The Properties of Cement-Sawdust Mortars, Plain, and with Various Admixtures

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Prefatory Note

By P. M. Brandt,

Professor of Dairy Husbandry

A MODERN dairy barn should have a floor impervious, easily cleaned, and made of durable materials. Ordinary concrete is the best material to meet these requirements but is objected to by many dairymen because of its coldness, which frequently results in injury to the udders of cows. This objection is well taken.

The possibility of preparing a concrete mixture that has all the sanitary advantages expected of any floor material, plus lasting qualities, and that eliminates the objection of coldness or high heat conductivity is definitely suggested in this bulletin. A durable concrete floor that is practically as warm as an ordinary wood floor is assured by using the cement-sawdust mixture. This makes it possible for dairymen to meet the most rigid sanitary requirements of floor construction and at the same time give the cows adequate protection from contact with the ordinary cold concrete barn floor or floors constructed of other impervious materials.

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I. INTRODUCTION

1. **Purpose and scope of study.** Inquiries from farmers, county agents, and contractors requesting information concerning the use of sawdust as an aggregate in Portland cement mortar or concrete have been received frequently enough to draw attention to the problem. This work was undertaken with the view of obtaining data regarding the properties of the cement-sawdust and of the cement-sand-sawdust systems, with particular interest centered on the compressive strengths and thermal conductivities.

Various admixtures were tried with the hope of increasing the strength or of reducing the cement requirements for a given strength. But in no case was the sawdust "processed" or "treated" other than in mixing.

2. **Historical.**[1] The use of sawdust or ground wood as an aggregate with various binding materials is very old. The Arabs, before the days of Egypt, used ground wood in their pottery, using a natural clay as a binder. This practice was later carried into central Europe and is still used to some extent in Germany. The Germans today use sawdust with lime, plaster of Paris, or cement, as a plaster for walls, floors, and roofs, much like the usual plaster in American construction where hair or other fibrous material is more commonly used.

The advantages of the sawdust in these materials are usually given as (1) lower thermal conductivity, (2) greater resistance to settling, vibration, and impact, and (3) better resistance to weather changes.

Lately a few attempts have been made to use sawdust with Portland cement in the manufacture of table tops for lunch counters and dining tables. Sand is usually incorporated here in order to obtain a finer, smoother surface, and in some cases by using a clean white sand to impart a luster to the mix.

Several American patents have been taken involving the use of sawdust as an aggregate in plaster and stucco construction. These patents, however, cover the use of a specific material added to the cement-sawdust mix or a specific preparation made from sawdust. At present there is in force no patent covering the mixtures used in this work, nor is it likely that such are patentable.

3. **Materials used.** It was not desired to evolve or formulate a manufacturing process or a preparation made from sawdust, but to use materials available to the small contractor or to persons making small constructions. In order to follow this plan more closely two samples of Douglas fir sawdust were used. The first consisted of sawdust taken from the resaw, containing little or no bark. The second consisted of sawdust taken from the main saw and containing appreciable amounts of bark. This latter sawdust is typical of the usual mill product and is available in enormous quantities in the Northwest.

The size of the sawdust particles depends on the saw from which they come. A sieve analysis, using Tyler standard-screen scale sieves, of the sawdust used in this work gave the following results:

	%
Passing 35-mesh	9.0
Passing 28-mesh and retained on 35-mesh	12.5
Passing 20-mesh and retained on 28-mesh	22.0
Passing 14-mesh and retained on 20-mesh	26.1
Passing 10-mesh and retained on 14-mesh	23.4
Passing 4-mesh and retained on 10-mesh	7.0
	100.0

A chemical analysis[2] of the water-soluble material in the sawdust gave the following results for the two types of sawdust:

	Bark free %	Containing bark %
Water soluble	3.6	4.3
Acid	0.66	0.77
Tannin	0.95	1.10
Reducing sugar	Traces	0.03
Colloidal material	1.05	1.40

The water extracts of both were strongly amphoteric, being pink in alkaline solution and slightly yellow in acid.

The sand used was from the Willamette River at Corvallis, and can be said to be representative of the sand available for general use. A sieve analysis of this sand, using Tyler standard-screen scale sieves, gave the following results:

	%
Passing 100-mesh	1.5
Passing 48-mesh and retained on 100-mesh	23.2
Passing 28-mesh and retained on 48-mesh	43.3
Passing 14-mesh and retained on 28-mesh	26.3
Passing 8-mesh and retained on 14-mesh	5.4
Passing 4-mesh and retained on 8-mesh	0.3
	100.0

The Portland cement used was a well-known Pacific Coast brand, and passed the standard A. S. T. M. tests.[3]

The materials added to the cement-sawdust and the cement-sand-sawdust systems include: lime, gypsum, sugar of lead (lead acetate), water-glass (sodium silicate, 40° solution), and diatomaceous earth.

4. **General procedure.** The water content of the sawdust does not appreciably affect the strength of the mix, for the total water in a mix is the same for any given consistency, regardless of whether the water is added with the sawdust or later. If the sawdust is oven dry the mix will be affected only as the dry sawdust may absorb water from the cement. Also, the water content of the sawdust has but little effect on the volume occupied. Owing to these facts, the method of proportioning the mixes was by volume, and the proportions by weight were calculated on the dry basis. A water determination on successive days was therefore unnecessary, no element of error due to possible changes in water content of the sawdust being involved.

The method of mixing the sawdust into the other components seems to be of some importance, for in the mixes containing sand greater strength was found when the dry sand was mixed with the dry cement before adding the damp sawdust. Also, if all the components were well mixed before the water, other than that in the sawdust, was added, the time necessary for thorough mixing was materially reduced.

In order to obtain comparative values for the strengths of the various mixes, the consistency was kept constant. The consistency was such that the mix, while quite plastic, would retain a small indentation, and was maintained by the use of a ten-inch flow-table, the reading on the flow-table after thirty drops being five inches. This method gives a conveniently workable mix.

5. **The test specimens.** The specimens used for the compression tests were cylinders, two by four inches, tamped in three layers, twenty-five tamps per layer. These specimens were of the standard ratio of height to diameter and of the standard amount of tamping. The specimens for the tensile test consisted of briquets of the A. S. T. M. standard shape and size. The plates for the thermal conductivity tests were twelve by twelve by one (inches), as suggested by the work of the Bureau of Standards. The tamping of the tensile specimens and of the plates was such that their density would be as nearly as possible that of the cylinders.

The samples were cured one day in moist air and the remainder of the time in water.

In order better to compare the values found for the cement-sawdust and the cement-sand-sawdust systems to concrete, specimens were made of cement-gravel and of cement-sand-gravel, using pebbles passing ½-inch and retained on ⅛-inch sieves.

6. **Definitions and units.** The compressive and tensile strengths are the maximum loads in pounds per square inch necessary to cause failure in the specimens.

The thermal conductivity is a measure of the ability of the material to conduct heat. It must then depend on the area exposed, the thickness, the time, and the temperature difference, and must be expressed in these terms. The unit used here is the British engineering unit of thermal conductivity, which is the flow of one British thermal unit (B.t.u.) in one hour, when the flow is steady, through a section of the material one square foot in area, the thickness of the plate being one foot, and the difference in temperature between the faces of the plate one degree Fahrenheit.

Compression and tension test results are the averages from three specimens and conductivities from two specimens.

II. THE COMPRESSIVE STRENGTH

The compressive strength is dependent to a large degree on the amount of cement present, while the nature of the aggregate used may influence the strength owing to the size of the particles or by a possible effect on the hydration of the cement.

It will be noted from Figure 1 that, in general, mixes containing less than 34 percent cement by volume have no strength. These mixes have an initial set, yet do not gain in strength on curing. This must be due to some property of the sawdust, for concrete employing sand and gravel as the aggregate requires generally a much lower cement content for the same strength.

1. **Effect of bark.** From Table I it is apparent that bark does weaken the mix. See Figure 2.

TABLE I. EFFECT OF BARK

No.	Percentage of cement	Percentage of sand	Compressive strength 90-day	
			No bark	Bark
	%	%	*lb. per sq. in.*	*lb. per sq. in.*
3	25	25	200	0
5	29	14	0	0
7	29	29	375	200
2	$33\frac{1}{3}$	0	1,110	1,065
6	$33\frac{1}{3}$	$16\frac{2}{3}$	1,150	1,030

A mix (No. 7) containing 29 percent cement or even 25 percent (No. 3) will set and have a measurable strength in ninety days if no bark is present, while the same mixes containing bark have little or no strength. This effect of bark cannot explain the high cement requirement, a mix containing 29 percent cement and no bark (No. 5) developing no strength. This mix attained sufficient initial set to permit curing under water, yet could easily be crumbled in the hand after ninety days. It will be noted that this mix (No. 5) contained the same cement content as mix No. 7, which did have some strength. The difference in strength of these two mixes may be due to the larger amount of sand in the former (No. 7).

2. **Effect of sand.** While these results suggest that the substitution of sand in the mix for part of the sawdust might be of decided advantage, further comparison of the mixes containing equal amounts of cement, but varying in their sand content, does not indicate a material increase in strength with the increase in sand (Table II).

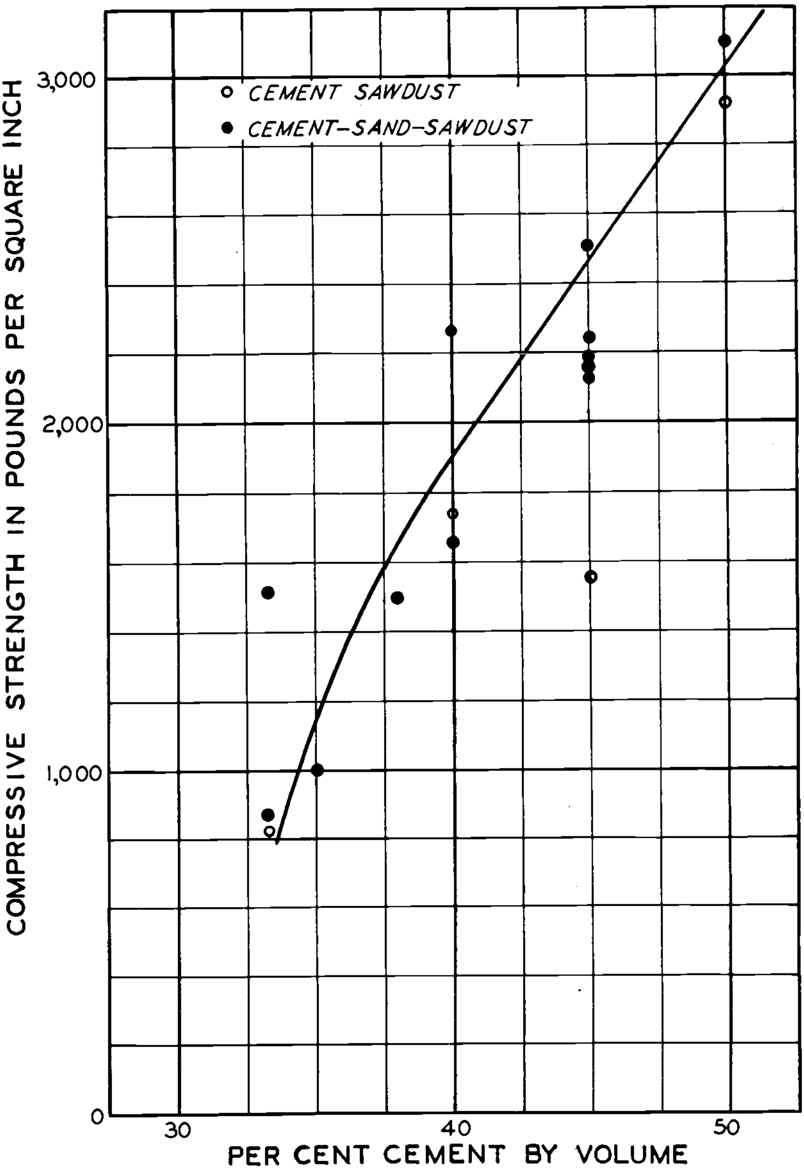

Figure. 1. Relation between compressive strength and cement content for cement-sawdust mortars at 28 days.

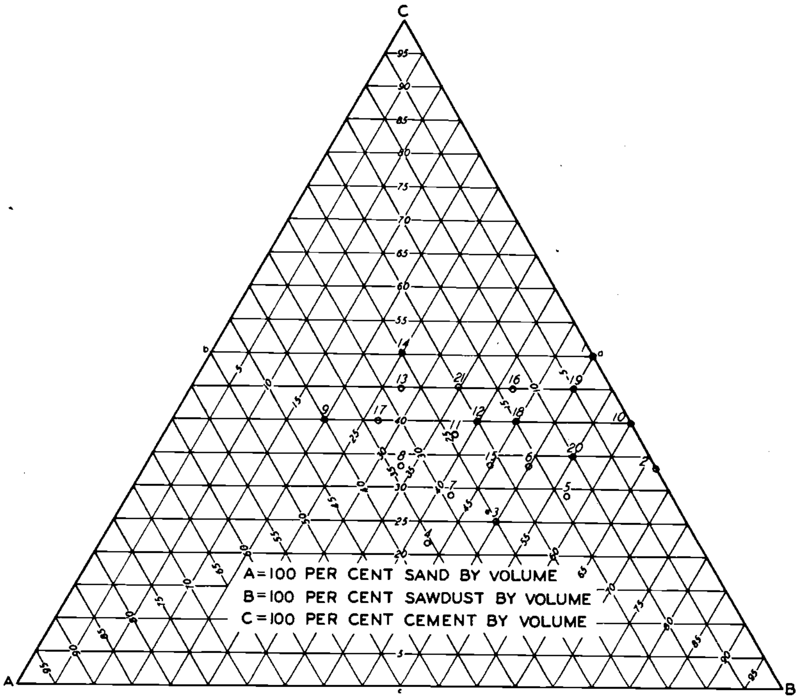

Figure 2. Volumetric composition of mixtures used. (Figures at points are the numbers of the mixtures.)

TABLE II. SUBSTITUTING SAND FOR SAWDUST

No. of mix	Percentage of cement	Percentage of sand	Compressive strength 90-day
	%	%	*lb. per sq. in.*
5	29	14	0
7	29	29	375
2	33⅓	0	1,110
6	33⅓	16⅔	1,150
15	33⅓	21⅔	1,225
18	40	15	1,875
12	40	20	2,075
17	40	33	2,550
9	40	40	2,750
19	45	5	2,470
16	45	18	2,530
13	45	27½	2,880

From Table III, moreover, it will be noted that adding sand to the mix without reducing the sawdust to maintain the cement constant reduces the strength.

TABLE III. EFFECT OF ADDING SAND TO SAWDUST

No. of mix	Mix by volume	Percentage of cement	Percentage of sand	Compressive strength 90-day
		%	%	*lb. per sq. in.*
2	1–0–2	33⅓	0	1,110
5	1–½–2	29	14	0
10	1–0–1½	40	0	2,125
6	1–½–1½	33⅓	16⅔	1,150
7	1–1–1½	29	29	375
12	1–½–1	40	20	2,050
8	1–1–1	33⅓	33⅓	1,850

This reduction in strength may largely be accounted for by the reduction in the cement content, caused by increasing the total aggregate on adding the sand.

3. **Effect of admixtures.** Various materials have been added to concrete in construction work with the view of increasing the hydration of the cement and thus increasing the strength. This suggests a possible method of improving the cement-sawdust system.

a. *Lime.* The addition of lime to the sement-sawdust system should neutralize the acid constituents of the wood and prevent a possible effect they might have on the hydration of the cement.

TABLE IV. EFFECT OF LIME

No. of mix	Mix by volume	Percentage of lime added (By weight of total mix)	Compressive strength 28-day	
			With lime	Without lime
			lb. per sq. in.	*lb. per sq. in.*
L–1	1–0–2	0.25	850	885
L–2	1–0–2	0.50	850	885
L–3	1–½–1½	0.25	890	890
L–4	1–½–1½	0.50	900	890
L–5	1–0–2	1.00	880	885

From Table IV it is readily apparent that small amounts of lime have little or no effect on the strength of the cement-sawdust or the cement-sand-sawdust systems. Since lime is one of the principal materials entering into the manufacture of Portland cement, the addition of further lime would hardly be expected to have an effect except for the fact that the lime originally present is in some form other than free lime—largely tri-calcium silicate.

b. *Gypsum.* From Table V it is apparent that the presence of gypsum has a slightly deleterious effect. Gypsum, owing to its sulfur content, however, retards the time of setting and hardening of any mix using Portland cement. This may, in part at least, account for the loss in strength, for the mix in Table V containing 0.75 percent gypsum could not be removed from the molds in twenty-four hours.

TABLE V. EFFECT OF GYPSUM

Mix by volume	Percentage added (by weight of total mix)	Compressive strength	
		7-day	28-day
	%	lb. per sq. in.	lb. per sq. in.
1-0-2	0.25	450	790
1-0-2	0.50	475	775
1-0-2	0.75	420	775
1-½-1½	0.25	495	800
1-½-1½	0.50	470	750

c. *Lead acetate.* When sugar of lead (crystalline lead acetate) is added to a cement mix by dissolving the crystals in the added water, a very smooth mix is obtained. Such a mix is much more easily handled and has the consistency, when mixed, of a thick sirup. Without the sugar of lead, the same mix is relatively stiff.

TABLE VI. EFFECT OF SUGAR OF LEAD

Mix by volume	Percentage of lead acetate added (by weight of total mix)	Compressive strength with		Compressive strength without	
		7-day	28-day	7-day	28-day
	%	lb. per sq. in.	lb. per sq. in.	lb. per sq. in.	lb. per sq. in.
1-1-1	0.35	720	1,255	725	1,450
1-1-1½	0.35	405	650	24	125
1-0-2	0.35	515	850	505	885

The sugar of lead is not very soluble in water and the 0.35 percent used is about all that will dissolve in the water. It will be noted in Table VI that the sugar of lead weakened the first and last mixes, while materially strengthening the second. Then, apparently, the addition of sugar of lead does not add strength to a mix, if that mix, without the sugar of lead, has a fair degree of strength, but will cause a mix that has very little strength to set more firmly.

d. *Sodium silicate.* Water-glass (sodium silicate) is used with sawdust and other materials in the manufacture of certain wallboards as a binder to hold the fibers or particles together. The addition of water-glass to the cement-sawdust or cement-sand-sawdust systems has much the same effect as the sugar of lead.

TABLE VII. EFFECT OF WATER-GLASS

Mix by volume	Percentage of sodium silicate added (by weight of total mix)	Compressive strength	
		7-day	28-day
	%	lb. per sq. in.	lb. per sq. in.
1-1-1	1.00	500	1,230
1-1-1	10.00	475	865
1-1-1½	1.00	385	480
1-1-1½	10.00	215	340
1-0-1	1.00	975	1,250
1-0-1	10.00	350	515

The loss in strength is greater than in the sugar-of-lead mixes, and the gain in strength of the 1-1-1½ mix is less. The amount added, however, is somewhat greater. At the time of mixing, the water-glass appears to adhere to the aggregate and thus prevents the cement from close contact. This may be the cause of the loss in strength of the mixes having a good strength without the presence of the water-glass.

Sugar of lead and water-glass produce a mix setting more firmly, as in the case of the 1-1-1½ mix, probably as a result of a form of colloidal precipitation. Both of these materials are colloidal in nature and are used in clarifying solutions. In these mixes, however, they may cause certain parts of the aggregate or of the cement to settle out and they do not, apparently, have much effect on the hydration of the cement.

e. *Diatomaceous earth.* Diatomaceous earth has been used as an aid in the hydration of cement in concrete. This addition is regarded as of decided advantage, particularly in its effect on workability.

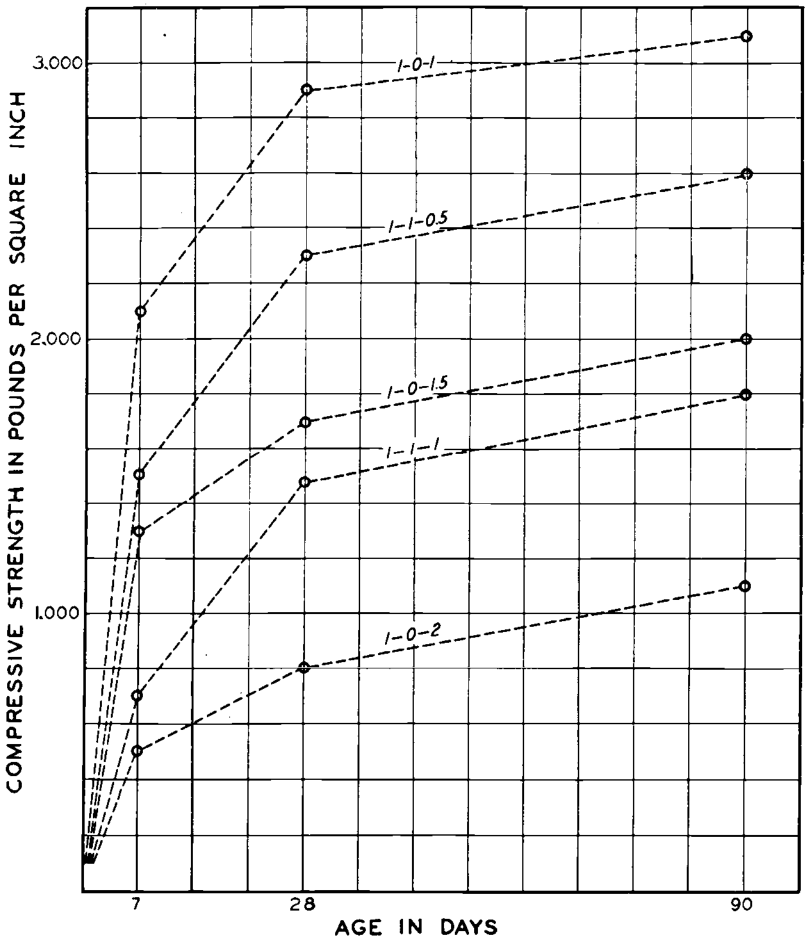

Figure 3. Relation between compressive strength and age for the various mixtures.

TABLE VIII. EFFECT OF DIATOMACEOUS EARTH

Mix by volume	Percentage of diatomite added (by weight of total mix)	Compressive strength	
		7-day	28-day
	%	*lb. per sq. in.*	*lb. per sq. in.*
1-1-1	1.00	1,100	1,535
1-1-1	3.00	1,005	1,485
1-1-1½	1.00	610	750
1-1-1½	3.00	675	730
1-1-1½	10.00	580	675
1-0-1	1.00	2,400	3,280
1-0-1	3.00	2,125	2,860
1-0-2	1.00	850	1,065
1-0-2	3.00	675	970

The effect of diatomaceous earth on the mix (1-1-1½) having little strength alone is much the same as that of the sugar of lead and of the water-glass. But in the other mixes, the diatomaceous earth adds to the strength, if 1 percent is added, while the sugar of lead and water-glass weaken the mixes. On adding more than 1 percent, the mixes are, in general, weakened. This suggests that the effect of diatomaceous earth is limited and that the addition of the larger amounts only adds to the total aggregate with a resulting loss in strength.

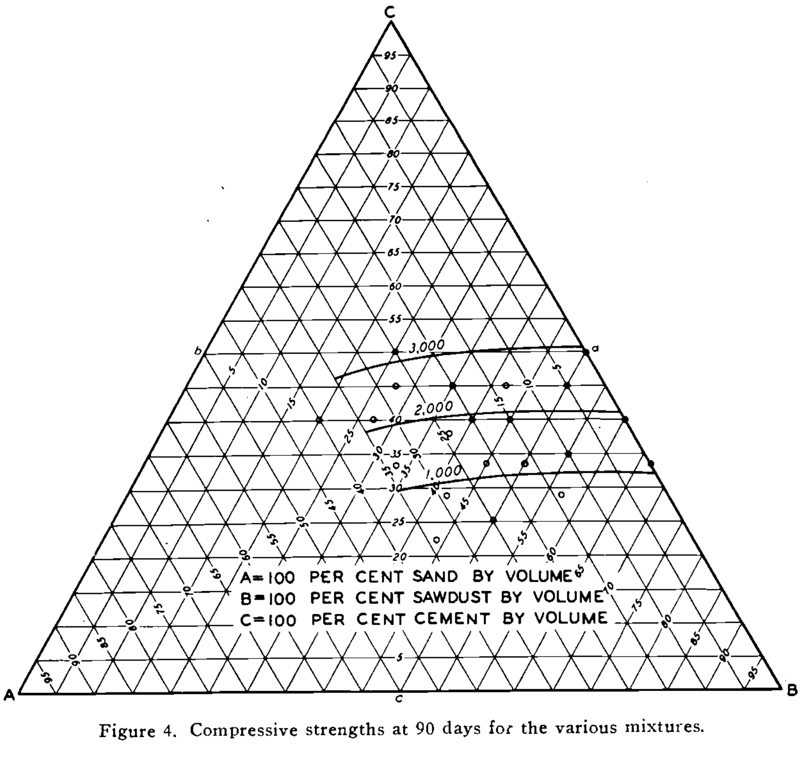

Figure 4. Compressive strengths at 90 days for the various mixtures.

TABLE IX. SUMMARY OF COMPRESSIVE STRENGTH TESTS OF CEMENT-SAND-SAWDUST MIXTURES

No. of mix	Mix by volume	7-day		28-day		90-day	
		No bark	Bark	No bark	Bark	No bark	Bark
		lb. per sq. in.	*lb. per sq. in.*	*lb. per sq. in.*	*lb. per sq. in.*	*lb. per sq. in.*	*lb. per sq. in.*
1	1–0–1	2,290	2,050	3,075	2,735	3,250	2,950
2	1–0–2	505	480	885	750	1,110	1,065
3	1–1–2	0	....	25	....	200	....
4	1–1.5–2	0	....	0	....	0	....
5	1–0.5–2	0	....	0	....	0	....
6	1–0.5–1.5	515	490	890	825	1,150	1,030
7	1–1–1.5	25	0	125	75	375	200
8	1–1–1	725	675	1,475	1,450	1,850	1,775
9	1–1–0.5	1,650	1,425	2,425	2,075	2,750	2,505
10	1–0–1.5	1,380	1,205	1,885	1,615	2,125	1,870
11	1–0.66–1	1,200	1,200	1,530	1,475	1,850	1,700
12	1–0.5–1	1,475	1,380	1,700	1,630	2,050	1,850
13	1–0.6–0.6	1,830	1,790	2,650	2,380	2,880	2,775
14	1–0.5–0.5	2,500	2,205	3,225	3,050	3,365	3,100
15	1–0.65–1.33	525	500	850	850	1,225	1,050
16	1–0.40–0.82	1,525	1,380	2,250	2,050	2,530	2,425
17	1–0.82–0.70	1,500	1,450	2,325	2,150	2,550	2,475
18	1–0.37–1.12	1,050	1,005	1,575	1,510	1,875	1,800
19	1–0.12–1.11	1,495	1,490	2,285	1,980	2,470	2,420
20	1–0.29–1.58	510	450	1,060	945	1,405	1,090
21	1–0.44–0.77	1,530	1,365	2,275	2,080	2,685	2,390
		All bark					
8b	1–1–1		475	525			685
10b	1–0–1.5		725	950			1,225

Note: Each figure given is the average from three cylinders.

III. THE TENSILE STRENGTH

In general, the tensile properties of the cement-sawdust and of the cement-sand-sawdust systems follow the characteristics found in the compression tests. That is, mixes having a high compressive strength also have a high tensile strength. However, while the compressive strength increases, on the average, 45 percent from seven to twenty-eight days, the tensile strength increased 80 percent in the same time.

1. **Effect of admixtures.** The effect of the various admixtures is greater on the compressive strength than on the tensile strength. The admixtures did not add to the tensile strength and in many cases even decreased it, although there may have been a decided increase in the compressive strength. The diatomaceous earth also tends to make the mix more brittle, for those specimens containing this material, tested in tension, broke with a decided snap, much like the usual cement-sand specimens. On the other hand, the mixes without the diatomaceous earth tended to yield before breaking, much like the failure of wallboard. The reason for this must lie in the effect of the diatomaceous earth on the hydration of the cement or on the bond between the sawdust and the cement.

The effect of the admixtures on the 1-1-1½ mix found in the compression tests also holds for the tension tests, but to a lesser degree. That is, on adding the lead acetate, sodium silicate, or the diatomaceous earth, the tensile strength of the 1-1-1½ mix does not increase in proportion to the increase found in the compressive strength.

Then, in general it may be said that the use of admixtures is of little effect in regard to the tensile strength. One percent of diatomaceous earth does tend to increase the tensile strength, but the main value of this material lies in its effect on the compressive strength and to a lesser degree on the thermal conductivity.

TABLE X. SUMMARY OF TENSILE STRENGTH TESTS ON CEMENT-SAND-SAWDUST MIXTURES

No. of mix	Mix by volume	Tensile strength		
		7-day	28-day	90-day
		lb. per sq. in.	*lb. per sq. in.*	*lb. per sq. in.*
1	1-1-1	195	405	560
2	1-0-2	170	265	310
3	1-1-2	0	0	0
4	1-1.5-2	0	0	0
5	1-0.5-2	0	0	0
6	1-0.5-1.5	175	285	315
7	1-1-1.5	0	65	120
8	1-1-1	185	315	340
9	1-1-0.5	190	310	345
10	1-0-1.5	175	295	320
11	1-0.66-1	170	305	320
12	1-0.5-1	175	300	330
13	1-0.6-0.6	205	385	455
14	1-0.5-0.5	215	400	575

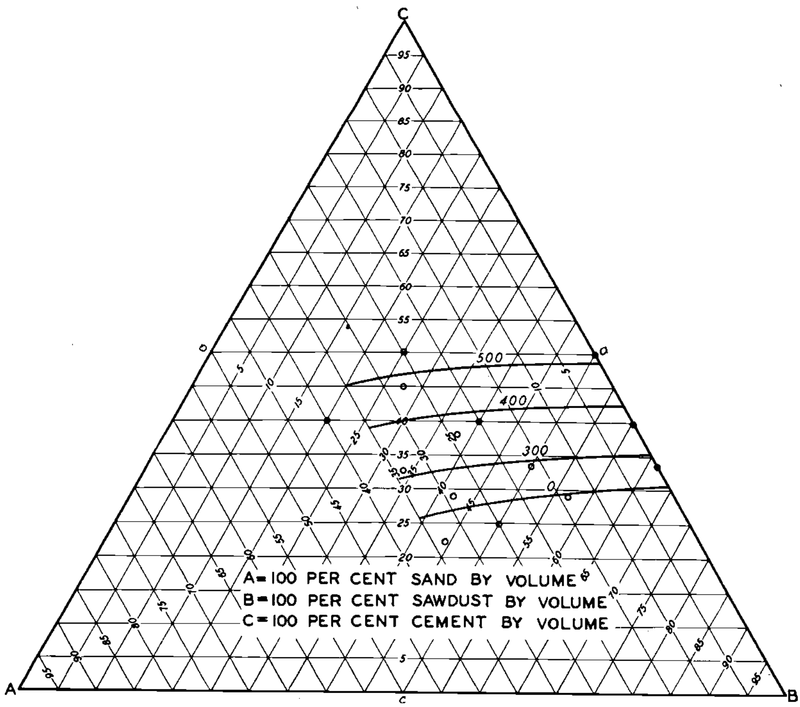

Figure 5. Tensile strengths at 90 days for the various mixtures.

TABLE XI. SUMMARY OF TENSILE STRENGTH TESTS USING ADMIXTURES

No. of mix	Mix by volume	Material added	Percentage added	Tensile strength	
				7-day	28-day
			%	*lb. per sq. in.*	*lb. per sq. in.*
A-1	1-1-1	Lead acetate (crys.)	0.35	122	130
A-2	1-1-1.5	Lead acetate (crys.)	0.35	90	140
A-3	1-0-2	Lead acetate (crys.)	0.35	160	230
B-1	1-1-1	Sodium silicate 40° Baumé	1.00	101	210
B-2	1-1-1.5	Sodium silicate 40° Baumé	1.00	65	70
B-3	1-0-1	Sodium silicate 40° Baumé	1.00	120	230
B-4	1-1-1	Sodium silicate 40° Baumé	10.00	100	175
B-5	1-1-1.5	Sodium silicate 40° Baumé	10.00	40	90
B-6	1-0-1	Sodium silicate 40° Baumé	10.00	77	185
C-1	1-1-1	Diatomaceous earth	1.00	185	290
C-2	1-1-1.5	Diatomaceous earth	1.00	105	140
C-7	1-0-1	Diatomaceous earth	1.00	190	405
C-5	1-0-2	Diatomaceous earth	1.00	180	205
C-3	1-1-1	Diatomaceous earth	3.00	160	275
C-4	1-1-1.5	Diatomaceous earth	3.00	120	135
C-8	1-0-1	Diatomaceous earth	3.00	190	380
C-6	1-0-2	Diatomaceous earth	3.00	120	190
C-9	1-1-1.5	Diatomaceous earth	10.00	105	120
1	1-0-1	0	0	195	405
2	1-0-2	0	0	170	265
7	1-1-1.5	0	0	0	65
8	1-1-1	0	0	185	315

IV. THE THERMAL CONDUCTIVITY

The thermal conductivity of a material such as the cement-sawdust system or of concrete must depend on the conductivity of the separate materials in the sample and on the method by which these separate materials are bound together.

Powdered cement has a thermal conductivity (K) of about 0.17 B.t.u. per hour per square foot per foot per degree Fahrenheit; loose sawdust has a corresponding thermal conductivity of 0 037; cork board wood of 0.024 to 0.038; wood of 0.10 to 0.22; sandstone of 0.75; and water (at rest) of 100. From this the conductivity of the cement-sawdust should be lower than that of concrete or rock-building material and the addition of sand should be expected to increase the conductivity.

TABLE XII. THERMAL CONDUCTIVITIES OF CEMENT-SAND-SAWDUST MORTARS

Mix by volume	K	Mean temperature, degrees F.
1-0-2	0.20	67.2°
1-½-1½	0.23	72.0
1-1-1	0.23	82.2

1. **Effect of sand.** From the results in Table XII sand does have the effect on the conductivity that could be expected. The sand is a better conductor of heat than the sawdust and its addition increases the thermal

conductivity or decreases the value of the material as an insulator. Since the sand has only a small advantageous effect on the strength of the material and greatly increases the weight, it can be said that the use of sand with sawdust and cement is in the main detrimental.

2. **Effect of diatomaceous earth.** The addition of 1 percent of diatomaceous earth decreases the thermal conductivity, thereby improving the insulating values of the material. This could be expected, for diatomaceous earth has a thermal conductivity of about 0.09 as a solid and 0.04 as a powder.

TABLE XIII. THERMAL CONDUCTIVITY OF CEMENT-SAND-SAWDUST CONTAINING 1 PERCENT DIATOMACEOUS EARTH

Mix by volume	K	Mean temperature, degrees F.
1-0-2	0.18	69.3°
1-½-1½	0.20	74.5
1-1-1	0.20	75.0

It will be remembered that the diatomaceous earth was of advantage in increasing the strength, but only to the extent of 1 percent. This indicates that the addition of 1 percent by weight (about 4.5 percent by volume) of powdered diatomaceous earth is of worth-while advantage.

The amount of water added to such a material should affect to some degree the thermal conductivity as well as the strength. The specimens tested here had the same water content as the specimens of the same proportions tested for compressive and tensile strengths. The amount of water added to a mix is determined by the desired plasticity and should be carefully controlled if optimum results are desired, either in regard to insulating value or to strength (see curve on strength vs. water-cement ratio, Figure 7).

TABLE XIV. SUMMARY COMPARING STRENGTHS AND THERMAL CONDUCTIVITIES OF VARIOUS MATERIALS

Mix by volume (Cement-sand-gravel)	Properties of concrete			
	Compressive strength			Thermal conductivity
	7-day	28-day	90-day	(B.t.u./hr./sq. ft./ft./°F.)
1-0-2	3,055	4,155	5,400	0.40
1-1-2	3,135	4,290	7,450	0.34
1-1.5-2	2,770	4,435	6,250	0.42
Average	2,987	4,293	6,433	0.387

Material	Comparison of cement-sawdust to other materials		
	Compressive strength	Tensile strength	Thermal conductivity
Cement-sawdust	1,000 to 3,000 (90-day)	300 to 500 (90-day)	0.20
Concrete (comparable mixes)	5,000 to 7,000 (90-day)	400 to 600† (90-day)	0.40
Wood (a)*	2,400 to 3,400	11,000 to 16,000	0.10 to 0.22
Brick (b)*	4,000	----	0.23 to 0.30
Sandstone*	9,300	----	0.75

(a) Douglas fir, parallel to grain. (b) Common building brick.
*From *Mechanical Engineers' Handbook* by Lionel S. Marks.
†From *The Chemistry and Testing of Cement* by C. H. Desch.

V. OTHER PROPERTIES

1. **The specific gravity.** The strength of a material is often related to its density or specific gravity. That is, in similar materials, the one having the greater density will in general have the greater strength. This is indicated to be true in the cement-sawdust system by Table XV, in which the increase in specific gravity must be due to the increase in cement content.

TABLE XV. SPECIFIC GRAVITIES OF CEMENT-SAWDUST MIXTURES

Mix by volume	Specific gravity	Compressive strength, 28-day
1–0–2	1.40	885
1–0–1½	1.55	1,885
1–0–1	1.80	3,075

Sand is a more dense solid than sawdust and should increase the specific gravity on being substituted for the sawdust. It will be remembered that the addition of sand in place of the sawdust had little effect on the strength.

TABLE XVI. SPECIFIC GRAVITY VS. STRENGTH ON SUBSTITUTING SAND FOR SAWDUST

Note: Compare with Table XV.

Mix by volume	Specific gravity	Compressive strength, 28-day
1–½–1½	1.46	890
1–½–1	1.64	1,700
1–½–½	1.87	3,225

The effect of sand on the specific gravity when substituted for the sawdust does not seem to be as great as would be expected from the difference in their respective specific gravities. This fact may be a partial explanation of the effect of the sand on the strength, and may be due to the sand acting as a free aggregate and not as a filler between the particles of sawdust.

This view is further substantiated by the relation found on adding sand to the cement-sawdust system without decreasing the sawdust.

TABLE XVII. SPECIFIC GRAVITY VS. STRENGTH ON ADDING SAND TO CEMENT-SAWDUST

Note: Compare with Table XV.

Mix by volume	Specific gravity	Compressive strength, 28-day
1–½–2	1.39	0
1–½–1½	1.46	890
1–½–1	1.64	1,700

The addition of the sand does not increase the specific gravity as might be expected, but actually lowers it and at the same time materially decreases the strength.

From this, the sand is apparently not the main factor determining the specific gravity of a cement-sand-sawdust system. The only other material present that can account for the relative increase of strength with the increase in specific gravity is the cement content. Hence, the cement content of a cement-sawdust or a cement-sand-sawdust mix is the determining factor in the strength and specific gravity relation.

The additions of lead acetate and sodium silicate increase the specific gravity of the cement-sand-sawdust system about 1.2 percent for the amounts used. This might be expected to cause a stronger mix, but the only effect of these two materials seems to be to decrease the cement content with resultant effect on the cement-sawdust bond. There is no gain in strength by their use and they have no advantageous properties, with the possible exception of those mixes that are on the borderline between the setting and non-setting mixes. (See previous discussion on the 1-1-1½ mix.)

The addition of diatomaceous earth decreases the specific gravity and yet adds to the strength. Perhaps this material improves the bond between the cement and sawdust enough and more to offset the decrease in relative cement content caused by its addition. The decrease of the specific gravity on adding 1 percent diatomaceous earth to cement-sawdust or to cement-sand-sawdust is about 5.6 percent, on adding 3 percent the decrease is 8.0 percent, and on adding 10 percent the decrease is 10.0 percent.

The microscopic air voids in diatomite resulting in decrease in specific gravity no doubt also supply the reason for the decrease found in the thermal conductivity.

TABLE XVIII. SPECIFIC GRAVITIES OF CEMENT-SAND-SAWDUST MIXTURES

Mix by volume	Specific gravity	Mix by volume	Specific gravity
1–0–1	1.80	1–0.66–1	1.62
1–0–2	1.40	1–0.5–1	1.64
1–1–2	1.41	1–0.6–0.6	1.80
1–1.5–2	1.42	1–0.5–0.5	1.87
1–0.5–2	1.39	1–0.65–1.33	1.52
1–0.5–1.5	1.46	1–0.40–0.82	1.77
1–1–1.5	1.57	1–0.82–0.70	1.80
1–1–1	1.64	1–0.37–1.12	1.64
1–1–0.5	1.79	1–0.12–1.11	1.70
1–0–1.5	1.55	1–0.29–1.58	1.51
		1–0.44–0.77	1.76

2. **The water-cement ratio.** The amount of water added to a mixture containing Portland cement has a decided effect on the properties of the mixture when set, for the water acts on the cement and forms the solid matrix surrounding the aggregate. The water content is usually such that the mix is of the required consistency and is expressed as the ratio, by volume, of the water to the cement.

The value of this water-cement ratio is well proved by its use in concrete design, for the strength of workable concrete mixes has been found to be dependent on this ratio more than on the percent of cement present or on the ratio of cement to aggregate. This same relationship of strength to the water-cement ratio holds true for the cement-sand-sawdust system. The strength is lower than that of concrete for a given water-cement ratio, but the difference is fairly uniform (see Figure 7).

The water present in a sawdust mix not only must act on the cement but must also enter the sawdust particles. This inert water in the pores of the wood no doubt accounts for the higher water-cement ratio found for the comparative amounts of aggregate.

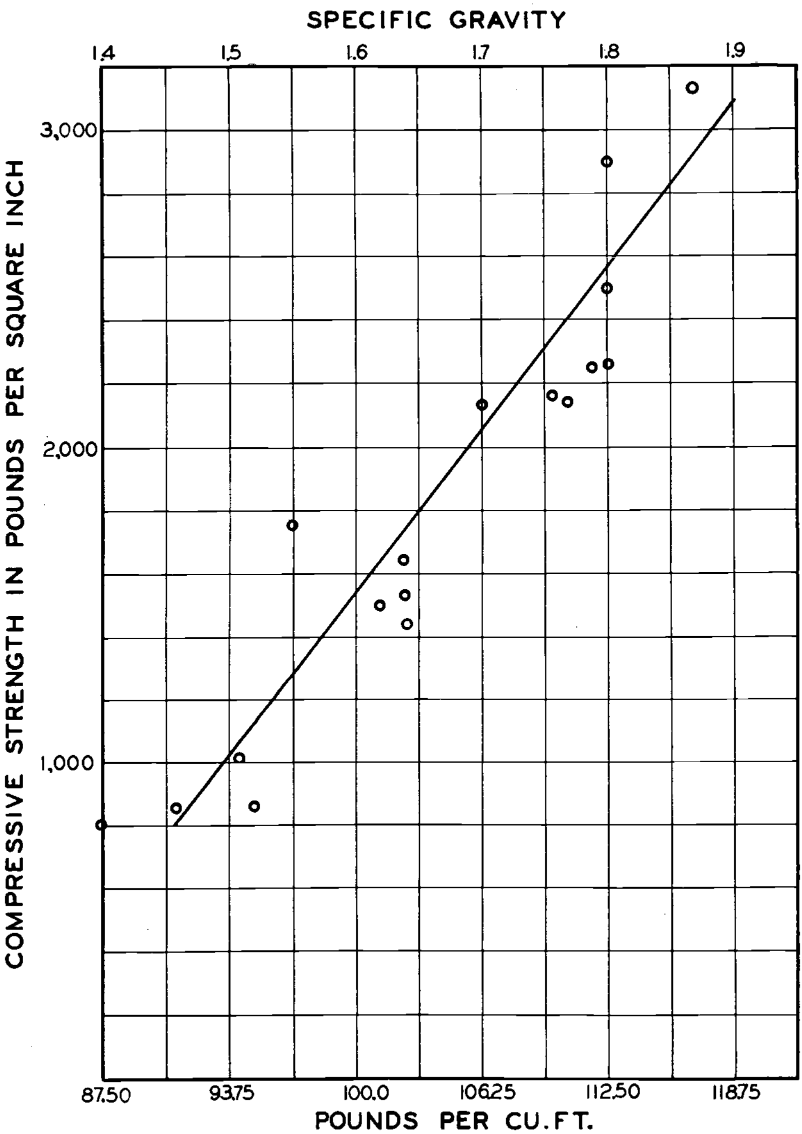

Figure 6. Relation between compressive strengths at 28 days and specific gravities of mortars.

TABLE XIX. WATER-CEMENT RATIO VS. STRENGTH

Mix by volume	Water-cement ratio	Compressive strength, 28-day
1–0–2	0.99	885
1–0–1½	0.84	1,885
1–0–1	0.66	3,075

The substituting of sand for the sawdust in part was found to have little effect on the strength. Likewise it has little effect on the water-cement ratio.

TABLE XX. WATER-CEMENT RATIO VS. STRENGTH ON SUBSTITUTING SAND FOR PART OF THE SAWDUST

Note: Compare with Table XIX.

Mix by volume	Water-cement ratio	Compressive strength, 28-day
1–½–1½	0.95	890
1–½–1	0.85	1,700
1–½–½	0.64	3,225

This would tend to indicate that the water present in the sawdust does have an effect on the cement and that the amount of water present as absorbed water is not great.

If this view is correct, the addition of sand to a mix, without at the same time correcting for the added sand by reducing the sawdust, should materially increase the water-cement ratio to obtain the same consistency as the mix formerly had. This is shown to be the case, for the water-cement ratio in the cement-sand-sawdust system tends to be dependent more on the total aggregate of sand and sawdust than on the amount of sawdust alone.

TABLE XXI. WATER-CEMENT RATIO VS. STRENGTH ON ADDING SAND TO THE CEMENT-SAWDUST

Note: Compare with Table XIX.

Mix by volume	Water-cement ratio	Compressive strength, 28-day
1–½–2	1.26	0
1–½–1½	0.95	890
1–½–1	0.85	1,700

From these values of the relation of the water-cement ratio to strength, it may be said that in general the lower this ratio, provided a workable mix is still maintained, the higher the strength. This relationship is not exactly inversely proportional, however; that is, the curve is not a straight line (see Figure 7).

TABLE XXII. PERCENT COMPOSITION BY VOLUME AND BY WEIGHT OF THE MIXTURES USED

No. of mix	Mix by volume	Percent cement		Percent sand		Percent sawdust	
		Volume	Weight	Volume	Weight	Volume	Weight
1	1–0–1	50	87.5	0	0	50	12.5
2	1–0–2	33.3	77.7	0	0	66.6	22.2
3	1–1–2	25	40.7	25	47.6	50	11.6
4	1–1.5–2	22.2	34.6	33.3	55.5	44.4	9.9
5	1–0.5–2	29	53.0	14	31.8	57	17.0
6	1–0.5–1.5	33.3	54.2	16.6	33.7	50	12.0
7	1–1–1.5	29	40.5	29	50.4	42	9.0
8	1–1–1	33.3	41.9	33.3	51.8	33.3	6.2
9	1–1–0.5	40	43.8	40	53.0	20	3.2
10	1–0–1.5	40	82.1	0	0	60	17.9
11	1–0.66–1	38	52.2	24	40.3	38	7.4
12	1–0.5–1	40	57.9	20	33.9	40	8.2
13	1–0.6–0.6	45	54.6	27.5	40.4	27.5	15.0
14	1–0.5–0.5	50	59.1	25	35.6	25	4.3
15	1–0.65–1.33	33.3	51.0	21.3	40.8	45	8.2
16	1–0.40–0.82	45	61.7	18	30.9	37	7.4
17	1–0.82–0.70	40	47.6	33	47.6	27	4.8
18	1–0.37–1.12	40	62.1	15	28.0	45	9.9
19	1–0.12–1.11	45	77.0	5	12.3	50	10.7
20	1–0.29–1.58	35	68.0	10	17.0	35	15.0

Note: On dry basis 1–1–1 mix by volume is equivalent to 1–1.2–0.14 by weight.

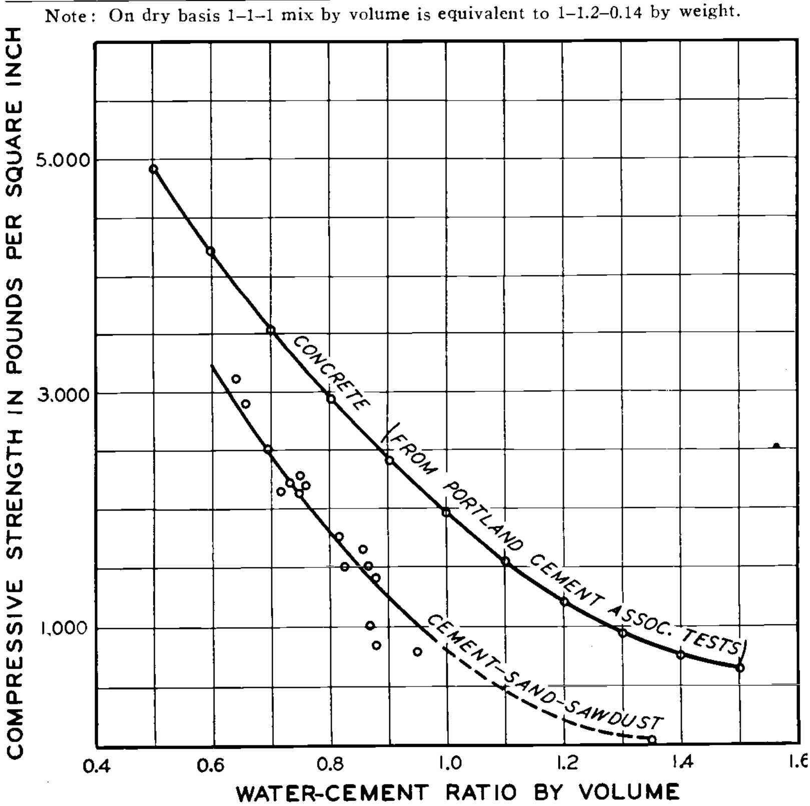

Figure 7. Compressive strength at 28 days vs. water-cement ratio.

3. **Resistance to corrosion.** The presence of the sawdust might be expected to cause the material to corrode more easily than ordinary cement mortar or concrete when exposed to the soil or acid. But comparing the corrosion loss of mortars containing sawdust to that of concrete under identical conditions does not indicate any serious effect due to the sawdust.

TABLE XXIII. CORROSION LOSS

Mix by volume	Exposed to	Percentage lost in 90 days
		%
*1-0-2	Damp soil	0.32
†1-1-1	Damp soil	0.24
Concrete 1-1-2	Damp soil	0.32
*1-0-2	2% Tannic acid	0.40
†1-1-1	2% Tannic acid	0.20
Concrete 1-1-2	2% Tannic acid	0.30
*1-0-2	1% Hydrochloric acid	0.44
†1-1-1	1% Hydrochloric acid	0.34
Concrete 1-1-2	1% Hydrochloric acid	0.38

*Cement-sawdust.
†Cement-sand-sawdust.

The matrix of cement surrounding the sawdust particles apparently protects the sawdust from corrosion.

The presence of sand apparently aids the cement-sawdust in resisting corrosion. This may be due to the sand increasing the total matrix and decreasing the porosity.

4. **The age of the sawdust.** When exposed to damp weather and when in contact with soil, wood will rot. From this, the use of old sawdust might be expected to weaken the cement-sawdust material. On using sawdust exposed to the weather for three months, however, only a small decrease in strength was found.

TABLE XXIV. EFFECT OF THE AGE OF SAWDUST

Mix by volume	Compressive strength, 28-day	
	Sawdust 3 months old	Fresh sawdust
1-0-2	685	750
1-0-1½	1,580	1,615
1-1-1	1,410	1,475

Since the properties of the cement-sawdust depend on the cement matrix and not on the sawdust, the effect of aging the sawdust must lie in the effect of the portion of the sawdust that weakens the cement matrix and not on the strength of the wood fibers in the sawdust.

VI. CONCLUSIONS

This investigation covers the practicability of using sawdust in Portland cement mortar and includes the effect of incorporating sand and certain other materials into the mixtures. From a consideration of the uses for which this material may be employed, the more important properties are the compressive and tensile strengths and the thermal conductivity. Tests were made on these points and also on the resistance of the material toward certain corrosive agents. The relationships existing between the foregoing properties and the presence of bark, the water-cement ratio, the specific gravity, and the age of the sawdust were noted.

From the tests made in this study, the following conclusions are indicated:

1. Safe strengths may be obtained from cement-sawdust mixtures. Tests were made both on sawdust from the main saw, containing some bark and on bark-free sawdust from the resaws. If bark-free sawdust is used there is a small but distinct improvement in strength.

2. The addition of sand has but little effect on the strength and is detrimental where light weight and the lowest thermal conductivity are important.

3. The ratio, by volume, of the total water to the cement is a fair index of the strength.

4. The addition of 1 percent by weight of powdered diatomaceous earth is of decided advantage.

5. The resistance to corrosion of the cement-sawdust compares favorably with that of ordinary concrete.

6. Sawdust which has been exposed to the weather for a comparatively short time may be used without a material loss in strength.

7. The cement-sawdust material is a better thermal insulator than ordinary concrete but does not have as high strength.

8. In order to obtain adequate strength in the cement-sawdust material, it is necessary to use such a rich mixture (large cement content) that the cost, in spite of the cheapness of sawdust, will be greater than that of ordinary concrete.

9. Special care must be taken in the control of the amount of mixing water and in the placing and curing of the cement-sawdust material if a sound and durable product is to be obtained.

10. In any given case, the desirability of using the sawdust-cement material in preference to ordinary concrete will depend on the value placed on light weight and on low thermal conductivity.

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