AN ABSTRACT OF THE THESIS OF

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It is difficult to treat the heartwood of many wood species with liquid preservatives using conventional liquid processes. Supercritical fluids (SCF) used as carriers of preservatives to impregnate refractory wood species may be an attractive alternative to conventional liquid carriers. While SCF impregnation has many potential advantages, some wood species exposed to elevated pressures can be subjected to excessive pressure gradients during treatment. These gradients can lead to treatment defects, such as collapse and splitting, and may also result in significant losses in bending properties.

This study examined the effects of three treatment parameters on the bending properties and the development of treatment defects in Douglas-fir (*Pseudotsuga menziesii*), yellow poplar (*Liriodendron tulipifera*), western redcedar (*Thuja plicata*), and

Engelmann spruce (*Picea engelmannii*). Two rates of pressurization (0.34, 3.44 MPa/min.), two treatment pressures (10.34, 20.69 MPa) and two rates of venting (0.34, 3.44 MPa/min.) were examined on small clear specimens of each species using one treatment temperature (60 °C) and one treatment time (30 min.).

SCF treatment of yellow poplar produced no significant reduction in bending properties, while bending properties increased in Douglas-fir. The latter increase appears to have resulted from differences in mean specific gravities between treatments since pressurization rate, treatment pressure, or venting rate did not significantly affect bending properties. Bending properties in western redcedar and Engelmann spruce were significantly reduced when exposed to SCF treatment conditions. Comparisons between treatment and control in western redcedar specimens showed 21.7 to 23.1% reductions in MOR and 26.0 to 31.0% reductions in WML. Properties of Engelmann spruce declined 10.8 to 21.6% in MOR, 16.0 to 21.4% in MOE, and 7.2 to 29.0% in WML following SCF treatment. Rapid venting, at a rate of 3.44 MPa/min., produced the most significant reductions on bending properties for western redcedar, while Engelmann spruce was affected by both the 0.34 and 3.44 MPa/min. pressurization and venting rates.

Examination of transverse sections for all species revealed that collapse can occur externally as well as internally within SCF treated samples of Douglas-fir, western redcedar and Engelmann spruce, while the anatomical characteristics of yellow poplar were observed to be unaffected by SCF treatments.

The results indicate that SCF treatments, while effective for treating refractory woods, must be used with some caution to avoid inducing negative effects on wood properties.

The Effects of Supercritical CO_2 on the Bending Properties and Treatment Defects of Four Refractory Wood Species

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1 INTRODUCTION

1.1 Refractory Wood

Wood is a complex and remarkable material with a matrix comprised of cellulose, hemi-cellulose and lignin. When properly used and maintained, wood is resistant to biological degradation from decay organisms and insects, but improper use often leads to degradation (Zabel and Morrell, 1992). Wood products used in areas susceptible to biological degradation are usually vacuum/pressure impregnated with preservative solutions to ensure their longevity. However, certain species of wood are impermeable to liquids and are called refractory, or difficult to treat. Several major wood species in North America are refractory, including Douglas-fir, spruce, true firs, cedars, western hemlock, larch and the white oaks (Baines and Saur, 1985).

There are numerous wood species that are naturally resistant to biological attack (Scheffer and Cowling, 1966), however, demand and finite supplies of these species prevent their use in all locations (Bowyer, 1995; Haynes and Adams, 1992). To meet demand for decay resistant wood products, less durable wood species can be treated with preservatives to increase their service lives. For long, reliable service lives, pressure treatment using combinations of vacuum and pressure with preservatives is essential (Zabel and Morrell, 1992). The biocides, or preservatives used, can be either oil or water-borne preservatives. In 1991, nearly 17 million cubic meters of wood products were pressure treated with preservatives and nearly three-quarters of this material was treated with water-borne preservatives (Micklewright, 1993).

1.2 Anatomy of Refractory Wood

1.2.1 Permeability of Wood

The ability of wood to accept liquid preservatives is dictated by anatomical features (Resch and Ecklund, 1964; Stamm, 1964). The permeability of dry unswollen wood is compounded by barriers such as aspirated pits, rigidity of pit membranes, air blockage of pit membranes and plugging by extraneous materials (Arsenault, 1973). Siau (1995) described the flow of liquids through wood as bulk flow, the magnitude of which is determined by the permeability of the wood species.

1.2.2 Permeability of Heartwood and Sapwood

The characteristics of heartwood and sapwood greatly influence the permeability of wood. Sapwood is the outer living portion of a tree stem and is typically lighter in color. The primary functions of sapwood are conduction and storage of nutrients. Heartwood is the dead inner portion of a tree stem and often is darker in color than sapwood. In terms of permeability, the bordered pits in sapwood are generally open, free from obstructions and permeable to liquid flow. The transition from sapwood to heartwood causes pits to aspirate, the formation of extractives, tyloses, and gums, and incrustation of bordered pits (Krahmer and Côté, 1963; Hunt and Garratt, 1967; Panshin and deZeeuw, 1980; Zabel and Morrell, 1992). These developments make heartwood highly impermeable to liquid flow and, thus, difficult to treat using conventional treatment processes. Refractory wood species are characterized by large amounts of heartwood with a smaller outer core of sapwood. In some instances, even the sapwood of refractory wood species can be difficult to treat, such as interior Douglas-fir (Miller and Graham, 1963).

1.2.3 Effect of Anatomy on Permeability of Softwoods and Hardwoods

The most important anatomical feature in affecting liquid and gas permeability in coniferous woods is the size and shape of the bordered pits (Côté, 1958; Côté and Krahmer, 1962; Krahmer and Côté, 1963;; Panshin and deZeeuw, 1980). Bordered pits in the heartwood often become aspirated or encrusted with extraneous materials blocking liquid and gas movement and reducing permeability (Fleischer, 1950; Côté, 1958; Côté and Krahmer, 1962; Resch and Eklund, 1964; Sebastian et al., 1965; Koran, 1974,).

In hardwoods, the vessels are most important for conducting liquids. Vessels are connected to one another by pits or perforations, which allow a continuous flow of liquids in the lateral direction (Hunt and Garratt, 1967; Panshin and deZeeuw, 1980). Fibers and tracheids generally limit the permeability of hardwoods. Fibers are long, narrow and closed-end cells, which constitute approximately 50 percent of the total volume of hardwoods (Hunt and Garratt, 1967, Panshin and deZeeuw, 1980). Other cells in hardwoods may be difficult to penetrate since lateral movement from vessels into these cells is limited to diffusion through pit membranes (Côté, 1958).

1.2.4 Decay Resistance of Refractory Wood

The decay resistance of refractory wood is variable. Some heartwood is profoundly more decay resistant than sapwood. The sapwood is responsible for conduction of water and storage of nutrients which supports the development of a wide variety of wood-inhibiting microorganisms while the heartwood is non-living and may contain high amounts of extractives (Scheffer and Cowling, 1966). Many extraneous materials that form in the transition from sapwood to heartwood are toxic to decay fungi and insects (Hunt and Garratt, 1967; Arsenault, 1973; Zabel and Morrell, 1992). Scheffer and Cowling (1966) classified major domestic woods by heartwood decay resistance. Important commercial refractory woods that are highly resistant to biological attack are the white oaks and many cedars while Douglas-fir is moderately resistant. Refractory commercial woods that are non-resistant or slightly resistant include the hemlocks, spruces, maples, birches and yellow poplar.

1.3 Methods for Preserving Refractory Woods

Refractory wood species do not readily accept liquid preservative treatments and cannot be adequately treated by conventional treatment methods. There has been no method developed that can adequately treat all wood species on a cost-effective basis (Hunt and Garrett, 1967). The most effective methods for the treatment of most wood species employ combinations of vacuum and pressure. The success of this method has facilitated the use of otherwise perishable wood species (Baines and Saur, 1985). Numerous methods have been developed to improve preservative penetration in refractory wood including fluid modification, incising, oscillating pressure, and ponding or water storage, but none of the processes completely overcome the inability to force a fluid across semi-permeable pit membranes (Baines and Saur, 1985).

The type of fluid used during treatment of refractory wood can have a marked effect on preservative penetration. Water and oil are two commonly used carriers for wood preservatives. Oil has a lower surface tension compared to water, however, because water has a strong affinity to wood, it generally has improved penetration compared to oil (Hunt and Garratt, 1967; Arsenault, 1973; Zabel and Morrell, 1992). Ammoniacal based preservative systems were created because ammonia acts to swell wood and dissolve encrustations on pits thereby improving penetration. Ammoniacal copper aresenate (ACA), Ammoniacal copper zinc arsenate (ACZA) and Ammoniacal copper quaternary - type B (ACQ-B) have all been shown to increase preservative penetration (Keith, 1985; Lebow and Morrell; 1993 and Anderson et. al, 1997)

Changing the viscosity of the treatment solution can also increase penetration (Arsenault, 1973; Hunt and Garratt, 1967). For example, the Cellon® process used liquefied petroleum gas as the solvent (Henry, 1959). The lower viscosity of this solvent increased preservative movement through the wood capillaries. Many researchers have used gases to estimate the permeability of woods. Air permeability in wood is far greater than water permeability (Krahmer and Côté, 1963; Sebastian et al., 1965). Gas phase treatments (fumigants) are used for remedial treatments of products in service. Although applied as liquids or solids these compounds have high vapor pressures and volatilize to move through wood as gases (Morrell and Corden, 1986).

Baines and Saur (1985) classified the methods used to treat refractory wood into green methods, which are conducted shortly after the tree is felled, and dry methods, which are performed after the wood has been dried below the fiber saturation point.

Green poles can be treated by pressure sap displacement of wood that is otherwise refractory when dry. The Boucherie process (1839) is similar to sap displacement, but uses hydrostatic pressure to distribute liquid preservative solutions through the sapwood of freshly felled trees. High pressure sap displacement is suitable for treating Scots pine (*Pinus sylvestris*), Corsican pine (*Pinus nigra*) and Norway spruce (*Picea abies*) poles, but inadequate for Sitka spruce (*Picea sitchensis*) poles (Evans et. al., 1991). Preservative penetration in these processes is dependent upon sapwood thickness and moisture content.

Heartwood can also be treated using water diffusible preservatives such as boron or fluoride, but free water must be present in the wood for diffusion to occur. Smith and Williams (1969) used boron to treat 102 mm x 51 mm timbers of Sitka spruce (*Picea sitchensis*) and Scots pine (*Pinus sylvestris*). Satisfactory treatment could be achieved in specimens above 50 to 60 percent moisture content in both the heartwood and sapwood. Lower moisture contents required much longer diffusion times and little or no diffusion occurred when the wood was below the fiber saturation point.

Double diffusion processes are used to treat freshly felled posts of hardwood and softwood species by soaking the wood in one chemical solution and then in a second chemical solution. Both solutions are water-soluble and react with one another to form an insoluble compound within the wood (Baechler et al., 1959; Baechler and Roth, 1964; Hunt and Garratt, 1967; Markstrom et. al., 1970; Arsenault, 1973,). The double diffusion process has been used to treat the sapwood of Engelmann spruce (*Picea engelmannii*), interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) and lodgepole pine (*Pinus contorta* var. *latifolia*), but the penetration is still dependent on sapwood depth (Markstrom et. al., 1970). The sapwood of many southern hardwoods has also shown acceptable treatments by the double-diffusion process (Baechler et al., 1959; Baechler and Roth, 1964; Vick et. al., 1967), but the processes are slow and not suitable for commercial treatment.

The oscillating pressure method, or pulsation process, uses repeated cycles of pressure and vacuum to increase the penetration of liquid preservative solutions. The process was derived from the phenomenon of decreasing flow through wood with respect to time. Increases in permeability were found when flow was reversed (Hudson and Henriksson, 1956; Resch and Eckland, 1964). However, Flynn and Goodell (1996) found that the pulsation process significantly reduced the modulus of rupture (MOR) in red spruce (*Picea rubens*).

Ponding green wood for several months has been shown to increase permeability in spruce (Keith, 1985). The increased permeability reflects bacterial dissolution of the pit membranes (Ellwood and Ecklund , 1959; Ward and Fogerty, 1973). The sapwood of white spruce (*Picea glauca*) bolts ponded for five or nine weeks could be completely treated, but the bolts also experienced reductions in; fiber strength at the proportional limit, MOR, and MOE (Unligil, 1971, 1972). Even though ponding can increase the permeability of sapwood, it does not influence the permeability of refractory heartwood. Therefore, the depth of improved preservative penetration is limited to the sapwood thickness.

Solvents such as hot water, ethanol, and ethanol/benzene have been found to increase the permeability of refractory heartwood because they remove extraneous materials from bordered pits (Krahmer and Côté, 1963; Resch and Ecklund, 1964; Arsenault, 1973). However, solvent extraction is expensive, requires excessive time and residual solvent in the wood can pose an environmental concern (Arsenault, 1973).

Incising is a means of using knives to make perforations into the surfaces of lumber, ties and large timbers to increase the amount of end grain exposed to preservative flow. This method results in more uniform penetration of preservatives (Hunt and Garratt, 1967). According to the American Wood Preservers' Association Standard C-2, species that are difficult to treat must be incised prior to preservative treatment (AWPA, 1998). Incision densities as high as 10,000 incisions/m^2 have produced marked improvements in preservative penetration (Lam and Morris, 1991; Lebow and Morrell, 1993; Anderson et al., 1997). However, incising decreases the flexural properties of dimensional lumber (Perrin, 1978; Lam and Morris, 1991; Winandy and Morrell, 1998). Another means of incising not commonly used is laser incising. Although not currently economically feasible, laser incised red spruce (*Picea rubens*) experienced no significant strength losses, and could be treated to industry standards (Goodell et al., 1991).

Dynamic transverse compression treatment was used to improve treatment of eastern white spruce (*Picea glauca*). At deformations above five percent, both average retention and penetration were increased, but higher compressive treatments significantly reduced modulus of rupture (MOR) and modulus of elasticity (MOE) (Cech and Huffman, 1970).

Steaming wood prior to preservative treatment can also increase preservative uptake. Pit aspiration in loblolly pine (*Pinus taeda*) was greatly reduced compared to non-steamed samples (Nicholas and Thomas, 1967). Erickson and Crawford (1959) found a significant increase in permeability of steamed green sapwood of Douglas-fir (*Pseudotsuga menziesii)* and western hemlock (*Tsuga heterophylla*). Redwood (*Sequia sempervirens*) permeability also increased following steaming treatments (Ellwood and Erickson, 1962). Baines and Saur (1985) found that steaming sitka spruce (*Picea sitchensis*) heartwood dry, and at 50 percent moisture content, did not significantly increase preservative uptake compared to unsteamed controls. Steaming dry lumber often reduced preservative retention. Some species are susceptible to strength loss when they are steamed while their moisture contents are above the fiber saturation point. Steaming is also energy intensive.

Attempts to use high-pressure to treat refractory woods have resulted in considerable physical and mechanical damage. Pressures up to 6.9 MPa have been used in Australia, the Philippines and the United States, but many woods collapsed from the high compressive stresses (Hunt and Garratt, 1967). Walters (1967) observed collapse in red gum (*Liquidambar styracifua*) treated at 5.55 MPa and 93.3 °C, while Walters and Whittington (1970) observed collapse in Douglas-fir (*Pseudotsuga menziesii*) at 5.55 MPa and 93.3 °C. Conventional treating pressures typically range between 1.03 MPa and 1.72 MPa (Anonymous, 1987).

While all of the processes discussed have been used commercially to treat a variety of wood products, none completely overcome the difficulty of forcing liquids into refractory wood. On a cost basis, no current method for the treatment of refractory wood with preservatives is more cost effective than vacuum/pressure treatments (Baines and Saur, 1985). One alternative process that has recently received considerable interest is the use of supercritical fluids as carriers for biocides.

2 SUPERCRITICAL FLUIDS

2.1 Supercritical Fluids

A supercritical fluid (SCF) is a substance that has been heated and compressed beyond its critical point that is defined by a critical temperature (T_c) and critical pressure (P_c) (Figure 2.1). The physical properties of SCF's are unique because they continuously change from gas-like to liquid-like in the supercritical region (Ekert et al., 1986; Wenclawiak, 1992; Westwood, 1993). The densities of the gas and liquid phases become indistinguishable near the critical point (Table 2.1). The liquid phase becomes less dense because of thermal expansion and the gas phase becomes more dense as the compression increases (Westwood, 1993).

SCF's are continuously adjustable solvents offering a convenient means of achieving solvating properties that have gas and liquid-like characteristics without actually changing chemical structure (McNally and Bright, 1992). The unique physical properties of SCF's make them ideal for extractions, chromatography, chemical reaction processes and oil recovery (McNally and Bright, 1992). Slight changes in temperature and pressure have a marked effect on SCF solubility properties. Density is especially sensitive to changes in pressure at constant temperatures (Williams, 1981; McNally and Bright, 1992; Wenclawiak, 1992). Many of the variable properties exhibited by supercritical fluids are related to their fluid density properties which directly affects their solvent characteristics (Matson and Smith, 1989).

There are a wide variety of SCF's (Table 2.2), but carbon dioxide is the most popular SCF because its critical temperature and pressure are relatively low and easily attained (31.7 °C and 7.4 MPa). Other attractive characteristics of supercritical carbon dioxide include that is has a low toxicity, is non-flammable, and is relatively cheap (Williams, 1981; Brogle, 1982; Fillipi, 1982; Eckert et al., 1986; Hawthorne, 1990; Westwood, 1993).

Table 2.1. Selected physical properties of gases, liquids and supercritical fluids (SCF's).

Phase	D (cm^2/s)	ρ (g/cm^3)	η (g/cm s)
Gas	10^{-1}	10^{-3}	10^{-4}
Liquid	10^{-6}	1.0	10^{-2}
SCF	10^{-3}	0.2-0.8	10^{-4}

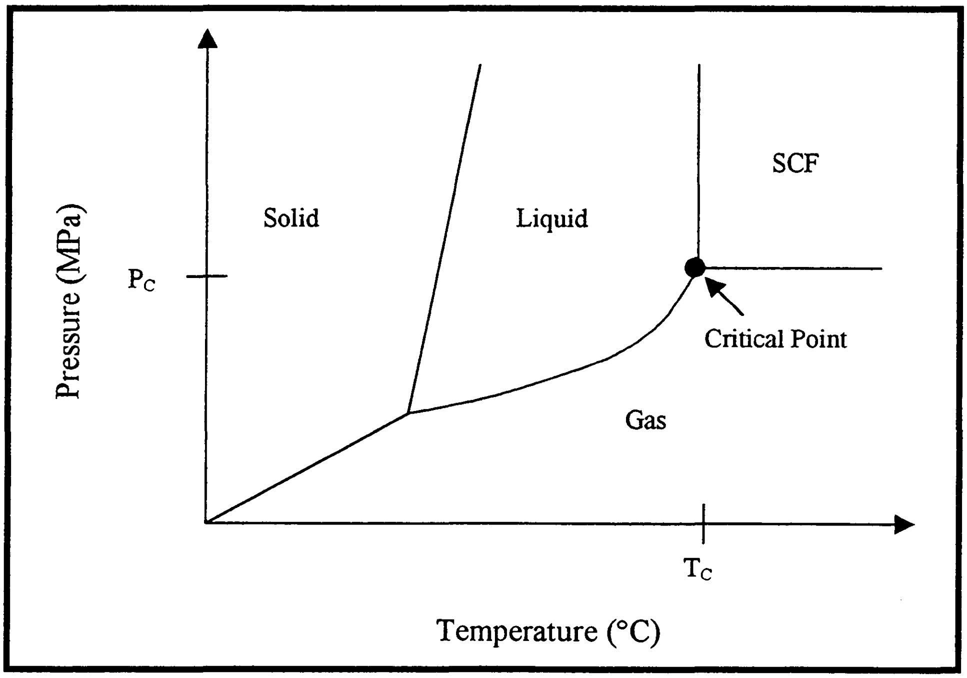

Figure 2.1. Phase diagram of a single substance.

Currently, SC CO_2 is used for the extraction of hops, caffeine, spices, tobacco, fatty oils, and the oxidation of toxic waste and organic materials (Zozel, 1974; Modell, 1982; Williams, 1981; McNally and Bright, 1992; Westwood, 1993).

While a large amount of detailed research is still needed to gain a better understanding of supercritical fluids, the technology is seeing ever-increasing application. Two areas within the forest products industry that have received attention are wood preservation and pulp and paper (Kiran , 1994).

Table 2.2 Critical parameters of common supercritical fluids.

Substance	T_c (°C)	P_c (MPa)	ρ_c (10^3kg/m^3)
CO_2	31.30	7.39	0.47
N_2O	36.50	7.35	0.45
SF_6	45.50	3.76	0.74
NH_3	132.50	11.40	0.24
H_2O	374.00	23.00	0.34
n-C_4H_{10}	152.00	3.80	0.23
n-C_5H_{12}	197.00	3.78	0.23
Xe	16.60	5.92	1.10
CCl_2F_2	112.00	4.13	0.56
CHF_3	25.90	4.75	0.52

2.2 Supercritical Fluid Technology in the Forest Products Industry

The primary applications of supercritical fluids in pulp and paper processing include selective extraction of wood-based chemicals, unconventional pulp and bleaching processes, unconventional bioconversion processes, recovery from waste streams, toxic materials removal and recycling (Tillman and Lee, 1990; Ritter and Campbell, 1991; Lee and Peart, 1992; Kiran, 1994). Supercritical fluids have also been used in selective chemical extractions of wood and wood based materials (Calimi and Oclay, 1978; Larsen et al., 1992; Kiran, 1994; Ohira et al., 1994; Acda et al., 1998). Finally, supercritical carbon dioxide (SC CO_2) has been investigated for use in wood impregnation with polymers and biocides (Kiran, 1994). Of particular interest is the use of SC CO_2 in wood preservation for the treatment of refractory wood species.

SC CO_2 is currently being investigated as a possible substitute for conventional liquid preservative carriers. To date, there has been no documentation of deleterious chemical interactions between CO_2 and the constituents of the wood cell wall (Ritter and Campbell, 1991; Kiran, 1994). The use of SC CO_2 for impregnation of refractory wood species has three distinct advantages over conventional preservatives. SC CO_2 has a higher diffusivity and lower viscosity than liquids, but the solvating potential of SC CO_2 approaches that of a liquid with many biocides. These properties are ideal for the preservation of refractory wood because they would allow deeper preservative penetration into otherwise difficult to treat species at levels that should confer biological protection.

2.3 Previous SC CO_2 Studies in Wood Impregnation

Previous studies using SC CO_2 have treated small clear specimens of wood at pressures ranging from 6.9 to 50.0 MPa and temperatures ranging from 35°C to 150°C (Morrell et al. 1993; Smith et al. 1993; Kiran, 1994; Demessie et al., 1995; Acda et al., 1997; Acda et al., In review). When wood is subjected to pressures and temperatures this extreme, collapse of the cell walls can occur (Acda et al., In review; Kim and Morrell, In preparation).

Collapse in wood is a phenomenon usually associated with drying where the cell walls are actually pulled together causing them to buckle. Collapse is believed to occur for three reasons; hydrostatic tension of water on wet and plastic cell walls, compressive stresses induced during drying that exceed the compressive strength of wood, or excessive amounts of extractives (Panshin and deZeeuw, 1980; Stamm, 1964; Meyer and Barton, 1971). Collapse during SCF treatments is believed to occur because of high compressive stresses induced as pressure gradient's form during pressurization to the supercritical region.

Pressures up to 6.9 MPa have been used to treat wood using conventional liquid preservatives in Australia, the Philippines and the United States, but many woods cannot withstand these pressures. Walters and Whittington (1967, 1970) treated 19 x 19 x 406 mm specimens of red gum (*Liquidambar styraciflua*) and Douglas-fir with pentachlorophenol and reported losses in MOR and MOE for Douglas-fir, but slight increases in both MOR and MOE for red gum. Collapse occurred for both species when pressures increased above 2.76 MPa and was greatest at 5.52 MPa.

Previous studies using supercritical fluid treatments found no significant losses in MOR and MOE for wood composites panels (38 mm x 500 mm x panel thickness) or small clear specimens of wood (2.4 x 2.4 x 54 mm) (Smith, 1993; Morrell et al., 1993; Acda, 1997). As small clear specimens of wood were increased to 19 x 19 mm and larger cross-sections, significant reductions in bending properties were found in western redcedar, white spruce, and southern yellow pine, but no significant losses were found in Douglas-fir, red alder or white oak (Acda et al., In review; Kim et al., 1997).

When wood is subjected to SCF conditions treatments defects may occur and cause physical degradation. Spruce seems to be the most susceptible to treatment defects. Kim (in review) found that spruce specimens (38 x 50 x 200 mm) were most affected by deformation during pressurization and venting. Acda et al. (In review) noted collapse in spruce and western red cedar with sample dimensions 25 x 25 x 503 mm. Collapse in spruce appears to occur during pressurization, but permanent deformation may also be affected by venting, or depressurization, at the end of the treatment period (Kim, In preparation). Kim (In preparation) found that using slower rates of pressurization when treating white spruce had the least effect on deformation suggesting that some equilibrium occurred. It is believed that collapse occurs during pressurization once the pressure gradients exceed the compressive strength of the wood perpendicular to the grain.

It was first theorized that SC CO_2 penetrated the wood matrix instantaneously and created no pressure gradients (Morrell et al., 1993). However, recent work by Schneider (in progress) indicates that substantial pressure gradients develop in 30 x 30 x 60 cm long clear samples of Douglas-fir, yellow poplar, white oak, fir, and red oak during SCF treatments. Pressure gradients as high as 10.34 MPa have been observed in white oak with the flow limited to the radial direction. Under the same treatment processes, pressure gradients of 3.44 MPa have been observed in Douglas-fir.

Developing effective processes for impregnating wood using SCF's will require a delineation of the effects of various process parameters on the material properties of wood.

2.4 Objective of This Study

The objective of this study was to determine the effect of SC CO_2 treatments, including pressurization rate (PR), venting rate (VR) and treatment pressure (TP) on the bending properties and treatment defects induced in refractory heartwood samples from Douglas-fir (*Pseudotsuga menziesii*), Engelmann spruce (*Picea engelmannii*), western redcedar (*Thuja plicata*), and yellow poplar (*Liriodendron tulipifera*).

3 MATERIALS AND METHODS

3.1 Experimental Design

This research was designed to examine the effects of pressurization rate (PR), venting rate (VR) and treatment pressure (TP) during SCF treatments on the modulus of rupture (MOR), modulus of elasticity (MOE) and work to maximum load (WML) of Douglas-fir, yellow poplar, western redcedar, and Engelmann spruce. Treatment defects incurred during SCF treatments were monitored concluding treatments to examine their effects on MOR, MOE and WML. All of the treatments examined were compared to untreated control treatments that were not introduced to SCF treatment conditions. The species examined in this study are resistant to conventional vacuum/pressure impregnation. Douglas-fir, western redcedar and Engelmann spruce are all resistant to vacuum/pressure treatments and require pre-treatments to enhance preservative penetration (AWPA, 1998). Western redcedar and spruce have both experienced collapse in previous SC CO_2 studies (Acda et al., in review; Kim and Morrell; in preparation). Yellow poplar is an important southern hardwood with a very low transverse heartwood permeability (Choong and Fogg, 1972).

The treatments parameters investigated in this study were: two rates of pressurization (0.34 and 3.44 MPa/min.), two treatment pressures (10.34 and 20.69 MPa), and two venting rates (0.34 and 3.44 MPa/min.) (Table 3.1). In previous research (Morrell et al., 1993; Smith et al., 1993; Demessie et al., 1995; Acda et al., 1997; Acda et al., In review), treatment temperature and time did not appear to affect MOE and MOR after the wood was reconditioned to the original equilibrium moisture content (EMC). Therefore, one temperature (60°C) and one treatment time (30 min.) were employed. Treatment time was considered the length of time after the pressure reached the target level. For the spruce specimens, only treatments 1, 3, 6, 8 and 9 were used due to the limited supply of test specimens.

All specimens were 38 x 38 x 585 mm. Small clear specimens of wood with dimensions this large have not yet been investigated under supercritical conditions. This size was expected to be large enough to encourage the formation of pressure gradients within specimens during SCF treatments. Excessive pressure gradients may cause defects and possible decreases in bending properties. This size was also an appropriate dimension for bending tests used to determine the MOR, MOE and WML for each specimen treated.

Table 3.1. SCF treatment process variables of the experimental design.

Treatment	**Initial Pressurization (MPa/min.)**	**Maximum Treatment Pressure (MPa)**	**Venting Rate (MPa/min.)**
1	0.34	10.34	0.34
2	3.44	10.34	0.34
3	0.34	20.69	0.34
4	3.44	20.69	0.34
5	0.34	10.34	3.44
6	3.44	10.34	3.44
7	0.34	20.69	3.44
8	3.44	20.69	3.44
9	-	-	-

The experimental design was a randomized complete block experiment where an individual board was defined as a block. A sample size of twelve specimens was tested for each species/treatment combination. The sample size was based on previous statistical findings and calculated using equation 3.1 and the MOE variance from Acda et al. (In review). MOE variance was smaller than the MOR variance for Acda et al. (In review) and was chosen because larger sample sizes would have been calculated with the larger variance. A practical significant difference (δ) of 1380 MPa, a confidence level (α) of 10%, and a power (β) of 70% were used. Power was defined as the probability of identifying a statistically significant difference given that there is indeed a difference.

$$n = ((Z_{1-(\alpha/2)} + Z_{1-(1-\beta/2)})^2 * 2 * \sigma^2 * (2/3))/\delta^2 \qquad (3.1)$$

Western redcedar (*Thuja plicata*) and yellow poplar (*Liriodendron tulipifera*) samples were replicated using a complete block design. An incomplete-block design was implemented for Douglas-fir and Engelmann spruce due to difficulties experienced in attaining twelve clear blocks for each species. Douglas-fir (*Pseudotsuga menziesii*) samples were replicated from nine blocks and spruce was replicated using samples taken from sixty 38 x 38 x 244 mm blocks. Spruce specimens were sorted from S-P-F (spruce-pine-fir) firing strips purchased locally and were later identified as Engelmann spruce (*Picea engelmannii*). Since clear grades of spruce were unattainable, an acceptable lumber grade for testing was established following ASTM Standard D 245-93 (ASTM, 1997 b) (Appendix A).

Douglas-fir, western redcedar and spruce were all purchased locally. Yellow poplar was provided by Koppers Industries (Pittsburgh, PA). All specimens were placed in the standard room (20 °C and 65 %RH) prior to SCF treatment.

Covariate measurements were recorded for each specimen before it was introduced to a SCF treatment. A covariate is a measurement taken on an experimental unit that is not included in the experimental design, does not directly answer any of the questions of interest, can potentially answer confounding effects in an analysis, and improves the precision in treatment experiments (Ramsey and Schafer, 1996). Covariates measured in this experiment were specific gravity, ring angle, percent heartwood, and the number of growth rings. Prior to treatment, specimen length, width, height and weight were also measured. Ring angle was measured using a ring angle template provided by Dr. Michael Milota at the Forest Research Laboratory (Bengtsson and Milota, 1998).

3.2 Testing Procedures and Data Acquisition

3.2.1 SCF Treatment Process

All treatments were performed in a SCF treatment apparatus (Figure 3.1). Pressurization and venting rates were controlled through one of two metering valves to achieve the desired treatment conditions. Each metering valve was equipped with a different flow coefficient. Faster flow rates were achieved though the metering valve with the higher flow coefficient, while slower flow rates were achieved by using the metering valve with the lower flow coefficient. This design allowed more precise control of pressurization and venting. Prior to pressurization, Vessel #3 was pressurized to approximately 33.10 MPa. The compressed CO_2 in this vessel was then vented

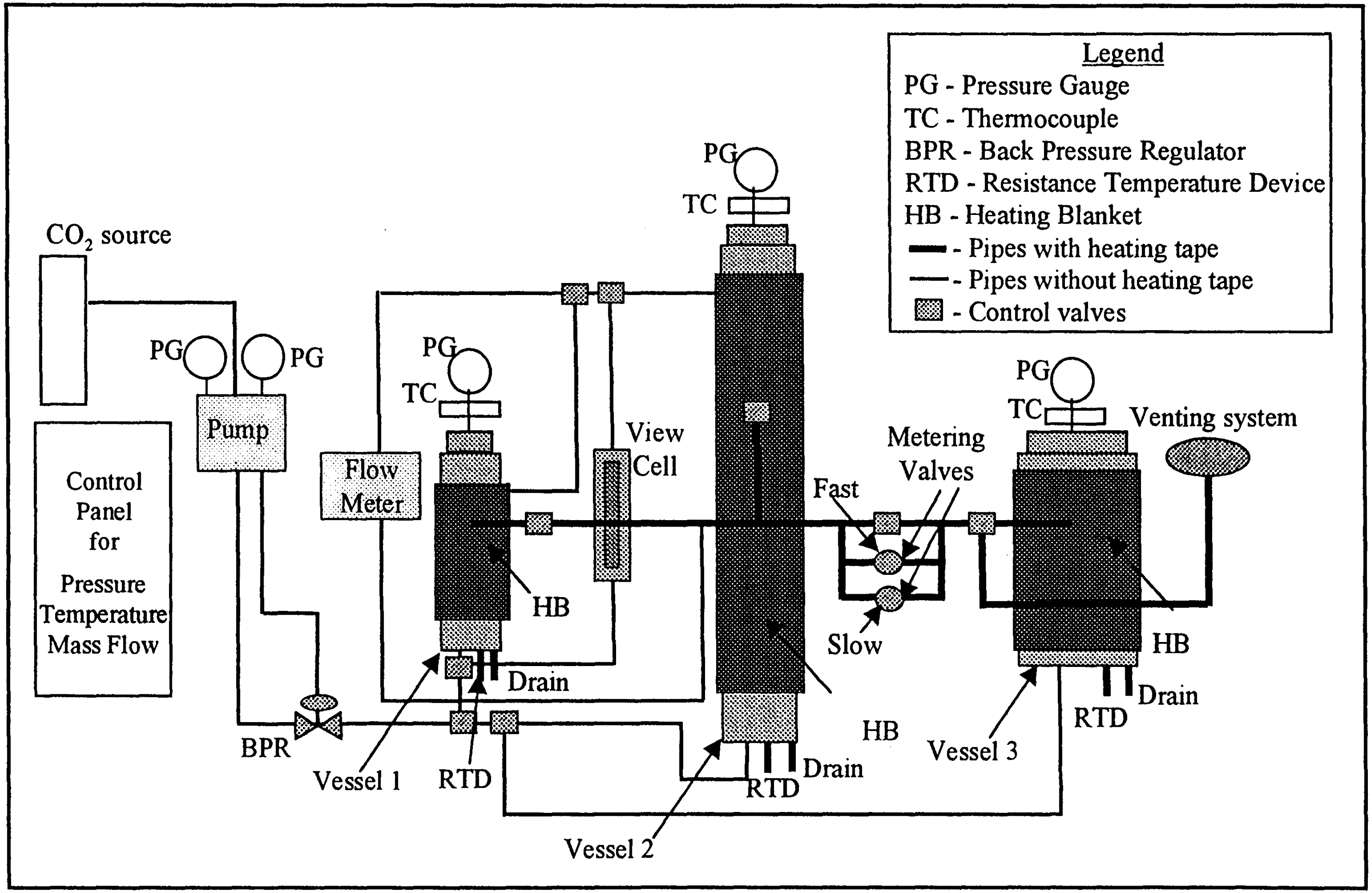

Figure 3.1. Supercritical fluid treating apparatus.

through one of the two metering valves and the flow meter and into Vessel #2. Compressed CO_2 was released back through the bi-directional flow meter during the venting process, through one of the metering valves and into the atmosphere.

Pressure in all three vessels was monitored using digital meters (Newport Electronics Quanta QXXXXP Process Signal Digital Meter, Model Q9000P). One of the three digital meters read the pressure from one of three pressure transducers (Omega, Model No. PX 420-5KGI). Each meter was calibrated by using known voltages to establish the maximum and minimum current set points. A calibration curve was created using a pressure transducer with a known resistance to read voltage outputs and known pressures from a pressure gauge (Heise Solid Front CMM-97140).

Each of the three vessels was wrapped with a heating blanket and controlled with two temperature process controllers (West Process Control Instrumentation) that were fixed into the control panel. One controller read the resistance temperature detector (RTD) within a specific vessel and one controller read the heating blanket temperature for that vessel. The two controllers worked together as a combined unit to maintain accurate operating temperatures for each vessel. This control system is referred to as a dual electrical loop, or cascade loop, where heating is activated if both devices requested heat based on the two temperature outputs compared to the targeted set-point vessel temperature. Heating tapes were applied to the stainless steel tubes connecting the three vessels and controlled using a rheostat (variable resistor that controls voltage output) to maintain constant temperature.

A Campbell 21X (Campbell 21X Micrologger, Campbell Scientific Inc.) and a personal computer were used to collect data for pressure from an Omega pressure transducer for Vessels #1, #2,and #3, temperature using Type K Omega thermocouples in Vessels #1, #2, and #3, and mass flow during pressurization and venting from the frequency output of the mass flow meter.

Twelve specimens were randomly allocated into the ten zones within the treatment vessel to account for positional effects during treatment. The vessel was divided into ten zones with five zones in the bottom of the cylinder and five zones in the top of the cylinder (Figure 3.2). Two specimens were capable of fitting into one zone. Stainless steel rods were used to occupy the excess volume within the cylinder and to keep specimens in their proper position. Vessel position was treated as a repeated measurement instead of a covariate. A repeated measurement is a special kind of multivariate response obtained by measuring the same variable on each subject several times and possibly under different conditions (Ramsey and Schafer, 1996). Vessel position was not a direct measurement performed on each specimen several times, it was

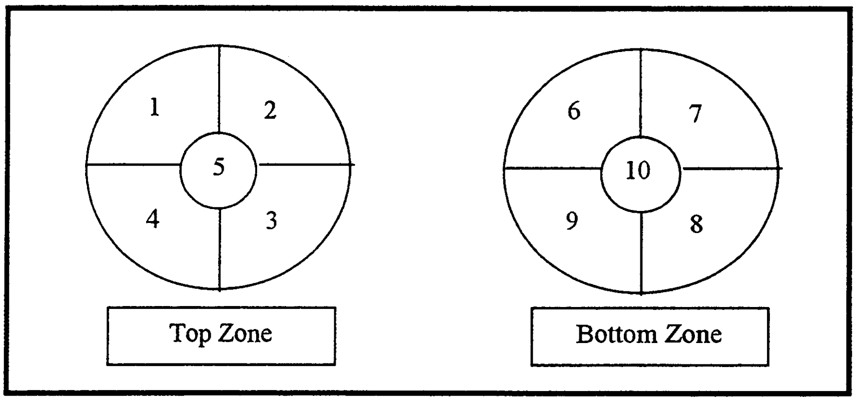

Figure 3.2. Zones inside vessels used for positioning specimens.

performed on each specimen once for all SCF treatment conditions. Vessel position was not treated as covariate because it was not a measurement performed on each experimental unit separately.

3.2.2 Treatment Defect Rating

In order to assess some of the treatment defects incurred during SCF treatments, two binary classifications were developed. These treatment defect classifications were defined as either continuous wood failures (CWF_T) or discontinuous wood failures ($DCWF_T$). Both classifications were evaluated on each specimen. A CWF_T was defined as a treatment defect where the cross-sectional dimensions had changed after being introduced to SCF treatments, but macroscopically the specimen still appeared as a continuous material. Dimensional changes during treatments were monitored by measuring the cross-sectional dimensions of both ends of each specimen to the nearest 0.01mm before and after each treatment. After treatments, an average of the left and right end height and the width of each specimen was calculated and the greater of the two averages was used as the response variable (See Appendix B). Then the CWF_T of each specimen was indicated using binary responses with the following levels of classification:

- < 0.10 mm.
- 0.11 – 0.50 mm.
- 0.51 – 1.00 mm.
- > 1.01 mm.

Dimensional changes less than 0.10 mm were not included because of concerns related to measurement error and dimensional changes due to wood desiccation from exposure to CO_2.

$DCWF_T$'s were rated based on visual observations of the specimens after supercritical fluid treatments. The $DCWF_T$ of each specimen was indicated using binary responses with the following classification levels:

- No defects observed.
- Radial failure.
- Tangential failure.
- Both radial and tangential failures observed.

After the specimens were rated for treatment defects, they were returned to the standard room (20 °C and 65 %RH) and equilibrated until the bending tests were conducted.

3.2.3 Control Specimens

Control specimens of treatment 9 (Table 3.1) were not introduced to supercritical treatment conditions. The control treatment was used for comparisons between treated and untreated specimens in the statistical analyses. The control specimens were maintained in the standard room (20 °C and 65 %RH) while all SCF treatments were being evaluated. Before the bending tests were conducted, the covariates of each control specimen were measured.

3.2.4 Bending

Bending tests are one of the most widely used methods for evaluating changes in wood properties (Bodig and Jayne, 1993). The bending properties evaluated in this project were the bending (apparent) MOE, MOR and WML. Specimen dimensions (38 x 38 x 585 mm) were in accordance with ASTM Standard D-143 (ASTM, 1997 a).

The test specimens were equilibrated before testing at 65% relative humidity and 21°C. The bending tests were conducted using a universal testing machine (Instron Testing Machine). The center-point loading method was conducted over a 533-mm span. Load was applied to the tangential surface nearest the pith at a rate of 1.3 mm/min. Load-deflection data were gathered using a Campbell 21X (Campbell 21X Micrologger, Campbell Scientific Inc.). The Campbell 21X monitored load using a Sensotec load cell (Model 41-573-02, 20K maximum) and deflection via a Celesco LVDT (Model PT 101-0010-111-1110). Deflection was recorded at the center of the span with respect to the neutral plane above the supports. MOR, MOE and WML were calculated from the load-deflection data. The specific gravity for each specimen group was measured using the displaced water method as described by ASTM Standard D 2395-93 (ASTM, 1997 c), except that the samples were not coated with wax to prevent water adsorption. The wet samples were weighed in and out of the water and then oven dried for 48 hours. After drying, the samples were weighed for oven-dry weight and oven-dry weight under water. Figure 3.3 illustrates the sampling pattern used to obtain the specific gravity and moisture content samples. The measurements were used to calculate the specific gravity (oven-dry volume) and moisture content during bending tests.

3.2.5 Microscopic Inspection

After completing the bending tests, two specimens from each species/treatment combination were examined by light microscopy to better assess microscopic treatment defects and determine which areas of the wood were most affected by SCF treatments. One sample (38 x 38 x 25 mm) was cut from each specimen for microscopic observation (Figure 3.3). Two plugs (6 x 6 x 9.5 mm) were cut from each sample representing inner and outer zones (Figure 3.4). The plugs were vacuum impregnated in a 50/50 (by volume) solution of water and ethanol until complete saturation. A single transverse section was cut from each plug. The sections were then mounted in glycerol on glass slides and examined using a Nikon microscope (Labophot-2). Three fields were assessed per section at 40X and 100X magnification. The treatment defect terminology previously described was extended so that treatment defects were defined as microscopic continuous wood failure (CWF_M) and microscopic discontinuous wood failure ($DCWF_M$). Both classification systems were evaluated on each section (Appendix C).

CWF_M's were classified under a binary classification system as one of the following:

- Present.
- Not present.

If CWF_M's were present, they were further classified using a binary indicator as being either one or both of the following:

- Plastic.
- Mechanical.

Plastic failure of the cell wall was defined as a continuous failure whereas mechanical failure was described as a discontinuous failure where the cell walls were torn or separated from one another causing them to collapse. The percentage of earlywood collapse was calculated for each field by counting the average number of collapsed earlywood tracheids in a growth ring and dividing by the average number of earlywood tracheids within that growth ring. An average percent collapse for each view was dependent upon the number of rings where earlywood collapse was present.

In order to distinguish microscopic treatment defects incurred during SCF treatments, visually degraded specimens were observed as well as non-visually degraded specimens. CWF_M failures were viewed to distinguish the differences between failures directly caused by sectioning and those caused by treatments. Wafers were first viewed under a dissecting lens and then sections for assessment at 40X and 100X were taken from areas of obvious collapse. The same process was performed on specimens with no collapse.

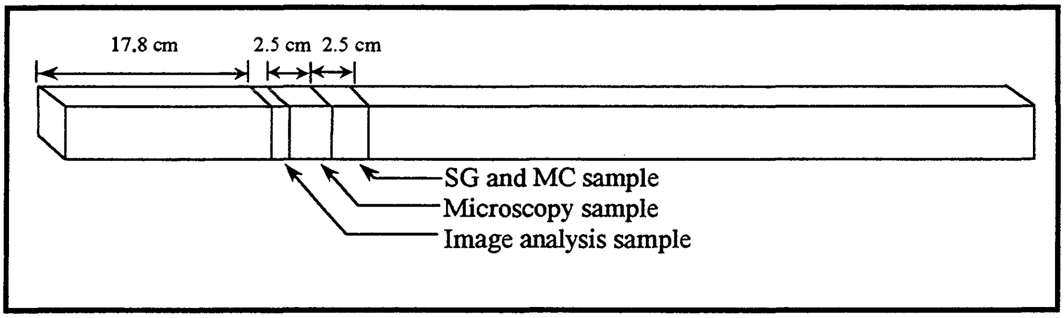

Figure 3.3. Sampling pattern for assessing specific gravity (SG), moisture content (MC), and image analysis of beams following bending tests.

$DCWF_M$'s were classified under a binary classification system as one of the following:

- No checks and splits present.
- Checks and splits present.
- Radial.
- Tangential.

If $DCWF_M$'s were present, then they were classified further as being in one or both of the following directions:

3.2.6 Image Analysis

Dimensional changes incurred during supercritical treatments were also assessed by cutting a 2-mm thick cross-section/wafer and measuring cross-sectional area using a MacIntosh NIH Image Analysis System (Figure 3.3). This additional information was used to collect data on dimensional changes after SCF treatments near the middle of each specimen, which is where collapse could be seen. The original classification system (CWF_T) only used cross-sectional dimensions to assess changes induced during SCF treatments. The most severe pressure gradients will occur toward the mid-length of a specimen because away from the ends longitudinal permeability becomes negligible compared to the transverse permeability (Siau, 1995). Before scanning, each wafer was lightly sanded to reduce edge roughness and then placed cross-section up under a video camera. The NIH system then scanned the wafer for an outer perimeter and calculated the area within the perimeter. These procedures were performed for all species/treatment combinations including the controls, which were used for comparison

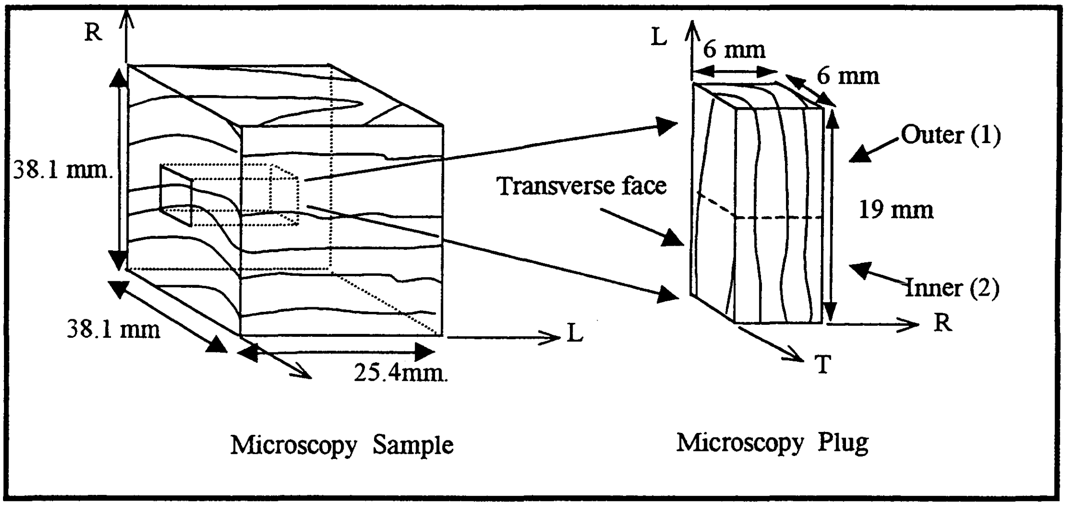

Figure 3.4. Sampling pattern for removing microscopy plugs.

3.2.7 Data Analysis

Statistical analyses were performed for each species separately. First, General Linear Models (GLM) modeled each flexural property against classification and continuous variables. The initial models tested for the effect of board, treatment, and treatment nested within a run, while ignoring covariates.

Second, a Dunnett's T-test was then performed to separate those treatments that were significantly different from the control. A Dunnett's T-test is a two-tailed t-test used to determine if any treatments differ from a control treatment (SAS Institute Inc., 1989). If no significant differences occurred within the GLM nor the Dunnett's T-test, then statistical evaluations were no longer conducted since because both tests indicated no significant differences between treatments. If significant differences were found between treatments and the control, then a third GLM was used to test for significance between treatments after accounting for the covariates.

An additional GLM was designed specifically to test for the effect of vessel positioning on each of the bending properties and the interaction between vessel position and treatment. After assessing the effects of covariates and vessel position on the bending properties, then the effects of treatment parameters were evaluated for each bending property.

The final analysis conducted was a Pearson Correlation Analysis. This procedure compared the binary responses from the classifications used to describe the treatment defects, CWF_T and $DCWF_T$, to the bending property responses. This correlation coefficient only measures the degree of linear association between two variables or two sets of variables (Ramsey and Schafer, 1996). A correlation coefficient falls between –1 and 1, with the extremes corresponding to exact linear relationships and correlations of zero representing situations with no linear association (Ramsey and Schafer, 1996). Interpretation of the correlation coefficient is that of association between two sets of variables and not one of cause-and-effect between the variables.

Statistical significance was positive for p-values less that 0.05. For p-values ranging between 0.051 and 0.10, the significance was suggestive, but inconclusive. P-values greater than 0.10 were not considered significant. P-values associated with the Pearson correlation coefficient that were less than 0.05 suggest that the slope of the correlation is significantly different than zero.

4 RESULTS AND DISCUSSION

4.1 Experimental Performance

Figures 4.1 and 4.2 show representative time-pressure diagrams of the eight SCF treatments examined. The treatment methodology worked very well for all the treatment regimes with the exception of treatments 4 and 8 (3.44 MPa/min. pressurization to 20.69 MPa). This combination of rapid pressurization to high treatment pressure was limited by pump capacity. To compensate for the limited pump capacity at rapid pressurization rate and high treatment pressure, Vessel #2 was initially pressurized to 6.89 MPa and held constant while Vessel #3 was re-pressurized to 33.10 MPa. A second phase of pressurization was then implemented to pressurize Vessel #2 to approximately 12.41 MPa. The pump then independently increased the pressure in Vessel #2 until it reached 20.69 MPa.

A down time of six weeks was experienced for Vessel #2 during the period of treatment processing. While this vessel was under repair, Vessel #3 was used as the treatment vessel for the treatments requiring 0.34 MPa/min. pressurization. The capacity of Vessel #3 was six specimens as opposed to the twelve-specimen capacity of Vessel #2. Six additional position variables were used for Vessel #3. As with the processes described for pressurizing Vessel #2, Vessel #3 was pressurized using Vessel #1 as the pre-pressurized port. CO_2 was compressed in Vessel #1 and released through the bi-directional flow meter using one of the metering valves and into Vessel #3 until the target treatment pressure was attained. Compressed CO_2 was released back through the

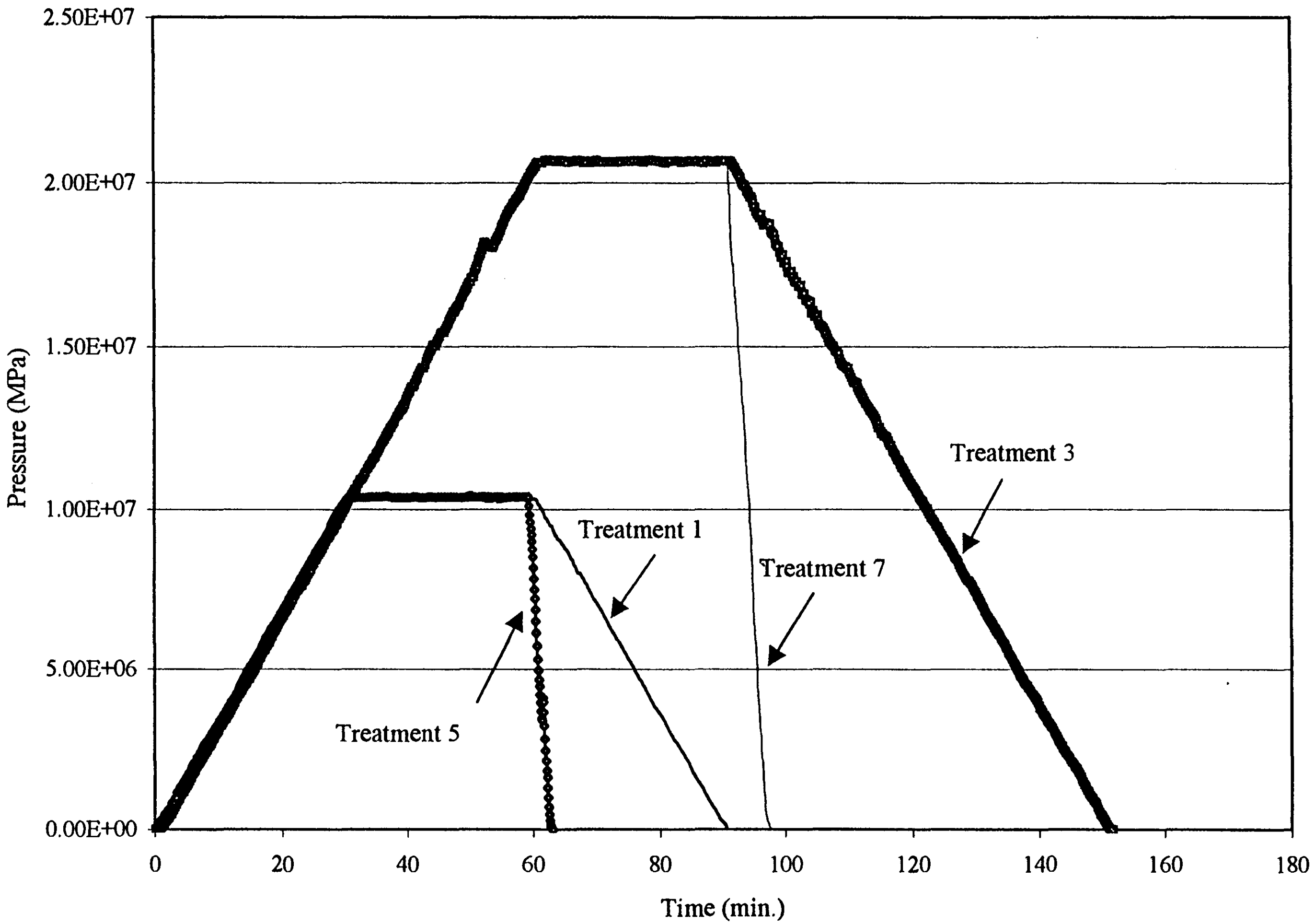

Figure 4.1. Representative time-pressure diagrams for treatments 1, 3, 5, and 7.

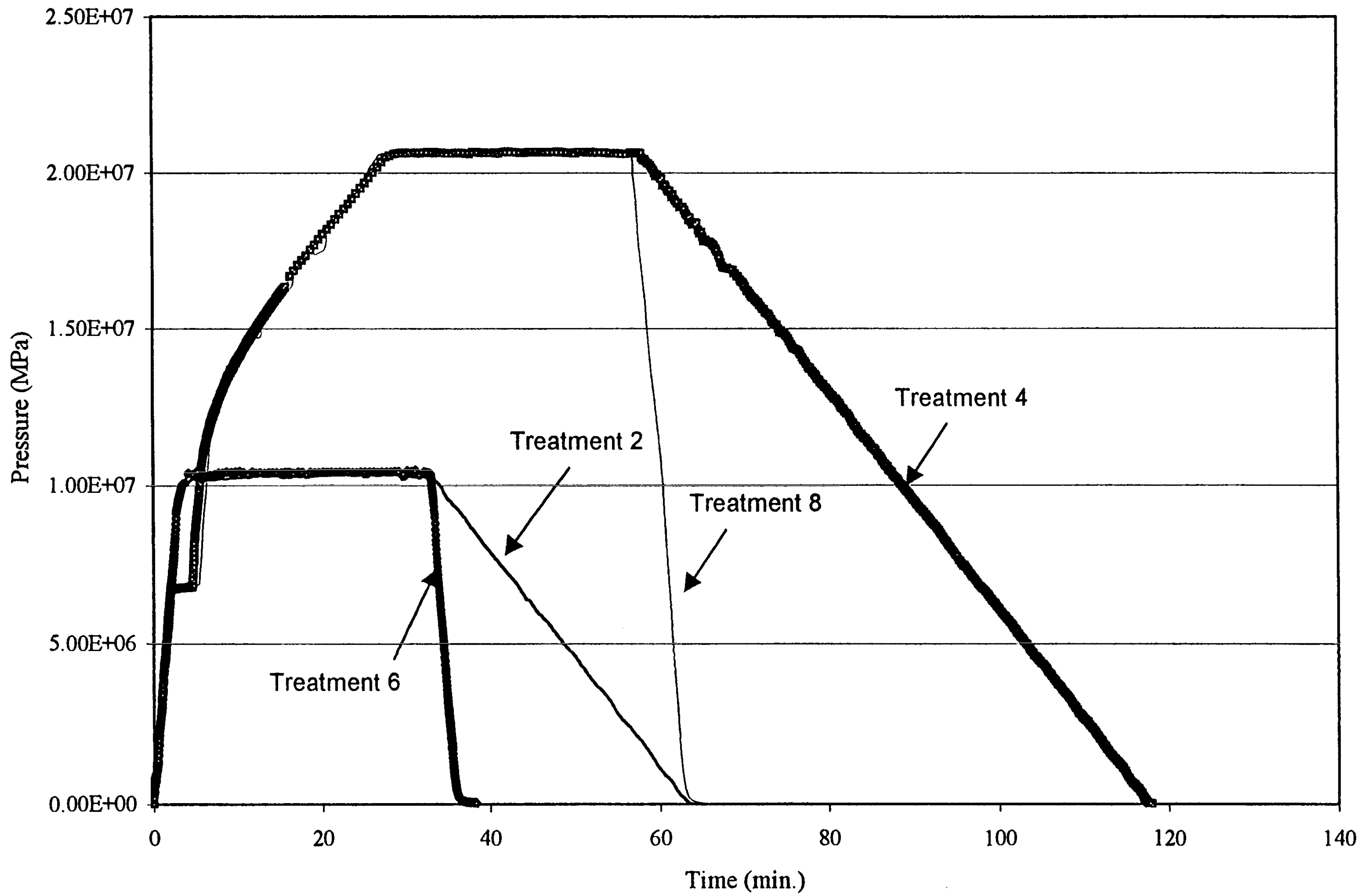

Figure 4.2. Representative time-pressure diagrams for treatments 2, 4, 6, and 8.

bi-directional flow meter during the venting process, through one of the metering valves and into the atmosphere.

The actual average treatment pressures attained were 10.40 and 20.60 MPa. The average slow pressurization rate was 0.34 MPa/min. for pressurization up to 10.40 and 20.60 MPa. The average fast pressurization rate to 10.40 MPa was 2.60 MPa/min. and the overall average fast pressurization rate to 20.60 MPa was 0.73 MPa/min., with an initial rate of 3.15 MPa/min. to 6.90 MPa followed by 0.53 MPa/min. to the final targeted treatment pressure. The targeted venting rates were more precisely achieved with the average slower and faster venting rates from 10.40 and 20.60 MPa were 0.34 MPa/min. and 3.27MPa/min., respectively.

4.2 Visual Assessment of Specimens

Douglas-fir and yellow poplar specimens were very consistent with no obvious treatment defects incurred from SCF treatments.

One characteristic of the Douglas-fir specimens was the presence of resin spots. This may be due in part to the resinous materials of the heartwood reacting with the CO_2 and/or outward migration of resinous material during the venting cycle.

One yellow poplar specimen exhibited a radial defect during treatment 5 (0.34 MPa/min pressurization rate, 10.34 MPa treatment pressure and a 3.44 MPa/min. venting rate). The ends of the yellow poplar specimens often had very small checks and splits resembling drying defects. These defects were always present on the surface and were no deeper than approximately 0.5 mm.

Western redcedar and Engelmann spruce exhibited the most severe treatment defects after treatment. Exposure to SCF conditions often caused western redcedar and Engelmann spruce to exhibit both collapse and splitting. Both species had specimens that were damaged to the point that bending tests could not be performed to assess bending properties. Dimensional changes that occurred on redcedar and spruce were often visually detectable. When collapse was present, it occurred to the highest degree at the center of the specimens. In Engelmann spruce, collapse was also concentrated around the small knots causing them to protrude from the transverse faces. Similar to Douglas-fir, Engelmann spruce often had resin spots scattered along its transverse faces. One characteristic treatment defect that was present in five specimens of western redcedar was called "Angel Hair" splitting, where the specimen was pulverized into hundreds of long slender sticks. This defect occurred during treatments with 3.44 MPa/min. venting rates. Angel hair was also observed in one specimens of Engelmann spruce. Finally, even though some specimens of western redcedar and Engelmann spruce specimens experienced drastic treatment defects, specimens of the same species exposed to the same treatments had virtually no visually detectable treatment defects. This observation suggests that there was a large variability in permeability within the specimens of these species.

For all species, a large number of specimens exposed to SCF treatment conditions experienced, to some degree, slight reductions in cross-sectional dimensions (less than 1%) while others experienced slight increases in dimensions (less than 1%). Some specimens increased in all cross-sectional dimensions that likely occurred from expansion due to splitting and checking during SCF treatments. Regardless of the treatment defects incurred from SCF treatments all samples were subjected to bending tests as long as they could be supported in the bending test apparatus.

4.3 Effect of Supercritical Treatments on MOR, MOE and WML

4.3.1 Effect of Supercritical Fluid Treatments on Bending Properties

Bending properties for all tested species/treatment combinations including the controls are listed in Table 4.1 (Appendix D). Table 4.2 presents the moisture content and specific gravity information attendant to the bending tests.

The sampling distribution for Douglas-fir in this experiment was such that boards with very high specific gravities and bending properties were distributed to treatments 1, 2, 3, and 4. Specific gravities as high as 0.65 were observed in some specimens with average specific gravities as high as 0.56 in these treatments (Table 4.2), which was 9.8 percent greater than the mean specific gravity of the control. In addition pre-treatment examination revealed specimens in treatments 7 and 9 had internal defects such as knots and insect damage. These specimens were withdrawn from the experiment and replaced with random specimens cut from the original material population, although the original board identifications of the replacement samples were lost in the process. Many of the replacement samples exhibited lower than average bending properties. In summary the large specific gravity variability within Douglas-fir lead to results suggesting that SCF treatments increased bending properties, but the sampling distribution within Douglas-fir most likely confounded these results (Appendix D). All further discussion of Douglas-fir results should be interpreted in light of these sampling issues.

Table 4.1. Average values of MOR, MOE, and WML and percent differences from the control for all treatments of Douglas-fir, yellow poplar, western redcedar and Engelmann spruce (standard deviations are indicated within parentheses).

Treatment				Douglas-fir						
Number	PR [a]	TP [b]	VR [a]	N =	MOR (MPa)	% Diff. [c]	MOE (MPa)	% Diff	WML (Nm/m³)	% Diff.
1	0.34	10.34	0.34	12	81.96 (14.50)	5.0	10366 (2731)	-9.1	4486 (1573)	34.5
2	3.44	10.34	0.34	12	82.12 (19.62)	5.0	12086 (3708)	6.0	3593 (1369)	7.7
3	0.34	20.69	0.34	12	84.63 (24.22)	8.4	12250 (3269)	7.4	3996 (1937)	19.8
4	3.44	20.69	0.34	12	84.88 (16.87)	8.7	11120 (2971)	-2.6	4372 (1586)	31.1
5	0.34	10.34	3.44	12	82.47 (19.94)	5.6	10924 (2395)	-4.2	4111 (2168)	23.2
6	3.44	10.34	3.44	12	83.84 (19.25)	7.4	11167 (2417)	-2.0	3914 (1296)	17.3
7	0.34	20.69	3.44	11	73.60 (11.71)	-5.7	10904 (1962)	-6.1	3122 (1414)	0.0
8	3.44	20.69	3.44	12	73.97 (17.91)	-5.3	10919 (2458)	-4.2	3028 (1414)	-9.3
9	Untreated control			11	78.08 (16.46)	-	11359 (2758)	-	3114 (1568)	-

Treatment				Yellow-poplar						
Number	PR [a]	TP [b]	VR [a]	N =	MOR (MPa)	% Diff. [c]	MOE (MPa)	% Diff	WML (Nm/m³)	% Diff.
1	0.34	10.34	0.34	11	71.07 (5.89)	-2.5	9809 (608)	2.1	3821 (695)	-13.6
2	3.44	10.34	0.34	12	71.84 (5.44)	-1.5	9885 (988)	2.9	4322 (1094)	-2.3
3	0.34	20.69	0.34	12	71.46 (6.09)	-2.0	9747 (1139)	1.5	4269 (1194)	-3.5
4	3.44	20.69	0.34	12	71.98 (7.78)	-1.3	9851 (862)	2.6	4211 (1019)	-4.8
5	0.34	10.34	3.44	12	69.55 (7.61)	-4.6	9740 (1393)	1.5	3875 (1034)	-12.4
6	3.44	10.34	3.44	12	70.34 (6.11)	-3.5	9819 (948)	2.3	4259 (1315)	-3.7
7	0.34	20.69	3.44	12	70.50 (4.84)	-3.3	9380 (1099)	-2.3	4379 (1222)	-1.0
8	3.44	20.69	3.44	12	69.90 (11.71)	-4.4	9483 (1546)	-1.2	4203 (1285)	-5.0
9	Untreated control			12	72.92 (5.60)	-	9600 (923)	-	4423 (1160)	-

Treatment				Western redcedar						
Number	PR [a]	TP [b]	VR [a]	N =	MOR (MPa)	% Diff. [c]	MOE (MPa)	% Diff	WML (Nm/m³)	% Diff.
1	0.34	10.34	0.34	12	53.72 (8.16)	0.4	7745 (1412)	6.1	2151 (499)	-6.2
2	3.44	10.34	0.34	12	51.58 (6.87)	-3.6	7308 (1258)	0.0	2029 (443)	-11.6
3	0.34	20.69	0.34	12	52.13 (9.50)	-2.5	7442 (1820)	1.9	2125 (573)	-7.4
4	3.44	20.69	0.34	12	52.87 (7.66)	-1.1	7290 (1612)	-0.2	2247 (414)	-2.0
5	0.34	10.34	3.44	9	41.88 (6.49)	-21.7	6303 (1631)	-13.7	1584 (296)	-31.0
6	3.44	10.34	3.44	12	48.67 (10.37)	-9.0	7338 (1883)	0.4	2014 (673)	-12.2
7	0.34	20.69	3.44	10	41.11 (7.27)	-23.1	6581 (1414)	-9.9	1502 (468)	-34.5
8	3.44	20.69	3.44	12	41.13 (7.27)	-23.1	6733 (1413)	-7.8	1697 (804)	-26.0
9	Untreated control			12	53.48 (7.36)	-	7303 (1349)	-	2294 (512)	-

Treatment				Engelmann spruce						
Number	PR [a]	TP [b]	VR [a]	N =	MOR (MPa)	% Diff. [c]	MOE (MPa)	% Diff	WML (Nm/m³)	% Diff.
1	0.34	10.34	0.34	11	58.01 (15.89)	7.2	9814 (2123)	4.1	2603 (1350)	17.2
2	3.44	10.34	0.34							
3	0.34	20.69	0.34	11	48.29 (5.97)	-10.8	7928 (1264)	-16.0	2062 (828)	-7.2
4	3.44	20.69	0.34							
5	0.34	10.34	3.44							
6	3.44	10.34	3.44	12	42.42 (13.23)	-21.6	7410 (2246)	-21.4	1581 (737)	-28.9
7	0.34	20.69	3.44							
8	3.44	20.69	3.44	11	43.53 (11.30)	-19.6	7755 (2513)	-17.8	1577 (709)	-29.0
9	Untreated control			11	54.13 (12.32)	-	9432 (1965)	-	2221 (1175)	-

a PR and VR: Pressurization and venting rates, respectively (MPa/min.)

b TP : Treatment pressure (MPa)

c % Differences are based on the difference between average bending properties of the treatment and control specimens.

Table 4.2. Average moisture contents (MC) and specific gravities (SG) (based on oven-dry volume) from all species/treatment combinations during ASTM D-143 bending tests (Standard deviations are indicated within parentheses).

Treatment				Species					
				Douglas-fir			Yellow poplar		
#[a]	PR[b]	TP[c]	VR[b]	n	MC	SG	n	MC	SG
1	0.34	10.34	0.34	11	10.94 (0.44)	0.53 (0.08)	12	10.34 (0.25)	0.46 (0.03)
2	3.44	10.34	0.34	12	10.53 (0.55)	0.56 (0.08)	12	10.09 (0.43)	0.47 (0.04)
3	0.34	20.69	0.34	12	10.84 (0.67)	0.55 (0.09)	12	10.30 (0.30)	0.48 (0.04)
4	3.44	20.69	0.34	12	10.75 (0.53)	0.55 (0.08)	12	10.23 (0.31)	0.47 (0.03)
5	0.34	10.34	3.44	11	11.06 (0.43)	0.50 (0.09)	12	10.39 (0.34)	0.47 (0.03)
6	3.44	10.34	3.44	12	10.86 (0.44)	0.52 (0.10)	12	10.27 (0.59)	0.47 (0.03)
7	0.34	20.69	3.44	12	11.06 (0.44)	0.50 (0.07)	12	10.56 (1.32)	0.47 (0.03)
8	3.44	20.69	3.44	12	11.25 (0.45)	0.52 (0.08)	12	10.14 (0.34)	0.47 (0.03)
9	Control			10	10.78 (0.69)	0.51 (0.09)	12	9.53 (0.08)	0.47 (0.04)
Treatment				Species					
				Western redcedar			Engelmann spruce		
#	PR	TP	VR	n	MC	SG	n	MC	SG
1	0.34	10.34	0.34	12	10.69 (1.79)	0.35 (0.04)	12	10.70 (0.96)	0.39 (0.11)
2	3.44	10.34	0.34	12	10.50 (0.98)	0.37 (0.04)			
3	0.34	20.69	0.34	12	10.23 (1.20)	0.36 (0.03)	12	10.76 (0.89)	0.39 (0.04)
4	3.44	20.69	0.34	12	10.24 (0.81)	0.38 (0.03)			
5	0.34	10.34	3.44	12	9.90 (0.89)	0.35 (0.03)			
6	3.44	10.34	3.44	12	10.54 (0.87)	0.35 (0.04)	12	10.00 (1.07)	0.39 (0.03)
7	0.34	20.69	3.44	11	10.37 (1.07)	0.34 (0.03)			
8	3.44	20.69	3.44	12	10.13 (0.82)	0.35 (0.04)	12	10.20 (0.95)	0.42 (0.04)
9	Control			12	11.07 (1.80)	0.35 (0.03)	9	11.14 (0.85)	0.39 (0.06)

a. # = Treatment number
b. PR and VR: Pressurization rate and venting rate respectively (MPa/min.)
c. TP: Treatment pressure (MPa)

The General Linear Models (GLM) conducted for testing differences between board, treatment and treatment nested within treatment run are listed in Tables 4.3, 4.4, and 4.5. All boards within each species block experiment were significantly different than one another (all p-values were <0.05 for each bending property and species).

4.3.1.1 MOR

No significant differences were observed between treatments for MOR in Douglas-fir or yellow poplar. However, significant differences were noted for both western redcedar and Engelmann spruce (Table 4.3c,d). The Dunnett's T-Test for MOR in western red cedar (Table 4.6c) indicated that treatments 5, 7 and 8 were significantly lower than the control, while the Dunnett's T-Test for MOR in Engelmann spruce (Table 4.6d) indicated that treatments 3, 6, and 8 were significantly lower than the control. When average MOR's from western redcedar SCF treatments 5, 7 and 8 were compared to controls, the percent differences were 21.7, 23.1, and 23.1 % respectively (Table 4.1). Percent differences from controls in Engelmann spruce treatments 3, 8 and 6 were 10.8, 19.6, and 21.6 % respectively (Table 4.1).

A significant difference was noted for treatment nested within a treatment run for western redcedar (Table 4.3c). This difference most likely reflected a sample variability within a treatment run, which may be due to differences in permeability.

4.3.1.2 MOE

No significant differences were observed for MOE between treatments for Douglas-fir, yellow poplar and western redcedar (Table 4.4a-c). No significant differences were noted between treatments for Engelmann spruce (Table 4.4d), but the Dunnett's T-test (Table 4.7d) indicated that treatments 3, 6 and 8 were significantly lower than the control. The percent differences from the control were 7.2, 21.4 and 17.8 %, respectively (Table 4.1). No significant differences were found between treatments nested within a treatment run for all species.

4.3.1.3 WML

No significant differences were found between treatments for yellow poplar and Engelmann spruce, but significant differences were noted for both Douglas- fir and western redcedar (Table 4.5a-d). Within Douglas-fir, treatments 1 and 4 were found to be significantly greater than the control (Table 4.8a). This is probably a result of the mean specific gravity as discussed in section 4.3.1. Western redcedar treatments 5, 7 and 8 were found to be significantly lower (Table 4.8c) and the percent differences from the controls were 31.0, 34.5 and 26.0 %, respectively (Table 4.1). Also, treatments 6 and 8 within Engelmann spruce were indicated as being significantly lower than the control (Table 4.8d) where the percent differences from controls were 28.9 and 29.0 % respectively (Table 4.1). The treatments indicated for western redcedar matched the indicated treatments from the MOR Dunnett's T-test (Table 4.6c) and the treatment effects indicated for Engelmann spruce were consistent with the treatment effects found in both the MOR and MOE Dunnett's T-tests (Table 4.6d, 4.7d).

No significant differences were found between treatments nested within a treatment run for all species (Table 4.5a-d). Since treatment nested within a treatment run was significant in only one test (Table 4.3c), it was assumed that no significant differences existed between treatment runs.

Table 4.3. MOR GLM on the effect of board, treatment and treatment nested within treatment run for Douglas-fir, yellow poplar, western redcedar and Engelmann spruce.

Source of variation	**d.f.**	**Sum of Squares**	**Mean Square**	**F-ratio**	**P-value**
(a). Douglas-fir					
Main Effects					
Board	10	198.18×10^{14}	198.18×10^{13}	32.84	0.0001
Treatment	8	4.72×10^{14}	5.91×10^{13}	0.98	0.4606
Treatment(Run)	20	11.12×10^{14}	5.56×10^{13}	0.92	0.5633
Residual	67	40.44×10^{14}	6.34×10^{13}		
Total	105	254.46×10^{14}			
(b). Yellow poplar					
Main Effects					
Board	11	19.50×10^{14}	17.73×10^{13}	7.41	0.0001
Treatment	8	1.13×10^{14}	1.42×10^{13}	0.59	0.7802
Treatment(Run)	20	3.43×10^{14}	1.71×10^{13}	0.72	0.7951
Residual	67	16.02×10^{14}	2.39×10^{13}		
Total	106	40.08×10^{14}			
(c). Western redcedar					
Main Effects					
Board	12	29.52×10^{14}	24.60×10^{13}	7.55	0.0001
Treatment	8	26.66×10^{14}	33.32×10^{13}	10.23	0.0001
Treatment(Run)	20	12.50×10^{14}	6.25×10^{13}	1.92	0.0266
Residual	62	20.19×10^{14}	3.26×10^{13}		
Total	102	88.87×10^{14}			
(d). Engelmann spruce					
Main Effects					
Board	29	57.36×10^{14}	19.78×10^{12}	10.34	0.0002
Treatment	4	3.26×10^{14}	8.16×10^{12}	4.26	0.0286
Treatment(Run)	12	3.17×10^{14}	2.66×10^{12}	1.39	0.3039
Residual	10	1.91×10^{14}	1.91×10^{12}		
Total	55	65.57×10^{14}			

Table 4.4. MOE GLM on the effect of board, treatment and treatment nested within treatment run for Douglas-fir, yellow poplar, western redcedar and Engelmann spruce.

Source of variation	d.f.	Sum of Squares	Mean Square	F-ratio	P-value
(a). Douglas-fir					
Main Effects					
Board	10	465.01 $\times 10^{18}$	46.50 $\times 10^{18}$	28.61	0.0001
Treatment	8	20.16 $\times 10^{18}$	2.52 $\times 10^{18}$	1.55	0.1568
Treatment(Run)	20	37.18 $\times 10^{18}$	1.86 $\times 10^{18}$	1.14	0.3302
Residual	67	108.91 $\times 10^{18}$	1.63 $\times 10^{18}$		
Total	105	703.26 $\times 10^{18}$			
(b). Yellow Poplar					
Main Effects					
Board	11	47.57 $\times 10^{18}$	43.25 $\times 10^{17}$	7.51	0.0001
Treatment	8	2.88 $\times 10^{18}$	3.59 $\times 10^{17}$	0.62	0.7544
Treatment(Run)	20	10.54 $\times 10^{18}$	5.27 $\times 10^{17}$	0.92	0.5703
Residual	67	38.57 $\times 10^{18}$	5.76 $\times 10^{17}$		
Total	106	99.57 $\times 10^{18}$			
(c). Western redcedar					
Main Effects					
Board	12	117.65 $\times 10^{18}$	98.04 $\times 10^{17}$	11.82	0.0001
Treatment	8	11.26 $\times 10^{18}$	14.07 $\times 10^{17}$	1.70	0.1169
Treatment(Run)	20	12.60 $\times 10^{18}$	6.30 $\times 10^{17}$	0.76	0.7487
Residual	62	51.43 $\times 10^{18}$	8.29 $\times 10^{17}$		
Total	102	192.94 $\times 10^{18}$			
(d). Engelmann spruce					
Main Effects					
Board	29	158.79 $\times 10^{18}$	54.76 $\times 10^{17}$	4.85	0.0061
Treatment	4	7.34 $\times 10^{18}$	18.36 $\times 10^{17}$	1.62	0.2429
Treatment(Run)	12	16.00 $\times 10^{18}$	13.33 $\times 10^{17}$	1.18	0.4022
Residual	10	11.30 $\times 10^{18}$	11.30 $\times 10^{17}$		
Total	55	193.43 $\times 10^{18}$			

Table 4.5. WML GLM on the effect of board, treatment and treatment nested within treatment run for Douglas-fir, yellow poplar, western redcedar and Engelmann spruce.

Source of variation	**d.f.**	**Sum of Squares**	**Mean Square**	**F-ratio**	**P-value**
(a). Douglas-fir					
Main Effects					
Board	10	146.47×10^6	146.47×10^5	26.88	0.0001
Treatment	8	9.80×10^6	12.25×10^5	2.25	0.0343
Treatment(Run)	20	21.16×10^6	10.58×10^5	1.94	0.0230
Residual	67	35.51×10^6			
Total	105	212.94×10^6			
(b). Yellow Poplar					
Main Effects					
Board	11	59.46×10^6	54.06×10^5	9.08	0.0001
Treatment	8	3.46×10^6	4.32×10^5	0.73	0.6687
Treatment(Run)	20	9.39×10^6	4.69×10^5	0.79	0.7180
Residual	67	39.91×10^6			
Total	106	112.22×10^6			
(c). Western redcedar					
Main Effects					
Board	12	6.14×10^6	5.12×10^5	2.51	0.0092
Treatment	8	7.13×10^6	8.91×10^5	4.38	0.0003
Treatment(Run)	20	6.71×10^6	3.36×10^5	1.65	0.0691
Residual	62	35.38×10^6	2.04×10^5		
Total	102	55.36×10^6			
(d). Engelmann spruce					
Main Effects					
Board	29	38.45×10^6	13.26×10^5	11.61	0.0001
Treatment	4	1.17×10^6	2.93×10^5	2.57	0.1032
Treatment(Run)	12	3.43×10^6	2.85×10^5	2.50	0.0781
Residual	10	1.14×10^6	1.14×10^5		
Total	55	44.19×10^6			

Table 4.6. MOR Dunnett's T-test for Douglas-fir, yellow poplar, western redcedar and Engelmann spruce (See Table 4.1 for treatment codes).

Treatment Comparison	Lower Confidence Limit (MPa)	Difference Between Means (MPa)	Upper Confidence Limit (MPa)	Sig.[a]
(a). Douglas-fir				
4 – 9	-2011743	6797197	15606137	
3 – 9	-2261743	6547197	15356137	
6 - 9	-3051743	5757197	14566137	
5 - 9	-4425077	4383864	13192804	
2 - 9	-4770910	4038030	12846971	
1 - 9	-4928410	3880530	12689471	
8 - 9	-12924243	-4115303	4693637	
7 - 9	-13479311	-4480909	4517493	
(b). Yellow-poplar				
4 - 9	-6381469	-940833	4499803	
2 - 9	-6544803	-1104167	4336469	
3 - 9	-6895636	-1455000	3985636	
1 - 9	-7409428	-1846515	3716398	
7 - 9	-7857303	-2416667	3023969	
6 - 9	-8015636	-2575000	2865636	
8 - 9	-8454803	-3014167	2426469	
5 - 9	-8800636	-3360000	2080636	
(c). Western redcedar				
1 - 9	-6132451	240833	6614117	
4 - 9	-6982451	-609167	5764117	
3 - 9	-7714951	-1341667	5031617	
2 - 9	-8266617	-1893333	4479951	
6 - 9	-11178284	-4805000	1568284	
5 - 9	-18483378	-11599444	-4715511	***
8 - 9	-18714951	-12341667	-5968383	***
7 - 9	-19048357	-12364000	-5679643	***
(d). Engelmann spruce				
1 - 9	-1503790	3881818	9267426	
3 - 9	-11228335	-5842727	-457119	***
8 - 9	-15983790	-10598182	-5212574	***
6 - 9	-16980547	-11708333	-6436119	***

a: Comparisons marked with '***' are significant at the 0.05 level.

Table 4.7. MOE Dunnett's T-test for Douglas-fir, yellow poplar, western redcedar and Engelmann spruce (See Table 4.1 for treatment codes).

Treatment Comparison	Lower Confidence Limit (MPa)	Difference Between Means (MPa)	Upper Confidence Limit (MPa)	Sig.[a]
(a). Douglas-fir				
3 - 9	-595736697	849924242	2295585182	
2 - 9	-759903364	685757576	2131418515	
6 - 9	-1.67907 x10^9	-233409091	1212251849	
4 - 9	-1.72574 x10^9	-280075758	1165585182	
5 - 9	-1.9224 x10^9	-476742424	968918515	
8 - 9	-1.9274 x10^9	-481742424	963918515	
7 - 9	-2.17312 x10^9	-69636363	780390343	
1 - 9	-2.48074 x10^9	-1.03508x10^9	41085182	
(b). Yellow-poplar				
2 – 9	-559093012	285000000	1129093012	
4 – 9	-593559679	250833333	1094926345	
6 – 9	-624926345	219166667	1063259679	
1 – 9	-653972854	209090909	1072154672	
3 – 9	-69746345	146666667	990759679	
5 – 9	-704093012	140000000	984093012	
8 – 9	-960759679	-116666667	727426345	
7 – 9	-1.06409 x10^9	-220000000	624093012	
(c). Western redcedar				
1 – 9	-575394916	441666667	1458728249	
3 – 9	-878728249	138333333	1155394619	
6 – 9	-982061583	35000000	1052061583	
2 – 9	-1.01206 x10^9	5000000	1022061583	
4 – 9	-1.02956 x10^9	-12500000	1004561583	
8 – 9	-1.58789 x10^9	-570833333	446228249	
7 – 9	-1.78904 x10^9	-722333333	344369854	
5 – 9	-2.09855 x10^9	-1000000000	98552065	
(d). Engelmann spruce				
1 – 9	-927347944	381818182	1690984307	
3 – 9	-2.812800000	-1.503640000	-194470238	***
8 – 9	-2.986440000	-1.677270000	-368106602	***
6 – 9	-3.303420000	-2.021820000	-740216535	***

a: Comparisons marked with '***' are significant at the 0.05 level.

Table 4.8. WML Dunnett's T-test for Douglas-fir, yellow poplar, western redcedar, and Engelmann spruce (See Table 4.1 for treatment codes).

Treatment Comparison	Lower Confidence Limit (Nm/m^3)	Difference Between Means (Nm/m^3)	Upper Confidence Limit (Nm/m^3)	Sig.[a]
(a). Douglas-fir				
1 - 9	313.2	1150.2	1987.1	***
4 - 9	199.2	1036.2	1873.1	***
5 - 9	-61.5	775.5	1612.5	
3 - 9	-176.6	660.4	1497.4	
6 - 9	-258.5	578.5	1415.5	
2 - 9	-580.1	256.9	1093.9	
7 - 9	-858.2	-3.3	851.7	
8 - 9	-1144.9	-307.9	529.1	
(b). Yellow-poplar				
7 - 9	-902.9	-44.3	814.3	
3 - 9	-959.8	-101.2	757.4	
2 - 9	-985.6	-127.0	731.5	
6 - 9	-1022.9	-164.3	694.3	
4 - 9	-1071.3	-212.7	645.9	
8 - 9	-1078.5	.219.9	638.7	
5 - 9	-1406.2	-547.6	311.0	
1 - 9	-1480.0	-602.1	275.8	
(c). Western redcedar				
4 - 9	-532.0	-48.1	455.7	
1 - 9	-647.6	-143.8	360.0	
3 - 9	-673.6	-169.8	334.0	
6 - 9	-769.3	-265.5	238.4	
2 - 9	-784.6	-280.8	223.1	
8 - 9	-1101.1	-597.3	-93.4	***
5 - 9	-1255.1	-710.9	-166.7	***
7 - 9	-1320.8	-792.4	-264.0	***
(d). Engelmann spruce				
1 - 9	-33.8	382.4	798.5	
3 - 9	-574.8	-158.7	257.5	
6 - 9	-1046.9	-636.5	-232.2	***
8 - 9	-1060.1	-643.9	-227.8	***

a: Comparisons marked with '***' are significant at the 0.05 level.

4.3.2 Effect of Covariates on Bending Properties

The covariates (specific gravity, ring angle, percent heartwood, and number of growth rings) measured for Douglas-fir, yellow poplar, western redcedar and Engelmann spruce did not have an affect on differences found between treatments (Tables 4.9 – 4.13). After accounting for each covariate in the GLM model for bending properties, all treatment differences initially observed when ignoring covariates were still present. It should be noted that after accounting for specific gravity within Douglas-fir, the treatment differences were still present (Tables 4.9a, 4.10a). This suggests that specific gravity may not have been a factor in the differences between treatments. However, the variability in specific gravity that was present between treatments within Douglas-fir (Table 4.2) may have been too large to distinguish a significant statistical difference.

4.3.3 Effect of Vessel Position on Bending Properties

The results of these analyses suggest that specimen position within the treatment vessel did not have a significant effect on the results found between treatments for Douglas-fir, yellow poplar and western redcedar (Tables 4.14-4.17). However, position did have a suggestive effect on MOR and significant effect on WML for Engelmann spruce (Table 4.17). In as much as this effect was only observed for Engelmann spruce, it is most likely that species and treatment may be confounding the results of vessel positioning for Engelmann spruce.

Table 4.9. Relationship between covariates and WML for Douglas-fir samples exposed to supercritical fluid treatment.

Source of variation	d.f.	Sum of Squares	Mean Square	F-ratio	P-value
(a). Specific gravity					
Main Effects					
Specific gravity	1	1.25×10^6	1.25×10^6	2.34	0.1308
Board	10	58.67×10^6	58.67×10^6	11.02	0.0001
Treatment	8	11.53×10^6	1.44×10^6	2.71	0.0123
Treatment(Run)	20	22.33×10^6	1.11×10^6	2.10	0.0133
Residual	65	34.61×10^6	0.53×10^6		
Total	104	128.39×10^6			
(b). Ring Angle					
Main Effects					
Ring Angle	1	1.43×10^6	1.43×10^6	2.70	0.1053
Board	10	147.87×10^6	14.79×10^6	27.83	0.0001
Treatment	8	9.94×10^6	1.24×10^6	2.34	0.0282
Treatment(Run)	20	20.20×10^6	1.01×10^6	1.90	0.0271
Residual	66	35.07×10^6	0.53×10^6		
Total	105	214.51×10^6			
(c). Percent Heartwood					
Main Effects					
% Heartwood	1	0.25×10^6	0.25×10^6	0.46	0.4996
Board	10	121.61×10^6	12.16×10^6	22.14	0.0001
Treatment	8	9.97×10^6	1.25×10^6	2.27	0.0330
Treatment(Run)	20	21.38×10^6	1.07×10^6	1.95	0.0229
Residual	66	36.25×10^6	0.55×10^6		
Total	105	189.46×10^6			
(d). Number of Growth Rings					
Main Effects					
# Growth Rings	1	0.27×10^6	0.29×10^6	0.52	0.4729
Board	10	146.70×10^6	14.67×10^6	26.73	0.0001
Treatment	8	10.00×10^6	1.25×10^6	2.28	0.0323
Treatment(Run)	20	20.73×10^6	1.04×10^6	1.89	0.0283
Residual	68	36.22×10^6	0.55×10^6		
Total	107	213.92×10^6			

Table 4.10. Relationship between covariates and MOR for western redcedar samples exposed to supercritical fluid treatment.

Source of variation	d.f.	Sum of Squares	Mean Square	F-ratio	P-value
(a). Specific gravity					
Main Effects					
Specific gravity	1	0.02×10^{14}	0.23×10^{12}	0.07	0.7915
Board	12	5.50×10^{14}	4.66×10^{12}	1.41	0.1860
Treatment	8	23.07×10^{14}	28.83×10^{12}	8.72	0.0001
Treatment(Run)	20	11.99×10^{14}	5.99×10^{12}	1.81	0.0394
Residual	61	20.17×10^{14}	33.07×10^{12}		
Total	102	60.75×10^{14}			
(b). Ring angle					
Main Effects					
Ring angle	1	0.08×10^{14}	0.80×10^{13}	0.24	0.6251
Board	12	29.35×10^{14}	24.46×10^{13}	7.42	0.0001
Treatment	8	26.70×10^{14}	33.37×10^{13}	10.12	0.0001
Treatment(Run)	20	12.55×10^{14}	6.27×10^{13}	1.90	0.0286
Residual	61	20.11×10^{14}	3.30×10^{13}		
Total	102	88.79×10^{14}			
(c). Percent Heartwood					
Main Effects					
% Heartwood	1	0.91×10^{14}	9.07×10^{13}	2.87	0.0955
Board	12	30.34×10^{14}	25.28×10^{13}	8.00	0.0001
Treatment	8	26.94×10^{14}	33.68×10^{13}	10.65	0.0001
Treatment(Run)	20	13.38×10^{14}	6.69×10^{13}	2.12	0.0132
Residual	61	19.29×10^{14}	3.16×10^{13}		
Total	102	90.86×10^{14}			
(d.) Number of Growth Rings					
Main Effects					
# Growth Rings	1	0.93×10^{14}	9.25×10^{13}	2.93	0.0921
Board	12	24.68×10^{14}	20.57×10^{13}	6.51	0.0001
Treatment	8	27.16×10^{14}	33.95×10^{13}	10.75	0.0001
Treatment(Run)	20	13.02×10^{14}	6.5×10^{13}	2.06	0.0161
Residual	61	19.27×10^{14}	3.6×10^{13}		
Total	102	85.06×10^{14}			

Table 4.11. Relationship between covariates and WML for western redcedar samples exposed to supercritical fluid treatment.

Source of variation	d.f.	Sum of Squares	Mean Square	F-ratio	P-value
(a). Specific gravity					
Main Effects					
Specific gravity	1	0.62×10^6	6.24×10^5	3.17	0.0798
Board	12	4.34×10^6	3.62×10^5	1.84	0.0610
Treatment	8	7.43×10^6	9.28×10^5	4.72	0.0002
Treatment(Run)	20	7.33×10^6	3.67×10^5	1.86	0.0328
Residual	61	11.99×10^6	1.97×10^5		
Total	102	31.71×10^6			
(b). Ring Angle					
Main Effects					
Ring Angle	1	0.01×10^6	0.1×10^5	0.04	0.8352
Board	12	6.14×10^6	5.12×10^5	2.48	0.0104
Treatment	8	7.11×10^6	8.89×10^5	4.30	0.0004
Treatment(Run)	20	6.72×10^6	3.36×10^5	1.63	0.0754
Residual	61	12.61×10^6	2.07×10^5		
Total	102	32.60×10^6			
(c). Percent Heartwood					
Main Effects					
% Heartwood	1	0.56×10^6	5.58×10^5	2.82	0.0980
Board	12	6.47×10^6	5.39×10^5	2.73	0.0051
Treatment	8	7.63×10^6	9.54×10^5	4.83	0.0001
Treatment(Run)	20	7.25×10^6	3.63×10^5	1.83	0.0365
Residual	61	12.06×10^6	1.98×10^5		
Total	102	33.42×10^6			
(d). Number of Growth Rings					
Main Effects					
# Growth Rings	1	0.0005×10^6	0.005×10^5	0.00	0.9592
Board	12	5.09×10^6	4.24×10^5	2.05	0.0343
Treatment	8	7.07×10^6	8.84×10^5	4.27	0.0004
Treatment(Run)	20	6.69×10^6	3.34×10^5	1.62	0.0777
Residual	61	12.61×10^6	2.07×10^5		
Total	102	31.47×10^6			

Table 4.12. Relationship between covariates and MOR for Engelmann spruce samples exposed to supercritical fluid treatment.

Source of variation	d.f.	Sum of Squares	Mean Square	F-ratio	P-value
(a). Specific gravity					
Main Effects					
Specific gravity	1	0.0004×10^{14}	0.005×10^{13}	0.00	0.9634
Board	29	37.49×10^{14}	12.93×10^{13}	6.09	0.0038
Treatment	4	3.26×10^{14}	8.15×10^{13}	3.84	0.0435
Treatment(Run)	12	2.42×10^{14}	2.06×10^{13}	0.97	0.5315
Residual	9	1.91×10^{14}			
Total	55	45.08×10^{14}			
(b). Ring Angle					
Main Effects					
Ring Angle	1	0.07×10^{14}	0.74×10^{13}	0.36	0.5619
Board	29	57.39×10^{14}	19.79×10^{13}	9.69	0.0006
Treatment	4	3.22×10^{14}	8.06×10^{13}	3.95	0.0405
Treatment(Run)	12	3.20×10^{14}	2.67×10^{13}	1.31	0.3501
Residual	9	1.84×10^{14}			
Total	55	65.72×10^{14}			
(c). Number of Growth Rings					
Main Effects					
# Growth Rings	1	0.04×10^{13}	0.38×10^{12}	0.02	0.8963
Board	29	547.44^{13}	188.77×10^{12}	8.90	0.0009
Treatment	4	28.43×10^{13}	71.08×10^{12}	3.35	0.0609
Treatment(Run)	12	24.39×10^{13}	20.32×10^{12}	0.96	0.5385
Residual	9	19.08×10^{13}	21.20×10^{12}		
Total	55	619.38×10^{13}			

Table 4.13. Relationship between covariates and WML for Engelmann spruce samples exposed to supercritical fluid treatment.

Source of variation	d.f.	Sum of Squares	Mean Square	F-ratio	P-value
(a). Specific gravity					
Main Effects					
Specific gravity	1	0.01×10^6	0.08×10^5	0.06	0.8120
Board	29	31.06×10^6	10.71×10^5	8.50	0.0010
Treatment	4	1.17×10^6	2.93×10^5	2.32	0.1351
Treatment(Run)	12	2.88×10^6	2.40×10^5	1.91	0.1694
Residual	9	1.13×10^6			
Total	55	36.24×10^6			
(b). Ring Angle					
Main Effects					
Ring Angle	1	52708.93	52708.93	0.44	0.5258
Board	29	37546067.45	1294691.98	10.70	0.0004
Treatment	4	1150236.47	287559.12	2.38	0.1292
Treatment(Run)	12	2575964.13	214663.68	1.77	0.1976
Residual	9	1088885.54	120987.28		
Total	55	42413062.52			
(c). Number of Growth Rings					
Main Effects					
# Growth Rings	1	129257.09	129257.09	1.15	0.3116
Board	29	38436835.82	1325408.13	11.78	0.0003
Treatment	4	1297293.94	324323.48	2.88	0.0862
Treatment(Run)	12	3033782.01	252815.17	2.25	0.1152
Residual	9	1012337.39	112481.93		
Total	55	43909506.25			

Table 4.14. Relationship between vessel position and MOR, MOE and WML for Douglas-fir samples exposed to supercritical fluid treatment.

Source of variation	d.f.	Sum of Squares	Mean Square	F-ratio	P-value
Main Effects (MOR)					
Position	16	4.02×10^{15}	1.94×10^{14}	0.82	0.6578
Position*Treatment	37	15.47×10^{15}	4.18×10^{14}	1.36	0.1681
Residual	41	12.57×10^{15}	3.07×10^{14}		
Total	94	32.06×10^{15}			
Main Effects (MOE)					
Position	16	76.50×10^{18}	44.16×10^{17}	0.62	0.8483
Position*Treatment	37	301.06×10^{18}	81.37×10^{17}	1.06	0.4299
Residual	41	315.62×10^{18}	77.00×10^{17}		
Total	94	698.63×10^{18}			
Main Effects (WML)					
Position	16	23.96×10^{6}	1.50×10^{6}	0.60	0.8621
Position*Treatment	37	117.84×10^{6}	3.18×10^{6}	1.28	0.2172
Residual	41	101.67×10^{6}			
Total	94	243.47×10^{6}			

Table 4.15. Relationship between vessel position and MOR, MOE, and WML for yellow poplar samples exposed to supercritical fluid treatment.

Source of variation	d.f.	Sum of Squares	Mean Square	F-ratio	P-value
Main Effects (MOR)					
Position	14	8.66×10^{14}	6.19×10^{13}	1.51	0.1515
Position*Treatment	41	17.10×10^{14}	4.17×10^{13}	1.02	0.4753
Residual	39	15.93×10^{14}	4.08×10^{13}		
Total	94	41.69×10^{14}			
Main Effects (MOE)					
Position	14	19.05×10^{18}	13.61×10^{17}	1.04	0.4371
Position*Treatment	41	39.74×10^{18}	9.69×10^{17}	0.74	0.8274
Residual	39	51.02×10^{18}	13.08×10^{17}		
Total	94	109.81×10^{18}			
Main Effects (WML)					
Position	14	40.71×10^{6}	1.82×10^{6}	1.74	0.0855
Position*Treatment	41	25.49×10^{6}	1.11×10^{6}	1.06	0.4273
Residual	39	45.41×10^{6}	1.04×10^{6}		
Total	94	111.61×10^{6}			

Table 4.16. Relationship between vessel position and MOR, MOE, and WML for western redcedar samples exposed to supercritical fluid treatment.

Source of variation	d.f.	Sum of Squares	Mean Square	F-ratio	P-value
Main Effects (MOR)					
Position	14	14.29 x10^{14}	1.02 x10^{14}	1.28	0.2752
Position*Treatment	46	49.46 x10^{14}	1.08 x10^{14}	1.35	0.1942
Residual	30	23.90 x10^{14}	0.80 x10^{14}		
Total	90	87.65 x10^{14}			
Main Effects (MOE)					
Position	14	43.85 x10^{18}	31.32 x10^{17}	1.44	0.1974
Position*Treatment	46	121.52 x10^{18}	26.42 x10^{17}	1.21	0.2933
Residual	30	65.48 x10^{18}	21.83 x10^{17}		
Total	90	230.85 x10^{18}			
Main Effects (WML)					
Position	14	4.42 x 10^6	0.32 x 10^6	0.99	0.4834
Position*Treatment	46	18.09 x 10^6	0.39 x 10^6	1.24	0.2721
Residual	30	9.54 x 10^6			
Total	90	22.05 x10^6			

Table 4.17. Relationship between vessel position and MOR, MOE, and WML for Engelmann spruce samples exposed to supercritical fluid treatment.

Source of variation	d.f.	Sum of Squares	Mean Square	F-ratio	P-value
Main Effects (MOR)					
Position	15	43.41 x10^{14}	2.89 x10^{13}	1.91	0.0882
Position*Treatment	9	3.36 x10^{14}	0.37 x10^{13}	0.25	0.9821
Residual	20	30.32 x10^{14}	15.16 x10^{13}		
Total	44	107.09 x 10^{14}			
Main Effects (MOE)					
Position	15	106.74 x10^{18}	71.16 x10^{17}	1.57	0.1708
Position*Treatment	9	20.55 x10^{18}	22.84 x10^{17}	0.50	0.8543
Residual	20	90.58 x10^{18}	45.29 x10^{17}		
Total	44	217.87 x10^{18}			
Main Effects (WML)					
Position	15	26.33 x 10^6	1.76 x 10^6	2.24	0.0464
Position*Treament	9	2.02 x 10^6	0.22 x 10^6	0.29	0.9708
Residual	20	15.65 x 10^6	0.78 x 10^6		
Total	44	64.00 x 10^6			

4.3.4 Effect of Pressurization Rate, Treatment Pressure, and Venting Rate on MOR, MOE and WML

The three treatment parameters; pressurization rate (PR), venting rate (VR) and treatment pressure (TP), had no evident effects on bending properties of Douglas-fir or yellow poplar (Table 4.18 a,b-4.20 a,b). This is especially important in evaluating the effect of SCF treatments on Douglas-fir. Previous statistical analysis noted significant differences between treatments 1 and 4 in WML that were greater than the control. This suggested that SCF treatments increased this strength property significantly, but the covariate analysis found that treatment differences were still present after accounting for specific gravity. It should be noted that specific gravity still appears to have affected the differences that were found between treatments in WML.

Strong evidence (in the form of small p-values) exists that venting rate had a deleterious effect on western redcedar for MOR and MOE, but only a suggestive effect on WML (Table 4.18c-4.20c). For Engelmann spruce both pressurization rate and venting rate had a significant deleterious effect on MOR, MOE, and WML (Table 4.18d-4.20d). Reductions in bending properties for western redcedar occurred at the 3.44 MPa/min. venting rates while reductions in bending properties for Engelmann spruce occurred at the 0.34 MPa/min. and 3.44 MPa/min pressurization and venting rates (Figures 4.3-4.5).

Table 4.18. MOR GLM on the effect of pressurization rate (PR), treatment pressure (TP), and venting rate (VR) for Douglas-fir, yellow poplar, western redcedar and Engelmann spruce samples exposed to supercritical fluid treatment.

Source of variation	d.f.	Sum of Squares	Mean Square	F-ratio	P-value
(a). Douglas-fir					
Main Effects					
PR	1	0.68×10^{13}	0.68×10^{13}	0.02	0.8874
TP	1	26.28×10^{13}	26.28×10^{13}	0.78	0.3809
PR*TP	1	0.12×10^{13}	0.12×10^{13}	0.00	0.9519
VR	1	57.66×10^{13}	57.67×10^{13}	1.70	0.1955
PR*VR	1	0.26×10^{13}	0.26×10^{13}	0.01	0.9300
TP*VR	1	86.59×10^{13}	86.59×10^{13}	2.56	0.1135
PR*TP*VR	1	0.17×10^{13}	0.18×10^{13}	0.01	0.9421
Residual	87	2947.81×10^{13}	33.88×10^{13}		
Total	94	3119.57×10^{13}			
(b). Yellow poplar					
Main Effects					
PR	1	30.93×10^{11}	30.93×10^{11}	0.06	0.7996
TP	1	16.63×10^{11}	16.63×10^{11}	0.03	0.8523
PR*TP	1	38.48×10^{11}	38.48×10^{11}	0.08	0.7770
VR	1	537.38×10^{11}	537.38×10^{11}	1.13	0.2914
PR*VR	1	16.95×10^{11}	16.95×10^{11}	0.04	0.8509
TP*VR	1	0.04×10^{11}	0.04×10^{11}	0.00	0.9929
PR*TP*VR	1	19.76×10^{11}	19.76×10^{11}	0.04	0.8392
Residual	87	4148.36×10^{11}	476.82×10^{11}		
Total	94	4808.53×10^{11}			
(c). Western redcedar					
Main Effects					
PR	1	4.12×10^{13}	4.12×10^{13}	0.55	0.4591
TP	1	10.40×10^{13}	10.40×10^{13}	1.39	0.2409
PR*TP	1	2.14×10^{13}	2.14×10^{13}	0.29	0.5931
VR	1	197.86×10^{13}	197.86×10^{13}	26.54	0.0001
PR*VR	1	9.50×10^{13}	9.50×10^{13}	1.27	0.2623
TP*VR	1	9.01×10^{13}	9.01×10^{13}	1.21	0.2749
PR*TP*VR	1	13.06×10^{13}	13.06×10^{13}	1.75	0.1892
Residual	83	618.76×10^{13}	7.45×10^{13}		
Total	90	924.85×10^{13}			
(d). Engelmann spruce					
Main Effects					
PR	1	116.26×10^{13}	116.26×10^{13}	7.83	0.0078
VR	1	116.26×10^{13}	116.26×10^{13}	7.83	0.0078
TP	1	20.84×10^{13}	20.84×10^{13}	1.40	0.2428
PR*TP	1	32.97×10^{13}	32.97×10^{13}	1.40	0.2428
VR*TP	1	32.97×10^{13}	32.97×10^{13}	2.22	0.1438
Residual	41	608.51×10^{13}	14.84×10^{13}		
Total	44	776.58×10^{13}			

Table 4.19. MOE GLM on the effect of pressurization rate (PR), treatment pressure (TP), and venting rate (VR) for Douglas-fir, yellow poplar, western redcedar and Engelmann spruce samples exposed to supercritical fluid treatment.

Source of variation	d.f.	Sum of Squares	Mean Square	F-ratio	P-value
(a). Douglas-fir					
Main Effects					
PR	1	16.31 $x10^{17}$	16.31 $x10^{17}$	0.22	0.64194
TP	1	3.02 $x10^{17}$	3.02 $x10^{17}$	0.04	0.8413
PR*TP	1	122.98 $x10^{17}$	122.98 $x10^{17}$	1.64	0.2035
VR	1	65.96 $x10^{17}$	65.96 $x10^{17}$	0.88	0.3507
PR*VR	1	0.26 $x10^{17}$	0.26 $x10^{17}$	0.00	0.9530
TP*VR	1	28.54 $x10^{17}$	28.54 $x10^{17}$	0.38	0.5387
PR*TP*VR	1	118.12 $x10^{17}$	118.12 $x10^{17}$	1.58	0.2126
Residual	88	6517.20 $x10^{17}$	74.91 $x10^{17}$		
Total	95	6872.36 $x10^{17}$			
(b). Yellow poplar					
Main Effects					
PR	1	1949.76 $x10^{14}$	1949.76 $x10^{14}$	0.16	0.6924
TP	1	9313.21 $x10^{14}$	9313.21 $x10^{14}$	0.75	0.3881
PR*TP	1	40.76 $x10^{14}$	40.76 $x10^{14}$	0.00	0.9544
VR	1	11202.48 $x10^{14}$	11202.48 $x10^{14}$	0.91	0.3441
PR*VR	1	0.09 $x10^{14}$	0.09 $x10^{14}$	0.00	0.9979
TP*VR	1	5325.85 $x10^{14}$	5325.85 $x10^{14}$	0.43	0.5136
PR*TP*VR	1	0.25 $x10^{14}$	0.25 $x10^{14}$	0.00	0.9964
Residual	87	1076899.08 $x10^{14}$	12378.15 $x10^{14}$		
Total	94	1104731.48 $x10^{14}$			
(c). Western redcedar					
Main Effects					
PR	1	50.46 $x10^{16}$	50.46 $x10^{16}$	0.20	0.6522
TP	1	52.23 $x10^{16}$	52.23 $x10^{16}$	0.24	0.6253
PR*TP	1	50.23 $x10^{16}$	50.23 $x10^{16}$	0.20	0.6529
VR	1	1126.78 $x10^{16}$	1126.78 $x10^{16}$	4.57	0.0355
PR*VR	1	442.56 $x10^{16}$	442.56 .$x10^{16}$	1.80	0.1839
TP*VR	1	0.01 $x10^{16}$	0.01 $x10^{16}$	0.00	0.9956
PR*TP*VR	1	192.28 $x10^{16}$	192.28 $x10^{16}$	0.78	0.3797
Residual	83	20460.76 $x10^{16}$	246.52 $x10^{16}$		
Total	90	22375.31 $x10^{16}$			
(d). Engelmann spruce					
Main Effects					
PR	1	186.55 $x10^{17}$	186.55 $x10^{17}$	4.26	0.0455
VR	1	186.55 $x10^{17}$	186.55 $x10^{17}$	4.26	0.0455
TP	1	66.69 $x10^{17}$	66.69 $x10^{17}$	1.52	0.2244
PR*TP	1	139.66 $x10^{17}$	139.66 $x10^{17}$	3.19	0.0817
VR*TP	1	139.66 $x10^{17}$	139.66 $x10^{17}$	3.19	0.0817
Residual	41	1797.12 $x10^{17}$	43.83 $x10^{17}$		
Total	44	2190.02 $x10^{17}$			

Table 4.20. WML GLM on the effect of pressurization rate (PR), treatment pressure (TP), and venting rate (VR) for Douglas-fir, yellow poplar, western redcedar and Engelmann spruce samples exposed to supercritical fluid treatment.

Source of variation	**d.f.**	**Sum of Squares**	**Mean Square**	**F-ratio**	**P-value**
(a). Douglas-fir					
Main Effects					
PR	1	1.54×10^6	1.54×10^6	0.60	0.4405
TP	1	2.81×10^6	2.81×10^6	1.09	0.2985
PR*TP	1	2.00×10^6	2.00×10^6	0.78	0.3797
VR	1	6.30×10^6	6.30×10^6	2.45	0.1208
PR*VR	1	0.00×10^6	0.00×10^6	0.00	0.9904
TP*VR	1	5.67×10^6	5.67×10^6	2.21	0.1409
PR*TP*VR	1	2.81×10^6	2.81×10^6	1.10	0.2981
Residual	87	223.24×10^6	2.56×10^6		
Total	94	274.71×10^6			
(b). Yellow poplar					
Main Effects					
PR	1	5.75×10^5	5.75×10^5	0.45	0.5027
TP	1	9.76×10^5	9.76×10^5	0.77	0.3831
PR*TP	1	19.46×10^5	19.46×10^5	1.53	0.2191
VR	1	0.07×10^5	0.07×10^5	0.01	0.9424
PR*VR	1	0.64×10^5	0.64×10^5	0.05	0.8230
TP*VR	1	0.10×10^5	0.10×10^5	0.01	0.9278
PR*TP*VR	1	0.01×10^5	0.01×10^5	0.00	0.9763
Residual	87	1104.81×10^5	126.99×10^5		
Total	94	1140.60×10^5			
(c). Western redcedar					
Main Effects					
PR	1	5.50×10^5	5.50×10^5	1.81	0.1817
TP	1	0.60×10^5	0.60×10^5	0.20	0.6573
PR*TP	1	0.0×10^5	1.0×10^5	0.00	0.9857
VR	1	43.27×10^5	43.27×10^5	14.28	0.0003
PR*VR	1	5.50×10^5	5.50×10^5	1.81	0.1817
TP*VR	1	4.88×10^5	4.88×10^5	1.61	0.2078
PR*TP*VR	1	3.22×10^5	3.22×10^5	1.06	0.3059
Residual	83	251.54×10^5	30.31×10^5		
Total	90	314.51×10^5			
(d). Engelmann spruce					
Main Effects					
PR	1	63.80×10^5	63.80×10^5	7.25	0.0102
VR	1	63.80×10^5	63.80×10^5	7.25	0.0102
TP	1	8.36×10^5	8.36×10^5	0.95	0.3356
PR*TP	1	8.09×10^5	8.09×10^5	0.92	0.3434
VR*TP	1	8.09×10^5	8.09×10^5	0.92	0.3434
Residual	41	360.85×10^5	26.65×10^5		
Total	44	441.10×10^5			

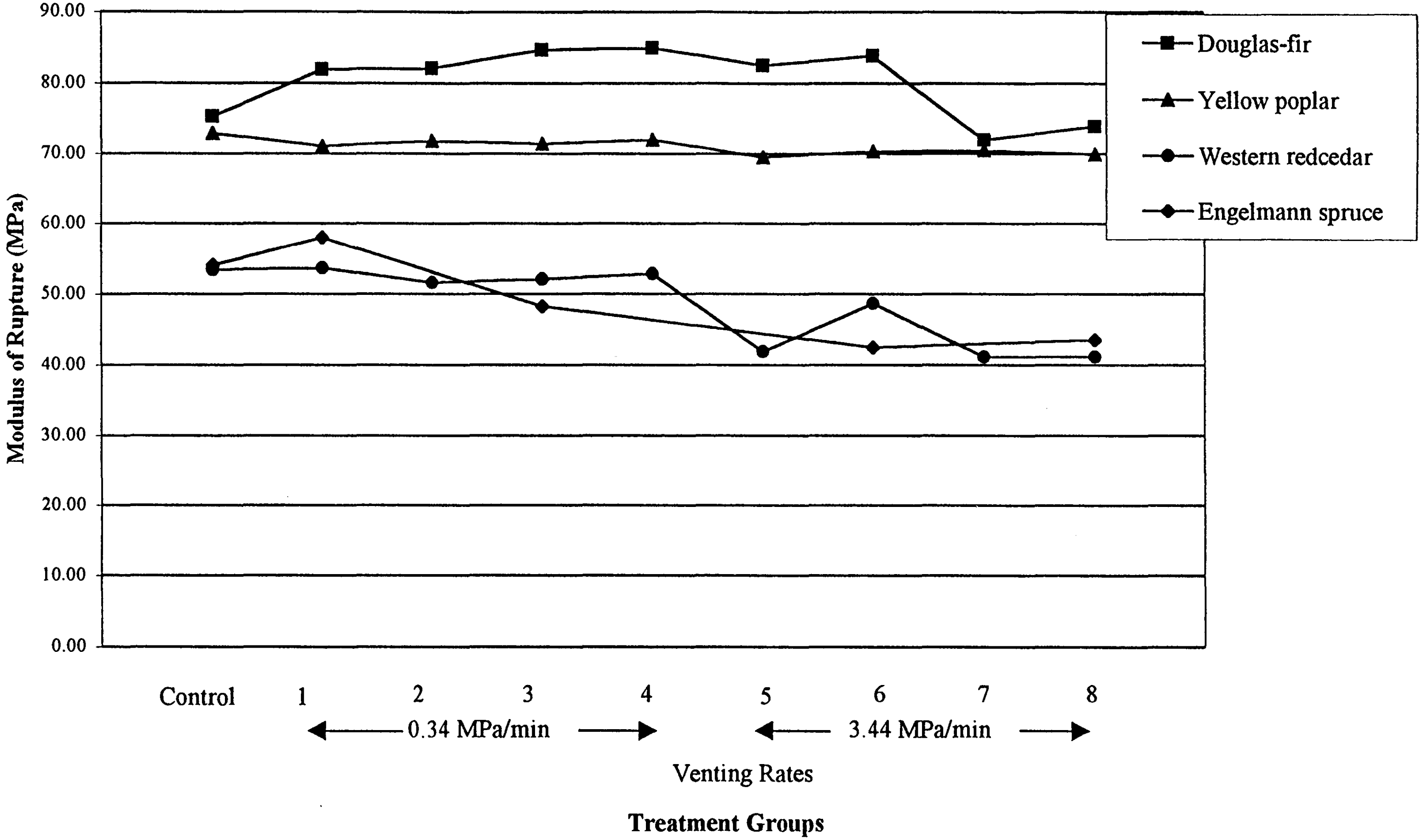

Figure 4.3. Relationship between venting and MOR for Douglas-fir, yellow poplar, western redcedar and Engelmann spruce.

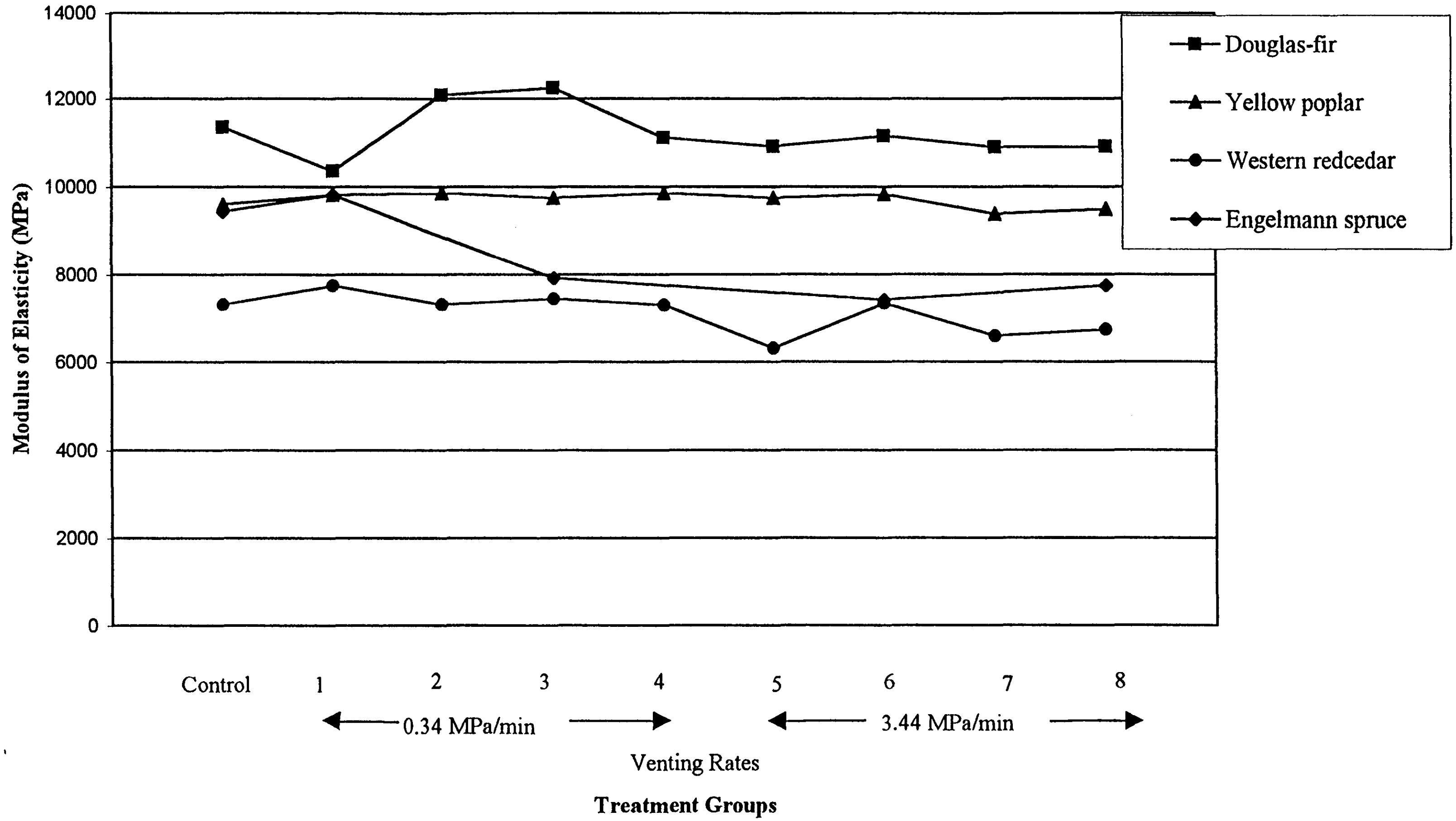

Figure 4.4. Relationship between venting and MOE for Douglas-fir, yellow poplar, western redcedar and Engelmann spruce.

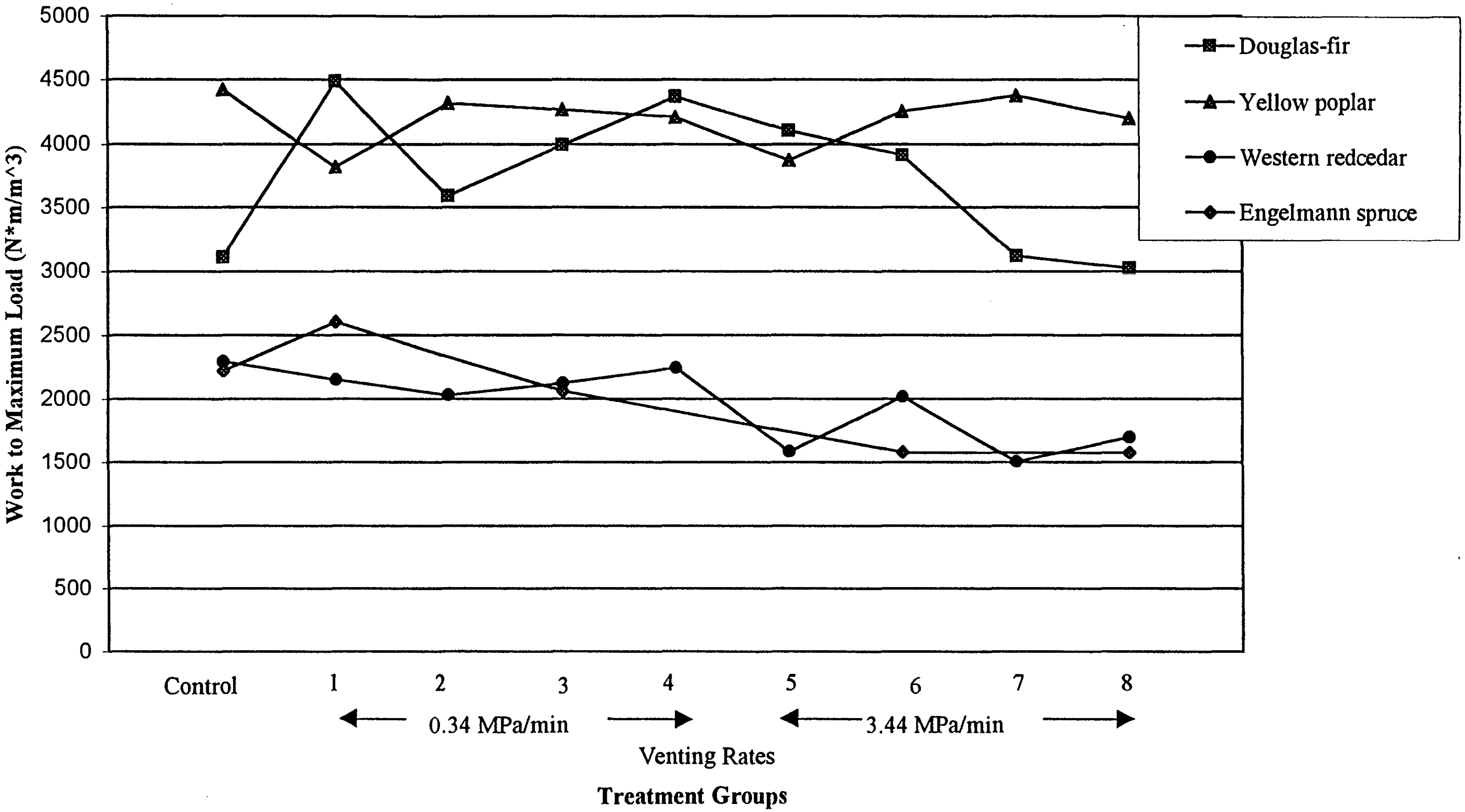

Figure 4.5. Relationship between venting and WML for Douglas-fir, yellow poplar, western red cedar and Engelmann spruce.

The bending properties loss in western redcedar and Engelmann spruce can be attributed to the formation of excessive pressure gradients during supercritical fluid treatments. Wood damaged during SCF treatments is likely to occur when pressure gradients exceed the compressive and tensile perpendicular-to-grain strengths. These failures may be evident as.collapse during pressurization or splits and checks during venting. The formation of pressure gradients is a function of wood permeability and anatomical characteristics, fluid properties, specific gravity and specimen size. Darcy's law for liquids (Eq. 4.1a) and gases (Eq. 4.1b) can be used to physically explain the

$$k = QL/\Delta PA \qquad (4.1a).$$

$$k = QL\overline{P}/\Delta PAP \qquad (4.1b).$$

formation of pressure gradients in wood. When sample size area (A) and length (L), and the volumetric flow rate (Q) are constant, the permeability (k) of a porous substance decreases as the pressure gradient (ΔP) increases. Fluid properties have a profound effect on the magnitude of the pressure gradients formed during treating processes. Liquid flow through wood is greatly inhibited by surface tensile forces, viscosity, and capillary forces that are caused by entrapped air and the presence of particulates in the liquid that can plug the pits between adjacent cells.

Gases flow through wood more easily because they have lower viscosities and are not inhibited by tensile forces (Siau, 1995). Previous studies using spruce, radiata pine, and Douglas-fir indicated that internal pressure lags behind surface pressure and samples treated with air experienced smaller pressure gradients during pressurization than those treated with liquids (Peek and St. Goetsch 1990, Cobham and Vinden, 1995, Schneider and Morrell, 1997). Pressure gradients have also been shown to form in Douglas-fir, white oak, true fir and red oak during treatments with SC CO_2 (Schneider, personal communication).

The anatomical characteristics of the species examined are responsible for differences in permeabilities that affect the formation of pressure gradients (Resch and Ecklund, 1964; Stamm, 1964). The bordered pit membranes in western redcedar and spruce are heavily encrusted and aspirated. While the pits in Douglas-fir are not encrusted, they are most always aspirated (Côté, 1958; Côté and Krahmer, 1962). Western redcedar and Engelmann spruce both have lower permeabilities than Douglas-fir and yellow poplar (Siau, 1995).

Specific gravity of the wood species may also be a factor in the magnitude and type of failure induced during high-pressure treatments. The woods in this study with the lower specific gravities were western redcedar and Engelmann spruce (Table 4.2 and 4.21). The physical and mechanical properties of the species examined in this study are listed in Table 4.21. Douglas-fir and yellow poplar both have higher mechanical properties than western redcedar and Engelmann spruce and do not seem to be affected by SCF treatments. Western redcedar and Engelmann spruce both have low compressive and tensile perpendicular-to-grain strength properties. These properties coupled with low permeabilities may make these species more susceptible to losses in flexural properties during SCF at the 3.44 MPa/min venting rates. When Schneider (personal communication) treated wood samples, treatment defects were observed when pressure gradients during treatment exceeded average perpendicular-to-grain strength properties of the wood being treated.

Table 4.21. Important mechanical properties of Douglas-fir, yellow poplar, western redcedar and Engelmann spruce (Anonymous, 1987).

Species	Specific Gravity	Modulus of Rupture (MPa)	Modulus of Elasticity (MPa)	Work to maximum load (Nm/m^3)	Compression ⊥ to grain (MPa)	Tension ⊥ to grain (MPa)
Douglas-fir	0.48	85.52	13448	3444	5.52	2.34
Yellow Poplar	0.42	69.66	10897	3060	3.45	3.72
Western redcedar	0.32	51.72	7655	2017	3.17	1.52
Engelmann Spruce	0.35	64.14	8966	2226	2.83	2.41

Specimen size clearly had an effect on the ability of western redcedar and Engelmann spruce to be treated using SC CO_2. The apparent relationship between losses in bending properties and dimensions is most likely the result of excessive pressure gradients induced during high-pressure treatments. The significant losses in bending properties examined in this study were greater than those reported in prior studies using very small solid wood and wood-based composite specimens (Smith et al., 1993; Morrell et al., 1993; Acda, 1997; Kim, et al., 1997; Acda et al., In review). The strength reductions are also larger than reported in previous (Walters and Whittington, 1967, 1970) studies that examined the effects of high-pressure treatments using liquid carriers on bending properties.

4.3.5 Relationship Between Treatment Defects and MOR, MOR and WML

4.3.5.1 Continuous Wood Failure (CWF_T) and Bending Property Correlations

The final statistical analyses conducted was a Pearson Correlation that related the continuous wood failure (CWF_T) and discontinuous wood failure ($DCWF_T$) treatment defect responses to the three bending properties. Correlations within Douglas-fir were not found to be significant (Table 4.22). There was a suggestive, but inconclusive correlation between MOR and CWF_T for yellow poplar (Table 4.23). Correlations between bending properties and CWF_T for western redcedar were significant in most zones even though the linear associations were relatively small (Table 4.24). For example, the significant Pearson correlation coefficient for MOR in the 0.00-0.10 mm zone was –0.2673 (Table 4.24). While the negative linear association would be stronger if the coefficient were closer to –1, the significant p-value indicates that the slope of the line within the correlation is significantly different than zero. This MOR correlation suggests that there may be evidence of a negative linear relationship between bending properties and small reductions in dimensions for western redcedar. The existing zones of CWF_T in MOR for western redcedar suggest that a positive linear relationship between reductions in dimensions, or densification, may be occurring up to 1.00 mm. Correlations between bending properties and CWF_T for Engelmann spruce were not significant (Table 4.25).

The CWF_T correlations for yellow poplar, western redcedar and Engelmann spruce were all negative when no deformation was found (0.00mm –0.10mm), positive when 0.11mm to 1.00 mm deformation occurred and negative above 1.01mm deformation. This phenomenon suggests that as collapse increases bending properties increase to a certain degree for each of these three species. Once deformation has attained a certain threshold, bending properties appear to decrease.

4.3.5.2 Discontinuous Wood Failure ($DCWF_T$) and Bending Property Correlations

Larger correlation coefficients were found between bending properties and $DCWF_T$'s. No significant correlations were found between $DCWF_T$'s and bending properties for Douglas-fir (Table 4.22). There was a positive linear correlation found between bending properties and $DCWF_T$'s for yellow poplar and western redcedar for specimens when no failures were present (Table 4.23, 4.24). Once specimens began to experience treatment defects, significant negative correlations were found. Significant reductions in bending properties were strongly correlated to radial failures in western redcedar specimens (Table 4.243 while, this was not evident with yellow poplar or Engelmann spruce. However, significant reductions in bending properties for yellow poplar and Engelmann spruce were strongly correlated when radial and tangential failures occurred together (Table 4.23, 4.25).

The results of this analysis reiterate that venting had the most significant effect on reductions in bending properties during SCF treatment because correlations between $DCWF_T$'s and bending properties were stronger than those for CWF_T's. The stronger correlations that occurred between wood failures and bending properties in yellow poplar and Engelmann spruce suggests that pressure gradients induced during venting can have drastic ramifications on wood quality. This was also evident in western redcedar where there was a strong negative correlation between radial failures and bending properties. The expansion of CO_2 during venting may further enhance the formation of pressure gradients.

Table 4.22. Pearson Correlation Coefficients between continuous wood failures (CWF_T) and discontinuous wood failures ($DCWF_T$) and MOR, MOE and WML for Douglas-fir.

	CWF_T (n=96)			
	0.00 – 0.10 mm	0.11 – 0.50 mm	0.51 – 0.100 mm	> 1.01 mm
MOR	0.0893 (0.3894)[a]	-0.0893 (0.3894)	- -	- -
MOE	-0.0429 (0.6798)	-0.0429 (0.6798)	- -	- -
WML	0.0016 (0.9875)	-0.0016 (0.9875)	- -	- -
	$DCWF_T$ (n=96)			
	None	Radial	Tangential	Both
MOR	0.1306 (0.2071)	-0.1306 (0.2071)	- -	- -
MOE	-0.0596 (0.5662)	0.0596 (0.5662)	- -	- -
WML	0.1134 (0.2750)	-0.1134 (0.2750)	- -	- -

a: p-values are indicated within parentheses.

Table 4.23. Pearson Correlation Coefficients between continuous wood failures (CWF_T) and discontinuous wood failures ($DCWF_T$) and MOR, MOE and WML for yellow poplar.

	CWF_T(n=95)			
	0.00 – 0.10 mm	0.11 – 0.50 mm	0.51 – 0.100 mm	> 1.01 mm
MOR	-0.1939 (0.0597)[a]	0.1939 (0.0597)	- -	- -
MOE	-0.0688 (0.5078)	0.0688 (0.5078)	- -	- -
WML	-0.1005 (0.3325)	0.1005 (0.3325)	- -	- -
	$DCWF_T$ (n=95)			
	None	Radial	Tangential	Both
MOR	0.2661 (0.0092)	-0.0883 (0.3946)	- -	-0.5466 (0.0001)
MOE	0.3134 (0.0020)	-0.1840 (0.0743)	- -	-0.4144 (0.0001)
WML	0.0508 (0.6243)	0.0310 (0.7575)	- -	-0.2451 (0.0167)

a: p-values are indicated within parentheses.

Table 4.24. Pearson Correlation Coefficients between continuous wood failures (CWF_T) and discontinuous wood failures ($DCWF_T$) and MOR, MOE and WML for western redcedar.

	CWF_T (n=91)			
	0.00 – 0.10 mm	0.11 – 0.50 mm	0.51 – 0.100 mm	> 1.01 mm
MOR	-0.2673 (0.0104)[a]	0.2806 (0.0070)	0.1440 (0.1734)	-0.2280 (0.0297)
MOE	-0.1931 (0.0666)	0.1628 (0.1231)	0.1510 (0.1531)	-0.0887 (0.4034)
WML	-0.2838 (0.0064)	0.3243 (0.0017)	0.1168 (0.2700)	-0.2873 (0.0058)
	$DCWF_T$ (n=91)			
	None	Radial	Tangential	Both
MOR	0.4546 (0.0001)	-0.4292 (0.0001)	- -	-0.0781 (0.4621)
MOE	0.3139 (0.0024)	-0.2894 (0.0054)	- -	-0.0732 (0.4906)
WML	0.4824 (0.0001)	-0.4617 (0.0001)	- -	-0.0655 (0.5376)

a: p-values are indicated with the parentheses.

Table 4.25. Pearson Correlation Coefficients between of continuous wood failures (CWF_T) and discontinuous wood failures ($DCWF_T$) and MOR, MOE and WML for Engelmann spruce.

	CWF_T (n=45)			
	0.00 – 0.10 mm	0.11 – 0.50 mm	0.51 – 0.100 mm	> 1.01 mm
MOR	-0.2402 (0.1120)[a]	0.2101 (0.1660)	-0.0787 (0.6072)	-0.0525 (0.7320)
MOE	-0.2028 (0.1816)	0.1317 (0.3884)	0.0195 (0.8989)	-0.0766 (0.6171)
WML	-0.0994 (0.5157)	0.1591 (0.2965)	-0.1236 (0.4185)	-0.0273 (0.8589)
	$DCWF_T$ (n=45)			
	None	Radial	Tangential	Both
MOR	0.2349 (0.1204)	0.1533 (0.3146)	- -	-0.4546 (0.0017)
MOE	0.2209 (0.1448)	0.1398 (0.3596)	- -	-0.4223 (0.0039)
WML	0.0706 (0.6447)	0.1400 (0.3589)	- -	-0.2474 (0.1013)

a: p-values are indicated with the parentheses.

4.4 Effects of Supercritical Fluid Treatments on Anatomical Characteristics

4.4.1 Effects of Supercritical Fluid Treatment on Microscopic Continuous Wood Failures (CWF_M'S)

Visual assessment of the gross specimens and bending properties are the two approaches that were used, up to this point, to evaluate the effects of SCF treatments on the wood specimens. When the wood specimens were examined at the microscopic level, effects that were not apparent at the macroscopic level were observed. CWF_M's were classified as either plastic or mechanical. A mechanical failure was defined as a separation of the wood cell walls whereas a plastic failure consisted of continuous deformation of the wood matrix. CWF_M's were identified in samples of Douglas-fir, western redcedar and Engelmann spruce that were exposed to SCF treatments (Tables 4.26 - 4.29), while there were no apparent effects observed for yellow poplar (Figure 4.6). This is consistent with the bending results because there were no adverse effects found in bending properties for yellow poplar specimens subjected to SCF treatments.

CWF_M degradations in Douglas-fir occurred in treatments consisting of 3.44 MPa/min. pressurization rate (Figure 4.7). Sections taken from two outer plugs for treatment 6 had an average percent earlywood failure of 2.6% while treatment 8 had 0.9% collapse in the inner zone (Table 4.26). The failure types of treatment 6 were both plastic and mechanical, while those in treatment 8 were entirely plastic. Collapse was observed in treatments that used 3.44 MPa/min. pressurization and venting rates suggesting that both rates have an affect on collapse.

Table 4.26. Effect of supercritical fluid impregnation on the anatomical characteristics of Douglas-fir.

Treatment						Frequency of Continuous Wood Failures (%)		Frequency of Discontinuous Wood Failures			
#	PR (MPa/min.)	TP (MPa)	VR (MPa/min.)	Plug [d]	Frequency of EW collapse (%) [a]	Plastic [b]	Mechanical [b]	Torn [c]	Split [c]	Tangential [c]	Radial [c]
1	0.34	10.34	0.34	O	0	-	-	4	1	0	1
				I	0	-	-	2	2	0	2
2	3.44	10.34	0.34	O	0	-	-	3	1	0	1
				I	0	-	-	2	2	0	2
3	0.34	20.69	0.34	O	0	-	-	5	0	-	-
				I	0	-	-	3	0	-	-
4	3.44	20.69	0.34	O	0	-	-	4	0	-	-
				I	0	-	-	5	3	0	3
5	0.34	10.34	3.44	O	0	-	-	4	0	-	-
				I	0	-	-	4	0	-	-
6	3.44	10.34	3.44	O	2.6 (2)	100	100	5	1	0	1
				I	0	-	-	3	1	0	1
7	0.34	20.69	3.44	O	0	-	-	4	3	0	3
				I	0	-	-	0	0	-	-
8	3.44	20.69	3.44	O	0	-	-	2	0	-	-
				I	0.9 (1)	100	0	5	0	-	-
9	Control	Control	Control	O	0	-	-	4	0	-	-
				I	0	-	-	3	0	-	-

a Average % EW is the overall average percent of earlywood collapsed from all six views. The % EW collapsed was calculated by counting the total number of collapsed tracheids and dividing by the total number of tracheids across the EW. Numbers within the parentheses are the total number of views, out of six, used to calculate the average.

b Percent calculated by : ((# of counts)/(# of views from average %EW)) *100. Each count represents a 1 if the failure was present.

c Number of counts, out of six views, that this failure was present.

d O - outer plug, I - center plug.

Table 4.27. Effect of supercritical fluid impregnation on the anatomical characteristics of yellow poplar

Treatment						Frequency of Continuous Wood Failures (%)		Frequency of Discontinuous Wood Failures			
#	PR (MPa/min.)	TP (MPa)	VR (MPa/min.)	Plug [d]	Frequency of EW collapse (%) [a]	Plastic [b]	Mechanical [b]	Torn [c]	Split [c]	Tangential [c]	Radial [c]
1	0.34	10.34	0.34	O	0	-	-	0	0	-	-
				I	0	-	-	2	0	-	-
2	3.44	10.34	0.34	O	0	-	-	2	0	-	-
				I	0	-	-	2	0	-	-
3	0.34	20.69	0.34	O	0	-	-	2	0	-	-
				I	0	-	-	2	0	-	-
4	3.44	20.69	0.34	O	0	-	-	0	0	-	-
				I	0	-	-	0	0	-	-
5	0.34	10.34	3.44	O	0	-	-	1	0	-	-
				I	0	-	-	5	0	-	-
6	3.44	10.34	3.44	O	0	-	-	3	0	-	-
				I	0	-	-	2	0	-	-
7	0.34	20.69	3.44	O	0	-	-	4	0	-	-
				I	0	-	-	1	0	-	-
8	3.44	20.69	3.44	O	0	-	-	4	0	-	-
				I	0	-	-	2	0	-	-
9	Control	Control	Control	O	0	-	-	2	0	-	-
				I	0	-	-	2	0	-	-

a Average % EW is the overall average percent of earlywood collapsed from all six views. The % EW collapsed was calculated by counting the total number of collapsed tracheids and dividing by the total number of tracheids across the EW. Numbers within the parentheses are the total number of views, out of six, used to calculate the average.

b Percent calculated by : ((# of counts)/(# of views from average %EW)) *100. Each count represents a 1 if the failure was present.

c Number of counts, out of six views, that this failure was present.

d O - outer plug, I - center plug.

Table 4.28. Effect of supercritical fluid impregnation on the anatomical characteristics of western redcedar.

Treatment					Frequency	Frequency of Continuous Wood Failures (%)		Frequency of Discontinuous Wood Failures			
#	PR (MPa/min.)	TP (MPa)	VR (MPa/min.)	Plug [d]	of EW collapse (%) [a]	Plastic [b]	Mechanical [b]	Torn [c]	Split [c]	Tangential [c]	Radial [c]
1	0.34	10.34	0.34	O	0	-	-	3	0	-	-
				I	0	-	-	4	0	-	-
2	3.44	10.34	0.34	O	2.8 (1)	100	100	6	0	-	-
				I	0	-	-	6	0	-	-
3	0.34	20.69	0.34	O	0	-	-	6	3	0	3
				I	0	-	-	5	2	0	2
4	3.44	20.69	0.34	O	13.5 (4)	100	100	5	0	-	-
				I	25.6 (5)	100	40	3	0	-	-
5	0.34	10.34	3.44	O	0	-	-	6	1	0	1
				I	0	-	-	4	0	-	-
6	3.44	10.34	3.44	O	6.3 (2)	100	50	2	1	0	1
				I	0	-	-	2	1	0	1
7	0.34	20.69	3.44	O	0	-	-	2	1	0	1
				I	0	-	-	4	3	0	3
8	3.44	20.69	3.44	O	0	-	-	3	0	-	-
				I	20.8 (2)	100	0	4	0	-	-
9	Control	Control	Control	O	0	-	-	0	2	0	2
				I	0	-	-	0	0	-	-

a Average % EW is the overall average percent of earlywood collapsed from all six views. The % EW collapsed was calculated by counting the total number of collapsed tracheids and dividing by the total number of tracheids across the EW. Numbers within the parentheses are the total number of views, out of six, used to calculate the average.

b Percent calculated by : ((# of counts)/(# of views from average %EW)) *100. Each count represents a 1 if the failure was present.

c Number of counts, out of six views, that this failure was present.

d O - outer plug, I - center plug.

Table 4.29. Effect of supercritical fluid impregnation on the anatomical characterisitcs of Engelmann spruce.

Treatment						Frequency of Continuous Wood Failures (%)		Frequency of Discontinuous Wood Failures			
#	PR (MPa/min.)	TP (MPa)	VR (MPa/min.)	Plug [d]	Frequency of EW collapse (%) [a]	Plastic [b]	Mechanical [b]	Torn [c]	Split [c]	Tangential [c]	Radial [c]
1	0.34	10.34	0.34	O	16.7 (2)	100	50	1	2	0	2
				I	0	-	-	6	0	-	-
3	0.34	20.69	0.34	O	7.4 (5)	100	100	4	1	0	1
				I	0	-	-	4	0	-	-
6	3.44	10.34	3.44	O	0	-	-	5	0	-	-
				I	0	-	-	4	0	-	-
8	3.44	20.69	3.44	O	0	-	-	1	1	0	1
				I	28.7 (4)	100	50	5	1	0	1
9	Control	Control	Control	O	0	-	-	6	0	-	-
				I	0	-	-	6	0	-	-

a Average % EW is the overall average percent of earlywood collapsed from all six views. The % EW collapsed was calculated by counting the total number of collapsed tracheids and dividing by the total number of tracheids across the EW. Numbers within the parentheses are the total number of views, out of six, used to calculate the average.

b Percent calculated by : ((# of counts)/(# of views from average %EW)) *100. Each count represents a 1 if the failure was present.

c Number of counts, out of six views, that this failure was present.

d O - outer plug, I - center plug.

The largest degree of CWF_M's in western redcedar occurred in the sections taken from outer microscopy plugs and were present in treatments using of 3.44 MPa/min pressurization (Table 4.28) (Figure 4.8). The frequency of plastic failures was 100 % for all CWF_M views while mechanical failure frequency ranged between 0 to 100 %. Western redcedar experienced collapse only at 3.44 the MPa/min. pressurization rate, while samples exposed to both the 0.34 and 3.44 MPa/min. venting rates experienced collapse. Venting rate in western redcedar appeared to have an effect on permanent deformation (Table 4.30). Reductions in cross-sectional deformation occurred at the 0.34 MPa/min. venting rate, while recovery and expansion seems to have occurred at the

Table 4.30. Average cross sectional area (mm^2) of samples exposed to supercritical fluid treatment as determined by Image Analysis (Standard deviations are indicated within parentheses).

Treatment				Cross-sectional area			
	PR (MPa/min.)	TP (MPa)	VR (MPa/min.)	Douglas-fir	Yellow poplar	Western redcedar	Engelmann spruce
1	0.34	10.34	0.34	1393 (26)	1416 (9)	1350 (34)	1389 (41)
2	3.44	10.34	0.34	1400 (26)	1425 (13)	1303 (34)	
3	0.34	20.69	0.34	1412 (30)	1429 (11)	1359 (31)	1400 (68)
4	3.44	20.69	0.34	1408 (29)	1418 (10)	1305 (52)	
5	0.34	10.34	3.44	1403 (36)	1432 (15)	1397 (39)	
6	3.44	10.34	3.44	1395 (27)	1420 (10)	1376 (27)	1343 (43)
7	0.34	20.69	3.44	1412 (35)	1413 (13)	1385 (50)	
8	3.44	20.69	3.44	1401 (28)	1422 (17)	1365 (42)	1393 (62)
Control				1415 (27)	1408 (10)	1356 (35)	1404 (26)

3.44 MPa/min venting rate. This recovery and expansion was mostly a product of specimen splitting.

Similar to western redcedar and Douglas-fir, collapse in Engelmann spruce was observed only in the sections taken from the outer plugs, except for treatment 8 where degradations were only observed in sections taken from an inner plug (Table 4.29). Collapse in Engelmann spruce was present in all treatments except treatment 6 which may be due to board variability since a permanent deformation in cross sectional area occurred (Table 4.29). Degradations were observed at both the fast and slow pressurization and venting rates suggesting that Engelmann spruce is more susceptible to collapse than either western redcedar or Douglas-fir (Figure 4.9, 4.10). Similar to both Douglas-fir and western redcedar, plastic failure was observed in each view containing collapse (Table 4.29). The frequency of mechanical failures in Engelmann spruce ranged between 50 and 100 %. The largest degree of external collapse was found in treatment 1 and the least was found treatment 3. Both treatments 6 and 8 had average cross sectional areas that were larger than the control suggesting that recovery had occurred (Table 4.30). However, similar to western redcedar this is mostly a function of radial and tangential failures.

The faster rate of pressurization appears to have a more profound effect on CWF_M's for western redcedar and Douglas-fir, whereas Engelmann spruce seems to be more variable. The largest percent of earlywood collapse for all species occurred at the faster pressurization rate further suggesting that the formation of excessive pressure gradients exceeded the maximum compressive strength perpendicular to grain. The aspiration of bordered pits during pressurization may be further enhancing the formation of these pressure gradients. Deleterious effects on wood quality were not found to be affected by pressurization rate for Douglas-fir or western redcedar. Densification may be occurring during pressurization, but the wood matrix remains continuous for each species. Plastic failure was observed in all views and was often accompanied with mechanical failures. Mechanical failures may actually result from cells torn during sectioning since they did not occur as often as plastic failures (Figure 4.12, 4.13).

4.4.2 Effects of Supercritical Fluids Treatments on Microscopic Discontinuous Wood Failures ($DCWF_M$'s)

Changes in anatomical characteristics due to discontinuous wood failures ($DCWF_M$'s) were observed in all species examined. $DCWF_M$ failures were categorized as either torn or split failures. Torn cells were those considered to be damaged during sectioning. Tearing, tear holes, and diagonal tearing across growth rings were observed in many views and were not considered as failures from SCF treatments (Figure 4.11, 4.12). However, splitting was defined as an obvious tangential or radial separation of wood cells (Figure 4.11). In this analysis, all splitting failure occurred in the radial direction. Section tearing occurred most often in western redcedar and Engelmann spruce and to a lesser degree in Douglas-fir. The least amount of tearing occurred in yellow poplar. In many instances, western redcedar and spruce sections nearly disintegrated when sectioned. For this reason, the section width was increased to adjust for difficulties. Due to the problems experienced in sectioning it is hard to say with any degree of certainty that the $DCWF_M$'s observed microscopically were actually a product of treatments failures. An unknown percentage of these failures were due to the inherent difficulties in sectioning lower specific gravity species with some level of existing cellular damage in the form of CWF_M's. The findings of this study regarding the change in wood morphology seem to contradict those of Ritter and Campbell (1991) and Kiran (1994). Also operator inexperience may have also been a factor in sectioning difficulties.

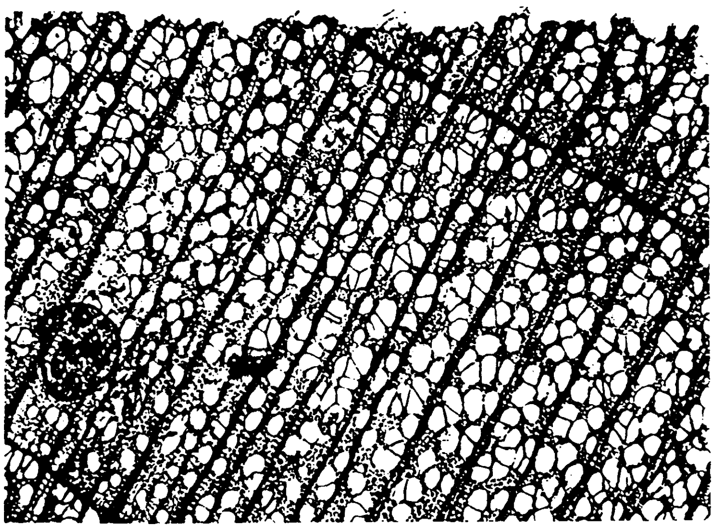

Figure 4.6. Transverse section of yellow poplar taken from an outer plug of a sample exposed to 3.44 MPa/min. pressurization and venting rate. No continuous wood failures (CWF_M's) or discontinuous wood failures ($DCWF_M$'s) present (40X).

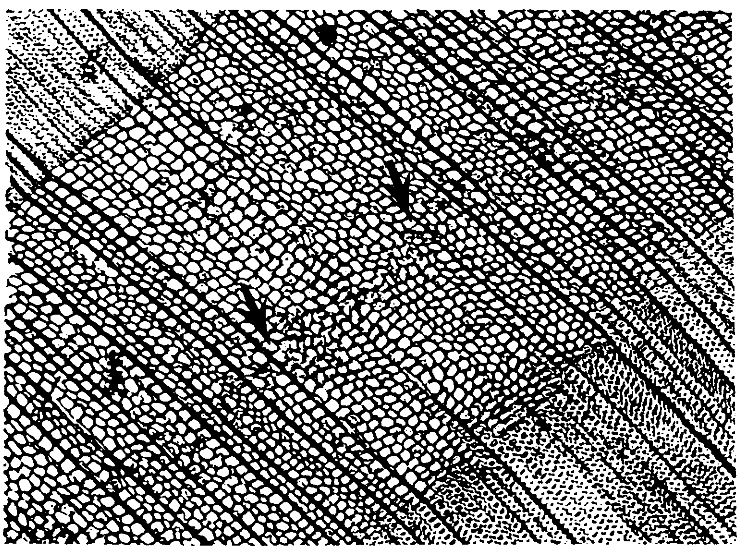

Figure 4.7. Transverse section of Douglas-fir taken from an inner plug of a sample exposed to 3.44 MPa/min pressurization and venting rates with a line of 10 percent earlywood collapse (40X).

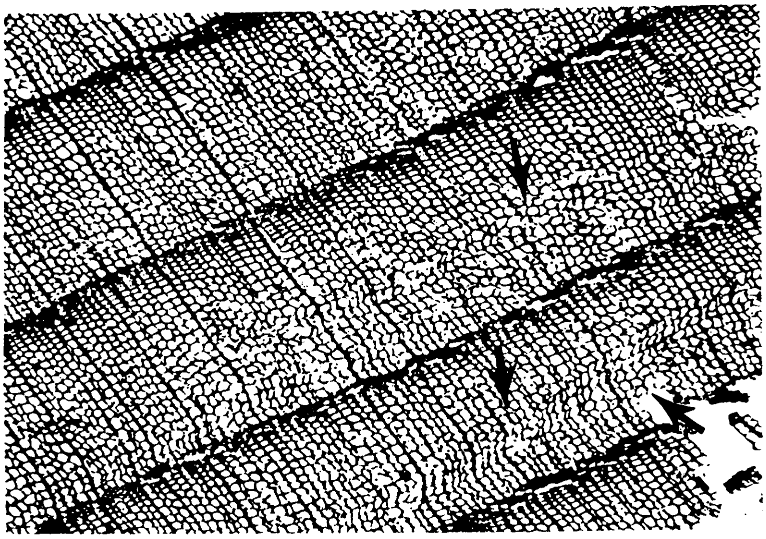

Figure 4.8. Transverse section of western redcedar taken from an inner plug of a sample exposed to 3.44 MPa/min. pressurization and venting rates showing 50 percent earlywood collapse. Mechanical tearing present in earlywood and latewood in addition to plastic failure in earlywood (40X).

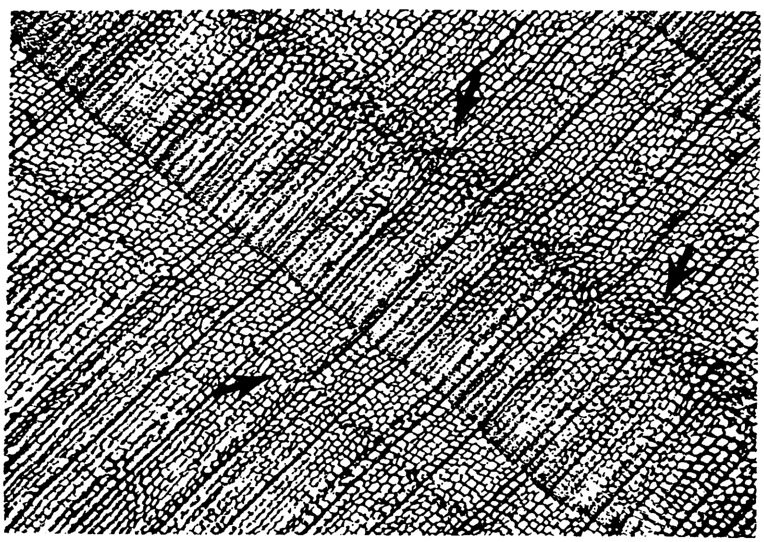

Figure 4.9. Transverse section of Engelmann spruce taken from an outer plug of a sample exposed to 0.34 MPa /min. pressurization and venting rates showing 19 percent earlywood collapse (40X).

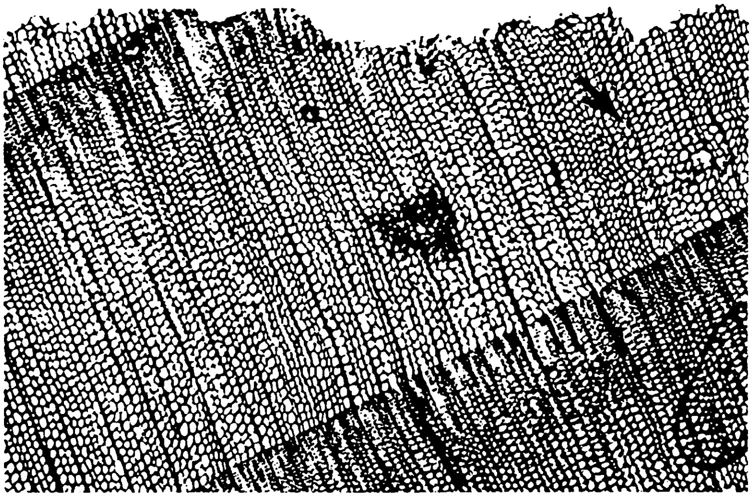

Figure 4.10. Transverse section of Engelmann spruce from an inner plug of a sample exposed to 3.44 MPa/min. pressurization and venting rates showing 13 percent earlywood collapse (100X).

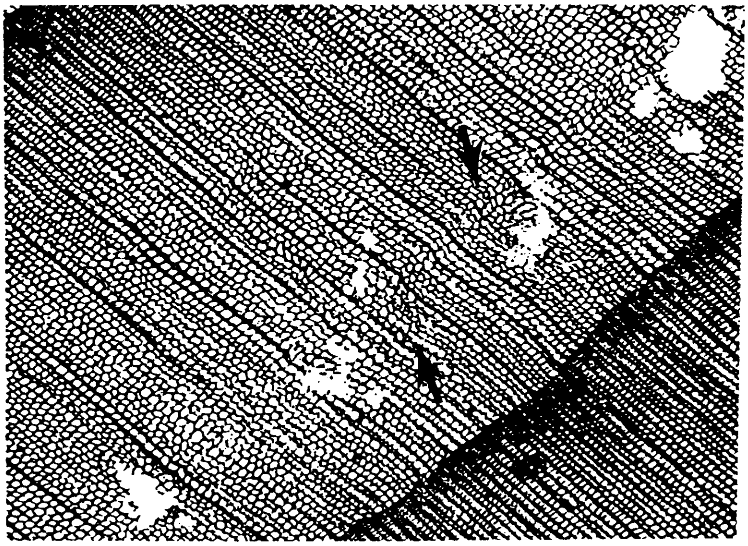

Figure 4.11. Transverse section of Western redcedar taken from an outer plug of a sample exposed to 3.44 MPa/min. pressurization and 0.34 MPa/min. venting rates showing 16 percent earlywood collapse. Plastic failure exists between mechanical tearing (40X).

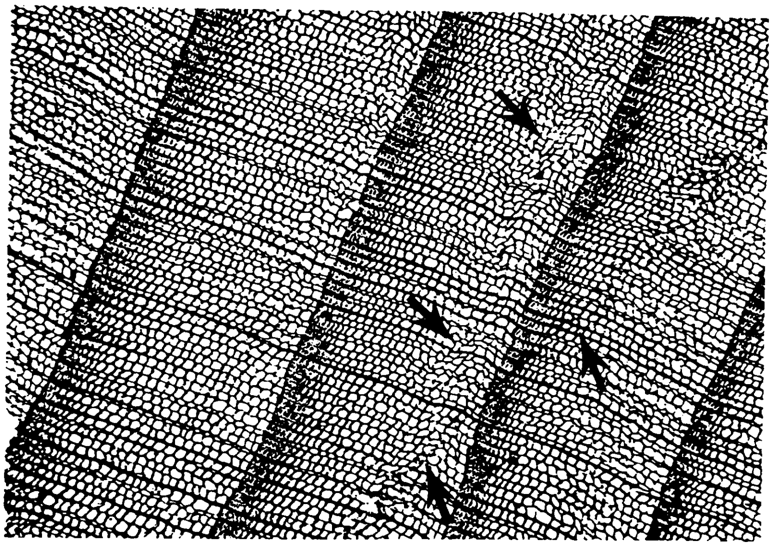

Figure 4.12. Transverse section of western redcedar taken from an outer plug of a sample exposed to 3.44 MPa/min. pressurization and 0.34 MPa/min. venting rates showing 50 percent earlywood collapse and a cross-annual-ring diagonal knife mark from sectioning (40X).

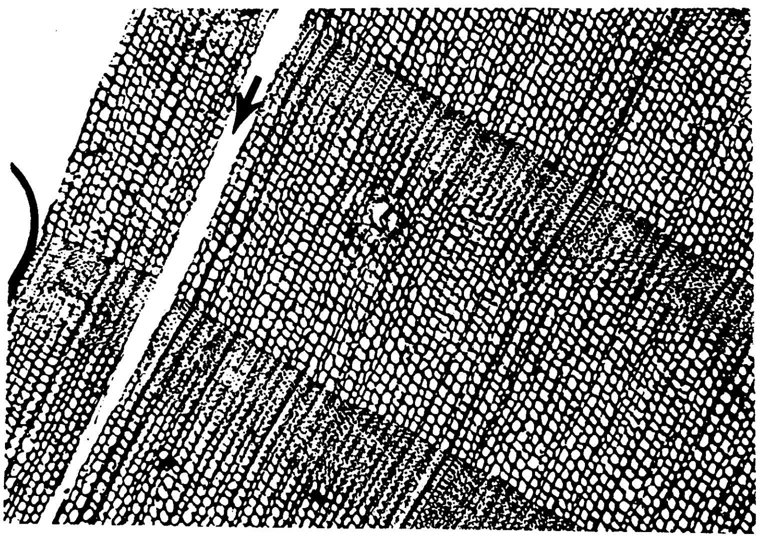

Figure 4.13. Transverse section of Engelmann spruce taken from an outer plug of a sample exposed to 0.34 MPa/min pressurization and venting rates with a complete radial split (40X).

5 CONCLUSIONS

The use of SC CO_2 had varying effects on the wood properties of the species examined. Exposure to SCF treatment conditions did not affect the bending properties of yellow poplar. Although Douglas-fir specimens appeared to have increased bending properties following SCF treatment, sampling anomalies within its species group related to mean specific gravity differences between treatments, confounded the results. Bending properties of western redcedar were adversely affected after exposure to rapid rates of venting, while Engelmann spruce bending properties were reduced by both the rapid and slow treatment rates. Rapid rates of pressurization seemed to affect anatomical characteristics of Douglas-fir and western redcedar, while both the fast and slow treatment rates appeared to affect Engelmann spruce.

The results of this study suggest that slower treatment rates during pressurization and venting should be employed when treating wood using SC CO_2 to avoid the development of steep internal pressure gradients that may negatively affect bending properties and anatomical characteristics of wood.

6 FUTURE RECOMMENDATIONS

It is recommended that further research be conducted to examine the effect of wood features such as knots, on the ability of wood to be treated using supercritical CO_2 and examine the distribution of preservatives in treated wood specimens. Treating wood-based composite materials with SCF's as preservative carriers would also be of interest because currently there are only a limited number of treatments available for preserving these materials. Investigating treatment of millwork is also of interest because most millwork treatment systems are only dip systems with limited preservative penetration. The potential for using supercritical fluid technology in the wood preservation industry to preserve forest products not currently protected are endless and the technology has the capability of creating many opportunities.

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APPENDICES

APPENDIX A – Grade for Engelmann spruce specimens

This appendix describes the procedure used to establish an allowable structural grade for non-clear Engelmann spruce test specimens. Specimen size was 38 mm x 38 mm x 533.4 mm (1.5 in. x 1.5 in. x 23 in.) in accordance with ASTM Standard D 143-94. A three point bending test was conducted as seen in Figure A1.

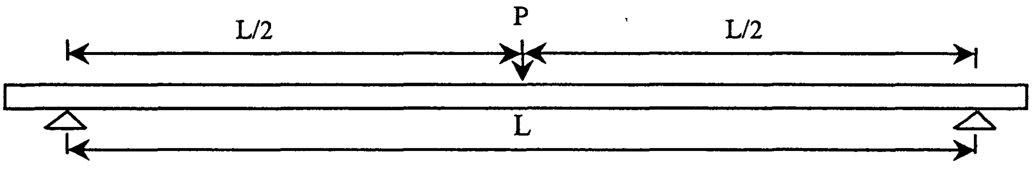

Figure A1. Bending test.

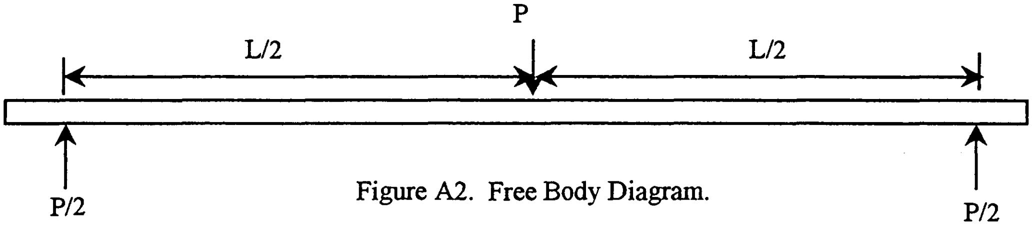

Figure A2. Free Body Diagram.

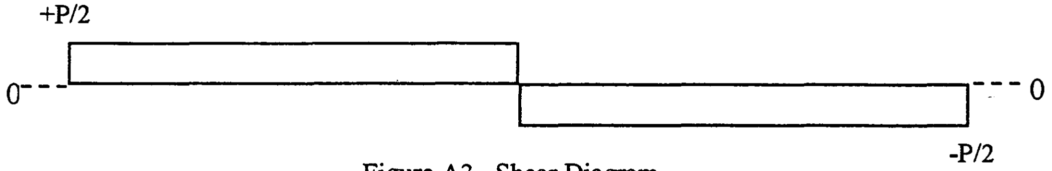

Figure A3. Shear Diagram.

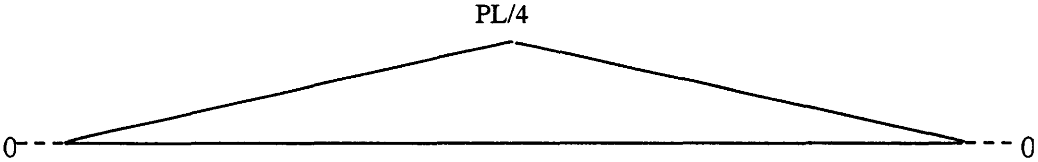

Figure A4. Moment Diagram.

Figure A2 is the free body diagram, Figure A3 is the shear diagram and Figure A4 is the moment diagram of the ASTM Standard D143-94 bending test. The shear stresses are maximum at P/2 a distance L/2 from the force P at the center of the specimen. Bending moment is a maximum at midspan (L/2).

In ASTM Standard D 245-93, Standard Practice for Establishing Structural Grades and Related Allowable Properties for Visually-Graded Lumber, the basic principles for establishing related unit stresses and stiffness values for design with visually-graded solid sawn lumber are covered. Grading is accomplished by examination of all four faces and ends. The location and size of knots and other defects are evaluated over the entire length of the specimen. The development of ASTM Standard D 245-93 was based on extensive research using small clear specimens and full size specimens.

ASTM Standard D 245-93 uses a strength ratio that compares the ratio of the strength property being considered to that of a material with no strength reducing characteristics. For example if a strength ratio (S) of 75% in bending strength was being considered, then the specimen evaluated would be expected to have 75% of the bending strength as that of a clear piece. This analysis permits an unlimited choice in establishing grades of any desired quality.

In order to establish an appropriate grade for this study two items were used in ASTM Standard D 2445-93, Figure 2 and formula X1.2. Figure 2 shows the maximum size of knots permitted in various parts of joists and planks, and beams and stringers. Strength ratio charts 2,3, and 4 list various size and location of knots and width of specimen face. For the specimen size used in this experiment a strength ratio was not listed so formula X1.2 was used to calculate maximum allowable knot size based on a 75 % strength ratio (S). The 75 % strength ratio was listed in Table 2. Formula X1.2 covers the bending members with knots along the center-line of a wide face at any point in the length of the piece. Equation A.1 shows formula X1.2.

$$S = 100 \left\{1 - \frac{k - (1/24)}{h + (3/8)}\right\} \qquad \text{(X.1)}$$

From Formula X1.2 the calculated allowable knot size, k, for bending parallel to grain was 7.55 mm in diameter. Using Figure 2 from ASTM Standard D 245-93 the dimensions A, B and C were calculated from k. B was equal to k and A and C were equal and one half the size of B. Knot sizes A, B, and C were designated as the allowable knot sizes for the Engelmann spruce specimens.

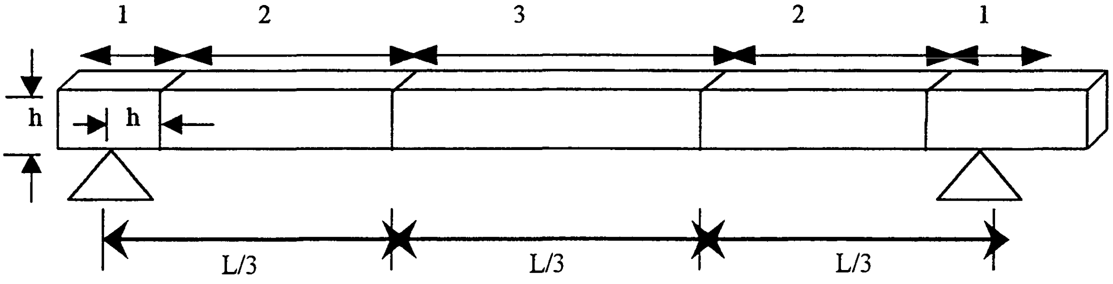

Figure. A5. Knot zones.

Areas 1 and 3 in Figure A5 were 100% clear, but knots were allowed in area 2. A distance, h, of 38 mm from each support was designated as clear following St. Vanants which avoids possible interference from shear stresses during loading. Area 3, the middle one third of the specimen, was also designated as clear to due to maximum bending moment.

The calculated knot sizes and designated clear areas were used as a criterion for selection of the spruce specimens. A stencil was created following ASTM Standard D 245-93 Figure 2. Due to the limited spruce resource only sixty specimens were accepted. Forty-eight were used for four treatment runs and twelve were used for controls.

APPENDIX B - Measurements of right and left side heights and widths of treated specimens which were used to calculate average change in cross sectional dimension for treatment defect classification.

Specimen ID	Left End (mm)				Right End (mm)				Ave. (mm)		(CWF) Zones (mm)				DCWF			
	Width (Left)	Width (Left)	Height (Left)	Height (Left)	Width (Right)	Width (Right)	Height (Right)	Height (Right)	Width	Height	0.00-0.10	0.11-0.50	0.51-1.00	>1.01	None	Radial	Tang.	Both
DE-1-8	38.15	38.06	37.40	37.36	38.33	38.18	37.36	37.40	0.12	0.00	0	1	0	0	1	0	0	0
DF-1-11	38.06	37.91	36.70	36.58	37.83	37.79	37.88	37.85	0.10	0.08	1	0	0	0	1	0	0	0
DC-1-3	38.46	38.38	36.84	36.44	38.11	38.10	36.98	36.69	0.04	0.35	0	1	0	0	1	0	0	0
D-RG-1	38.21	38.14	37.78	37.73	38.46	38.28	37.95	37.86	0.13	0.07	0	1	0	0	1	0	0	0
DB-1-4	38.25	38.20	36.30	36.27	38.07	37.93	36.22	36.16	0.09	0.04	1	0	0	0	1	0	0	0
DG1-6	38.22	37.97	37.79	37.31	38.47	38.06	37.94	37.73	0.33	0.34	0	1	0	0	1	0	0	0
DC-1-13	37.17	37.10	38.33	38.27	37.06	37.05	38.24	38.20	0.04	0.05	1	0	0	0	1	0	0	0
DA-1-6	38.26	38.18	36.30	36.20	38.17	38.06	36.35	36.32	0.09	0.06	1	0	0	0	1	0	0	0
DF-1-17	38.14	37.98	37.89	37.89	37.97	37.95	37.33	37.45	0.09	-0.06	1	0	0	0	1	0	0	0
DH-1	38.19	38.12	37.41	37.72	38.15	38.26	37.74	37.86	-0.02	-0.22	1	0	0	0	1	0	0	0
DA-1-15	36.40	36.37	38.12	38.03	36.53	36.42	38.19	38.09	0.07	0.09	1	0	0	0	1	0	0	0
DD-1-7	38.29	38.27	37.27	37.21	38.28	38.25	37.28	37.23	0.02	0.06	1	0	0	0	1	0	0	0
DC-2-11	38.15	38.11	37.11	37.07	38.26	38.22	37.15	37.10	0.04	0.04	1	0	0	0	1	0	0	0
DA-2-13	38.21	38.05	36.44	36.38	37.99	37.92	36.49	36.46	0.12	0.04	0	1	0	0	1	0	0	0
DF-2-4	37.93	37.77	37.95	37.93	37.97	37.89	37.96	37.85	0.12	0.07	0	1	0	0	1	0	0	0
DH-2-2	38.53	38.76	37.49	37.51	38.10	38.03	37.81	37.74	-0.08	0.03	1	0	0	0	1	0	0	0
DG-2-11	38.00	37.95	37.70	37.63	38.00	37.85	37.79	37.71	0.10	0.07	1	0	0	0	1	0	0	0
DH-2	38.26	38.15	37.87	37.81	38.28	38.25	37.98	37.85	0.07	0.09	1	0	0	0	1	0	0	0
DB-2-10	38.02	37.93	36.06	35.98	37.97	37.94	36.49	36.44	0.06	0.07	1	0	0	0	1	0	0	0
DF-2-3	38.35	38.25	37.36	37.44	37.94	37.82	37.71	37.71	0.11	-0.04	0	1	0	0	1	0	0	0
DD-2-12	38.44	38.41	37.17	37.08	38.30	38.24	37.20	37.17	0.04	0.06	1	0	0	0	1	0	0	0
DC-2-6	38.26	38.18	37.07	36.98	38.31	38.24	37.29	37.10	0.07	0.14	0	1	0	0	1	0	0	0
DA-2-7	38.15	37.80	36.55	36.36	38.01	38.04	36.49	36.41	0.16	0.14	0	1	0	0	1	0	0	0
DD-2-8	38.30	38.27	37.39	37.45	38.40	38.36	37.29	37.19	0.03	0.02	1	0	0	0	1	0	0	0
DD-3-2	38.38	38.38	37.28	37.25	38.25	38.27	37.14	37.10	-0.01	0.04	1	0	0	0	1	0	0	0
DE-3-3	38.51	38.59	37.62	37.60	38.27	38.20	37.58	37.55	-0.01	0.02	1	0	0	0	1	0	0	0
DC-3-14	38.32	38.21	36.73	36.34	38.26	38.23	37.19	37.05	0.07	0.26	0	1	0	0	1	0	0	0
DG-3-12	38.08	37.86	38.00	37.80	38.20	38.01	37.78	37.66	0.21	0.16	0	1	0	0	0	1	0	0
DI-3-2	38.35	38.15	37.91	37.89	38.22	38.17	38.16	38.39	0.13	-0.11	0	1	0	0	1	0	0	0
DB-3-5	38.17	38.11	36.31	36.30	37.89	37.86	36.23	36.25	0.05	0.00	1	0	0	0	1	0	0	0
DA-3-11	36.45	36.33	38.13	37.97	36.42	36.36	37.79	37.63	0.09	0.16	0	1	0	0	1	0	0	0
D-RG-3	38.39	38.24	37.89	37.82	38.22	38.12	38.05	38.00	0.13	0.06	0	1	0	0	1	0	0	0
DE-3-7	38.17	38.10	37.32	37.28	38.23	38.10	37.30	37.28	0.10	0.03	1	0	0	0	1	0	0	0
DF-3-6	38.19	38.05	37.74	37.78	38.06	37.95	37.92	37.81	0.13	0.04	0	1	0	0	1	0	0	0
DC-3-5	38.43	38.35	37.05	36.98	38.13	38.17	37.04	37.03	0.02	0.04	1	0	0	0	1	0	0	0
DH-3-1	38.44	38.50	37.39	37.40	38.11	38.12	37.78	37.74	-0.04	0.02	1	0	0	0	0	1	0	0
DE4-9	38.14	38.10	37.60	37.53	38.21	38.14	37.53	37.50	0.05	0.05	1	0	0	0	1	0	0	0
DA-4-3	35.97	35.86	38.34	38.24	36.47	36.31	37.98	37.87	0.13	0.11	0	1	0	0	1	0	0	0
DD4-4	38.45	38.47	37.20	37.21	38.34	38.30	37.25	37.22	0.01	0.01	1	0	0	0	1	0	0	0
DH-4	38.11	37.83	37.79	37.67	38.11	38.00	37.96	37.86	0.20	0.11	0	1	0	0	1	0	0	0
DA-4-10	38.07	37.83	36.45	36.41	38.19	38.00	36.38	36.29	0.22	0.07	0	1	0	0	1	0	0	0
DB-4-8	38.09	37.94	36.26	36.24	38.02	37.75	36.00	36.00	0.21	0.01	0	1	0	0	1	0	0	0
DF-4-13	38.08	37.94	37.86	37.76	37.87	37.85	37.97	37.92	0.08	0.07	1	0	0	0	1	0	0	0
DC-4-7	38.40	38.24	37.11	37.04	38.24	38.16	37.11	37.03	0.12	0.07	0	1	0	0	1	0	0	0
DD-4-10	38.27	38.21	37.24	37.14	38.31	38.25	37.29	37.20	0.06	0.09	1	0	0	0	1	0	0	0
DC-4-2	38.47	38.92	37.12	36.98	38.30	38.30	37.02	37.03	-0.23	0.07	1	0	0	0	1	0	0	0
DF-4-8	37.94	37.80	38.01	38.02	37.91	37.73	37.96	37.83	0.16	0.06	0	1	0	0	1	0	0	0
DG-4-7	38.13	37.89	37.97	37.74	38.16	37.97	37.91	37.90	0.22	0.12	0	1	0	0	1	0	0	0
DB-5-3	38.47	38.49	36.15	36.12	38.01	37.90	36.37	36.35	0.04	0.02	1	0	0	0	1	0	0	0
D-RG-5	38.38	38.35	37.74	37.80	38.33	38.23	37.83	37.70	0.07	0.04	1	0	0	0	0	1	0	0
DB-5-9	38.23	38.16	36.27	36.18	38.26	37.95	36.10	35.91	0.19	0.14	0	1	0	0	1	0	0	0
DE-5-6	38.29	38.13	37.28	37.18	38.28	38.42	37.48	37.30	0.01	0.14	0	1	0	0	1	0	0	0
DF-5-14	38.03	37.95	37.96	37.75	37.95	37.88	37.88	37.79	0.07	0.15	0	1	0	0	1	0	0	0
DC-5-10	37.18	37.12	38.76	38.66	37.27	37.20	38.39	38.36	0.07	0.07	1	0	0	0	1	0	0	0
DB-5-15	38.31	38.20	36.51	36.38	38.22	38.19	35.80	35.76	0.07	0.08	1	0	0	0	1	0	0	0
DA-5-2	38.71	38.81	35.75	35.99	38.25	38.11	36.41	36.35	0.02	-0.09	1	0	0	0	0	1	0	0
DG-5-9	38.17	38.08	37.64	37.62	38.04	37.97	37.53	37.47	0.08	0.04	1	0	0	0	1	0	0	0
DG-5-2	38.33	38.23	37.60	37.57	38.11	38.05	37.94	37.88	0.08	0.04	1	0	0	0	1	0	0	0
DE-5-11	38.44	38.43	35.88	35.60	38.10	38.06	37.23	37.21	0.02	0.15	0	1	0	0	1	0	0	0
D-5-4	38.25	38.23	37.13	37.07	38.29	38.24	37.10	37.06	0.04	0.05	1	0	0	0	1	0	0	0
DG-6-10	37.97	37.79	37.87	37.81	38.22	38.13	37.79	37.50	0.13	0.17	0	1	0	0	1	0	0	0
DE-6-1	38.39	38.50	37.34	37.34	38.08	38.09	37.49	37.60	-0.06	-0.05	1	0	0	0	1	0	0	0
DD-6-3	38.46	38.38	37.01	36.96	38.17	38.16	37.06	37.00	0.05	0.05	1	0	0	0	1	0	0	0
DF-6-10	37.96	37.87	37.91	37.87	37.84	37.87	37.99	37.86	0.03	0.09	1	0	0	0	1	0	0	0
DG-6-3	38.25	38.25	37.28	37.24	37.93	37.99	37.79	37.72	-0.03	0.05	1	0	0	0	1	0	0	0
DE-6-12	38.17	38.13	37.19	37.23	37.98	38.01	37.32	37.30	0.00	-0.01	1	0	0	0	1	0	0	0
DB-6-2	38.34	38.35	35.93	35.96	38.14	38.07	36.35	36.25	0.03	0.04	1	0	0	0	1	0	0	0
DB-6-6	38.10	38.04	36.27	36.19	38.11	38.07	36.18	35.90	0.05	0.18	0	1	0	0	1	0	0	0
DC-6-15	38.18	38.18	37.05	37.03	38.08	38.05	37.03	36.97	0.02	0.04	1	0	0	0	1	0	0	0
DB-6-14	38.07	37.96	36.50	36.46	38.10	37.99	36.35	36.26	0.11	0.07	0	1	0	0	1	0	0	0
DF-6-18	38.08	38.17	37.78	37.71	38.27	38.15	37.87	37.78	0.02	0.08	1	0	0	0	1	0	0	0
DA-6-8	38.01	37.89	36.37	36.27	37.89	37.64	36.46	36.33	0.18	0.11	0	1	0	0	1	0	0	0

APPENDIX B (Continued)

Specimen ID	Left End (mm)				Right End (mm)				Ave. (mm)		(CWF) Zones (mm)				DCWF			
	Width (Left)	Width (Left)	Height (Left)	Height (Left)	Width (Right)	Width (Right)	Height (Right)	Height (Right)	Width	Height	0.00-0.10	0.11-0.50	0.51-1.00	>1.01	None	Radial	Tang.	Both
DC-7-9	37.96	37.89	37.03	36.96	38.21	38.17	37.00	36.99	0.05	0.04	1	0	0	0	1	0	0	0
DG-7-4	38.09	37.79	37.83	37.89	38.35	38.20	37.75	37.81	0.23	-0.06	0	1	0	0	1	0	0	0
D-RA-7	38.25	38.06	36.80	36.85	38.18	38.00	37.91	37.82	0.18	0.02	0	1	0	0	1	0	0	0
DA-7-9	38.17	38.00	36.48	36.45	38.22	38.10	36.49	36.51	0.15	0.00	0	1	0	0	1	0	0	0
DI-7-3	37.94	37.74	38.36	38.15	37.86	37.75	38.20	38.09	0.15	0.16	0	1	0	0	1	0	0	0
DF-7-16	38.09	37.96	37.95	37.92	38.15	37.85	37.73	37.75	0.22	0.00	0	1	0	0	1	0	0	0
DB-7-12	38.01	38.01	35.94	35.91	38.22	38.23	36.15	36.09	0.00	0.04	1	0	0	0	1	0	0	0
D-RG-7-1	38.17	38.10	37.67	37.54	38.16	38.04	37.60	37.64	0.09	0.05	1	0	0	0	1	0	0	0
DC-7-1	38.52	38.44	36.41	36.30	38.31	38.33	37.13	37.07	0.03	0.09	1	0	0	0	1	0	0	0
DF-7-1	38.42	38.46	37.71	37.54	37.93	37.89	37.88	37.85	0.00	0.10	1	0	0	0	0	1	0	0
D-RG-7-2	38.23	38.11	37.52	37.46	38.21	38.20	37.74	37.66	0.06	0.07	1	0	0	0	0	1	0	0
DA-7-12	36.14	36.02	38.16	38.03	36.25	36.09	38.20	37.96	0.14	0.18	0	1	0	0	1	0	0	0
DE-8-10	38.21	38.12	37.10	37.11	38.05	38.02	37.19	37.21	0.06	-0.02	1	0	0	0	1	0	0	0
DB-8-13	38.14	38.06	36.57	36.44	38.14	37.97	36.40	36.37	0.13	0.08	0	1	0	0	1	0	0	0
DD-8-6	38.14	38.04	37.07	37.03	38.12	38.10	37.10	37.08	0.06	0.03	1	0	0	0	1	0	0	0
DI-8-1	38.25	38.18	37.94	37.76	38.14	38.09	37.96	37.98	0.06	0.08	1	0	0	0	1	0	0	0
DD-8-11	38.32	38.28	37.15	37.10	38.27	38.29	37.30	37.11	0.01	0.12	0	1	0	0	1	0	0	0
DB-8-11	38.13	38.04	36.03	35.98	38.10	37.99	36.32	36.28	0.10	0.05	1	0	0	0	1	0	0	0
DC-8-12	38.16	38.12	36.96	36.96	38.25	38.21	37.08	37.11	0.04	-0.02	1	0	0	0	1	0	0	0
DB-8-1	38.40	38.37	36.01	35.95	38.26	38.12	36.34	36.29	0.09	0.05	1	0	0	0	1	0	0	0
DA-8-5	37.99	37.93	36.49	36.23	38.12	37.99	36.15	36.06	0.09	0.18	0	1	0	0	1	0	0	0
DF-8-15	38.18	37.96	37.83	37.83	38.18	38.12	37.95	37.84	0.14	0.05	0	1	0	0	1	0	0	0
DG-8-8	38.13	37.97	37.92	37.76	38.06	37.90	37.88	37.77	0.16	0.14	0	1	0	0	1	0	0	0
DF-8-5	38.02	37.88	37.89	37.99	37.82	37.74	37.88	37.94	0.11	-0.08	0	1	0	0	1	0	0	0
D-RG-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
DG-9-5	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
DD-9-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
DC-9-8	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
DG-9-1	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
D-RA-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
DB-9-7	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
DA-9-14	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
DH-9-3	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
DF-9-2	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
DA-9-1	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
DF-9-12	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
SP-28-4-1	37.46	37.28	37.64	37.49	37.25	37.69	37.88	37.78	-0.13	0.13	0	1	0	0	1	0	0	0
SP-41-1	37.37	36.92	37.60	37.38	37.76	37.66	37.68	37.41	0.27	0.25	0	1	0	0	1	0	0	0
SP-22-1	37.36	37.15	37.26	37.05	35.50	35.37	37.45	37.29	0.17	0.19	0	1	0	0	1	0	0	0
SP-29-4-1	37.77	37.57	37.83	37.58	38.38	38.32	38.17	38.08	0.13	0.17	0	1	0	0	1	0	0	0
SP-38-1	38.26	38.24	38.30	38.28	37.46	37.66	37.53	37.58	-0.09	-0.02	1	0	0	0	1	0	0	0
SP-9-4-1	37.41	37.25	37.79	37.33	37.36	37.28	37.87	37.67	0.12	0.33	0	1	0	0	1	0	0	0
SP-40-1	37.24	37.12	36.54	36.39	37.16	36.95	36.81	36.75	0.16	0.11	0	1	0	0	1	0	0	0
SP-54-7-1	36.62	36.12	37.79	37.71	37.38	37.30	37.76	37.51	0.29	0.16	0	1	0	0	0	1	0	0
SP-69-1	37.03	36.57	36.57	36.62	37.28	37.02	37.06	37.05	0.36	-0.02	0	1	0	0	1	0	0	0
SP-64-1	36.37	36.10	37.35	37.17	37.21	37.19	37.43	37.57	0.15	0.02	0	1	0	0	1	0	0	0
SP-60-1	37.65	37.40	37.56	36.48	37.89	37.32	37.00	36.70	0.41	0.69	0	0	1	0	1	0	0	0
SP-64-4-1	38.55	38.79	36.82	36.68	38.61	38.59	38.07	38.00	-0.11	0.11	0	1	0	0	0	1	0	0
SP-59-2-3	38.78	38.72	38.05	37.90	38.76	38.73	38.52	38.44	0.05	0.12	0	1	0	0	0	1	0	0
SP-44-3	38.06	38.15	38.61	38.31	38.80	38.86	37.83	37.76	-0.07	0.18	0	1	0	0	0	0	0	1
SP-38-3	37.76	37.48	37.35	37.26	37.85	37.40	37.59	37.78	0.37	-0.05	0	1	0	0	0	1	0	0
SP-70-3	38.76	41.12	38.65	38.37	38.46	40.17	37.74	39.29	-2.04	-0.63	1	0	0	0	0	0	0	1
SP-63-3	38.30	38.35	38.02	37.39	37.55	38.18	38.00	37.82	-0.34	0.41	0	1	0	0	0	1	0	0
SP-18-2-3	37.50	37.11	37.70	37.49	37.48	37.16	37.41	37.23	0.36	0.20	0	1	0	0	0	1	0	0
SP-32-3	37.74	37.74	38.51	38.22	37.50	37.24	37.79	37.83	0.13	0.13	0	1	0	0	0	1	0	0
SP-38-5-3	37.39	37.13	37.30	37.14	37.61	37.26	37.53	37.36	0.31	0.16	0	1	0	0	0	1	0	0
SP-45-2-3	37.53	37.35	38.46	38.36	37.79	37.74	38.21	38.12	0.11	0.10	0	1	0	0	1	0	0	0
SP-5-5-3	37.15	37.31	37.46	36.53	37.31	36.35	37.31	37.48	0.40	0.38	0	1	0	0	0	0	0	1
SP-17-3	36.90	36.60	37.07	36.82	36.86	36.67	36.71	36.37	0.24	0.30	0	1	0	0	1	0	0	0
SP-29-3	38.17	37.99	38.07	37.94	37.62	37.42	37.83	37.70	0.19	0.13	0	1	0	0	1	0	0	0
SP-60-5-6	37.43	37.13	37.28	37.29	37.10	36.65	37.00	36.56	0.38	0.22	0	1	0	0	1	0	0	0
SP-28-6	37.43	37.37	37.84	37.73	37.92	37.57	37.89	37.88	0.21	0.06	0	1	0	0	1	0	0	0
SP-32-4-6	38.27	38.11	37.48	37.38	37.84	37.43	37.50	37.25	0.29	0.17	0	1	0	0	0	1	0	0
SP-17-6	37.18	36.88	36.87	36.55	36.88	35.80	36.81	37.00	0.69	0.07	0	0	1	0	1	0	0	0
SP-5-2-6	37.47	37.82	37.51	36.11	37.49	37.12	37.42	36.52	0.01	1.15	0	0	0	1	0	0	0	1
SP-11-6	37.54	37.40	37.68	37.32	37.41	37.59	37.61	37.38	-0.02	0.29	0	1	0	0	0	1	0	0
SP-16-7-6	38.12	37.26	38.06	38.35	37.71	38.95	37.93	36.88	-0.19	0.38	0	1	0	0	0	0	0	1
SP-41-5-6	36.86	36.63	37.15	36.91	37.52	37.11	37.55	37.20	0.32	0.29	0	1	0	0	0	1	0	0
SP-59-6	38.74	38.69	38.34	38.21	38.75	38.60	37.31	37.25	0.10	0.10	0	1	0	0	0	1	0	0
SP-44-6	38.85	39.81	37.97	37.71	38.78	38.85	37.58	37.35	-0.52	0.24	0	1	0	0	0	0	0	1
SP-13-6	37.35	37.24	37.26	37.21	36.75	36.91	36.88	36.39	-0.02	0.27	0	1	0	0	0	1	0	0
SP-67-6	38.18	38.06	37.46	36.94	38.15	38.01	37.67	37.29	0.13	0.45	0	1	0	0	0	1	0	0
SP-8-5-8	38.19	38.24	37.98	38.01	37.39	37.68	38.14	38.12	-0.17	0.00	1	0	0	0	0	1	0	0
SP-47-8	38.42	38.42	36.99	36.67	38.45	38.04	37.38	36.68	0.21	0.51	0	0	1	0	0	0	0	1
SP-54-4-8	37.47	36.40	37.80	37.72	37.15	36.00	37.91	37.68	1.11	0.15	0	0	0	1	0	1	0	0

APPENDIX B (Continued)

Specimen ID	Left End (mm)				Right End (mm)				Ave. (mm)		(CWF) Zones (mm)				DCWF			
	Width (Left)	Width (Left)	Height (Left)	Height (Left)	Width (Right)	Width (Right)	Height (Right)	Height (Right)	Width	Height	0.00-0.10	0.11-0.50	0.51-1.00	>1.01	None	Radial	Tang.	Both
SP-13-5-8	37.30	37.08	36.80	36.03	37.49	37.55	37.08	36.28	0.08	0.78	0	0	1	0	0	1	0	0
SP-9-8	37.24	37.80	37.44	36.62	36.89	36.16	37.16	37.13	0.09	0.42	0	1	0	0	0	1	0	0
SP-24-8	37.61	37.44	37.54	37.08	37.70	37.30	37.73	37.71	0.29	0.24	0	1	0	0	0	0	0	1
SP-2-2-8	37.20	35.65	37.54	38.65	37.21	37.47	37.47	37.35	0.65	-0.50	0	0	1	0	0	0	0	1
SP-42-8	37.62	36.78	37.64	37.34	37.05	35.80	37.45	36.76	1.05	0.50	0	0	0	1	0	1	0	0
SP-38-8	38.02	37.85	37.86	37.77	38.15	37.97	37.77	37.48	0.18	0.19	0	1	0	0	1	0	0	0
SP-64-8	38.50	38.46	38.29	38.14	38.00	38.78	37.86	37.66	-0.37	0.18	0	1	0	0	0	1	0	0
SP-11-8	37.38	36.63	37.31	37.27	37.19	37.31	37.23	36.88	0.31	0.19	0	1	0	0	0	0	0	1
SP-70-7-8	38.12	38.96	38.50	39.34	38.29	37.98	38.33	39.52	-0.27	-1.02	1	0	0	0	0	0	0	1
SP-9-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
SP-29-7-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
SP-11-7-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
SP-29-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
SP-47-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
SP-24-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
SP-69-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
SP-67-7-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
SP-18-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
SP-36-7-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
SP-62-2-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
W-J-1	39.08	39.09	37.73	37.48	38.66	38.44	37.96	37.87	0.10	0.17	0	1	0	0	1	0	0	0
W-B-1	38.42	37.39	36.81	38.07	37.46	36.79	37.25	37.50	0.85	-0.75	0	0	1	0	1	0	0	0
W-I-1	37.53	38.19	38.13	36.71	36.88	37.39	37.61	37.07	-0.58	0.98	0	0	1	0	1	0	0	0
W-D-1	37.19	37.05	38.15	38.08	36.73	36.60	37.85	37.78	0.13	0.07	0	1	0	0	1	0	0	0
W-E-1	37.47	37.39	37.41	37.30	37.56	37.54	37.12	37.05	0.05	0.09	1	0	0	0	1	0	0	0
W-K-1	38.33	38.15	38.06	38.18	37.62	37.60	37.48	37.43	0.10	-0.04	0	1	0	0	1	0	0	0
W-H-1	38.26	38.04	36.95	36.92	37.71	37.60	37.43	37.35	0.16	0.05	0	1	0	0	0	1	0	0
W-G-1	37.85	37.72	37.50	37.33	37.61	37.58	37.61	37.39	0.08	0.20	0	1	0	0	1	0	0	0
W-F-1	37.78	37.88	38.82	38.65	36.72	36.68	37.77	37.78	-0.03	0.08	0	1	0	0	0	1	0	0
W-L-1	38.00	37.88	39.26	39.31	38.06	37.97	39.26	39.18	0.11	0.01	0	1	0	0	1	0	0	0
W-A-1	37.26	37.17	37.76	37.62	37.69	37.60	37.80	37.70	0.09	0.12	0	1	0	0	1	0	0	0
W-X-1	37.87	37.64	37.02	36.90	38.02	37.96	37.16	36.87	0.15	0.21	0	1	0	0	1	0	0	0
W-I-2	37.02	37.03	37.91	37.91	37.05	36.78	37.98	37.87	0.13	0.05	0	1	0	0	1	0	0	0
W-E-2	37.55	37.44	37.69	37.57	37.50	37.54	37.68	37.48	0.04	0.16	0	1	0	0	1	0	0	0
W-D-2	37.35	37.35	37.79	37.73	37.05	37.13	37.96	37.93	-0.04	0.05	1	0	0	0	1	0	0	0
W-C-2	38.38	38.24	37.88	37.76	38.23	38.14	38.04	37.94	0.11	0.11	0	1	0	0	1	0	0	0
W-J-2	37.90	37.70	39.24	39.22	37.64	37.46	38.72	38.65	0.19	0.05	0	1	0	0	1	0	0	0
W-H-2	36.52	36.35	37.67	37.71	36.47	36.77	37.78	37.48	-0.07	0.13	0	1	0	0	1	0	0	0
W-A-2	36.99	36.86	37.84	37.82	37.44	37.37	37.88	37.75	0.10	0.08	0	1	0	0	1	0	0	0
W-B-2	36.81	36.67	37.81	37.77	36.86	36.74	37.66	37.62	0.13	0.04	0	1	0	0	1	0	0	0
W-K-2	38.32	38.08	38.26	37.98	37.96	37.71	37.53	37.67	0.25	0.07	0	1	0	0	0	1	0	0
W-F-2	37.47	37.63	38.15	38.02	37.26	37.29	37.77	37.78	-0.10	0.06	1	0	0	0	1	0	0	0
W-G-2	37.29	37.14	37.31	37.32	37.22	37.14	37.48	37.43	0.11	0.02	0	1	0	0	1	0	0	0
W-L-2	38.37	38.30	38.98	38.96	37.90	37.93	39.05	38.99	0.02	0.04	1	0	0	0	1	0	0	0
W-A-3	36.94	36.81	38.23	38.11	37.46	37.26	37.96	37.90	0.16	0.09	0	1	0	0	1	0	0	0
W-J-3	38.79	38.53	38.14	37.98	38.87	38.76	38.25	38.15	0.18	0.13	0	1	0	0	1	0	0	0
W-B-3	38.43	38.26	37.88	37.88	37.62	37.43	37.11	36.74	0.18	0.18	0	1	0	0	1	0	0	0
W-H-3	36.93	36.78	37.84	37.70	36.76	36.56	37.80	37.68	0.17	0.13	0	1	0	0	1	0	0	0
W-I-3	37.06	36.89	37.74	37.50	36.75	36.65	38.27	37.98	0.14	0.27	0	1	0	0	0	1	0	0
W-F-3	37.36	37.08	38.02	37.88	37.00	36.83	37.78	37.78	0.23	0.07	0	1	0	0	0	1	0	0
W-G-3	38.28	38.14	36.41	36.42	37.37	37.30	37.31	37.34	0.11	-0.02	0	1	0	0	0	1	0	0
W-X-3	36.80	36.65	38.14	37.96	37.22	37.11	38.14	38.08	0.13	0.12	0	1	0	0	1	0	0	0
W-E-3	37.22	37.02	37.13	37.09	37.04	36.91	37.27	37.42	0.16	-0.05	0	1	0	0	1	0	0	0
W-D-3	37.27	37.49	38.03	37.94	37.18	37.13	39.96	37.94	-0.09	1.06	0	0	0	1	0	1	0	0
W-C-3	38.42	38.35	37.94	37.81	38.52	38.97	37.91	37.80	-0.19	0.12	0	1	0	0	0	1	0	0
W-K-3	37.57	37.39	37.53	37.61	37.78	37.50	37.62	37.47	0.23	0.04	0	1	0	0	1	0	0	0
W-K-4	37.67	37.62	37.40	37.25	37.81	37.78	37.48	37.38	0.04	0.12	0	1	0	0	1	0	0	0
W-C-4	38.26	37.96	37.74	37.65	38.16	37.88	37.94	37.72	0.29	0.16	0	1	0	0	1	0	0	0
W-F-4	37.08	36.96	37.97	37.95	37.01	36.95	37.81	37.56	0.09	0.13	0	1	0	0	1	0	0	0
W-A-4	37.70	37.44	37.72	37.73	36.89	36.85	37.83	37.71	0.15	0.05	0	1	0	0	1	0	0	0
W-J-4	38.92	38.74	38.05	37.97	38.83	38.78	38.28	38.19	0.11	0.09	0	1	0	0	1	0	0	0
W-G-4	37.85	37.61	37.32	37.35	37.72	37.50	37.37	37.30	0.23	0.02	0	1	0	0	1	0	0	0
W-E-4	38.40	38.19	37.31	37.22	37.22	37.16	37.50	37.37	0.14	0.11	0	1	0	0	1	0	0	0
W-H-4	38.11	37.81	36.72	36.75	37.63	37.45	37.06	37.11	0.24	-0.04	0	1	0	0	1	0	0	0
W-I-4	37.67	37.47	37.07	36.78	37.61	37.43	37.22	37.05	0.19	0.23	0	1	0	0	1	0	0	0
W-L-4	38.38	38.17	38.92	38.82	37.88	37.86	39.12	38.91	0.12	0.16	0	1	0	0	1	0	0	0
W-B-4	36.93	36.86	37.65	37.58	36.78	36.67	37.67	37.62	0.09	0.06	0	1	0	0	1	0	0	0
W-D-4	36.99	36.40	37.80	37.93	37.29	37.30	37.90	37.58	0.29	0.09	0	1	0	0	1	0	0	0
W-B-5	37.60	37.40	36.94	36.86	37.58	37.50	36.99	36.89	0.14	0.09	0	1	0	0	0	1	0	0
W-F-5	37.09	36.93	37.83	37.97	37.18	37.12	37.94	37.87	0.11	-0.04	0	1	0	0	0	1	0	0
W-K-5	38.20	37.93	37.08	37.59	37.87	37.91	36.87	37.30	0.12	-0.47	0	1	0	0	0	1	0	0
W-J-5	38.76	38.70	37.97	37.82	38.46	38.27	38.30	38.14	0.12	0.15	0	1	0	0	1	0	0	0
W-H-5	37.76	37.54	37.51	37.44	37.67	37.67	36.83	37.24	0.11	-0.17	0	1	0	0	0	0	0	1
W-G-5	37.64	37.61	37.71	37.66	37.30	37.23	37.26	37.69	0.05	-0.19	1	0	0	0	0	1	0	0
W-L-5	37.80	37.69	39.33	39.24	38.03	37.92	39.33	39.26	0.11	0.08	0	1	0	0	0	1	0	0

APPENDIX B (Continued)

Specimen ID	Left End (mm)				Right End (mm)				Ave. (mm)		(CWF) Zones (mm)				DCWF			
	Width (Left)	Width (Left)	Height (Left)	Height (Left)	Width (Right)	Width (Right)	Height (Right)	Height (Right)	Width	Height	0.00-0.10	0.11-0.50	0.51-1.00	>1.01	None	Radial	Tang.	Both
W-I-5	37.20	37.00	37.93	37.24	36.95	36.86	38.01	37.98	0.15	0.36	0	1	0	0	0	1	0	0
W-A-5	37.11	37.07	38.41	38.27	36.28	36.19	37.71	37.65	0.07	0.10	0	1	0	0	0	1	0	0
W-D-5	36.57	36.63	37.98	37.93	37.22	37.33	37.90	37.86	-0.09	0.04	1	0	0	0	0	0	0	1
W-C-5	38.63	38.63	38.37	38.33	38.71	39.60	37.95	38.09	-0.45	-0.05	1	0	0	0	0	1	0	0
W-E-5	37.27	37.23	37.38	37.29	37.17	37.14	37.24	37.25	0.04	0.04	1	0	0	0	0	1	0	0
W-I-6	37.47	37.52	37.19	37.33	37.35	37.38	37.22	37.21	-0.04	-0.07	1	0	0	0	1	0	0	0
W-E-6	38.05	37.79	37.10	37.13	37.33	37.27	37.26	37.15	0.16	0.04	0	1	0	0	1	0	0	0
W-J-6	38.27	38.10	38.84	38.79	37.48	37.38	38.92	38.83	0.13	0.07	0	1	0	0	1	0	0	0
W-A-6	37.46	37.41	37.55	37.55	36.99	37.12	37.82	37.69	-0.04	0.07	1	0	0	0	0	1	0	0
W-X-6	37.07	36.85	37.73	37.69	36.94	36.86	37.76	37.62	0.15	0.09	0	1	0	0	1	0	0	0
W-K-6	37.41	37.32	37.44	37.40	37.57	37.21	37.55	37.50	0.22	0.04	0	1	0	0	0	1	0	0
W-D-6	37.11	37.09	37.71	37.73	37.37	37.25	37.97	37.80	0.07	0.08	1	0	0	0	0	1	0	0
W-G-6	37.32	37.35	37.60	37.62	37.18	37.15	36.94	36.94	0.00	-0.01	1	0	0	0	0	1	0	0
W-B-6	37.55	37.46	36.94	36.83	37.52	37.38	36.79	36.58	0.11	0.16	0	1	0	0	1	0	0	0
W-C-6	38.74	38.74	38.32	38.16	38.33	38.45	37.68	37.49	-0.06	0.18	0	1	0	0	0	1	0	0
W-F-6	37.62	37.68	38.07	38.07	37.27	37.28	37.90	37.85	-0.04	0.02	1	0	0	0	0	1	0	0
W-H-6	37.41	37.38	36.73	36.71	37.74	37.65	36.72	36.67	0.06	0.03	1	0	0	0	0	1	0	0
W-G-7	38.38	38.54	36.48	36.66	37.23	37.41	37.48	37.55	-0.17	-0.13	1	0	0	0	0	1	0	0
W-D-7-X	36.71	36.47	37.97	37.84	36.74	36.60	37.89	37.74	0.19	0.14	0	1	0	0	0	1	0	0
W-L-7	38.20	38.12	38.56	38.61	37.88	37.80	38.88	39.00	0.08	-0.08	1	0	0	0	0	1	0	0
W-F-7	37.14	38.86	37.94	37.87	37.43	37.40	38.13	38.08	-0.84	0.06	1	0	0	0	0	1	0	0
W-K-7	37.98	38.07	37.75	37.90	37.97	38.73	37.74	37.88	-0.43	-0.15	1	0	0	0	0	0	0	1
W-E-7	37.21	37.48	37.46	37.52	36.98	36.89	37.45	37.37	-0.09	0.01	1	0	0	0	0	0	0	1
W-A-7	36.85	38.28	38.31	37.12	36.84	36.02	37.67	37.57	-0.31	0.65	0	0	1	0	0	0	0	1
W-I-7	Treatment failure														0	1	0	0
W-B-7	38.05	38.15	38.23	38.04	36.83	36.68	37.43	37.30	0.02	0.16	0	1	0	0	0	1	0	0
W-C-7	38.23	38.28	37.75	37.78	37.91	38.18	38.08	37.91	-0.16	0.07	1	0	0	0	0	1	0	0
W-J-7	38.12	37.89	38.55	38.52	37.89	37.78	39.20	39.10	0.17	0.06	0	1	0	0	1	0	0	0
W-H-7	36.60	37.98	38.18	36.39	36.90	36.86	37.70	36.66	-0.67	1.42	0	0	0	1	0	1	0	0
W-J-8	38.80	38.61	37.86	37.70	38.48	38.39	37.98	37.91	0.14	0.11	0	1	0	0	1	0	0	0
W-H-8	37.64	37.51	37.16	37.03	37.66	37.57	36.73	36.56	0.11	0.15	0	1	0	0	0	1	0	0
W-C-8	38.79	39.18	38.17	38.58	38.39	38.22	37.78	37.63	-0.11	-0.13	1	0	0	0	0	1	0	0
W-G-8	37.25	37.35	37.35	37.21	37.14	37.02	37.37	37.20	0.01	0.15	0	1	0	0	0	1	0	0
W-B-8	37.66	37.57	36.90	36.77	37.50	37.30	36.99	36.54	0.15	0.29	0	1	0	0	0	0	0	1
W-E-8	38.00	37.74	37.38	37.38	37.14	37.08	37.34	37.34	0.16	0.00	0	1	0	0	0	1	0	0
W-F-8	37.16	37.07	37.93	37.90	37.18	37.29	37.80	37.81	-0.01	0.01	1	0	0	0	0	1	0	0
W-I-8	36.76	36.80	38.02	37.90	37.03	36.95	37.91	37.79	0.02	0.12	0	1	0	0	0	1	0	0
W-D-8	37.40	37.26	37.84	37.68	37.16	37.04	37.97	37.73	0.13	0.20	0	1	0	0	0	1	0	0
W-A-8	37.39	37.30	37.77	37.62	37.10	36.94	37.78	37.72	0.13	0.11	0	1	0	0	0	1	0	0
W-L-8	38.09	38.34	38.96	39.00	37.94	37.80	38.92	38.98	-0.05	-0.05	1	0	0	0	0	1	0	0
W-K-8	37.90	37.84	37.77	37.65	37.93	37.85	37.78	37.56	0.07	0.17	0	1	0	0	0	1	0	0
W-F-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
W-L-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
W-C-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
W-K-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
W-E-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
W-A-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
W-H-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
W-J-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
W-D-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
W-G-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
W-B-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
W-I-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
YP-I-1	38.09	37.98	38.49	38.40	38.00	37.91	38.53	38.49	0.10	0.07	1	0	0	0	1	0	0	0
YP-K-1	38.04	37.96	37.98	37.92	38.09	38.16	38.37	38.27	0.01	0.08	1	0	0	0	1	0	0	0
YP-J-1	38.05	37.95	38.31	38.21	37.97	37.92	38.25	38.25	0.07	0.05	1	0	0	0	1	0	0	0
YP-F-1	38.06	37.99	38.50	38.43	38.10	38.06	38.58	38.58	0.05	0.04	1	0	0	0	1	0	0	0
YP-B-1	38.11	38.06	38.24	38.15	38.01	37.95	38.45	38.43	0.05	0.06	1	0	0	0	1	0	0	0
YP-D-1	37.92	37.96	38.27	38.18	38.19	38.04	38.58	38.49	0.05	0.09	1	0	0	0	1	0	0	0
YP-E-1	38.13	38.12	38.23	38.14	38.04	37.89	37.50	37.32	0.08	0.13	0	1	0	0	1	0	0	0
YP-A-1	38.03	37.90	38.35	38.29	38.07	37.97	38.62	38.52	0.12	0.08	0	1	0	0	1	0	0	0
YP-C-1	38.17	38.07	38.57	38.52	38.13	38.10	38.52	38.44	0.07	0.07	1	0	0	0	1	0	0	0
YP-H-1	38.13	38.12	38.11	37.95	37.97	37.86	38.46	38.45	0.06	0.08	1	0	0	0	1	0	0	0
YP-L-1	38.16	38.04	38.32	38.27	38.33	38.23	38.39	38.37	0.11	0.04	0	1	0	0	1	0	0	0
YP-G-1	37.90	37.85	38.40	38.25	38.01	37.89	38.38	38.37	0.08	0.08	1	0	0	0	0	1	0	0
YP-J-2	38.33	38.17	38.34	38.38	38.09	38.07	38.20	38.16	0.09	0.00	1	0	0	0	1	0	0	0
YP-D-2	38.01	37.82	38.49	38.50	38.00	37.96	38.59	38.56	0.11	0.01	0	1	0	0	1	0	0	0
YP-C-2	37.82	37.77	38.64	38.53	37.69	37.67	38.47	38.52	0.03	0.03	1	0	0	0	1	0	0	0
YP-L-2	38.32	38.18	38.33	38.32	38.24	38.36	38.20	38.12	0.01	0.05	1	0	0	0	0	1	0	0
YP-E-2	38.20	38.23	38.28	38.20	37.83	37.72	38.54	38.53	0.04	0.04	1	0	0	0	1	0	0	0
YP-K-2	37.88	37.80	38.51	38.46	38.06	37.99	38.56	38.41	0.08	0.10	1	0	0	0	1	0	0	0
YP-A-2	37.97	37.95	38.34	38.28	38.04	37.97	38.50	38.47	0.04	0.05	1	0	0	0	1	0	0	0
YP-B-2	38.00	37.86	38.57	38.53	38.05	37.96	38.49	38.43	0.11	0.05	0	1	0	0	1	0	0	0
YP-H-2	38.06	37.98	38.41	38.36	37.91	37.77	38.41	38.43	0.11	0.01	0	1	0	0	1	0	0	0
YP-G-2	37.84	37.77	38.10	38.00	38.08	37.97	38.38	38.20	0.09	0.14	0	1	0	0	1	0	0	0

APPENDIX B (Continued)

Specimen ID	Left End (mm)				Right End (mm)				Ave. (mm)		(CWF) Zones (mm)				DCWF			
	Width (Left)	Width (Left)	Height (Left)	Height (Left)	Width (Right)	Width (Right)	Height (Right)	Height (Right)	Width	Height	0.00-0.10	0.11-0.50	0.51-1.00	>1.01	None	Radial	Tang.	Both
YP-F-2	37.85	37.76	38.52	38.41	37.91	37.81	38.49	38.44	0.09	0.08	1	0	0	0	1	0	0	0
YP-I-2	38.01	38.05	38.45	38.43	38.07	37.93	38.15	38.46	0.05	-0.15	1	0	0	0	1	0	0	0
YP-D-3	38.71	38.63	38.05	37.83	38.37	38.32	38.13	38.05	0.06	0.15	0	1	0	0	1	0	0	0
YP-L-3	38.29	38.29	38.09	37.84	38.21	38.16	38.00	37.88	0.03	0.18	0	1	0	0	1	0	0	0
YP-E-3	38.00	37.77	38.39	38.37	38.13	37.92	38.21	38.21	0.22	0.01	0	1	0	0	1	0	0	0
YP-J-3	38.15	37.96	38.36	38.39	38.06	37.90	38.40	38.30	0.18	0.04	0	1	0	0	1	0	0	0
YP-B-3	38.38	38.29	38.28	38.18	37.94	37.94	38.53	38.57	0.05	0.03	1	0	0	0	1	0	0	0
YP-C-3	38.22	37.95	38.52	38.42	38.05	38.09	38.39	38.32	0.11	0.09	0	1	0	0	0	1	0	0
YP-K-3	37.04	37.79	37.79	38.53	36.71	37.85	38.29	38.30	-0.94	-0.38	1	0	0	0	1	0	0	0
YP-G-3	37.92	37.99	38.37	38.21	38.33	38.13	38.42	38.36	0.06	0.11	0	1	0	0	0	1	0	0
YP-F-3	38.06	38.15	38.49	38.33	38.11	38.04	38.52	38.47	-0.01	0.11	0	1	0	0	0	1	0	0
YP-I-3	38.55	38.11	38.72	38.58	38.26	38.02	38.54	38.46	0.34	0.11	0	1	0	0	1	0	0	0
YP-A-3	38.09	37.86	38.51	38.45	38.11	38.05	38.45	38.38	0.15	0.06	1	0	0	0	1	0	0	0
YP-H-3	37.92	37.71	38.57	38.38	37.90	37.74	38.48	38.43	0.18	0.12	0	1	0	0	1	0	0	0
YP-I-4	38.10	37.93	38.45	38.37	37.99	38.01	38.28	38.07	0.08	0.15	0	1	0	0	0	1	0	0
YP-A-4	38.19	37.98	38.59	38.49	38.04	37.92	38.57	38.48	0.16	0.10	0	1	0	0	1	0	0	0
YP-D-4	38.45	38.40	38.12	38.00	38.53	38.42	37.94	37.70	0.08	0.18	0	1	0	0	1	0	0	0
YP-C-4	38.15	38.06	38.45	38.35	37.92	37.80	38.43	38.37	0.11	0.08	0	1	0	0	1	0	0	0
YP-H-4	38.28	38.56	38.09	38.00	37.94	37.82	38.43	38.35	-0.08	0.09	1	0	0	0	1	0	0	0
YP-B-4	38.51	38.34	38.11	37.92	38.55	38.50	37.91	37.80	0.11	0.15	0	1	0	0	1	0	0	0
YP-L-4	38.32	38.34	38.07	37.96	38.19	38.12	38.03	37.90	0.02	0.12	0	1	0	0	1	0	0	0
YP-F-4	37.84	37.75	38.43	38.29	38.02	37.92	38.48	38.40	0.10	0.11	0	1	0	0	1	0	0	0
YP-E-4	38.05	38.03	38.38	38.27	37.84	37.68	38.59	38.55	0.09	0.08	1	0	0	0	1	0	0	0
YP-G-4	37.92	37.73	38.30	38.17	37.88	37.73	38.47	38.35	0.17	0.12	0	1	0	0	1	0	0	0
YP-K-4	38.06	37.74	38.49	38.45	37.97	37.79	38.52	38.42	0.25	0.07	0	1	0	0	1	0	0	0
YP-J-4	38.19	37.97	38.23	38.11	38.05	37.84	38.32	38.34	0.21	0.05	0	1	0	0	1	0	0	0
YP-E-5	37.27	37.40	38.47	38.40	37.98	37.91	38.51	38.46	-0.03	0.06	1	0	0	0	1	0	0	0
YP-J-5	38.14	38.25	38.51	38.34	36.68	38.35	38.39	38.19	-0.89	0.18	0	1	0	0	1	0	0	0
YP-H-5	38.05	38.04	38.49	38.50	38.05	37.83	38.40	38.31	0.11	0.04	1	0	0	0	1	0	0	0
YP-A-5	38.27	38.02	38.54	38.50	38.10	37.93	38.39	38.35	0.21	0.04	0	1	0	0	1	0	0	0
YP-L-5	37.89	37.77	38.17	38.13	38.11	38.04	38.27	38.19	0.09	0.06	1	0	0	0	1	0	0	0
YP-F-5	37.99	37.91	38.70	38.56	38.26	38.11	38.65	38.61	0.12	0.09	0	1	0	0	1	0	0	0
YP-G-5	37.84	37.71	38.47	38.35	37.90	37.77	38.31	38.23	0.13	0.10	0	1	0	0	1	0	0	0
YP-I-5	38.11	37.91	38.46	38.30	38.07	37.97	38.56	38.51	0.15	0.11	0	1	0	0	1	0	0	0
YP-K-5	38.03	37.93	38.53	38.54	38.26	38.08	38.51	38.53	0.14	-0.02	1	0	0	0	0	1	0	0
YP-D-5	38.30	38.22	38.25	38.09	38.47	38.33	38.18	37.95	0.11	0.19	0	1	0	0	1	0	0	0
YP-C-5	38.19	38.13	38.69	38.71	38.15	38.09	38.48	38.49	0.06	-0.02	1	0	0	0	1	0	0	0
YP-B-5	38.55	38.57	38.11	38.04	38.58	38.57	38.16	38.02	-0.01	0.10	1	0	0	0	1	0	0	0
YP-F-6	37.95	37.82	38.51	38.44	38.10	38.01	38.56	38.49	0.11	0.07	0	1	0	0	1	0	0	0
YP-K-6	37.72	37.80	38.40	38.30	38.08	37.97	38.43	38.40	0.02	0.07	1	0	0	0	1	0	0	0
YP-I-6	38.04	37.95	38.58	38.46	38.07	37.95	38.52	38.49	0.10	0.07	1	0	0	0	1	0	0	0
YP-A-6	37.91	38.78	38.57	38.52	38.02	37.96	38.41	38.40	-0.41	0.03	1	0	0	0	1	0	0	0
YP-D-6	37.98	37.88	38.43	38.35	38.06	37.96	38.38	38.33	0.10	0.07	1	0	0	0	1	0	0	0
YP-L-6	38.22	38.15	37.82	37.76	38.24	38.19	37.96	38.00	0.06	0.01	1	0	0	0	1	0	0	0
YP-G-6	37.94	37.79	38.43	38.35	38.07	37.95	38.47	38.49	0.13	0.03	0	1	0	0	1	0	0	0
YP-J-6	38.12	37.98	38.33	38.28	37.88	37.83	38.23	38.17	0.10	0.05	1	0	0	0	1	0	0	0
YP-B-6	38.47	38.51	38.11	37.99	38.55	38.54	38.06	38.01	-0.02	0.09	1	0	0	0	1	0	0	0
YP-H-6	37.99	37.92	38.45	38.43	37.79	37.70	38.38	38.40	0.08	0.00	1	0	0	0	1	0	0	0
YP-E-6	38.04	37.93	38.49	38.49	37.87	37.82	38.50	38.48	0.08	0.01	1	0	0	0	1	0	0	0
YP-C-6	38.05	37.97	38.39	38.41	37.99	38.05	38.47	38.38	0.01	0.04	1	0	0	0	0	1	0	0
YP-D-7	38.39	38.41	38.07	37.99	38.45	38.42	38.09	37.93	0.01	0.12	0	1	0	0	1	0	0	0
YP-L-7	38.20	38.13	37.99	37.76	38.27	38.16	38.21	37.95	0.09	0.25	0	1	0	0	1	0	0	0
YP-F-7	37.94	38.10	38.40	38.23	38.15	38.12	38.45	38.26	-0.07	0.18	0	1	0	0	1	0	0	0
YP-G-7	37.81	37.51	38.34	38.19	38.08	37.82	38.43	38.35	0.28	0.12	0	1	0	0	1	0	0	0
YP-J-7	38.09	37.97	38.18	38.28	37.98	37.83	38.61	38.75	0.14	-0.12	0	1	0	0	1	0	0	0
YP-I-7	37.96	37.89	38.41	38.32	38.10	37.88	38.50	38.34	0.15	0.12	0	1	0	0	1	0	0	0
YP-K-7	38.62	38.63	38.10	38.00	38.52	38.72	37.96	37.87	-0.11	0.10	0	1	0	0	1	0	0	0
YP-E-7	38.16	38.02	38.34	38.35	37.92	37.76	38.69	38.70	0.15	-0.01	0	1	0	0	1	0	0	0
YP-C-7	38.04	37.88	38.36	38.20	37.86	37.78	38.40	38.36	0.12	0.10	0	1	0	0	1	0	0	0
YP-B-7	38.19	38.10	38.14	38.07	38.49	38.57	38.09	38.03	0.00	0.07	1	0	0	0	1	0	0	0
YP-H-7	37.81	37.77	38.16	38.01	37.79	37.69	38.45	38.49	0.07	0.05	1	0	0	0	1	0	0	0
YP-A-7	38.03	37.89	38.21	38.19	38.07	37.95	38.48	38.47	0.13	0.02	0	1	0	0	0	1	0	0
YP-J-8	38.10	37.95	38.40	38.34	38.13	38.02	38.36	38.28	0.13	0.07	0	1	0	0	1	0	0	0
YP-L-8	38.25	38.30	37.98	37.93	38.05	37.93	38.03	37.92	0.04	0.08	1	0	0	0	1	0	0	0
YP-B-8	38.41	38.34	38.09	37.97	38.50	38.45	38.04	37.89	0.06	0.14	0	1	0	0	1	0	0	0
YP-A-8	38.10	37.97	38.43	38.37	38.03	37.94	38.54	38.49	0.11	0.05	0	1	0	0	1	0	0	0
YP-K-8	37.89	37.72	38.44	38.38	38.09	38.25	38.40	38.37	0.01	0.04	1	0	0	0	0	0	0	1
YP-F-8	38.03	38.03	38.55	38.48	38.14	38.06	38.41	38.42	0.04	0.03	1	0	0	0	1	0	0	0
YP-C-8	38.15	38.08	38.45	38.43	38.22	38.07	38.56	38.56	0.11	0.01	1	0	0	0	1	0	0	0
YP-G-8	37.92	37.72	38.44	38.41	38.02	37.92	38.49	38.45	0.15	0.04	0	1	0	0	1	0	0	0
YP-I-8	38.07	37.91	38.56	38.49	38.10	37.99	38.38	38.21	0.14	0.12	0	1	0	0	1	0	0	0
YP-E-8	38.05	37.88	38.61	38.51	37.95	37.79	38.53	38.55	0.16	0.04	0	1	0	0	1	0	0	0
YP-D-8	37.58	38.00	38.28	38.25	38.15	37.94	38.46	38.44	-0.11	0.03	1	0	0	0	1	0	0	0
YP-H-8	38.05	37.86	38.45	38.42	37.86	37.72	38.49	38.44	0.16	0.04	0	1	0	0	1	0	0	0
YP-B-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA

APPENDIX B (Continued)

Specimen	Left End (mm)				Right End (mm)				Ave. (mm)		(CWF) Zones (mm)				DCWF			
ID	Width	Width	Height	Height	Width	Width	Height	Height	Width	Height	0.00-	0.11-	0.51-	>1.01				
	(Left)	(Left)	(Left)	(Left)	(Right)	(Right)	(Right)	(Right)			0.10	0.50	1.00		None	Radial	Tang.	Both
YP-J-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
YP-F-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
YP-I-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
YP-A-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
YP-K-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
YP-L-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
YP-D-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
YP-G-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
YP-H-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
YP-E-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA
YP-C-9	C	C	C	C	C	C	C	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA

APPENDIX C - Continuous wood failure (CWF_M) and discontinuous wood failure ($DCWF_M$) data collected during microscopic examination of sections

Slide #	ID	Zone	Filed of view	CWF							DCWF					
				% EW	% LW	# collpased	#tracheids	P	M	B	Torn	Split	B	Tang.	Rad.	B
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
104	DC-1-3	Outer	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
74	DC-1-3	Inner	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
109	DE-1-8	Outer	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	1	0	0	0
			1	0	0	0	0	0	0	0	0	1	0	0	0	0
90	DE-1-8	Inner	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	1	0	1	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
18	DF-2-4	Outer	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	1	0	1	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
9	DF-2-4	Inner	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
75	DD-2-8	Outer	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
88	DD-2-8	Inner	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
71	DC-3-5	Outer	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
20	DC-3-5	Inner	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
121	DG-3-12	Outer	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
127	DG-3-12	Inner	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
94	DB-4-8	Outer	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
23	DB-4-8	Inner	2	0	0	0	0	0	0	0	0	1	0	0	1	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
46	DF-4-8	Outer	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
69	DF-4-8	Inner	2	0	0	0	0	0	0	0	0	0	1	0	1	0
			3	0	0	0	0	0	0	0	0	0	1	0	1	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
89	D-5-4	Outer	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
82	D-5-4	Inner	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
62	DB-5-9	Outer	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3.	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
108	DB-5-9	Inner	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	6.3	0	2	32	0	0	1	1	0	0	0	0	0
41	DA-6-8	Outer	2	7.4	0	3	32	0	0	1	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
3	DA-6-8	Inner	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
16	DG-6-3	Outer	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
63	DG-6-3	Inner	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	1	0	1	0	0
			1	0	0	0	0	0	0	0	0	0	1	0	0	0
49	DG-7-4	Outer	2	0	0	0	0	0	0	0	0	0	1	0	0	0
			3	0	0	0	0	0	0	0	0	0	1	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
81	DG-7-4	Inner	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
95	DC-7-9	Outer	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
123	DC-7-9	Inner	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX C (Continued)

Slide #	ID	Zone	Filed of view	CWF							DCWF					
				% EW	% LW	# collpased	#tracheids	P	M	B	Torn	Split	B	Tang.	Rad.	B
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
17	DC-8-12	Outer	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
11	DC-8-12	Inner	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
78	DI-8-1	Outer	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
116	DI-8-1	Inner	2	5.6	0	5	90	1	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
2	DG-9-5	Outer	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
14	DG-9-5	Inner	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	1	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
113	DC-9-8	Outer	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
21	DC-9-8	Inner	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
38	YP-D-1	Outer	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
7	YP-D-1	Inner	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
80	YP-H-1	Outer	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
96	YP-H-1	Inner	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
99	YP-D-2	Outer	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
10	YP-D-2	Inner	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
35	YP-H-2	Outer	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
77	YP-H-2	Inner	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
13	YP-D-3	Outer	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
57	YP-D-3	Inner	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
76	YP-H-3	Outer	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
98	YP-H-3	Inner	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
28	YP-D-4	Outer	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
42	YP-D-4	Inner	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
32	YP-H-4	Outer	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
34	YP-H-4	Inner	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
37	YP-D-5	Outer	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
15	YP-D-5	Inner	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
26	YP-H-5	Outer	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
30	YP-H-5	Inner	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0

APPENDIX C (Continued)

Slide #	ID	Zone	Filed of view	CWF							DCWF					
				% EW	% LW	# collpased	#tracheids	P	M	B	Torn	Split	B	Tang.	Rad.	B
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
22	YP-D-6	Outer	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
27	YP-D-6	Inner	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
55	YP-H-6	Outer	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
93	YP-H-6	Inner	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
29	YP-D-7	Outer	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
111	YP-D-7	Inner	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
60	YP-H-7	Outer	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
73	YP-H-7	Inner	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
117	YP-D-8	Outer	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
115	YP-D-8	Inner	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
119	YP-H-8	Outer	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
120	YP-H-8	Inner	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
68	YP-D-9	Outer	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
6	YP-D-9	Inner	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
24	YP-H-9	Outer	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
110	YP-H-9	Inner	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
84	WRC -D-1	Outer	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
51	WRC-D-1	Inner	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
112	WRC-H-1	Outer	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
5	WRC-H-1	Inner	2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
106	WRC-D-2	Outer	2	16.67	0	10	60	0	0	1	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
66	WRC-D-2	Inner	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
25	WRC-H-2	Outer	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
36	WRC-H-2	Inner	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	1	0	1	0
118	WRC-D-3	Outer	2	0	0	0	0	0	0	0	0	0	1	0	1	0
			3	0	0	0	0	0	0	0	0	0	1	0	1	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
128	WRC-D-3	Inner	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	1	0	0	0	0	0
40	WRC-H-3	Outer	2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
			1	0	0	0	0	0	0	0	0	0	0	0	0	0
58	WRC-H-3	Inner	2	0	0	0	0	0	0	0	0	0	1	0	1	0
			3	0	0	0	0	0	0	0	0	0	1	0	1	0

APPENDIX C (Continued)

Slide #	ID	Zone	Filed of view	CWF							DCWF					
				% EW	% LW	# collpased	#tracheids	P	M	B	Torn	Split	B	Tang.	Rad.	B
45	WRC-D-4	Outer	1	0	0	0	0	0	0	0	1	0	0	0	0	0
			2	37.8	0	8	26	0	0	1	0	0	0	0	0	0
			3	50.0	0	9	18	0	0	1	1	0	0	0	0	0
125	WRC-D-4	Inner	1	0	0	0	0	1	0	0	0	0	0	0	0	0
			2	50.0	0	8	16	1	0	0	0	0	0	0	0	0
			3	60.0	0	12	20	1	0	0	0	0	0	0	0	0
61	WRC-H-4	Outer	1	0	0	0	0	0	0	1	1	0	0	0	0	0
			2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
12	WRC-H-4	Inner	1	20.4	0	10	49	0	0	1	1	0	0	0	0	0
			2	23.4	0	11	47	0	0	1	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
43	WRC-D-5	Outer	1	0	0	0	0	0	0	0	1	0	0	0	0	0
			2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
64	WRC-D-5	Inner	1	0	0	0	0	0	0	0	1	0	0	0	0	0
			2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
19	WRC-H-5	Outer	1	0	0	0	0	0	0	0	1	0	0	0	0	0
			2	0	0	0	0	0	0	0	0	0	1	0	1	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
126	WRC-H-5	Inner	1	0	0	0	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
114	WRC-D-6	Outer	1	0	0	0	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	1	0	0	0	0	0	0	0	0
100	WRC-D-6	Inner	1	0	0	0	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
103	WRC-H-6	Outer	1	0	0	0	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	0	0	0	1	0	0	0	0	0	0
			3	37.5	0	6	16	0	0	0	0	0	0	0	0	0
70	WRC-H-6	Inner	1	0	0	0	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	1	0	0	0	0	0	0	0	0
48	WRC-D-7	Outer	1	0	0	0	0	0	0	0	0	1	0	0	1	0
			2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
8	WRC-D-7	Inner	1	0	0	0	0	0	0	0	1	1	0	0	1	0
			2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	1	0	0	1	0
31	WRC-H-7	Outer	1	0	0	0	0	0	0	0	1	0	0	0	0	0
			2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
72	WRC-H-7	Inner	1	0	0	0	0	0	0	0	0	0	1	0	1	0
			2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	1	0	0	0
101	WRC-D-8	Outer	1	0	0	0	0	0	0	1	1	0	0	0	0	0
			2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
87	WRC-D-8	Inner	1	75.0	0	15	20	1	0	0	1	0	0	0	0	0
			2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	50.0	0	10	20	1	0	0	1	0	0	0	0	0
53	WRC-H-8	Outer	1	0	0	0	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
91	WRC-H-8	Inner	1	0	0	0	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0	0	0	0
97	WRC-D-9	Outer	1	0	0	0	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	0	0	0	0	0	1	0	0	1	0
			3	0	0	0	0	0	0	0	0	1	0	0	1	0
122	WRC-D-9	Inner	1	0	0	0	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
4	WRC-H-9	Outer	1	0	0	0	0	0	0	0	1	0	0	0	0	0
			2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	1	0	0	1	0	0	0	0	0
33	WRC-H-9	Inner	1	0	0	0	0	0	0	1	1	0	0	0	0	0
			2	0	0	0	0	0	0	1	1	0	0	0	0	0
			3	0	0	0	0	0	0	1	1	0	0	0	0	0
85	SP-54-7-(1)	Outer	1	0	0	0	0	0	0	0	1	0	0	0	0	0
			2	50.0	0	7	14	1	0	0	0	1	0	1	0	0
			3	50.0	0	7	14	0	0	1	0	1	0	1	0	0
79	SP-54-7-(1)	Inner	1	0	0	0	0	0	0	0	1	0	0	0	0	0
			2	0	0	0	0	1	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
44	SP-29-4(1)	Outer	1													
			2													
			3													
47	SP-29-4(1)	Inner	1	0	0	0	0	0	0	0	1	0	0	0	0	0
			2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0

APPENDIX C (Continued)

Slide #	ID	Zone	Filed of	CWF							DCWF					
			view	% EW	% LW	# collpased	#tracheids	P	M	B	Torn	Split	B	Tang.	Rad.	B
83	SP-70-3	Outer	1	18.8	0	6	32	0	0	1	0	0	0	0	0	0
			2	18.8	0	6	32	0	0	1	1	0	0	0	0	0
			3	13.3	0	4	30	0	0	1	0	0	0	0	0	0
92	SP-70-3	Inner	1	0	0	0	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
102	SP-38-5(3)	Outer	1	0	0	0	0	0	0	1	1	0	0	0	0	0
			2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	1	1	0	0	0	0	0
59	SP-38-5(3)	Inner	1	0	0	0	0	0	0	0	1	0	0	0	0	0
			2	0	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
52	SP-17-6	Outer	1	0	0	0	0	0	0	0	1	0	0	0	0	0
			2	0	0	0	0	0	0	1	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
107	SP-17-6	Inner	1	0	0	0	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
54	SP-41-5(6)	Outer	1	0	0	0	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
56	SP-41-5(6)	Inner	1	0	0	0	0	0	0	0	1	0	0	0	0	0
			2	0	0	0	0	0	0	0	0	0	1	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
39	SP-13-5(8)	Outer	1	0	0	0	0	0	0	0	1	0	0	0	0	0
			2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
65	SP-13-5(8)	Inner	1	100.0	0	26	26	1	0	0	1	0	0	0	0	0
			2	28.6	0	8	28	0	0	1	1	0	0	0	0	0
			3	13.3	0	4	30	0	0	1	1	0	0	0	0	0
1	SP-42-8	Outer	1	0	0	0	0	0	0	0	1	0	0	0	0	0
			2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
105	SP-42-8	Inner	1	0	0	0	0	0	0	0	0	1	0	1	0	0
			2	30.3	0	10	33	1	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
124	SP-29-9	Outer	1	0	0	0	0	0	0	0	1	0	0	0	0	0
			2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
67	SP-29-9	Inner	1	0	0	0	0	0	0	0	1	0	0	0	0	0
			2	0	0	0	0	0	0	0	1	0	0	0	0	0
			3	0	0	0	0	0	0	0	1	0	0	0	0	0
50	SP-67-7(9)	Outer	1	0	0	0	0	0	0	0	1	0	0	1	0	0
			2	0	0	0	0	0	0	0	1	0	0	1	0	0
			3	0	0	0	0	0	0	0	1	0	0	1	0	0
86	SP-67-7(9)	Inner	1	0	0	0	0	0	0	0	1	0	0	1	0	0
			2	0	0	0	0	0	0	0	1	0	0	1	0	0
			3	0	0	0	0	0	0	0	1	0	0	1	0	0

APPENDIX C (Continued)

Slide #	ID	Description
		1 small tear hole
104	DC-1-3	Diagonal tearing
		Diagonal tearing
74	DC-1-3	
		2 tear holes in Ew
		Excellent view
109	DE-1-8	Excellent view
		Diagonal knife mark may have caused knife split
		Small radial splits
90	DE-1-8	
		1 small radial split, 1 tear hole
		Diagonal knife mark
18	DF-2-4	Major tearing half way into EW
		Slight tearing, small radial splits
9	DF-2-4	Small amount of tearing
		Small tangential tear in center of EW
75	DD-2-8	
88	DD-2-8	1 small tear hole in EW.
		Very large growth rings
71	DC-3-5	Large hole at half the distance into the EW
		Large diagonal tear
		Very lage growth rings
20	DC-3-5	
		Tearing from knife marks
121	DG-3-12	Localized tearing at EW/LW boundary
		Small amount of tearing from knife marks
		View shows some torn cells
127	DG-3-12	View shows some torn cells
		View showed a small amount of torn cells
94	DB-4-8	1 tear hole, false collapse from diagonal knife mark
		3 to 4 small tear holes at diagonal knife marks
		EW/LW separation
23	DB-4-8	Split along ray near edge
		Diagonal knife marks caused tearing
		Diagonal tearing from knife
46	DF-4-8	Diagonal tearing form knife
		3 small tear holes, diagonal knife marks
69	DF-4-8	2 radial plits, 1 small tear hole
		1 split in same ray in 2 EW sections, 4 tear holes
89	D-5-4	
		two small tear holes in EW
		1 small tear home one half into EW
82	D-5-4	
		Torn form diagonal knife mark
62	DB-5-9	Torn form diagonal knife mark
		1 large tear hole
		Scattered tear holes throughout EW
108	DB-5-9	Scattered tear holes throughout EW
		Scattered tear holes throughout EW
		Line of collapse 2 cells in width
41	DA-6-8	Line of collapse 3 cells in width
		Tear holes in EW
3	DA-6-8	3 tear holes in EW
		Slight tearing througout EW
16	DG-6-3	Slight tearing througout EW
		Slight tearing througout EW
		Slight tearing througout EW
63	DG-6-3	2 tear holes half way into Ew
		Split along ray in two consecutive growth rings
		Some tangential tearing
49	DG-7-4	Localized tearing and splitting resembling collapse
		Localized tearing and splitting resembling collapse
		Collapse seems to be spotty, may be a function of knife
81	DG-7-4	
		4 small tear holes in EW
95	DC-7-9	
123	DC-7-9	

APPENDIX C (Continued)

Slide #	ID	Description
		Very large growth rings
17	DC-8-12	
		2 holes half way into EW
11	DC-8-12	1 hole at same distatnce as above view
		2 holes half way into EW
		Slight tearing half way into the EW
78	DI-8-1	Diagonal tearing
		Large growth rings, some tear holes half way into EW
116	DI-8-1	Small amount of localized collpase 30 cells in length
		Large growth rings, sever collpase throughout EW
		Small tear holes in center of Ew
2	DG-9-5	Small tear holes in center of Ew
		Severe tearing in Ew
		1 small tear hole
14	DG-9-5	1 small tear hole
		Radial line of severe tearing
113	DC-9-8	1 small tear hole
21	DC-9-8	
38	YP-D-1	
7	YP-D-1	
80	YP-H-1	2 small tear holes, some vessel tearing
		some vessel tearing
96	YP-H-1	
99	YP-D-2	
		Tearing at ring boundary
		2 tear holes, some vessels tearing
10	YP-D-2	some vessel tearing
		some vessel tearing
35	YP-H-2	Some tear holes and vessel tearing
		some vessel tearing
77	YP-H-2	some vessel tearing
		some vessel tearing, 1 large tear hole.
13	YP-D-3	Severe tearing near edge and corner
		1 small tear hole
		1 tear hole
57	YP-D-3	
76	YP-H-3	
		Some vessel tearing
98	YP-H-3	
		1 small tear hole
28	YP-D-4	
42	YP-D-4	
		some vessel tearing
32	YP-H-4	some vessel tearing
		some vessel tearing
34	YP-H-4	
		Vessel tearing
37	YP-D-5	
		2 small tear holes
15	YP-D-5	Severe tearing near corner
		Small tear holes
26	YP-H-5	Small tear holes
		Vessel tearing
		Small tear holes at vessels
30	YP-H-5	Small tear holes at vessels
		Small tear holes at vessels

APPENDIX C (Continued)

Slide #	ID	Description
22	YP-D-6	Some vessel tearing
		1 small tear hole
27	YP-D-6	Some vessel tearing, very small, 1 to 3 vessels
		Some vessel tearing, very small, 1 to 3 vessels
55	YP-H-6	
		4 tear holes
		Severe tearing
93	YP-H-6	1 tear hole, some vessel tearing
		1 tear hole, some vessel tearing
		some vessel tearing
29	YP-D-7	
		1 small tear hole
		2 small tear holes
111	YP-D-7	
		Some torn vessels
		Some torn vessels
60	YP-H-7	
		Diagonal knife marks resembling collapse.
		Small tear holes at vessels
73	YP-H-7	Some vessel tearing
		Some vessel tearing
		1 small tear hole
117	YP-D-8	
		some vessel tearing
		2 small tear holes, some vessel tearing
115	YP-D-8	1 large tear hole
		some vessel tearing
		some vessel tearing
119	YP-H-8	Tearing, no collapse because rays are still straight
		Some tear holes
		tearing near edge, some small tear holes at vessels
120	YP-H-8	some vessel tearing
		Some large tear holes near edge
		some vessel tearing
68	YP-D-9	
6	YP-D-9	1 small tear hole and some vessel tearing
24	YP-H-9	Small tear holes at vessels
		Small tear holes
110	YP-H-9	
		3 small tear holes
84	WRC -D-1	Diagonal tear marks
		Diagonal tear marks
		Diagonal tear marks
51	WRC-D-1	Diagonal tear marks
		Diagonal tear marks
		Diagonal tear marks
112	WRC-H-1	
5	WRC-H-1	Diagonal knife marks
		Diagonal knife marks
		Diagonal knife marks
106	WRC-D-2	1 large tear hole
		small lime of collapse and tearing
66	WRC-D-2	2 large tear holes
		1 small tear hole
25	WRC-H-2	1 small tear hole
		2 small tear holes, diagonal knife marks
		1 tear hole
36	WRC-H-2	1 tear hole, diagonal knife marks
		1 large tear hole, 3 small tear holes
		2 small tear hole
118	WRC-D-3	Severe teartring and splitting
		Severe tearing and splitting
		Severe tearing and splitting
128	WRC-D-3	Diagonal knife marks, EW/LW separtaions
		Diagonal knife marks, EW/LW separtaions
		EW/LW separations. Some tear holes
40	WRC-H-3	1 tear hole
		3 small tear holes
		3 tear holes
58	WRC-H-3	
		Small radial splits and 3 to 5 tear holes
		3 tear holes, 2 small radial splits

APPENDIX C (Continued)

Slide #	ID	Description
45	WRC-D-4	Slight tearing
		Collapse appears in ring - one half into
		Collapse appeard in all rings
125	WRC-D-4	Appears to be some slight collapse in some growth rings
		Lines of slight collapse, not difinitive
61	WRC-H-4	Collapse in all rings, EW, ranging in width
		No visible collaspe, 3 large tear holes
		Tear holes may be causing collapse
12	WRC-H-4	Thin lines of collapse, some tear holes
		Thin lines of collapse, some tear holes
		2 tear holes
43	WRC-D-5	1 small tear hole
		1 tear hole at EW/LW boundary
		Some tearing from edges
64	WRC-D-5	1 tear hole, diagonal knife marks
		3 tear holes, diagonal knife marks
		3 tear holes, diagonal knife marks
19	WRC-H-5	1 large tear hole
		Large tear/split in radial direction
		1 large tear hole
126	WRC-H-5	
		Diagonal knife marks causing collapse
		4 tear holes, diagonal knife marks
114	WRC-D-6	
		Spotty areas similar to tear holes
		1-10 cell band of slight collapse
100	WRC-D-6	
103	WRC-H-6	
		In 3 rings some bands of collapse
		Long knife mark resembling collapse
70	WRC-H-6	Diagonal knife marks
		Diagonal knife marks
		Tracheids 5-10, long band about 35 cells long.
48	WRC-D-7	Small split along ray
		Diagonal knife marks
		3 small tear holes
8	WRC-D-7	Radially tearing and splitting
		Radially tearing and splitting
31	WRC-H-7	Slight tearing in Ew
		Diagonal knife marks
72	WRC-H-7	Section radially split and torn along ray cells
		Crushed line resembling collapse in EW
		Section radially split and torn along ray cells
101	WRC-D-8	Collapse about 3 to 5 cells in width, some tearing near collapse
		Severe tearing along EW
		Severe tearing along EW
87	WRC-D-8	All rings show collapse, area of tear holes - lin\e of collapse
		Appears to be collapse, but not distinctive like previous view
		Slightly visible collapse lines, some tearing
53	WRC-H-8	
		Diagonal knife marks causing collapse
91	WRC-H-8	
		2 tear holes in EW
97	WRC-D-9	
		Small splits along 3 to 4 rays
		Small splits along 3 to 4 rays
122	WRC-D-9	
		1 tear hole
4	WRC-H-9	
		2 rings show slightly collapse lines
33	WRC-H-9	Lines of collpase on outer rings. Severe tearing as well
		Pockets of collapse and some tearing
		Pockets of collapse and some tearing
85	SP-54-7-(1)	Tear holes in EW
		Clean radial split, collpse near edge
		Clean radial split, collpse near edge
79	SP-54-7-(1)	2 small tear holes
		1 small tear hole
		1 small tear hole
44	SP-29-4(1)	Could not section
		Could not section
		Could not section
47	SP-29-4(1)	Radial tears, EW/LW separations
		Some radial tearing, large tear hole at EW/LW boundary
		1 radial tear, 2 small tear holes

APPENDIX C (Continued)

Slide #	ID	Description
83	SP-70-3	Long tangential line of collapse
		Spotty collapse, 1 tear hole
		Line of collpase at center of EW
92	SP-70-3	Tracheids appear collapsed, radial
		1 small tear hole, diagonal knife marks
		Multiple tears and holes
102	SP-38-5(3)	Spotty collpase and numerous tear
		Small tear holes
		Spotty collapse, 2 small tear hole
59	SP-38-5(3)	1 small tear hole
		Diagonal knife marks
		Multiple tear holes
52	SP-17-6	2 tear holes
		1 tear hole
107	SP-17-6	
		Large tear hole near edge of section
		1 small tear hole
54	SP-41-5(6)	
		2 tear holes, diagonal knife marks
		2 small tear holes, diagonal knife marks
56	SP-41-5(6)	4 tears holes
		1 radial split along ray
		3 tear holes
39	SP-13-5(8)	Diagonal tearing creating collapse
		Tear holes in EW
		Diagonal tearing creating collapse
65	SP-13-5(8)	Located in Ew
		Line of cells radially across EW
		Tearing and collapse present
1	SP-42-8	Severe tear holes
		Diagonal tearing
		Multiple tear holes throughout EW and LW
105	SP-42-8	Entire section is split
		Entire edge is collpased
		3 tear holes
124	SP-29-9	Multiple tear holes
		Multiple tear holes
		3 tear holes
67	SP-29-9	Multiple tear holes
		Multiple tear holes
		Multiple tear holes
50	SP-67-7(9)	2 radial tears, 3 tear holes
		Multiple radial tears
		2 radial tears, 1 small tear hole
86	SP-67-7(9)	Large radial tear, small tear holes
		Large radial tear, small tear holes
		Large radial tear hole

APPENDIX D - Pre-treatment data and modulus of rupture(MOR), modulus of elasticity (MOE), work to maximum load (WML), moisture content and specific gravity.

Sample	ID	Measurements before treatment						Bending Properties			MC and SG blocks				MC	SG	
#		Wt. (g)	Length (mm)	Ring Angle	%HW	# GR	Pos	MOR (Pa)	MOE (Pa)	WML ($N*m/m^3$)	Intl Wt.(g)	Intl Wt. of H_2O(g)	OD Wt.(g)	OD Wt. of H_2O(g)		Wet	Dry
1	DE-1-8	574.18	578	7	100	13	T4	01.13E+08	1.39E+10	8006.13	26.48	11.11	23.94	12.40	10.61	0.64	0.66
2	DF-1-11	429.26	576	5	80	17	T2	80.74E+06	1.14E+10	3896.48	20.78	18.44	18.61	18.34	11.66	0.47	0.50
3	DC-1-3	493.58	578	22	100	7	T2	84.78E+06	1.04E+10	3971.41	20.00	12.99	18.05	13.40	10.80	0.55	0.57
4	D-RG-1	369.57	578	20	50	23	T4	67.78E+06	9.21E+09	2641.14	17.50	21.70	15.82	21.83	10.62	0.40	0.42
5	DB-1-4	374.80	578	13	25	10	T1	74.62E+06	9.99E+09	3215.17							
6	DG1-6	351.02	579	0	40	25	T2	67.93E+06	8.88E+09	3545.80	16.64	22.33	15.04	22.26	10.64	0.39	0.40
7	DC-1-13	486.58	578	32	100	6	T1	85.11E+06	8.69E+09	6170.76	21.64	14.20	19.39	15.20	11.60	0.54	0.56
8	DA-1-6	439.48	578	41	100	14	T4	70.04E+06	8.11E+09	4025.44	19.96	15.80	17.89	16.34	11.57	0.50	0.52
9	DF-1-17	427.95	578	0	50	17	B5	82.59E+06	1.12E+10	4256.48	18.88	16.77	17.03	16.85	10.86	0.48	0.50
10	DH-1	537.65	578	8	100	30	T3	01.07E+08	1.52E+10	6195.32	26.88	14.81	24.31	14.82	10.57	0.58	0.62
11	DA-1-15	443.49	579	31	100	16	T4	72.76E+06	8.58E+09	4881.61	20.71	16.97	18.70	17.43	10.75	0.50	0.52
12	DD-1-7	512.23	578	17	100	7	T2	77.22E+06	8.83E+09	3026.20	24.33	14.30	21.99	15.54	10.64	0.57	0.59
13	DC-2-11	491.07	578	45	100	6	B2	76.25E+06	8.89E+09	3560.25	25.36	17.14	22.81	17.99	11.18	0.54	0.56
14	DA-2-13	499.06	580	33	100	15	T9	93.90E+06	1.52E+10	4240.12	23.97	14.35	21.67	14.57	10.61	0.57	0.60
15	DF-2-4	417.06	579	7	25	21	B3	76.02E+06	1.24E+10	3703.29	18.10	17.60	16.34	17.48	10.77	0.46	0.48
16	DH-2-2	553.37	578	14	100	22	T6	01.21E+08	1.86E+10	5397.17	25.92	13.05	23.46	12.78	10.49	0.60	0.65
17	DG-2-11	359.46	579	0	50	24	B5	73.12E+06	1.01E+10	3249.31	16.95	21.85	15.45	21.93	9.71	0.40	0.41
18	DH-2	561.55	578	10	100	21	B5	01.15E+08	1.88E+10	6494.77	25.74	12.25	23.35	12.17	10.24	0.61	0.66
19	DB-2-10	402.27	580	15	40	9	B4	67.35E+06	9.40E+09	2251.63	16.59	16.65	15.14	16.85	9.58	0.46	0.47
20	DF-2-3	426.23	579	16	40	22	B1	55.46E+06	1.08E+10	2533.73	19.61	18.43	17.78	18.58	10.29	0.47	0.49
21	DD-2-12	533.42	579	38	100	9	T7	71.59E+06	9.48E+09	2168.98	24.86	13.82	22.28	14.93	11.58	0.58	0.60
22	DC-2-6	522.91	578	24	100	6	T6	79.19E+06	9.30E+09	3072.92	23.69	12.89	21.41	13.81	10.65	0.59	0.61
23	DA-2-7	498.81	579	35	100	15	T9	89.96E+06	1.37E+10	4422.12	22.48	13.21	20.31	13.32	10.68	0.57	0.60
24	DD-2-8	503.68	578	27	100	6	B1	66.62E+06	8.37E+09	2018.18	23.33	14.67	21.09	15.95	10.62	0.56	0.57
25	DD-3-2	534.76	578	18	100	7	T3	80.82E+06	8.64E+09	3374.17	21.95	10.94	19.77	12.07	11.03	0.60	0.62
26	DE-3-3	560.13	577	9	100	11	T3	01.22E+08	1.43E+10	7677.60	25.48	12.10	23.10	12.54	10.30	0.61	0.65
27	DC-3-14	483.91	578	45	100	5	T5	73.89E+06	8.89E+09	3013.87	20.94	14.49	18.78	15.10	11.50	0.53	0.55
28	DG-3-12	364.57	578	0	75	23	T1	66.71E+06	1.10E+10	2971.56	19.34	24.38	17.51	24.29	10.45	0.40	0.42
29	DI-3-2	454.25	578	43	100	10	T1	63.78E+06	1.34E+10	1128.10	19.90	16.81	17.98	16.80	10.68	0.49	0.52
30	DB-3-5	378.02	577	0	10	9	B2	72.37E+06	8.86E+09	3664.27	16.11	17.55	14.46	17.96	11.41	0.43	0.45
31	DA-3-11	473.13	578	41	100	15	T2	77.55E+06	1.20E+10	4584.01	21.24	14.79	18.92	15.29	12.26	0.53	0.55
32	D-RG-3	340.38	578	6	15	31	T5	43.39E+06	9.22E+09	945.25	16.20	23.29	14.76	23.41	9.76	0.37	0.39
33	DE-3-7	579.77	578	15	100	15	T2	01.24E+08	1.71E+10	6292.65	26.39	10.96	23.92	11.51	10.33	0.64	0.68
34	DF-3-6	447.86	578	15	100	20	T4	89.00E+06	1.21E+10	4520.56	19.41	15.56	17.51	15.99	10.85	0.50	0.52
35	DC-3-5	512.12	577	37	100	6	B3	92.06E+06	1.28E+10	4583.21	23.05	13.56	20.75	14.58	11.08	0.57	0.59
36	DH-3-1	543.45	577	20	100	23	B3	01.10E+08	1.87E+10	5199.36	27.33	14.07	24.76	14.00	10.38	0.60	0.64
37	DE4-9	567.60	579	15	100	14	B1	01.19E+08	1.38E+10	7373.19	23.93	10.51	21.75	11.11	10.02	0.63	0.66
38	DA-4-3	434.49	578	37	100	14	B4	74.52E+06	8.70E+09	3883.56	19.29	15.92	17.48	16.43	10.35	0.50	0.52
39	DD4-4	525.25	578	0	100	5	B5	90.76E+06	9.16E+09	4424.84	23.19	11.79	20.93	13.01	10.80	0.60	0.62
40	DH-4	551.19	577	10	100	21	T7	01.17E+08	1.76E+10	6860.41	23.03	11.67	20.87	11.82	10.35	0.60	0.64
41	DA-4-10	506.14	578	38	50	15	T10	87.90E+06	1.47E+10	4492.23	21.90	13.04	19.81	13.10	10.55	0.57	0.60
42	DB-4-8	377.01	579	17	20	9	T9	69.17E+06	9.38E+09	2363.47	18.14	20.14	16.38	20.33	10.74	0.43	0.45
43	DF-4-13	423.64	579	14	100	17	B3	82.33E+06	1.25E+10	4279.89	17.65	17.11	15.91	16.98	10.94	0.46	0.48
44	DC-4-7	507.49	577	42	100	6	B3	81.11E+06	8.79E+09	4660.28	23.35	14.05	20.89	14.82	11.78	0.56	0.58
45	DD-4-10	514.93	578	14	100	6	T10	74.44E+06	8.87E+09	2514.48	22.97	13.45	20.82	14.64	10.33	0.57	0.59
46	DC-4-2	497.04	577	35	100	6	B5	75.64E+06	8.91E+09	3031.23	21.16	13.44	19.07	14.02	10.96	0.55	0.58
47	DF-4-8	422.81	578	12	100	19	B1	78.66E+06	1.20E+10	5480.42	22.96	21.55	20.56	21.51	11.67	0.46	0.49
48	DG-4-7	392.48	578	10	40	27	T6	68.04E+06	9.04E+09	3099.90	16.09	21.20	14.56	21.36	10.51	0.39	0.41
49	DB-5-3	368.33	577	22	25	10	B4	68.94E+06	9.24E+09	2808.32	16.55	18.41	14.87	19.00	11.30	0.43	0.44
50	D-RG-5	357.07	577	0	40	27	T3	64.45E+06	9.49E+09	2338.67	16.09	20.75	14.55	20.92	10.58	0.39	0.41
51	DB-5-9	375.78	577	25	50	11	B1	71.10E+06	1.02E+10	2523.50	17.20	19.26	15.50	19.64	10.97	0.43	0.44
52	DE-5-6	563.31	577	10	100	11	T2	01.20E+08	1.22E+10	8631.78	26.09	11.64	23.56	12.62	10.74	0.62	0.65
53	DF-5-14	437.09	578	12	100	18	T1	82.43E+06	1.35E+10	2769.22	20.22	17.57	18.19	17.66	11.16	0.48	0.51
54	DC-5-10	494.81	577	39	100	. 6	T3	85.11E+06	9.55E+09	5040.10	20.28	12.90	18.17	13.60	11.61	0.55	0.57
55	DB-5-15	387.55	578	19	25	11	T1	74.02E+06	1.11E+10	2622.06	18.46	19.45	16.61	19.70	11.14	0.44	0.46
56	DA-5-2	456.20	577	45	100	14	T4	80.50E+06	1.04E+10	5230.70	18.81	22.09	16.80	16.13	11.96	0.41	0.51
57	DG-5-9	356.37	577	12	50	29	T5	67.89E+06	9.73E+09	3321.18	15.81	20.49	14.28	20.64	10.71	0.39	0.41
58	DG-5-2	353.66	577	5	50	27	T2	71.96E+06	9.85E+09	2845.37	20.92	15.71	15.18	22.45	37.81	0.41	0.40
59	DE-5-11	569.32	578	10	10	14	T5	01.26E+08	1.72E+10	7958.39	25.27	11.50	22.85	12.15	10.59	0.62	0.65
60	D-5-4	508.50	578	28	100	6	T1	77.21E+06	8.63E+09	3246.48	22.53	13.79	20.31	15.02	10.93	0.56	0.57
61	DG-6-10	354.75	579	0	50	26	B4	71.58E+06	9.29E+09	2968.37	15.21	19.71	13.75	19.93	10.62	0.39	0.41
62	DE-6-1	572.77	579	5	100	12	B5	01.23E+08	1.52E+10	6541.07	25.90	11.34	23.51	11.90	10.17	0.63	0.66
63	DD-6-3	547.02	578	30	100	7	T8	81.09E+06	8.56E+09	3735.70	24.65	11.79	22.34	13.28	10.34	0.61	0.63
64	DF-6-10	424.05	579	5	100	119	B2	79.55E+06	1.22E+10	3741.61	19.73	17.97	17.77	19.97	11.03	0.47	0.47
65	DG-6-3	354.74	578	10	40	30	B4	67.39E+06	9.66E+09	2772.52	16.69	21.02	15.08	21.09	10.68	0.40	0.42
66	DE-6-12	572.80	578	25	100	17	B2	01.22E+08	1.53E+10	6201.35	24.30	10.17	22.00	10.70	10.45	0.64	0.67
67	DB-6-2	369.77	578	7	75	9	B3	63.28E+06	8.77E+09	2260.60	17.17	19.02	15.46	19.62	11.06	0.43	0.44
68	DB-6-6	376.88	577	22	50	9	B2	71.94E+06	9.13E+09	3470.51	18.49	20.01	16.60	20.42	11.39	0.43	0.45
69	DC-6-15	512.18	578	35	100	6	T9	82.63E+06	1.02E+10	3342.26	22.76	12.60	20.54	13.31	10.81	0.58	0.61
70	DB-6-14	391.14	579	7	50	10	T9	77.23E+06	1.10E+10	3251.05	17.07	17.30	15.39	17.41	10.92	0.45	0.47
71	DF-6-18	441.23	578	17	100	19	T8	87.05E+06	1.37E+10	4448.40	19.86	16.98	17.86	16.99	11.20	0.48	0.51
72	DA-6-8	465.62	579	35	100	12	T7	79.35E+06	1.10E+10	4238.54	19.21	13.84	17.20	14.24	11.69	0.52	0.55
73	DC-7-9	525.58	577	32	100	5	B2	85.24E+06	9.19E+09	4637.54	23.75	12.00	21.23	12.89	11.87	0.59	0.62
74	DG-7-4	354.04	577	9	50	28	T1	67.62E+06	9.73E+09	2260.06	15.53	20.47	14.05	20.41	10.53	0.39	0.41
75	D-RA-7	438.45	578	38	100	9	T4	54.40E+06	1.31E+10	802.03	19.48	16.55	17.61	16.43	10.62	0.49	0.52
76	DA-7-9	442.63	578	45	100	15	T1	73.74E+06	9.36E+09	3979.73	18.74	15.53	16.78	15.94	11.68	0.49	0.51
77	DI-7-3	498.35	578	42	100	12	B4	92.69E+06	1.54E+10	3384.43	21.12	13.75	19.05	13.80	10.87	0.55	0.58
78	DF-7-16	419.35	577	10	0	18	T4	74.84E+06	1.23E+10	4385.69	18.05	17.03	16.22	16.85	11.28	0.46	0.49
79	DB-7-12	386.07	578	27	100	13	T5	76.56E+06	1.17E+10	3008.19	16.52	17.55	14.92	17.53	10.72	0.44	0.46
80	D-RG-7-1	374.33	578	5	75	25	T4	72.64E+06	1.08E+10	3032.07	17.15	20.23	15.49	20.14	10.72	0.41	0.43
81	DC-7-1	474.71	578	45	100	7	T4	79.21E+06	9.23E+09	3700.67	20.34	14.65	18.26	15.25	11.39	0.52	0.54
82	DF-7-1	418.71	577	5	66	21	B3	high slope of grain			17.26	16.48	15.65	16.49	10.29	0.46	0.49
83	D-RG-7-2	368.51	578	0	75	27	B1	61.13E+06	1.11E+10	2201.77	16.94	20.77	15.25	20.73	11.08	0.40	0.42
84	DA-7-12	452.55	578	34	100	15	T1	77.34E+06	8.74E+09	5045.23	19.00	14.77	17.08	15.70	11.24	0.51	0.52
85	DE-8-10	573.04	578	4	100	15	T8	01.25E+08	1.69E+10	6095.36	27.30	11.71	24.65	12.15	10.75	0.63	0.67
86	DB-8-13	385.52	579	0	20	10	T10	75.84E+06	1.06E+10	3598.44	18.34	20.83	16.47	20.61	11.35	0.42	0.44
87	DD-8-6	520.00	578	34	100	7	B5	65.99E+06	8.41E+09	2009.64	23.25	13.18	20.96	14.50	10.93	0.58	0.59
88	DI-8-1	434.74	578	34	100	8	B4	55.45E+06	1.24E+10	884.03	18.83	18.01	17.01	18.04	10.70	0.46	0.49
89	DD-8-11	513.79	578	25	100	8	B2	74.39E+06	9.18E+09	2526.91	23.55	14.66	21.13	15.87	11.45	0.55	0.57
90	DB-8-11	389.40	579	5	40	9	B1	72.08E+06	1.04E+10	3668.67	17.21	17.74	15.42	19.97	11.61	0.44	0.44

APPENDIX D (Continued)

Sample	ID	Measurements before treatment						Bending Properties			MC and SG blocks				MC	SG	
#		Wt. (g)	Length (mm)	Ring Angle	%HW	# GR	Pos	MOR (Pa)	MOE (Pa)	WML, (N^*m/m^3)	Intl Wt.(g)	Intl Wt. of H_2O(g)	OD Wt.(g)	OD Wt. of H_2O(g)		Wet	Dry
91	DC-8-12	503.51	579	28	100	5	B3	66.98E+06	9.52E+09	2146.39	22.39	14.22	20.08	14.82	11.50	0.55	0.58
92	DB-8-1	368.77	579	10	10	9	T6	61.34E+06	8.53E+09	2416.10	17.00	19.62	15.31	19.86	11.04	0.42	0.44
93	DA-8-5	468.33	579	40	100	14	B4	77.42E+06	1.13E+10	3163.55	20.32	13.81	18.16	13.95	11.89	0.53	0.57
94	DF-8-15	439.77	579	17	100	18	B1	82.86E+06	1.35E+10	2809.20	20.47	18.21	18.45	18.02	10.95	0.48	0.51
95	DG-8-8	348.80	579	0	50	25	T6	59.89E+06	8.89E+09	2042.83	16.73	22.92	15.10	23.04	10.79	0.38	0.40
96	DF-8-5	428.93	579	10	100	20	B3	70.38E+06	1.14E+10	4973.65	20.20	18.46	18.03	18.51	12.04	0.47	0.49
97	D-RG-9	358.03	577	10	66	24		71.86E+06	9.98E+09	2711.65	16.68	21.61	15.13	21.57	10.24	0.40	0.41
98	DG-9-5	352.23	578	0	50	25		68.61E+06	9.67E+09	2663.92	15.92	21.22	14.43	21.13	10.33	0.39	0.41
99	DD-9-9	514.93	577	40	100	8		70.37E+06	8.92E+09	2236.29	22.93	13.05	20.65	14.19	11.04	0.57	0.59
100	DC-9-8	514.70	577	40	100	5		82.84E+06	8.37E+09	5315.10	20.96	12.22	18.71	12.90	12.03	0.56	0.59
101	DG-9-1	359.22	577	8	50	26		72.09E+06	9.82E+09	2556.57	16.86	22.14	15.23	22.01	10.70	0.39	0.41
102	D-RA-9	412.21	577	27	100	9		51.89E+06	1.23E+10	754.69	19.41	18.99	17.71	18.71	9.60	0.46	0.49
103	DB-9-7	373.38	578	0	40	9		70.16E+06	9.65E+09	3100.82	17.50	19.97	15.77	19.94	10.97	0.42	0.44
104	DA-9-14	475.04	578	40	100	16		85.20E+06	1.34E+10	4574.66	20.34	14.14	18.20	14.03	11.76	0.53	0.56
105	DH-9-3	558.15	577	15	100	24		01.18E+08	1.85E+10	5675.67	22.89	11.64	20.75	11.39	10.31	0.60	0.65
106	DF-9-2	419.76	578	15	66	22		high slope of grain			20.34	19.65	18.60	19.46	9.35	0.47	0.49
107	DA-9-1	490.17	578	35	100	16		85.03E+06	1.20E+10	3257.89	23.19	14.98	20.91	15.04	10.90	0.55	0.58
108	DF-9-12	438.28	578	20	100	21		82.87E+06	1.28E+10	3846.80	20.62	17.69	18.64	17.54	10.62	0.49	0.52
109	SP-28-4-1	288.30	578	35		48	B4	40.36E+06	7.42E+09	1106.67	14.19	25.22	12.76	23.54	11.21	0.32	0.35
110	SP-41-1	347.23	578	12		13	T5	63.90E+06	9.28E+09	3292.60	15.48	19.64	14.05	19.86	10.18	0.40	0.41
111	SP-22-1	410.56	578	38		51	T3	76.99E+06	1.23E+10	4187.21	18.08	17.31	16.10	17.12	12.30	0.45	0.48
112	SP-29-4-1	276.78	578	12		27	T1	33.92E+06	6.87E+09	701.19	12.51	23.09	11.44	21.84	9.35	0.32	0.34
113	SP-38-1	284.71	577	12		28	T5	38.21E+06	7.31E+09	778.31	13.69	25.09	12.49	23.46	9.61	0.32	0.35
114	SP-9-4-1	361.72	579	30		39	T1	55.22E+06	9.77E+09	1995.74	17.21	19.85	15.32	19.94	12.34	0.41	0.43
115	SP-40-1	353.65	578	35		28	T1	60.36E+06	9.68E+09	2633.84	15.87	19.49	14.34	19.46	10.67	0.41	0.42
116	SP-54-7-1	414.17	578	31		44	T3	75.09E+06	1.20E+10	3976.42	16.15	13.95	14.73	13.83	9.64	0.49	0.52
117	SP-69-1	404.26	578	45		47	T3	78.64E+06	1.29E+10	4378.40	18.32	16.88	16.58	16.33	10.49	0.47	0.50
118	SP-64-1	352.77	579	38		32	T5	65.29E+06	1.15E+10	3326.52	15.68	18.73	14.14	118.32	10.89	0.41	0.11
119	SP-60-1	315.89	579	20		25	T2	50.15E+06	8.92E+09	2260.09	14.28	21.37	12.87	21.06	10.96	0.36	0.38
120	SP-64-4-1	354.46	578	22		18	T1				15.28	20.79	13.80	21.39	10.72	0.38	0.39
121	SP-59-2-3	345.90	579	5		12	B2	37.84E+06	6.33E+09	1005.40	16.39	21.63	14.84	21.93	10.44	0.39	0.40
122	SP-44-3	331.07	579	0		30	T2	53.10E+06	8.90E+09	2378.06	15.60	22.39	14.17	21.55	10.09	0.37	0.40
123	SP-38-3	299.12	579	35		29	T4	48.71E+06	7.13E+09	2866.44	12.65	20.94	11.46	20.74	10.38	0.34	0.36
124	SP-70-3	348.78	579	45		28	T3				11.66	16.71	10.66	16.31	9.38	0.38	0.40
125	SP-63-3	337.00	578	30		37	T5	51.30E+06	9.64E+09	3126.06	16.44	23.22	14.69	22.74	11.91	0.37	0.39
126	SP-18-2-3	346.26	578	11		23	T5	52.30E+06	1.03E+10	1236.85	15.23	19.80	13.64	19.72	11.66	0.39	0.41
127	SP-32-3	318.46	578	38		29	T5	43.59E+06	6.32E+09	2304.68	14.15	22.98	12.82	22.78	10.37	0.35	0.36
128	SP-38-5-3	300.67	578	25		28	T4	52.72E+06	8.11E+09	2808.03	13.37	21.25	11.95	21.48	11.88	0.35	0.36
129	SP-45-2-3	339.81	577	13		31	B2	54.17E+06	7.68E+09	2757.09	15.51	22.26	14.14	22.50	9.69	0.37	0.39
130	SP-5-5-3	322.66	578	35		25	B2	47.47E+06	7.56E+09	2030.82	12.14	16.52	10.92	16.17	11.17	0.38	0.40
131	SP-17-3	392.31	578	40		65	T4	52.06E+06	7.99E+09	1377.30	17.52	15.97	15.67	16.25	11.81	0.47	0.49
132	SP-29-3	286.88	577	18		29	T2	37.90E+06	7.25E+09	795.10	12.41	22.45	11.25	23.07	10.31	0.32	0.33
133	SP-60-5-6	316.01	580	14		33	B5	50.62E+06	8.25E+09	2209.20	13.35	19.95	11.96	19.67	11.62	0.36	0.38
134	SP-28-6	279.29	579	30		38	T6	32.99E+06	6.77E+09	700.45	12.81	23.62	11.83	21.96	8.28	0.32	0.35
135	SP-32-4-6	304.98	578	9		23	T10	43.67E+06	6.59E+09	1979.53	13.48	21.72	12.20	21.50	10.49	0.35	0.36
136	SP-17-6	373.74	578	45		70	B3	49.90E+06	8.71E+09	1167.16	16.70	17.26	15.02	17.11	11.19	0.44	0.47
137	SP-5-2-6	309.66	578	40		23	B4	26.84E+06	4.84E+09	1259.41	14.18	20.36	12.77	20.46	11.04	0.37	0.38
138	SP-11-6	352.33	579	45		28	B1	44.41E+06	8.10E+09	1334.49	16.65	20.36	15.05	20.24	10.63	0.41	0.43
139	SP-16-7-6	314.77	580	35		49	T7	09.90E+06	1.82E+09	206.23	10.75	16.70	9.91	17.13	8.48	0.36	0.37
140	SP-41-5-6	357.58	579	12		17	B1	57.02E+06	8.74E+09	2520.70	15.04	18.82	13.62	18.70	10.43	0.40	0.42
141	SP-59-6	344.36	578	0		12	T6	43.18E+06	6.99E+09	1338.02	14.65	20.78	13.35	21.37	9.74	0.38	0.38
142	SP-44-6	329.71	579	5		44	T9	52.11E+06	9.17E+09	2316.31	14.42	22.30	13.22	21.46	9.08	0.36	0.38
143	SP-13-6	335.72	578	30		40	T7	47.21E+06	9.73E+09	1408.33	15.73	20.39	14.34	20.27	9.69	0.40	0.41
144	SP-67-6	317.31	579	12		21	B1	51.21E+06	9.21E+09	2537.70	15.47	24.04	14.15	23.34	9.33	0.36	0.38
145	SP-8-5-8	350.66	578	18		29	T10				15.49	20.46	14.17	20.60	9.32	0.39	0.41
146	SP-47-8	277.25	580	30		21	T9	28.92E+06	5.74E+09	1129.80	12.28	20.64	11.26	19.98	9.06	0.34	0.36
147	SP-54-4-8	415.22	579	30		48	T9	68.46E+06	1.13E+10	3280.52	19.51	17.44	17.60	16.95	10.85	0.48	0.51
148	SP-13-5-8	341.90	578	35		39	T9	51.28E+06	1.03E+10	1882.57	16.57	20.76	14.93	20.35	10.98	0.40	0.42
149	SP-9-8	357.42	579	34		38	T6	50.62E+06	1.04E+10	1512.89	16.66	19.23	15.13	19.31	10.11	0.42	0.44
150	SP-24-8	336.66	578	30		21	T8	35.76E+06	3.59E+09	1106.42	18.70	23.70	16.80	23.47	11.31	0.40	0.42
151	SP-2-2-8	313.80	578	37		29	B5	44.80E+06	7.98E+09	1830.63	13.37	17.67	12.11	18.44	10.40	0.39	0.40
152	SP-42-8	362.00	580	30		21	B4	40.77E+06	6.59E+09	981.04	16.85	20.75	15.27	20.60	10.35	0.41	0.43
153	SP-38-8	289.13	579	10		27	B2	41.67E+06	7.57E+09	992.00	12.70	22.01	11.44	20.40	11.01	0.33	0.36
154	SP-64-8	340.87	578	22		16	T9	47.94E+06	6.77E+09	1729.09	15.40	20.93	14.01	21.43	9.92	0.39	0.40
155	SP-11-8	349.95	579	35		28	T10	40.26E+06	1.01E+10	820.56	16.47	19.73	14.84	19.39	10.98	0.41	0.43
156	SP-70-7-8	339.13	580	43		28	T9	28.37E+06	4.96E+09	2082.02	15.41	21.85	14.25	21.44	8.14	0.38	0.40
157	SP-9-9	357.03	579	27		33		57.73E+06	1.07E+10	1656.54	16.54	19.86	14.80	19.91	11.76	0.41	0.43
158	SP-29-7-9	294.79	579	17		25		40.28E+06	7.59E+09	854.21	13.42	23.92	12.81	22.33	4.76	0.34	0.36
159	SP-11-7-9	348.75	579	45		27		58.30E+06	1.09E+10	1769.40	15.25	19.81	13.59	19.86	12.21	0.39	0.41
160	SP-29-9	292.45	579	15		27		35.76E+06	6.15E+09	657.56	16.66	25.45	13.09	24.92	27.27	0.31	0.34
161	SP-47-9	271.49	580	32		22		43.91E+06	7.60E+09	1975.09	12.59	25.89	11.37	25.11	10.73	0.30	0.31
162	SP-24-9	328.99	578	30		23		53.66E+06	8.75E+09	2404.87	16.22	25.06	14.51	25.16	11.78	0.35	0.37
163	SP-69-9	406.63	579	45		46		79.80E+06	1.31E+10	4701.88	18.76	17.37	17.02	16.46	10.22	0.47	0.51
164	SP-67-7-9	310.37	579	5		18		52.67E+06	9.73E+09	2608.52	13.35	21.79	12.18	20.78	9.61	0.35	0.37
165	SP-18-9	340.54	580	0		21		59.91E+06	9.42E+09	1986.60	15.87	21.89	14.29	21.82	11.06	0.38	0.40
166	SP-36-7-9	363.41	579	38		31		65.27E+06	1.11E+10	3792.36	16.49	19.40	14.75	19.65	11.80	0.41	0.43
167	SP-62-2-9	306.80	578	22		19		48.14E+06	8.71E+09	2023.96	15.00	25.56	13.50	25.02	11.11	0.33	0.35
168	W-J-1	259.09	578	37	100	39	T4	38.91E+06	6.76E+09	1808.86	11.79	26.41	10.59	26.32	11.33	0.28	0.29
169	W-B-1	309.98	577	31	100	30	T2	59.61E+06	8.60E+09	2771.44	14.73	22.71	12.72	22.75	15.80	0.34	0.36
170	W-I-1	310.60	577	19	100	35	T3	55.53E+06	8.81E+09	2018.64	14.54	23.37	13.06	23.22	11.33	0.34	0.36
171	W-D-1	268.46	577	35	100	45	T1	48.53E+06	7.20E+09	1618.00	12.24	24.20	11.15	24.59	9.78	0.31	0.31
172	W-E-1	325.48	578	20	100	65	T3	67.75E+06	9.47E+09	2794.36	15.47	22.17	14.08	22.29	9.87	0.37	0.39
173	W-K-1	336.32	576	35	100	44	T2	51.35E+06	4.87E+09	2399.09	16.81	23.38	15.47	23.81	8.66	0.38	0.39
174	W-H-1	315.59	578	39	100	25	T5	57.50E+06	8.67E+09	2069.44	14.64	22.58	13.26	22.51	10.41	0.36	0.37
175	W-G-1	332.15	578	16	100	65	B3	64.54E+06	8.84E+09	2887.20	14.93	21.79	13.55	21.99	10.18	0.37	0.38
176	W-F-1	269.87	578	11	100	30	T4	43.92E+06	5.58E+09	1415.31	12.47	24.80	11.40	24.91	9.39	0.31	0.31
177	W-L-1	286.32	577	17	100	26	B1	49.52E+06	7.49E+09	1976.49	13.25	26.22	11.95	26.38	10.88	0.30	0.31
178	W-A-1	302.56	578	36	100	31	T2	54.33E+06	8.14E+09	2420.78	13.68	23.27	12.34	23.31	10.86	0.33	0.35
179	W-X-1	314.04	577	37	100	35	T5	53.10E+06	8.51E+09	1633.66	13.98	21.56	12.73	21.60	9.82	0.36	0.37
180	W-I-2	313.69	578	32	100	34	B1	56.62E+06	8.70E+09	2351.87	14.65	20.86	13.26	20.34	10.48	0.37	0.39
181	W-E-2	334.86	578	5	100	60	B5	61.11E+06	8.44E+09	2562.96	15.92	20.73	14.36	20.37	10.86	0.39	0.41
182	W-D-2	270.34	578	20	100	49	T6	46.59E+06	6.95E+09	1545.08	13.32	26.15	12.13	25.92	9.81	0.31	0.32

APPENDIX D (Continued)

Sample	ID	Measurements before treatment						Bending Properties			MC and SG blocks				MC	SG	
#		Wt. (g)	Length (mm)	Ring Angle	%HW	# GR	Pos	MOR (Pa)	MOE (Pa)	WML, (N^*m/m^3)	Intl Wt.(g)	Intl Wt. of H_2O(g)	OD Wt.(g)	OD Wt. of H_2O(g)		Wet	Dry
183	W-C-2	298.38	580	13	100	25	T8	50.25E+06	7.60E+09	2018.63	13.15	20.92	11.78	20.42	11.63	0.35	0.37
184	W-J-2	262.33	577	32	100	40	T10	38.08E+06	6.53E+09	1500.53	11.86	23.49	10.52	22.90	12.74	0.30	0.31
185	W-H-2	307.60	578	35	100	19	B3	49.38E+06	7.06E+09	1785.88	17.37	24.16	15.67	23.27	10.85	0.38	0.40
186	W-A-2	312.69	578	15	100	23	B4	58.70E+06	8.53E+09	1929.83	15.58	21.58	14.12	20.98	10.34	0.38	0.40
187	W-B-2	306.21	578	15	100	30	T7	54.44E+06	7.77E+09	2033.52	14.23	21.27	12.89	20.59	10.40	0.36	0.39
188	W-K-2	319.50	578	18	100	60	B2	46.40E+06	4.49E+09	2090.89	17.99	27.03	16.41	26.64	9.63	0.36	0.38
189	W-F-2	272.19	578	20	100	36	T7	49.08E+06	6.03E+09	1694.21	14.82	28.04	13.55	27.98	9.37	0.32	0.33
190	W-G-2	323.71	578	7	100	52	T10	60.65E+06	8.68E+09	3037.23	15.19	20.87	13.90	20.60	9.28	0.39	0.40
191	W-L-2	289.65	578	10	100	25	T6	47.68E+06	6.92E+09	1802.57	13.07	23.42	11.82	23.05	10.58	0.32	0.34
192	W-A-3	311.31	578	15	100	28	T4	61.87E+06	8.83E+09	2988.84	13.91	22.09	12.61	21.76	10.31	0.35	0.37
193	W-J-3	271.19	576	18	100	15	T2	37.43E+06	5.02E+09	2087.01	13.65	25.91	12.15	26.06	12.35	0.31	0.32
194	W-B-3	325.96	578	38	100	40	T4	58.68E+06	9.60E+09	2427.42	14.49	20.66	12.93	20.55	12.06	0.37	0.39
195	W-H-3	311.75	577	29	100	22	T1	56.73E+06	8.46E+09	1966.19	14.17	22.90	12.83	22.84	10.44	0.35	0.36
196	W-I-3	312.83	578	42	100	32	T5	57.24E+06	8.91E+09	2162.08	13.81	21.52	12.44	21.28	11.01	0.35	0.37
197	W-F-3	250.36	577	12	100	21	T3	43.18E+06	5.62E+09	1476.38	13.48	30.10	12.31	29.65	9.50	0.28	0.29
198	W-G-3	327.07	577	22	100	60	T3	54.20E+06	6.65E+09	1929.49	14.47	21.02	13.32	21.06	8.63	0.38	0.39
199	W-X-3	316.53	578	38	100	37	B5	57.10E+06	8.95E+09	2785.09	13.73	21.66	12.37	21.42	10.99	0.35	0.37
200	W-E-3	330.31	578	4	100	60	T2	66.60E+06	9.72E+09	2416.99	15.19	22.04	13.81	21.96	9.99	0.37	0.39
201	W-D-3	281.32	578	18	100	43	T2	37.36E+06	5.88E+09	1005.15	10.01	19.89	9.20	19.87	8.80	0.31	0.32
202	W-C-3	294.67	576	5	100	24	B4	44.88E+06	6.77E+09	1624.98	13.34	24.39	12.19	24.21	9.43	0.32	0.33
203	W-K-3	314.11	577	20	100	64	B1	50.33E+06	4.89E+09	2631.53	13.28	21.04	12.16	21.29	9.21	0.35	0.36
204	W-K-4	336.72	577	18	100	45	T6	53.03E+06	5.18E+09	2558.55	16.66	24.05	15.20	24.04	9.61	0.37	0.39
205	W-C-4	300.38	579	12	100	28	B3	49.45E+06	7.13E+09	2268.78	14.87	23.86	13.40	23.11	10.97	0.35	0.37
206	W-F-4	268.04	579	5	100	30	T10	41.76E+06	5.60E+09	1410.23	11.66	22.18	10.71	21.01	8.87	0.32	0.34
207	W-A-4	307.18	579	28	100	25	T8	53.92E+06	7.58E+09	1906.06	13.66	19.50	12.33	18.84	10.79	0.37	0.40
208	W-J-4	326.04	578	15	100	20	T7	46.28E+06	4.95E+09	2030.64	14.40	24.64	12.92	24.35	11.46	0.33	0.35
209	W-G-4	335.77	577	28	100	75	T8	67.81E+06	9.19E+09	2641.07	14.86	19.45	13.56	19.25	9.59	0.40	0.41
210	W-E-4	325.54	578	10	100	60	T8	56.32E+06	8.08E+09	2464.03	14.28	19.75	13.01	18.93	9.76	0.38	0.41
211	W-H-4	312.48	578	39	100	27	B4	61.60E+06	9.49E+09	2753.63	14.40	20.11	13.08	19.51	10.09	0.38	0.40
212	W-I-4	311.42	579	40	100	33	B3	59.64E+06	9.29E+09	2717.53	14.26	19.62	12.92	19.14	10.37	0.38	0.40
213	W-L-4	288.49	577	26	90	31	B2	47.72E+06	6.53E+09	2373.02	12.32	22.45	11.11	21.83	10.89	0.32	0.34
214	W-B-4	308.60	577	28	100	29	B5	53.02E+06	8.24E+09	1987.25	14.22	20.03	12.80	19.29	11.09	0.37	0.40
215	W-D-4	261.82	579	20	100	42	B4	43.84E+06	6.23E+09	1850.22	10.41	18.70	9.52	17.80	9.35	0.33	0.35
216	W-B-5	322.86	578	45	100	38	T2	34.99E+06	6.62E+09	1337.94	17.57	25.67	15.85	24.97	10.85	0.37	0.39
217	W-F-5	273.54	576	18	100	41	B5	48.67E+06	6.91E+09	1973.35	11.70	23.08	10.68	22.71	9.55	0.31	0.32
218	W-K-5	332.23	576	25	100	50	T1	43.82E+06	4.75E+09	1537.64	15.22	22.61	13.94	22.73	9.18	0.37	0.38
219	W-J-5	258.34	577	20	100	34	T4	40.22E+06	6.52E+09	1782.57	12.30	27.65	10.97	27.10	12.12	0.27	0.29
220	W-H-5	310.29	577	40	100	23	T4				11.17	18.23	10.16	18.01	9.94	0.35	0.36
221	W-G-5	327.44	577	26	100	55	B4	32.61E+06	3.23E+09	1865.61	15.21	22.67	13.89	22.54	9.50	0.37	0.38
222	W-L-5	288.75	577	15	100	30	T4	38.81E+06	6.69E+09	1684.66	12.50	24.68	11.37	24.54	9.94	0.31	0.32
223	W-I-5	313.16	578	39	100	37	T5				12.21	19.39	11.05	19.22	10.50	0.35	0.37
224	W-A-5	309.53	577	38	75	27	T2	47.53E+06	7.46E+09	1701.87	13.53	22.15	12.38	21.70	9.29	0.35	0.36
225	W-D-5	273.42	577	15	100	37	T4				10.49	20.98	9.63	20.57	8.93	0.31	0.32
226	W-C-5	286.03	576	20	100	19	T3	38.45E+06	5.61E+09	1059.87	12.92	23.13	11.83	23.14	9.21	0.33	0.34
227	W-E-5	330.66	577	17	100	96	T4	51.78E+06	8.94E+09	1312.81	19.02	27.96	17.32	27.89	9.82	0.37	0.38
228	W-I-6	308.65	578	27	100	31	T9	51.58E+06	8.68E+09	2035.67	14.77	23.75	13.24	23.39	11.56	0.34	0.36
229	W-E-6	334.74	578	5	100	60	B5	65.59E+06	9.69E+09	3125.26	15.05	21.14	13.60	21.03	10.66	0.38	0.39
230	W-J-6	266.18	578	41	100	40	T6	37.15E+06	5.38E+09	1911.54	12.83	28.23	11.43	28.24	12.25	0.28	0.29
231	W-A-6	307.80	576	28	100	24	T7	47.08E+06	8.09E+09	1868.98	14.21	23.41	12.89	23.01	10.24	0.34	0.36
232	W-X-6	319.14	578	40	100	32	T10	56.57E+06	9.44E+09	2495.24	14.11	21.50	12.72	21.21	10.93	0.36	0.37
233	W-K-6	320.22	578	20	100	42	B2	53.88E+06	4.93E+09	3274.92	14.75	23.08	13.50	23.46	9.26	0.36	0.37
234	W-D-6	261.35	577	27	100	44	B4	31.93E+06	5.69E+09	1244.57	13.01	27.05	11.78	26.88	10.44	0.29	0.30
235	W-G-6	325.05	578	5	100	36	T8	60.52E+06	8.55E+09	1987.07	13.72	20.72	12.51	20.54	9.67	0.36	0.38
236	W-B-6	321.62	578	39	100	41	B1	55.17E+06	9.42E+09	2037.82	14.29	21.07	12.83	20.73	11.38	0.36	0.38
237	W-C-6	288.38	578	20	100	28	T6	44.62E+06	6.38E+09	1708.64	12.42	22.79	11.31	22.47	9.81	0.32	0.33
238	W-F-6	249.26	578	15	100	21	T10	35.94E+06	4.58E+09	1190.38	11.88	26.58	10.81	26.20	9.90	0.28	0.29
239	W-H-6	304.38	577	42	100	19	T7	44.01E+06	7.23E+09	1289.44	15.38	24.82	13.93	24.69	10.41	0.35	0.36
240	W-G-7	322.96	577	6	100	50	T3	42.44E+06	6.15E+09	2238.73	7.69	11.45	7.02	11.46	9.54	0.37	0.38
241	W-D-7-X	308.79	577	18	100	29	B1	50.93E+06	8.38E+09	1682.41	13.95	22.59	12.65	22.00	10.28	0.35	0.37
242	W-L-7	286.60	577	40	95	34	B5	39.50E+06	6.21E+09	1383.00	13.83	27.84	12.53	27.59	10.38	0.30	0.31
243	W-F-7	269.76	577	20	100	39	T5	44.59E+06	6.34E+09	1543.34	11.89	24.03	10.83	24.43	9.79	0.30	0.31
244	W-K-7	317.28	578	15	100	50	B3	36.16E+06	4.32E+09	1517.03	19.11	31.23	17.56	31.83	8.83	0.35	0.36
245	W-E-7	327.50	575	5	80	60	T3	50.42E+06	8.22E+09	2057.12	9.78	14.79	8.85	14.80	10.51	0.36	0.37
246	W-A-7	310.08	577	28	100	24	T5				11.56	18.98	10.54	18.97	9.68	0.35	0.36
247	W-I-7	312.73	577	38	100	33	T2										
248	W-B-7	310.80	577	45	100	34	T3	47.62E+06	8.59E+09	1687.48	15.30	24.28	13.73	24.01	11.43	0.35	0.36
249	W-C-7	295.33	577	10	100	27	B5	34.87E+06	5.95E+09	1036.34	14.10	25.91	12.59	25.72	11.99	0.31	0.33
250	W-J-7	255.52	577	20	100	32	T2	35.05E+06	5.12E+09	1249.23	10.98	25.91	9.79	25.90	12.16	0.27	0.27
251	W-H-7	314.63	577	34	100	25	T3	29.53E+06	6.53E+09	630.36	12.16	18.80	11.10	18.84	9.55	0.36	0.37
252	W-J-8	255.97	578	22	100	26	T7	35.76E+06	5.43E+09	2403.86	12.39	28.07	11.09	27.97	11.72	0.27	0.28
253	W-H-8	309.89	579	43	100	24	B3	53.25E+06	8.05E+09	2132.48	13.57	21.18	12.23	20.84	10.96	0.35	0.37
254	W-C-8	308.98	578	20	100	29	B5	48.72E+06	7.49E+09	2495.10	12.92	21.62	11.65	20.93	10.90	0.34	0.36
255	W-G-8	322.59	579	10	100	50	B2	49.60E+06	8.73E+09	2558.40	13.63	20.69	12.48	20.61	9.21	0.36	0.38
256	W-B-8	308.77	579	30	100	33	B4	45.79E+06	6.99E+09	1620.67	15.04	24.18	13.59	24.00	10.67	0.35	0.36
257	W-E-8	327.62	577	4	100	56	B4	25.36E+06	6.70E+09	324.07	11.05	16.23	10.12	16.10	9.19	0.37	0.39
258	W-F-8	253.57	577	30	100	33	T9	40.02E+06	5.31E+09	1993.80	10.27	22.96	9.37	22.76	9.61	0.28	0.29
259	W-I-8	314.29	578	32	100	29	T8	48.32E+06	8.77E+09	2416.58	13.99	21.78	12.79	21.63	9.38	0.36	0.37
260	W-D-8	269.74	578	21	100	44	B2	33.72E+06	5.40E+09	1169.52	13.32	23.70	12.14	24.00	9.72	0.33	0.34
261	W-A-8	316.55	579	15	100	20	T8	49.61E+06	7.65E+09	1337.10	13.89	21.41	12.66	21.51	9.72	0.36	0.37
262	W-L-8	286.58	578	38	90	36	T6	18.14E+06	5.13E+09	234.47	14.57	29.24	13.17	28.87	10.63	0.30	0.31
263	W-K-8	313.00	578	10	100	65	B5	45.31E+06	5.14E+09	1685.51	14.41	22.11	13.12	22.41	9.83	0.36	0.37
264	W-F-9	271.11	578	22	100	42		48.28E+06	6.76E+09	1732.78	12.51	23.88	11.30	23.92	10.71	0.31	0.32
265	W-L-9	282.62	579	27	100	28		47.95E+06	7.21E+09	2153.83	13.88	26.48	12.42	26.75	11.76	0.31	0.32
266	W-C-9	308.04	579	10	100	28		53.46E+06	8.13E+09	1947.44	14.94	23.99	13.20	23.90	13.18	0.34	0.36
267	W-K-9	327.77	577	20	100	35		59.44E+06	5.19E+09	1913.67	17.56	25.14	15.85	26.02	10.79	0.37	0.38
268	W-E-9	327.50	579	10	100	60		66.11E+06	9.20E+09	2510.60	13.71	19.29	12.35	19.65	11.01	0.37	0.39
269	W-A-9	284.54	578	20	100	19		51.93E+06	7.54E+09	1792.04	13.62	21.91	12.19	22.07	11.73	0.34	0.36
270	W-H-9	289.45	578	22	100	19		56.34E+06	7.94E+09	2279.51	14.13	22.44	12.80	22.72	10.39	0.35	0.36
271	W-J-9	260.39	578	17	100	24		39.69E+06	4.85E+09	2847.84	11.65	26.66	10.98	26.74	6.10	0.29	0.29
272	W-D-9	246.29	579	27	100	47		44.84E+06	6.84E+09	1856.44	12.14	24.66	10.81	25.12	12.30	0.29	0.30
273	W-G-9	323.41	578	32	100	70		60.14E+06	6.62E+09	2776.74	14.59	20.73	13.18	21.45	10.70	0.37	0.38
274	W-B-9	303.75	578	17	100	32		57.85E+06	8.61E+09	2314.44	12.48	19.66	11.21	20.02	11.33	0.35	0.36

APPENDIX D (Continued)

Sample	ID	Measurements before treatment						Bending Properties			MC and SG blocks				MC	SG	
#		Wt. (g)	Length (mm)	Ring Angle	%HW	# GR	Pos	MOR (Pa)	MOE (Pa)	WML, (N^*m/m^3)	Intl Wt.(g)	Intl Wt. of H_2O(g)	OD Wt.(g)	OD Wt. of H_2O(g)		Wet	Dry
275	W-I-9	300.95	578	22	100	33		55.67E+06	8.75E+09	3413.36	14.81	23.59	13.12	23.87	12.88	0.34	0.35
276	YP-I-1	362.82	579	36	100	17	T2	65.62E+06	1.02E+10	4355.02	15.58	20.49	14.16	20.34	10.03	0.39	0.41
277	YP-K-1	375.84	578	35	100	10	T2	60.56E+06	9.93E+09	2466.03	19.28	23.24	17.45	23.32	10.49	0.41	0.43
278	YP-J-1	406.09	577	15	100	10	T3	78.19E+06	1.04E+10	4208.19	18.70	19.19	16.96	19.15	10.26	0.45	0.47
279	YP-F-1	407.84	579	9	100	7	B2	72.09E+06	1.06E+10	3627.66	19.46	20.58	17.70	20.68	9.94	0.44	0.46
280	YP-B-1	409.79	578	40	100	9	T3	74.03E+06	8.85E+09	3756.42	19.85	20.50	17.99	20.59	10.34	0.45	0.47
281	YP-D-1	418.40	579	30	100	11	T1				18.64	18.81	16.85	18.81	10.62	0.45	0.47
282	YP-E-1	401.21	578	27	75	15	T5	69.00E+06	1.03E+10	3756.88	17.57	19.34	15.88	19.59	10.64	0.43	0.45
283	YP-A-1	438.02	578	30	100	10	T2	76.84E+06	9.96E+09	4387.58	20.33	18.36	18.43	18.72	10.31	0.48	0.50
284	YP-C-1	409.27	578	0	100	6	B2	72.17E+06	8.71E+09	4643.04	21.51	22.80	19.57	22.88	9.91	0.44	0.46
285	YP-H-1	400.61	577	25	50	24	T1	69.28E+06	9.88E+09	3478.67	18.76	19.61	17.01	19.71	10.29	0.44	0.46
286	YP-L-1	451.84	579	31	75	8	T5	79.17E+06	9.46E+09	4502.75	21.47	18.41	19.44	18.59	10.44	0.49	0.51
287	YP-G-1	396.92	579	16	100	9	T4	64.84E+06	9.61E+09	2850.99	17.33	19.19	15.68	19.34	10.52	0.43	0.45
288	YP-J-2	394.29	578	21	50	15	T10	69.22E+06	9.54E+09	4212.79	16.80	18.84	15.24	18.90	10.24	0.43	0.45
289	YP-D-2	433.23	578	30	100	9	T8	77.51E+06	9.92E+09	6069.30	20.25	18.52	18.33	18.42	10.47	0.47	0.50
290	YP-C-2	415.56	577	30	75	9	B4	72.49E+06	8.83E+09	5101.27	19.30	19.07	17.56	18.84	9.91	0.46	0.48
291	YP-L-2	478.44	578	31	80	7	B2	69.70E+06	9.07E+09	3705.16	21.16	16.07	19.21	16.15	10.15	0.52	0.54
292	YP-E-2	395.73	579	11	0	17	T7	70.42E+06	9.97E+09	3677.17	19.25	22.17	17.51	22.26	9.94	0.42	0.44
293	YP-K-2	400.41	578	45	100	18	B3	62.78E+06	1.06E+10	3563.10	17.73	18.91	16.00	19.07	10.81	0.44	0.46
294	YP-A-2	429.18	579	14	75	10	T9	75.23E+06	1.03E+10	3913.14	18.10	16.93	16.43	17.09	10.16	0.47	0.49
295	YP-B-2	469.79	579	45	100	7	T8	79.93E+06	8.13E+09	6832.50	21.35	16.05	19.35	16.29	10.34	0.52	0.54
296	YP-H-2	414.51	579	0	100	21	B2	79.88E+06	1.15E+10	3803.48	18.92	19.57	17.19	19.87	10.06	0.45	0.46
297	YP-G-2	399.07	578	12	100	10	B3	67.21E+06	9.47E+09	3583.55	18.00	19.83	16.33	19.90	10.23	0.43	0.45
298	YP-F-2	400.12	578	23	100	14	T8	71.44E+06	1.14E+10	3882.14	17.69	19.31	16.13	19.63	9.67	0.44	0.45
299	YP-I-2	369.80	579	25	80	19	B1	65.96E+06	9.89E+09	3521.44	16.71	20.96	15.32	21.16	9.07	0.41	0.42
300	YP-D-3	448.78	578	41	100	8	B5	74.73E+06	9.23E+09	5513.54	20.78	18.24	18.74	18.43	10.89	0.48	0.50
301	YP-L-3	442.26	578	38	100	10	T4	76.57E+06	1.01E+10	4597.95	19.82	17.05	17.95	16.53	10.42	0.49	0.52
302	YP-E-3	405.55	579	35	100	14	T4	68.69E+06	1.12E+10	4017.92	17.97	19.21	16.25	19.45	10.58	0.44	0.46
303	YP-J-3	439.32	578	31	85	10	T4	80.01E+06	1.02E+10	4911.82	21.93	16.06	19.93	16.32	10.04	0.52	0.55
304	YP-B-3	409.69	578	45	75	8	B1	67.65E+06	8.38E+09	3689.50	19.60	20.03	17.79	20.26	10.17	0.45	0.47
305	YP-C-3	463.60	578	10	100	6	T1	75.87E+06	7.54E+09	6912.05	23.55	18.05	21.33	18.40	10.41	0.51	0.54
306	YP-K-3	387.64	578	40	100	12	T1	62.69E+06	1.06E+10	3380.31	16.10	18.38	14.60	18.66	10.27	0.42	0.44
307	YP-G-3	396.89	578	0	100	8	T2	65.71E+06	9.88E+09	2832.55	17.13	18.84	15.59	19.10	9.88	0.43	0.45
308	YP-F-3	432.92	578	15	100	8	B4	78.20E+06	1.12E+10	4236.38	19.67	17.71	17.85	17.94	10.20	0.48	0.50
309	YP-I-3	379.56	578	28	100	19	T1	69.21E+06	1.05E+10	3796.07	16.75	19.88	15.19	20.13	10.27	0.41	0.43
310	YP-A-3	432.33	578	7	66	9	T4	75.62E+06	9.55E+09	5014.41	21.20	19.69	19.17	20.02	10.59	0.47	0.49
311	YP-H-3	362.62	578	38	100	45	T2	62.61E+06	8.58E+09	2652.55	15.84	20.60	14.42	20.94	9.85	0.40	0.41
312	YP-I-4	374.78	578	8	0	11	T7	68.60E+06	1.00E+10	4150.46	16.48	20.07	14.97	20.11	10.09	0.41	0.43
313	YP-A-4	458.71	578	40	100	11	T9	81.69E+06	9.64E+09	6711.08	20.14	16.38	18.24	16.50	10.42	0.50	0.53
314	YP-D-4	439.54	579	45	100	10	T6	73.97E+06	9.33E+09	5308.03	20.23	18.61	18.26	18.90	10.79	0.47	0.49
315	YP-C-4	471.41	578	13	90	6	T9	71.91E+06	8.83E+09	4138.88	18.21	18.69	16.56	18.69	9.96	0.45	0.47
316	YP-H-4	417.17	578	0	100	19	B2	70.66E+06	1.11E+10	2732.31	18.90	18.10	17.15	18.26	10.20	0.46	0.48
317	YP-B-4	412.87	578	27	95	8	B4	67.72E+06	8.49E+09	3608.50	17.92	18.52	16.22	18.66	10.48	0.45	0.47
318	YP-L-4	441.56	579	29	100	11	B1	78.03E+06	1.01E+10	4059.84	19.56	17.59	17.77	17.29	10.07	0.48	0.51
319	YP-F-4	401.43	578	18	100	11	B2	71.97E+06	1.07E+10	3930.90	17.51	18.28	15.92	18.41	9.99	0.44	0.46
320	YP-E-4	412.54	579	40	66	22	B1	75.56E+06	1.13E+10	4702.86	18.58	18.97	16.85	19.13	10.27	0.45	0.47
321	YP-G-4	400.30	578	25	95	18	T9	71.67E+06	9.74E+09	3872.09	18.17	20.01	16.45	20.25	10.46	0.43	0.45
322	YP-K-4	406.28	580	5	0	13	T8	65.42E+06	9.16E+09	3244.53	18.48	20.12	16.73	20.57	10.46	0.43	0.45
323	YP-J-4	389.51	579	30	75	12	T6	66.53E+06	9.82E+09	4067.55	17.56	19.70	16.02	19.87	9.61	0.43	0.45
324	YP-E-5	409.09	577	20	100	9	T3	71.71E+06	1.08E+10	4165.28	19.49	20.00	17.63	20.41	10.55	0.45	0.46
325	YP-J-5	451.85	578	45	25	16	B1	75.60E+06	1.03E+10	3621.59	19.87	15.57	17.95	15.48	10.70	0.51	0.54
326	YP-H-5	411.93	577	5	100	20	T3	74.16E+06	1.17E+10	3344.14	19.50	19.80	17.69	19.97	10.23	0.45	0.47
327	YP-A-5	438.54	576	19	100	10	T5	76.64E+06	1.00E+10	4804.60	20.84	18.99	18.88	19.30	10.38	0.47	0.49
328	YP-L-5	423.94	578	31	60	11	T1	70.87E+06	9.75E+09	3121.91	20.98	18.86	19.02	19.14	10.30	0.48	0.50
329	YP-F-5	409.01	578	9	50	10	T3	75.28E+06	1.16E+10	3964.27	18.11	19.22	16.50	19.52	9.76	0.44	0.46
330	YP-G-5	395.16	578	18	100	14	T3	63.38E+06	9.00E+09	2456.11	18.62	20.48	16.85	20.75	10.50	0.43	0.45
331	YP-I-5	380.60	577	37	100	25	T5	65.29E+06	1.05E+10	3423.67	16.74	20.46	15.13	20.65	10.64	0.41	0.42
332	YP-K-5	394.19	578	29	100	10	T2	48.91E+06	7.63E+09	2428.70	19.48	21.71	17.57	22.03	10.87	0.43	0.44
333	YP-D-5	416.71	577	35	33	12	T1	70.09E+06	9.18E+09	4719.30	20.74	20.09	18.75	20.10	10.61	0.46	0.48
334	YP-C-5	408.06	578	17	100	6	T4	71.60E+06	9.20E+09	4456.09	18.22	19.87	16.53	19.94	10.22	0.43	0.45
335	YP-B-5	452.93	578	35	40	8	T1	71.17E+06	7.22E+09	6003.16	19.78	17.11	18.00	17.38	9.89	0.49	0.51
336	YP-F-6	403.77	578	5	50	10	B3	72.38E+06	1.15E+10	3836.72	19.06	20.35	17.36	20.64	9.79	0.44	0.46
337	YP-K-6	401.79	578	35	100	12	T9	62.68E+06	9.55E+09	3564.20	17.84	19.67	15.98	19.91	11.64	0.43	0.45
338	YP-I-6	370.91	579	5	0	11	B2	65.08E+06	1.04E+10	3799.21	17.95	22.92	16.33	23.13	9.92	0.40	0.41
339	YP-A-6	447.49	579	30	100	10	B2	78.01E+06	1.02E+10	5267.03	19.69	16.39	17.89	16.76	10.06	0.50	0.52
340	YP-D-6	442.75	578	30	100	11	T7	76.03E+06	9.63E+09	5626.85	20.23	18.16	18.28	18.27	10.67	0.48	0.50
341	YP-L-6	425.40	578	40	25	11	B3	77.58E+06	1.00E+10	4499.52	19.05	18.38	17.29	18.39	10.18	0.46	0.48
342	YP-G-6	401.68	578	10	100	8	B2	69.36E+06	9.37E+09	3414.91	19.39	21.35	17.66	21.58	9.80	0.43	0.45
343	YP-J-6	388.57	579	34	15	17	T7	62.82E+06	1.04E+10	3549.93	16.81	19.18	15.17	18.97	10.81	0.42	0.44
344	YP-B-6	431.95	578	25	25	12	T10	73.53E+06	9.18E+09	4885.89	18.99	17.83	17.25	17.86	10.09	0.47	0.49
345	YP-H-6	395.81	578	25	100	32	B4	64.48E+06	1.01E+10	3001.45	18.10	19.93	16.45	20.36	10.03	0.43	0.45
346	YP-E-6	402.17	578	5	0	8	T8	65.01E+06	1.00E+10	2447.63	19.16	20.22	17.30	20.83	10.75	0.44	0.45
347	YP-C-6	457.92	579	26	100	8	B5	77.16E+06	7.50E+09	7214.92	20.84	18.18	19.03	18.75	9.51	0.49	0.50
348	YP-D-7	428.09	578	38	33	12	T5	71.27E+06	8.87E+09	4702.51	18.82	18.33	16.98	18.27	10.84	0.46	0.48
349	YP-L-7	438.09	578	41	50	10	T5	78.93E+06	9.71E+09	4606.49	19.75	17.23	17.66	17.19	11.83	0.48	0.51
350	YP-F-7	421.16	577	5	100	7	B3	79.42E+06	1.13E+10	4684.06	19.95	18.77	18.17	18.85	9.80	0.47	0.49
351	YP-G-7	396.66	578	0	100	8	T2	67.11E+06	9.49E+09	3199.22	18.82	19.81	16.47	20.13	14.27	0.43	0.45
352	YP-J-7	400.10	578	35	15	14	T3	67.25E+06	9.95E+09	4161.83	19.39	20.60	17.59	20.54	10.23	0.44	0.46
353	YP-I-7	365.82	578	5	100	14	T2	67.35E+06	9.91E+09	3720.37	16.81	21.39	15.36	21.56	9.44	0.40	0.42
354	YP-K-7	403.42	578	41	100	10	B4	64.65E+06	8.98E+09	3550.08	18.83	20.67	17.11	20.70	10.05	0.43	0.45
355	YP-E-7	395.85	577	32	100	12	T1	67.18E+06	1.05E+10	3852.55	18.69	20.54	16.97	20.80	10.14	0.43	0.45
356	YP-C-7	441.76	578	28	100	6	T4	70.28E+06	6.85E+09	7841.98	21.72	18.88	19.74	19.11	10.03	0.49	0.51
357	YP-B-7	416.51	578	30	10	13	B2	73.93E+06	8.87E+09	4723.97	20.20	20.73	18.38	20.80	9.90	0.45	0.47
358	YP-H-7	376.19	578	38	100	38	T1	66.57E+06	8.66E+09	3286.86	18.09	22.09	16.49	22.17	9.70	0.41	0.43
359	YP-A-7	419.27	578	12	65	9	B2	72.08E+06	9.47E+09	4218.36	19.40	19.99	17.56	20.05	10.48	0.45	0.47
360	YP-J-8	407.18	578	32	100	11	T7	70.99E+06	9.79E+09	3141.67	18.98	19.71	17.18	19.58	10.48	0.44	0.47
361	YP-L-8	478.10	579	45	100	6	B1	78.92E+06	9.24E+09	5151.83	22.14	16.51	20.20	16.44	9.60	0.52	0.55
362	YP-B-8	429.88	578	33	100	12	T9	74.19E+06	8.68E+09	4812.78	20.26	20.25	18.38	20.25	10.23	0.45	0.48
363	YP-A-8	448.32	579	22	100	10	B3	80.70E+06	1.01E+10	5720.81	21.30	18.68	19.33	19.06	10.19	0.48	0.50
364	YP-K-8	383.78	578	15	0	9	B4	35.53E+06	5.38E+09	1571.37	19.78	22.85	17.96	22.76	10.13	0.42	0.44
365	YP-F-8	420.88	578	5	100	9	B1	78.69E+06	1.17E+10	5190.09	20.50	19.87	18.65	20.10	9.92	0.46	0.48
366	YP-C-8	417.98	578	5	100	5	T10	70.76E+06	8.53E+09	4983.32	20.33	20.89	18.49	21.09	9.95	0.45	0.47

APPENDIX D (Continued)

Sample	ID	Measurements before treatment						Bending Properties			MC and SG blocks				MC	SG	
#		Wt (g)	Length (mm)	Ring Angle	%HW	# GR	Pos	MOR (Pa)	MOE (Pa)	WML, (N^*m/m^3)	Intl Wt(g)	Intl Wt of H_20(g)	OD Wt(g)	OD Wt of H_20(g)		Wet	Dry
367	YP-G-8	404.91	577	6	33	9	T7	70.70E+06	9.91E+09	3702.75	19.69	20.10	17.80	20.25	10.62	0.45	0.47
368	YP-I-8	377.11	578	18	100	14	B3	65.90E+06	1.05E+10	3668.49	18.17	21.84	16.57	21.90	9.66	0.41	0.43
369	YP-E-8	396.46	579	0	0	8	T8	69.93E+06	9.95E+09	4057.96	19.72	22.09	17.83	22.38	10.60	0.43	0.44
370	YP-D-8	424.65	578	42	100	10	T7	73.79E+06	9.52E+09	5702.25	19.75	19.26	17.90	19.51	10.34	0.46	0.48
371	YP-H-8	404.36	579	18	100	26	B4	68.75E+06	1.05E+10	2737.07	20.37	21.98	18.53	22.06	9.93	0.44	0.46
372	YP-B-9	447.27	579	40	100	6		76.53E+06	7.65E+09	6373.54	21.36	18.20	19.43	18.40	9.93	0.49	0.51
373	YP-J-9	406.45	578	40	45	16		69.17E+06	9.79E+09	4251.88	18.85	19.80	17.30	19.36	8.96	0.45	0.47
374	YP-F-9	402.80	578	10	100	8		73.09E+06	1.07E+10	4201.97	19.56	20.77	17.92	20.92	9.15	0.44	0.46
375	YP-I-9	381.43	579	30	100	20		68.31E+06	1.02E+10	3368.86	17.74	21.31	16.25	21.28	9.17	0.42	0.43
376	YP-A-9	445.23	578	42	100	9		80.97E+06	1.03E+10	6147.89	18.78	16.98	17.17	17.28	9.38	0.48	0.50
377	YP-K-9	388.60	578	13	100	6		69.41E+06	9.77E+09	3488.64	17.92	21.43	16.21	21.63	10.55	0.41	0.43
378	YP-L-9	479.98	579	38	33	8		81.92E+06	1.01E+10	5125.61	22.71	17.01	20.75	17.05	9.45	0.52	0.55
379	YP-D-9	448.29	580	30	40	10		74.04E+06	8.91E+09	5007.51	21.61	19.54	19.56	19.66	10.48	0.48	0.50
380	YP-G-9	402.26	578	5	100	12		68.65E+06	9.40E+09	3006.14	18.82	20.35	17.10	20.54	10.06	0.44	0.45
381	YP-H-9	360.07	579	35	100	37		63.16E+06	8.45E+09	3161.87	18.34	24.92	16.88	24.99	8.65	0.39	0.40
382	YP-E-9	398.06	579	30	100	15		72.10E+06	1.07E+10	3598.46	18.57	20.56	16.93	20.73	9.69	0.43	0.45
383	YP-C-9	424.04	578	20	100	7		77.67E+06	9.23E+09	5347.27	19.24	18.84	17.67	18.97	8.89	0.46	0.48