	0.0958	60	0.0668	0.066
4.37 pm	80.4	60	0.0785	0.078	60	0.0830	0.084	60	0.1016	0.1016	60	0.0691	0.068
5.07 pm	80.4	60	0.0824	0.082	60	0.0942	0.095	60	0.1068	0.1068	60	0.072	0.071
5.37 pm	80.6	60	0.0871	0.086	60	0.0930	0.094	60	0.1111	0.1111	60	0.0764	0.076
6.07 pm	80.4	60	0.0896	0.089	60	0.0975	0.098	60	0.1157	0.1157	60	0.0771	0.076
6.37 pm	80.4	60	0.0890	0.088	60	0.0980	0.099	60	0.1186	0.1186	60	0.0802	0.079
7.07 pm	80.6	60	0.0922	0.091	60	0.0983	0.099	60	0.1217	0.1217	60	0.0819	0.081
7.37 pm	80.6	60	0.0942	0.093	60	0.1020	0.103	60	0.1245	0.1245	60	0.0831	0.082
8.07 pm	80.4	60	0.0934	0.092	60	0.1081	0.109	60	0.1263	0.1263	60	0.0895	0.089
8.37 pm		60	0.0970	0.096	60	0.1056	0.107	60	0.128	0.128	60	0.0851	0.084
Total Charge Passed		Q1=	1766.228	Coulombs	Q2 =	1991.273	Coulombs	Q2 =	2328.66	Coulombs	Q2 =	1600.129	Coulombs
	Average Charge Passed, Coulombs								**1921.57**				

Appendix Table 13: EBW

Date of Casting		2-Apr-08		Date of Testing			8.02 am			
Mix Id	EBW			Mix Type			95 days			
Resistance		Cell 1	1.01	ohm	Cell 2	1.00 ohm		Cell 4	1.01 ohm	
		Cell 1			Cell 2			Cell 4		
Time	Temperature	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp
3.06 pm	79.5	60	0.0465	0.046	60	0.0468	0.0468	60	0.0473	0.047
3.36 pm	78.8	60	0.0414	0.041	60	0.0511	0.0511	60	0.0447	0.044
4.06 pm	79.5	60	0.0407	0.040	60	0.0515	0.0515	60	0.0435	0.043
4.36 pm	79.3	60	0.0426	0.042	60	0.0507	0.0507	60	0.0482	0.048
5.06 pm	79.5	60	0.0452	0.045	60	0.0485	0.0485	60	0.0486	0.048
5.36 pm	79.3	60	0.0448	0.044	60	0.0496	0.0496	60	0.0503	0.050
6.06 pm	79.9	60	0.0464	0.046	60	0.05	0.05	60	0.0483	0.048
6.36 pm	79.9	60	0.0479	0.047	60	0.0509	0.0509	60	0.0515	0.051
7.06 pm	79.9	60	0.0479	0.047	60	0.051	0.051	60	0.0514	0.051
7.36 pm	79.5	60	0.0493	0.049	60	0.0517	0.0517	60	0.0516	0.051
8.06 pm	79.7	60	0.0488	0.048	60	0.0517	0.0517	60	0.0533	0.053
8.36 pm	79.5	60	0.0490	0.049	60	0.0517	0.0517	60	0.0547	0.054
9.06 pm	80.8	60	0.0498	0.049	60	0.0518	0.0518	60	0.0562	0.056
Total Charge Passed		Q1=	984.0297	Coulombs	Q2 =	1093.86	Coulombs	Q2 =	1065.475	Coulombs
Average Charge Passed, Coulombs								**1047.79**		

Appendix Table 14: EBSA

Date of Casting				Date of Testing		6-Jul-08		Time of Testing		2.02 pm			
Mix Id	EBSA			Mix Type				Curing Period		95 days			
Resistance		Cell 1	1.01	ohm	Cell 2	0.99	ohm	Cell 3	1.00 ohm		Cell 4	1.01 ohm	
		Cell 1			Cell 2			Cell 3			Cell 4		
Time	Temperature	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp
2.02 pm	79.9	60	0.0747	0.074	60	0.0833	0.084	60	0.0776	0.0776	60	0.0846	0.084
2.32 pm	79.3	60	0.0712	0.070	60	0.0831	0.084	60	0.0746	0.0746	60	0.0774	0.077
3.02 pm	79.2	60	0.0765	0.076	60	0.0870	0.088	60	0.0785	0.0785	60	0.0856	0.085
3.32 pm	79.2	60	0.0845	0.084	60	0.0927	0.094	60	0.082	0.082	60	0.0882	0.087
4.02 pm	79.3	60	0.0840	0.083	60	0.0947	0.096	60	0.0855	0.0855	60	0.0901	0.089
4.32 pm	79.9	60	0.0869	0.086	60	0.1015	0.103	60	0.0893	0.0893	60	0.0933	0.092
5.02 pm	79.2	60	0.0924	0.091	60	0.1016	0.103	60	0.0913	0.0913	60	0.0989	0.098
5.32 pm	80.2	60	0.0973	0.096	60	0.1127	0.114	60	0.0952	0.0952	60	0.0996	0.099
6.02 pm	79.7	60	0.0978	0.097	60	0.1054	0.106	60	0.0967	0.0967	60	0.1044	0.103
6.32 pm	79.5	60	0.1014	0.100	60	0.1095	0.111	60	0.1006	0.1006	60	0.1054	0.104
7.02 pm	79.3	60	0.1014	0.100	60	0.1208	0.122	60	0.1022	0.1022	60	0.1044	0.103
7.32 pm	79.7	60	0.0996	0.099	60	0.1138	0.115	60	0.1037	0.1037	60	0.1109	0.110
8.02 pm	79.7	60	0.1049	0.104	60	0.1198	0.121	60	0.105	0.105	60	0.1088	0.108
Total Charge Passed		Q1=	1929.743	Coulombs	Q2 =	2226.091	Coulombs	Q2 =	1963.62	Coulombs	Q2 =	2058.238	Coulombs
Average Charge Passed, Coulombs									**1983.87**				

Appendix Table 15: EBSB

Date of Casting				Date of Testing		5-Jul-08		Time of Testing		2.37 pm			
Mix Id		EBSB		Mix Type				Curing Period		95 days			
Resistance		Cell 1	1.01	ohm	Cell 2	0.99	ohm	Cell 3	1.00 ohm		Cell 4	1.01 ohm	
		Cell 1			Cell 2			Cell 3			Cell 4		
Time	Temperature	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp
2.37 pm	80.4	60	0.0863	0.085	60	0.0995	0.101	60	0.0895	0.0895	60	0.0731	0.072
3.07 pm	80.6	60	0.0697	0.069	60	0.0976	0.099	60	0.0927	0.0927	60	0.0668	0.066
3.37 pm	80.4	60	0.0870	0.086	60	0.1121	0.113	60	0.0973	0.0973	60	0.071	0.070
4.07 pm	80.8	60	0.0890	0.088	60	0.1132	0.114	60	0.102	0.102	60	0.0732	0.072
4.37 pm	80.6	60	0.0900	0.089	60	0.1231	0.124	60	0.1072	0.1072	60	0.0793	0.079
5.07 pm	80.6	60	0.1014	0.100	60	0.1308	0.132	60	0.1119	0.1119	60	0.082	0.081
5.37 pm	80.6	60	0.0977	0.097	60	0.1388	0.140	60	0.1153	0.1153	60	0.0875	0.087
6.07 pm	80.6	60	0.1069	0.106	60	0.1375	0.139	60	0.1189	0.1189	60	0.0906	0.090
6.37 pm	80.6	60	0.1128	0.112	60	0.1462	0.148	60	0.1224	0.1224	60	0.0913	0.090
7.07 pm	80.8	60	0.1117	0.111	60	0.1451	0.147	60	0.1292	0.1292	60	0.0933	0.092
7.37 pm	80.6	60	0.1177	0.117	60	0.1468	0.148	60	0.1284	0.1284	60	0.0955	0.095
8.07 pm	80.6	60	0.1158	0.115	60	0.1474	0.149	60	0.1303	0.1303	60	0.0974	0.096
8.37 pm	80.6	60	0.1185	0.117	60	0.1464	0.148	60	0.1325	0.1325	60	0.1034	0.102
Total Charge Passed		Q1=	2142.356	Coulombs	Q2 =	2839.182	Coulombs	Q2 =	2459.88	Coulombs	Q2 =	1810.96	Coulombs
Average Charge Passed, Coulombs									2313.09				

Appendix Table 16: ECW

Date of Casting				Date of Testing		30-Jun-08		Time of Testing		11.27 am			
Mix Id		ECW		Mix Type		Flyash + Gravel		Curing Period		95 days			
Resistance		Cell 1	1.01	ohm	Cell 2	0.99	ohm	Cell 3	1.00 ohm		Cell 4	1.01 ohm	
		Cell 1			Cell 2			Cell 3			Cell 4		
Time	Temperature	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp
11.27 am	80.2	60	0.0377	0.037	60	0.0386	0.039	60	0.0385	0.0385	60	0.0393	0.039
11.57 am	80.2	60	0.0361	0.036	60	0.0368	0.037	60	0.0425	0.0425	60	0.039	0.039
12.27 pm	80.2	60	0.0372	0.037	60	0.0400	0.040	60	0.0448	0.0448	60	0.0387	0.038
12.57 pm	80.4	60	0.0379	0.038	60	0.0419	0.042	60	0.0467	0.0467	60	0.0395	0.039
1.27 pm	80.4	60	0.0382	0.038	60	0.0419	0.042	60	0.0485	0.0485	60	0.0405	0.040
1.57 pm	80.4	60	0.0401	0.040	60	0.0448	0.045	60	0.0499	0.0499	60	0.0429	0.042
2.27 pm	80.6	60	0.0409	0.040	60	0.0434	0.044	60	0.0512	0.0512	60	0.0443	0.044
2.57 pm	80.4	60	0.0410	0.041	60	0.0444	0.045	60	0.0525	0.0525	60	0.0452	0.045
3.27 pm	80.8	60	0.0430	0.043	60	0.0446	0.045	60	0.0535	0.0535	60	0.046	0.046
3.57 pm	80.8	60	0.0439	0.043	60	0.0459	0.046	60	0.0544	0.0544	60	0.0464	0.046
4.27 pm	81	60	0.0444	0.044	60	0.0461	0.047	60	0.055	0.055	60	0.0459	0.045
4.57 pm	80.8	60	0.0451	0.045	60	0.0474	0.048	60	0.0557	0.0557	60	0.0457	0.045
5.27 pm		60	0.0448	0.044	60	0.0477	0.048	60	0.0561	0.0561	60	0.0471	0.047
Total Charge Passed		Q1=	871.5743	Coulombs	Q2 =	946.0909	Coulombs	Q2 =	1083.6	Coulombs	Q2 =	921.9208	Coulombs
Average Charge Passed, Coulombs									955.80				

Appendix Table 17: ECSA

Date of Casting				Date of Testing		2-Jul-08		Time of Testing		8.01 am			
Mix Id	ECSA			Mix Type		Flyash + Gravel		Curing Period		95 days			
Resistance		Cell 1	1.01	ohm	Cell 2	0.99	ohm	Cell 3	1.00 ohm		Cell 4	1.01 ohm	
		Cell 1			Cell 2			Cell 3			Cell 4		
Time	Temperature	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp
8.01 am	79.5	60	0.0975	0.097	60	0.0850	0.086	60	0.0993	0.0993	60	0.1089	0.108
8.31 am	79.7	60	0.1022	0.101	60	0.0854	0.086	60	0.1201	0.1201	60	0.0976	0.097
9.01 am	80.2	60	0.1086	0.108	60	0.0988	0.100	60	0.1333	0.1333	60	0.1099	0.109
9.31 am	79.9	60	0.1240	0.123	60	0.1120	0.113	60	0.146	0.146	60	0.1283	0.127
10.01 am	80.2	60	0.1326	0.131	60	0.1088	0.110	60	0.1542	0.1542	60	0.1366	0.135
10.31 am	79.9	60	0.1447	0.143	60	0.1163	0.117	60	0.1631	0.1631	60	0.1352	0.134
11.01 am	79.9	60	0.1499	0.148	60	0.1263	0.128	60	0.1704	0.1704	60	0.1505	0.149
11.31 am	79.9	60	0.1563	0.155	60	0.1256	0.127	60	0.1771	0.1771	60	0.1488	0.147
12.01 pm	79.9	60	0.1590	0.157	60	0.1309	0.132	60	0.1819	0.1819	60	0.1611	0.160
12.31 pm	80.2	60	0.1675	0.166	60	0.1334	0.135	60	0.1849	0.1849	60	0.1524	0.151
1.01 pm	80.4	60	0.1674	0.166	60	0.1305	0.132	60	0.1871	0.1871	60	0.1529	0.151
1.31 pm	80.4	60	0.1685	0.167	60	0.1386	0.140	60	0.1893	0.1893	60	0.166	0.164
2.01 am	80.4	60	0.1655	0.164	60	0.1291	0.130	60	0.1889	0.1889	60	0.168	0.166
Total Charge Passed		Q1=	3051.446	Coulombs	Q2 =	2570.273	Coulombs	Q2 =	3512.7	Coulombs	Q2 =	2990.05	Coulombs
Average Charge Passed, Coulombs									3031.12				

Appendix Table 18: ECSB

Date of Casting				Date of Testing		2-Jul-08		Time of Testing		3.01 pm			
Mix Id	ECSB			Mix Type				Curing Period		95 days			
Resistance		Cell 1	1.01	ohm	Cell 2	0.99	ohm	Cell 3	1.00 ohm		Cell 4	1.01 ohm	
		Cell 1			Cell 2			Cell 3			Cell 4		
Time	Temperature	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp
3.01 pm	80.6	60	0.1690	0.167	60	0.1741	0.176	60	0.1732	0.1732	60	0.141	0.140
3.31 pm	80.6	60	0.1878	0.186	60	0.2056	0.208	60	0.2244	0.2244	60	0.1513	0.150
4.01 pm	80.8	60	0.2233	0.221	60	0.2352	0.238	60	0.2544	0.2544	60	0.1753	0.174
4.31 pm	80.8	60	0.2560	0.254	60	0.2553	0.258	60	0.274	0.274	60	0.1980	0.196
5.01 pm	80.8	60	0.2807	0.278	60	0.2460	0.248	60	0.2984	0.2984	60	0.2055	0.203
5.31 pm	81	60	0.3032	0.300	60	0.2653	0.268	60	0.3152	0.3152	60	0.212	0.210
6.01 pm	81	60	0.3258	0.323	60	0.2763	0.279	60	0.3188	0.3188	60	0.2421	0.240
6.31 pm	81	60	0.3215	0.318	60	0.2655	0.268	60	0.3159	0.3159	60	0.2295	0.227
7.01 pm	81	60	0.3346	0.331	60	0.2844	0.287	60	0.3155	0.3155	60	0.2351	0.233
7.31 pm	81	60	0.3382	0.335	60	0.2722	0.275	60	0.3062	0.3062	60	0.2363	0.234
8.01 pm	80.8	60	0.3320	0.329	60	0.2755	0.278	60	0.2975	0.2975	60	0.25	0.248
8.31 pm	80.8	60	0.3243	0.321	60	0.2720	0.275	60	0.301	0.301	60	0.2282	0.226
9.01 pm	80.6	60	0.3292	0.326	60	0.2793	0.282	60	0.2976	0.2976	60	0.2226	0.220
Total Charge Passed		Q1=	6195.814	Coulombs	Q2 =	5600	Coulombs	Q2 =	6222.06	Coulombs	Q2 =	4535.822	Coulombs
Average Charge Passed, Coulombs									5638.42				

Appendix Table 19: EDW

Date of Casting		2-Apr-08		Date of Testing		7-Jul-08		Time of Testing		8.02 am			
Mix Id		EDW		Mix Type				Curing Period		95 days			
Resistance		Cell 1	1.01	ohm	Cell 2	0.99	ohm	Cell 3	1.00 ohm		Cell 4	1.01 ohm	
Time	Temperature	Cell 1			Cell 2			Cell 3			Cell 4		
		Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp
8.02 am	79.9	60	0.0243	0.024	60	0.0278	0.028	60	0.0315	0.0315	60	0.0323	0.032
8.32 am	79.5	60	0.0255	0.025	60	0.0280	0.028	60	0.0334	0.0334	60	0.0306	0.030
9.02 am	79.7	60	0.0238	0.024	60	0.0282	0.028	60	0.035	0.035	60	0.0294	0.029
9.32 am	79.5	60	0.0245	0.024	60	0.0283	0.029	60	0.0361	0.0361	60	0.0306	0.030
10.02 am	79.5	60	0.0245	0.024	60	0.0300	0.030	60	0.0371	0.0371	60	0.0313	0.031
10.32 am	78.8	60	0.0251	0.025	60	0.0291	0.029	60	0.0381	0.0381	60	0.0331	0.033
11.02 am	78.8	60	0.0267	0.026	60	0.0303	0.031	60	0.039	0.039	60	0.0326	0.032
11.32 am	78.8	60	0.0270	0.027	60	0.0309	0.031	60	0.0396	0.0396	60	0.0343	0.034
12.02 pm	79.3	60	0.0283	0.028	60	0.0302	0.031	60	0.0402	0.0402	60	0.0337	0.033
12.32 pm	79.2	60	0.0269	0.027	60	0.0305	0.031	60	0.0407	0.0407	60	0.0354	0.035
1.02 pm	79.2	60	0.0270	0.027	60	0.0315	0.032	60	0.0413	0.0413	60	0.0355	0.035
1.32 pm	79.2	60	0.0282	0.028	60	0.0328	0.033	60	0.042	0.042	60	0.0353	0.035
2.02pm	79.2	60	0.0293	0.029	60	0.0320	0.032	60	0.0422	0.0422	60	0.0358	0.035
Total Charge Passed		Q1=	560.1386	Coulombs	Q2 =	654	Coulombs	Q2 =	826.83	Coulombs	Q2 =	705.4752	Coulombs
Average Charge Passed, Coulombs									686.61				

Appendix Table 20: EDSA

Date of Casting				Date of Testing		4-Jul-08		Time of Testing		7.48 am			
Mix Id		EDSA		Mix Type				Curing Period		95 days			
Resistance		Cell 1	1.01	ohm	Cell 2	0.99	ohm	Cell 3	1.00 ohm		Cell 4	1.01 ohm	
Time	Temperature	Cell 1			Cell 2			Cell 3			Cell 4		
		Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp
7.48 am	79.7	60	0.1111	0.110	60	0.1202	0.121	60	0.1229	0.1229	60	0.1321	0.131
8.18 am	80.4	60	0.1137	0.113	60	0.1292	0.131	60	0.1488	0.1488	60	0.1258	0.125
8.48 am	80.8	60	0.1188	0.118	60	0.1462	0.148	60	0.1646	0.1646	60	0.14	0.139
9.18 am	80.6	60	0.1283	0.127	60	0.1560	0.158	60	0.1769	0.1769	60	0.1518	0.150
9.48 am	80.6	60	0.1351	0.134	60	0.1642	0.166	60	0.1862	0.1862	60	0.1597	0.158
10.18 am	80.4	60	0.1446	0.143	60	0.1750	0.177	60	0.1939	0.1939	60	0.1652	0.164
10.48 am	80.6	60	0.1466	0.145	60	0.1783	0.180	60	0.2005	0.2005	60	0.1689	0.167
11.18 am	80.8	60	0.1498	0.148	60	0.1818	0.184	60	0.2023	0.2023	60	0.173	0.171
11.48 am	80.2	60	0.1592	0.158	60	0.1946	0.197	60	0.203	0.203	60	0.182	0.180
12.18 pm	80.4	60	0.1562	0.155	60	0.1841	0.186	60	0.2023	0.2023	60	0.1765	0.175
12.48 pm	80.6	60	0.1586	0.157	60	0.1866	0.188	60	0.2018	0.2018	60	0.1783	0.177
1.18 pm	80.6	60	0.1569	0.155	60	0.1870	0.189	60	0.1995	0.1995	60	0.18	0.178
1.48 pm	80.8	60	0.1588	0.157	60	0.1860	0.188	60	0.1971	0.1971	60	0.1908	0.189
Total Charge Passed		Q1=	3034.604	Coulombs	Q2 =	3702	Coulombs	Q2 =	4031.64	Coulombs	Q2 =	3497.792	Coulombs
Average Charge Passed, Coulombs									3566.51				

Appendix Table 21: EDSB

Date of Casting				Date of Testing		4-Jul-08			Time of Testing		3.20 pm			
Mix Id		EDSB		Mix Type					Curing Period		95 days			
Resistance		Cell 1	1.01	ohm	Cell 2	0.99	ohm		Cell 3	1.00 ohm		Cell 4	1.01 ohm	
Time	Temperature	Cell 1			Cell 2			Cell 3			Cell 4			
		Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	
3.20 pm	81	60	0.1463	0.145	60	0.1438	0.145	60	0.1221	0.1221	60	0.13	0.129	
3.50 pm	81	60	0.1500	0.149	60	0.1580	0.160	60	0.1449	0.1449	60	0.1308	0.130	
4.20 pm	81	60	0.1777	0.176	60	0.1710	0.173	60	0.1641	0.1641	60	0.1479	0.146	
4.50 pm	80.8	60	0.2037	0.202	60	0.1935	0.195	60	0.1852	0.1852	60	0.1645	0.163	
5.20 pm	80.8	60	0.2170	0.215	60	0.2040	0.206	60	0.1914	0.1914	60	0.1846	0.183	
5.50 pm	80.6	60	0.2334	0.231	60	0.2115	0.214	60	0.2033	0.2033	60	0.1894	0.188	
6.20 pm	81	60	0.2482	0.246	60	0.2245	0.227	60	0.2102	0.2102	60	0.1968	0.195	
6.50 pm	80.6	60	0.2450	0.243	60	0.2307	0.233	60	0.2144	0.2144	60	0.2154	0.213	
7.20 pm	80.6	60	0.2418	0.239	60	0.2174	0.220	60	0.2145	0.2145	60	0.204	0.202	
7.50 pm	80.8	60	0.2523	0.250	60	0.2210	0.223	60	0.2111	0.2111	60	0.1846	0.183	
8.20 pm	80.8	60	0.2289	0.227	60	0.2102	0.212	60	0.2079	0.2079	60	0.1808	0.179	
8.50 pm	80.6	60	0.2389	0.237	60	0.2005	0.203	60	0.2009	0.2009	60	0.17	0.168	
9.20 pm		60	0.2221	0.220	60	0.2024	0.204	60	0.1947	0.1947	60	0.164	0.162	
Total Charge Passed		Q1=	4671.267	Coulombs	Q2 =	4391.636	Coulombs	Q2 =	4151.34	Coulombs	Q2 =	3770.733	Coulombs	
Average Charge Passed, Coulombs									**4246.24**					

Abrasion Test

Appendix Table 22: CW

Date of Casting	29-Mar-08		Date of Testing		29-Jun-08	Time of Testing		
Mix ID	Control Mix		Mix Type		None	Curing Peroid		93 days
	Mix Id No.	CW-1	Mix Id No.		CW-2	Mix Id No.		CW-3
Wear depth (in.) at time (min.)								
Pos.	0	30	Difference	0	30	Difference	0	30	Difference
1	0.104	0.152	0.048	0.093	0.128	0.04	0.107	0.153	0.05
2	0.104	0.152	0.048	0.094	0.128	0.03	0.115	0.153	0.04
3	0.106	0.152	0.046	0.088	0.128	0.04	0.108	0.153	0.05
4	0.105	0.152	0.047	0.086	0.128	0.04	0.108	0.153	0.05
5	0.106	0.152	0.046	0.087	0.128	0.04	0.114	0.153	0.04
6	0.106	0.152	0.046	0.080	0.128	0.05	0.112	0.153	0.04
7	0.105	0.152	0.047	0.081	0.128	0.05	0.110	0.153	0.04
8	0.109	0.152	0.043	0.089	0.128	0.04	0.107	0.153	0.05
9	0.108	0.152	0.044	0.093	0.138	0.05	0.108	0.153	0.05
10	0.110	0.152	0.042	0.085	0.138	0.05	0.104	0.153	0.05
11	0.102	0.152	0.050	0.077	0.138	0.06	0.095	0.153	0.06
12	0.095	0.152	0.057	0.088	0.138	0.05	0.098	0.153	0.06
13	0.093	0.152	0.059	0.079	0.138	0.06	0.090	0.153	0.06
14	0.095	0.152	0.057	0.083	0.138	0.06	0.087	0.153	0.07
15	0.089	0.152	0.063	0.082	0.138	0.06	0.088	0.153	0.07
16	0.087	0.152	0.065	0.086	0.138	0.05	0.088	0.153	0.07
17	0.084	0.152	0.068	0.093	0.138	0.05	0.091	0.153	0.06
18	0.084	0.152	0.068	0.098	0.138	0.04	0.093	0.153	0.06
19	0.087	0.152	0.065	0.095	0.138	0.04	0.088	0.153	0.07
20	0.087	0.152	0.065	0.092	0.138	0.05	0.083	0.153	0.07
21	0.091	0.152	0.061	0.088	0.138	0.05	0.082	0.153	0.07
22	0.100	0.152	0.052	0.094	0.138	0.04	0.083	0.153	0.07
23	0.108	0.152	0.044	0.096	0.138	0.04	0.094	0.153	0.06
24	0.106	0.152	0.046	0.089	0.138	0.05	0.103	0.153	0.05
Average	0.099	0.152	0.053	0.088	0.135	0.046	0.098	0.153	0.055

Appendix Table 23: CSA

Date of Casting		29-Mar-08		Date of Testing		29-Jun-08	Time of Testing		
Mix ID		Control Mix, Steam Curing A		Mix Type		None	Curing Peroid		93 days
	Mix Id No.		CSA-1	Mix Id No.		CSA-2	Mix Id No.		CSA-3
Wear depth (in.) at time (min.)									
Pos.	0	30	Difference	0	30	Difference	0	30	Difference
1	0.126	0.200	0.074	0.135	0.202	0.07	0.107	0.186	0.08
2	0.129	0.199	0.070	0.128	0.199	0.07	0.103	0.191	0.09
3	0.129	0.189	0.060	0.111	0.187	0.08	0.104	0.183	0.08
4	0.122	0.194	0.072	0.104	0.195	0.09	0.107	0.185	0.08
5	0.125	0.094	-0.031	0.104	0.186	0.08	0.108	0.181	0.07
6	0.117	0.185	0.068	0.108	0.183	0.08	0.108	0.174	0.07
7	0.109	0.198	0.089	0.107	0.187	0.08	0.105	0.176	0.07
8	0.109	0.178	0.069	0.110	0.188	0.08	0.109	0.174	0.07
9	0.106	0.198	0.092	0.111	0.194	0.08	0.113	0.170	0.06
10	0.113	0.179	0.066	0.121	0.199	0.08	0.113	0.159	0.05
11	0.109	0.177	0.068	0.115	0.207	0.09	0.119	0.169	0.05
12	0.110	0.186	0.076	0.119	0.212	0.09	0.102	0.164	0.06
13	0.107	0.181	0.074	0.134	0.216	0.08	0.105	0.163	0.06
14	0.106	0.188	0.082	0.141	0.222	0.08	0.107	0.160	0.05
15	0.104	0.180	0.076	0.144	0.220	0.08	0.111	0.174	0.06
16	0.107	0.172	0.065	0.138	0.231	0.09	0.112	0.178	0.07
17	0.111	0.182	0.071	0.130	0.226	0.10	0.107	0.177	0.07
18	0.113	0.180	0.067	0.128	0.223	0.10	0.102	0.166	0.06
19	0.115	0.182	0.067	0.133	0.220	0.09	0.101	0.177	0.08
20	0.110	0.190	0.080	0.127	0.219	0.09	0.114	0.186	0.07
21	0.123	0.179	0.056	0.131	0.219	0.09	0.115	0.194	0.08
22	0.118	0.184	0.066	0.133	0.213	0.08	0.109	0.187	0.08
23	0.118	0.190	0.072	0.134	0.216	0.08	0.106	0.177	0.07
24	0.137	0.181	0.044	0.141	0.209	0.07	0.111	0.181	0.07
Average	0.116	0.182	0.066	0.124	0.207	0.083	0.108	0.176	0.068

Appendix Table 24: CSB

Date of Casting		3/29/2008		Date of Testing		6/29/2008	Time of Testing		
Mix ID		Control Mix, Steam Curing B		Mix Type		None	Curing Peroid		93 days
	Mix Id No.		CSB-1	Mix Id No.		CSB-2	Mix Id No.		CSB-3
Wear depth (in.) at time (min.)									
Pos.	0	30	Difference	0	30	Difference	0	30	Difference
1	0.141	0.238	0.097	0.133	0.262	0.13	0.142	0.246	0.10
2	0.140	0.242	0.102	0.140	0.262	0.12	0.148	0.240	0.09
3	0.137	0.233	0.096	0.152	0.263	0.11	0.157	0.241	0.08
4	0.131	0.244	0.113	0.162	0.271	0.11	0.152	0.234	0.08
5	0.123	0.231	0.108	0.164	0.258	0.09	0.150	0.224	0.07
6	0.113	0.217	0.104	0.155	0.244	0.09	0.150	0.240	0.09
7	0.107	0.222	0.115	0.142	0.241	0.10	0.142	0.244	0.10
8	0.110	0.214	0.104	0.143	0.235	0.09	0.129	0.222	0.09
9	0.120	0.212	0.092	0.138	0.222	0.08	0.127	0.223	0.10
10	0.131	0.208	0.077	0.125	0.229	0.10	0.128	0.223	0.10
11	0.120	0.220	0.100	0.120	0.237	0.12	0.125	0.230	0.11
12	0.119	0.220	0.101	0.116	0.225	0.11	0.117	0.224	0.11
13	0.109	0.226	0.117	0.119	0.223	0.10	0.118	0.193	0.08
14	0.111	0.227	0.116	0.120	0.226	0.11	0.120	0.222	0.10
15	0.131	0.236	0.105	0.118	0.233	0.12	0.114	0.210	0.10
16	0.133	0.235	0.102	0.121	0.230	0.11	0.110	0.194	0.08
17	0.132	0.249	0.117	0.126	0.231	0.11	0.120	0.181	0.06
18	0.136	0.251	0.115	0.145	0.239	0.09	0.123	0.192	0.07
19	0.140	0.246	0.106	0.119	0.237	0.12	0.114	0.207	0.09
20	0.136	0.237	0.101	0.126	0.229	0.10	0.129	0.224	0.10
21	0.143	0.236	0.093	0.122	0.242	0.12	0.140	0.225	0.09
22	0.152	0.236	0.084	0.129	0.233	0.10	0.135	0.225	0.09
23	0.148	0.231	0.083	0.131	0.255	0.12	0.139	0.224	0.09
24	0.143	0.238	0.095	0.130	0.265	0.14	0.139	0.233	0.09
Average	0.129	0.231	0.102	0.133	0.241	0.108	0.132	0.222	0.090

Appendix Table 25: EAW

Date of Casting		24-Mar-08		Date of Testing		22-Jun-08	Time of Testing		
Mix ID		Exp A, Water Curing		Mix Type		Slag + Gravel	Curing Peroid		91 days
	Mix Id No.		EAW-3	Mix Id No.		EAW-1	Mix Id No.		EAW-2
Wear depth (in.) at time (min.)									
Pos.	0	30	Difference	0	30	Difference	0	30	Difference
1	0.149	0.288	0.139	0.144	0.210	0.066	0.167	0.231	0.064
2	0.164	0.277	0.113	0.154	0.221	0.067	0.153	0.230	0.077
3	0.153	0.253	0.100	0.163	0.228	0.065	0.152	0.224	0.072
4	0.156	0.264	0.108	0.168	0.230	0.062	0.133	0.207	0.074
5	0.156	0.262	0.106	0.176	0.238	0.062	0.126	0.192	0.066
6	0.153	0.260	0.107	0.177	0.239	0.062	0.107	0.176	0.069
7	0.154	0.252	0.098	0.183	0.252	0.069	0.122	0.177	0.055
8	0.153	0.260	0.107	0.176	0.240	0.064	0.115	0.167	0.052
9	0.156	0.261	0.105	0.171	0.243	0.072	0.109	0.158	0.049
10	0.152	0.255	0.103	0.170	0.232	0.062	0.118	0.166	0.048
11	0.143	0.253	0.110	0.159	0.230	0.071	0.117	0.146	0.029
12	0.152	0.230	0.078	0.152	0.224	0.072	0.110	0.167	0.057
13	0.145	0.244	0.099	0.141	0.207	0.066	0.109	0.170	0.061
14	0.146	0.241	0.095	0.131	0.195	0.064	0.112	0.164	0.052
15	0.147	0.233	0.086	0.128	0.184	0.056	0.117	0.191	0.074
16	0.154	0.255	0.101	0.132	0.196	0.064	0.131	0.206	0.075
17	0.158	0.245	0.087	0.126	0.189	0.063	0.139	0.210	0.071
18	0.164	0.248	0.084	0.132	0.185	0.053	0.147	0.208	0.061
19	0.159	0.257	0.098	0.136	0.194	0.058	0.156	0.217	0.061
20	0.158	0.262	0.104	0.137	0.189	0.052	0.168	0.222	0.054
21	0.155	0.257	0.102	0.137	0.190	0.053	0.168	0.223	0.055
22	0.164	0.261	0.097	0.134	0.196	0.062	0.168	0.227	0.059
23	0.171	0.283	0.112	0.131	0.197	0.066	0.169	0.228	0.059
24	0.164	0.280	0.116	0.136	0.200	0.064	0.171	0.229	0.058
Average	0.155	0.258	0.102	0.150	0.213	0.063	0.137	0.197	0.061

Appendix Table 26: EASA

Date of Casting		25-Mar-08		Date of Testing		23-Jun-08	Time of Testing		
Mix ID		Exp A, Steam Curing A		Mix Type		Slag + Gravel	Curing Peroid		91 days
	Mix Id No.		EASA-2	Mix Id No.		EASA-3	Mix Id No.		EASA-1
Wear depth (in.) at time (min.)									
Pos.	0	30	Difference	0	30	Difference	0	30	Difference
1	0.102	0.162	0.060	0.096	0.138	0.042	0.102	0.140	0.038
2	0.103	0.157	0.054	0.098	0.136	0.038	0.088	0.134	0.046
3	0.105	0.162	0.057	0.089	0.130	0.041	0.089	0.117	0.028
4	0.101	0.148	0.047	0.089	0.137	0.048	0.088	0.122	0.034
5	0.104	0.153	0.049	0.093	0.142	0.049	0.082	0.135	0.053
6	0.106	0.148	0.042	0.091	0.144	0.053	0.085	0.133	0.048
7	0.106	0.146	0.040	0.103	0.148	0.045	0.086	0.141	0.055
8	0.109	0.154	0.045	0.093	0.144	0.051	0.085	0.139	0.054
9	0.109	0.145	0.036	0.096	0.144	0.048	0.082	0.136	0.054
10	0.109	0.156	0.047	0.104	0.164	0.060	0.081	0.132	0.051
11	0.106	0.149	0.043	0.099	0.153	0.054	0.081	0.141	0.060
12	0.104	0.164	0.060	0.100	0.163	0.063	0.078	0.136	0.058
13	0.103	0.162	0.059	0.106	0.157	0.051	0.078	0.146	0.068
14	0.103	0.158	0.055	0.104	0.153	0.049	0.086	0.122	0.036
15	0.107	0.165	0.058	0.103	0.144	0.041	0.093	0.121	0.028
16	0.104	0.163	0.059	0.108	0.162	0.054	0.083	0.133	0.050
17	0.097	0.155	0.058	0.108	0.176	0.068	0.078	0.133	0.055
18	0.099	0.164	0.065	0.110	0.162	0.052	0.085	0.144	0.059
19	0.106	0.167	0.061	0.117	0.166	0.049	0.083	0.134	0.051
20	0.108	0.163	0.055	0.110	0.158	0.048	0.081	0.139	0.058
21	0.102	0.153	0.051	0.104	0.155	0.051	0.078	0.136	0.058
22	0.103	0.163	0.060	0.100	0.144	0.044	0.080	0.124	0.044
23	0.098	0.164	0.066	0.102	0.140	0.038	0.084	0.132	0.048
24	0.100	0.160	0.060	0.102	0.131	0.029	0.087	0.113	0.026
Average	0.104	0.158	0.054	0.101	0.150	0.049	0.084	0.133	0.048

Appendix Table 27: EASB

Date of Casting	25-Mar-08		Date of Testing		23-Jun-08	Time of Testing		
Mix ID	Exp A, Steam Curing B		Mix Type		Slag + Gravel	Curing Peroid		91 days
	Mix Id No.	EASB-1	Mix Id No.		EASB-3	Mix Id No.		EASB-2
Wear depth (in.) at time (min.)								
Pos.	0	30	Difference	0	30	Difference	0	30	Difference
1	0.112	0.179	0.067	0.098	0.174	0.076	0.114	0.179	0.065
2	0.121	0.194	0.073	0.099	0.166	0.067	0.105	0.181	0.076
3	0.132	0.198	0.066	0.104	0.174	0.070	0.100	0.170	0.070
4	0.134	0.197	0.063	0.114	0.192	0.078	0.101	0.176	0.075
5	0.127	0.194	0.067	0.124	0.187	0.063	0.087	0.162	0.075
6	0.126	0.212	0.086	0.118	0.189	0.071	0.095	0.152	0.057
7	0.124	0.198	0.074	0.119	0.212	0.093	0.105	0.150	0.045
8	0.127	0.190	0.063	0.124	0.206	0.082	0.097	0.163	0.066
9	0.120	0.183	0.063	0.126	0.214	0.088	0.097	0.155	0.058
10	0.110	0.179	0.069	0.120	0.217	0.097	0.098	0.156	0.058
11	0.110	0.175	0.065	0.122	0.232	0.110	0.105	0.172	0.067
12	0.104	0.167	0.063	0.124	0.208	0.084	0.101	0.186	0.085
13	0.109	0.158	0.049	0.124	0.211	0.087	0.109	0.180	0.071
14	0.107	0.157	0.050	0.122	0.206	0.084	0.109	0.190	0.081
15	0.110	0.170	0.060	0.122	0.195	0.073	0.113	0.184	0.071
16	0.113	0.173	0.060	0.116	0.203	0.087	0.110	0.195	0.085
17	0.115	0.174	0.059	0.103	0.193	0.090	0.107	0.202	0.095
18	0.110	0.177	0.067	0.101	0.196	0.095	0.107	0.190	0.083
19	0.111	0.165	0.054	0.097	0.194	0.097	0.113	0.190	0.077
20	0.115	0.171	0.056	0.098	0.181	0.083	0.113	0.182	0.069
21	0.104	0.170	0.066	0.103	0.169	0.066	0.113	0.189	0.076
22	0.100	0.171	0.071	0.107	0.173	0.066	0.114	0.184	0.070
23	0.101	0.164	0.063	0.104	0.173	0.069	0.118	0.185	0.067
24	0.107	0.163	0.056	0.097	0.175	0.078	0.111	0.175	0.064
Average	0.115	0.178	0.064	0.112	0.193	0.081	0.106	0.177	0.071

Appendix Table 28: EBW

Date of Casting		02-Apr-08		Date of Testing		3-Jul-08	Time of Testing		
Mix ID		Exp-B, Water Curing		Mix Type		Slag + Crushed rock	Curing Peroid		93 days
	Mix Id No.		EBW-1	Mix Id No.		EBW-2	Mix Id No.		EBW-3
Wear depth (in.) at time (min.)									
Pos.	0	30	Difference	0	30	Difference	0	30	Difference
1	0.096	0.125	0.029	0.125	0.149	0.02	0.103	0.113	0.01
2	0.092	0.121	0.029	0.123	0.147	0.02	0.108	0.131	0.02
3	0.091	0.120	0.029	0.112	0.144	0.03	0.112	0.142	0.03
4	0.093	0.126	0.033	0.108	0.131	0.02	0.125	0.147	0.02
5	0.098	0.129	0.031	0.105	0.135	0.03	0.117	0.149	0.03
6	0.098	0.130	0.032	0.100	0.129	0.03	0.131	0.152	0.02
7	0.093	0.135	0.042	0.101	0.124	0.02	0.129	0.148	0.02
8	0.100	0.124	0.024	0.094	0.119	0.03	0.118	0.142	0.02
9	0.096	0.124	0.028	0.084	0.111	0.03	0.122	0.137	0.02
10	0.097	0.122	0.025	0.084	0.107	0.02	0.109	0.125	0.02
11	0.100	0.132	0.032	0.082	0.106	0.02	0.099	0.123	0.02
12	0.100	0.128	0.028	0.088	0.106	0.02	0.094	0.123	0.03
13	0.104	0.134	0.030	0.094	0.114	0.02	0.096	0.116	0.02
14	0.100	0.132	0.032	0.096	0.121	0.03	0.094	0.123	0.03
15	0.103	0.138	0.035	0.101	0.120	0.02	0.103	0.127	0.02
16	0.104	0.135	0.031	0.096	0.125	0.03	0.099	0.124	0.03
17	0.107	0.133	0.026	0.096	0.125	0.03	0.111	0.133	0.02
18	0.112	0.134	0.022	0.103	0.130	0.03	0.103	0.130	0.03
19	0.111	0.137	0.026	0.112	0.133	0.02	0.103	0.127	0.02
20	0.107	0.132	0.025	0.118	0.142	0.02	0.104	0.128	0.02
21	0.105	0.125	0.020	0.113	0.146	0.03	0.102	0.116	0.01
22	0.096	0.121	0.025	0.111	0.134	0.02	0.099	0.130	0.03
23	0.094	0.117	0.023	0.116	0.140	0.02	0.094	0.123	0.03
24	0.099	0.123	0.024	0.124	0.145	0.02	0.099	0.122	0.02
Average	0.100	0.128	0.028	0.104	0.128	0.025	0.107	0.130	0.023

Appendix Table 29: EBSA

Date of Casting		31-Mar-08		Date of Testing		1-Jul-08	Time of Testing		
Mix ID		Exp-B, Steam Curing A		Mix Type		Slag + Crushed rock	Curing Peroid		93 days
	Mix Id No.		EBSA-1	Mix Id No.		EBSA-2	Mix Id No.		EBSA-3
Wear depth (in.) at time (min.)									
Pos.	0	30	Difference	0	30	Difference	0	30	Difference
1	0.082	0.146	0.064	0.111	0.160	0.05	0.112	0.154	0.04
2	0.093	0.158	0.065	0.115	0.150	0.04	0.112	0.170	0.06
3	0.096	0.159	0.063	0.101	0.149	0.05	0.120	0.171	0.05
4	0.100	0.161	0.061	0.103	0.138	0.04	0.119	0.177	0.06
5	0.104	0.171	0.067	0.095	0.136	0.04	0.124	0.157	0.03
6	0.104	0.168	0.064	0.095	0.141	0.05	0.125	0.166	0.04
7	0.106	0.152	0.046	0.087	0.139	0.05	0.121	0.163	0.04
8	0.103	0.164	0.061	0.103	0.138	0.04	0.117	0.155	0.04
9	0.104	0.162	0.058	0.093	0.144	0.05	0.113	0.151	0.04
10	0.105	0.158	0.053	0.094	0.136	0.04	0.116	0.152	0.04
11	0.117	0.161	0.044	0.095	0.132	0.04	0.116	0.149	0.03
12	0.115	0.173	0.058	0.098	0.132	0.03	0.111	0.148	0.04
13	0.123	0.183	0.060	0.093	0.134	0.04	0.110	0.148	0.04
14	0.130	0.174	0.044	0.098	0.140	0.04	0.111	0.155	0.04
15	0.143	0.183	0.040	0.106	0.144	0.04	0.118	0.158	0.04
16	0.132	0.182	0.050	0.113	0.156	0.04	0.121	0.162	0.04
17	0.127	0.176	0.049	0.122	0.161	0.04	0.124	0.164	0.04
18	0.115	0.162	0.047	0.124	0.164	0.04	0.127	0.165	0.04
19	0.107	0.158	0.051	0.125	0.156	0.03	0.126	0.160	0.03
20	0.108	0.157	0.049	0.125	0.172	0.05	0.123	0.169	0.05
21	0.108	0.156	0.048	0.122	0.180	0.06	0.125	0.170	0.05
22	0.098	0.155	0.057	0.119	0.165	0.05	0.109	0.169	0.06
23	0.091	0.158	0.067	0.123	0.168	0.05	0.107	0.153	0.05
24	0.090	0.160	0.070	0.120	0.167	0.05	0.105	0.165	0.06
Average	0.108	0.164	0.056	0.108	0.150	0.043	0.117	0.160	0.043

Appendix Table 30: EBSB

Date of Casting		31-Mar-08		Date of Testing		1-Jul-08	Time of Testing		
Mix ID		Exp-B, Steam Curing B		Mix Type		Slag + Crushed rock	Curing Peroid		93 days
	Mix Id No.		EBSB-1	Mix Id No.		EBSB-2	Mix Id No.		EBSB-3
Wear depth (in.) at time (min.)									
Pos.	0	30	Difference	0	30	Difference	0	30	Difference
1	0.100	0.136	0.036	0.094	0.149	0.06	0.099	0.151	0.05
2	0.094	0.133	0.039	0.105	0.143	0.04	0.104	0.133	0.03
3	0.088	0.132	0.044	0.094	0.138	0.04	0.108	0.158	0.05
4	0.093	0.143	0.050	0.101	0.138	0.04	0.124	0.165	0.04
5	0.090	0.139	0.049	0.108	0.141	0.03	0.109	0.164	0.06
6	0.102	0.143	0.041	0.104	0.141	0.04	0.112	0.148	0.04
7	0.113	0.155	0.042	0.108	0.135	0.03	0.110	0.150	0.04
8	0.118	0.152	0.034	0.102	0.128	0.03	0.102	0.135	0.03
9	0.122	0.162	0.040	0.111	0.130	0.02	0.093	0.135	0.04
10	0.133	0.166	0.033	0.108	0.137	0.03	0.098	0.135	0.04
11	0.137	0.160	0.023	0.116	0.137	0.02	0.101	0.123	0.02
12	0.142	0.158	0.016	0.115	0.138	0.02	0.095	0.140	0.05
13	0.140	0.160	0.020	0.119	0.138	0.02	0.101	0.132	0.03
14	0.122	0.160	0.038	0.112	0.141	0.03	0.100	0.138	0.04
15	0.124	0.164	0.040	0.107	0.142	0.04	0.105	0.134	0.03
16	0.112	0.168	0.056	0.103	0.135	0.03	0.102	0.130	0.03
17	0.113	0.148	0.035	0.095	0.143	0.05	0.096	0.130	0.03
18	0.110	0.159	0.049	0.092	0.133	0.04	0.102	0.135	0.03
19	0.110	0.143	0.033	0.094	0.131	0.04	0.103	0.139	0.04
20	0.113	0.165	0.052	0.103	0.144	0.04	0.098	0.138	0.04
21	0.116	0.158	0.042	0.102	0.154	0.05	0.101	0.141	0.04
22	0.103	0.154	0.051	0.108	0.154	0.05	0.098	0.144	0.05
23	0.093	0.145	0.052	0.100	0.143	0.04	0.102	0.138	0.04
24	0.098	0.140	0.042	0.090	0.133	0.04	0.088	0.154	0.07
Average	0.112	0.152	0.040	0.104	0.139	0.036	0.102	0.141	0.039

Appendix Table 31: ECW

Date of Casting		26-Mar-08		Date of Testing		24-Jun-08	Time of Testing		
Mix ID		Exp C, Water Curing		Mix Type		Fly ash + Gravel	Curing Peroid		91 days
	Mix Id No.		ECW-3	Mix Id No.		ECW-2	Mix Id No.		ECW-1
Wear depth (in.) at time (min.)									
Pos.	0	30	Difference	0	30	Difference	0	30	Difference
1	0.135	0.213	0.078	0.141	0.222	0.081	0.130	0.201	0.071
2	0.137	0.215	0.078	0.140	0.222	0.082	0.129	0.207	0.078
3	0.136	0.222	0.086	0.131	0.217	0.086	0.121	0.198	0.077
4	0.128	0.226	0.098	0.139	0.213	0.074	0.114	0.204	0.090
5	0.125	0.202	0.077	0.123	0.207	0.084	0.114	0.193	0.079
6	0.124	0.205	0.081	0.116	0.206	0.090	0.119	0.194	0.075
7	0.119	0.213	0.094	0.115	0.207	0.092	0.108	0.196	0.088
8	0.101	0.200	0.099	0.117	0.203	0.086	0.111	0.189	0.078
9	0.120	0.205	0.085	0.115	0.194	0.079	0.112	0.191	0.079
10	0.128	0.200	0.072	0.116	0.184	0.068	0.120	0.195	0.075
11	0.132	0.203	0.071	0.119	0.182	0.063	0.126	0.197	0.071
12	0.118	0.188	0.070	0.119	0.195	0.076	0.119	0.206	0.087
13	0.126	0.207	0.081	0.128	0.193	0.065	0.121	0.203	0.082
14	0.121	0.208	0.087	0.128	0.210	0.082	0.122	0.204	0.082
15	0.126	0.202	0.076	0.143	0.218	0.075	0.123	0.216	0.093
16	0.133	0.206	0.073	0.145	0.218	0.073	0.122	0.226	0.104
17	0.126	0.199	0.073	0.140	0.211	0.071	0.136	0.205	0.069
18	0.133	0.199	0.066	0.143	0.221	0.078	0.128	0.207	0.079
19	0.126	0.183	0.057	0.151	0.221	0.070	0.140	0.204	0.064
20	0.131	0.196	0.065	0.137	0.201	0.064	0.142	0.211	0.069
21	0.125	0.201	0.076	0.149	0.220	0.071	0.140	0.202	0.062
22	0.110	0.201	0.091	0.154	0.214	0.060	0.133	0.193	0.060
23	0.128	0.209	0.081	0.155	0.219	0.064	0.124	0.241	0.117
24	0.130	0.186	0.056	0.149	0.206	0.057	0.130	0.203	0.073
Average	0.126	0.204	0.078	0.134	0.209	0.075	0.124	0.204	0.079

Appendix Table 32: ECSA

Date of Casting		3/28/2008		Date of Testing		6/26/2008	Time of Testing		
Mix ID		Exp C, Steam Curing A		Mix Type		Fly ash + Gravel	Curing Peroid		91 days
	Mix Id No.		ECSA-1	Mix Id No.		ECSA-2	Mix Id No.		ECSA-3
Wear depth (in.) at time (min.)									
Pos.	0	30	Difference	0	30	Difference	0	30	Difference
1	0.107	0.200	0.093	0.120	0.188	0.068	0.128	0.199	0.071
2	0.103	0.201	0.098	0.111	0.191	0.080	0.125	0.203	0.078
3	0.105	0.203	0.098	0.102	0.173	0.071	0.129	0.213	0.084
4	0.101	0.182	0.081	0.097	0.179	0.082	0.130	0.204	0.074
5	0.093	0.195	0.102	0.097	0.187	0.090	0.128	0.195	0.067
6	0.096	0.193	0.097	0.096	0.186	0.090	0.125	0.205	0.080
7	0.094	0.196	0.102	0.098	0.164	0.066	0.114	0.204	0.090
8	0.092	0.195	0.103	0.102	0.170	0.068	0.108	0.167	0.059
9	0.096	0.176	0.080	0.098	0.145	0.047	0.103	0.169	0.066
10	0.093	0.161	0.068	0.091	0.154	0.063	0.101	0.168	0.067
11	0.093	0.155	0.062	0.097	0.152	0.055	0.100	0.190	0.090
12	0.093	0.162	0.069	0.092	0.156	0.064	0.106	0.169	0.063
13	0.094	0.150	0.056	0.092	0.165	0.073	0.107	0.194	0.087
14	0.094	0.165	0.071	0.101	0.151	0.050	0.107	0.180	0.073
15	0.092	0.155	0.063	0.095	0.177	0.082	0.109	0.181	0.072
16	0.101	0.161	0.060	0.100	0.158	0.058	0.116	0.194	0.078
17	0.101	0.167	0.066	0.107	0.179	0.072	0.116	0.188	0.072
18	0.104	0.177	0.073	0.111	0.181	0.070	0.119	0.188	0.069
19	0.119	0.168	0.049	0.114	0.193	0.079	0.128	0.199	0.071
20	0.127	0.198	0.071	0.114	0.182	0.068	0.128	0.184	0.056
21	0.130	0.197	0.067	0.116	0.196	0.080	0.134	0.190	0.056
22	0.127	0.206	0.079	0.118	0.178	0.060	0.128	0.189	0.061
23	0.126	0.206	0.080	0.121	0.191	0.070	0.130	0.195	0.065
24	0.113	0.196	0.083	0.118	0.189	0.071	0.139	0.192	0.053
Average	0.104	0.182	0.078	0.105	0.174	0.070	0.119	0.190	0.071

Appendix Table 33: ECSB

Date of Casting		3/28/2008		Date of Testing		6/26/2008	Time of Testing		
Mix ID		Exp C, Steam Curing B		Mix Type		Fly ash + Gravel	Curing Peroid		91 days
	Mix Id No.		ECSB-1	Mix Id No.		ECSB-2	Mix Id No.		ECSB-3
Wear depth (in.) at time (min.)									
Pos.	0	30	Difference	0.000	30	Difference	0.000	30.000	Difference
1	0.122	0.360	0.238	0.113	0.30	0.19	0.121	0.219	0.10
2	0.111	0.351	0.240	0.119	0.30	0.19	0.124	0.323	0.20
3	0.112	0.345	0.233	0.122	0.29	0.16	0.126	0.339	0.21
4	0.105	0.351	0.246	0.125	0.27	0.14	0.120	0.333	0.21
5	0.102	0.340	0.238	0.139	0.28	0.14	0.130	0.340	0.21
6	0.103	0.340	0.237	0.151	0.28	0.13	0.119	0.316	0.20
7	0.098	0.339	0.241	0.157	0.27	0.11	0.117	0.298	0.18
8	0.101	0.343	0.242	0.146	0.30	0.16	0.112	0.306	0.19
9	0.101	0.365	0.264	0.150	0.31	0.16	0.118	0.314	0.20
10	0.097	0.313	0.216	0.143	0.32	0.18	0.117	0.306	0.19
11	0.106	0.317	0.211	0.139	0.34	0.20	0.111	0.306	0.20
12	0.107	0.329	0.222	0.144	0.35	0.20	0.119	0.291	0.17
13	0.112	0.337	0.225	0.151	0.36	0.21	0.124	0.301	0.18
14	0.104	0.340	0.236	0.147	0.38	0.23	0.125	0.276	0.15
15	0.104	0.331	0.227	0.154	0.40	0.24	0.130	0.326	0.20
16	0.108	0.321	0.213	0.155	0.39	0.23	0.144	0.320	0.18
17	0.104	0.314	0.210	0.148	0.37	0.22	0.143	0.297	0.15
18	0.109	0.305	0.196	0.149	0.39	0.24	0.142	0.325	0.18
19	0.114	0.293	0.179	0.141	0.37	0.23	0.146	0.326	0.18
20	0.116	0.308	0.192	0.128	0.33	0.20	0.139	0.324	0.19
21	0.115	0.316	0.201	0.117	0.32	0.21	0.134	0.321	0.19
22	0.114	0.330	0.216	0.115	0.31	0.20	0.123	0.292	0.17
23	0.124	0.336	0.212	0.117	0.31	0.20	0.123	0.306	0.18
24	0.118	0.354	0.236	0.121	0.31	0.19	0.122	0.300	0.18
Average	0.109	0.332	0.224	0.137	0.326	0.189	0.126	0.309	0.182

Appendix Table 34: EDW

Date of Casting		02-Apr-08		Date of Testing		3-Jul-08	Time of Testing		
Mix ID		Exp-D, Water Curing		Mix Type		FA+ Crushed Rock	Curing Peroid		93 days
	Mix Id No.		EDW-1	Mix Id No.		EDW-2	Mix Id No.		EDW-3
Wear depth (in.) at time (min.)									
Pos.	0	30	Difference	0	30	Difference	0	30	Difference
1	0.108	0.144	0.036	0.113	0.142	0.03	0.103	0.146	0.04
2	0.105	0.146	0.041	0.113	0.141	0.03	0.104	0.146	0.04
3	0.100	0.139	0.039	0.112	0.139	0.03	0.107	0.142	0.04
4	0.087	0.132	0.045	0.105	0.141	0.04	0.105	0.132	0.03
5	0.091	0.132	0.041	0.110	0.144	0.03	0.115	0.132	0.02
6	0.083	0.126	0.043	0.111	0.149	0.04	0.131	0.126	(0.01)
7	0.092	0.140	0.048	0.111	0.146	0.04	0.111	0.140	0.03
8	0.099	0.131	0.032	0.107	0.140	0.03	0.108	0.131	0.02
9	0.107	0.147	0.040	0.107	0.133	0.03	0.107	0.147	0.04
10	0.109	0.147	0.038	0.105	0.132	0.03	0.109	0.147	0.04
11	0.110	0.142	0.032	0.102	0.129	0.03	0.100	0.142	0.04
12	0.108	0.146	0.038	0.103	0.135	0.03	0.094	0.146	0.05
13	0.108	0.151	0.043	0.106	0.133	0.03	0.095	0.151	0.06
14	0.107	0.148	0.041	0.103	0.131	0.03	0.094	0.148	0.05
15	0.110	0.154	0.044	0.106	0.134	0.03	0.103	0.154	0.05
16	0.108	0.161	0.053	0.102	0.136	0.03	0.100	0.161	0.06
17	0.112	0.162	0.050	0.106	0.137	0.03	0.111	0.162	0.05
18	0.111	0.158	0.047	0.105	0.151	0.05	0.103	0.158	0.06
19	0.114	0.162	0.048	0.106	0.156	0.05	0.103	0.162	0.06
20	0.103	0.160	0.057	0.109	0.161	0.05	0.104	0.160	0.06
21	0.098	0.148	0.050	0.118	0.165	0.05	0.103	0.148	0.05
22	0.110	0.156	0.046	0.112	0.164	0.05	0.099	0.156	0.06
23	0.112	0.152	0.040	0.101	0.145	0.04	0.094	0.152	0.06
24	0.096	0.144	0.048	0.102	0.141	0.04	0.099	0.144	0.05
Average	0.104	0.147	0.043	0.107	0.143	0.035	0.104	0.147	0.043

Appendix Table 35: EDSA

Date of Casting	30-Mar-08		Date of Testing		30-Jun-08	Time of Testing		
Mix ID	Exp-D, Steam Curing A		Mix Type		FA+ Crushed Rock	Curing Peroid		93 days
	Mix Id No.	EDSA-1	Mix Id No.		EDSA-2	Mix Id No.		EDSA-3
Wear depth (in.) at time (min.)								
Pos.	0	30	Difference	0	30	Difference	0	30	Difference
1	0.107	0.179	0.072	0.115	0.205	0.09	0.111	0.185	0.07
2	0.105	0.175	0.070	0.112	0.211	0.10	0.114	0.207	0.09
3	0.107	0.182	0.075	0.107	0.197	0.09	0.114	0.211	0.10
4	0.099	0.178	0.079	0.109	0.215	0.11	0.109	0.199	0.09
5	0.106	0.186	0.080	0.113	0.174	0.06	0.119	0.203	0.08
6	0.097	0.182	0.085	0.122	0.192	0.07	0.131	0.225	0.09
7	0.099	0.203	0.104	0.116	0.207	0.09	0.118	0.233	0.12
8	0.122	0.202	0.080	0.117	0.178	0.06	0.137	0.245	0.11
9	0.099	0.186	0.087	0.116	0.178	0.06	0.116	0.215	0.10
10	0.104	0.160	0.056	0.118	0.172	0.05	0.109	0.200	0.09
11	0.111	0.179	0.068	0.114	0.178	0.06	0.107	0.217	0.11
12	0.111	0.180	0.069	0.113	0.168	0.06	0.112	0.179	0.07
13	0.111	0.158	0.047	0.113	0.157	0.04	0.115	0.201	0.09
14	0.110	0.167	0.057	0.104	0.164	0.06	0.125	0.201	0.08
15	0.111	0.174	0.063	0.097	0.162	0.07	0.130	0.184	0.05
16	0.118	0.167	0.049	0.096	0.162	0.07	0.136	0.204	0.07
17	0.116	0.174	0.058	0.096	0.157	0.06	0.129	0.203	0.07
18	0.117	0.178	0.061	0.099	0.172	0.07	0.119	0.198	0.08
19	0.118	0.163	0.045	0.100	0.178	0.08	0.122	0.173	0.05
20	0.110	0.174	0.064	0.099	0.184	0.09	0.113	0.176	0.06
21	0.114	0.161	0.047	0.106	0.182	0.08	0.114	0.171	0.06
22	0.114	0.174	0.060	0.110	0.199	0.09	0.109	0.155	0.05
23	0.109	0.172	0.063	0.108	0.195	0.09	0.109	0.166	0.06
24	0.106	0.165	0.059	0.108	0.197	0.09	0.108	0.185	0.08
Average	0.109	0.176	0.067	0.109	0.183	0.074	0.118	0.197	0.080

Appendix Table 36: EDSB

Date of Casting		30-Mar-08		Date of Testing		30-Jun-08	Time of Testing		
Mix ID		Exp-D, Steam Curing B		Mix Type		FA+ Crushed Rock	Curing Peroid		93 days
	Mix Id No.		EDSB-2	Mix Id No.		EDSB-1	Mix Id No.		EDSB-3
Wear depth (in.) at time (min.)									
Pos.	0	30	Difference	0	30	Difference	0	30	Difference
1	0.108	0.169	0.061	0.109	0.188	0.08	0.147	0.197	0.05
2	0.109	0.187	0.078	0.110	0.188	0.08	0.141	0.218	0.08
3	0.100	0.175	0.075	0.110	0.195	0.09	0.141	0.195	0.05
4	0.109	0.187	0.078	0.108	0.187	0.08	0.142	0.207	0.07
5	0.110	0.196	0.086	0.105	0.189	0.08	0.135	0.204	0.07
6	0.105	0.185	0.080	0.105	0.203	0.10	0.130	0.189	0.06
7	0.098	0.183	0.085	0.097	0.172	0.08	0.111	0.211	0.10
8	0.105	0.182	0.077	0.090	0.189	0.10	0.107	0.156	0.05
9	0.100	0.172	0.072	0.087	0.173	0.09	0.102	0.172	0.07
10	0.095	0.182	0.087	0.097	0.179	0.08	0.108	0.181	0.07
11	0.099	0.155	0.056	0.097	0.164	0.07	0.107	0.193	0.09
12	0.095	0.175	0.080	0.108	0.181	0.07	0.100	0.206	0.11
13	0.094	0.181	0.087	0.107	0.175	0.07	0.108	0.215	0.11
14	0.098	0.177	0.079	0.105	0.180	0.08	0.105	0.205	0.10
15	0.096	0.191	0.095	0.111	0.170	0.06	0.107	0.197	0.09
16	0.091	0.189	0.098	0.123	0.185	0.06	0.118	0.201	0.08
17	0.094	0.177	0.083	0.119	0.188	0.07	0.120	0.203	0.08
18	0.097	0.180	0.083	0.126	0.197	0.07	0.120	0.215	0.10
19	0.100	0.171	0.071	0.125	0.208	0.08	0.127	0.204	0.08
20	0.100	0.178	0.078	0.123	0.205	0.08	0.133	0.213	0.08
21	0.106	0.181	0.075	0.123	0.186	0.06	0.147	0.209	0.06
22	0.108	0.203	0.095	0.121	0.188	0.07	0.148	0.201	0.05
23	0.112	0.183	0.071	0.115	0.183	0.07	0.142	0.199	0.06
24	0.114	0.183	0.069	0.114	0.178	0.06	0.153	0.210	0.06
Average	0.102	0.181	0.079	0.110	0.185	0.076	0.125	0.200	0.075

Freeze-Thaw Tests

Appendix Table 37: CW

Oregon State University

Resistance of Concrete to Rapid Freezing and Thawing.

ASTM C 666 - Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing.

ASTM C 215- Standard Test Method for Fundamental Transverse, Longitudinal, and Torsional Resonant

Lab Identification No: CW		**Date of Casting:**	9-Apr-08
Concrete Mix Type:		**Curing Period:**34 days	
Length of Specimen,	0.280	**Radius of Gyration, K:**	0.0789
Breadth of Specimen,	0.0774 0.078976	**Correction Factor, T:**	1.470
		C=0.9464 $L^3T/bt^{3:}$	877.741748

Serial	Date	Weight of specimen, Kg	Number of Freeze & Thaw cycle, C	Cumulative number of freeze and thaw cycle	Fundamental Frequency, Hz	Dynamic Modulus, Gpa		Relative Dynamic Modulus
1	13-May-08	3.566	0	0	2788	E_0	24.33	100
2	14-May-08	3.566	6	6	2748	E_6	23.64	97.15
3	15-May-08	3.566	5	11	2728	E_{11}	23.29	95.74
4	16-May-08	3.566	5	16	2725	E_{16}	23.24	95.53
5	17-May-08	3.566	5	21	2722	E_{21}	23.19	95.32
6	19-May-08	3.566	11	32	2721	E_{32}	23.17	95.25
7	22-May-08	3.566	18	50	2712	E_{50}	23.02	94.62
8	26-May-08	3.566	23	73	2720	E_{73}	23.16	95.18
9	1-Jun-08	3.566	33	106	2720	E_{106}	23.16	95.18
10	7-Jun-08	3.566	30	136	2716	E_{136}	23.09	94.90
11	12-Jun-08	3.566	32	168	2704	E_{168}	22.89	94.06
12	18-Jun-08	3.566	34	202	2699	E_{202}	22.80	93.72
13	24-Jun-08	3.566	35	237	2686	E_{237}	22.58	92.82
14	29-Jun-08	3.566	31	268	2675	E_{268}	22.40	92.06
15	5-Jul-08	3.566	33	301	2665	E_{301}	22.23	91.37

Appendix Table 38: CSA

Lab Identification No: CSA 2...				**Date of Casting:**	/ 29-Mar-08
Concrete Mix Type:	Control Mix, Steam Curing A			**Curing Period:**days	
Length of Specimen, in.,	11.064	0.280		**Radius of Gyration, K:**	0.0794
Breadth of Specimen, in.:	3.062	0.0780	0.079388	**Correction Factor, T:**	1.474
Width of specimen, in. :	3.02	0.0770	1.47388	**C=0.9464 $L^3T/bt^{3:}$**	859.89

Serial No.	Date	Weight of specimen, Kg	Number of Freeze & Thaw cycle, C	Cumulative number of freeze and thaw cycle	Fundamental Frequency, Hz	Dynamic Modulus, Gpa		Relative Dynamic Modulus
1	13-May-08	3.7224	0	0	2968	E_0	28.20	100
2	14-May-08	3.7224	6	6	2937	E_6	27.61	97.92196
3	15-May-08	3.7224	5	11	2924	E_{11}	27.37	97.05702
4	16-May-08	3.7224	5	16	2915	E_{16}	27.20	96.46046
5	17-May-08	3.7224	5	21	2900	E_{21}	26.92	95.47028
6	19-May-08	3.7224	11	32	2897	E_{32}	26.86	95.27286
7	22-May-08	3.7224	18	50	2896	E_{50}	26.85	95.2071
8	26-May-08	3.7224	23	73	2909	E_{73}	27.09	96.06378
9	1-Jun-08	3.7224	33	106	2905	E_{106}	27.01	95.79977
10	7-Jun-08	3.7224	30	136	2895	E_{136}	26.83	95.14136
11	12-Jun-08	3.7224	32	168	2876	E_{168}	26.48	93.89662
12	18-Jun-08	3.7224	34	202	2875	E_{202}	26.46	93.83134
13	24-Jun-08	3.7224	35	237	2870	E_{237}	26.37	93.50525
14	29-Jun-08	3.7224	31	268	2870	E_{268}	26.37	93.50525
15	5-Jul-08	3.7224	33	301	2870	E_{301}	26.37	93.51

Appendix Table 39: CSB

Lab Identification No: CSB 2………………………………………						**Date of Casting:**	/	29-Mar-08
Concrete Mix Type:	Control Mix, Steam Curing B					**Curing Period:**days		
Length of Specimen, in.,	11.052	0.281				**Radius of Gyration, K:**		0.0781
Breadth of Specimen, in.:	3.075	0.0780	0.078078			**Correction Factor, T:**		1.461
Width of specimen, in. :	3	0.0760	1.460781			**C=0.9464 L^3T/bt^3:**		895.87

Serial No.	Date	Weight of specimen, Kg	Number of Freeze & Thaw cycle, C	Cumulative number of freeze and thaw cycle	Fundamental Frequency, Hz	Dynamic Modulus, Gpa		Relative Dynamic Modulus
1	13-May-08	3.77	0	0	3003	E_0	30.46	100
2	14-May-08	3.77	6	6	2955	E_6	29.49	96.82875
3	15-May-08	3.77	5	11	2953	E_{11}	29.45	96.69772
4	16-May-08	3.77	5	16	2946	E_{16}	29.31	96.23982
5	17-May-08	3.77	5	21	2935	E_{21}	29.09	95.52247
6	19-May-08	3.77	11	32	2935	E_{32}	29.09	95.52247
7	22-May-08	3.77	18	50	2932	E_{50}	29.03	95.32729
8	26-May-08	3.77	23	73	2968	E_{73}	29.75	97.68258
9	1-Jun-08	3.77	33	106	2963	E_{106}	29.65	97.35374
10	7-Jun-08	3.77	30	136	2950	E_{136}	29.39	96.50135
11	12-Jun-08	3.77	32	168	2950	E_{168}	29.39	96.50135
12	18-Jun-08	3.77	34	202	2949	E_{202}	29.37	96.43593
13	24-Jun-08	3.77	35	237	2947	E_{237}	29.33	96.30517
14	29-Jun-08	3.77	31	268	2941	E_{268}	29.21	95.91342
15	5-Jul-08	3.77	33	301	2938	E_{301}	29.15	95.72

Appendix Table 40: EAW

Lab Identification No: EAW 1………………………………………						**Date of Casting:**	/	24-Mar-08
Concrete Mix Type:	Exp A- Water Curing					**Curing Period:**days		
Length of Specimen, in.,	11.034	0.280				**Radius of Gyration, K:**		0.0789
Breadth of Specimen, in.:	3.034	0.0771	0.07887			**Correction Factor, T:**		1.469
Width of specimen, in. :	3.011	0.0765	1.468725			**C=0.9464 L^3T/bt^3:**		884.00

Serial No.	Date	Weight of specimen, Kg	Number of Freeze & Thaw cycle, C	Cumulative number of freeze and thaw cycle	Fundamental Frequency, Hz	Dynamic Modulus, Gpa		Relative Dynamic Modulus
1	13-May-08	3.78	0	0	3148	E_0	33.11	100
2	14-May-08	3.78	6	6	3114	E_6	32.40	97.85156
3	15-May-08	3.78	5	11	3109	E_{11}	32.30	97.53758
4	16-May-08	3.78	5	16	3078	E_{16}	31.66	95.60218
5	17-May-08	3.78	5	21	3074	E_{21}	31.58	95.35386
6	19-May-08	3.78	11	32	3073	E_{32}	31.55	95.29183
7	22-May-08	3.78	18	50	3073	E_{50}	31.55	95.29183
8	26-May-08	3.78	23	73	3103	E_{73}	32.17	97.16148
9	1-Jun-08	3.78	33	106	3094	E_{106}	31.99	96.59868
10	7-Jun-08	3.78	30	136	3090	E_{136}	31.91	96.34907
11	12-Jun-08	3.78	32	168	3084	E_{168}	31.78	95.97526
12	18-Jun-08	3.78	34	202	3082	E_{202}	31.74	95.85082
13	24-Jun-08	3.78	35	237	3078	E_{237}	31.66	95.60218
14	29-Jun-08	3.78	31	268	3063	E_{268}	31.35	94.67265
15	5-Jul-08	3.78	33	301	3061	E_{301}	31.31	94.55

Appendix Table 41: EASA

Lab Identification No: EASA 1…………………………………………					**Date of Casting:**	/ 25-Mar-08	
Concrete Mix Type:	Exp A- Steam Curing A				**Curing Period:**days		
Length of Specimen, in.,	11.008	0.2800			**Radius of Gyration, K:**	0.0794	
Breadth of Specimen, in.:	3.092	0.0785	0.07939		**Correction Factor, T:**	1.474	
Width of specimen, in. :	3.042	0.0770	1.47388		**$C=0.9464\ L^3T/bt^3$:**	854.42	

Serial No.	Date	Weight of specimen, Kg	Number of Freeze & Thaw cycle, C	Cumulative number of freeze and thaw cycle	Fundamental Frequency, Hz	Dynamic Modulus, Gpa		Relative Dynamic Modulus
1	13-May-08	3.72	0	0	3168	E_0	31.90	100
2	14-May-08	3.72	6	6	3138	E_6	31.30	98.11503
3	15-May-08	3.72	5	11	3120	E_{11}	30.94	96.99265
4	16-May-08	3.72	5	16	3096	E_{16}	30.47	95.5062
5	17-May-08	3.72	5	21	3085	E_{21}	30.25	94.82874
6	19-May-08	3.72	11	32	3084	E_{32}	30.23	94.76728
7	22-May-08	3.72	18	50	3082	E_{50}	30.19	94.6444
8	26-May-08	3.72	23	73	3099	E_{73}	30.52	95.69138
9	1-Jun-08	3.72	33	106	3097	E_{106}	30.49	95.5679
10	7-Jun-08	3.72	30	136	3095	E_{136}	30.45	95.44451
11	12-Jun-08	3.72	32	168	3092	E_{168}	30.39	95.25957
12	18-Jun-08	3.72	34	202	3092	E_{202}	30.39	95.25957
13	24-Jun-08	3.72	35	237	3088	E_{237}	30.31	95.01326
14	29-Jun-08	3.72	31	268	3085	E_{268}	30.25	94.82874
15	5-Jul-08	3.72	33	301	3082	E_{301}	30.19	94.64

Appendix Table 42: EASB

Lab Identification No: EASB 3…………………………………………					**Date of Casting:**	/ 25-Mar-08	
Concrete Mix Type:	Exp A- Steam Curing B				**Curing Period:**days		
Length of Specimen, in.,	11.047	0.2810			**Radius of Gyration, K:**	0.0781	
Breadth of Specimen, in.:	3.068	0.0779	0.07808		**Correction Factor, T:**	1.461	
Width of specimen, in. :	3.005	0.0760	1.460781		**$C=0.9464\ L^3T/bt^3$:**	897.02	

Serial No.	Date	Weight of specimen, Kg	Number of Freeze & Thaw cycle, C	Cumulative number of freeze and thaw cycle	Fundamental Frequency, Hz	Dynamic Modulus, Gpa		Relative Dynamic Modulus
1	13-May-08	3.65	0	0	3027	E_0	30.00	100
2	14-May-08	3.65	6	6	3003	E_6	29.53	98.42056
3	15-May-08	3.65	5	11	2994	E_{11}	29.35	97.83151
4	16-May-08	3.65	5	16	2987	E_{16}	29.21	97.37458
5	17-May-08	3.65	5	21	2984	E_{21}	29.15	97.17908
6	19-May-08	3.65	11	32	2984	E_{32}	29.15	97.17908
7	22-May-08	3.65	18	50	2982	E_{50}	29.11	97.04886
8	26-May-08	3.65	23	73	3008	E_{73}	29.62	98.74857
9	1-Jun-08	3.65	33	106	2997	E_{106}	29.41	98.02766
10	7-Jun-08	3.65	30	136	2990	E_{136}	29.27	97.57028
11	12-Jun-08	3.65	32	168	2989	E_{168}	29.25	97.50502
12	18-Jun-08	3.65	34	202	2988	E_{202}	29.23	97.43979
13	24-Jun-08	3.65	35	237	2985	E_{237}	29.17	97.24423
14	29-Jun-08	3.65	31	268	2983	E_{268}	29.13	97.11396
15	5-Jul-08	3.65	33	301	2983	E_{301}	29.13	97.11

Appendix Table 43: EBW

Lab Identification No: EBW 1..				**Date of Casting:**	/ 2-Apr-08	
Concrete Mix Type:	Exp B- Water Curing			**Curing Period:**days		
Length of Specimen, in.,	11.1	0.2820		**Radius of Gyration, K:**	0.0788	
Breadth of Specimen, in.:	3.092	0.0785	0.07882	**Correction Factor, T:**	1.468	
Width of specimen, in. :	3.022	0.0770	1.46825	**$C=0.9464\ L^3T/bt^3$:**	869.52	

Serial No.	Date	Weight of specimen, Kg	Number of Freeze & Thaw cycle, C	Cumulative number of freeze and thaw cycle	Fundamental Frequency, Hz	Dynamic Modulus, Gpa		Relative Dynamic Modulus	
1	13-May-08	3.92	0	0	3273	E_0	36.51	100	
2	14-May-08	3.92	6	6	3236	E_6	35.69	97.75186	
3	15-May-08	3.92	5	11	3219	E_{11}	35.32	96.7275	
4	16-May-08	3.92	5	16	3195	E_{16}	34.79	95.29052	
5	17-May-08	3.92	5	21	3190	E_{21}	34.69	94.99251	
6	19-May-08	3.92	11	32	3188	E_{32}	34.64	94.87343	
7	22-May-08	3.92	18	50	3187	E_{50}	34.62	94.81392	
8	26-May-08	3.92	23	73	3205	E_{73}	35.01	95.88796	
9	1-Jun-08	3.92	33	106	3200	E_{106}	34.90	95.58901	
10	7-Jun-08	3.92	30	136	3195	E_{136}	34.79	95.29052	
11	12-Jun-08	3.92	32	168	3193	E_{168}	34.75	95.17126	
12	18-Jun-08	3.92	34	202	3186	E_{202}	34.60	94.75443	
13	24-Jun-08	3.92	35	237	3178	E_{237}	34.43	94.27918	
14	29-Jun-08	3.92	31	268	3163	E_{268}	34.10	93.39129	
15	5-Jul-08	3.92	33	301	3161	E_{301}	34.06	93.27	

Appendix Table 44: EBSA

Lab Identification No: EBSA 1...				**Date of Casting:**	/ 31-Mar-08	
Concrete Mix Type:	Exp B- Steam Curing A			**Curing Period:**days		
Length of Specimen, in.,	11.0275	0.2800		**Radius of Gyration, K:**	0.0794	
Breadth of Specimen, in.:	3.083	0.0780	0.07939	**Correction Factor, T:**	1.474	
Width of specimen, in. :	3.023	0.0770	1.47388	**$C=0.9464\ L^3T/bt^3$:**	859.89	

Serial No.	Date	Weight of specimen, Kg	Number of Freeze & Thaw cycle, C	Cumulative number of freeze and thaw cycle	Fundamental Frequency, Hz	Dynamic Modulus, Gpa		Relative Dynamic Modulus	
1	13-May-08	3.79	0	0	3133	E_0	31.99	100	
2	14-May-08	3.79	6	6	3085	E_6	31.02	96.95932	
3	15-May-08	3.79	5	11	3075	E_{11}	30.82	96.33175	
4	16-May-08	3.79	5	16	3056	E_{16}	30.44	95.14499	
5	17-May-08	3.79	5	21	3054	E_{21}	30.40	95.02049	
6	19-May-08	3.79	11	32	3052	E_{32}	30.36	94.89608	
7	22-May-08	3.79	18	50	3051	E_{50}	30.34	94.8339	
8	26-May-08	3.79	23	73	3075	E_{73}	30.82	96.33175	
9	1-Jun-08	3.79	33	106	3067	E_{106}	30.66	95.83116	
10	7-Jun-08	3.79	30	136	3056	E_{136}	30.44	95.14499	
11	12-Jun-08	3.79	32	168	3055	E_{168}	30.42	95.08273	
12	18-Jun-08	3.79	34	202	3055	E_{202}	30.42	95.08273	
13	24-Jun-08	3.79	35	237	3054	E_{237}	30.40	95.02049	
14	29-Jun-08	3.79	31	268	3052	E_{268}	30.36	94.89608	
15	5-Jul-08	3.79	33	301	3052	E_{301}	30.36	94.90	

Appendix Table 45: EBSB

Lab Identification No: EBSB 3………………………………………				**Date of Casting:**	/	31-Mar-08
Concrete Mix Type:	Exp B- Steam Curing B			**Curing Period:**days		
Length of Specimen, in.,	11.029	0.2800		**Radius of Gyration, K:**		0.0794
Breadth of Specimen, in.:	3.085	0.0784	0.07939	**Correction Factor, T:**		1.474
Width of specimen, in. :	3.014	0.0770	1.47388	**C=0.9464 L^3T/bt^3:**		855.51

Serial No.	Date	Weight of specimen, Kg	Number of Freeze & Thaw cycle, C	Cumulative number of freeze and thaw cycle	Fundamental Frequency, Hz	Dynamic Modulus, Gpa		Relative Dynamic Modulus
1	13-May-08	3.82	0	0	3126	E_0	31.93	100
2	14-May-08	3.82	6	6	3095	E_6	31.30	98.02647
3	15-May-08	3.82	5	11	3092	E_{11}	31.24	97.83653
4	16-May-08	3.82	5	16	3073	E_{16}	30.86	96.63783
5	17-May-08	3.82	5	21	3065	E_{21}	30.70	96.13533
6	19-May-08	3.82	11	32	3064	E_{32}	30.68	96.07261
7	22-May-08	3.82	18	50	3062	E_{50}	30.64	95.94723
8	26-May-08	3.82	23	73	3095	E_{73}	31.30	98.02647
9	1-Jun-08	3.82	33	106	3094	E_{106}	31.28	97.96313
10	7-Jun-08	3.82	30	136	3094	E_{136}	31.28	97.96313
11	12-Jun-08	3.82	32	168	3095	E_{168}	31.30	98.02647
12	18-Jun-08	3.82	34	202	3090	E_{202}	31.20	97.71
13	24-Jun-08	3.82	35	237	3088	E_{237}	31.16	97.58356
14	29-Jun-08	3.82	31	268	3084	E_{268}	31.08	97.33091

Appendix Table 46: ECW

Lab Identification No: ECW 3………………………………………				**Date of Casting:**	/	26-Mar-08
Concrete Mix Type:	Exp C- Water Curing			**Curing Period:**days		
Length of Specimen, in.,	11.035	0.2800		**Radius of Gyration, K:**		0.0789
Breadth of Specimen, in.:	3.041	0.0770	0.07887	**Correction Factor, T:**		1.469
Width of specimen, in. :	3.013	0.0765	1.468725	**C=0.9464 L^3T/bt^3:**		885.14

Serial No.	Date	Weight of specimen, Kg	Number of Freeze & Thaw cycle, C	Cumulative number of freeze and thaw cycle	Fundamental Frequency, Hz	Dynamic Modulus, Gpa		Relative Dynamic Modulus
1	13-May-08	3.62	0	0	2978	E_0	28.42	100
2	14-May-08	3.62	6	6	2926	E_6	27.43	97
3	15-May-08	3.62	5	11	2913	E_{11}	27.19	96
4	16-May-08	3.62	5	16	2903	E_{16}	27.00	95
5	17-May-08	3.62	5	21	2900	E_{21}	26.95	95
6	19-May-08	3.62	11	32	2900	E_{32}	26.95	95
7	22-May-08	3.62	18	50	2897	E_{50}	26.89	95
8	26-May-08	3.62	23	73	2915	E_{73}	27.23	96
9	1-Jun-08	3.62	33	106	2890	E_{106}	26.76	94
10	7-Jun-08	3.62	30	136	2867	E_{136}	26.34	93
11	12-Jun-08	3.62	32	168	2862	E_{168}	26.25	92
12	18-Jun-08	3.62	34	202	2854	E_{202}	26.10	92
13	24-Jun-08	3.62	35	237	2850	E_{237}	26.03	92
14	29-Jun-08	3.62	31	268	2835	E_{268}	25.75	91
15	5-Jul-08	3.62	33	301	2828	E_{301}	25.63	90

Appendix Table 47: ECSA

Lab Identification No: ECSA 1…………………………………………					**Date of Casting:**	/ 28-Mar-08		
Concrete Mix Type:	Exp C- Steam Curing A				**Curing Period:**days			
Length of Specimen, in.,	11.061	0.2810			**Radius of Gyration, K:**	0.0784		
Breadth of Specimen, in.:	3.068	0.0780	0.07839		**Correction Factor, T:**	1.464		
Width of specimen, in. :	3.003	0.0763	1.463863		**C=0.9464 L^3T/bt^3:**	887.21		

Serial No.	Date	Weight of specimen, Kg	Number of Freeze & Thaw cycle, C	Cumulative number of freeze and thaw cycle	Fundamental Frequency, Hz	Dynamic Modulus, Gpa		Relative Dynamic Modulus
1	13-May-08	3.65	0	0	2984	E_0	28.83	100
2	14-May-08	3.65	6	6	2930	E_6	27.80	96
3	15-May-08	3.65	5	11	2923	E_{11}	27.67	96
4	16-May-08	3.65	5	16	2906	E_{16}	27.35	95
5	17-May-08	3.65	5	21	2882	E_{21}	26.90	93
6	19-May-08	3.65	11	32	2881	E_{32}	26.88	93
7	22-May-08	3.65	18	50	2881	E_{50}	26.88	93
8	26-May-08	3.65	23	73	2906	E_{73}	27.35	95
9	1-Jun-08	3.65	33	106	2900	E_{106}	27.23	94
10	7-Jun-08	3.65	30	136	2897	E_{136}	27.18	94
11	12-Jun-08	3.65	32	168	2886	E_{168}	26.97	94
12	18-Jun-08	3.65	34	202	2877	E_{202}	26.80	93
13	24-Jun-08	3.65	35	237	2853	E_{237}	26.36	91
14	29-Jun-08	3.65	31	268	2848	E_{268}	26.27	91
15	5-Jul-08	3.65	33	301	2842	E_{301}	26.16	91

Appendix Table 48: ECSB

Lab Identification No: ECSB 2………………………………………					**Date of Casting:**	/ 28-Mar-08		
Concrete Mix Type:	Exp C- Steam Curing B				**Curing Period:**days			
Length of Specimen, in.,	11.045	0.2810			**Radius of Gyration, K:**	0.0786		
Breadth of Specimen, in.:	3.083	0.0780	0.07859		**Correction Factor, T:**	1.466		
Width of specimen, in. :	3.013	0.0765	1.465918		**C=0.9464 L^3T/bt^3:**	881.50		

Serial No.	Date	Weight of specimen, Kg	Number of Freeze & Thaw cycle, C	Cumulative number of freeze and thaw cycle	Fundamental Frequency, Hz	Dynamic Modulus, Gpa		Relative Dynamic Modulus
1	13-May-08	3.65	0	0	2930	E_0	27.62	100
2	14-May-08	3.65	6	6	2886	E_6	26.80	97.01914
3	15-May-08	3.65	5	11	2862	E_{11}	26.35	95.41222
4	16-May-08	3.65	5	16	2850	E_{16}	26.13	94.6138
5	17-May-08	3.65	5	21	2848	E_{21}	26.10	94.48105
6	19-May-08	3.65	11	32	2848	E_{32}	26.10	94.48105
7	22-May-08	3.65	18	50	2846	E_{50}	26.06	94.3484
8	26-May-08	3.65	23	73	2868	E_{73}	26.47	95.81269
9	1-Jun-08	3.65	33	106	2862	E_{106}	26.35	95.41222
10	7-Jun-08	3.65	30	136	2856	E_{136}	26.24	95.01259
11	12-Jun-08	3.65	32	168	2850	E_{168}	26.13	94.6138
12	18-Jun-08	3.65	34	202	2849	E_{202}	26.12	94.54741
13	24-Jun-08	3.65	35	237	2842	E_{237}	25.99	94.08338
14	29-Jun-08	3.65	31	268	2839	E_{268}	25.93	93.88486
15	5-Jul-08	3.65	33	301	2836	E_{301}	25.88	93.69

Appendix Table 49: EDW

Lab Identification No: EDW 1………………………………………….					**Date of Casting:**	/ 2-Apr-08
Concrete Mix Type:	Exp D- Water Curing				**Curing Period:**days	
Length of Specimen, in.,	11.074	0.2810			**Radius of Gyration, K:**	0.0786
Breadth of Specimen, in.:	3.11	0.0791	0.07859		**Correction Factor, T:**	1.466
Width of specimen, in. :	3.01	0.0765	1.465918		**$C=0.9464\ L^3T/bt^3$:**	869.25

Serial No.	Date	Weight of specimen, Kg	Number of Freeze & Thaw cycle, C	Cumulative number of freeze and thaw cycle	Fundamental Frequency, Hz	Dynamic Modulus, Gpa		Relative Dynamic Modulus
1	13-May-08	3.88	0	0	3157	E_0	33.61	100
2	14-May-08	3.88	6	6	3100	E_6	32.41	96.42158
3	15-May-08	3.88	5	11	3080	E_{11}	31.99	95.18144
4	16-May-08	3.88	5	16	3074	E_{16}	31.87	94.81096
5	17-May-08	3.88	5	21	3062	E_{21}	31.62	94.07218
6	19-May-08	3.88	11	32	3052	E_{32}	31.42	93.45873
7	22-May-08	3.88	18	50	3050	E_{50}	31.37	93.33629
8	26-May-08	3.88	23	73	3059	E_{73}	31.56	93.88794
9	1-Jun-08	3.88	33	106	3053	E_{106}	31.44	93.51999
10	7-Jun-08	3.88	30	136	3042	E_{136}	31.21	92.8473
11	12-Jun-08	3.88	32	168	3042	E_{168}	31.21	92.8473
12	18-Jun-08	3.88	34	202	3041	E_{202}	31.19	92.78626
13	24-Jun-08	3.88	35	237	3039	E_{237}	31.15	92.66425
14	29-Jun-08	3.88	31	268	3038	E_{268}	31.13	92.60328
15	5-Jul-08	3.88	33	301	3037	E_{301}	31.11	92.54

Appendix Table 50: EDSA

Lab Identification No: EDSA 2………………………………………….					**Date of Casting:**	/ 30-Mar-08
Concrete Mix Type:	Exp D- Steam Curing A				**Curing Period:**days	
Length of Specimen, in.,	11.024	0.2800			**Radius of Gyration, K:**	0.0788
Breadth of Specimen, in.:	3.06	0.0776	0.07877		**Correction Factor, T:**	1.468
Width of specimen, in. :	3.009	0.0764	1.467694		**$C=0.9464\ L^3T/bt^3$:**	881.14

Serial No.	Date	Weight of specimen, Kg	Number of Freeze & Thaw cycle, C	Cumulative number of freeze and thaw cycle	Fundamental Frequency, Hz	Dynamic Modulus, Gpa		Relative Dynamic Modulus
1	13-May-08	3.73	0	0	2970	E_0	28.99	100
2	14-May-08	3.73	6	6	2926	E_6	28.14	97
3	15-May-08	3.73	5	11	2915	E_{11}	27.93	96
4	16-May-08	3.73	5	16	2897	E_{16}	27.58	95
5	17-May-08	3.73	5	21	2892	E_{21}	27.49	95
6	19-May-08	3.73	11	32	2882	E_{32}	27.30	94
7	22-May-08	3.73	18	50	2882	E_{50}	27.30	94
8	26-May-08	3.73	23	73	2902	E_{73}	27.68	95
9	1-Jun-08	3.73	33	106	2896	E_{106}	27.56	95
10	7-Jun-08	3.73	30	136	2889	E_{136}	27.43	95
11	12-Jun-08	3.73	32	168	2884	E_{168}	27.34	94
12	18-Jun-08	3.73	34	202	2876	E_{202}	27.18	94
13	24-Jun-08	3.73	35	237	2876	E_{237}	27.18	94
14	29-Jun-08	3.73	31	268	2872	E_{268}	27.11	94
15	5-Jul-08	3.73	33	301	2872	E_{301}	27.11	94

Appendix Table 51: EDSB

Lab Identification No: EDSB 3...						**Date of Casting:**	/ 30-Mar-08
Concrete Mix Type:	Exp D- Steam Curing B					**Curing Period:**days	
Length of Specimen, in.,	11.043	0.2800				**Radius of Gyration, K:**	0.0792
Breadth of Specimen, in.:	3.087	0.0784	0.07918			**Correction Factor, T:**	1.472
Width of specimen, in. :	3.025	0.0768	1.471818			**C=0.9464 L^3T/bt^3:**	861.00

Serial No.	Date	Weight of specimen, Kg	Number of Freeze & Thaw cycle, C	Cumulative number of freeze and thaw cycle	Fundamental Frequency, Hz	Dynamic Modulus, Gpa		Relative Dynamic Modulus	
1	13-May-08	3.72	0	0	2975	E_0	28.35	100	
2	14-May-08	3.72	6	6	2935	E_6	27.59	97.329	
3	15-May-08	3.72	5	11	2924	E_{11}	27.38	96.60082	
4	16-May-08	3.72	5	16	2905	E_{16}	27.03	95.34948	
5	17-May-08	3.72	5	21	2904	E_{21}	27.01	95.28385	
6	19-May-08	3.72	11	32	2901	E_{32}	26.96	95.08708	
7	22-May-08	3.72	18	50	2900	E_{50}	26.94	95.02154	
8	26-May-08	3.72	23	73	2924	E_{73}	27.38	96.60082	
9	1-Jun-08	3.72	33	106	2919	E_{106}	27.29	96.27073	
10	7-Jun-08	3.72	30	136	2918	E_{136}	27.27	96.20478	
11	12-Jun-08	3.72	32	168	2917	E_{168}	27.25	96.13885	
12	18-Jun-08	3.72	34	202	2915	E_{202}	27.22	96.00706	
13	24-Jun-08	3.72	35	237	2913	E_{237}	27.18	95.87536	
14	29-Jun-08	3.72	31	268	2898	E_{268}	26.90	94.89052	
15	5-Jul-08	3.72	33	301	2895	E_{301}	26.84	94.69	

9.4 APPENDIX D

Compressive Strength, Pilot Study

Appendix Table 52: Mix 1

Lab Identification No: ...... Mix 1_ Water Curing for 28 Day

Date of Casting:............23 Nov 2008...........................

Concrete Grade: ......Pilot Study_Mix 1

Specim. No.	Age	Testing date	Dia ,(in.)	Area , (in.2)	Max. Load , (lbf)	Compressive Strength , (psi)	Avg. Strength , (psi)	STDEV	Co.of Variation	Standard Error	Type of Fracture	Remarks
A	1	24Nov-08	4.014	12.648	60800	4807.0561	4871.694	178.645	3.666999	206.2814	Columnar	Pulling out of aggregate, Mortar Faliure, breaking of weathered rock
B			4.018	12.673	60000	4734.3649					Shear	
C			4.018	12.673	64300	5073.6611					Shear	Pulling out of aggregate, Mortar Faliure, breaking of weathered rock
D	3	26Nov-08	4.005	12.591	97500	7743.3683	8065.788	300.124	3.72095	346.5533	Shear	Aggregate Failure
E			4.015	12.654	105500	8337.0365					Shear	
F			4.001	12.566	102000	8116.9601						Columnar Failure
O	7	30Nov-08	4.017	12.667	123000	9710.2809	9801.039	182.8358	1.865474	211.1206		Columnar Failure
G			4.023	12.705	123000	9681.3382					Shear	
N			4.012	12.635	126500	10011.497					Shear	
M	14	7Dec-08	4.021	12.692	126500	9966.7307	10450.52	456.7502	4.370597	527.4098	Columnar	Pulling out of aggregate, Mortar Faliure, breaking of weathered rock
J			4.028	12.736	138500	10874.297					Shear	
I			4.03	12.749	134000	10510.54					Crushed	Pulling out of aggregate, Mortar Faliure, breaking of weathered rock
K	28	21Dec-08	4.0138	12.647	143320	11332.499	11258.84	219.1401	1.946384	253.0412	Shear	Sample was cured for 27 effective days and 1 day cured outside water
L			4.0143	12.650	144610	11431.653					Crushed	
Extra			4.0263	12.726	140140	11012.355					Shear	

Appendix Table 53: Mix 2

Lab Identification No: ...... Mix 2_ 14 days water curing + a

Date of Casting:............23 Nov 2008...........................

Concrete Grade: ......Pilot Study_Mix 2

Specim. No.	Age	Testing date	Dia ,(in.)	Area , (in.2)	Max. Load , (lbf)	Compressive Strength , (psi)	Avg. Strength , (psi)	STDEV	Co.of Variation	Standard Error	Type of Fracture	Remarks
A	28	21-Dec-08	4.0158	12.659	148630	11740.664	11689.54	740.0264	6.33067	854.5089	Shear	Pulling out of aggregate, Mortar Failure, breaking of weathered rock
B			4.0176	12.671	157150	12402.684					crushed failure	Crushing of aggregate and brusting of sample
C			4.0138	12.647	138170	10925.282					Shear	

Appendix Table 54: Mix 3

Lab Identification No: ......Mix 3_ 7 day water curing + Am

Date of Casting:............23 Nov 2008............................

Concrete Grade: ......Pilot Study_Mix 3

Specim. No.	Age	Testing date	Dia ,(in.)	Area , (in.2)	Max. Load , (lbf)	Compressive Strength , (psi)	Avg. Strength , (psi)	STDEV	Co.of Variation	Standard Error	Type of Fracture	Remarks
F	14	7-Dec-08	4.01	12.623	121500	9625.3798	10456.86	858.4497	8.209443	991.2524	Crushed	
E			4.015	12.654	143500	11339.95					Shear	
D			4.02	12.686	132000	10405.242					Shear	
A	28	21-Dec-08	4	12.560	132610	10558.121	11187.5	580.6708	5.190353	670.5008	Crushed	
B			4.005	12.591	147350	11702.414					Crushed	Breaking of aggregate
C			4.007	12.604	142450	11301.969					Crushed	

Appendix Table 55: Mix 4

Lab Identification No: ...... Mix 4_ 14 days Water Curing + curing compound + ambient curing upto 28 Days

Date of Casting:............23 Nov 2008............................

Concrete Grade: ......Pilot Study_Mix 4

Specim. No.	Age	Testing date	Dia ,(in.)	Area , (in.2)	Max. Load , (lbf)	Compressive Strength , (psi)	Avg. Strength , (psi)	STDEV	Co.of Variation	Standard Error	Type of Fracture	Remarks
C	28	21-Dec-08	4.0113	12.631	145790	11542.179	11521.43	47.90087	0.415755	55.31116	Columnar	Pulling out of aggregate, Mortar Faliure, breaking of weathered rock
A			4.009	12.617	144670	11466.654					Crushed	Brusting of aggregate
B			4.016	12.661	146300	11555.461					Shear	Pulling out of aggregate, Mortar Faliure, breaking of weathered rock

Appendix Table 56: Mix 5

Concrete Grade: ......Pilot Study_Mix 5

Specim. No.	Age	Testing date	Dia ,(in.)	Length (in.)	Area , (in.2)	Weight in air, (kg)	Weight in water, (kg)	Density in air , (lb/ ft.^{3})	Density in water , (lb/ ft.^{3})	Max. Load , (lbf)	Compressive Strength , (psi)	Avg. Strength , (psi)	STDEV	Co.of Variation	Standard Error	Type of Fracture
C	14	25-Dec-08	4.016	8.034	12.661	3.791	2.132	141.9852	79.8503	117250	9260.9553	9165.986	306.86	3.347813	354.3314	Crushed
F			4.01	8.01	12.623	3.765	2.114	141.8574	79.6512	111370	8822.8687					Shear
B			4.015	8.0135	12.654	3.767	2.114	141.5177	79.4182	119130	9414.1342					Shear
A	28	8-Jan-09	4.014	8.025	12.648	3.792	2.131	142.3236	79.9820	130180	10292.476	10125.6	396.8629	3.919403	458.2578	Shear
D			4.015	8.066	12.654	3.818	2.155	142.5001	80.4315	122400	9672.5428					Crushed
E			4.023	8.015	12.705	3.752	2.099	140.3679	78.5267	132280	10411.768					Shear

Appendix Table 57: Mix 6

Lab Identification No: …… Mix 6_ 1Day water curing + Curing Compound + ambient Curing **Date of Casting:…………11 Dec 2008………………………**

Concrete Grade: ……Pilot Study_Mix 6

Specim. No.	Age	Testing date	Dia ,(in.)	Area , (in.2)	Max. Load , (lbf)	Compressive Strength , (psi)	Avg. Strength , (psi)	STDEV	Co.of Variation	Standard Error	Type of Fracture	Remarks
I			4.01	12.623	89500	7090					Columnar	Pulling out of aggregate, Mortar Failure, breaking of weathered rock
K	3	14-Dec-08	4.01	12.623	81000	6417	6754	476.1519	7.050332	673.3805	Shear	
L			4.015	12.654	2000	158					Shear	Breaking of Machine, wrong results
A			4.01	12.623	90750	7189					Shear	Aggregate Failure
C	7	18-Dec-08	4.16	13.585	104730	7709	7663	451.7875	5.895982	521.6793	Shear	
B			4.01	12.623	102110	8089						Columnar Failure
E			4.01	12.623	119870	9496.2492						Columnar Failure
F	14	25-Dec-08	4.014	12.648	118720	9386.4094	9343.231	178.5674	1.911195	206.1919	Shear	
D			4.015	12.654	115750	9147.033					Shear	
J			4.014	12.648	109790	8680					Crushed	
G	28	8-Jan-09	4.006	12.598	114850	9117	9109	425.0142	4.665801	601.0609	Shear	Pulling out of aggregate, Mortar Failure, breaking of weathered rock
H			4.015	12.654	120600	9530					Columnar	

Appendix Table 58: Mix 7

Lab Identification No: ......Mix 7_ 3 Day water curing + Curing Compound + ambient Curing **Date of Casting:............11 Dec 2008............................**

Concrete Grade: ......Pilot Study_Mix 7

Specim. No.	Age	Testing date	Dia ,(in.)	Length (in.)	Area , (in.2)	Weight in air, (kg)	Weight in water, (kg)	Density in air , (lb/ ft.^{3})	Density in water , (lb/ ft.^{3})	Max. Load , (lbf)	Compressive Strength , (psi)	Avg. Strength , (psi)	STDEV	Co.of Variation	Standard Error	Type of Fracture	Remarks
A			4.007	8.023	12.604	3.798	2.144	143.0830	80.7714	112540	8929					Columnar	Pulling out of aggregate, Mortar Failure, breaking of weathered rock
B	7	18-Dec-08	4.008	8.06	12.610	3.803	2.138	142.5425	80.1356	112390	8913	8921	11.56122	0.129599	16.35004	Shear	
C			4.011	8.05	12.629	3.796	2.136	142.2438	80.0403	108120	8561					Shear	Breaking of Machine, wrong results
F			4.01	8.02	12.623	3.773	2.12	141.9816	79.7776	120920	9579					Shear	Aggregate Failure
E	14	25-Dec-08	4.0165	8.0375	12.664	3.768	2.102	141.0272	78.6728	114750	9061	9346	262.866	2.812622	303.5315	Shear	
D			4.009	8.065	12.617	3.717	2.056	139.1632	76.9759	118560	9397						Columnar Failure
I			4.011	8.0425	12.629	3.809	2.142	142.8641	80.3399	126190	9992					Crushed	Breaking of aggregate
J	28	8-Jan-09	4.017	8.0375	12.667	3.776	2.114	141.2914	79.1022	129390	10215	9943	299.0797	3.007914	345.3475	Crushed	Breaking of aggregate
H			4.018	8.026	12.673	3.745	2.088	140.2624	78.2024	121950	9623					Crushed	Breaking of aggregate

Appendix Table 59: Mix 8

Lab Identification No: …… Mix 8_ 3 Day water curing + am

Date of Casting:…………17 Dec 2008……………………….

Concrete Grade: ……Pilot Study_Mix8

Specim. No.	Age	Testing date	Dia ,(in.)	Area , (in.2)	Max. Load , (lbf)	Compressive Strength , (psi)	Avg. Strength , (psi)	STDEV	Co.of Variation	Standard Error	Type of Fracture	Remarks
A	7	24-Dec-08	4.0123	12.637	130160	10300	9989	439.4137	4.399017	621.4248	Columnar	Pulling out of aggregate, Mortar Faliure, breaking of weathered rock
D			4.0135	12.645	122380	9678					Shear	
F			4.01	12.623	127850	10128					Shear	
H	14	31-Dec-08	4.009	12.617	126870	10056	10221	167.0644	1.634558	192.9094	Shear	Aggregate Failure
B			4.025	12.717	129930	10217					Shear	
C			4.01	12.623	131150	10390					Crushed	
G	28	14-Jan-09	4.0063	12.600	139990	11111	11004	674.2905	6.127416	778.6036	Shear	Breaking of aggregate
I			4.01	12.623	146670	11619					Crushed	Breaking of aggregate
E			4.015	12.654	130130	10283					Shear	Breaking of aggregate

Appendix Table 60: Mix 9

Lab Identification No: ……Mix9_ 1 Day Water Curing + ambient Curing

Date of Casting:…………12 Dec 2008……………………….

Concrete Grade: ……Pilot Study_Mix 9

Specim. No.	Age	Testing date	Dia ,(in.)	Length (in.)	Area , (in.2)	Weight in air, (kg)	Weight in water, (kg)	Density in air , (lb/ ft.^{3})	Density in water , (lb/ ft.^{3})	Max. Load , (lbf)	Compressive Strength , (psi)	Avg. Strength , (psi)	STDEV	Co.of Variation	Standard Error	Type of Fracture	Remarks
K	3	15-Dec-08	4.01	8.025	12.623	3.542	1.885	133.2058	70.8902	1000	79.221233	4423.196	970.3609	21.938	1372.298	Crushed	Problem in Machine, Wrong Results, Pointer not moving up
J			4.015	8.03	12.654	3.563	1.915	133.5788	71.7944	47290	3737.047					Shear	Pulling out of aggregate, Mortar Faliure, breaking of weathered rock
L			4.017	8.027	12.667	3.582	1.924	134.2076	72.0869	64720	5109.3445					Shear	Pulling out of aggregate, Mortar Faliure, breaking of weathered rock
D	7	19-Dec-08	4.005	8.035	12.591	3.522	1.9	132.6193	71.5437	69250	5499.777	5590.846	94.12344	1.683528	108.6844	Shear	Aggregate Failure
E			4.009	8.024	12.617	3.544	1.886	133.3641	70.9720	71760	5687.7521					Shear	
A			4.016	8.03	12.661	3.57	1.914	133.7746	71.7212	70710	5585.0076					Shear	
G	14	26-Dec-08	4.015	8.03	12.654	3.498	1.844	131.1419	69.1326	81090	6408.0596	6411.388	288.0235	4.492373	332.5808	Shear	Pulling out of aggregate, Mortar Faliure, breaking of weathered rock
H			4.014	8.054	12.648	3.578	1.922	133.8081	71.8779	77470	6125.0433					Shear	
F			4.016	8.0275	12.661	3.572	1.915	133.8912	71.7810	84840	6701.0614					Crushed	
B	28	9-Jan-09	4.012	8.021	12.635	3.351	1.883	125.9599	70.7796	80150	6343	6172	153.9657	2.4945	217.7404	Shear	Presence of unhydrated cement in form of white patch
C			4.016	8.04	12.661	3.563	1.908	133.3462	71.4074	76530	6045					Shear	Presence of unhydrated cement in form of white patch
I			4.011	8.035	12.629	3.546	1.895	133.1239	71.1421	77400	6129					Shear	Presence of unhydrated cement in form of white patch

Appendix Table 61: Mix 10

Lab Identification No: ...... Mix 10_ Steam Curing + ambient Curing

Date of Casting:............12 Dec 2008...........................

Concrete Grade: ......Pilot Study_Mix 10

Specim. No.	Age	Testing date	Dia ,(in.)	Area , (in.2)	Max. Load , (lbf)	Compressive Strength , (psi)	Avg. Strength , (psi)	STDEV	Co.of Variation	Standard Error	Type of Fracture	Remarks
N	1	13Dec08	4.16	13.585	70000	5153	5387.726	229.1971	4.25406	264.654	Columnar	Pulling out of aggregate, Mortar Faliure, breaking of weathered rock
M			4.02	12.686	68500	5400					Shear	
O			4.015	12.654	71000	5611					Shear	Pulling out of aggregate, Mortar Faliure, breaking of weathered rock
J	3	15Dec08	4.017	12.667	83460	6589	6574	134.6822	2.048706	155.5176	Shear	Aggregate Failure
K			4.018	12.673	84920	6701					Shear	
L			4.015	12.654	81400	6433						Columnar Failure
O	7	30Nov08	4.015	12.654	88600	7001.5302	7210.643	185.3368	2.570323	214.0085	Columnar Failure	Crushing of aggregate
G			4.02	12.686	92300	7275.7864					Shear	
N			4.02	12.686	93300	7354.6139					Shear	
D	14	25Dec08	4.0125	12.639	94260	7458	7159.691	301.9606	4.217509	348.6741	Columnar	Pulling out of aggregate, Mortar Faliure, breaking of weathered rock
H			4.015	12.654	90690	7167					Shear	
I			4.016	12.661	86780	6854					Shear	Presence of unhydrated cement in form of white patch
G	28	9 Jan 08	4.007	12.604	88140	6993	6858	187.8803	2.739691	216.9454	Shear	Aggregate Failure
F			4.017	12.667	87870	6937					Shear	
E			4.012	12.635	83940	6643						Columnar Failure

Appendix Table 62: Mix 11

Lab Identification No: ...... Mix 11_ Steam Curing + Curing compound + ambient Curing

Date of Casting:............17 Dec 2008...........................

Concrete Grade: ......Pilot Study_Mix 11

Specim. No.	Age	Testing date	Dia ,(in.)	Area , (in.2)	Max. Load , (lbf)	Compressive Strength , (psi)	Avg. Strength , (psi)	STDEV	Co.of Variation	Standard Error	Type of Fracture	Remarks
M	1	18Dec08	4.019	12.680	118250	9326	8867.442	527.8024	5.952138	609.4537	Columnar	Pulling out of aggregate, Mortar Faliure, breaking of weathered rock
N			4.015	12.654	113710	8986					Shear	
O			4.01	12.623	104650	8291					Shear	Pulling out of aggregate, Mortar Faliure, breaking of weathered rock
I	3	20Dec08	4.0113	12.631	127660	10107	9808	454.611	4.634934	524.9396	Shear	Aggregate Failure
H			4.007	12.604	117030	9285					Shear	
G			4.0148	12.653	126950	10033						Columnar Failure
K	7	24Nov08	4.01	12.623	133220	10553.853	10479.27	65.78475	0.627761	75.96169	Columnar Failure	Crushing of aggregate
C			4.001	12.566	131060	10429.498					Shear	Broken edge
D			4.0125	12.639	132130	10454.462					Shear	
A	14	31Dec08	4.01	12.623	129900	10291	10549.07	258.5802	2.451214	298.5827	Columnar	Pulling out of aggregate, Mortar
B			4.009	12.617	136360	10808					Shear	
J			4.013	12.642	133350	10548					Shear	Pulling out of aggregate, Mortar Faliure, breaking of weathered rock
L	28	14 Jan 08	4.0112	12.630	136870	10837	10934	439.153	4.016234	507.0902	Shear	Aggregate Failure
E			4.0095	12.620	133170	10553					Shear	
F			4.0026	12.576	143550	11414						Columnar Failure

9.5 Appendix E

Tests Results -Phase II

Chloride Ion Test

Appendix Table 63: Control Mix

Mix Id	Control		Mix Type				Curing Period		56 days			
Resistance	Cell 1	0.98	ohm	Cell 2	0.98	ohm	Cell 3	1	ohm	Cell 4	0.99	ohm
	Cell 1			**Cell 2**			**Cell 3**			**Cell 4**		
Time	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp
12.34 pm	60	0.0300	0.031	60	0.0372	0.038	60	0.0188	0.01877	60	0.01892	0.019
1.04 pm	60	0.0310	0.032	60	0.0391	0.040	60	0.01906	0.01906	60	0.01866	0.019
1.34 pm	60	0.0321	0.033	60	0.0395	0.040	60	0.0193	0.0193	60	0.01903	0.019
2.04 pm	60	0.0331	0.034	60	0.0404	0.041	60	0.01956	0.01956	60	0.0187	0.019
2.34 pm	60	0.0341	0.035	60	0.0422	0.043	60	0.01992	0.01992	60	0.01905	0.019
3.04 pm	60	0.0352	0.036	60	0.0435	0.044	60	0.0202	0.02024	60	0.01958	0.020
3.34 pm	60	0.0361	0.037	60	0.0437	0.045	60	0.02029	0.02029	60	0.02005	0.020
4.04 pm	60	0.0368	0.038	60	0.0444	0.045	60	0.0212	0.02116	60	0.02046	0.021
4.34 pm	60	0.0362	0.037	60	0.0463	0.047	60	0.02133	0.02133	60	0.02192	0.022
5.04 pm	60	0.0377	0.038	60	0.0473	0.048	60	0.0220	0.0220	60	0.02242	0.023
5.34 pm	60	0.0386	0.039	60	0.0461	0.047	60	0.02204	0.02204	60	0.02288	0.023
6.04 pm	60	0.0392	0.040	60	0.0470	0.048	60	0.02215	0.02215	60	0.02325	0.023
6.34 pm	60	0.0393	0.040	60	0.0475	0.048	60	0.0224	0.0224	60	0.02354	0.024
otal Charge Passe	Q1=	780.1531	Coulombs	Q2 =	958.3806	Coulombs	Q2 =	445.725	Coulombs	Q2 =	449.4727	Coulombs
Average Charge Passed, Coulombs								**658.43**				

Appendix Table 64: Mix A

Mix Id	A			Mix Type			Curing Period		56 days				
Resistance		Cell 1	0.98	ohm	Cell 2	0.97	ohm	Cell 3	0.98	ohm	Cell 4	0.97	ohm
		Cell 1			**Cell 2**			**Cell 3**			**Cell 4**		
Time	Temperature	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp
3.20 pm		60	0.0141	0.014	60	0.0131	0.014	60	0.0125	0.0128	60	0.0128	0.013
3.50 pm		60	0.0144	0.015	60	0.0138	0.014	60	0.0129	0.0132	60	0.0131	0.014
4.20 pm		60	0.0147	0.015	60	0.0142	0.015	60	0.0131	0.0134	60	0.0135	0.014
4.50 pm		60	0.0145	0.015	60	0.0143	0.015	60	0.013	0.0133	60	0.0137	0.014
5.20 pm		60	0.0144	0.015	60	0.0142	0.015	60	0.0128	0.0131	60	0.0138	0.014
5.50 pm		60	0.0145	0.015	60	0.0144	0.015	60	0.0134	0.0137	60	0.014	0.014
6.20 pm		60	0.0149	0.015	60	0.0146	0.015	60	0.0136	0.0139	60	0.0141	0.015
6.50 pm		60	0.0155	0.016	60	0.0151	0.016	60	0.0138	0.0141	60	0.0145	0.015
7.20 pm		60	0.0155	0.016	60	0.0150	0.015	60	0.0144	0.0147	60	0.0145	0.015
7.50 pm		60	0.0159	0.016	60	0.0155	0.016	60	0.0141	0.0144	60	0.0147	0.015
8.20 pm		60	0.0162	0.017	60	0.0153	0.016	60	0.0144	0.0147	60	0.0151	0.016
8.50 pm		60	0.0161	0.016	60	0.0153	0.016	60	0.0146	0.0149	60	0.015	0.015
9.20 pm		60	0.0164	0.017	60	0.0159	0.016	60	0.0144	0.0147	60	0.0152	0.016
Total Charge Passed		Q1=	334.0837	Coulombs	Q2 =	326.9691	Coulombs	Q2 =	300.398	Coulombs	Q2 =	315.4639	Coulombs
Average Charge Passed, Coulombs									**319.23**				

Appendix Table 65: Mix B

Mix Id- B	Curing Period		56 days			
Resistance	Cell 3	0.97	ohm	Cell 4	0.99	ohm
	Cell 3			Cell 4		
Time	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp
2.37 pm	60	0.0107	0.011031	60	0.0105	0.01061
3.07 pm	60	0.0112	0.011546	60	0.0111	0.01121
3.37 pm	60	0.0111	0.011443	60	0.0112	0.01131
4.07 pm	60	0.0112	0.011546	60	0.0112	0.01131
4.37 pm	60	0.0111	0.011443	60	0.0111	0.01121
5.07 pm	60	0.0113	0.011649	60	0.0114	0.01152
5.37 pm	60	0.0116	0.011959	60	0.0116	0.01172
6.07 pm	60	0.0116	0.011959	60	0.0117	0.01182
6.37 pm	60	0.0121	0.012474	60	0.012	0.01212
7.07 pm	60	0.0121	0.012474	60	0.0121	0.01222
7.37 pm	60	0.0125	0.012887	60	0.0123	0.01242
8.07 pm	60	0.0125	0.012887	60	0.0126	0.01273
8.37 pm	60	0.0129	0.013299	60	0.0126	0.01273
Charge Pa	Q2 =	259.9794	Coulombs	Q2 =	254.2727	Coulombs

Appendix Table 66: Mix C

Mix Id			Mix Type			Curing Period		56 days				
Resistance	Cell 1	0.96	ohm	Cell 2	0.96	ohm	Cell 3	0.96	ohm	Cell 4	0.97	ohm
	Cell 1			Cell 2			Cell 3			Cell 4		
Time	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp
12.40 pm	60	0.0212	0.022	60	0.0268	0.028	60	0.0185	0.019271	60	0.02121	0.022
1.10 pm	60	0.0215	0.022	60	0.0290	0.030	60	0.0193	0.020104	60	0.02148	0.022
1.40 pm	60	0.0216	0.022	60	0.0305	0.032	60	0.01942	0.020229	60	0.02121	0.022
2.10 pm	60	0.0220	0.023	60	0.0320	0.033	60	0.01955	0.020365	60	0.0215	0.022
2.40 pm	60	0.0218	0.023	60	0.0319	0.033	60	0.01984	0.020667	60	0.02203	0.023
3.10 pm	60	0.0224	0.023	60	0.0311	0.032	60	0.0200	0.020823	60	0.02287	0.024
3.40 pm	60	0.0233	0.024	60	0.0323	0.034	60	0.02054	0.021396	60	0.02279	0.023
4.10 pm	60	0.0231	0.024	60	0.0323	0.034	60	0.0208	0.021635	60	0.02266	0.023
4.40 pm	60	0.0240	0.025	60	0.0330	0.034	60	0.02133	0.022219	60	0.02304	0.024
5.10 pm	60	0.0241	0.025	60	0.0340	0.035	60	0.0212	0.022073	60	0.0232	0.024
5.40 pm	60	0.0248	0.026	60	0.0344	0.036	60	0.02154	0.022438	60	0.02364	0.024
6.10 pm	60	0.0257	0.027	60	0.0343	0.036	60	0.02182	0.022729	60	0.02375	0.024
6.40 pm	60	0.0256	0.027	60	0.0360	0.038	60	0.02182	0.022729	60	0.02393	0.025
tal Charge Pass	Q1=	520.6125	Coulombs	Q2 =	723.9188	Coulombs	Q2 =	460.2188	Coulombs	Q2 =	502.3299	Coulombs
Average Charge Passed, Coulombs								551.77				

Appendix Table 67: Mix D

Mix Id	D		Mix Type				Curing Period		56 days			
Resistance	Cell 1	0.96	ohm	Cell 2	0.94	ohm	Cell 3	0.95	ohm	Cell 4	1.01	ohm
Time	Cell 1			Cell 2			Cell 3			Cell 4		
	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp
1.40 pm	60	0.0118	0.012	60	0.0103	0.011	60	0.0119	0.012547	60	0.01107	0.011
2.10 pm	60	0.0119	0.012	60	0.0105	0.011	60	0.01227	0.012916	60	0.0113	0.011
2.40 pm	60	0.0121	0.013	60	0.0106	0.011	60	0.01231	0.012958	60	0.01143	0.011
3.10 pm	60	0.0120	0.012	60	0.0107	0.011	60	0.0123	0.012947	60	0.0115	0.011
3.40 pm	60	0.0119	0.012	60	0.0106	0.011	60	0.01224	0.012884	60	0.01173	0.012
4.10 pm	60	0.0119	0.012	60	0.0105	0.011	60	0.0126	0.013232	60	0.01185	0.012
4.40 pm	60	0.0124	0.013	60	0.0104	0.011	60	0.01272	0.013389	60	0.012	0.012
5.10 pm	60	0.0124	0.013	60	0.0105	0.011	60	0.0129	0.013568	60	0.01234	0.012
5.40 pm	60	0.0129	0.013	60	0.0105	0.011	60	0.01308	0.013768	60	0.01248	0.012
6.10 pm	60	0.0127	0.013	60	0.0106	0.011	60	0.0133	0.013968	60	0.0126	0.012
6.40 pm	60	0.0127	0.013	60	0.0107	0.011	60	0.01347	0.014179	60	0.01304	0.013
7.10 pm	60	0.0131	0.014	60	0.0109	0.012	60	0.01376	0.014484	60	0.013	0.013
7.40 pm	60	0.0132	0.014	60	0.0109	0.012	60	0.0139	0.014632	60	0.01282	0.013
Total Charge Passed	Q1=	278.0719	Coulombs	Q2 =	243.45	Coulombs	Q2 =	291.3916	Coulombs	Q2 =	258.7099	Coulombs
Average Charge Passed, Coulombs								267.9				

Appendix Table 68: Mix E

Mix Id	E		Mix Type				Curing Period		56 days			
Resistance	Cell 1	0.98	ohm	Cell 2	0.97	ohm	Cell 3	0.98	ohm	Cell 4	0.97	ohm
Time	Cell 1			Cell 2			Cell 3			Cell 4		
	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp
1.05 pm	60	0.0144	0.015	60	0.0119	0.012	60	0.0137	0.013959	60	0.01068	0.011
1.35 pm	60	0.0151	0.015	60	0.0124	0.013	60	0.01428	0.014571	60	0.011096	0.011
2.05 pm	60	0.0154	0.016	60	0.0128	0.013	60	0.01457	0.014867	60	0.01122	0.012
2.35 pm	60	0.0152	0.016	60	0.0130	0.013	60	0.01459	0.014888	60	0.0113	0.012
3.05 pm	60	0.0155	0.016	60	0.0133	0.014	60	0.01458	0.014878	60	0.0114	0.012
3.35 pm	60	0.0157	0.016	60	0.0134	0.014	60	0.0148	0.015061	60	0.01137	0.012
4.05 pm	60	0.0162	0.017	60	0.0136	0.014	60	0.01505	0.015357	60	0.01169	0.012
4.35 pm	60	0.0160	0.016	60	0.0138	0.014	60	0.0154	0.015673	60	0.01178	0.012
5.05 pm	60	0.0164	0.017	60	0.0139	0.014	60	0.01567	0.01599	60	0.01168	0.012
5.35 pm	60	0.0168	0.017	60	0.0142	0.015	60	0.0158	0.016071	60	0.01156	0.012
6.05 pm	60	0.0173	0.018	60	0.0142	0.015	60	0.01595	0.016276	60	0.01166	0.012
6.35 pm	60	0.0170	0.017	60	0.0143	0.015	60	0.01623	0.016561	60	0.01161	0.012
7.05 pm	60	0.0171	0.017	60	0.0143	0.015	60	0.01623	0.016561	60	0.01175	0.012
Charge Pa	Q1=	353.5255	Coulombs	Q2 =	300.5072	Coulombs	Q2 =	333.8173	Coulombs	Q2 =	255.3421	Coulombs
Average Charge Passed, Coulombs								310.80				

Appendix Table 69: Mix S

Mix Id	S		Mix Type			Curing Period	56					
Resistance	Cell 1	0.99	ohm	Cell 2	1.1	ohm	Cell 3	0.98	ohm	Cell 4	0.98	ohm
Time	Cell 1			Cell 2			Cell 3			Cell 4		
	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp
12.51 pm	60	0.0120	0.012	60	0.0127	0.012	60	0.0095	0.0097	60	0.01028	0.010
1.21 pm	60	0.0121	0.012	60	0.0128	0.012	60	0.00936	0.0096	60	0.0101	0.010
1.51 pm	60	0.0120	0.012	60	0.0128	0.012	60	0.00929	0.0095	60	0.00994	0.010
2.21 pm	60	0.0122	0.012	60	0.0126	0.011	60	0.00915	0.0093	60	0.0097	0.010
2.51 pm	60	0.0122	0.012	60	0.0125	0.011	60	0.00907	0.0093	60	0.00937	0.010
3.21 pm	60	0.0119	0.012	60	0.0123	0.011	60	0.0090	0.0092	60	0.00953	0.010
3.51 pm	60	0.0120	0.012	60	0.0122	0.011	60	0.00895	0.0091	60	0.00942	0.010
4.21 pm	60	0.0119	0.012	60	0.0119	0.011	60	0.0088	0.0090	60	0.00932	0.010
4.51 pm	60	0.0119	0.012	60	0.0116	0.011	60	0.00882	0.0090	60	0.00941	0.010
5.21 pm	60	0.0118	0.012	60	0.0118	0.011	60	0.0088	0.0090	60	0.0094	0.010
5.51 pm	60	0.0116	0.012	60	0.0116	0.011	60	0.00866	0.0088	60	0.00914	0.009
6.21 pm	60	0.0116	0.012	60	0.0116	0.011	60	0.00875	0.0089	60	0.00914	0.009
6.51 pm	60	0.0117	0.012	60	0.0113	0.010	60	0.00867	0.0088	60	0.00934	0.010
Total Charge Passed	Q1=	260.0364	Coulombs	Q2 =	238.23	Coulombs	Q2 =	197.9816	Coulombs	Q2 =	209.8837	Coulombs
Average Charge Passed, Coulombs								**226.53**				

Appendix Table 70: Mix T

Mix Id	T		Mix Type			Curing Period	56					
Resistance	Cell 1	0.99	ohm	Cell 2	1.1	ohm	Cell 3	1	ohm	Cell 4	1	ohm
Time	Cell 1			Cell 2			Cell 3			Cell 4		
	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp	Voltage across binding, V	Voltage across shunt, V	Current through Shunt, amp
12.51 pm	60	0.0124	0.012	60	0.0151	0.014	60	0.0135	0.0135	60	0.01294	0.013
1.21 pm	60	0.0125	0.013	60	0.0157	0.014	60	0.01387	0.0139	60	0.01322	0.013
1.51 pm	60	0.0122	0.012	60	0.0160	0.015	60	0.01394	0.0139	60	0.01291	0.013
2.21 pm	60	0.0121	0.012	60	0.0159	0.014	60	0.01382	0.0138	60	0.0130	0.013
2.51 pm	60	0.0120	0.012	60	0.0158	0.014	60	0.01377	0.0138	60	0.01324	0.013
3.21 pm	60	0.0119	0.012	60	0.0155	0.014	60	0.0135	0.0135	60	0.01378	0.014
3.51 pm	60	0.0118	0.012	60	0.0156	0.014	60	0.01337	0.0134	60	0.01355	0.014
4.21 pm	60	0.0117	0.012	60	0.0156	0.014	60	0.0136	0.0136	60	0.01361	0.014
4.51 pm	60	0.0116	0.012	60	0.0155	0.014	60	0.01377	0.0138	60	0.01403	0.014
5.21 pm	60	0.0115	0.012	60	0.0155	0.014	60	0.0136	0.0136	60	0.01417	0.014
5.51 pm	60	0.0116	0.012	60	0.0157	0.014	60	0.01336	0.0134	60	0.0143	0.014
6.21 pm	60	0.0115	0.012	60	0.0158	0.014	60	0.01368	0.0137	60	0.01431	0.014
6.51 pm	60	0.0116	0.012	60	0.0156	0.014	60	0.01343	0.0134	60	0.01439	0.014
tal Charge Pass	Q1=	258.5091	Coulombs	Q2 =	307.3745	Coulombs	Q2 =	294.714	Coulombs	Q2 =	294.885	Coulombs
Average Charge Passed, Coulombs								**288.87**				

Compressive Strength Tests

Appendix Table 71: Control Mixture

Lab Identification No: ……………

Mix Con Control (Fly ash 30% + MC 4%)

Date of Casting:…………05/7/09………………………

Concrete Grade: ……Phase II_Mix Con

Specim. No.	Age	Testing date	Dia ,(in.)	Area , (in.2)	Max. Load , (lbf)	Compressive Strength , (psi)	Avg. Strength , (psi)	STDEV	Co.of Variation	Standard Error	Type of Fracture	Remarks
3	2	9-May-09	4.01	12.623	82950	6571	6609	44.94152	0.679994	51.894	Columnar	Pulling out of aggregate, Mortar Faliure, breaking of weathered rock
8			4	12.560	83635	6659					Shear	
11			4.02	12.686	83690	6597						
1	28	5-Jun-09	4.01	12.623	100080	7928.461	7859.57	438.8704	5.583898	506.7639	Shear	Aggregate Failure
2			4.015	12.654	93520	7390.3285					Shear	
4			4.008	12.610	104160	8259.9209						Columnar Failure
5	56	3-Jul-09	4.012	12.635	96790	7660.1802	7515.92	175.8777	2.340069	203.0861	columnar	Columnar Failure
9			4.015	12.654	92630	7319.9971					Shear	
10			4.012	12.635	95620	7567.5837					Shear	

Appendix Table 72: Mix A

Lab Identification No: ……Mix A (Slag 27% Silica Fume 7

Date of Casting:…………04/18/09………………………

Concrete Grade: ……Phase II_Mix A

Specim. No.	Age	Testing date	Dia ,(in.)	Area , (in.2)	Max. Load , (lbf)	Compressive Strength , (psi)	Avg. Strength , (psi)	STDEV	Co.of Variation	Standard Error	Type of Fracture	Remarks
1	1	19-Apr-09	4.01	12.623	91110	7218	7684	419.719	5.462351	484.6498	Columnar	Pulling out of aggregate, Mortar Faliure, breaking of weathered rock
2			4.008	12.610	98380	7802					Shear	
3			4.012	12.635	101490	8032						
4	28	16-May-09	4.01	12.623	123500	9784	9540.226	320.7989	3.362592	370.4266	Shear	Aggregate Failure
5			4.012	12.635	122060	9660						Columnar Failure
6			4	12.560	115260	9177					Shear	
7	56	13-Jun-09	4.015	12.654	118430	9358.8174	9259.108	426.1786	4.602804	492.1086		Columnar Failure
8			4	12.560	120910	9626.5924					Shear	
9			4.012	12.635	111090	8791.9146					Shear	

Appendix Table 73: Mix B

Lab Identification No: ……………Mix B (Slag 24% Silica Fume 10%)

Date of Casting:…………04/17/09………………………

Concrete Grade: ……Phase II_Mix B

Specim. No.	Age	Testing date	Dia ,(in.)	Area , (in.2)	Weight in air, (kg)	Max. Load , (lbf)	Compressive Strength , (psi)	Avg. Strength , (psi)	STDEV	Co.of Variation	Standard Error	Type of Fracture	Remarks
1	1	18-Apr-09	4.015	12.654	3663	94640	7479	7695	200.2913	2.603007	231.2764	Columnar	Pulling out of aggregate, Mortar Faliure, breaking of weathered rock
4			4.01	12.623	3747	99400	7875					Shear	
6			4.01	12.623	3708	97580	7730						
7	28	15-May-09	4.075	13.035	3.652	119609	9176	9702.889	514.9274	5.30695	594.587	Shear	
8			4.012	12.635	3.64	128940	10205					Shear	Aggregate Failure
9			4.01	12.623	3.645	122800	9728						Aggregate Failure
O	56	12-Jun-09	4.005	12.591	3.68	122550	9732.8184	9895.43	279.1065	2.820559	322.2844		
G			4.015	12.654	3.697	123200	9735.7621					Shear	
N			4.022	12.699	3.72	129750	10217.71					Shear	

Appendix Table 74: Mix C

Lab Identification No: ……………Mix C (Fly ash 27% + MC 7%)

Date of Casting:…………04/25/09………………………

Concrete Grade: ……Phase II_Mix C

Specim. No.	Age	Testing date	Dia ,(in.)	Area , (in.2)	Max. Load , (lbf)	Compressive Strength , (psi)	Avg. Strength , (psi)	STDEV	Co.of Variation	Standard Error	Type of Fracture
1	2	26-Apr-09	4.02	12.686	66830	5268	5226	66.23087	1.267406	76.47682	Columnar
8			4.01	12.623	65000	5149					Shear
5			4.025	12.717	66890	5260					
D	28	23-May-09	4.02	12.686	69670	5492	5755.302	265.6762	4.616198	306.7764	Shear
7			4.013	12.642	72700	5751					Shear
2			4.015	12.654	76220	6023					
12	56	20-Jun-09	4.013	12.642	70350	5565	5753.718	179.9485	3.127516	207.7866	
10			4.019	12.680	73200	5773					Shear
3			4.013	12.642	74880	5923					Shear

Appendix Table 75: Mix D

Lab Identification No: ....Mix D

Date of Casting:............04/24/09...........................

Concrete Grade: ......Phase II_Mix D

Specim. No.	Age	Testing date	Dia ,(in.)	Area , (in.2)	Max. Load , (lbf)	Compressive Strength , (psi)	Avg. Strength , (psi)	STDEV	Co.of Variation	Standard Error	Type of Fracture
3	1	25-Apr-09	4	12.560	91870	7314	7265	169.519	2.333217	195.7437	Columnar
4			4.01	12.623	89330	7077					Shear
11			4.02	12.686	93940	7405					Columnar
2	28	22-May-09	4	12.560	116160	9248	8823.164	381.7642	4.32684	440.8233	Shear
6			4.01	12.623	107420	8510					Columnar
9			4.008	12.610	109850	8711					Columnar
O	56	19-Jun-09	4	12.560	113720	9054.1401	9065.481	133.7731	1.475631	154.4678	Shear
G			4.014	12.648	116420	9204.5636					Shear
N			4.01	12.623	112820	8937.7395					Columnar

Appendix Table 76: Mix E

Lab Identification No: ....Mix E

Date of Casting:............04/21/09...........................

Concrete Grade: ......Phase II_Mix E

Specim. No.	Age	Testing date	Dia ,(in.)	Area , (in.2)	Max. Load , (lbf)			STDEV	Co.of Variation	Standard Error	Type of Fracture
11	1	22-Apr-09	4.02	12.686	103200	8135	8204	67.55545	0.823456	78.00632	Columnar
5			4.015	12.654	103850	8207					Shear
9			4.014	12.648	104600	8270					
2	28	19-May-09	4.018	12.673	134340	10600.243	10683.16	369.4957	3.458674	426.6569	Shear
7			4.008	12.610	130670	10362.172					Shear
10			4.015	12.654	140300	11087.073					
8	56	16-Jun-09	4	12.560	127700	10167.197	10165.61	301.9165	2.969978	348.6231	
6			4.015	12.654	132450	10466.734					Shear
1			4.02	12.686	125120	9862.9078					Shear

Appendix Table 77: Mix S

Lab Identification No: .... Mix T

Date of Casting:............05/21/09............................

Concrete Grade: ......Phase II_Mix T

Specim. No.	Age	Testing date	Dia ,(in.)	Length (in.)	Area , (in.2)	Weight in air, (kg)	Weight in water, (kg)	Density in air , (lb/ ft.^{3})	Density in water , (lb/ ft.^{3})	Max. Load , (lbf)	Compressive Strength , (psi)	Avg. Strength , (psi)	STDEV	Co.of Variation	Standard Error	Type of Fracture
2	28	18-Jun-09	4.01	8.05	12.623	3.9		146.2138	0.0000	169500	13427.999	**13595.79**	**149.4508**	**1.099244**	**172.5709**	Shear
3			4.009	8.061	12.617	3.892		145.7875	0.0000	172150	13644.74					Shear
4			4.015	8.025	12.654	3.912		146.7544	0.0000	173550	13714.623					
1	56	16-Jul-09	4.01	7.95	12.623	4.06		154.1269	0.0000	174730	13842.326	**13898.67**	**86.48258**	**0.622236**	**99.86148**	
5			4.009	8.025	12.617	4.09		153.8915	0.0000	176610	13998.243					Shear
6			4.012	8.02	12.635	4.056		152.4790	0.0000	175070	13855.437					Shear

Appendix Table 78: Mix T

Lab Identification No: .... Mix T

Date of Casting:............05/21/09...........................

Concrete Grade: ......Phase II_Mix T

Specim. No.	Age	Testing date	Dia ,(in.)	Area , (in.2)	Max. Load , (lbf)	Compressive Strength , (psi)	Avg. Strength , (psi)	STDEV	Co.of Variation	Standard Error	Type of Fracture
10	1	22-May-09	4.015	12.654	118660	9377	**8868**	**440.9927**	**4.972959**	**509.2146**	Columnar
8			4.01	12.623	108790	8618					Shear
			4.02	12.686	109200	8608					
D	28	18-Jun-09	4.001	12.566	134100	10671.415	**10436.56**	**206.3111**	**1.976811**	**238.2275**	Shear
E			4.012	12.635	129950	10284.538					Shear
F			4.015	12.654	131020	10353.73					
1	56	16-Jul-09	4.015	12.654	145380	11488.515	**11055.22**	**424.4868**	**3.839695**	**490.1551**	
4			4.008	12.610	139180	11037.018					Shear
9			4	12.560	133640	10640.127					Shear

Abrasion Resistance Test

Appendix Table 79: Control-C1

Mix ID		Mix P, Control 1			Mix Type : MC- 4 %						Curing Peroid
Mix Id No.	Weight	34.9	lb	Weight	34.45	lb	0.450	Weight	34.3	lb	0.15
Wear depth (in.) at time (min.)											
Pos.	0 min			30 min				60 Min			
	R1	R2	Average	R1	R2	Average	Difference	R1	R2	Average	Difference
1	0.126	0.128	0.127	0.216	0.214	0.215	0.088	0.269	0.269	0.269	0.054
2	0.123	0.123	0.123	0.211	0.207	0.209	0.086	0.268	0.268	0.268	0.059
3	0.115	0.115	0.115	0.207	0.207	0.207	0.092	0.256	0.256	0.256	0.049
4	0.111	0.110	0.111	0.190	0.190	0.190	0.080	0.241	0.243	0.242	0.052
5	0.116	0.117	0.117	0.188	0.186	0.187	0.071	0.233	0.234	0.234	0.047
6	0.114	0.114	0.114	0.181	0.180	0.181	0.067	0.219	0.219	0.219	0.039
7	0.106	0.107	0.107	0.180	0.179	0.180	0.073	0.221	0.222	0.222	0.042
8	0.102	0.102	0.102	0.177	0.177	0.177	0.075	0.223	0.228	0.226	0.049
9	0.096	0.096	0.096	0.169	0.170	0.170	0.074	0.210	0.213	0.212	0.042
10	0.092	0.093	0.093	0.168	0.167	0.168	0.075	0.210	0.211	0.211	0.043
11	0.095	0.102	0.099	0.165	0.166	0.166	0.067	0.212	0.213	0.213	0.047
12	0.095	0.098	0.097	0.175	0.176	0.176	0.079	0.225	0.227	0.226	0.051
13	0.095	0.096	0.096	0.175	0.176	0.176	0.080	0.221	0.222	0.222	0.046
14	0.100	0.100	0.100	0.179	0.179	0.179	0.079	0.219	0.221	0.220	0.041
15	0.103	0.102	0.103	0.178	0.177	0.178	0.075	0.223	0.224	0.224	0.046
16	0.102	0.103	0.103	0.180	0.181	0.181	0.078	0.216	0.217	0.217	0.036
17	0.103	0.105	0.104	0.171	0.174	0.173	0.069	0.214	0.214	0.214	0.042
18	0.107	0.106	0.107	0.182	0.183	0.183	0.076	0.220	0.221	0.221	0.038
19	0.113	0.113	0.113	0.198	0.199	0.199	0.086	0.242	0.242	0.242	0.044
20	0.140	0.140	0.140	0.217	0.216	0.217	0.077	0.259	0.258	0.259	0.042
21	0.163	0.164	0.164	0.222	0.223	0.223	0.059	0.264	0.264	0.264	0.042
22	0.162	0.159	0.161	0.223	0.224	0.224	0.063	0.266	0.265	0.266	0.042
23	0.157	0.158	0.158	0.229	0.229	0.229	0.072	0.275	0.274	0.275	0.046
24	0.134	0.153	0.144	0.225	0.225	0.225	0.082	0.276	0.276	0.276	0.051
Average	0.115	0.117	0.116	0.192	0.192	0.192	**0.076**	0.237	0.238	0.237	**0.045**

Appendix Table 80: Control- C2

Mix ID		Mix P, Control 2			Mix Type : MC- 4 %						Curing Peroid
Mix Id No.	Weight	35.95	lb	Weight	35.7	lb	0.250	Weight	35.6	lb	0.1
Wear depth (in.) at time (min.)											
Pos.	0 min			30 min				60 Min			
	R1	R2	Average	R1	R2	Average	Difference	R1	R2	Average	Difference
1	0.115	0.115	0.115	0.179	0.178	0.179	0.064	0.219	0.221	0.220	0.042
2	0.116	0.117	0.117	0.164	0.164	0.164	0.048	0.202	0.203	0.203	0.039
3	0.113	0.115	0.114	0.168	0.168	0.168	0.054	0.206	0.206	0.206	0.038
4	0.117	0.119	0.118	0.175	0.175	0.175	0.057	0.207	0.206	0.207	0.032
5	0.121	0.122	0.122	0.171	0.177	0.174	0.053	0.198	0.198	0.198	0.024
6	0.117	0.117	0.117	0.168	0.168	0.168	0.051	0.196	0.196	0.196	0.028
7	0.111	0.105	0.108	0.163	0.163	0.163	0.055	0.186	0.186	0.186	0.023
8	0.106	0.105	0.106	0.152	0.156	0.154	0.049	0.184	0.184	0.184	0.030
9	0.112	0.107	0.110	0.152	0.152	0.152	0.043	0.182	0.180	0.181	0.029
10	0.113	0.119	0.116	0.151	0.154	0.153	0.037	0.178	0.179	0.179	0.026
11	0.104	0.107	0.106	0.156	0.159	0.158	0.052	0.182	0.185	0.184	0.026
12	0.113	0.116	0.115	0.155	0.153	0.154	0.040	0.184	0.184	0.184	0.030
13	0.103	0.108	0.106	0.153	0.153	0.153	0.048	0.192	0.191	0.192	0.039
14	0.102	0.103	0.103	0.165	0.165	0.165	0.063	0.197	0.198	0.198	0.033
15	0.103	0.098	0.101	0.167	0.168	0.168	0.067	0.206	0.206	0.206	0.039
16	0.119	0.119	0.119	0.179	0.179	0.179	0.060	0.214	0.216	0.215	0.036
17	0.133	0.135	0.134	0.188	0.188	0.188	0.054	0.226	0.227	0.227	0.039
18	0.152	0.152	0.152	0.202	0.204	0.203	0.051	0.240	0.242	0.241	0.038
19	0.185	0.185	0.185	0.214	0.214	0.214	0.029	0.244	0.247	0.246	0.032
20	0.153	0.154	0.154	0.208	0.209	0.209	0.055	0.241	0.243	0.242	0.034
21	0.136	0.136	0.136	0.194	0.196	0.195	0.059	0.235	0.236	0.236	0.041
22	0.129	0.133	0.131	0.188	0.190	0.189	0.058	0.230	0.231	0.231	0.042
23	0.115	0.115	0.115	0.178	0.178	0.178	0.063	0.223	0.225	0.224	0.046
24	0.111	0.112	0.112	0.183	0.184	0.184	0.072	0.227	0.229	0.228	0.045
Average	0.121	0.121	0.121	0.174	0.175	0.174	**0.053**	0.208	0.209	0.209	**0.034**

Appendix Table 81: Control- C3

Mix ID		Mix P, Control 3			Mix Type : MC- 4 %						Curing Peroid
Mix Id No.	Weight	35.7	lb	Weight	35.5	lb	0.200	Weight	35.4	lb	0.1
Wear depth (in.) at time (min.)											
Pos.	0 min			30 min				60 Min			
	R1	R2	Average	R1	R2	Average	Difference	R1	R2	Average	Difference
1	0.134	0.137	0.136	0.173	0.176	0.175	0.039	0.196	0.200	0.198	0.024
2	0.135	0.139	0.137	0.167	0.169	0.168	0.031	0.192	0.203	0.198	0.030
3	0.136	0.140	0.138	0.169	0.171	0.170	0.032	0.199	0.214	0.207	0.037
4	0.142	0.146	0.144	0.171	0.174	0.173	0.029	0.198	0.200	0.199	0.027
5	0.117	0.121	0.119	0.164	0.166	0.165	0.046	0.185	0.194	0.190	0.025
6	0.098	0.105	0.102	0.152	0.157	0.155	0.053	0.175	0.176	0.176	0.021
7	0.091	0.093	0.092	0.145	0.151	0.148	0.056	0.171	0.171	0.171	0.023
8	0.087	0.089	0.088	0.137	0.140	0.139	0.051	0.168	0.164	0.166	0.028
9	0.095	0.102	0.099	0.137	0.140	0.139	0.040	0.164	0.160	0.162	0.024
10	0.091	0.097	0.094	0.144	0.144	0.144	0.050	0.176	0.174	0.175	0.031
11	0.100	0.097	0.099	0.135	0.136	0.136	0.037	0.162	0.161	0.162	0.026
12	0.103	0.101	0.102	0.137	0.142	0.140	0.038	0.162	0.160	0.161	0.022
13	0.112	0.112	0.112	0.131	0.140	0.136	0.024	0.157	0.154	0.156	0.020
14	0.114	0.113	0.114	0.131	0.144	0.138	0.024	0.161	0.159	0.160	0.023
15	0.100	0.102	0.101	0.136	0.150	0.143	0.042	0.165	0.161	0.163	0.020
16	0.096	0.118	0.107	0.136	0.151	0.144	0.037	0.165	0.164	0.165	0.021
17	0.098	0.124	0.111	0.140	0.152	0.146	0.035	0.178	0.175	0.177	0.031
18	0.100	0.117	0.109	0.140	0.145	0.143	0.034	0.171	0.169	0.170	0.028
19	0.097	0.112	0.105	0.145	0.149	0.147	0.043	0.172	0.171	0.172	0.025
20	0.111	0.121	0.116	0.151	0.154	0.153	0.037	0.180	0.182	0.181	0.029
21	0.118	0.124	0.121	0.154	0.158	0.156	0.035	0.181	0.181	0.181	0.025
22	0.125	0.126	0.126	0.163	0.163	0.163	0.038	0.189	0.189	0.189	0.026
23	0.126	0.123	0.125	0.164	0.165	0.165	0.040	0.200	0.195	0.198	0.033
24	0.124	0.127	0.126	0.166	0.165	0.166	0.040	0.194	0.196	0.195	0.030
Average	0.110	0.116	0.113	0.150	0.154	0.152	**0.039**	0.178	0.178	0.178	**0.026**

Appendix Table 82: Mixture A1

Mix ID		Mix A 1			Mix Type :						Curing Peroid - 56 day
Mix Id No.	Weight	36.75	lb	Weight	36.3	lb	0.450	Weight	35.6	lb	0.7
Wear depth (in.) at time (min.)											
Pos.	0 min			30 min				60 Min			
	R1	R2	Average	R1	R2	Average	Difference	R1	R2	Average	Difference
1	0.125	0.123	0.124	0.259	0.260	0.260	0.136	0.324	0.324	0.324	0.065
2	0.136	0.136	0.136	0.235	0.235	0.235	0.099	0.309	0.309	0.309	0.074
3	0.121	0.121	0.121	0.243	0.245	0.244	0.123	0.307	0.306	0.307	0.063
4	0.108	0.108	0.108	0.238	0.240	0.239	0.131	0.304	0.302	0.303	0.064
5	0.106	0.107	0.107	0.228	0.231	0.230	0.123	0.304	0.304	0.304	0.075
6	0.105	0.105	0.105	0.220	0.222	0.221	0.116	0.288	0.288	0.288	0.067
7	0.097	0.107	0.102	0.213	0.215	0.214	0.112	0.272	0.271	0.272	0.058
8	0.099	0.100	0.100	0.212	0.215	0.214	0.114	0.278	0.279	0.279	0.065
9	0.104	0.103	0.104	0.205	0.208	0.207	0.103	0.281	0.269	0.275	0.069
10	0.106	0.105	0.106	0.210	0.213	0.212	0.106	0.277	0.270	0.274	0.062
11	0.113	0.124	0.119	0.220	0.223	0.222	0.103	0.281	0.287	0.284	0.063
12	0.117	0.119	0.118	0.203	0.212	0.208	0.090	0.293	0.279	0.286	0.079
13	0.127	0.130	0.129	0.232	0.235	0.234	0.105	0.281	0.300	0.291	0.057
14	0.120	0.121	0.121	0.233	0.229	0.231	0.111	0.297	0.306	0.302	0.071
15	0.118	0.118	0.118	0.245	0.239	0.242	0.124	0.314	0.310	0.312	0.070
16	0.121	0.122	0.122	0.243	0.241	0.242	0.121	0.303	0.297	0.300	0.058
17	0.127	0.128	0.128	0.250	0.249	0.250	0.122	0.305	0.305	0.305	0.056
18	0.134	0.133	0.134	0.254	0.243	0.249	0.115	0.317	0.316	0.317	0.068
19	0.135	0.135	0.135	0.260	0.261	0.261	0.126	0.334	0.328	0.331	0.071
20	0.140	0.141	0.141	0.271	0.267	0.269	0.129	0.330	0.330	0.330	0.061
21	0.138	0.138	0.138	0.270	0.268	0.269	0.131	0.339	0.305	0.322	0.053
22	0.135	0.136	0.136	0.274	0.274	0.274	0.139	0.336	0.336	0.336	0.062
23	0.139	0.140	0.140	0.246	0.246	0.246	0.107	0.318	0.318	0.318	0.072
24	0.136	0.138	0.137	0.262	0.263	0.263	0.126	0.332	0.332	0.332	0.070
Average	0.121	0.122	0.122	0.195	0.239	0.239	**0.117**	0.305	0.303	0.304	**0.065**

Appendix Table 83: Mixture A2

Mix ID		Mix A 2			Mix Type :						Curing Peroid - 56 day
Mix Id No.	Weight	37.6	lb	Weight	37.3	lb	0.300	Weight	37.2	lb	0.1
Wear depth (in.) at time (min.)											
Pos.	0 min			30 min				60 Min			
	R1	R2	Average	R1	R2	Average	Difference	R1	R2	Average	Difference
1	0.082	0.083	0.083	0.152	0.151	0.152	0.069	0.185	0.187	0.186	0.035
2	0.080	0.081	0.081	0.148	0.147	0.148	0.067	0.192	0.191	0.192	0.044
3	0.086	0.087	0.087	0.155	0.152	0.154	0.067	0.196	0.193	0.195	0.041
4	0.089	0.089	0.089	0.164	0.162	0.163	0.074	0.208	0.208	0.208	0.045
5	0.090	0.099	0.095	0.169	0.169	0.169	0.075	0.209	0.209	0.209	0.040
6	0.098	0.097	0.098	0.165	0.167	0.166	0.069	0.214	0.213	0.214	0.048
7	0.110	0.111	0.111	0.175	0.178	0.177	0.066	0.228	0.227	0.228	0.051
8	0.111	0.111	0.111	0.173	0.177	0.175	0.064	0.232	0.264	0.248	0.073
9	0.109	0.108	0.109	0.182	0.185	0.184	0.075	0.234	0.236	0.235	0.052
10	0.115	0.115	0.115	0.184	0.187	0.186	0.071	0.234	0.234	0.234	0.049
11	0.127	0.124	0.126	0.185	0.187	0.186	0.061	0.238	0.242	0.240	0.054
12	0.123	0.122	0.123	0.185	0.185	0.185	0.063	0.235	0.235	0.235	0.050
13	0.119	0.120	0.120	0.184	0.180	0.182	0.063	0.232	0.232	0.232	0.050
14	0.121	0.126	0.124	0.178	0.181	0.180	0.056	0.218	0.218	0.218	0.039
15	0.138	0.138	0.138	0.182	0.184	0.183	0.045	0.219	0.215	0.217	0.034
16	0.136	0.133	0.135	0.178	0.178	0.178	0.044	0.225	0.221	0.223	0.045
17	0.127	0.127	0.127	0.187	0.186	0.187	0.060	0.232	0.226	0.229	0.043
18	0.120	0.124	0.122	0.176	0.176	0.176	0.054	0.220	0.217	0.219	0.043
19	0.113	0.114	0.114	0.173	0.172	0.173	0.059	0.224	0.221	0.223	0.050
20	0.107	0.111	0.109	0.167	0.166	0.167	0.058	0.215	0.213	0.214	0.048
21	0.103	0.104	0.104	0.161	0.161	0.161	0.058	0.206	0.206	0.206	0.045
22	0.100	0.101	0.101	0.161	0.161	0.161	0.061	0.198	0.199	0.199	0.038
23	0.097	0.100	0.099	0.154	0.151	0.153	0.054	0.199	0.197	0.198	0.046
24	0.089	0.088	0.089	0.142	0.142	0.142	0.054	0.192	0.191	0.192	0.050
Average	0.108	0.109	0.108	0.195	0.170	0.170	**0.062**	0.216	0.216	0.216	**0.046**

Appendix Table 84: Mixture A3

Mix ID		Mix A 3			Mix Type :						Curing Peroid - 56 day
Mix Id No.	Weight	36.85	lb	Weight	36.7	lb	0.150	Weight	36.55	lb	0.15
Wear depth (in.) at time (min.)											
Pos.	0 min			30 min				60 Min			
	R1	R2	Average	R1	R2	Average	Difference	R1	R2	Average	Difference
1	0.091	0.091	0.091	0.136	0.137	0.137	0.046	0.175	0.176	0.176	0.039
2	0.081	0.082	0.082	0.136	0.136	0.136	0.055	0.179	0.180	0.180	0.044
3	0.089	0.087	0.088	0.132	0.133	0.133	0.045	0.171	0.172	0.172	0.039
4	0.091	0.091	0.091	0.146	0.147	0.147	0.056	0.187	0.187	0.187	0.041
5	0.109	0.112	0.111	0.151	0.153	0.152	0.042	0.196	0.197	0.197	0.045
6	0.120	0.120	0.120	0.164	0.160	0.162	0.042	0.202	0.203	0.203	0.041
7	0.113	0.116	0.115	0.160	0.162	0.161	0.047	0.199	0.199	0.199	0.038
8	0.110	0.111	0.111	0.155	0.159	0.157	0.047	0.197	0.199	0.198	0.041
9	0.109	0.111	0.110	0.155	0.154	0.155	0.045	0.198	0.196	0.197	0.043
10	0.106	0.110	0.108	0.156	0.157	0.157	0.049	0.197	0.197	0.197	0.041
11	0.114	0.112	0.113	0.156	0.153	0.155	0.042	0.192	0.192	0.192	0.038
12	0.117	0.120	0.119	0.155	0.154	0.155	0.036	0.194	0.198	0.196	0.042
13	0.121	0.119	0.120	0.150	0.152	0.151	0.031	0.179	0.185	0.182	0.031
14	0.115	0.117	0.116	0.150	0.152	0.151	0.035	0.180	0.181	0.181	0.030
15	0.105	0.106	0.106	0.145	0.147	0.146	0.041	0.177	0.177	0.177	0.031
16	0.103	0.102	0.103	0.140	0.142	0.141	0.039	0.177	0.176	0.177	0.036
17	0.097	0.099	0.098	0.140	0.137	0.139	0.041	0.168	0.163	0.166	0.027
18	0.109	0.107	0.108	0.143	0.147	0.145	0.037	0.182	0.173	0.178	0.033
19	0.101	0.105	0.103	0.143	0.142	0.143	0.040	0.175	0.172	0.174	0.031
20	0.090	0.098	0.094	0.135	0.135	0.135	0.041	0.176	0.175	0.176	0.041
21	0.093	0.097	0.095	0.135	0.136	0.136	0.041	0.179	0.177	0.178	0.043
22	0.094	0.095	0.095	0.140	0.140	0.140	0.046	0.181	0.182	0.182	0.042
23	0.093	0.099	0.096	0.141	0.142	0.142	0.046	0.186	0.187	0.187	0.045
24	0.094	0.098	0.096	0.138	0.138	0.138	0.042	0.182	0.184	0.183	0.045
Average	0.103	0.104	0.104	0.195	0.146	0.146	**0.043**	0.185	0.185	0.185	**0.038**

Appendix Table 85: Mixture B1

Mix ID		Mix B 1			Mix Type :						Curing Peroid - 57 day
Mix Id No.	Weight	35.45	lb	Weight	35.25	lb	0.200	Weight	35.15	lb	0.1
Wear depth (in.) at time (min.)											
Pos.	0 min			30 min				60 Min			
	R1	R2	Average	R1	R2	Average	Difference	R1	R2	Average	Difference
1	0.113	0.116	0.115	0.157	0.158	0.158	0.043	0.186	0.186	0.186	0.029
2	0.120	0.121	0.121	0.166	0.166	0.166	0.046	0.187	0.189	0.188	0.022
3	0.126	0.125	0.126	0.170	0.170	0.170	0.045	0.209	0.207	0.208	0.038
4	0.133	0.126	0.130	0.180	0.181	0.181	0.051	0.199	0.198	0.199	0.018
5	0.117	0.115	0.116	0.182	0.182	0.182	0.066	0.211	0.210	0.211	0.029
6	0.116	0.116	0.116	0.163	0.166	0.165	0.049	0.205	0.204	0.205	0.040
7	0.124	0.125	0.125	0.166	0.168	0.167	0.043	0.195	0.195	0.195	0.028
8	0.111	0.110	0.111	0.170	0.171	0.171	0.060	0.206	0.202	0.204	0.034
9	0.105	0.110	0.108	0.165	0.164	0.165	0.057	0.208	0.208	0.208	0.044
10	0.127	0.124	0.126	0.167	0.168	0.168	0.042	0.221	0.219	0.220	0.053
11	0.108	0.108	0.108	0.160	0.159	0.160	0.052	0.195	0.197	0.196	0.037
12	0.101	0.104	0.103	0.152	0.152	0.152	0.050	0.178	0.179	0.179	0.027
13	0.107	0.109	0.108	0.153	0.152	0.153	0.045	0.181	0.185	0.183	0.031
14	0.099	0.100	0.100	0.150	0.151	0.151	0.051	0.178	0.174	0.176	0.026
15	0.097	0.097	0.097	0.158	0.158	0.158	0.061	0.187	0.186	0.187	0.029
16	0.110	0.110	0.110	0.161	0.162	0.162	0.052	0.191	0.188	0.190	0.028
17	0.110	0.114	0.112	0.153	0.156	0.155	0.043	0.182	0.180	0.181	0.027
18	0.107	0.108	0.108	0.152	0.151	0.152	0.044	0.188	0.191	0.190	0.038
19	0.107	0.107	0.107	0.158	0.157	0.158	0.051	0.189	0.185	0.187	0.030
20	0.112	0.113	0.113	0.159	0.160	0.160	0.047	0.185	0.185	0.185	0.026
21	0.125	0.126	0.126	0.153	0.153	0.153	0.028	0.177	0.176	0.177	0.024
22	0.122	0.127	0.125	0.154	0.155	0.155	0.030	0.180	0.177	0.179	0.024
23	0.132	0.128	0.130	0.166	0.168	0.167	0.037	0.180	0.180	0.180	0.013
24	0.116	0.116	0.116	0.154	0.154	0.154	0.038	0.178	0.176	0.177	0.023
Average	0.114	0.115	0.115	0.195	0.162	0.161	**0.047**	0.192	0.191	0.191	**0.030**

Appendix Table 86: Mixture B2

Mix ID		Mix B 2			Mix Type :						Curing Peroid - 57 day
Mix Id No.	Weight	35.4	lb	Weight	35.15	lb	0.250	Weight	35	lb	0.15
Wear depth (in.) at time (min.)											
Pos.	0 min			30 min				60 Min			
	R1	R2	Average	R1	R2	Average	Difference	R1	R2	Average	Difference
1	0.133	0.132	0.133	0.171	0.172	0.172	0.039	0.203	0.204	0.204	0.032
2	0.126	0.125	0.126	0.178	0.179	0.179	0.053	0.218	0.218	0.218	0.040
3	0.132	0.132	0.132	0.173	0.173	0.173	0.041	0.210	0.209	0.210	0.037
4	0.123	0.124	0.124	0.177	0.179	0.178	0.055	0.219	0.217	0.218	0.040
5	0.123	0.125	0.124	0.184	0.184	0.184	0.060	0.236	0.234	0.235	0.051
6	0.123	0.121	0.122	0.181	0.179	0.180	0.058	0.228	0.228	0.228	0.048
7	0.138	0.137	0.138	0.186	0.189	0.188	0.050	0.221	0.222	0.222	0.034
8	0.131	0.131	0.131	0.183	0.186	0.185	0.054	0.228	0.227	0.228	0.043
9	0.143	0.139	0.141	0.191	0.192	0.192	0.051	0.234	0.230	0.232	0.041
10	0.143	0.141	0.142	0.185	0.188	0.187	0.045	0.223	0.219	0.221	0.035
11	0.144	0.142	0.143	0.185	0.186	0.186	0.043	0.220	0.221	0.221	0.035
12	0.159	0.155	0.157	0.170	0.171	0.171	0.014	0.205	0.203	0.204	0.034
13	0.145	0.141	0.143	0.171	0.172	0.172	0.029	0.211	0.210	0.211	0.039
14	0.156	0.153	0.155	0.176	0.176	0.176	0.022	0.205	0.206	0.206	0.030
15	0.157	0.149	0.153	0.170	0.159	0.165	0.012	0.215	0.214	0.215	0.050
16	0.158	0.159	0.159	0.169	0.161	0.165	0.007	0.211	0.212	0.212	0.047
17	0.162	0.165	0.164	0.180	0.176	0.178	0.015	0.212	0.215	0.214	0.036
18	0.160	0.160	0.160	0.175	0.174	0.175	0.015	0.207	0.207	0.207	0.033
19	0.148	0.147	0.148	0.163	0.163	0.163	0.016	0.201	0.200	0.201	0.038
20	0.160	0.160	0.160	0.174	0.174	0.174	0.014	0.207	0.206	0.207	0.033
21	0.152	0.156	0.154	0.169	0.171	0.170	0.016	0.214	0.212	0.213	0.043
22	0.159	0.158	0.159	0.169	0.168	0.169	0.010	0.220	0.223	0.222	0.053
23	0.164	0.165	0.165	0.174	0.168	0.171	0.006	0.208	0.210	0.209	0.038
24	0.138	0.139	0.139	0.167	0.171	0.169	0.031	0.201	0.203	0.202	0.033
Average	0.145	0.144	0.144	0.195	0.175	0.176	**0.031**	0.215	0.215	0.215	**0.039**

Appendix Table 87: Mixture B3

Mix ID		Mix B 3							Curing Peroid - 57 day
Mix Id No.	Weight	36.4	lb	Weight	lb	0.400	Weight	lb	0.25
Wear depth (in.) at time (min.)									
Pos.	0 min			30 min			60 Min		
	R1	R2	Average	R1	Average	Difference	R1	Average	Difference
1	0.147	0.147	0.147	0.232	0.232	0.085	0.295	0.295	0.063
2	0.143	0.143	0.143	0.242	0.242	0.099	0.288	0.288	0.046
3	0.137	0.137	0.137	0.250	0.250	0.113	0.290	0.290	0.040
4	0.138	0.138	0.138	0.218	0.218	0.080	0.273	0.273	0.055
5	0.138	0.138	0.138	0.234	0.234	0.096	0.291	0.291	0.057
6	0.120	0.120	0.120	0.232	0.232	0.112	0.293	0.293	0.061
7	0.130	0.130	0.130	0.240	0.240	0.110	0.291	0.291	0.051
8	0.122	0.122	0.122	0.233	0.233	0.111	0.288	0.288	0.055
9	0.123	0.123	0.123	0.244	0.244	0.121	0.298	0.298	0.054
10	0.129	0.129	0.129	0.217	0.217	0.088	0.290	0.290	0.073
11	0.134	0.134	0.134	0.237	0.237	0.103	0.285	0.285	0.048
12	0.127	0.127	0.127	0.237	0.237	0.110	0.294	0.294	0.057
13	0.145	0.145	0.145	0.235	0.235	0.090	0.294	0.294	0.059
14	0.132	0.132	0.132	0.242	0.242	0.110	0.308	0.308	0.066
15	0.134	0.134	0.134	0.243	0.243	0.109	0.301	0.301	0.058
16	0.156	0.156	0.156	0.249	0.249	0.093	0.302	0.302	0.053
17	0.153	0.153	0.153	0.247	0.247	0.094	0.299	0.299	0.052
18	0.160	0.160	0.160	0.264	0.264	0.104	0.308	0.308	0.044
19	0.157	0.157	0.157	0.261	0.261	0.104	0.323	0.323	0.062
20	0.162	0.162	0.162	0.255	0.255	0.093	0.309	0.309	0.054
21	0.152	0.152	0.152	0.260	0.260	0.108	0.320	0.320	0.060
22	0.153	0.153	0.153	0.264	0.264	0.111	0.317	0.317	0.053
23	0.141	0.141	0.141	0.261	0.261	0.120	0.313	0.313	0.052
24	0.141	0.141	0.141	0.254	0.254	0.113	0.321	0.321	0.067
Average	0.141	0.141	0.141	0.195	0.244	**0.103**	0.300	0.300	**0.056**

Appendix Table 88: Mixture C1

Mix ID		Mix C -1			Mix Type : MC-7 %						Curing Peroid - 56 day
Mix Id No.	Weight	33.15	lb	Weight	32.6	lb	0.550	Weight	32.45	lb	0.15
Wear depth (in.) at time (min.)											
Pos.	0 min			30 min				60 Min			
	R1	R2	Average	R1	R2	Average	Difference	R1	R2	Average	Difference
1	0.150	0.152	0.151	0.292	0.287	0.290	0.139	0.319	0.319	0.319	0.030
2	0.143	0.141	0.142	0.271	0.271	0.271	0.129	0.299	0.300	0.300	0.029
3	0.135	0.136	0.136	0.260	0.260	0.260	0.125	0.300	0.305	0.303	0.043
4	0.131	0.132	0.132	0.264	0.264	0.264	0.133	0.297	0.298	0.298	0.034
5	0.120	0.120	0.120	0.256	0.253	0.255	0.135	0.300	0.300	0.300	0.046
6	0.121	0.121	0.121	0.246	0.247	0.247	0.126	0.295	0.295	0.295	0.049
7	0.119	0.120	0.120	0.249	0.249	0.249	0.130	0.304	0.304	0.304	0.055
8	0.121	0.122	0.122	0.255	0.256	0.256	0.134	0.310	0.313	0.312	0.056
9	0.132	0.131	0.132	0.266	0.268	0.267	0.136	0.308	0.308	0.308	0.041
10	0.130	0.132	0.131	0.268	0.264	0.266	0.135	0.310	0.310	0.310	0.044
11	0.138	0.135	0.137	0.291	0.287	0.289	0.153	0.326	0.325	0.326	0.037
12	0.150	0.150	0.150	0.288	0.282	0.285	0.135	0.338	0.332	0.335	0.050
13	0.150	0.150	0.150	0.294	0.295	0.295	0.145	0.332	0.341	0.337	0.042
14	0.173	0.174	0.174	0.301	0.304	0.303	0.129	0.349	0.350	0.350	0.047
15	0.165	0.165	0.165	0.309	0.309	0.309	0.144	0.347	0.353	0.350	0.041
16	0.156	0.159	0.158	0.275	0.274	0.275	0.117	0.309	0.309	0.309	0.035
17	0.157	0.155	0.156	0.283	0.285	0.284	0.128	0.311	0.315	0.313	0.029
18	0.191	0.191	0.191	0.307	0.310	0.309	0.118	0.333	0.339	0.336	0.028
19	0.197	0.199	0.198	0.325	0.325	0.325	0.127	0.366	0.366	0.366	0.041
20	0.208	0.208	0.208	0.315	0.321	0.318	0.110	0.360	0.360	0.360	0.042
21	0.200	0.198	0.199	0.323	0.323	0.323	0.124	0.364	0.365	0.365	0.042
22	0.193	0.190	0.192	0.313	0.312	0.313	0.121	0.352	0.358	0.355	0.043
23	0.177	0.176	0.177	0.309	0.312	0.311	0.134	0.355	0.360	0.358	0.047
24	0.170	0.169	0.170	0.301	0.303	0.302	0.133	0.334	0.336	0.335	0.033
Average	0.155	0.155	0.155	0.195	0.286	0.286	**0.131**	0.326	0.328	0.327	**0.041**

Appendix Table 89: Mixture C2

Mix ID		Mix C -2			Mix Type :						Curing Peroid - 56 day
Mix Id No.	Weight	33.5	lb	Weight	33.1	lb	0.400	Weight	32.9	lb	0.2
Wear depth (in.) at time (min.)											
Pos.	0 min			30 min				60 Min			
	R1	R2	Average	R1	R2	Average	Difference	R1	R2	Average	Difference
1	0.106	0.108	0.107	0.204	0.204	0.204	0.097	0.262	0.262	0.262	0.058
2	0.112	0.110	0.111	0.216	0.216	0.216	0.105	0.273	0.273	0.273	0.057
3	0.112	0.113	0.113	0.216	0.216	0.216	0.104	0.282	0.281	0.282	0.066
4	0.116	0.119	0.118	0.213	0.214	0.214	0.096	0.277	0.268	0.273	0.059
5	0.128	0.131	0.130	0.199	0.202	0.201	0.071	0.259	0.260	0.260	0.059
6	0.115	0.116	0.116	0.208	0.209	0.209	0.093	0.273	0.272	0.273	0.064
7	0.108	0.107	0.108	0.211	0.212	0.212	0.104	0.267	0.266	0.267	0.055
8	0.113	0.114	0.114	0.210	0.211	0.211	0.097	0.258	0.267	0.263	0.052
9	0.102	0.099	0.101	0.202	0.203	0.203	0.102	0.262	0.266	0.264	0.062
10	0.106	0.109	0.108	0.199	0.197	0.198	0.091	0.254	0.265	0.260	0.062
11	0.106	0.105	0.106	0.216	0.214	0.215	0.110	0.265	0.268	0.267	0.052
12	0.104	0.102	0.103	0.210	0.207	0.209	0.106	0.262	0.266	0.264	0.056
13	0.105	0.101	0.103	0.202	0.199	0.201	0.098	0.256	0.257	0.257	0.056
14	0.100	0.103	0.102	0.207	0.205	0.206	0.105	0.266	0.266	0.266	0.060
15	0.108	0.107	0.108	0.199	0.196	0.198	0.090	0.251	0.251	0.251	0.054
16	0.109	0.106	0.108	0.214	0.209	0.212	0.104	0.256	0.258	0.257	0.046
17	0.114	0.116	0.115	0.221	0.215	0.218	0.103	0.274	0.279	0.277	0.059
18	0.134	0.133	0.134	0.227	0.229	0.228	0.095	0.274	0.275	0.275	0.047
19	0.133	0.135	0.134	0.232	0.230	0.231	0.097	0.298	0.300	0.299	0.068
20	0.136	0.139	0.138	0.228	0.226	0.227	0.090	0.289	0.290	0.290	0.063
21	0.131	0.128	0.130	0.220	0.220	0.220	0.091	0.273	0.273	0.273	0.053
22	0.127	0.128	0.128	0.210	0.210	0.210	0.083	0.260	0.260	0.260	0.050
23	0.120	0.125	0.123	0.205	0.205	0.205	0.083	0.269	0.268	0.269	0.064
24	0.110	0.108	0.109	0.195	0.194	0.195	0.086	0.249	0.247	0.248	0.054
Average	0.115	0.115	0.115	0.195	0.210	0.211	**0.096**	0.267	0.268	0.268	**0.057**

Appendix Table 90: Mixture C3

Mix ID		Mix C -3			Mix Type :						Curing Peroid - 56 day
Mix Id No.	Weight	33.6	lb	Weight	33.15	lb	0.450	Weight	32.85	lb	0.3
Wear depth (in.) at time (min.)											
Pos.	0 min			30 min				60 Min			
	R1	R2	Average	R1	R2	Average	Difference	R1	R2	Average	Difference
1	0.118	0.121	0.120	0.212	0.213	0.213	0.093	0.275	0.277	0.276	0.064
2	0.110	0.112	0.111	0.218	0.221	0.220	0.109	0.277	0.274	0.276	0.056
3	0.107	0.107	0.107	0.205	0.207	0.206	0.099	0.267	0.268	0.268	0.062
4	0.102	0.103	0.103	0.209	0.209	0.209	0.107	0.271	0.271	0.271	0.062
5	0.105	0.108	0.107	0.217	0.218	0.218	0.111	0.271	0.271	0.271	0.054
6	0.102	0.100	0.101	0.194	0.195	0.195	0.094	0.263	0.262	0.263	0.068
7	0.108	0.112	0.110	0.220	0.222	0.221	0.111	0.282	0.287	0.285	0.064
8	0.111	0.114	0.113	0.222	0.223	0.223	0.110	0.280	0.281	0.281	0.058
9	0.108	0.115	0.112	0.225	0.225	0.225	0.114	0.288	0.292	0.290	0.065
10	0.117	0.118	0.118	0.230	0.228	0.229	0.112	0.296	0.298	0.297	0.068
11	0.121	0.122	0.122	0.250	0.255	0.253	0.131	0.300	0.308	0.304	0.052
12	0.120	0.121	0.121	0.231	0.227	0.229	0.109	0.292	0.291	0.292	0.063
13	0.123	0.121	0.122	0.236	0.236	0.236	0.114	0.286	0.288	0.287	0.051
14	0.119	0.120	0.120	0.252	0.252	0.252	0.133	0.313	0.309	0.311	0.059
15	0.121	0.119	0.120	0.253	0.254	0.254	0.134	0.300	0.304	0.302	0.049
16	0.117	0.115	0.116	0.252	0.258	0.255	0.139	0.292	0.297	0.295	0.040
17	0.123	0.125	0.124	0.258	0.260	0.259	0.135	0.295	0.296	0.296	0.037
18	0.125	0.123	0.124	0.258	0.258	0.258	0.134	0.312	0.312	0.312	0.054
19	0.126	0.125	0.126	0.244	0.241	0.243	0.117	0.301	0.299	0.300	0.058
20	0.132	0.129	0.131	0.247	0.249	0.248	0.118	0.307	0.304	0.306	0.058
21	0.133	0.137	0.135	0.233	0.233	0.233	0.098	0.294	0.294	0.294	0.061
22	0.136	0.135	0.136	0.245	0.248	0.247	0.111	0.311	0.310	0.311	0.064
23	0.124	0.120	0.122	0.239	0.241	0.240	0.118	0.298	0.297	0.298	0.058
24	0.120	0.118	0.119	0.232	0.232	0.232	0.113	0.285	0.286	0.286	0.054
Average	0.118	0.118	0.118	0.195	0.234	0.233	**0.115**	0.290	0.291	0.290	**0.057**

Appendix Table 91: Mixture D1

Mix ID		Mix D -1			Mix Type :						Curing Peroid - 56 day
Mix Id No.	Weight	36.55	lb	Weight	36.4	lb	0.150	Weight	36.3	lb	0.1
Wear depth (in.) at time (min.)											
Pos.	0 min			30 min				60 Min			
	R1	R2	Average	R1	R2	Average	Difference	R1	R2	Average	Difference
1	0.103	0.107	0.105	0.141	0.141	0.141	0.036	0.173	0.173	0.173	0.032
2	0.096	0.097	0.097	0.133	0.133	0.133	0.037	0.157	0.157	0.157	0.024
3	0.091	0.093	0.092	0.132	0.129	0.131	0.039	0.151	0.155	0.153	0.023
4	0.085	0.087	0.086	0.126	0.121	0.124	0.038	0.148	0.150	0.149	0.026
5	0.086	0.085	0.086	0.121	0.119	0.120	0.035	0.140	0.140	0.140	0.020
6	0.083	0.084	0.084	0.115	0.116	0.116	0.032	0.135	0.137	0.136	0.021
7	0.082	0.088	0.085	0.118	0.122	0.120	0.035	0.144	0.145	0.145	0.025
8	0.087	0.088	0.088	0.123	0.125	0.124	0.037	0.147	0.148	0.148	0.024
9	0.099	0.100	0.100	0.127	0.125	0.126	0.027	0.148	0.147	0.148	0.022
10	0.102	0.103	0.103	0.131	0.129	0.130	0.028	0.149	0.150	0.150	0.020
11	0.109	0.110	0.110	0.141	0.145	0.143	0.034	0.159	0.160	0.160	0.017
12	0.117	0.119	0.118	0.151	0.151	0.151	0.033	0.179	0.181	0.180	0.029
13	0.123	0.124	0.124	0.158	0.158	0.158	0.035	0.180	0.182	0.181	0.023
14	0.120	0.120	0.120	0.161	0.157	0.159	0.039	0.175	0.175	0.175	0.016
15	0.118	0.117	0.118	0.154	0.154	0.154	0.037	0.186	0.189	0.188	0.034
16	0.098	0.099	0.099	0.160	0.158	0.159	0.061	0.195	0.196	0.196	0.037
17	0.120	0.115	0.118	0.158	0.156	0.157	0.040	0.203	0.205	0.204	0.047
18	0.118	0.118	0.118	0.160	0.160	0.160	0.042	0.201	0.211	0.206	0.046
19	0.113	0.113	0.113	0.170	0.172	0.171	0.058	0.193	0.194	0.194	0.023
20	0.124	0.129	0.127	0.160	0.163	0.162	0.035	0.187	0.187	0.187	0.026
21	0.123	0.119	0.121	0.164	0.160	0.162	0.041	0.186	0.186	0.186	0.024
22	0.112	0.113	0.113	0.155	0.153	0.154	0.042	0.176	0.177	0.177	0.023
23	0.112	0.116	0.114	0.147	0.150	0.149	0.035	0.170	0.170	0.170	0.022
24	0.109	0.110	0.110	0.158	0.157	0.158	0.048	0.176	0.176	0.176	0.019
Average	0.105	0.106	0.106	0.195	0.144	0.144	**0.038**	0.169	0.000	0.170	**0.026**

Appendix Table 92: Mixture D2

Mix ID		Mix D 2			Mix Type : MC- 4 %						Curing Peroid-56
Mix Id No.	Weight	36.45	lb	Weight	36.3	lb	0.150	Weight	36.1	lb	0.200
Wear depth (in.) at time (min.)											
Pos.	0 min			30 min				60 Min			
	R1	R2	Average	R1	R2	Average	Difference	R1	R2	Average	Difference
1	0.104	0.104	0.104	0.150	0.150	0.150	0.046	0.169	0.170	0.170	0.020
2	0.096	0.096	0.096	0.147	0.147	0.147	0.051	0.174	0.175	0.175	0.028
3	0.090	0.090	0.090	0.147	0.147	0.147	0.057	0.176	0.177	0.177	0.030
4	0.094	0.094	0.094	0.145	0.139	0.142	0.048	0.186	0.187	0.187	0.045
5	0.095	0.095	0.095	0.143	0.142	0.143	0.048	0.190	0.189	0.190	0.047
6	0.090	0.090	0.090	0.140	0.137	0.139	0.049	0.183	0.188	0.186	0.047
7	0.096	0.096	0.096	0.137	0.136	0.137	0.041	0.162	0.162	0.162	0.026
8	0.090	0.091	0.091	0.133	0.133	0.133	0.043	0.193	0.181	0.187	0.054
9	0.085	0.084	0.085	0.137	0.138	0.138	0.053	0.207	0.199	0.203	0.066
10	0.087	0.087	0.087	0.146	0.143	0.145	0.058	0.188	0.189	0.189	0.044
11	0.098	0.099	0.099	0.149	0.147	0.148	0.050	0.187	0.194	0.191	0.043
12	0.104	0.105	0.105	0.154	0.153	0.154	0.049	0.222	0.226	0.224	0.071
13	0.107	0.106	0.107	0.160	0.159	0.160	0.053	0.218	0.219	0.219	0.059
14	0.111	0.113	0.112	0.173	0.174	0.174	0.062	0.222	0.224	0.223	0.050
15	0.109	0.109	0.109	0.168	0.169	0.169	0.060	0.223	0.223	0.223	0.055
16	0.109	0.111	0.110	0.160	0.163	0.162	0.052	0.202	0.207	0.205	0.043
17	0.111	0.111	0.111	0.171	0.168	0.170	0.059	0.214	0.206	0.210	0.041
18	0.107	0.107	0.107	0.174	0.175	0.175	0.068	0.201	0.198	0.200	0.025
19	0.114	0.115	0.115	0.168	0.170	0.169	0.055	0.195	0.193	0.194	0.025
20	0.115	0.114	0.115	0.167	0.165	0.166	0.052	0.190	0.191	0.191	0.025
21	0.114	0.114	0.114	0.164	0.164	0.164	0.050	0.177	0.177	0.177	0.013
22	0.116	0.113	0.115	0.165	0.164	0.165	0.050	0.176	0.175	0.176	0.011
23	0.108	0.109	0.109	0.155	0.155	0.155	0.047	0.166	0.165	0.166	0.011
24	0.110	0.109	0.110	0.154	0.150	0.152	0.043	0.163	0.164	0.164	0.012
Average	0.103	0.103	0.103	0.154	0.154	0.154	**0.052**	0.191	0.191	0.191	**0.037**

Appendix Table 93: Mixture D3

Mix ID		Mix D 3			Mix Type : MC- 4 %						Curing Peroid-56
Mix Id No.	Weight	35.9	lb	Weight	35.6	lb	0.300	Weight	35.4	lb	0.200
Wear depth (in.) at time (min.)											
Pos.	0 min			30 min				60 Min			
	R1	R2	Average	R1	R2	Average	Difference	R1	R2	Average	Difference
1	0.097	0.097	0.097	0.174	0.174	0.174	0.077	0.222	0.219	0.221	0.047
2	0.094	0.095	0.095	0.172	0.173	0.173	0.078	0.222	0.220	0.221	0.049
3	0.095	0.097	0.096	0.174	0.175	0.175	0.079	0.221	0.224	0.223	0.048
4	0.101	0.100	0.101	0.172	0.173	0.173	0.072	0.215	0.218	0.217	0.044
5	0.086	0.088	0.087	0.178	0.176	0.177	0.090	0.218	0.219	0.219	0.042
6	0.103	0.104	0.104	0.187	0.185	0.186	0.083	0.225	0.217	0.221	0.035
7	0.102	0.107	0.105	0.186	0.187	0.187	0.082	0.225	0.217	0.221	0.035
8	0.101	0.103	0.102	0.194	0.194	0.194	0.092	0.231	0.224	0.228	0.034
9	0.102	0.103	0.103	0.197	0.201	0.199	0.097	0.236	0.228	0.232	0.033
10	0.112	0.109	0.111	0.199	0.200	0.200	0.089	0.235	0.230	0.233	0.033
11	0.111	0.113	0.112	0.199	0.199	0.199	0.087	0.238	0.238	0.238	0.039
12	0.122	0.022	0.072	0.199	0.198	0.199	0.127	0.237	0.230	0.234	0.035
13	0.132	0.133	0.133	0.188	0.189	0.189	0.056	0.226	0.228	0.227	0.039
14	0.126	0.127	0.127	0.195	0.195	0.195	0.069	0.238	0.244	0.241	0.046
15	0.121	0.124	0.123	0.194	0.195	0.195	0.072	0.271	0.238	0.255	0.060
16	0.120	0.120	0.120	0.199	0.200	0.200	0.080	0.279	0.247	0.263	0.064
17	0.125	0.124	0.125	0.196	0.197	0.197	0.072	0.224	0.250	0.237	0.041
18	0.118	0.119	0.119	0.193	0.194	0.194	0.075	0.244	0.246	0.245	0.052
19	0.116	0.117	0.117	0.193	0.191	0.192	0.076	0.237	0.238	0.238	0.046
20	0.112	0.112	0.112	0.178	0.177	0.178	0.066	0.231	0.232	0.232	0.054
21	0.110	0.111	0.111	0.184	0.184	0.184	0.074	0.233	0.234	0.234	0.050
22	0.107	0.108	0.108	0.175	0.176	0.176	0.068	0.222	0.223	0.223	0.047
23	0.107	0.106	0.107	0.166	0.166	0.166	0.060	0.205	0.206	0.206	0.040
24	0.096	0.096	0.096	0.186	0.186	0.186	0.090	0.219	0.218	0.219	0.033
Average	0.109	0.106	0.107	0.186	0.187	0.187	**0.079**	0.231	0.229	0.230	**0.043**

Appendix Table 94: Mixture E1

Mix ID		Mix E 1			Mix Type :						Curing Peroid - 56 day
Mix Id No.	Weight	36.95	lb	Weight	36.9	lb	0.050	Weight	36.8	lb	0.1
Wear depth (in.) at time (min.)											
Pos.	0 min			30 min				60 Min			
	R1	R2	Average	R1	R2	Average	Difference	R1	R2	Average	Difference
1	0.140	0.141	0.141	0.162	0.162	0.162	0.022	0.176	0.175	0.176	0.014
2	0.130	0.131	0.131	0.161	0.162	0.162	0.031	0.179	0.179	0.179	0.018
3	0.119	0.119	0.119	0.150	0.149	0.150	0.031	0.166	0.166	0.166	0.017
4	0.096	0.094	0.095	0.125	0.126	0.126	0.031	0.147	0.149	0.148	0.023
5	0.105	0.104	0.105	0.135	0.134	0.135	0.030	0.151	0.153	0.152	0.018
6	0.085	0.087	0.086	0.114	0.113	0.114	0.028	0.132	0.132	0.132	0.019
7	0.087	0.084	0.086	0.128	0.122	0.125	0.040	0.137	0.138	0.138	0.013
8	0.107	0.107	0.107	0.121	0.119	0.120	0.013	0.134	0.134	0.134	0.014
9	0.091	0.091	0.091	0.114	0.114	0.114	0.023	0.130	0.129	0.130	0.016
10	0.098	0.098	0.098	0.125	0.122	0.124	0.026	0.136	0.135	0.136	0.012
11	0.118	0.119	0.119	0.132	0.130	0.131	0.013	0.138	0.139	0.139	0.008
12	0.118	0.120	0.119	0.142	0.140	0.141	0.022	0.152	0.154	0.153	0.012
13	0.122	0.123	0.123	0.143	0.141	0.142	0.020	0.152	0.151	0.152	0.010
14	0.116	0.111	0.114	0.145	0.142	0.144	0.030	0.159	0.162	0.161	0.017
15	0.101	0.105	0.103	0.137	0.135	0.136	0.033	0.152	0.154	0.153	0.017
16	0.093	0.094	0.094	0.130	0.130	0.130	0.037	0.150	0.151	0.151	0.021
17	0.099	0.099	0.099	0.132	0.133	0.133	0.034	0.152	0.151	0.152	0.019
18	0.096	0.096	0.096	0.128	0.129	0.129	0.033	0.151	0.150	0.151	0.022
19	0.104	0.104	0.104	0.137	0.138	0.138	0.034	0.159	0.159	0.159	0.022
20	0.103	0.106	0.105	0.139	0.138	0.139	0.034	0.165	0.165	0.165	0.027
21	0.117	0.117	0.117	0.157	0.157	0.157	0.040	0.173	0.174	0.174	0.017
22	0.124	0.124	0.124	0.155	0.155	0.155	0.031	0.172	0.173	0.173	0.018
23	0.134	0.134	0.134	0.156	0.156	0.156	0.022	0.174	0.175	0.175	0.019
24	0.135	0.136	0.136	0.161	0.161	0.161	0.026	0.177	0.178	0.178	0.017
Average	0.110	0.110	0.110	0.195	0.138	0.138	**0.028**	0.155	0.155	0.155	**0.017**

Appendix Table 95: Mixture E2

Mix ID		Mix E 2			Mix Type :						Curing Peroid - 56 day
Mix Id No.	Weight	37.5	lb	Weight	37.25	lb	0.250	Weight	37.1	lb	0.15
Wear depth (in.) at time (min.)											
Pos.	0 min			30 min				60 Min			
	R1	R2	Average	R1	R2	Average	Difference	R1	R2	Average	Difference
1	0.097	0.096	0.097	0.161	0.161	0.161	0.065	0.201	0.197	0.199	0.038
2	0.113	0.114	0.114	0.176	0.176	0.176	0.063	0.217	0.213	0.215	0.039
3	0.131	0.133	0.132	0.193	0.193	0.193	0.061	0.233	0.229	0.231	0.038
4	0.149	0.149	0.149	0.203	0.203	0.203	0.054	0.240	0.236	0.238	0.035
5	0.157	0.160	0.159	0.219	0.215	0.217	0.059	0.248	0.245	0.247	0.030
6	0.163	0.163	0.163	0.228	0.228	0.228	0.065	0.260	0.260	0.260	0.032
7	0.162	0.165	0.164	0.227	0.228	0.228	0.064	0.259	0.260	0.260	0.032
8	0.163	0.163	0.163	0.220	0.222	0.221	0.058	0.253	0.253	0.253	0.032
9	0.139	0.140	0.140	0.211	0.213	0.212	0.073	0.244	0.245	0.245	0.033
10	0.120	0.121	0.121	0.192	0.191	0.192	0.071	0.224	0.223	0.224	0.032
11	0.107	0.106	0.107	0.180	0.179	0.180	0.073	0.218	0.215	0.217	0.037
12	0.106	0.106	0.106	0.181	0.182	0.182	0.076	0.214	0.210	0.212	0.031
13	0.118	0.116	0.117	0.187	0.187	0.187	0.070	0.209	0.211	0.210	0.023
14	0.129	0.128	0.129	0.193	0.194	0.194	0.065	0.207	0.209	0.208	0.015
15	0.137	0.136	0.137	0.192	0.188	0.190	0.054	0.203	0.206	0.205	0.015
16	0.133	0.137	0.135	0.184	0.184	0.184	0.049	0.198	0.200	0.199	0.015
17	0.129	0.129	0.129	0.182	0.183	0.183	0.054	0.199	0.199	0.199	0.017
18	0.112	0.113	0.113	0.175	0.172	0.174	0.061	0.195	0.196	0.196	0.022
19	0.101	0.102	0.102	0.163	0.163	0.163	0.062	0.186	0.187	0.187	0.024
20	0.104	0.104	0.104	0.168	0.168	0.168	0.064	0.198	0.199	0.199	0.031
21	0.108	0.108	0.108	0.167	0.166	0.167	0.059	0.198	0.199	0.199	0.032
22	0.109	0.105	0.107	0.175	0.175	0.175	0.068	0.204	0.207	0.206	0.031
23	0.108	0.108	0.108	0.166	0.166	0.166	0.058	0.189	0.191	0.190	0.024
24	0.097	0.099	0.098	0.160	0.160	0.160	0.062	0.197	0.197	0.197	0.037
Average	0.125	0.125	0.125	0.195	0.187	0.188	**0.063**	0.216	0.216	0.216	**0.029**

Appendix Table 96: Mixture E3

Mix ID		Mix E 3			Mix Type :						Curing Peroid - 56 day
Mix Id No.	Weight	37.55	lb	Weight	37.45	lb	0.100	Weight	37.35	lb	0.1
Wear depth (in.) at time (min.)											
Pos.	0 min			30 min				60 Min			
	R1	R2	Average	R1	R2	Average	Difference	R1	R2	Average	Difference
1	0.146	0.151	0.149	0.172	0.171	0.172	0.023	0.224	0.223	0.224	0.052
2	0.151	0.163	0.157	0.198	0.187	0.193	0.036	0.231	0.231	0.231	0.039
3	0.152	0.154	0.153	0.200	0.202	0.201	0.048	0.231	0.233	0.232	0.031
4	0.145	0.154	0.150	0.196	0.194	0.195	0.046	0.225	0.224	0.225	0.030
5	0.135	0.136	0.136	0.191	0.191	0.191	0.056	0.213	0.210	0.212	0.021
6	0.138	0.136	0.137	0.191	0.190	0.191	0.054	0.216	0.212	0.214	0.024
7	0.142	0.147	0.145	0.179	0.181	0.180	0.036	0.200	0.197	0.199	0.019
8	0.143	0.139	0.141	0.175	0.176	0.176	0.035	0.190	0.190	0.190	0.015
9	0.120	0.119	0.120	0.163	0.159	0.161	0.042	0.176	0.174	0.175	0.014
10	0.111	0.109	0.110	0.146	0.144	0.145	0.035	0.165	0.165	0.165	0.020
11	0.107	0.100	0.104	0.131	0.130	0.131	0.027	0.151	0.152	0.152	0.021
12	0.104	0.093	0.099	0.126	0.122	0.124	0.026	0.143	0.143	0.143	0.019
13	0.090	0.083	0.087	0.116	0.116	0.116	0.030	0.136	0.134	0.135	0.019
14	0.089	0.084	0.087	0.113	0.113	0.113	0.027	0.136	0.133	0.135	0.022
15	0.092	0.086	0.089	0.116	0.119	0.118	0.029	0.133	0.133	0.133	0.016
16	0.098	0.094	0.096	0.121	0.123	0.122	0.026	0.145	0.141	0.143	0.021
17	0.098	0.096	0.097	0.123	0.125	0.124	0.027	0.147	0.143	0.145	0.021
18	0.090	0.087	0.089	0.120	0.121	0.121	0.032	0.140	0.142	0.141	0.021
19	0.109	0.112	0.111	0.127	0.127	0.127	0.017	0.146	0.146	0.146	0.019
20	0.093	0.098	0.096	0.132	0.137	0.135	0.039	0.152	0.155	0.154	0.019
21	0.113	0.110	0.112	0.143	0.138	0.141	0.029	0.173	0.173	0.173	0.033
22	0.140	0.123	0.132	0.152	0.145	0.149	0.017	0.187	0.184	0.186	0.037
23	0.136	0.130	0.133	0.156	0.160	0.158	0.025	0.199	0.198	0.199	0.041
24	0.136	0.142	0.139	0.164	0.163	0.164	0.025	0.212	0.214	0.213	0.050
Average	0.120	0.119	0.119	0.195	0.151	0.152	**0.033**	0.178	0.177	0.178	**0.026**

Appendix Table 97: Mixture S1

Mix ID		Mix S 1			Mix Type :						Curing Peroid- 56 day
Mix Id No.	Weight	39.05	lb	Weight	39	lb	0.050	Weight	38.9	lb	0.100
Wear depth (in.) at time (min.)											
Pos.	0 min			30 min				60 Min			
	R1	R2	Average	R1	R2	Average	Difference	R1	R2	Average	Difference
1	0.064	0.064	0.064	0.067	0.068	0.068	0.004	0.075	0.074	0.075	0.007
2	0.065	0.065	0.065	0.069	0.070	0.070	0.005	0.077	0.078	0.078	0.008
3	0.061	0.063	0.062	0.064	0.065	0.065	0.003	0.076	0.076	0.076	0.012
4	0.062	0.063	0.063	0.069	0.071	0.070	0.008	0.076	0.076	0.076	0.006
5	0.064	0.063	0.064	0.068	0.067	0.068	0.004	0.077	0.077	0.077	0.009
6	0.067	0.065	0.066	0.069	0.069	0.069	0.003	0.079	0.081	0.080	0.011
7	0.064	0.064	0.064	0.077	0.077	0.077	0.013	0.079	0.078	0.079	0.002
8	0.071	0.074	0.073	0.078	0.077	0.078	0.005	0.078	0.081	0.080	0.002
9	0.070	0.070	0.070	0.077	0.075	0.076	0.006	0.080	0.080	0.080	0.004
10	0.068	0.067	0.068	0.074	0.072	0.073	0.005	0.076	0.077	0.077	0.004
11	0.064	0.063	0.064	0.071	0.070	0.071	0.007	0.076	0.075	0.076	0.005
12	0.062	0.062	0.062	0.068	0.069	0.069	0.007	0.071	0.072	0.072	0.003
13	0.063	0.063	0.063	0.069	0.068	0.069	0.006	0.071	0.073	0.072	0.003
14	0.062	0.062	0.062	0.067	0.066	0.067	0.005	0.072	0.073	0.073	0.006
15	0.062	0.062	0.062	0.066	0.065	0.066	0.004	0.070	0.072	0.071	0.006
16	0.061	0.061	0.061	0.066	0.065	0.066	0.005	0.071	0.073	0.072	0.006
17	0.061	0.061	0.061	0.065	0.066	0.066	0.005	0.072	0.072	0.072	0.006
18	0.062	0.062	0.062	0.066	0.068	0.067	0.005	0.074	0.073	0.074	0.006
19	0.066	0.066	0.066	0.070	0.066	0.068	0.002	0.077	0.077	0.077	0.009
20	0.063	0.063	0.063	0.066	0.069	0.068	0.005	0.074	0.074	0.074	0.007
21	0.064	0.064	0.064	0.068	0.069	0.069	0.005	0.078	0.078	0.078	0.009
22	0.066	0.066	0.066	0.070	0.068	0.069	0.003	0.075	0.075	0.075	0.006
23	0.063	0.062	0.063	0.066	0.066	0.066	0.004	0.074	0.075	0.075	0.008
24	0.062	0.062	0.062	0.066	0.067	0.067	0.005	0.074	0.075	0.075	0.008
Average	0.064	0.064	0.064	0.069	0.069	0.069	**0.005**	0.075	0.076	0.075	**0.006**

Appendix Table 98: Mixtures S2

Mix ID		Mix S2			Mix Type :						Curing Peroid- 56 day
Mix Id No.	Weight	38.9	lb	Weight	38.8	lb	0.100	Weight	38.75	lb	0.050
Wear depth (in.) at time (min.)											
Pos.	0 min			30 min				60 Min			
	R1	R2	Average	R1	R2	Average	Difference	R1	R2	Average	Difference
1	0.066	0.061	0.064	0.072	0.073	0.073	0.009	0.079	0.079	0.079	0.007
2	0.066	0.064	0.065	0.077	0.079	0.078	0.013	0.085	0.084	0.085	0.007
3	0.069	0.067	0.068	0.082	0.084	0.083	0.015	0.094	0.089	0.092	0.008
4	0.075	0.071	0.073	0.088	0.088	0.088	0.015	0.091	0.092	0.092	0.004
5	0.080	0.079	0.080	0.085	0.088	0.087	0.007	0.097	0.096	0.097	0.010
6	0.080	0.080	0.080	0.084	0.089	0.087	0.006	0.100	0.098	0.099	0.013
7	0.082	0.080	0.081	0.092	0.091	0.092	0.011	0.097	0.098	0.098	0.006
8	0.083	0.081	0.082	0.090	0.089	0.090	0.007	0.100	0.098	0.099	0.010
9	0.075	0.071	0.073	0.084	0.081	0.083	0.010	0.088	0.089	0.089	0.006
10	0.069	0.067	0.068	0.080	0.079	0.080	0.012	0.086	0.086	0.086	0.006
11	0.060	0.060	0.060	0.073	0.072	0.073	0.013	0.079	0.080	0.080	0.007
12	0.061	0.060	0.061	0.070	0.072	0.071	0.011	0.076	0.078	0.077	0.006
13	0.062	0.061	0.062	0.071	0.070	0.071	0.009	0.077	0.078	0.078	0.007
14	0.063	0.063	0.063	0.073	0.072	0.073	0.009	0.081	0.079	0.080	0.008
15	0.067	0.066	0.067	0.076	0.075	0.076	0.009	0.082	0.081	0.082	0.006
16	0.071	0.071	0.071	0.080	0.081	0.081	0.010	0.087	0.087	0.087	0.006
17	0.076	0.076	0.076	0.080	0.081	0.081	0.005	0.087	0.087	0.087	0.006
18	0.072	0.073	0.073	0.081	0.080	0.081	0.008	0.085	0.084	0.085	0.004
19	0.075	0.074	0.075	0.079	0.081	0.080	0.006	0.085	0.085	0.085	0.005
20	0.074	0.073	0.074	0.076	0.077	0.077	0.003	0.082	0.080	0.081	0.005
21	0.073	0.072	0.073	0.074	0.076	0.075	0.003	0.081	0.080	0.081	0.006
22	0.068	0.068	0.068	0.069	0.070	0.070	0.002	0.077	0.077	0.077	0.007
23	0.063	0.062	0.063	0.067	0.068	0.068	0.005	0.076	0.076	0.076	0.008
24	0.062	0.062	0.062	0.067	0.067	0.067	0.005	0.075	0.075	0.075	0.008
Average	0.071	0.069	0.070	0.078	0.078	0.078	**0.008**	0.085	0.085	0.085	**0.007**

Appendix Table 99: Mixture T1

Mix ID		Mix T 1			Mix Type :						Curing Peroid- 56 day
Mix Id No.	Weight	36.15	lb	Weight	35.9	lb	0.250	Weight	35.75	lb	0.150
Wear depth (in.) at time (min.)											
Pos.	0 min			30 min				60 Min			
	R1	R2	Average	R1	R2	Average	Difference	R1	R2	Average	Difference
1	0.092	0.086	0.089	0.128	0.128	0.128	0.039	0.159	0.155	0.157	0.029
2	0.091	0.084	0.088	0.131	0.134	0.133	0.045	0.153	0.150	0.152	0.019
3	0.100	0.094	0.097	0.129	0.130	0.130	0.033	0.154	0.152	0.153	0.024
4	0.082	0.083	0.083	0.136	0.138	0.137	0.055	0.165	0.162	0.164	0.027
5	0.079	0.083	0.081	0.144	0.146	0.145	0.064	0.171	0.169	0.170	0.025
6	0.081	0.085	0.083	0.149	0.148	0.149	0.066	0.169	0.179	0.174	0.026
7	0.088	0.089	0.089	0.148	0.149	0.149	0.060	0.179	0.175	0.177	0.029
8	0.089	0.089	0.089	0.143	0.143	0.143	0.054	0.175	0.172	0.174	0.031
9	0.082	0.083	0.083	0.138	0.137	0.138	0.055	0.171	0.172	0.172	0.034
10	0.083	0.084	0.084	0.136	0.136	0.136	0.053	0.171	0.164	0.168	0.032
11	0.079	0.077	0.078	0.139	0.139	0.139	0.061	0.162	0.162	0.162	0.023
12	0.073	0.073	0.073	0.137	0.138	0.138	0.065	0.164	0.167	0.166	0.028
13	0.077	0.077	0.077	0.133	0.134	0.134	0.057	0.156	0.155	0.156	0.022
14	0.073	0.072	0.073	0.124	0.131	0.128	0.055	0.156	0.156	0.156	0.029
15	0.081	0.081	0.081	0.137	0.136	0.137	0.056	0.163	0.162	0.163	0.026
16	0.086	0.086	0.086	0.145	0.139	0.142	0.056	0.162	0.164	0.163	0.021
17	0.087	0.086	0.087	0.143	0.143	0.143	0.057	0.167	0.169	0.168	0.025
18	0.086	0.088	0.087	0.148	0.145	0.147	0.060	0.168	0.166	0.167	0.021
19	0.084	0.084	0.084	0.140	0.131	0.136	0.052	0.159	0.160	0.160	0.024
20	0.084	0.084	0.084	0.147	0.139	0.143	0.059	0.157	0.158	0.158	0.015
21	0.084	0.081	0.083	0.142	0.133	0.138	0.055	0.155	0.156	0.156	0.018
22	0.086	0.087	0.087	0.137	0.129	0.133	0.047	0.151	0.153	0.152	0.019
23	0.078	0.079	0.079	0.141	0.131	0.136	0.058	0.152	0.154	0.153	0.017
24	0.086	0.086	0.086	0.134	0.127	0.131	0.045	0.148	0.150	0.149	0.019
Average	0.084	0.083	0.084	0.139	0.137	0.138	**0.054**	0.162	0.162	0.162	**0.024**

Appendix Table 100: Mixture T2

Mix ID		Mix T 2			Mix Type :						Curing Peroid- 56 day
Mix Id No.	Weight	36.15	lb	Weight	35.95	lb	0.200	Weight	35.85	lb	0.100
Wear depth (in.) at time (min.)											
Pos.	0 min			30 min				60 Min			
	R1	R2	Average	R1	R2	Average	Difference	R1	R2	Average	Difference
1	0.071	0.069	0.070	0.113	0.110	0.112	0.042	0.123	0.123	0.123	0.012
2	0.068	0.068	0.068	0.113	0.109	0.111	0.043	0.119	0.118	0.119	0.007
3	0.068	0.068	0.068	0.112	0.108	0.110	0.042	0.119	0.119	0.119	0.009
4	0.069	0.065	0.067	0.100	0.096	0.098	0.031	0.113	0.113	0.113	0.015
5	0.062	0.062	0.062	0.107	0.099	0.103	0.041	0.112	0.113	0.113	0.009
6	0.062	0.059	0.061	0.096	0.095	0.096	0.035	0.114	0.116	0.115	0.020
7	0.066	0.065	0.066	0.089	0.091	0.090	0.025	0.114	0.112	0.113	0.023
8	0.064	0.064	0.064	0.094	0.094	0.094	0.030	0.116	0.117	0.117	0.023
9	0.065	0.065	0.065	0.092	0.089	0.091	0.026	0.112	0.112	0.112	0.022
10	0.063	0.063	0.063	0.095	0.093	0.094	0.031	0.111	0.111	0.111	0.017
11	0.064	0.066	0.065	0.099	0.092	0.096	0.031	0.114	0.115	0.115	0.019
12	0.063	0.064	0.064	0.091	0.089	0.090	0.027	0.112	0.112	0.112	0.022
13	0.067	0.067	0.067	0.096	0.096	0.096	0.029	0.113	0.113	0.113	0.017
14	0.066	0.066	0.066	0.099	0.099	0.099	0.033	0.116	0.116	0.116	0.017
15	0.070	0.070	0.070	0.102	0.102	0.102	0.032	0.122	0.122	0.122	0.020
16	0.070	0.069	0.070	0.106	0.105	0.106	0.036	0.120	0.120	0.120	0.015
17	0.070	0.069	0.070	0.112	0.113	0.113	0.043	0.121	0.121	0.121	0.008
18	0.069	0.068	0.069	0.112	0.111	0.112	0.043	0.124	0.123	0.124	0.012
19	0.073	0.072	0.073	0.110	0.110	0.110	0.038	0.123	0.122	0.123	0.013
20	0.074	0.073	0.074	0.114	0.114	0.114	0.041	0.127	0.127	0.127	0.013
21	0.074	0.075	0.075	0.114	0.114	0.114	0.040	0.127	0.127	0.127	0.013
22	0.074	0.074	0.074	0.112	0.112	0.112	0.038	0.131	0.130	0.131	0.019
23	0.069	0.068	0.069	0.112	0.112	0.112	0.044	0.132	0.132	0.132	0.020
24	0.069	0.067	0.068	0.111	0.111	0.111	0.043	0.131	0.130	0.131	0.020
Average	0.068	0.067	0.068	0.104	0.103	0.103	**0.036**	0.119	0.119	0.119	**0.016**

9.6 Appendix F

S-Plus Data Output- t-test

Compressive Strength

```
      Pooled-Variance
Two-Sample t-Test

data:  x: A in data ,
and y: Con in data
t = 5.3548, df = 4, p-
value = 0.0029
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 1011.561       NA
sample estimates:
 mean of x mean of y
  9540.226   7859.57


      Pooled-Variance
Two-Sample t-Test

data:  x: B in data ,
and y: Con in data
t = 4.7189, df = 4, p-
value = 0.0046
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 1010.572       NA
sample estimates:
 mean of x mean of y
  9702.889   7859.57


      Pooled-Variance
Two-Sample t-Test

data:  x: C in data ,
and y: Con in data
t = -7.1044, df = 4,
p-value = 0.999
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -2735.706       NA
sample estimates:
 mean of x mean of y
  5755.302   7859.57


      Pooled-Variance
Two-Sample t-Test

data:  x: D in data ,
and y: Con in data
t = 2.8693, df = 4, p-
value = 0.0228
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 247.6497       NA
sample estimates:
 mean of x mean of y
  8823.164   7859.57


      Pooled-Variance
Two-Sample t-Test

data:  x: E in data ,
and y: Con in data
t = 8.5246, df = 4, p-
value = 0.0005
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 2117.467       NA
sample estimates:
 mean of x mean of y
  10683.16   7859.57


      Pooled-Variance
Two-Sample t-Test

data:  x: S in data ,
and y: Con in data
t = 21.4301, df = 4,
p-value = 0
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 5165.584       NA
sample estimates:
 mean of x mean of y
  13595.79   7859.57


      Pooled-Variance
Two-Sample t-Test

data:  x: T in data ,
and y: Con in data
t = 9.2041, df = 4, p-
value = 0.0004
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 1980.11      NA
sample estimates:
 mean of x mean of y
  10436.56   7859.57


      Pooled-Variance
Two-Sample t-Test

data:  x: B in data ,
and y: A in data
t = 0.4644, df = 4, p-
value = 0.3333
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -584.0544       NA
sample estimates:
 mean of x mean of y
  9702.889  9540.226


      Pooled-Variance
Two-Sample t-Test

data:  x: C in data ,
and y: A in data
t = -15.7389, df = 4,
p-value = 1
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -4297.596       NA
sample estimates:
 mean of x mean of y
  5755.302  9540.226


      Pooled-Variance
Two-Sample t-Test

data:  x: E in data ,
and y: A in data
t = 4.0456, df = 4, p-
value = 0.0078
```

```
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 540.6642       NA
sample estimates:
 mean of x mean of y
  10683.16  9540.226


      Pooled-Variance
Two-Sample t-Test

data:  x: S in data ,
and y: A in data
t = 19.8485, df = 4,
p-value = 0
alternative
hypothesis:
difference in means is
not equal to 0
95 percent confidence
interval:
 3488.261 4622.861
sample estimates:
 mean of x mean of y
  13595.79  9540.226


      Pooled-Variance
Two-Sample t-Test

data:  x: T in data ,
and y: A in data
t = 4.0704, df = 4, p-
value = 0.0152
alternative
hypothesis:
difference in means is
not equal to 0
95 percent confidence
interval:
  284.9361 1507.7332
sample estimates:
 mean of x mean of y
  10436.56  9540.226


      Pooled-Variance
Two-Sample t-Test

data:  x: C in data ,
and y: B in data
t = -11.8003, df = 4,
p-value = 0.0003
alternative
hypothesis:
difference in means is
not equal to 0
95 percent confidence
interval:
 -4876.395 -3018.778
sample estimates:
 mean of x mean of y
  5755.302  9702.889


      Pooled-Variance
Two-Sample t-Test

data:  x: D in data ,
and y: B in data
t = -2.3771, df = 4,
p-value = 0.0762
alternative
hypothesis:
difference in means is
not equal to 0
95 percent confidence
interval:
 -1907.2523   147.8027
sample estimates:
 mean of x mean of y
  8823.164  9702.889


      Pooled-Variance
Two-Sample t-Test

data:  x: E in data ,
and y: B in data
t = 2.679, df = 4, p-
value = 0.0553
alternative
hypothesis:
difference in means is
not equal to 0
95 percent confidence
interval:
   -35.66393
1996.21182
sample estimates:
 mean of x mean of y
  10683.16  9702.889


      Pooled-Variance
Two-Sample t-Test

data:  x: S in data ,
and y: B in data
t = 12.5755, df = 4,
p-value = 0.0002
alternative
hypothesis:
difference in means is
not equal to 0
95 percent confidence
interval:
 3033.416 4752.380
sample estimates:
 mean of x mean of y
  13595.79  9702.889


      Pooled-Variance
Two-Sample t-Test

data:  x: T in data ,
and y: B in data
t = 2.2908, df = 4, p-
value = 0.0838
alternative
hypothesis:
difference in means is
not equal to 0
95 percent confidence
interval:
  -155.534  1622.878
sample estimates:
 mean of x mean of y
  10436.56  9702.889


      Pooled-Variance
Two-Sample t-Test

data:  x: D in data ,
and y: C in data
t = 11.4246, df = 4,
p-value = 0.0003
alternative
hypothesis:
difference in means is
not equal to 0
95 percent confidence
interval:
 2322.299 3813.425
sample estimates:
 mean of x mean of y
  8823.164  5755.302


      Pooled-Variance
Two-Sample t-Test

data:  x: E in data ,
and y: C in data
t = 18.755, df = 4, p-
value = 0
alternative
hypothesis:
difference in means is
not equal to 0
95 percent confidence
interval:
 4198.353 5657.369
sample estimates:
 mean of x mean of y
  10683.16  5755.302
```

```
      Pooled-Variance
Two-Sample t-Test

data:  x: S in data ,
and y: C in data
t = 44.5503, df = 4,
p-value = 0
alternative
hypothesis:
difference in means is
not equal to 0
95 percent confidence
interval:
 7351.853 8329.117
sample estimates:
 mean of x mean of y
  13595.79  5755.302


      Pooled-Variance
Two-Sample t-Test

data:  x: T in data ,
and y: C in data
t = 24.1046, df = 4,
p-value = 0
alternative
hypothesis:
difference in means is
not equal to 0
95 percent confidence
interval:
 4142.056 5220.462
sample estimates:
 mean of x mean of y
  10436.56  5755.302


      Pooled-Variance
Two-Sample t-Test

data:  x: E in data ,
and y: D in data
t = 6.0637, df = 4, p-
value = 0.0037
alternative
hypothesis:
difference in means is
not equal to 0
95 percent confidence
interval:
 1008.348 2711.650
sample estimates:
 mean of x mean of y
  10683.16  8823.164


      Pooled-Variance
Two-Sample t-Test

data:  x: S in data ,
and y: D in data
t = 20.1632, df = 4,
p-value = 0
alternative
hypothesis:
difference in means is
not equal to 0
95 percent confidence
interval:
 4115.441 5429.805
sample estimates:
 mean of x mean of y
  13595.79  8823.164


      Pooled-Variance
Two-Sample t-Test

data:  x: T in data ,
and y: D in data
t = 6.4397, df = 4, p-
value = 0.003
alternative
hypothesis:
difference in means is
not equal to 0
95 percent confidence
interval:
  917.7914 2309.0025
sample estimates:
 mean of x mean of y
  10436.56  8823.164


      Pooled-Variance
Two-Sample t-Test

data:  x: S in data ,
and y: E in data
t = 12.6571, df = 4,
p-value = 0.0002
alternative
hypothesis:
difference in means is
not equal to 0
95 percent confidence
interval:
 2273.715 3551.534
sample estimates:
 mean of x mean of y
  13595.79  10683.16


      Pooled-Variance
Two-Sample t-Test

data:  x: E in data ,
and y: T in data
t = 1.0093, df = 4, p-
value = 0.3699
alternative
hypothesis:
difference in means is
not equal to 0
95 percent confidence
interval:
 -431.7669  924.9705
sample estimates:
 mean of x mean of y
  10683.16  10436.56


      Pooled-Variance
Two-Sample t-Test

data:  x: T in data ,
and y: S in data
t = -21.4793, df = 4,
p-value = 0
alternative
hypothesis:
difference in means is
not equal to 0
95 percent confidence
interval:
 -3567.593 -2750.860
sample estimates:
 mean of x mean of y
  10436.56  13595.79
```

Chloride Test Phase I

```
      Pooled-Variance
Two-Sample t-Test

data:     x:   CW   in
data.analysis.chloride
.test.st.I  ,  and  y:
CSA                 in
data.analysis.chloride
.test.st.I
t = -16.4308, df = 6,
p-value = 1
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -2845.66      NA
sample estimates:
 mean of x mean of y
  1709.039   4253.75


      Pooled-Variance
Two-Sample t-Test
```

```
data: x: CW in
data.analysis.chloride
.test.st.I , and y:
CSB in
data.analysis.chloride
.test.st.I
t = -10.9124, df = 6,
p-value = 1
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -3192.232        NA
sample estimates:
 mean of x mean of y
  1709.039   4418.75


      Pooled-Variance
Two-Sample t-Test

data: x: CW in
data.analysis.chloride
.test.st.I , and y:
EAW in
data.analysis.chloride
.test.st.I
t = 5.4178, df = 6, p-
value = 0.0008
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 375.3799       NA
sample estimates:
 mean of x mean of y
  1709.039   1123.73


      Pooled-Variance
Two-Sample t-Test

data: x: CW in
data.analysis.chloride
.test.st.I , and y:
EASA in
data.analysis.chloride
.test.st.I
t = -1.9812, df = 6,
p-value = 0.9526
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -797.825       NA
sample estimates:
 mean of x mean of y
  1709.039  2111.812


      Pooled-Variance
Two-Sample t-Test

data: x: CW in
data.analysis.chloride
.test.st.I , and y:
EASB in
data.analysis.chloride
.test.st.I
t = -1.1574, df = 6,
p-value = 0.8545
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -569.3478        NA
sample estimates:
 mean of x mean of y
  1709.039  1921.572


      Pooled-Variance
Two-Sample t-Test

data: x: CW in
data.analysis.chloride
.test.st.I , and y:
EBW in
data.analysis.chloride
.test.st.I
t = 6.7831, df = 6, p-
value = 0.0003
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 469.8857       NA
sample estimates:
 mean of x mean of y
  1709.039    1050.5


      Pooled-Variance
Two-Sample t-Test

data: x: CW in
data.analysis.chloride
.test.st.I , and y:
EBSA in
data.analysis.chloride
.test.st.I
t = -2.9037, df = 6,
p-value = 0.9864
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -559.1175        NA
sample estimates:
 mean of x mean of y
  1709.039      2044


      Pooled-Variance
Two-Sample t-Test

data: x: CW in
data.analysis.chloride
.test.st.I , and y:
EBSB in
data.analysis.chloride
.test.st.I
t = -2.5224, df = 6,
p-value = 0.9774
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -1068.344        NA
sample estimates:
 mean of x mean of y
  1709.039    2312.5


      Pooled-Variance
Two-Sample t-Test

data: x: CW in
data.analysis.chloride
.test.st.I , and y:
ECW in
data.analysis.chloride
.test.st.I
t = 7.2088, df = 6, p-
value = 0.0002
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 550.4949       NA
sample estimates:
 mean of x mean of y
  1709.039  955.3936


      Pooled-Variance
Two-Sample t-Test

data: x: CW in
data.analysis.chloride
.test.st.I , and y:
ECSA in
```

```
data.analysis.chloride
.test.st.I
t = -6.1595, df = 6,
p-value = 0.9996
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -1738.68       NA
sample estimates:
 mean of x mean of y
  1709.039   3030.75


      Pooled-Variance
Two-Sample t-Test

data:     x:  CW  in
data.analysis.chloride
.test.st.I  ,  and  y:
ECSB                in
data.analysis.chloride
.test.st.I
t = -9.6884, df = 6,
p-value = 1
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -4717.284       NA
sample estimates:
 mean of x mean of y
  1709.039   5638.25


      Pooled-Variance
Two-Sample t-Test

data:     x:  CW  in
data.analysis.chloride
.test.st.I  ,  and  y:
EDW                 in
data.analysis.chloride
.test.st.I
t = 9.355, df = 6, p-
value = 0
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 810.3405       NA
sample estimates:
 mean of x mean of y
  1709.039    686.25

      Pooled-Variance
Two-Sample t-Test

data:     x:  CW  in
data.analysis.chloride
.test.st.I  ,  and  y:
EDSA                in
data.analysis.chloride
.test.st.I
t = -8.1104, df = 6,
p-value = 0.9999
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -2301.875       NA
sample estimates:
 mean of x mean of y
  1709.039      3566


      Pooled-Variance
Two-Sample t-Test

data:     x:  CW  in
data.analysis.chloride
.test.st.I  ,  and  y:
EDSB                in
data.analysis.chloride
.test.st.I
t = -11.916, df = 6,
p-value = 1
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -2950.38       NA
sample estimates:
 mean of x mean of y
  1709.039   4245.75


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSA  in
data.analysis.chloride
.test.st.I  ,  and  y:
CSB                 in
data.analysis.chloride
.test.st.I
t = -0.6333, df = 6,
p-value = 0.725
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -671.2856       NA
sample estimates:
 mean of x mean of y
   4253.75   4418.75


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSA  in
data.analysis.chloride
.test.st.I  ,  and  y:
EAW                 in
data.analysis.chloride
.test.st.I
t = 23.3984, df = 6,
p-value = 0
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 2870.079       NA
sample estimates:
 mean of x mean of y
   4253.75   1123.73


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSA  in
data.analysis.chloride
.test.st.I  ,  and  y:
EASA                in
data.analysis.chloride
.test.st.I
t = 9.8222, df = 6, p-
value = 0
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 1718.187       NA
sample estimates:
 mean of x mean of y
   4253.75  2111.812


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSA  in
data.analysis.chloride
.test.st.I  ,  and  y:
EASB                in
data.analysis.chloride
.test.st.I
t = 11.6695, df = 6,
p-value = 0
```

```
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 1943.828       NA
sample estimates:
 mean of x mean of y
   4253.75  1921.572


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSA  in
data.analysis.chloride
.test.st.I  ,  and  y:
EBW                 in
data.analysis.chloride
.test.st.I
t = 25.6065, df = 6,
p-value = 0
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 2960.167       NA
sample estimates:
 mean of x mean of y
   4253.75    1050.5


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSA  in
data.analysis.chloride
.test.st.I  ,  and  y:
EBSA                in
data.analysis.chloride
.test.st.I
t = 15.8121, df = 6,
p-value = 0
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 1938.189       NA
sample estimates:
 mean of x mean of y
   4253.75      2044


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSA  in
data.analysis.chloride
.test.st.I  ,  and  y:
EBSB                in
data.analysis.chloride
.test.st.I
t = 7.7062, df = 6, p-
value = 0.0001
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 1451.745       NA
sample estimates:
 mean of x mean of y
   4253.75    2312.5


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSA  in
data.analysis.chloride
.test.st.I  ,  and  y:
ECW                 in
data.analysis.chloride
.test.st.I
t = 25.1841, df = 6,
p-value = 0
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 3043.859       NA
sample estimates:
 mean of x mean of y
   4253.75  955.3936


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSA  in
data.analysis.chloride
.test.st.I  ,  and  y:
ECSA                in
data.analysis.chloride
.test.st.I
t = 5.3494, df = 6, p-
value = 0.0009
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 778.7451       NA
sample estimates:
 mean of x mean of y
   4253.75   3030.75


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSA  in
data.analysis.chloride
.test.st.I  ,  and  y:
ECSB                in
data.analysis.chloride
.test.st.I
t = -3.351, df = 6, p-
value = 0.9923
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -2187.343       NA
sample estimates:
 mean of x mean of y
   4253.75   5638.25


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSA  in
data.analysis.chloride
.test.st.I  ,  and  y:
EDW                 in
data.analysis.chloride
.test.st.I
t = 26.4612, df = 6,
p-value = 0
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 3305.52      NA
sample estimates:
 mean of x mean of y
   4253.75    686.25


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSA  in
data.analysis.chloride
.test.st.I  ,  and  y:
EDSA                in
data.analysis.chloride
.test.st.I
t = 2.8399, df = 6, p-
value = 0.0148
alternative
hypothesis:
difference in means is
greater than 0
```

95 percent confidence interval:
 217.1677 NA
sample estimates:
 mean of x mean of y
 4253.75 3566

Pooled-Variance Two-Sample t-Test

data: x: CSA in data.analysis.chloride .test.st.I , and y: EDSB in data.analysis.chloride .test.st.I
t = 0.0352, df = 6, p-value = 0.4865
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -433.1588 NA
sample estimates:
 mean of x mean of y
 4253.75 4245.75

Pooled-Variance Two-Sample t-Test

data: x: CSB in data.analysis.chloride .test.st.I , and y: EAW in data.analysis.chloride .test.st.I
t = 13.9779, df = 6, p-value = 0
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 2836.953 NA
sample estimates:
 mean of x mean of y
 4418.75 1123.73

Pooled-Variance Two-Sample t-Test

data: x: CSB in data.analysis.chloride .test.st.I , and y: EASA in data.analysis.chloride .test.st.I
t = 7.9021, df = 6, p-value = 0.0001
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 1739.646 NA
sample estimates:
 mean of x mean of y
 4418.75 2111.812

Pooled-Variance Two-Sample t-Test

data: x: CSB in data.analysis.chloride .test.st.I , and y: EASB in data.analysis.chloride .test.st.I
t = 8.9635, df = 6, p-value = 0.0001
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 1955.817 NA
sample estimates:
 mean of x mean of y
 4418.75 1921.572

Pooled-Variance Two-Sample t-Test

data: x: CSB in data.analysis.chloride .test.st.I , and y: EBW in data.analysis.chloride .test.st.I
t = 14.5864, df = 6, p-value = 0
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 2919.535 NA
sample estimates:
 mean of x mean of y
 4418.75 1050.5

Pooled-Variance Two-Sample t-Test

data: x: CSB in data.analysis.chloride .test.st.I , and y: EBSA in data.analysis.chloride .test.st.I
t = 9.9289, df = 6, p-value = 0
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 1909.991 NA
sample estimates:
 mean of x mean of y
 4418.75 2044

Pooled-Variance Two-Sample t-Test

data: x: CSB in data.analysis.chloride .test.st.I , and y: EBSB in data.analysis.chloride .test.st.I
t = 6.6232, df = 6, p-value = 0.0003
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 1488.293 NA
sample estimates:
 mean of x mean of y
 4418.75 2312.5

Pooled-Variance Two-Sample t-Test

data: x: CSB in data.analysis.chloride .test.st.I , and y: ECW in data.analysis.chloride .test.st.I
t = 14.791, df = 6, p-value = 0
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 3008.357 NA
sample estimates:
 mean of x mean of y

4418.75 955.3936

Pooled-Variance Two-Sample t-Test

data: x: CSB in data.analysis.chloride .test.st.I , and y: ECSA in data.analysis.chloride .test.st.I
t = 4.6281, df = 6, p-value = 0.0018
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
805.2323 NA
sample estimates:
mean of x mean of y
4418.75 3030.75

Pooled-Variance Two-Sample t-Test

data: x: CSB in data.analysis.chloride .test.st.I , and y: ECSB in data.analysis.chloride .test.st.I
t = -2.6715, df = 6, p-value = 0.9815
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
-2106.525 NA
sample estimates:
mean of x mean of y
4418.75 5638.25

Pooled-Variance Two-Sample t-Test

data: x: CSB in data.analysis.chloride .test.st.I , and y: EDW in data.analysis.chloride .test.st.I
t = 15.7938, df = 6, p-value = 0
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
3273.273 NA
sample estimates:
mean of x mean of y
4418.75 686.25

Pooled-Variance Two-Sample t-Test

data: x: CSB in data.analysis.chloride .test.st.I , and y: EDSA in data.analysis.chloride .test.st.I
t = 2.7476, df = 6, p-value = 0.0167
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
249.6717 NA
sample estimates:
mean of x mean of y
4418.75 3566

Pooled-Variance Two-Sample t-Test

data: x: CSB in data.analysis.chloride .test.st.I , and y: EDSB in data.analysis.chloride .test.st.I
t = 0.5792, df = 6, p-value = 0.2918
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
-407.4109 NA
sample estimates:
mean of x mean of y
4418.75 4245.75

Pooled-Variance Two-Sample t-Test

data: x: EAW in data.analysis.chloride .test.st.I , and y: EASA in data.analysis.chloride .test.st.I
t = -5.2635, df = 6, p-value = 0.9991
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
-1352.862 NA
sample estimates:
mean of x mean of y
1123.73 2111.812

Pooled-Variance Two-Sample t-Test

data: x: EAW in data.analysis.chloride .test.st.I , and y: EASB in data.analysis.chloride .test.st.I
t = -4.8002, df = 6, p-value = 0.9985
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
-1120.821 NA
sample estimates:
mean of x mean of y
1123.73 1921.572

Pooled-Variance Two-Sample t-Test

data: x: EAW in data.analysis.chloride .test.st.I , and y: EBW in data.analysis.chloride .test.st.I
t = 1.2683, df = 6, p-value = 0.1258
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
-38.96984 NA
sample estimates:
mean of x mean of y
1123.73 1050.5

```
      Pooled-Variance
Two-Sample t-Test

data:     x:  EAW  in
data.analysis.chloride
.test.st.I  ,  and  y:
EBSA                in
data.analysis.chloride
.test.st.I
t = -10.8339, df = 6,
p-value = 1
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -1085.33       NA
sample estimates:
 mean of x mean of y
   1123.73      2044


      Pooled-Variance
Two-Sample t-Test

data:     x:  EAW  in
data.analysis.chloride
.test.st.I  ,  and  y:
EBSB                in
data.analysis.chloride
.test.st.I
t = -5.2566, df = 6,
p-value = 0.999
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -1628.218       NA
sample estimates:
 mean of x mean of y
   1123.73    2312.5


      Pooled-Variance
Two-Sample t-Test

data:     x:  EAW  in
data.analysis.chloride
.test.st.I  ,  and  y:
ECW                 in
data.analysis.chloride
.test.st.I
t = 2.4201, df = 6, p-
value = 0.0259
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 33.17418       NA
sample estimates:
 mean of x mean of y
   1123.73  955.3936


      Pooled-Variance
Two-Sample t-Test

data:     x:  EAW  in
data.analysis.chloride
.test.st.I  ,  and  y:
ECSA                in
data.analysis.chloride
.test.st.I
t = -9.5407, df = 6,
p-value = 1
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -2295.429       NA
sample estimates:
 mean of x mean of y
   1123.73   3030.75


      Pooled-Variance
Two-Sample t-Test

data:     x:  EAW  in
data.analysis.chloride
.test.st.I  ,  and  y:
ECSB                in
data.analysis.chloride
.test.st.I
t = -11.3437, df = 6,
p-value = 1
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -5287.861       NA
sample estimates:
 mean of x mean of y
   1123.73   5638.25


      Pooled-Variance
Two-Sample t-Test

data:     x:  EAW  in
data.analysis.chloride
.test.st.I  ,  and  y:
EDW                 in
data.analysis.chloride
.test.st.I
t = 5.7141, df = 6, p-
value = 0.0006
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 288.7082       NA
sample estimates:
 mean of x mean of y
   1123.73    686.25


      Pooled-Variance
Two-Sample t-Test

data:     x:  EAW  in
data.analysis.chloride
.test.st.I  ,  and  y:
EDSA                in
data.analysis.chloride
.test.st.I
t = -11.3463, df = 6,
p-value = 1
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -2860.537       NA
sample estimates:
 mean of x mean of y
   1123.73      3566


      Pooled-Variance
Two-Sample t-Test

data:     x:  EAW  in
data.analysis.chloride
.test.st.I  ,  and  y:
EDSB                in
data.analysis.chloride
.test.st.I
t = -15.7631, df = 6,
p-value = 1
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -3506.884       NA
sample estimates:
 mean of x mean of y
   1123.73   4245.75


      Pooled-Variance
Two-Sample t-Test

data:    x:  EASA  in
data.analysis.chloride
```

```
.test.st.I  ,  and  y:
EASB                in
data.analysis.chloride
.test.st.I
t = 0.7948, df = 6, p-
value = 0.2285
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 -274.8535        NA
sample estimates:
 mean of x mean of y
  2111.812  1921.572


      Pooled-Variance
Two-Sample t-Test

data:    x:  EASA  in
data.analysis.chloride
.test.st.I  ,  and  y:
EBW                 in
data.analysis.chloride
.test.st.I
t = 5.8428, df = 6, p-
value = 0.0006
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 708.3458       NA
sample estimates:
 mean of x mean of y
  2111.812    1050.5


      Pooled-Variance
Two-Sample t-Test

data:    x:  EASA  in
data.analysis.chloride
.test.st.I  ,  and  y:
EBSA                in
data.analysis.chloride
.test.st.I
t = 0.3531, df = 6, p-
value = 0.368
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 -305.3384        NA
sample estimates:
 mean of x mean of y
  2111.812      2044


      Pooled-Variance
Two-Sample t-Test

data:    x:  EASA  in
data.analysis.chloride
.test.st.I  ,  and  y:
EBSB                in
data.analysis.chloride
.test.st.I
t = -0.706, df = 6, p-
value = 0.7467
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 -753.0564        NA
sample estimates:
 mean of x mean of y
  2111.812    2312.5


      Pooled-Variance
Two-Sample t-Test

data:    x:  EASA  in
data.analysis.chloride
.test.st.I  ,  and  y:
ECW                 in
data.analysis.chloride
.test.st.I
t = 6.2261, df = 6, p-
value = 0.0004
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 795.4957       NA
sample estimates:
 mean of x mean of y
  2111.812  955.3936


      Pooled-Variance
Two-Sample t-Test

data:    x:  EASA  in
data.analysis.chloride
.test.st.I  ,  and  y:
ECSA                in
data.analysis.chloride
.test.st.I
t  =  -3.4829,  df  =  6,
p-value = 0.9935
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 -1431.635        NA
sample estimates:
 mean of x mean of y
  2111.812   3030.75


      Pooled-Variance
Two-Sample t-Test

data:    x:  EASA  in
data.analysis.chloride
.test.st.I  ,  and  y:
ECSB                in
data.analysis.chloride
.test.st.I
t  =  -8.1321,  df  =  6,
p-value = 0.9999
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 -4369.085        NA
sample estimates:
 mean of x mean of y
  2111.812   5638.25


      Pooled-Variance
Two-Sample t-Test

data:    x:  EASA  in
data.analysis.chloride
.test.st.I  ,  and  y:
EDW                 in
data.analysis.chloride
.test.st.I
t = 7.5638, df = 6, p-
value = 0.0001
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 1059.325       NA
sample estimates:
 mean of x mean of y
  2111.812    686.25


      Pooled-Variance
Two-Sample t-Test

data:    x:  EASA  in
data.analysis.chloride
.test.st.I  ,  and  y:
EDSA                in
data.analysis.chloride
.test.st.I
```

```
t = -5.2752, df = 6,
p-value = 0.9991
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -1989.859        NA
sample estimates:
 mean of x mean of y
  2111.812      3566


      Pooled-Variance
Two-Sample t-Test

data:    x:  EASA  in
data.analysis.chloride
.test.st.I  ,  and  y:
EDSB                in
data.analysis.chloride
.test.st.I
t = -8.1304, df = 6,
p-value = 0.9999
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -2643.955        NA
sample estimates:
 mean of x mean of y
  2111.812   4245.75


      Pooled-Variance
Two-Sample t-Test

data:    x:  EASB  in
data.analysis.chloride
.test.st.I  ,  and  y:
EBW                 in
data.analysis.chloride
.test.st.I
t = 5.4677, df = 6, p-
value = 0.0008
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 561.4995       NA
sample estimates:
 mean of x mean of y
  1921.572    1050.5


      Pooled-Variance
Two-Sample t-Test

data:    x:  EASB  in
data.analysis.chloride
.test.st.I  ,  and  y:
EBSA                in
data.analysis.chloride
.test.st.I
t = -0.7157, df = 6,
p-value = 0.7495
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -454.8301        NA
sample estimates:
 mean of x mean of y
  1921.572      2044


      Pooled-Variance
Two-Sample t-Test

data:    x:  EASB  in
data.analysis.chloride
.test.st.I  ,  and  y:
EBSB                in
data.analysis.chloride
.test.st.I
t = -1.445, df = 6, p-
value = 0.9007
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -916.6281        NA
sample estimates:
 mean of x mean of y
  1921.572    2312.5


      Pooled-Variance
Two-Sample t-Test

data:    x:  EASB  in
data.analysis.chloride
.test.st.I  ,  and  y:
ECW                 in
data.analysis.chloride
.test.st.I
t = 5.8926, df = 6, p-
value = 0.0005
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 647.564      NA
sample estimates:
 mean of x mean of y
  1921.572  955.3936


      Pooled-Variance
Two-Sample t-Test

data:    x:  EASB  in
data.analysis.chloride
.test.st.I  ,  and  y:
ECSA                in
data.analysis.chloride
.test.st.I
t = -4.4546, df = 6,
p-value = 0.9978
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -1593.025        NA
sample estimates:
 mean of x mean of y
  1921.572   3030.75


      Pooled-Variance
Two-Sample t-Test

data:    x:  EASB  in
data.analysis.chloride
.test.st.I  ,  and  y:
ECSB                in
data.analysis.chloride
.test.st.I
t = -8.7498, df = 6,
p-value = 0.9999
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -4542.089        NA
sample estimates:
 mean of x mean of y
  1921.572   5638.25


      Pooled-Variance
Two-Sample t-Test

data:    x:  EASB  in
data.analysis.chloride
.test.st.I  ,  and  y:
EDW                 in
data.analysis.chloride
.test.st.I
t = 7.3946, df = 6, p-
value = 0.0002
alternative
hypothesis:
```

```
difference in means is
greater than 0
95 percent confidence
interval:
 910.7001       NA
sample estimates:
 mean of x mean of y
  1921.572    686.25


      Pooled-Variance
Two-Sample t-Test

data:    x:  EASB  in
data.analysis.chloride
.test.st.I  ,  and  y:
EDSA                in
data.analysis.chloride
.test.st.I
t = -6.2886, df = 6,
p-value = 0.9996
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -2152.556        NA
sample estimates:
 mean of x mean of y
  1921.572      3566


      Pooled-Variance
Two-Sample t-Test

data:    x:  EASB  in
data.analysis.chloride
.test.st.I  ,  and  y:
EDSB                in
data.analysis.chloride
.test.st.I
t = -9.3893, df = 6,
p-value = 1
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -2805.184        NA
sample estimates:
 mean of x mean of y
  1921.572   4245.75


      Pooled-Variance
Two-Sample t-Test

data:     x:  EBW  in
data.analysis.chloride
.test.st.I  ,  and  y:
EBSA                in
data.analysis.chloride
.test.st.I
t = -14.0931, df = 6,
p-value = 1
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -1130.485        NA
sample estimates:
 mean of x mean of y
    1050.5      2044


      Pooled-Variance
Two-Sample t-Test

data:     x:  EBW  in
data.analysis.chloride
.test.st.I  ,  and  y:
EBSB                in
data.analysis.chloride
.test.st.I
t = -5.7071, df = 6,
p-value = 0.9994
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -1691.691        NA
sample estimates:
 mean of x mean of y
    1050.5    2312.5


      Pooled-Variance
Two-Sample t-Test

data:     x:  EBW  in
data.analysis.chloride
.test.st.I  ,  and  y:
ECW                 in
data.analysis.chloride
.test.st.I
t = 1.8679, df = 6, p-
value = 0.0555
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -3.832478        NA
sample estimates:
 mean of x mean of y
    1050.5  955.3936


      Pooled-Variance
Two-Sample t-Test

data:     x:  EBW  in
data.analysis.chloride
.test.st.I  ,  and  y:
ECSA                in
data.analysis.chloride
.test.st.I
t = -10.1978, df = 6,
p-value = 1
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -2357.586        NA
sample estimates:
 mean of x mean of y
    1050.5   3030.75


      Pooled-Variance
Two-Sample t-Test

data:     x:  EBW  in
data.analysis.chloride
.test.st.I  ,  and  y:
ECSB                in
data.analysis.chloride
.test.st.I
t = -11.6103, df = 6,
p-value = 1
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -5355.589        NA
sample estimates:
 mean of x mean of y
    1050.5   5638.25


      Pooled-Variance
Two-Sample t-Test

data:     x:  EBW  in
data.analysis.chloride
.test.st.I  ,  and  y:
EDW                 in
data.analysis.chloride
.test.st.I
t = 6.0575, df = 6, p-
value = 0.0005
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
```

```
 247.4034       NA
sample estimates:
 mean of x mean of y
    1050.5    686.25


      Pooled-Variance
Two-Sample t-Test

data:     x:  EBW  in
data.analysis.chloride
.test.st.I  ,  and  y:
EDSA                in
data.analysis.chloride
.test.st.I
t = -11.9804, df = 6,
p-value = 1
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 -2923.504       NA
sample estimates:
 mean of x mean of y
    1050.5      3566


      Pooled-Variance
Two-Sample t-Test

data:     x:  EBW  in
data.analysis.chloride
.test.st.I  ,  and  y:
EDSB                in
data.analysis.chloride
.test.st.I
t = -16.6154, df = 6,
p-value = 1
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 -3568.935       NA
sample estimates:
 mean of x mean of y
    1050.5   4245.75


      Pooled-Variance
Two-Sample t-Test

data:    x:  EBSA  in
data.analysis.chloride
.test.st.I  ,  and  y:
EBSB                in
data.analysis.chloride
.test.st.I
t = -1.1687, df = 6,
p-value = 0.8566
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 -714.9197       NA
sample estimates:
 mean of x mean of y
      2044    2312.5


      Pooled-Variance
Two-Sample t-Test

data:    x:  EBSA  in
data.analysis.chloride
.test.st.I  ,  and  y:
ECW                 in
data.analysis.chloride
.test.st.I
t = 13.5297, df = 6,
p-value = 0
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 932.2577       NA
sample estimates:
 mean of x mean of y
      2044  955.3936


      Pooled-Variance
Two-Sample t-Test

data:    x:  EBSA  in
data.analysis.chloride
.test.st.I  ,  and  y:
ECSA                in
data.analysis.chloride
.test.st.I
t = -4.8386, df = 6,
p-value = 0.9986
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 -1383.03       NA
sample estimates:
 mean of x mean of y
      2044   3030.75


      Pooled-Variance
Two-Sample t-Test

data:    x:  EBSA  in
data.analysis.chloride
.test.st.I  ,  and  y:
ECSB                in
data.analysis.chloride
.test.st.I
t = -8.985, df = 6, p-
value = 0.9999
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 -4371.574       NA
sample estimates:
 mean of x mean of y
      2044   5638.25


      Pooled-Variance
Two-Sample t-Test

data:    x:  EBSA  in
data.analysis.chloride
.test.st.I  ,  and  y:
EDW                 in
data.analysis.chloride
.test.st.I
t = 15.6808, df = 6,
p-value = 0
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 1189.497       NA
sample estimates:
 mean of x mean of y
      2044    686.25


      Pooled-Variance
Two-Sample t-Test

data:    x:  EBSA  in
data.analysis.chloride
.test.st.I  ,  and  y:
EDSA                in
data.analysis.chloride
.test.st.I
t = -6.9493, df = 6,
p-value = 0.9998
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 -1947.586       NA
sample estimates:
 mean of x mean of y
      2044      3566
```

```
      Pooled-Variance
Two-Sample t-Test

data:    x:  EBSA  in
data.analysis.chloride
.test.st.I  ,  and  y:
EDSB                in
data.analysis.chloride
.test.st.I
t = -10.8919, df = 6,
p-value = 1
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 -2594.556        NA
sample estimates:
 mean of x mean of y
      2044   4245.75


      Pooled-Variance
Two-Sample t-Test

data:    x:  EBSB  in
data.analysis.chloride
.test.st.I  ,  and  y:
ECW                 in
data.analysis.chloride
.test.st.I
t = 6.0449, df = 6, p-
value = 0.0005
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 920.8559       NA
sample estimates:
 mean of x mean of y
    2312.5  955.3936


      Pooled-Variance
Two-Sample t-Test

data:    x:  EBSB  in
data.analysis.chloride
.test.st.I  ,  and  y:
ECSA                in
data.analysis.chloride
.test.st.I
t  =  -2.4561,  df  =  6,
p-value = 0.9753
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 -1286.5      NA
sample estimates:
 mean of x mean of y
    2312.5   3030.75


      Pooled-Variance
Two-Sample t-Test

data:    x:  EBSB  in
data.analysis.chloride
.test.st.I  ,  and  y:
ECSB                in
data.analysis.chloride
.test.st.I
t  =  -7.3642,  df  =  6,
p-value = 0.9998
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 -4203.305        NA
sample estimates:
 mean of x mean of y
    2312.5   5638.25


      Pooled-Variance
Two-Sample t-Test

data:    x:  EBSB  in
data.analysis.chloride
.test.st.I  ,  and  y:
EDW                 in
data.analysis.chloride
.test.st.I
t = 7.1713, df = 6, p-
value = 0.0002
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 1185.593       NA
sample estimates:
 mean of x mean of y
    2312.5    686.25


      Pooled-Variance
Two-Sample t-Test

data:    x:  EBSB  in
data.analysis.chloride
.test.st.I  ,  and  y:
EDSA                in
data.analysis.chloride
.test.st.I
t = -4.135, df = 6, p-
value = 0.9969
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 -1842.561        NA
sample estimates:
 mean of x mean of y
    2312.5      3566


      Pooled-Variance
Two-Sample t-Test

data:    x:  EBSB  in
data.analysis.chloride
.test.st.I  ,  and  y:
EDSB                in
data.analysis.chloride
.test.st.I
t  =  -6.6392,  df  =  6,
p-value = 0.9997
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 -2499.083        NA
sample estimates:
 mean of x mean of y
    2312.5   4245.75


      Pooled-Variance
Two-Sample t-Test

data:     x:  ECW  in
data.analysis.chloride
.test.st.I  ,  and  y:
ECSA                in
data.analysis.chloride
.test.st.I
t = -10.4805, df = 6,
p-value = 1
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 -2460.145        NA
sample estimates:
 mean of x mean of y
  955.3936   3030.75


      Pooled-Variance
Two-Sample t-Test
```

data: x: ECW in data.analysis.chloride .test.st.I , and y: ECSB in data.analysis.chloride .test.st.I
t = -11.7943, df = 6, p-value = 1
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -5454.386 NA
sample estimates:
 mean of x mean of y
 955.3936 5638.25

Pooled-Variance Two-Sample t-Test

data: x: ECW in data.analysis.chloride .test.st.I , and y: EDW in data.analysis.chloride .test.st.I
t = 3.7614, df = 6, p-value = 0.0047
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 130.0998 NA
sample estimates:
 mean of x mean of y
 955.3936 686.25

Pooled-Variance Two-Sample t-Test

data: x: ECW in data.analysis.chloride .test.st.I , and y: EDSA in data.analysis.chloride .test.st.I
t = -12.2266, df = 6, p-value = 1
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -3025.513 NA
sample estimates:
 mean of x mean of y
 955.3936 3566

Pooled-Variance Two-Sample t-Test

data: x: ECW in data.analysis.chloride .test.st.I , and y: EDSB in data.analysis.chloride .test.st.I
t = -16.7723, df = 6, p-value = 1
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -3671.566 NA
sample estimates:
 mean of x mean of y
 955.3936 4245.75

Pooled-Variance Two-Sample t-Test

data: x: ECSA in data.analysis.chloride .test.st.I , and y: ECSB in data.analysis.chloride .test.st.I
t = -5.939, df = 6, p-value = 0.9995
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -3460.642 NA
sample estimates:
 mean of x mean of y
 3030.75 5638.25

Pooled-Variance Two-Sample t-Test

data: x: ECSA in data.analysis.chloride .test.st.I , and y: EDW in data.analysis.chloride .test.st.I
t = 11.6882, df = 6, p-value = 0
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 1954.723 NA
sample estimates:
 mean of x mean of y
 3030.75 686.25

Pooled-Variance Two-Sample t-Test

data: x: ECSA in data.analysis.chloride .test.st.I , and y: EDSA in data.analysis.chloride .test.st.I
t = -1.8841, df = 6, p-value = 0.9457
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -1087.283 NA
sample estimates:
 mean of x mean of y
 3030.75 3566

Pooled-Variance Two-Sample t-Test

data: x: ECSA in data.analysis.chloride .test.st.I , and y: EDSB in data.analysis.chloride .test.st.I
t = -4.4785, df = 6, p-value = 0.9979
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -1742.176 NA
sample estimates:
 mean of x mean of y
 3030.75 4245.75

Pooled-Variance Two-Sample t-Test

data: x: ECSB in data.analysis.chloride .test.st.I , and y: EDW in

```
data.analysis.chloride.test.st.I
t = 12.4319, df = 6, p-value = 0
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 4177.971       NA
sample estimates:
 mean of x mean of y
   5638.25    686.25
```

```
        Pooled-Variance Two-Sample t-Test

data: x: ECSB in data.analysis.chloride.test.st.I , and y: EDSA in data.analysis.chloride.test.st.I
t = 4.6437, df = 6, p-value = 0.0018
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 1205.108       NA
sample estimates:
 mean of x mean of y
   5638.25      3566
```

```
        Pooled-Variance Two-Sample t-Test

data: x: ECSB in data.analysis.chloride.test.st.I , and y: EDSB in data.analysis.chloride.test.st.I
t = 3.1777, df = 6, p-value = 0.0096
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 540.9665       NA
sample estimates:
 mean of x mean of y
   5638.25   4245.75
```

```
        Pooled-Variance Two-Sample t-Test

data: x: EDW in data.analysis.chloride.test.st.I , and y: EDSA in data.analysis.chloride.test.st.I
t = -13.3382, df = 6, p-value = 1
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -3299.288       NA
sample estimates:
 mean of x mean of y
    686.25      3566
```

```
        Pooled-Variance Two-Sample t-Test

data: x: EDW in data.analysis.chloride.test.st.I , and y: EDSB in data.analysis.chloride.test.st.I
t = -17.9077, df = 6, p-value = 1
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -3945.745       NA
sample estimates:
 mean of x mean of y
    686.25   4245.75
```

```
        Pooled-Variance Two-Sample t-Test

data: x: EDSA in data.analysis.chloride.test.st.I , and y: EDSB in data.analysis.chloride.test.st.I
t = -2.4036, df = 6, p-value = 0.9735
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -1229.295       NA
sample estimates:
 mean of x mean of y
      3566   4245.75
```

Chloride ion Test Phase II

```
        Pooled-Variance Two-Sample t-Test

data: x: Con in data.analysis.chloride.test.st.II. , and y: A in data.analysis.chloride.test.st.II.
t = 2.6641, df = 6, p-value = 0.0187
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 91.80603       NA
sample estimates:
 mean of x mean of y
       658    318.75
```

```
        Pooled-Variance Two-Sample t-Test

data: x: Con in data.analysis.chloride.test.st.II. , and y: B in data.analysis.chloride.test.st.II.
t = 2.1028, df = 4, p-value = 0.0517
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -5.540443       NA
sample estimates:
 mean of x mean of y
       658       257
```

```
        Pooled-Variance Two-Sample t-Test
```

```
data: x: Con in
data.analysis.chloride
.test.st.II. , and y:
C in
data.analysis.chloride
.test.st.II.
t = 0.7626, df = 6, p-
value = 0.2373
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -165.2725 NA
sample estimates:
 mean of x mean of y
       658    551.25


      Pooled-Variance
Two-Sample t-Test

data: x: Con in
data.analysis.chloride
.test.st.II. , and y:
D in
data.analysis.chloride
.test.st.II.
t = 3.0611, df = 6, p-
value = 0.0111
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 142.6099 NA
sample estimates:
 mean of x mean of y
       658    267.5


      Pooled-Variance
Two-Sample t-Test

data: x: Con in
data.analysis.chloride
.test.st.II. , and y:
E in
data.analysis.chloride
.test.st.II.
t = 2.6838, df = 6, p-
value = 0.0182
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 95.55166 NA
sample estimates:
 mean of x mean of y
       658    311.75


      Pooled-Variance
Two-Sample t-Test

data: x: Con in
data.analysis.chloride
.test.st.II. , and y:
S in
data.analysis.chloride
.test.st.II.
t = 3.3771, df = 6, p-
value = 0.0075
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 183.4273 NA
sample estimates:
 mean of x mean of y
       658       226


      Pooled-Variance
Two-Sample t-Test

data: x: Con in
data.analysis.chloride
.test.st.II. , and y:
T in
data.analysis.chloride
.test.st.II.
t = 2.8965, df = 6, p-
value = 0.0137
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 121.615 NA
sample estimates:
 mean of x mean of y
       658     288.5


      Pooled-Variance
Two-Sample t-Test

data: x: A in
data.analysis.chloride
.test.st.II. , and y:
B in
data.analysis.chloride
.test.st.II.
t = 5.5145, df = 4, p-
value = 0.0026
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 37.87802 NA
sample estimates:
 mean of x mean of y
    318.75       257


      Pooled-Variance
Two-Sample t-Test

data: x: A in
data.analysis.chloride
.test.st.II. , and y:
C in
data.analysis.chloride
.test.st.II.
t = -3.9357, df = 6,
p-value = 0.9962
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -347.2923 NA
sample estimates:
 mean of x mean of y
    318.75    551.25


      Pooled-Variance
Two-Sample t-Test

data: x: A in
data.analysis.chloride
.test.st.II. , and y:
D in
data.analysis.chloride
.test.st.II.
t = 3.9661, df = 6, p-
value = 0.0037
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 26.14014 NA
sample estimates:
 mean of x mean of y
    318.75     267.5


      Pooled-Variance
Two-Sample t-Test

data: x: A in
data.analysis.chloride
.test.st.II. , and y:
E in
```

```
data.analysis.chloride
.test.st.II.
t = 0.3018, df = 6, p-
value = 0.3865
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -38.063      NA
sample estimates:
 mean of x mean of y
    318.75    311.75


      Pooled-Variance
Two-Sample t-Test

data:      x:   A   in
data.analysis.chloride
.test.st.II. , and y:
S                    in
data.analysis.chloride
.test.st.II.
t = 5.7886, df = 6, p-
value = 0.0006
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 61.61487       NA
sample estimates:
 mean of x mean of y
    318.75       226


      Pooled-Variance
Two-Sample t-Test

data:      x:   A   in
data.analysis.chloride
.test.st.II. , and y:
T                    in
data.analysis.chloride
.test.st.II.
t = 2.3456, df = 6, p-
value = 0.0287
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 5.190319       NA
sample estimates:
 mean of x mean of y
    318.75     288.5

      Pooled-Variance
Two-Sample t-Test

data:      x:   C   in
data.analysis.chloride
.test.st.II. , and y:
D                    in
data.analysis.chloride
.test.st.II.
t = 4.7635, df = 6, p-
value = 0.0016
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 167.9992       NA
sample estimates:
 mean of x mean of y
    551.25     267.5


      Pooled-Variance
Two-Sample t-Test

data:      x:   C   in
data.analysis.chloride
.test.st.II. , and y:
E                    in
data.analysis.chloride
.test.st.II.
t = 3.8257, df = 6, p-
value = 0.0044
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 117.8512       NA
sample estimates:
 mean of x mean of y
    551.25    311.75


      Pooled-Variance
Two-Sample t-Test

data:      x:   C   in
data.analysis.chloride
.test.st.II. , and y:
S                    in
data.analysis.chloride
.test.st.II.
t = 5.3924, df = 6, p-
value = 0.0008
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 208.0445       NA
sample estimates:
 mean of x mean of y
    551.25       226


      Pooled-Variance
Two-Sample t-Test

data:      x:   C   in
data.analysis.chloride
.test.st.II. , and y:
T                    in
data.analysis.chloride
.test.st.II.
t = 4.4114, df = 6, p-
value = 0.0023
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 147.0101       NA
sample estimates:
 mean of x mean of y
    551.25     288.5


      Pooled-Variance
Two-Sample t-Test

data:      x:   D   in
data.analysis.chloride
.test.st.II. , and y:
E                    in
data.analysis.chloride
.test.st.II.
t = -1.8121, df = 6,
p-value = 0.94
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -91.70151       NA
sample estimates:
 mean of x mean of y
     267.5    311.75


      Pooled-Variance
Two-Sample t-Test

data:      x:   D   in
data.analysis.chloride
.test.st.II. , and y:
S                    in
data.analysis.chloride
.test.st.II.
t = 2.3373, df = 6, p-
value = 0.029
```

alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 6.998288   NA
sample estimates:
 mean of x mean of y
     267.5   226

Pooled-Variance Two-Sample t-Test

data: x: D in data.analysis.chloride.test.st.II. , and y: T in data.analysis.chloride.test.st.II.
t = -1.4005, df = 6, p-value = 0.8946
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -50.13691   NA
sample estimates:
 mean of x mean of y
     267.5   288.5

Pooled-Variance Two-Sample t-Test

data: x: E in data.analysis.chloride.test.st.II. , and y: S in data.analysis.chloride.test.st.II.
t = 3.2738, df = 6, p-value = 0.0085
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 34.85268   NA
sample estimates:
 mean of x mean of y
    311.75   226

Pooled-Variance Two-Sample t-Test

data: x: E in data.analysis.chloride.test.st.II. , and y: T in data.analysis.chloride.test.st.II.
t = 0.9526, df = 6, p-value = 0.1888
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -24.17498   NA
sample estimates:
 mean of x mean of y
    311.75   288.5

Pooled-Variance Two-Sample t-Test

data: x: S in data.analysis.chloride.test.st.II. , and y: T in data.analysis.chloride.test.st.II.

t = -3.5238, df = 6, p-value = 0.9938
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -96.96521   NA
sample estimates:
 mean of x mean of y
       226   288.5

Compressive Strength Test – Phase I

Pooled-Variance Two-Sample t-Test

data: x: CW in Compressive.Strength.28.day.phase.I , and y: CSA in Compressive.Strength.28.day.phase.I
t = 13.9513, df = 4, p-value = 0.0001
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 2237.189   NA
sample estimates:
 mean of x mean of y
  6517.303 3876.598

Pooled-Variance Two-Sample t-Test

data: x: CW in Compressive.Strength.28.day.phase.I , and y: CSB in Compressive.Strength.28.day.phase.I
t = 23.0359, df = 4, p-value = 0
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 3213.049   NA
sample estimates:
 mean of x mean of y
  6517.303 2976.579

Pooled-Variance Two-Sample t-Test

data: x: CW in Compressive.Strength.28.day.phase.I , and y: EAW in Compressive.Strength.28.day.phase.I
t = -2.1289, df = 4, p-value = 0.9498
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -1353.144   NA
sample estimates:
 mean of x mean of y
  6517.303 7193.406

```
      Pooled-Variance
Two-Sample t-Test

data:     x:  CW  in
Compressive.Strength.2
8.day.phase.I , and y:
EASA               in
Compressive.Strength.2
8.day.phase.I
t = 2.9836, df = 4, p-
value = 0.0203
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 181.9377       NA
sample estimates:
 mean of x mean of y
  6517.303  5880.002


      Pooled-Variance
Two-Sample t-Test

data:     x:  CW  in
Compressive.Strength.2
8.day.phase.I , and y:
EASB               in
Compressive.Strength.2
8.day.phase.I
t = 11.5018, df = 4,
p-value = 0.0002
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 1585.727       NA
sample estimates:
 mean of x mean of y
  6517.303   4570.79


      Pooled-Variance
Two-Sample t-Test

data:     x:  CW  in
Compressive.Strength.2
8.day.phase.I , and y:
EBW                in
Compressive.Strength.2
8.day.phase.I
t = -17.1404, df = 4,
p-value = 1
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -3299.995       NA
sample estimates:
 mean of x mean of y
  6517.303  9452.261


      Pooled-Variance
Two-Sample t-Test

data:     x:  CW  in
Compressive.Strength.2
8.day.phase.I , and y:
EBSA               in
Compressive.Strength.2
8.day.phase.I
t = -9.3682, df = 4,
p-value = 0.9996
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -1595.623       NA
sample estimates:
 mean of x mean of y
  6517.303  7817.133


      Pooled-Variance
Two-Sample t-Test

data:     x:  CW  in
Compressive.Strength.2
8.day.phase.I , and y:
EBSB               in
Compressive.Strength.2
8.day.phase.I
t = -0.1882, df = 4,
p-value = 0.5701
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -436.3451       NA
sample estimates:
 mean of x mean of y
  6517.303  6552.702


      Pooled-Variance
Two-Sample t-Test

data:     x:  CW  in
Compressive.Strength.2
8.day.phase.I , and y:
ECW                in
Compressive.Strength.2
8.day.phase.I
t = 7.4247, df = 4, p-
value = 0.0009
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 1477.425       NA
sample estimates:
 mean of x mean of y
  6517.303  4444.803


      Pooled-Variance
Two-Sample t-Test

data:     x:  CW  in
Compressive.Strength.2
8.day.phase.I , and y:
ECSA               in
Compressive.Strength.2
8.day.phase.I
t = 15.3614, df = 4,
p-value = 0.0001
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 2484.83      NA
sample estimates:
 mean of x mean of y
  6517.303  3632.061


      Pooled-Variance
Two-Sample t-Test

data:     x:  CW  in
Compressive.Strength.2
8.day.phase.I , and y:
ECSB               in
Compressive.Strength.2
8.day.phase.I
t = 12.3712, df = 4,
p-value = 0.0001
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 3576.222       NA
sample estimates:
 mean of x mean of y
  6517.303  2196.503


      Pooled-Variance
Two-Sample t-Test

data:     x:  CW  in
Compressive.Strength.2
```

```
8.day.phase.I , and y:
EDW                 in
Compressive.Strength.2
8.day.phase.I
t = -0.0437, df = 4,
p-value = 0.5164
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -380.2708        NA
sample estimates:
 mean of x mean of y
  6517.303  6524.941


      Pooled-Variance
Two-Sample t-Test

data:     x:  CW  in
Compressive.Strength.2
8.day.phase.I , and y:
EDSA                in
Compressive.Strength.2
8.day.phase.I
t = 17.169, df = 4, p-
value = 0
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 1924.884       NA
sample estimates:
 mean of x mean of y
  6517.303  4319.525


      Pooled-Variance
Two-Sample t-Test

data:     x:  CW  in
Compressive.Strength.2
8.day.phase.I , and y:
EDSB                in
Compressive.Strength.2
8.day.phase.I
t = 21.0516, df = 4,
p-value = 0
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 3144.771       NA
sample estimates:
 mean of x mean of y
  6517.303  3018.184


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSA  in
Compressive.Strength.2
8.day.phase.I , and y:
CSB                 in
Compressive.Strength.2
8.day.phase.I
t = 5.3076, df = 4, p-
value = 0.003
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 538.5156       NA
sample estimates:
 mean of x mean of y
  3876.598  2976.579


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSA  in
Compressive.Strength.2
8.day.phase.I , and y:
EAW                 in
Compressive.Strength.2
8.day.phase.I
t = -10.188, df = 4,
p-value = 0.9997
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -4010.853        NA
sample estimates:
 mean of x mean of y
  3876.598  7193.406


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSA  in
Compressive.Strength.2
8.day.phase.I , and y:
EASA                in
Compressive.Strength.2
8.day.phase.I
t = -8.8926, df = 4,
p-value = 0.9996
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -2483.685        NA
sample estimates:
 mean of x mean of y
  3876.598  5880.002


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSA  in
Compressive.Strength.2
8.day.phase.I , and y:
EASB                in
Compressive.Strength.2
8.day.phase.I
t = -3.7775, df = 4,
p-value = 0.9903
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -1085.958        NA
sample estimates:
 mean of x mean of y
  3876.598   4570.79


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSA  in
Compressive.Strength.2
8.day.phase.I , and y:
EBW                 in
Compressive.Strength.2
8.day.phase.I
t = -30.0403, df = 4,
p-value = 1
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -5971.348        NA
sample estimates:
 mean of x mean of y
  3876.598  9452.261


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSA  in
Compressive.Strength.2
8.day.phase.I , and y:
EBSA                in
Compressive.Strength.2
8.day.phase.I
```

```
t = -25.2364, df = 4,
p-value = 1
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -4273.413        NA
sample estimates:
 mean of x mean of y
  3876.598  7817.133


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSA  in
Compressive.Strength.2
8.day.phase.I , and y:
EBSB               in
Compressive.Strength.2
8.day.phase.I
t = -13.2974, df = 4,
p-value = 0.9999
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -3105.14       NA
sample estimates:
 mean of x mean of y
  3876.598  6552.702


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSA  in
Compressive.Strength.2
8.day.phase.I , and y:
ECW                in
Compressive.Strength.2
8.day.phase.I
t = -1.9717, df = 4,
p-value = 0.94
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -1182.557        NA
sample estimates:
 mean of x mean of y
  3876.598  4444.803


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSA  in
Compressive.Strength.2
8.day.phase.I , and y:
ECSA               in
Compressive.Strength.2
8.day.phase.I
t = 1.2165, df = 4, p-
value = 0.1453
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -183.9999        NA
sample estimates:
 mean of x mean of y
  3876.598  3632.061


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSA  in
Compressive.Strength.2
8.day.phase.I , and y:
ECSB               in
Compressive.Strength.2
8.day.phase.I
t = 4.7123, df = 4, p-
value = 0.0046
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 920.0228       NA
sample estimates:
 mean of x mean of y
  3876.598  2196.503


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSA  in
Compressive.Strength.2
8.day.phase.I , and y:
EDW                in
Compressive.Strength.2
8.day.phase.I
t = -14.0199, df = 4,
p-value = 0.9999
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -3051.045        NA
sample estimates:
 mean of x mean of y
  3876.598  6524.941


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSA  in
Compressive.Strength.2
8.day.phase.I , and y:
EDSA               in
Compressive.Strength.2
8.day.phase.I
t = -3.0196, df = 4,
p-value = 0.9804
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -755.6328        NA
sample estimates:
 mean of x mean of y
  3876.598  4319.525


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSA  in
Compressive.Strength.2
8.day.phase.I , and y:
EDSB               in
Compressive.Strength.2
8.day.phase.I
t = 4.7429, df = 4, p-
value = 0.0045
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 472.5685       NA
sample estimates:
 mean of x mean of y
  3876.598  3018.184


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSB  in
Compressive.Strength.2
8.day.phase.I , and y:
EAW                in
Compressive.Strength.2
8.day.phase.I
t = -13.7694, df = 4,
p-value = 0.9999
alternative
hypothesis:
```

```
difference in means is
greater than 0
95 percent confidence
interval:
 -4869.7      NA
sample estimates:
 mean of x mean of y
  2976.579  7193.406


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSB  in
Compressive.Strength.2
8.day.phase.I , and y:
EASA                in
Compressive.Strength.2
8.day.phase.I
t = -14.787, df = 4,
p-value = 0.9999
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -3322.009        NA
sample estimates:
 mean of x mean of y
  2976.579  5880.002


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSB  in
Compressive.Strength.2
8.day.phase.I , and y:
EASB                in
Compressive.Strength.2
8.day.phase.I
t = -10.8551, df = 4,
p-value = 0.9998
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -1907.3      NA
sample estimates:
 mean of x mean of y
  2976.579   4570.79


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSB  in
Compressive.Strength.2
8.day.phase.I , and y:
EBW                 in
Compressive.Strength.2
8.day.phase.I
t = -43.4152, df = 4,
p-value = 1
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -6793.662        NA
sample estimates:
 mean of x mean of y
  2976.579  9452.261


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSB  in
Compressive.Strength.2
8.day.phase.I , and y:
EBSA                in
Compressive.Strength.2
8.day.phase.I
t = -43.8614, df = 4,
p-value = 1
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -5075.825        NA
sample estimates:
 mean of x mean of y
  2976.579  7817.133


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSB  in
Compressive.Strength.2
8.day.phase.I , and y:
EBSB                in
Compressive.Strength.2
8.day.phase.I
t = -21.2579, df = 4,
p-value = 1
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -3934.754        NA
sample estimates:
 mean of x mean of y
  2976.579  6552.702


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSB  in
Compressive.Strength.2
8.day.phase.I , and y:
ECW                 in
Compressive.Strength.2
8.day.phase.I
t = -5.5162, df = 4,
p-value = 0.9974
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -2035.65       NA
sample estimates:
 mean of x mean of y
  2976.579  4444.803


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSB  in
Compressive.Strength.2
8.day.phase.I , and y:
ECSA                in
Compressive.Strength.2
8.day.phase.I
t = -3.9029, df = 4,
p-value = 0.9913
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -1013.516        NA
sample estimates:
 mean of x mean of y
  2976.579  3632.061


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSB  in
Compressive.Strength.2
8.day.phase.I , and y:
ECSB                in
Compressive.Strength.2
8.day.phase.I
t = 2.3012, df = 4, p-
value = 0.0414
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
```

```
 57.40454       NA
sample estimates:
 mean of x mean of y
  2976.579  2196.503


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSB  in
Compressive.Strength.2
8.day.phase.I , and y:
EDW                in
Compressive.Strength.2
8.day.phase.I
t = -23.1565, df = 4,
p-value = 1
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 -3875.033        NA
sample estimates:
 mean of x mean of y
  2976.579  6524.941


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSB  in
Compressive.Strength.2
8.day.phase.I , and y:
EDSA               in
Compressive.Strength.2
8.day.phase.I
t = -13.9152, df = 4,
p-value = 0.9999
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 -1548.688        NA
sample estimates:
 mean of x mean of y
  2976.579  4319.525


      Pooled-Variance
Two-Sample t-Test

data:     x:  CSB  in
Compressive.Strength.2
8.day.phase.I , and y:
EDSB               in
Compressive.Strength.2
8.day.phase.I
t = -0.2902, df = 4,
p-value = 0.607
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 -347.2544        NA
sample estimates:
 mean of x mean of y
  2976.579  3018.184


      Pooled-Variance
Two-Sample t-Test

data:     x:  EAW  in
Compressive.Strength.2
8.day.phase.I , and y:
EASA               in
Compressive.Strength.2
8.day.phase.I
t = 3.8598, df = 4, p-
value = 0.0091
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 587.9893       NA
sample estimates:
 mean of x mean of y
  7193.406  5880.002


      Pooled-Variance
Two-Sample t-Test

data:     x:  EAW  in
Compressive.Strength.2
8.day.phase.I , and y:
EASB               in
Compressive.Strength.2
8.day.phase.I
t = 8.3435, df = 4, p-
value = 0.0006
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 1952.514       NA
sample estimates:
 mean of x mean of y
  7193.406   4570.79


      Pooled-Variance
Two-Sample t-Test

data:     x:  EAW  in
Compressive.Strength.2
8.day.phase.I , and y:
EBW                in
Compressive.Strength.2
8.day.phase.I
t = -7.1617, df = 4,
p-value = 0.999
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 -2931.256        NA
sample estimates:
 mean of x mean of y
  7193.406  9452.261


      Pooled-Variance
Two-Sample t-Test

data:     x:  EAW  in
Compressive.Strength.2
8.day.phase.I , and y:
EBSA               in
Compressive.Strength.2
8.day.phase.I
t = -2.0859, df = 4,
p-value = 0.9473
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 -1261.194        NA
sample estimates:
 mean of x mean of y
  7193.406  7817.133


      Pooled-Variance
Two-Sample t-Test

data:     x:  EAW  in
Compressive.Strength.2
8.day.phase.I , and y:
EBSB               in
Compressive.Strength.2
8.day.phase.I
t = 1.9722, df = 4, p-
value = 0.0599
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 -51.84839        NA
sample estimates:
 mean of x mean of y
  7193.406  6552.702
```

```
      Pooled-Variance
Two-Sample t-Test

data:     x:  EAW  in
Compressive.Strength.2
8.day.phase.I , and y:
ECW                 in
Compressive.Strength.2
8.day.phase.I
t = 7.1427, df = 4, p-
value = 0.001
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 1928.246       NA
sample estimates:
 mean of x mean of y
  7193.406  4444.803


      Pooled-Variance
Two-Sample t-Test

data:     x:  EAW  in
Compressive.Strength.2
8.day.phase.I , and y:
ECSA                in
Compressive.Strength.2
8.day.phase.I
t  =  10.9676,  df  =  4,
p-value = 0.0002
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 2869.102       NA
sample estimates:
 mean of x mean of y
  7193.406  3632.061


      Pooled-Variance
Two-Sample t-Test

data:     x:  EAW  in
Compressive.Strength.2
8.day.phase.I , and y:
ECSB                in
Compressive.Strength.2
8.day.phase.I
t  =  11.3994,  df  =  4,
p-value = 0.0002
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 4062.416       NA
sample estimates:
 mean of x mean of y
  7193.406  2196.503


      Pooled-Variance
Two-Sample t-Test

data:     x:  EAW  in
Compressive.Strength.2
8.day.phase.I , and y:
EDW                 in
Compressive.Strength.2
8.day.phase.I
t = 2.1064, df = 4, p-
value = 0.0515
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 -8.089511       NA
sample estimates:
 mean of x mean of y
  7193.406  6524.941


      Pooled-Variance
Two-Sample t-Test

data:     x:  EAW  in
Compressive.Strength.2
8.day.phase.I , and y:
EDSA                in
Compressive.Strength.2
8.day.phase.I
t = 9.7688, df = 4, p-
value = 0.0003
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 2246.711       NA
sample estimates:
 mean of x mean of y
  7193.406  4319.525


      Pooled-Variance
Two-Sample t-Test

data:     x:  EAW  in
Compressive.Strength.2
8.day.phase.I , and y:
EDSB                in
Compressive.Strength.2
8.day.phase.I
t  =  13.3516,  df  =  4,
p-value = 0.0001
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 3508.563       NA
sample estimates:
 mean of x mean of y
  7193.406  3018.184


      Pooled-Variance
Two-Sample t-Test

data:     x:  EASA  in
Compressive.Strength.2
8.day.phase.I , and y:
EASB                in
Compressive.Strength.2
8.day.phase.I
t = 6.2722, df = 4, p-
value = 0.0016
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 864.2278       NA
sample estimates:
 mean of x mean of y
  5880.002   4570.79
```


```
      Pooled-Variance
Two-Sample t-Test

data:     x:  EASA  in
Compressive.Strength.2
8.day.phase.I , and y:
EASB                in
Compressive.Strength.2
8.day.phase.I
t = 6.2722, df = 4, p-
value = 0.0016
alternative
hypothesis:
difference in means is
greater than 0
95  percent  confidence
interval:
 864.2278       NA
sample estimates:
 mean of x mean of y
  5880.002   4570.79
```


```
      Pooled-Variance
Two-Sample t-Test
```

data: x: EASA in Compressive.Strength.28.day.phase.I , and y: EBW in Compressive.Strength.28.day.phase.I
t = -16.9823, df = 4, p-value = 1
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
-4020.698 NA
sample estimates:
mean of x mean of y
5880.002 9452.261

Pooled-Variance Two-Sample t-Test

data: x: EASA in Compressive.Strength.28.day.phase.I , and y: EBSA in Compressive.Strength.28.day.phase.I
t = -10.4779, df = 4, p-value = 0.9998
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
-2331.261 NA
sample estimates:
mean of x mean of y
5880.002 7817.133

Pooled-Variance Two-Sample t-Test

data: x: EASA in Compressive.Strength.28.day.phase.I , and y: EBSB in Compressive.Strength.28.day.phase.I
t = -2.9994, df = 4, p-value = 0.98
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
-1150.824 NA
sample estimates:
mean of x mean of y
5880.002 6552.702

Pooled-Variance Two-Sample t-Test

data: x: EASA in Compressive.Strength.28.day.phase.I , and y: ECW in Compressive.Strength.28.day.phase.I
t = 4.7101, df = 4, p-value = 0.0046
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
785.6153 NA
sample estimates:
mean of x mean of y
5880.002 4444.803

Pooled-Variance Two-Sample t-Test

data: x: EASA in Compressive.Strength.28.day.phase.I , and y: ECSA in Compressive.Strength.28.day.phase.I
t = 10.0325, df = 4, p-value = 0.0003
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
1770.265 NA
sample estimates:
mean of x mean of y
5880.002 3632.061

Pooled-Variance Two-Sample t-Test

data: x: EASA in Compressive.Strength.28.day.phase.I , and y: ECSB in Compressive.Strength.28.day.phase.I
t = 9.9549, df = 4, p-value = 0.0003
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
2894.677 NA
sample estimates:
mean of x mean of y
5880.002 2196.503

Pooled-Variance Two-Sample t-Test

data: x: EASA in Compressive.Strength.28.day.phase.I , and y: EDW in Compressive.Strength.28.day.phase.I
t = -3.0242, df = 4, p-value = 0.9805
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
-1099.582 NA
sample estimates:
mean of x mean of y
5880.002 6524.941

Pooled-Variance Two-Sample t-Test

data: x: EASA in Compressive.Strength.28.day.phase.I , and y: EDSA in Compressive.Strength.28.day.phase.I
t = 8.8183, df = 4, p-value = 0.0005
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
1183.23 NA
sample estimates:
mean of x mean of y
5880.002 4319.525

Pooled-Variance Two-Sample t-Test

data: x: EASA in Compressive.Strength.28.day.phase.I , and y: EDSB in

```
Compressive.Strength.28.day.phase.I
t = 13.8727, df = 4, p-value = 0.0001
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 2422.037       NA
sample estimates:
 mean of x mean of y
  5880.002  3018.184


      Pooled-Variance Two-Sample t-Test

data: x: EASB in Compressive.Strength.28.day.phase.I , and y: EDSB in Compressive.Strength.28.day.phase.I
t = 9.7092, df = 4, p-value = 0.0003
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 1211.699       NA
sample estimates:
 mean of x mean of y
   4570.79  3018.184


      Pooled-Variance Two-Sample t-Test

data: x: EASB in Compressive.Strength.28.day.phase.I , and y: EBW in Compressive.Strength.28.day.phase.I
t = -29.5637, df = 4, p-value = 1
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -5233.475       NA
sample estimates:
 mean of x mean of y
   4570.79  9452.261


      Pooled-Variance Two-Sample t-Test

data: x: EASB in Compressive.Strength.28.day.phase.I , and y: EBSA in Compressive.Strength.28.day.phase.I
t = -24.7566, df = 4, p-value = 1
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -3525.893       NA
sample estimates:
 mean of x mean of y
   4570.79  7817.133


      Pooled-Variance Two-Sample t-Test

data: x: EASB in Compressive.Strength.28.day.phase.I , and y: EBSB in Compressive.Strength.28.day.phase.I
t = -10.8582, df = 4, p-value = 0.9998
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -2371.03       NA
sample estimates:
 mean of x mean of y
   4570.79  6552.702


      Pooled-Variance Two-Sample t-Test

data: x: EASB in Compressive.Strength.28.day.phase.I , and y: ECW in Compressive.Strength.28.day.phase.I
t = 0.4574, df = 4, p-value = 0.3356
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -461.1832       NA
sample estimates:
 mean of x mean of y
   4570.79  4444.803


      Pooled-Variance Two-Sample t-Test

data: x: EASB in Compressive.Strength.28.day.phase.I , and y: ECSA in Compressive.Strength.28.day.phase.I
t = 5.1503, df = 4, p-value = 0.0034
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 550.1617       NA
sample estimates:
 mean of x mean of y
   4570.79  3632.061


      Pooled-Variance Two-Sample t-Test

data: x: EASB in Compressive.Strength.28.day.phase.I , and y: ECSB in Compressive.Strength.28.day.phase.I
t = 6.856, df = 4, p-value = 0.0012
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 1636.012       NA
sample estimates:
 mean of x mean of y
   4570.79  2196.503


      Pooled-Variance Two-Sample t-Test

data: x: EASB in Compressive.Strength.28.day.phase.I , and y: EDW in Compressive.Strength.28.day.phase.I
t = -11.5761, df = 4, p-value = 0.9998
```

alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
-2314.026 NA
sample estimates:
mean of x mean of y
4570.79 6524.941

Pooled-Variance Two-Sample t-Test

data: x: EASB in Compressive.Strength.28.day.phase.I , and y: EDSA in Compressive.Strength.28.day.phase.I
t = 2.099, df = 4, p-value = 0.0519
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
-3.932345 NA
sample estimates:
mean of x mean of y
4570.79 4319.525

Pooled-Variance Two-Sample t-Test

data: x: EASB in Compressive.Strength.28.day.phase.I , and y: EDSB in Compressive.Strength.28.day.phase.I
t = 9.7092, df = 4, p-value = 0.0003
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
1211.699 NA
sample estimates:
mean of x mean of y
4570.79 3018.184

Pooled-Variance Two-Sample t-Test

data: x: EBW in Compressive.Strength.28.day.phase.I , and y: EBSA in Compressive.Strength.28.day.phase.I
t = 12.2303, df = 4, p-value = 0.0001
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
1350.112 NA
sample estimates:
mean of x mean of y
9452.261 7817.133

Pooled-Variance Two-Sample t-Test

data: x: EBW in Compressive.Strength.28.day.phase.I , and y: EBSB in Compressive.Strength.28.day.phase.I
t = 15.7263, df = 4, p-value = 0
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
2506.497 NA
sample estimates:
mean of x mean of y
9452.261 6552.702

Pooled-Variance Two-Sample t-Test

data: x: EBW in Compressive.Strength.28.day.phase.I , and y: ECW in Compressive.Strength.28.day.phase.I
t = 18.0998, df = 4, p-value = 0
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
4417.666 NA
sample estimates:
mean of x mean of y
9452.261 4444.803

Pooled-Variance Two-Sample t-Test

data: x: EBW in Compressive.Strength.28.day.phase.I , and y: ECSA in Compressive.Strength.28.day.phase.I
t = 31.6107, df = 4, p-value = 0
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
5427.682 NA
sample estimates:
mean of x mean of y
9452.261 3632.061

Pooled-Variance Two-Sample t-Test

data: x: EBW in Compressive.Strength.28.day.phase.I , and y: ECSB in Compressive.Strength.28.day.phase.I
t = 20.8927, df = 4, p-value = 0
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
6515.396 NA
sample estimates:
mean of x mean of y
9452.261 2196.503

Pooled-Variance Two-Sample t-Test

data: x: EBW in Compressive.Strength.28.day.phase.I , and y: EDW in Compressive.Strength.28.day.phase.I
t = 17.138, df = 4, p-value = 0
alternative hypothesis: difference in means is greater than 0

95 percent confidence interval:
 2563.183 NA
sample estimates:
 mean of x mean of y
 9452.261 6524.941

Pooled-Variance Two-Sample t-Test

data: x: EBW in Compressive.Strength.28.day.phase.I , and y: EDSA in Compressive.Strength.28.day.phase.I
t = 41.8963, df = 4, p-value = 0
alternative hypothesis:
difference in means is greater than 0
95 percent confidence interval:
 4871.563 NA
sample estimates:
 mean of x mean of y
 9452.261 4319.525

Pooled-Variance Two-Sample t-Test

data: x: EBW in Compressive.Strength.28.day.phase.I , and y: EDSB in Compressive.Strength.28.day.phase.I
t = 39.7115, df = 4, p-value = 0
alternative hypothesis:
difference in means is greater than 0
95 percent confidence interval:
 6088.674 NA
sample estimates:
 mean of x mean of y
 9452.261 3018.184

Pooled-Variance Two-Sample t-Test

data: x: EBSA in Compressive.Strength.28.day.phase.I , and y: EBSB in Compressive.Strength.28.day.phase.I
t = 8.1744, df = 4, p-value = 0.0006
alternative hypothesis:
difference in means is greater than 0
95 percent confidence interval:
 934.6737 NA
sample estimates:
 mean of x mean of y
 7817.133 6552.702

Pooled-Variance Two-Sample t-Test

data: x: EBSA in Compressive.Strength.28.day.phase.I , and y: ECW in Compressive.Strength.28.day.phase.I
t = 13.0802, df = 4, p-value = 0.0001
alternative hypothesis:
difference in means is greater than 0
95 percent confidence interval:
 2822.697 NA
sample estimates:
 mean of x mean of y
 7817.133 4444.803

Pooled-Variance Two-Sample t-Test

data: x: EBSA in Compressive.Strength.28.day.phase.I , and y: ECSA in Compressive.Strength.28.day.phase.I
t = 27.1094, df = 4, p-value = 0
alternative hypothesis:
difference in means is greater than 0
95 percent confidence interval:
 3855.964 NA
sample estimates:
 mean of x mean of y
 7817.133 3632.061

Pooled-Variance Two-Sample t-Test

data: x: EBSA in Compressive.Strength.28.day.phase.I , and y: ECSB in Compressive.Strength.28.day.phase.I
t = 16.9054, df = 4, p-value = 0
alternative hypothesis:
difference in means is greater than 0
95 percent confidence interval:
 4911.844 NA
sample estimates:
 mean of x mean of y
 7817.133 2196.503

Pooled-Variance Two-Sample t-Test

data: x: EBSA in Compressive.Strength.28.day.phase.I , and y: EDW in Compressive.Strength.28.day.phase.I
t = 9.3482, df = 4, p-value = 0.0004
alternative hypothesis:
difference in means is greater than 0
95 percent confidence interval:
 997.5102 NA
sample estimates:
 mean of x mean of y
 7817.133 6524.941

Pooled-Variance Two-Sample t-Test

data: x: EBSA in Compressive.Strength.28.day.phase.I , and y: EDSA in Compressive.Strength.28.day.phase.I
t = 49.7609, df = 4, p-value = 0
alternative hypothesis:
difference in means is greater than 0
95 percent confidence interval:
 3347.764 NA
sample estimates:
 mean of x mean of y

7817.133 4319.525

Pooled-Variance Two-Sample t-Test

data: x: EBSA in Compressive.Strength.28.day.phase.I , and y: EDSB in Compressive.Strength.28.day.phase.I
t = 37.7247, df = 4, p-value = 0
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 4527.757 NA
sample estimates:
 mean of x mean of y
  7817.133 3018.184

Pooled-Variance Two-Sample t-Test

data: x: EBSB in Compressive.Strength.28.day.phase.I , and y: ECW in Compressive.Strength.28.day.phase.I
t = 7.3347, df = 4, p-value = 0.0009
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 1495.232 NA
sample estimates:
 mean of x mean of y
  6552.702 4444.803

Pooled-Variance Two-Sample t-Test

data: x: EBSB in Compressive.Strength.28.day.phase.I , and y: ECSA in Compressive.Strength.28.day.phase.I
t = 14.6118, df = 4, p-value = 0.0001
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 2494.524 NA
sample estimates:
 mean of x mean of y
  6552.702 3632.061

Pooled-Variance Two-Sample t-Test

data: x: EBSB in Compressive.Strength.28.day.phase.I , and y: ECSB in Compressive.Strength.28.day.phase.I
t = 12.2402, df = 4, p-value = 0.0001
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 3597.488 NA
sample estimates:
 mean of x mean of y
  6552.702 2196.503

Pooled-Variance Two-Sample t-Test

data: x: EBSB in Compressive.Strength.28.day.phase.I , and y: EDW in Compressive.Strength.28.day.phase.I
t = 0.1479, df = 4, p-value = 0.4448
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -372.3656 NA
sample estimates:
 mean of x mean of y
  6552.702 6524.941

Pooled-Variance Two-Sample t-Test

data: x: EBSB in Compressive.Strength.28.day.phase.I , and y: EDSA in Compressive.Strength.28.day.phase.I
t = 15.3881, df = 4, p-value = 0.0001
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 1923.795 NA
sample estimates:
 mean of x mean of y
  6552.702 4319.525

Pooled-Variance Two-Sample t-Test

data: x: EBSB in Compressive.Strength.28.day.phase.I , and y: EDSB in Compressive.Strength.28.day.phase.I
t = 19.6657, df = 4, p-value = 0
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 3151.361 NA
sample estimates:
 mean of x mean of y
  6552.702 3018.184

Pooled-Variance Two-Sample t-Test

data: x: ECW in Compressive.Strength.28.day.phase.I , and y: ECSA in Compressive.Strength.28.day.phase.I
t = 2.8296, df = 4, p-value = 0.0237
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 200.4248 NA
sample estimates:
 mean of x mean of y
  4444.803 3632.061

Pooled-Variance Two-Sample t-Test

data: x: ECW in Compressive.Strength.28.day.phase.I , and y: ECSB in Compressive.Strength.28.day.phase.I
t = 5.4657, df = 4, p-value = 0.0027
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 1371.375 NA
sample estimates:
 mean of x mean of y
 4444.803 2196.503

Pooled-Variance Two-Sample t-Test

data: x: ECW in Compressive.Strength.28.day.phase.I , and y: EDW in Compressive.Strength.28.day.phase.I
t = -7.459, df = 4, p-value = 0.9991
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -2674.661 NA
sample estimates:
 mean of x mean of y
 4444.803 6524.941

Pooled-Variance Two-Sample t-Test

data: x: ECW in Compressive.Strength.28.day.phase.I , and y: EDSA in Compressive.Strength.28.day.phase.I
t = 0.4967, df = 4, p-value = 0.3227
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -412.3775 NA
sample estimates:
 mean of x mean of y
 4444.803 4319.525

Pooled-Variance Two-Sample t-Test

data: x: ECW in Compressive.Strength.28.day.phase.I , and y: EDSB in Compressive.Strength.28.day.phase.I
t = 5.2146, df = 4, p-value = 0.0032
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 843.382 NA
sample estimates:
 mean of x mean of y
 4444.803 3018.184

Pooled-Variance Two-Sample t-Test

data: x: ECSA in Compressive.Strength.28.day.phase.I , and y: EDW in Compressive.Strength.28.day.phase.I
t = -15.4337, df = 4, p-value = 0.9999
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -3292.472 NA
sample estimates:
 mean of x mean of y
 3632.061 6524.941

Pooled-Variance Two-Sample t-Test

data: x: ECSA in Compressive.Strength.28.day.phase.I , and y: EDSA in Compressive.Strength.28.day.phase.I
t = -4.7477, df = 4, p-value = 0.9955
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -996.1542 NA
sample estimates:
 mean of x mean of y
 3632.061 4319.525

Pooled-Variance Two-Sample t-Test

data: x: ECSA in Compressive.Strength.28.day.phase.I , and y: EDSB in Compressive.Strength.28.day.phase.I
t = 3.4205, df = 4, p-value = 0.0134
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 231.2787 NA
sample estimates:
 mean of x mean of y
 3632.061 3018.184

Pooled-Variance Two-Sample t-Test

data: x: ECSB in Compressive.Strength.28.day.phase.I , and y: EDW in Compressive.Strength.28.day.phase.I
t = -12.4004, df = 4, p-value = 0.9999
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -5072.573 NA
sample estimates:
 mean of x mean of y
 2196.503 6524.941

Pooled-Variance Two-Sample t-Test

data: x: ECSB in Compressive.Strength.2

```
8.day.phase.I , and y: EDSA in Compressive.Strength.28.day.phase.I
t = -6.4699, df = 4, p-value = 0.9985
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -2822.56       NA
sample estimates:
 mean of x mean of y
  2196.503  4319.525
```

```
       Pooled-Variance Two-Sample t-Test

data:  x: ECSB in Compressive.Strength.28.day.phase.I , and y: EDSB in Compressive.Strength.28.day.phase.I
t = -2.3828, df = 4, p-value = 0.9621
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -1556.831        NA
sample estimates:
 mean of x mean of y
  2196.503  3018.184
```

```
       Pooled-Variance Two-Sample t-Test

data:  x: EDW in Compressive.Strength.28.day.phase.I , and y: EDSA in Compressive.Strength.28.day.phase.I
t = 17.3051, df = 4, p-value = 0
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 1933.727       NA
sample estimates:
 mean of x mean of y
  6524.941  4319.525
```

```
       Pooled-Variance Two-Sample t-Test

data:  x: EDW in Compressive.Strength.28.day.phase.I , and y: EDSB in Compressive.Strength.28.day.phase.I
t = 21.1528, df = 4, p-value = 0
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 3153.335       NA
sample estimates:
 mean of x mean of y
  6524.941  3018.184
```

```
       Pooled-Variance Two-Sample t-Test

data:  x: EDSA in Compressive.Strength.28.day.phase.I , and y: EDSB in Compressive.Strength.28.day.phase.I
t = 11.2769, df = 4, p-value = 0.0002
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 1055.328       NA
sample estimates:
 mean of x mean of y
  4319.525  3018.184
```

Compressive Strength Pilot Study

```
       Pooled-Variance Two-Sample t-Test

data:  x: C1 in compressive.strength..pilot.Study , and y: C5 in compressive.strength..pilot.Study
t = 4.3296, df = 4, p-value = 0.0062
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 575.2515       NA
sample estimates:
 mean of x mean of y
  11258.84   10125.6
```

```
       Pooled-Variance Two-Sample t-Test

data:  x: C1 in compressive.strength..pilot.Study , and y: C6 in compressive.strength..pilot.Study
t = 7.7865, df = 4, p-value = 0.0007
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 1561.14      NA
sample estimates:
 mean of x mean of y
  11258.84  9109.137
```

```
       Pooled-Variance Two-Sample t-Test

data:  x: C1 in compressive.strength..pilot.Study , and y: C7 in compressive.strength..pilot.Study
t = 6.1465, df = 4, p-value = 0.0018
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 859.3884       NA
sample estimates:
 mean of x mean of y
  11258.84  9943.094
```

```
      Pooled-Variance
Two-Sample t-Test

data:  x: C1 in
compressive.strength..
pilot.Study , and y:
C9 in
compressive.strength..
pilot.Study
t = 32.8963, df = 4,
p-value = 0
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 4756.99      NA
sample estimates:
 mean of x mean of y
  11258.84  6172.206


      Pooled-Variance
Two-Sample t-Test

data:  x: C1 in
compressive.strength..
pilot.Study , and y:
C10 in
compressive.strength..
pilot.Study
t = 26.4086, df = 4,
p-value = 0
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 4045.836       NA
sample estimates:
 mean of x mean of y
  11258.84  6857.717


      Pooled-Variance
Two-Sample t-Test

data:  x: C2 in
compressive.strength..
pilot.Study , and y:
C4 in
compressive.strength..
pilot.Study
t = 0.3926, df = 4, p-
value = 0.3573
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 -744.6351       NA
sample estimates:
 mean of x mean of y
  11689.54  11521.43


      Pooled-Variance
Two-Sample t-Test

data:  x: C2 in
compressive.strength..
pilot.Study , and y:
C5 in
compressive.strength..
pilot.Study
t = 3.2259, df = 4, p-
value = 0.0161
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 530.3945       NA
sample estimates:
 mean of x mean of y
  11689.54   10125.6


      Pooled-Variance
Two-Sample t-Test

data:  x: C2 in
compressive.strength..
pilot.Study , and y:
C6 in
compressive.strength..
pilot.Study
t = 5.2372, df = 4, p-
value = 0.0032
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 1530.034       NA
sample estimates:
 mean of x mean of y
  11689.54  9109.137


      Pooled-Variance
Two-Sample t-Test

data:  x: C2 in
compressive.strength..
pilot.Study , and y:
C7 in
compressive.strength..
pilot.Study
t = 3.7898, df = 4, p-
value = 0.0096
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 764.0343       NA
sample estimates:
 mean of x mean of y
  11689.54  9943.094


      Pooled-Variance
Two-Sample t-Test

data:  x: C2 in
compressive.strength..
pilot.Study , and y:
C9 in
compressive.strength..
pilot.Study
t = 12.6427, df = 4,
p-value = 0.0001
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 4586.991       NA
sample estimates:
 mean of x mean of y
  11689.54  6172.206


      Pooled-Variance
Two-Sample t-Test

data:  x: C2 in
compressive.strength..
pilot.Study , and y:
C10 in
compressive.strength..
pilot.Study
t = 10.9613, df = 4,
p-value = 0.0002
alternative
hypothesis:
difference in means is
greater than 0
95 percent confidence
interval:
 3892.089       NA
sample estimates:
 mean of x mean of y
  11689.54  6857.717


      Pooled-Variance
Two-Sample t-Test
```

data: x: C2 in compressive.strength.. pilot.Study , and y: C11 in compressive.strength.. pilot.Study
t = 1.5199, df = 4, p-value = 0.1016
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -304.0516 NA
sample estimates:
 mean of x mean of y
  11689.54 10934.45

Pooled-Variance Two-Sample t-Test

data: x: C3 in compressive.strength.. pilot.Study , and y: C4 in compressive.strength.. pilot.Study
t = -0.9927, df = 4, p-value = 0.8115
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -1051.06 NA
sample estimates:
 mean of x mean of y
   11187.5 11521.43

Pooled-Variance Two-Sample t-Test

data: x: C3 in compressive.strength.. pilot.Study , and y: C5 in compressive.strength.. pilot.Study
t = 2.6151, df = 4, p-value = 0.0296
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 196.2265 NA
sample estimates:
 mean of x mean of y
   11187.5 10125.6

Pooled-Variance Two-Sample t-Test

data: x: C3 in compressive.strength.. pilot.Study , and y: C6 in compressive.strength.. pilot.Study
t = 5.0026, df = 4, p-value = 0.0037
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 1192.672 NA
sample estimates:
 mean of x mean of y
   11187.5 9109.137

Pooled-Variance Two-Sample t-Test

data: x: C3 in compressive.strength.. pilot.Study , and y: C7 in compressive.strength.. pilot.Study
t = 3.2999, df = 4, p-value = 0.015
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 440.4747 NA
sample estimates:
 mean of x mean of y
   11187.5 9943.094

Pooled-Variance Two-Sample t-Test

data: x: C3 in compressive.strength.. pilot.Study , and y: C9 in compressive.strength.. pilot.Study
t = 14.4602, df = 4, p-value = 0.0001
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 4275.896 NA
sample estimates:
 mean of x mean of y
   11187.5 6172.206

Pooled-Variance Two-Sample t-Test

data: x: C3 in compressive.strength.. pilot.Study , and y: C10 in compressive.strength.. pilot.Study
t = 12.2879, df = 4, p-value = 0.0001
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 3578.602 NA
sample estimates:
 mean of x mean of y
   11187.5 6857.717

Pooled-Variance Two-Sample t-Test

data: x: C3 in compressive.strength.. pilot.Study , and y: C11 in compressive.strength.. pilot.Study
t = 0.602, df = 4, p-value = 0.2898
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -643.0273 NA
sample estimates:
 mean of x mean of y
   11187.5 10934.45

Pooled-Variance Two-Sample t-Test

data: x: C4 in compressive.strength.. pilot.Study , and y: C5 in

compressive.strength..
pilot.Study
t = 6.048, df = 4, p-value = 0.0019
alternative hypothesis:
difference in means is greater than 0
95 percent confidence interval:
 903.8226 NA
sample estimates:
 mean of x mean of y
 11521.43 10125.6

Pooled-Variance Two-Sample t-Test

data: x: C4 in compressive.strength.. pilot.Study , and y: C6 in compressive.strength.. pilot.Study
t = 9.7689, df = 4, p-value = 0.0003
alternative hypothesis:
difference in means is greater than 0
95 percent confidence interval:
 1885.866 NA
sample estimates:
 mean of x mean of y
 11521.43 9109.137

Pooled-Variance Two-Sample t-Test

data: x: C4 in compressive.strength.. pilot.Study , and y: C7 in compressive.strength.. pilot.Study
t = 9.0255, df = 4, p-value = 0.0004
alternative hypothesis:
difference in means is greater than 0
95 percent confidence interval:
 1205.532 NA
sample estimates:
 mean of x mean of y
 11521.43 9943.094

Pooled-Variance Two-Sample t-Test

data: x: C4 in compressive.strength.. pilot.Study , and y: C8 in compressive.strength.. pilot.Study
t = 1.142, df = 3, p-value = 0.1682
alternative hypothesis:
difference in means is greater than 0
95 percent confidence interval:
 -604.6826 NA
sample estimates:
 mean of x mean of y
 11521.43 10951.39

Pooled-Variance Two-Sample t-Test

data: x: C4 in compressive.strength.. pilot.Study , and y: C9 in compressive.strength.. pilot.Study
t = 57.46, df = 4, p-value = 0
alternative hypothesis:
difference in means is greater than 0
95 percent confidence interval:
 5150.761 NA
sample estimates:
 mean of x mean of y
 11521.43 6172.206

Pooled-Variance Two-Sample t-Test

data: x: C4 in compressive.strength.. pilot.Study , and y: C10 in compressive.strength.. pilot.Study
t = 41.6616, df = 4, p-value = 0
alternative hypothesis:
difference in means is greater than 0
95 percent confidence interval:
 4425.07 NA
sample estimates:
 mean of x mean of y
 11521.43 6857.717

Pooled-Variance Two-Sample t-Test

data: x: C4 in compressive.strength.. pilot.Study , and y: C11 in compressive.strength.. pilot.Study
t = 2.3015, df = 4, p-value = 0.0414
alternative hypothesis:
difference in means is greater than 0
95 percent confidence interval:
 43.25817 NA
sample estimates:
 mean of x mean of y
 11521.43 10934.45

Pooled-Variance Two-Sample t-Test

data: x: C5 in compressive.strength.. pilot.Study , and y: C6 in compressive.strength.. pilot.Study
t = 3.0276, df = 4, p-value = 0.0194
alternative hypothesis:
difference in means is greater than 0
95 percent confidence interval:
 300.7409 NA
sample estimates:
 mean of x mean of y
 10125.6 9109.137

Pooled-Variance Two-Sample t-Test

data: x: C5 in compressive.strength.. pilot.Study , and y: C7 in compressive.strength.. pilot.Study
t = 0.6361, df = 4, p-value = 0.2796

alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -429.1425 NA
sample estimates:
 mean of x mean of y
 10125.6 9943.094

Pooled-Variance Two-Sample t-Test

data: x: C5 in compressive.strength.. pilot.Study , and y: C9 in compressive.strength.. pilot.Study
t = 16.0859, df = 4, p-value = 0
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 3429.45 NA
sample estimates:
 mean of x mean of y
 10125.6 6172.206

Pooled-Variance Two-Sample t-Test

data: x: C5 in compressive.strength.. pilot.Study , and y: C10 in compressive.strength.. pilot.Study
t = 12.8906, df = 4, p-value = 0.0001
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 2727.438 NA
sample estimates:
 mean of x mean of y
 10125.6 6857.717

Pooled-Variance Two-Sample t-Test

data: x: C6 in compressive.strength.. pilot.Study , and y: C7 in compressive.strength.. pilot.Study
t = -0.7794, df = 4, p-value = 0.9751
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 -1473.613 NA
sample estimates:
 mean of x mean of y
 9109.137 9943.094

Pooled-Variance Two-Sample t-Test

data: x: C6 in compressive.strength.. pilot.Study , and y: C9 in compressive.strength.. pilot.Study
t = 11.2532, df = 4, p-value = 0.0002
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 2380.547 NA
sample estimates:
 mean of x mean of y
 9109.137 6172.206

Pooled-Variance Two-Sample t-Test

data: x: C6 in compressive.strength.. pilot.Study , and y: C10 in compressive.strength.. pilot.Study
t = 8.3918, df = 4, p-value = 0.0006
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 1679.47 NA
sample estimates:
 mean of x mean of y
 9109.137 6857.717

Pooled-Variance Two-Sample t-Test

data: x: C7 in compressive.strength.. pilot.Study , and y: C9 in compressive.strength.. pilot.Study
t = 19.4164, df = 4, p-value = 0
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 3356.859 NA
sample estimates:
 mean of x mean of y
 9943.094 6172.206

Pooled-Variance Two-Sample t-Test

data: x: C7 in compressive.strength.. pilot.Study , and y: C10 in compressive.strength.. pilot.Study
t = 15.1305, df = 4, p-value = 0.0001
alternative hypothesis: difference in means is greater than 0
95 percent confidence interval:
 2650.655 NA
sample estimates:
 mean of x mean of y
 9943.094 6857.717

Pooled-Variance Two-Sample t-Test

data: x: C9 in compressive.strength.. pilot.Study , and y: C11 in compressive.strength.. pilot.Study
t = -17.7248, df = 4, p-value = 0.0001

9.7 Appendix G

Stat Graphics Test Results- Multiple Sample comparison

Compressive Strength Tests – Phase II

Multiple-Sample Comparison

Summary Statistics

	Count	*Average*	*Standard deviation*	*Coeff. of variation*	*Minimum*	*Maximum*	*Range*	*Stnd. skewness*
E	3	10683.2	369.496	3.45867%	10362.2	11087.1	724.901	0.678117
T	3	10436.6	206.311	1.97681%	10284.5	10671.4	386.877	1.0716
B	3	9702.89	514.927	5.30695%	9175.7	10204.6	1028.91	-0.157058
A	3	9540.23	320.799	3.36259%	9176.75	9783.82	607.071	-1.02302
C	3	5755.3	265.676	4.6162%	5491.92	6023.21	531.294	0.0541959
Con	3	7859.57	438.87	5.5839%	7390.33	8259.92	869.592	-0.487178
D	3	8823.16	381.764	4.32684%	8509.94	9248.41	738.463	0.853317
S	3	13595.8	149.451	1.09924%	13428.0	13714.6	286.624	-0.930435
Total	24	9549.58	2193.86	22.9733%	5491.92	13714.6	8222.7	0.210525

Multiple Range Tests

Method: 95.0 percent LSD

	Count	*Mean*	*Homogeneous Groups*
C	3	5755.3	X
Con	3	7859.57	X
D	3	8823.16	X
A	3	9540.23	X
B	3	9702.89	X
T	3	10436.6	X
E	3	10683.2	X
S	3	13595.8	X

Contrast	*Sig.*	*Difference*	*+/- Limits*
E - T		246.602	605.327
E - B	*	980.274	605.327
E - A	*	1142.94	605.327
E - C	*	4927.86	605.327
E - Con	*	2823.59	605.327
E - D	*	1860.0	605.327
E - S	*	-2912.62	605.327
T - B	*	733.672	605.327
T - A	*	896.335	605.327
T - C	*	4681.26	605.327
T - Con	*	2576.99	605.327
T - D	*	1613.4	605.327
T - S	*	-3159.23	605.327
B - A		162.663	605.327
B - C	*	3947.59	605.327
B - Con	*	1843.32	605.327
B - D	*	879.725	605.327
B - S	*	-3892.9	605.327
A - C	*	3784.92	605.327
A - Con	*	1680.66	605.327
A - D	*	717.062	605.327
A - S	*	-4055.56	605.327
C - Con	*	-2104.27	605.327
C - D	*	-3067.86	605.327
C - S	*	-7840.49	605.327
Con - D	*	-963.594	605.327
Con - S	*	-5736.22	605.327
D - S	*	-4772.62	605.327

* denotes a statistically significant difference.

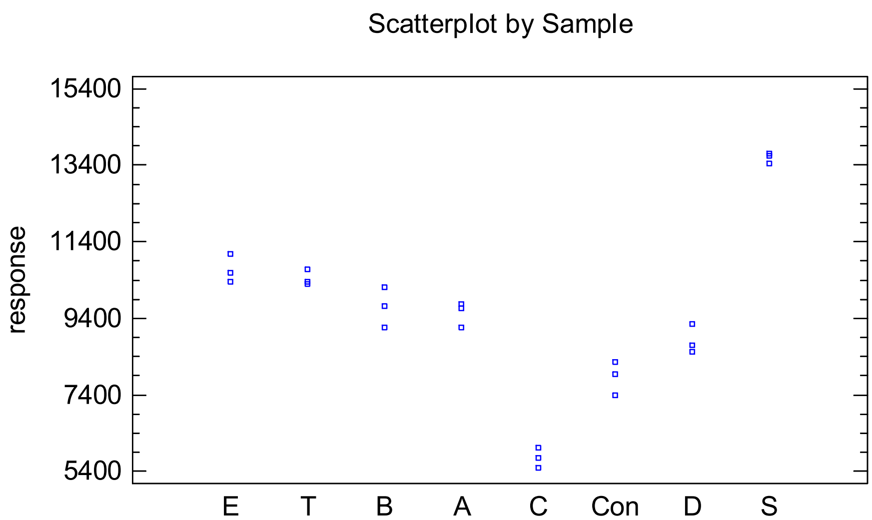
The StatAdvisor
This table applies a multiple comparison procedure to determine which means are significantly different from which others. The bottom half of the output shows the estimated difference between each pair of means. An asterisk has been placed next to 26 pairs, indicating that these pairs show statistically significant differences at the 95.0% confidence level. At the top of the page, 6

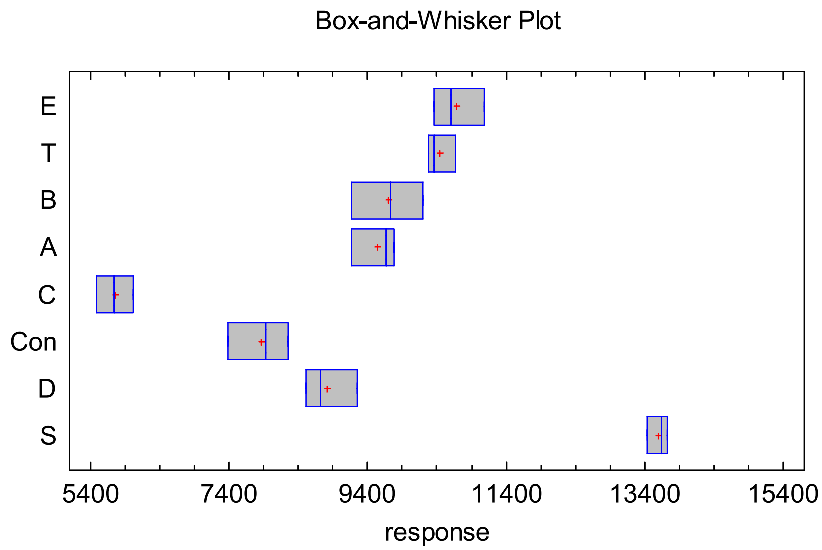
homogenous groups are identified using columns of X's. Within each column, the levels containing X's form a group of means within which there are no statistically significant differences. The method currently being used to discriminate among the means is Fisher's least significant difference (LSD) procedure. With this method, there is a 5.0% risk of calling each pair of means significantly different when the actual difference equals 0.

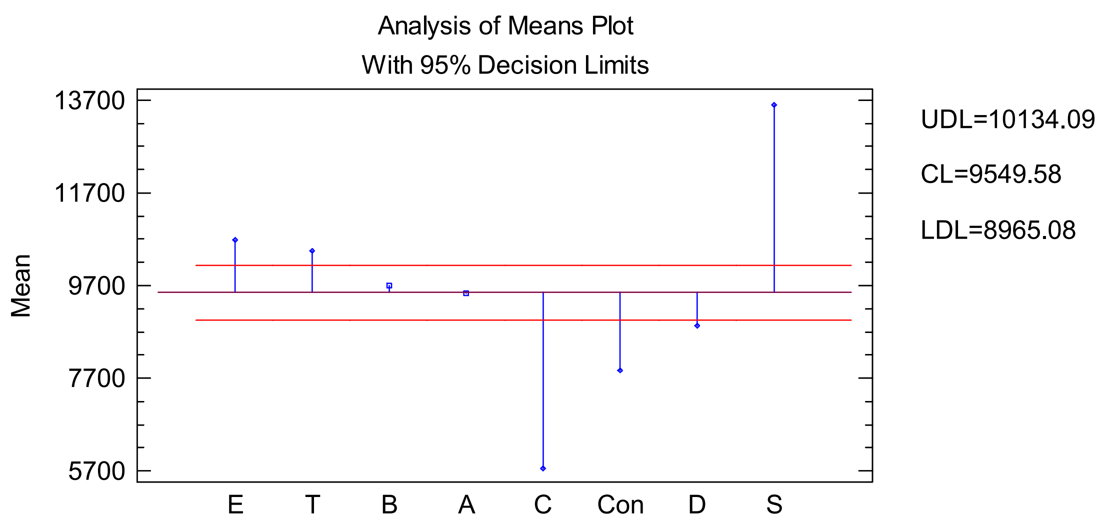
Variance Check

	Test	*P-Value*
Levene's	0.380298	0.900565

The StatAdvisor
The statistic displayed in this table tests the null hypothesis that the standard deviations within each of the 8 columns are the same. Of particular interest is the P-value. Since the the P-value is greater than or equal to 0.05, there is not a statistically significant difference amongst the standard deviations at the 95.0% confidence level.




Box-and-Whisker Plot
E
T
B
A
C
Con
D
S
5400
7400
9400
11400
13400
15400
response


Analysis of Means Plot
With 95% Decision Limits
13700
11700
9700
7700
5700
Mean
E
T
B
A
C
Con
D
S
UDL=10134.09
CL=9549.58
LDL=8965.08

****

Chloride Ion Penetration test- Phase I

Summary Statistics

	Count	*Average*	*Standard deviation*	*Coeff. of variation*	*Minimum*	*Maximum*	*Range*	*Stnd. skewness*
CSA	4	4253.75	245.803	5.77849%	4042.0	4532.0	490.0	0.231304
CSB	4	4418.75	459.473	10.3983%	3940.0	5043.0	1103.0	0.740261
CW	4	1709.04	188.482	11.0285%	1449.09	1896.21	447.121	-0.875367
EASA	4	2111.81	360.279	17.0602%	1830.12	2632.86	802.741	1.30505
EASB	4	1921.57	315.191	16.4028%	1600.13	2328.66	728.531	0.536096
EAW	4	1123.73	105.639	9.40071%	1060.18	1281.69	221.508	1.6021
EBSA	4	2044.0	133.049	6.50924%	1929.0	2226.0	297.0	0.919609
EBSB	4	2312.5	439.788	19.0179%	1810.0	2839.0	1029.0	0.11039
EBW	3	1047.33	56.6068	5.40485%	984.0	1093.0	109.0	-0.896349
ECSA	4	3030.75	385.557	12.7215%	2570.0	3512.0	942.0	0.12903
ECSB	4	5638.25	788.913	13.9922%	4536.0	6222.0	1686.0	-1.07284
ECW	4	955.394	90.5175	9.47436%	871.574	1083.0	211.426	1.06237
EDSA	4	3566.0	417.335	11.7032%	3034.0	4031.0	997.0	-0.35824
EDSB	4	4245.75	381.773	8.99187%	3770.0	4671.0	901.0	-0.27944
EDW	4	686.25	110.846	16.1525%	560.0	826.0	266.0	0.275798
Total	59	2630.72	1502.41	57.1103%	560.0	6222.0	5662.0	1.83343

ANOVA Table

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	1.25303E8	14	8.95023E6	70.12	0.0000
Within groups	5.61617E6	44	127640.		
Total (Corr.)	1.30919E8	58			

The StatAdvisor

The ANOVA table decomposes the variance of the data into two components: a between-group component and a within-group component. The F-ratio, which in this case equals 70.1208, is a ratio of the between-group estimate to the within-group estimate. Since the P-value of the F-test is less than 0.05, there is a statistically significant difference between the means of the 15 variables at the 95.0% confidence level. To determine which means are significantly different from which others, select Multiple Range Tests from the list of Tabular Options.

Multiple Range Tests

Method: 95.0 percent LSD

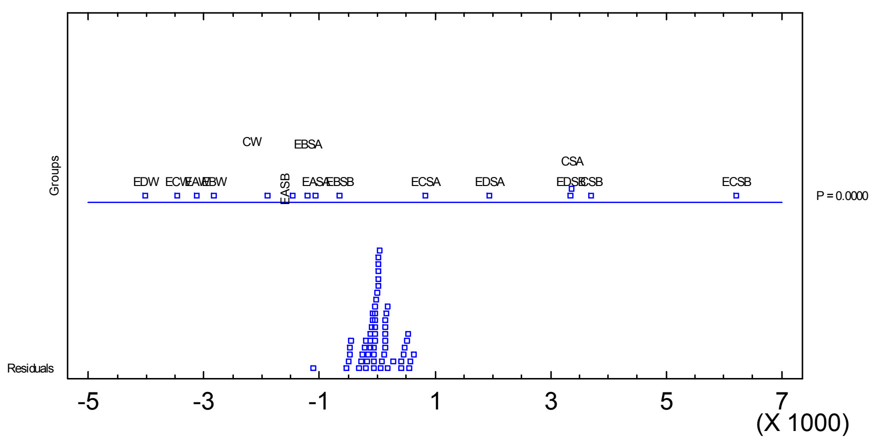
	Count	*Mean*	*Homogeneous Groups*
EDW	4	686.25	X
ECW	4	955.394	X
EBW	3	1047.33	X
EAW	4	1123.73	X
CW	4	1709.04	X
EASB	4	1921.57	XX
EBSA	4	2044.0	XX
EASA	4	2111.81	XX
EBSB	4	2312.5	X
ECSA	4	3030.75	X
EDSA	4	3566.0	X
EDSB	4	4245.75	X
CSA	4	4253.75	X
CSB	4	4418.75	X
ECSB	4	5638.25	X

Contrast	Sig.	Difference	+/- Limits
CSA - CSB		-165.0	509.136
CSA - CW	*	2544.71	509.136
CSA - EASA	*	2141.94	509.136
CSA - EASB	*	2332.18	509.136
CSA - EAW	*	3130.02	509.136
CSA - EBSA	*	2209.75	509.136
CSA - EBSB	*	1941.25	509.136
CSA - EBW	*	3206.42	549.93
CSA - ECSA	*	1223.0	509.136
CSA - ECSB	*	-1384.5	509.136
CSA - ECW	*	3298.36	509.136
CSA - EDSA	*	687.75	509.136
CSA - EDSB		8.0	509.136
CSA - EDW	*	3567.5	509.136
CSB - CW	*	2709.71	509.136
CSB - EASA	*	2306.94	509.136
CSB - EASB	*	2497.18	509.136
CSB - EAW	*	3295.02	509.136
CSB - EBSA	*	2374.75	509.136
CSB - EBSB	*	2106.25	509.136
CSB - EBW	*	3371.42	549.93
CSB - ECSA	*	1388.0	509.136
CSB - ECSB	*	-1219.5	509.136
CSB - ECW	*	3463.36	509.136
CSB - EDSA	*	852.75	509.136
CSB - EDSB		173.0	509.136
CSB - EDW	*	3732.5	509.136
CW - EASA		-402.773	509.136
CW - EASB		-212.534	509.136
CW - EAW	*	585.308	509.136
CW - EBSA		-334.961	509.136
CW - EBSB	*	-603.461	509.136
CW - EBW	*	661.705	549.93
CW - ECSA	*	-1321.71	509.136
CW - ECSB	*	-3929.21	509.136
CW - ECW	*	753.645	509.136
CW - EDSA	*	-1856.96	509.136
CW - EDSB	*	-2536.71	509.136
CW - EDW	*	1022.79	509.136
EASA - EASB		190.239	509.136
EASA - EAW	*	988.081	509.136
EASA - EBSA		67.8118	509.136
EASA - EBSB		-200.688	509.136
EASA - EBW	*	1064.48	549.93
EASA - ECSA	*	-918.938	509.136
EASA - ECSB	*	-3526.44	509.136
EASA - ECW	*	1156.42	509.136
EASA - EDSA	*	-1454.19	509.136
EASA - EDSB	*	-2133.94	509.136
EASA - EDW	*	1425.56	509.136
EASB - EAW	*	797.842	509.136
EASB - EBSA		-122.428	509.136
EASB - EBSB		-390.928	509.136
EASB - EBW	*	874.239	549.93
EASB - ECSA	*	-1109.18	509.136
EASB - ECSB	*	-3716.68	509.136
EASB - ECW	*	966.179	509.136
EASB - EDSA	*	-1644.43	509.136
EASB - EDSB	*	-2324.18	509.136
EASB - EDW	*	1235.32	509.136
EAW - EBSA	*	-920.27	509.136
EAW - EBSB	*	-1188.77	509.136
EAW - EBW		76.397	549.93
EAW - ECSA	*	-1907.02	509.136
EAW - ECSB	*	-4514.52	509.136
EAW - ECW		168.337	509.136
EAW - EDSA	*	-2442.27	509.136
EAW - EDSB	*	-3122.02	509.136
EAW - EDW		437.48	509.136
EBSA - EBSB		-268.5	509.136
EBSA - EBW	*	996.667	549.93
EBSA - ECSA	*	-986.75	509.136
EBSA - ECSB	*	-3594.25	509.136
EBSA - ECW	*	1088.61	509.136
EBSA - EDSA	*	-1522.0	509.136
EBSA - EDSB	*	-2201.75	509.136
EBSA - EDW	*	1357.75	509.136
EBSB - EBW	*	1265.17	549.93
EBSB - ECSA	*	-718.25	509.136
EBSB - ECSB	*	-3325.75	509.136
EBSB - ECW	*	1357.11	509.136
EBSB - EDSA	*	-1253.5	509.136
EBSB - EDSB	*	-1933.25	509.136
EBSB - EDW	*	1626.25	509.136
EBW - ECSA	*	-1983.42	549.93
EBW - ECSB	*	-4590.92	549.93
EBW - ECW		91.9398	549.93
EBW - EDSA	*	-2518.67	549.93
EBW - EDSB	*	-3198.42	549.93
EBW - EDW		361.083	549.93
ECSA - ECSB	*	-2607.5	509.136
ECSA - ECW	*	2075.36	509.136
ECSA - EDSA	*	-535.25	509.136
ECSA - EDSB	*	-1215.0	509.136
ECSA - EDW	*	2344.5	509.136
ECSB - ECW	*	4682.86	509.136
ECSB - EDSA	*	2072.25	509.136
ECSB - EDSB	*	1392.5	509.136
ECSB - EDW	*	4952.0	509.136
ECW - EDSA	*	-2610.61	509.136
ECW - EDSB	*	-3290.36	509.136
ECW - EDW		269.144	509.136
EDSA - EDSB	*	-679.75	509.136
EDSA - EDW	*	2879.75	509.136
EDSB - EDW	*	3559.5	509.136

* denotes a statistically significant difference.

The StatAdvisor
This table applies a multiple comparison procedure to determine which means are significantly different from which others. The bottom half of the output shows the estimated difference between each pair of means. An asterisk has been placed next to 87 pairs, indicating that these pairs show statistically significant differences at the 95.0% confidence level. At the top of the page, 7 homogenous groups are identified using columns of X's. Within each column, the levels containing X's form a group of means within which there are no statistically significant differences. The method currently being used to discriminate among the means is Fisher's least significant difference (LSD) procedure. With this method, there is a 5.0% risk of calling each pair of means significantly different when the actual difference equals 0.

Graphical ANOVA for CSA



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Chloride Ion Penetration test- Phase II

Summary Statistics

	Count	*Average*	*Standard deviation*	*Coeff. of variation*	*Minimum*	*Maximum*	*Range*	*Stnd. skewness*	*Stnd. kurtosis*
E	4	311.75	43.9801	14.1075%	255.0	353.0	98.0	-0.601256	-0.478144
T	4	288.5	21.1739	7.3393%	258.0	307.0	49.0	-1.23856	1.15864
A	4	318.75	14.7281	4.62058%	300.0	334.0	34.0	-0.462907	-0.286955
C	4	551.25	117.227	21.2657%	460.0	723.0	263.0	1.40445	1.30761
Con	4	658.0	254.253	38.6403%	445.0	958.0	513.0	0.331939	-1.50992
D	4	267.5	21.2368	7.93898%	243.0	291.0	48.0	-0.0811571	-0.924567
S	4	226.0	28.4605	12.5931%	197.0	260.0	63.0	0.276971	-1.05641
Total	28	374.536	181.043	48.3379%	197.0	958.0	761.0	4.19231	3.89927

ANOVA Table

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	638223.	6	106370.	9.05	0.0001
Within groups	246742.	21	11749.6		
Total (Corr.)	884965.	27			

The StatAdvisor
The ANOVA table decomposes the variance of the data into two components: a between-group component and a within-group component. The F-ratio, which in this case equals 9.05309, is a ratio of the between-group estimate to the within-group estimate. Since the P-value of the F-test is less than 0.05, there is a statistically significant difference between the means of the 7 variables at the 95.0% confidence level. To determine which means are significantly different from which others, select Multiple Range Tests from the list of Tabular Options.

Multiple Range Tests

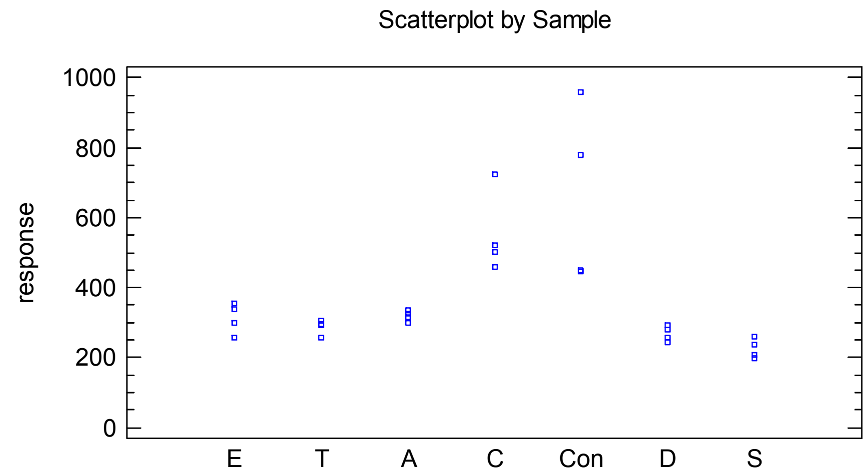
Method: 95.0 percent LSD

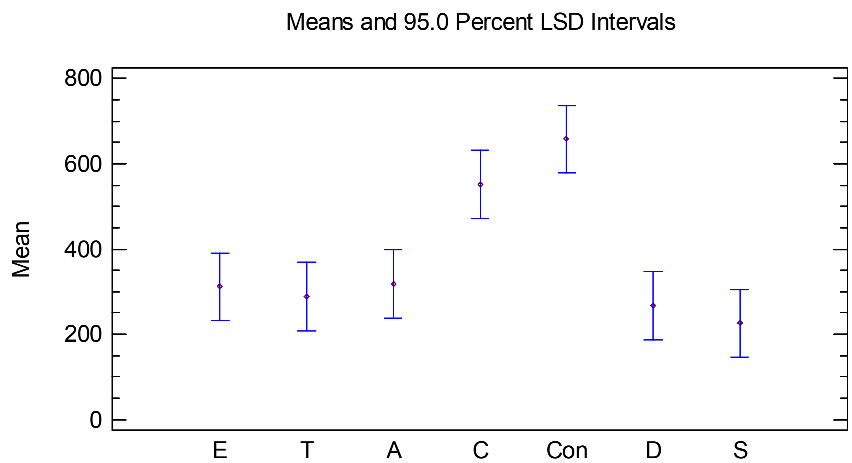
	Count	*Mean*	*Homogeneous Groups*
S	4	226.0	X
D	4	267.5	X
T	4	288.5	X
E	4	311.75	X
A	4	318.75	X
C	4	551.25	X
Con	4	658.0	X

Contrast	*Sig.*	*Difference*	*+/- Limits*
E - T		23.25	159.397
E - A		-7.0	159.397
E - C	*	-239.5	159.397
E - Con	*	-346.25	159.397
E - D		44.25	159.397
E - S		85.75	159.397
T - A		-30.25	159.397
T - C	*	-262.75	159.397
T - Con	*	-369.5	159.397
T - D		21.0	159.397
T - S		62.5	159.397
A - C	*	-232.5	159.397
A - Con	*	-339.25	159.397
A - D		51.25	159.397
A - S		92.75	159.397
C - Con		-106.75	159.397
C - D	*	283.75	159.397
C - S	*	325.25	159.397
Con - D	*	390.5	159.397
Con - S	*	432.0	159.397
D - S		41.5	159.397

* denotes a statistically significant difference.

The StatAdvisor
This table applies a multiple comparison procedure to determine which means are significantly different from which others. The bottom half of the output shows the estimated difference between each pair of means. An asterisk has been placed next to 10 pairs, indicating that these pairs show statistically significant differences at the 95.0% confidence level. At the top of the page, 2 homogenous groups are identified using columns of X's. Within each column, the levels containing X's form a group of means within which there are no statistically significant differences. The method currently being used to discriminate among the means is Fisher's least significant difference (LSD) procedure. With this method, there is a 5.0% risk of calling each pair of means significantly different when the actual difference equals 0.





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Compressive Strength test- Phase I

Summary Statistics

	Count	*Average*	*Standard deviation*	*Coeff. of variation*	*Minimum*	*Maximum*	*Range*	*Stnd. skewness*
CSA	3	3876.6	247.861	6.39378%	3612.34	4103.92	491.578	-0.463588
CSB	3	2976.58	157.574	5.29378%	2806.4	3117.43	311.026	-0.571727
CW	3	6517.3	214.583	3.29251%	6329.62	6751.24	421.619	0.654108
EASA	3	5880.0	301.38	5.12551%	5533.46	6080.87	547.409	-1.1787

EASB	3	4570.79	199.692	4.36887%	4374.36	4773.59	399.232	0.10128
EAW	3	7193.41	506.491	7.04104%	6679.28	7691.9	1012.62	-0.0980901
EBSA	3	7817.13	108.207	1.38423%	7710.71	7927.04	216.329	0.10241
EBSB	3	6552.7	245.092	3.74033%	6277.72	6748.15	470.43	-0.923845
EBW	3	9452.26	204.729	2.16592%	9313.24	9687.36	374.122	1.16437
ECSA	3	3632.06	244.516	6.73215%	3351.73	3801.38	449.648	-1.14685
ECSB	3	2196.5	565.606	25.7503%	1823.18	2847.26	1024.07	1.18527
ECW	3	4444.8	433.249	9.74732%	4097.29	4930.22	832.927	0.910208
EDSA	3	4319.52	55.7908	1.2916%	4256.69	4363.25	106.559	-0.962074
EDSB	3	3018.18	191.933	6.35921%	2883.61	3237.97	354.355	1.13427
EDW	3	6524.94	213.571	3.27315%	6310.05	6737.16	427.118	-0.0397661
Total	45	5264.85	2025.27	38.4677%	1823.18	9687.36	7864.17	0.97808

ANOVA Table

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	1.77903E8	14	1.27073E7	148.20	0.0000
Within groups	2.57242E6	30	85747.3		
Total (Corr.)	1.80475E8	44			

The StatAdvisor

The ANOVA table decomposes the variance of the data into two components: a between-group component and a within-group component. The F-ratio, which in this case equals 148.195, is a ratio of the between-group estimate to the within-group estimate. Since the P-value of the F-test is less than 0.05, there is a statistically significant difference between the means of the 15 variables at the 95.0% confidence level. To determine which means are significantly different from which others, select Multiple Range Tests from the list of Tabular Options.

Multiple Range Tests

Method: 95.0 percent LSD

	Count	*Mean*	*Homogeneous Groups*
ECSB	3	2196.5	X
CSB	3	2976.58	X
EDSB	3	3018.18	X
ECSA	3	3632.06	X
CSA	3	3876.6	XX
EDSA	3	4319.52	XX
ECW	3	4444.8	X
EASB	3	4570.79	X
EASA	3	5880.0	X
CW	3	6517.3	X
EDW	3	6524.94	X
EBSB	3	6552.7	X
EAW	3	7193.41	X
EBSA	3	7817.13	X
EBW	3	9452.26	X

Contrast	*Sig.*	*Difference*	*+/- Limits*
CSA - CSB	*	900.018	488.291
CSA - CW	*	-2640.71	488.291
CSA - EASA	*	-2003.4	488.291
CSA - EASB	*	-694.192	488.291
CSA - EAW	*	-3316.81	488.291
CSA - EBSA	*	-3940.54	488.291
CSA - EBSB	*	-2676.1	488.291
CSA - EBW	*	-5575.66	488.291
CSA - ECSA		244.537	488.291
CSA - ECSB	*	1680.09	488.291
CSA - ECW	*	-568.205	488.291
CSA - EDSA		-442.927	488.291
CSA - EDSB	*	858.414	488.291
CSA - EDW	*	-2648.34	488.291
CSB - CW	*	-3540.72	488.291
CSB - EASA	*	-2903.42	488.291
CSB - EASB	*	-1594.21	488.291

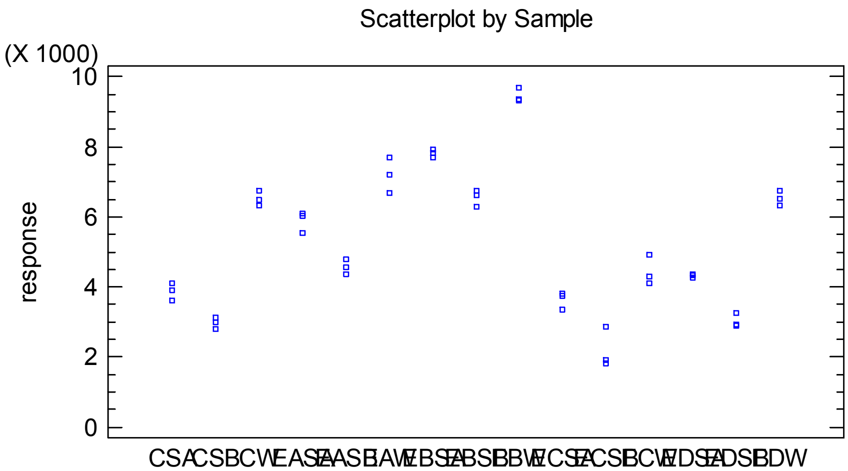
CSB - EAW	*	-4216.83	488.291
CSB - EBSA	*	-4840.55	488.291
CSB - EBSB	*	-3576.12	488.291
CSB - EBW	*	-6475.68	488.291
CSB - ECSA	*	-655.481	488.291
CSB - ECSB	*	780.076	488.291
CSB - ECW	*	-1468.22	488.291
CSB - EDSA	*	-1342.95	488.291
CSB - EDSB		-41.6047	488.291
CSB - EDW	*	-3548.36	488.291
CW - EASA	*	637.301	488.291
CW - EASB	*	1946.51	488.291
CW - EAW	*	-676.104	488.291
CW - EBSA	*	-1299.83	488.291
CW - EBSB		-35.3992	488.291
CW - EBW	*	-2934.96	488.291
CW - ECSA	*	2885.24	488.291
CW - ECSB	*	4320.8	488.291
CW - ECW	*	2072.5	488.291
CW - EDSA	*	2197.78	488.291
CW - EDSB	*	3499.12	488.291
CW - EDW		-7.63778	488.291
EASA - EASB	*	1309.21	488.291
EASA - EAW	*	-1313.4	488.291
EASA - EBSA	*	-1937.13	488.291
EASA - EBSB	*	-672.7	488.291
EASA - EBW	*	-3572.26	488.291
EASA - ECSA	*	2247.94	488.291
EASA - ECSB	*	3683.5	488.291
EASA - ECW	*	1435.2	488.291
EASA - EDSA	*	1560.48	488.291
EASA - EDSB	*	2861.82	488.291
EASA - EDW	*	-644.939	488.291
EASB - EAW	*	-2622.62	488.291
EASB - EBSA	*	-3246.34	488.291
EASB - EBSB	*	-1981.91	488.291
EASB - EBW	*	-4881.47	488.291
EASB - ECSA	*	938.729	488.291
EASB - ECSB	*	2374.29	488.291
EASB - ECW		125.987	488.291
EASB - EDSA		251.265	488.291
EASB - EDSB	*	1552.61	488.291
EASB - EDW	*	-1954.15	488.291
EAW - EBSA	*	-623.726	488.291
EAW - EBSB	*	640.704	488.291
EAW - EBW	*	-2258.85	488.291

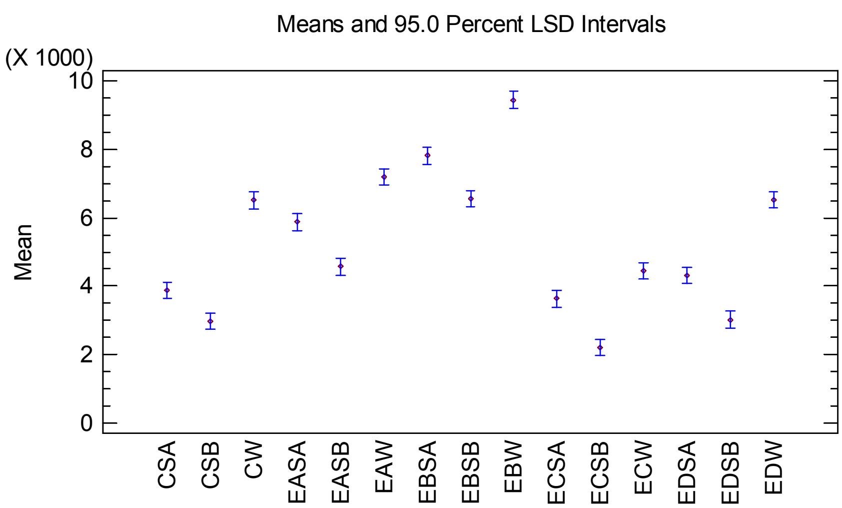
EAW - ECSA	*	3561.35	488.291
EAW - ECSB	*	4996.9	488.291
EAW - ECW	*	2748.6	488.291
EAW - EDSA	*	2873.88	488.291
EAW - EDSB	*	4175.22	488.291
EAW - EDW	*	668.466	488.291
EBSA - EBSB	*	1264.43	488.291
EBSA - EBW	*	-1635.13	488.291
EBSA - ECSA	*	4185.07	488.291
EBSA - ECSB	*	5620.63	488.291
EBSA - ECW	*	3372.33	488.291
EBSA - EDSA	*	3497.61	488.291
EBSA - EDSB	*	4798.95	488.291
EBSA - EDW	*	1292.19	488.291
EBSB - EBW	*	-2899.56	488.291
EBSB - ECSA	*	2920.64	488.291
EBSB - ECSB	*	4356.2	488.291
EBSB - ECW	*	2107.9	488.291
EBSB - EDSA	*	2233.18	488.291
EBSB - EDSB	*	3534.52	488.291
EBSB - EDW		27.7615	488.291
EBW - ECSA	*	5820.2	488.291
EBW - ECSB	*	7255.76	488.291
EBW - ECW	*	5007.46	488.291
EBW - EDSA	*	5132.74	488.291
EBW - EDSB	*	6434.08	488.291
EBW - EDW	*	2927.32	488.291
ECSA - ECSB	*	1435.56	488.291
ECSA - ECW	*	-812.742	488.291
ECSA - EDSA	*	-687.464	488.291
ECSA - EDSB	*	613.877	488.291
ECSA - EDW	*	-2892.88	488.291
ECSB - ECW	*	-2248.3	488.291
ECSB - EDSA	*	-2123.02	488.291
ECSB - EDSB	*	-821.681	488.291
ECSB - EDW	*	-4328.44	488.291
ECW - EDSA		125.278	488.291
ECW - EDSB	*	1426.62	488.291
ECW - EDW	*	-2080.14	488.291
EDSA - EDSB	*	1301.34	488.291
EDSA - EDW	*	-2205.42	488.291
EDSB - EDW	*	-3506.76	488.291

* denotes a statistically significant difference.

The StatAdvisor

This table applies a multiple comparison procedure to determine which means are significantly different from which others. The bottom half of the output shows the estimated difference between each pair of means. An asterisk has been placed next to 96 pairs, indicating that these pairs show statistically significant differences at the 95.0% confidence level. At the top of the page, 10 homogenous groups are identified using columns of X's. Within each column, the levels containing X's form a group of means within which there are no statistically significant differences. The method currently being used to discriminate among the means is Fisher's least significant difference (LSD) procedure. With this method, there is a 5.0% risk of calling each pair of means significantly different when the actual difference equals 0.





Compressive Strength Test-Pilot study

Summary Statistics

	Count	*Average*	*Standard deviation*	*Coeff. of variation*	*Minimum*	*Maximum*	*Range*	*Stnd. skewness*
Col_1	3	11258.8	219.14	1.94638%	11012.4	11431.7	419.298	-0.948754
Col_10	3	6857.72	187.88	2.73969%	6643.2	6993.02	349.817	-1.10309
Col_11	3	10934.4	439.153	4.01623%	10552.5	11414.3	861.774	0.674252
Col_2	3	11689.5	740.026	6.33067%	10925.3	12402.7	1477.4	-0.218763
Col_3	3	11187.5	580.671	5.19035%	10558.1	11702.4	1144.29	-0.602889

Col_4	3	11521.4	47.9009	0.415755%	11466.7	11555.5	88.8065	-1.11966
Col_5	3	10125.6	396.863	3.9194%	9672.54	10411.8	739.225	-1.10143
Col_6	3	9109.14	425.014	4.6658%	8680.37	9530.3	849.926	-0.0568873
Col_7	3	9943.09	299.08	3.00791%	9622.6	10214.7	592.145	-0.505855
Col_9	3	6172.21	153.966	2.4945%	6044.7	6343.25	298.554	0.827866
Total	30	9879.95	1911.17	19.3439%	6044.7	12402.7	6357.98	-2.12626

ANOVA Table

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	1.02695E8	9	1.14106E7	70.67	0.0000
Within groups	3.22916E6	20	161458.		
Total (Corr.)	1.05925E8	29			

The StatAdvisor

The ANOVA table decomposes the variance of the data into two components: a between-group component and a within-group component. The F-ratio, which in this case equals 70.6723, is a ratio of the between-group estimate to the within-group estimate. Since the P-value of the F-test is less than 0.05, there is a statistically significant difference between the means of the 10 variables at the 95.0% confidence level. To determine which means are significantly different from which others, select Multiple Range Tests from the list of Tabular Options.

Multiple Range Tests

Method: 95.0 percent LSD

	Count	*Mean*	*Homogeneous Groups*
Col_9	3	6172.21	X
Col_10	3	6857.72	X
Col_6	3	9109.14	X
Col_7	3	9943.09	X
Col_5	3	10125.6	X
Col_11	3	10934.4	X
Col_3	3	11187.5	XX
Col_1	3	11258.8	XX
Col_4	3	11521.4	XX
Col_2	3	11689.5	X

Contrast	*Sig.*	*Difference*	*+/- Limits*
Col_1 - Col_10	*	4401.12	684.371
Col_1 - Col_11		324.388	684.371
Col_1 - Col_2		-430.708	684.371
Col_1 - Col_3		71.3342	684.371
Col_1 - Col_4		-262.596	684.371
Col_1 - Col_5	*	1133.24	684.371
Col_1 - Col_6	*	2149.7	684.371
Col_1 - Col_7	*	1315.74	684.371
Col_1 - Col_9	*	5086.63	684.371
Col_10 - Col_11	*	-4076.73	684.371
Col_10 - Col_2	*	-4831.83	684.371
Col_10 - Col_3	*	-4329.78	684.371
Col_10 - Col_4	*	-4663.71	684.371
Col_10 - Col_5	*	-3267.88	684.371
Col_10 - Col_6	*	-2251.42	684.371
Col_10 - Col_7	*	-3085.38	684.371
Col_10 - Col_9	*	685.511	684.371
Col_11 - Col_2	*	-755.095	684.371
Col_11 - Col_3		-253.053	684.371
Col_11 - Col_4		-586.983	684.371
Col_11 - Col_5	*	808.852	684.371
Col_11 - Col_6	*	1825.31	684.371
Col_11 - Col_7	*	991.354	684.371
Col_11 - Col_9	*	4762.24	684.371
Col_2 - Col_3		502.042	684.371
Col_2 - Col_4		168.112	684.371
Col_2 - Col_5	*	1563.95	684.371
Col_2 - Col_6	*	2580.41	684.371
Col_2 - Col_7	*	1746.45	684.371
Col_2 - Col_9	*	5517.34	684.371
Col_3 - Col_4		-333.93	684.371
Col_3 - Col_5	*	1061.91	684.371
Col_3 - Col_6	*	2078.36	684.371
Col_3 - Col_7	*	1244.41	684.371
Col_3 - Col_9	*	5015.3	684.371
Col_4 - Col_5	*	1395.84	684.371
Col_4 - Col_6	*	2412.29	684.371
Col_4 - Col_7	*	1578.34	684.371
Col_4 - Col_9	*	5349.23	684.371

Col_5 - Col_6	*	1016.46	684.371
Col_5 - Col_7		182.502	684.371
Col_5 - Col_9	*	3953.39	684.371

Col_6 - Col_7	*	-833.957	684.371
Col_6 - Col_9	*	2936.93	684.371
Col_7 - Col_9	*	3770.89	684.371

* denotes a statistically significant difference.

The StatAdvisor

This table applies a multiple comparison procedure to determine which means are significantly different from which others. The bottom half of the output shows the estimated difference between each pair of means. An asterisk has been placed next to 35 pairs, indicating that these pairs show statistically significant differences at the 95.0% confidence level. At the top of the page, 6 homogenous groups are identified using columns of X's. Within each column, the levels containing X's form a group of means within which there are no statistically significant differences. The method currently being used to discriminate among the means is Fisher's least significant difference (LSD) procedure. With this method, there is a 5.0% risk of calling each pair of means significantly different when the actual difference equals 0.