EFFECTS OF WATERBORNE PRESERVATIVE TREAMENT ON MECHANICAL PROPERTIES: A REVIEW

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ABSTRACT: Waterborne preservative treatments generally reduce the mechanical properties of wood. This paper reviews the effects of waterborne preservative treatments on mechanical properties, which are directly related to several key wood material factors and pretreatment, treatment, and post-treatment processing factors, The key factors discussed include preservative chemistry or chemical type, retention, post-treatment drying temperature, initial kiln-drying temperature, material quality and grade, and incising (if required). In addition, recent reports are reviewed, which infer that North American design guidelines regarding incising effects and in-service temperature, in-service moisture content, and short-term duration-of-load adjustments for CCA-treated lumber (currently based on untreated lumber) may require modification.

Keywords: Preservative, treatment, mechanical properties, strength

INTRODUCTION

In North America, the primary waterborne wood preseservatives are chromated copper arsenate (CCA) and ammoniacal-based waterborne preservatives, such as ammoniacal copper arsenate (ACA), ammoniacal copper zinc arsenate (ACZA), and ammoniacal copper quats (ACQ). The effects of some waterborne preservative treatments on allowable design stresses have been studied extensively. These studies have produced a series of processing limitations in treatment standards intended to control the impact of the treatment processes. However, several problems remain when formulating design recommendations, because fundamental understanding is limited on preservative chemistry, alternative species, and important design adjustment factors, such as load duration (i.e., the C_D factor that adjusts design stresses for the time-dependent nature of the load) and service-use condition (i.e., the C_M factor that adjusts design stresses for moisture content in-service).

This paper reviews the effects of preservative treatment on the mechanical properties of wood, especially waterborne preservative treatment. Where appropriate, limitations are discussed that have been implemented in treating standards to control the preservative treatment effects on strength. In the final section of this paper, modifications to allowable design stresses are discussed.

OIL-TYPE PRESERVATIVES

Oil-type preservatives, which were extensively studied in the early part of the 20th century (Hatt, 1906; Betts and Newlin, 1915; Gregory, 1915; Harkom and Rochester, 1930; Harkom and Alexander, 1931; Wilson, 1930;

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[1] The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin.

Thunell, 1941; Luxford and MacLean, 1951), usually result in no appreciable strength loss because they do not react with wood cell-wall components. However, treatment with oil-type preservatives can adversely affect strength if certain allowable in-retort seasoning parameters are exceeded (e.g., boultonizing, steam conditioning, vapor drying) or if excessive temperatures or pressures are used during the treating process. The effect of thermal exposure during oil-type preservative treatments was extensively studied by Hunt (1915), Hatt (1927), and MacLean (1927, 1951, 1952, 1953). As a result, specific limitations were implemented in the American Wood Preservers' Association (AWPA) standards to minimize these effects (Barnes and Winandy, 1986).

WATERBORNE PRESERVATIVES

In North America, zinc chloride was the first large-scale commercial waterborne preservative. Partially because of its negative effects on strength, but mostly because of related problems like decreased dimensional stability and increased hygroscopicity, blooming, and fastener corrosion, waterborne preservative use declined during the first half of the 20th century. However, the 1973 oil embargo of the United States together with increased environmental awareness of potential mammalian effects associated with the use of oil-type preservatives rekindled an interest in waterborne preservatives, especially the leach-resistant waterborne preservatives, such as CCA, ACA, ACZA and arsenic-free preservatives, such as ACQ (both ammoniacal- (ACQ Type B) and amine-based (ACQ Type D), ammoniacal copper citrate (ACCit), Copper Azole (CuAz), and copper dimethyldithiocarbamate (CDDC). Since the early 1970s, the use of waterborne preservatives has increased ten- to twenty-fold; today waterborne preservatives represent the most prevalent preservative chemical used in North America (Mickelwright, 1990).

Many metallic oxides commonly used in acidic chromium-containing waterborne preservative formulations (pH 1.6 to 2.5) react with the cell wall components by undergoing hydrolytic reduction upon contact with wood sugars. In this process, known as fixation, the metals are reduced to less water-soluble forms by oxidizing the wood cell-wall components. Fixation is a time-dependent function of temperature that can be accomplished in a couple of hours at ≥ 100°C (Wood *et al.,* 1980), or 4 to 7 days at 50°C, or 2 to 6 weeks at 20°C (Dahlgren and Hartford, 1972). To overcome preservative treatability problems with many refractory (i.e., difficult-to-treat) species, it is common to use an ammoniacal-based waterborne preservative and elevated temperatures. Heat and ammonia cause the wood to swell, thereby increasing preservative penetration. Ammoniacal waterborne preservative formulations (pH ≥ 11) do not react with the cellulose or the hexose hemicelluloses of the cell wall, but the ammonia can solubilize and/or react with the lignin and pentose hemicelluloses (Ostmeyer, 1987; Ostmeyer *et al.,* 1988, 1989). Some metallic components of ammoniacal formulations precipitate to water-insoluble complexes on or in the cell wall as some ammonia co-solvent evaporates, while the rest of the nitrogen complexes with metals as it undergoes ion-exchange reactions with the lignin and/or hemicellulose (Ruddick, 1979; Lebow, 1992). The rate of this completing and the permanence of ammoniacal preservatives can be significantly altered by lipophilicity of the ammonia as it influences adsorption (Loubinoux *et al.,* 1992).

The addition of heat, during and after treatment, potentially accelerates these hydrolytic reactions magnifying strength reduction (Barnes, 1985). The sensitivity to strength loss on exposure to elevated temperatures with waterborne preservative formulations is also magnified by the high moisture content induced by the water solvent in the systems.

Waterborne preservative treatments generally reduce the mechanical properties of wood. The effects of waterborne preservative treatment on mechanical properties appear to be directly related to several key wood material factors and pretreatment, treatment, and post-treatment processing factors. These ten factors include the following:

- Species
- Mechanical Property
- Chemistry or Chemical Type
- Retention
- Post-Rreatment Drying Temperature
- Size of Material
- Grade of Material
- Product Type
- Initial Kiln-drying Temperature
- Incising (if reqired)

These factors have the potential to influence the effects of the treatment on the mechanical properties and are reviewed in this paper.

Species

The general magnitude of the effect of various waterborne preservatives on mechanical properties does not appear to vary for different species. Burmeister and Becker (1963) evaluated small, clear specimens of European beech, pine, and spruce using 10 waterborne preservative formulations at retention levels ranging from 0.5 to 1.5 lb/ft^3 (8 to 24 kg/m^3). They found no consistent differences related to species in modulus of rupture (MOR), maximum crushing strength parallel-to-grain, or impact bending strength. Burmeister (1970) again compared European beech and pine treated with CCA, chromated copper borate, and chromated fluorinated arsenate and found no species-related differences. Thompson (1964) studied four waterborne preservatives and noted no practical differences in loss of toughness between yellow poplar and sweetgum at retention levels up to 4.0 lb/ft^3 (64 kg/m^3) or with blackgum up to 2.0 lb/ft^3 (32 kg/m^3). Baechler *et al.* (1966) evaluated the effects of four waterborne preservatives on toughness for four species. They found that when species-related differences existed, these differences seemed to be related more to differential preservative penetration rather than to an inherent difference in chemical sensitivity between species. McMillen and Drew (1956) reported losses in toughness for CCA-treated red oak comparable to the impact bending strength later reported for other species (Burmeister and Becker, 1963; Thompson, 1964; and Baechler, *et al.*, 1966). Hesp and Watson (1964) found Scots pine had nearly identical changes in MOR when compared to three other species reported by Burmeister and Becker (1963). Resch and Parker (1982) compared Southern Pine and Douglas-fir round stock treated to 2.5 lb/ft^3 (40 kg/m^3) with ACA and small, clear specimens cut from that round stock. They found no species-related difference in strength loss. Winandy *et al.* (1989) compared results with CCA-treated Douglas-fir to previous results with CCA-treated Southern Pine (Winandy *et al.*, 1985) and concluded that no species effect existed, but that an interaction did exist between species and the effects of redrying temperature. They proposed that when species-related differences appear, they are probably related as much to differential resistance of thermal exposure as to chemical exposure, because Douglas-fir is recognized as being more sensitive to thermal degradation than is Southern Pine (Kozlik, 1968; Koch, 1976; Yao and Taylor, 1979). Kim (1991) evaluated the effect of CCA on the bending properties of lodgepole pine dimension lumber and concluded that strength reductions were similar to Southern Pine (Mitchell and Barnes, 1986; Winandy *et al.*, 1985) and Douglas-fir (Winandy *et al.*, 1989).

Mechanical Properties

Each mechanical property is affected differently by waterborne preservative treatment. Some waterborne preservatives, such as zinc chloride, have no significant effect on modulus of elasticity (MOE) and maximum crushing strength, but significantly reduce MOR and energy-related properties like work-to-maximum load and impact bending (Luther, 1921; Wilson and Bateman, 1921; Becker, 1966; Zaarudnaua *et al.*, 1980). Burmeister and Becker (1963) studied 10 waterborne preservatives and found little effect from treatment on static bending and compression strength, but generally noted 5 to 20 percent reductions in impact strength after air redrying. Others have also noted significant reduction in energy related properties without corresponding losses in other properties (McMillen and Drow, 1956; Pechman and Aufsess, 1968; Burmeister, 1970; Bendtsen *et al.*, 1983).

Numerous researchers have reported that MOE, measured destructively and non-destructively, is unaffected by many waterborne preservative treatments (Bendtsen *et al.*, 1983; Lacey, 1983; Lee, 1985; Winandy *et al.*, 1983; Winandy *et al.*, 1985; Mitchell and Barnes, 1986; Barnes and Moore, 1987).

Waterborne preservatives can have varying effects on maximum crushing strength as shown by reported decreases (Nishimoto and Inoye, 1955; Wazny and Krajewski, 1987), no changes (Koukal *et al.*, 1960), or slight increases (Shibamoto and Inoue, 1962; Wood *et al.*, 1980; Mitchell and Barnes, 1986; Burmeister and Becker, 1963) as retention increases when air dried. However, maximum crushing strength can be significantly reduced when redrying temperatures exceed 180°F (70°C) (Winandy *et al.*, 1985).

Bending strength is the most studied wood property. A comprehensive review of the waterborne-preservative-treatment literature concluded that MOR was reduced from 0 to 20 percent, depending on the severity of many factors (Winandy, 1988). The magnitude of the general effect on MOR was related to waterborne preservative chemistry and redrying temperature. Thus, the effect of waterborne treatments on bending strength cannot be completely understood independently and is more fully discussed in the post-treatment redrying temperature section, after the critical influences of waterborne preservative chemistry and redrying are introduced.

A variety of other mechanical properties have also been evaluated. Tensile strength parallel-to-grain data are limited and indicate that tensile strength is affected by CCA treatment and redrying in a manner similar to MOR (Winandy *et al.*, 1992). Tensile strength perpendicular-to-grain was reported to be differentially affected in the radial and tangential direction (Bariska *et al.*, 1988), but a second study found no differential effect between tensile strength perpendicular-to-grain in the radial or tangential direction.[2] Lee (1985) evaluated shear strength parallel-to-grain and found no CCA treatment-induced effect. Hardness was unchanged (Mitchell and Barnes, 1986) or slightly increased (Williams, 1986).[3]

In summation, the effects of waterborne preservative treatment on the mechanical properties of wood under standard-specified conditions (AWPA, 1994) are as follows:

- MOE is usually unaffected.
- Maximum crushing strength is usually unaffected to slightly increased.
- MOR is often reduced from 0 to 20 percent, depending on the retention and severity of the redrying temperature employed.
- Energy-related properties are usually reduced from 10 to 50 percent.

Chemistry or Chemical Type

The magnitude of the differential effect between waterborne preservative chemical systems on strength appears small when compared to the effects of other treatment processing factors. Those differences seem to be related to waterborne preservative chemistry and the severity of that preservative's fixation/precipitation reaction. Burmeister and Becker (1963) compared 10 waterborne preservative systems and found no consistent chemistry-related differences in strength effects. Burmeister (1970) compared several chromium-containing preservatives and found no preservative-related differences in strength effects. A comprehensive study designed to detect subtle chemistry-related differences between the effects of three waterborne preservative formulations found that CCA Type A resulted in greater loss in rapid-bending strength than treatment with CCA Type B, which in turn resulted in greater losses than did treatment with ACA (Bendtsen *et al.*, 1983). Bendtsen *et al.* (1983) postulated that loss in rapid-bending strength appeared to be related to chromium content.

Winandy *et al. (1983)* showed a significant reduction in toughness following conventional full-cell treatment followed by simulated kiln redrying. These reductions ranged from 16 to 23 percent for specimens treated with 0.6 lb/ft^3 (9.6 kg/m^3) CCA Type C and from 36 to 47 percent for specimens treated with 2.5 lb/ft^3 (40 kg/m^3) when dried after treatment at 190°F (88°C). Delay between treatment and initiation of redrying had no practical effect on toughness, suggesting that from a strength-effects standpoint, it did not matter whether the CCA was rapidly fixed during the initial stages of the kiln redrying process or whether it was allowed to first undergo slow fixation at room temperature, then dried in a kiln.

Evans *et al.* (1991) noted no difference in impact bending strength for slash pine treated with CCA, CCA with a wax emulsion added to the treating solution, or CCA with an oil emulsion added when tested at 12 percent or green moisture content conditions. They concluded that the water repellent CCA had no practical effect on impact bending strength at either moisture content.

Resch and Parker (1982) compared small, clear specimens of Southern Pine and Douglas-Fir treated to 2.5 lb/ft^3 (40 kg/m^3) with ACA and CCA and found no differential effects between treatments.

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[2] Winandy, J. E. 1988. The effect of CCA treatment and redrying temperature on the perpendicular-to-grain tensile strength of small clear specimens of Southern Pine. (Unpublished data from study-4714-1-85-4) Forest Products Laboratory, Madison, WI.

[3] Pierce, B. 1986. internal report to Arizona Public Service. Tucson, AZ.

Anderson *et al.* (1993) compared small, clear specimens of Southern Pine treated to 0.6 lb/ft^3 (9.6 kg/m^3) with ACA and ACCit and found no differential effects between treatments. In another study comparing the effects of redrying after ACA- or CCA-treatment, no differences were found in their effects on bending strength between ACA- or CCA-treatments on small, clear specimens of Douglas-fir when air dried, kiln dried at 140°F (60°C), or with ACA-treated material when kiln dried at 170°F (77°C) (Winandy *et al.*, 1989). However, bending strength of CCA-treated Douglas-fir was significantly reduced when kiln dried after treatment at 170°F (77°C).

Ammoniacal copper quaternary (ACQ) treatments were found to have no differential effect on mechanical properties of small, clear specimens when comparing ACQ with Copper-to-Quat ratios of 1:1 to 1:3 to ACA or CCA Type C (Zahora *et al.*, 1991; Archer *et al.*, 1992). However, later work studying the effects of ACQ Type B (Copper-to-Quat ratio-2:1) on lumber properties found a larger reduction in bending properties with ACQ Type B when kiln redried than with CCA Type C when similarly redried (Barnes *et al., 1993).*

Effects of amine-based copper (Amine-Cu) systems, rather than ammoniacal-based systems, on mechanical properties have also recently been evaluated using limited samples of small, clear specimens (CSI, 1994 Fox *et al.*, 1994 McIntyre *et al.*, 1994). Results of these evaluations have consistently shown the effects of ACQ Type D (CSI, 1994), Copper Azole (Fox *et al.*, 1994), and Copper Dimethyldithiocarbamate (McIntyre *et al.*, 1994) to be similar to the effects of CCA.

In conclusion, the AWPA-approved waterborne preservative systems can be generally classified by their effects on strength as

(least effect)
(most effect)
ACA = ACZA = ACCit ≤ ACQ-B == Amine-Cu = CCA-C < CCA-A

However, in practical terms, other factors such as variable retention and penetration, lumber grade, and species factors have a greater effect on strength than does preservative chemistry. This makes the small differences in strength effects related to waterborne preservative chemistry of little practical importance when choosing a chemical system.

Retention

In general, waterborne preservative retention levels of ≤ 1.0 lb/ft^3 (16 kg/m^3) appear to have little negative effects on strength (Bendtsen *et al.*, 1983; Lee, 1985; Lutomski, 1976; Nishimoto and Inoye, 1955; Resch and Parker, 1982; Terentjev, 1972; Winandy *et al.*, 1985; Winandy *et al.*, 1989; Wood *et al.*, 1980). At CCA and ACA retention levels of 2.5 lb/ft^3 (40 kg/m^3), MOR is often reduced and energy-related properties are significantly reduced (Thompson ,1964 Wood *et al*, 1980; Resch and Parker, 1982; Bendtsen *et al.*, 1983; Winandy *et al.*, 1983; Winandy *et al.*, 1985).

Post-Treatment Drying Temperature

Air drying after treatment caused little apparent reduction in strength in wood treated with waterborne preservative at retention levels of ≤ 1.0 lb/ft^3 (≤ 16 kg/m^3) (Burmeister and Becker, 1963; Hesp and Watson, 1964; Bendtsen, *et al.*, 1983; Lee, 1985; Lutomski, 1976; Nishimoto and Inoye, 1955; Resch and Parker, 1982; Siemon, 1981; Winandy *et al.*, 1985; Winandy *et al.*, 1989; Wood *et al.*, 1980). However, energy-related properties were reduced (Wood *et al.*, 1980; Resch and Parker, 1982; Bendtsen *et al*, 1983; Winandy *et al*, 1983; Winandy *et al*, 1985).

Effects of waterborne preservative treatment and post-treatment kiln-drying temperature, especially the maximum dry-bulb temperature, on mechanical properties have repeatedly shown to be critical in evaluating treatment effects (Barnes and Mitchell, 1984; Bendtsen *et al.*, 1983; Siemon, 1979; Kim, 1991; Winandy *et al.*, 1985; Winandy *et al.*, 1989; Wood *et al.*, 1980).

Wood *et al.* (1980) snowed significant reductions in MOR for Southern Pine treated with CCA Type Cat a retention of 2.5 lb/ft^3 (40 kg/m^3) when exposed to in-cylinder fixation of about 212°F (100°C) using the MSU process. This same effect on MOR was not noted at a lower retention level of 1.0 lb/ft^3 (16 kg/m^3). Losses of toughness ranging from about 10 percent at 1.0 lb/ft^3 (16 kg/m^3) to 32 percent at 2.5 lb/ft^3 (40 kg/m^3) were also noted.

Bendtsen *et al., (1983)* studied the energy-to-failure in a near-impact bending scenario using a rapid bending test (0.02 s to failure) of longleaf pine treated with ACA, CCA Type A, or CCA Type B. For material kiln dried after treatment at 140°F (60°C), MOR generally decreased with increasing retention for all preservatives. This loss in rapid-bending strength associated with a redrying temperature of 140°F (60°C) was significant for CCA Type Bat a retention of 2.5 lb/ft^3 (40 kg/m^3) and for CCA Type A at retention levels of 0.6 and 2.5 lb/ft^3 (9.6 and 40 kg/m^3). Treatment with ACA resulted in significant reductions only for work to maximum load (WML), even at a retention of 2.5 lb/ft^3 (40 kg/m^3), The losses in MOR ranged from 11 to 16 percent. The losses in WML were more severe, with significant reductions ranging from about 16 to 50 percent depending on the type of treatment. Their conclusion was that kiln redrying consistently caused more severe strength loss than did air drying after treatment.

Siemon (1981) showed that high temperature redrying could double the effect of CCA treatment on MOE and MOR of Caribbean pine when compared to air drying after treatment. Kim (1991) showed that high-temperature redrying could significantly increase the magnitude of the CCA treatment effect on MOE and MOR of lodgepole pine when compared to conventual kiln drying after treatment. Barnes and Mitchell (1984) found that average MOR of Southern Pine was significantly reduced by 8 percent when redried at 190°F (88°C) and reduced by 12 percent at 240°F (116°C) when compared to untreated controls.

The relationship between CCA Type C preservative retention level and dry-bulb redrying temperature was empirically modeled and shown to have no effect on maximum crushing strength, MOR, MOE, and WML for CCA Type C retention levels from 0.25 to 1.0 lb/ft^3 (4.0 to 16 kg/m^3) and redrying of $\leq$ 140°F ($\leq$ 60°C) when compared to similarly dried controls (Winandy *et al.,* 1985). However, when redrying temperatures for small, clear CCA-treated specimens were increased to $\geq$ 180°F (82°C), MOR and WML were reduced 11 and 37 percent, respectively, and maximum crushing strength and MOE remained unaffected. For material treated to a marine (2.5 lb/ft^3 (40 kg/m^3)) retention level, they noted an even greater sensitivity to redrying temperature, At redrying of $\leq$ 140°F ($\leq$ 60°C), maximum crushing strength increased 15 percent, and WML was reduced 27 percent, and MOR and MOE were not affected. At 180°F (82°C), maximum crushing strength was increased 9 percent, and MOR and WML were reduced by 12 and 46 percent, respectively. At 220°F (104°C), maximum crushing strength was reduced 9 percent, MOR was reduced 30 percent, and WML was reduced 68 percent. They concluded that at a retention of $\leq$ 1.00 lb/ft^3 ($\leq$ 16 kg/m^3) and redrying of $\leq$ 140°F ($\leq$ 60°C), the reduction levels in strength and stiffness from waterborne preservative treatments were probably not severe enough to warrant concern. However, in instances where dry-bulb redrying exceeded 180°F (82°C), losses in bending strength became significant. Using their quadratic model, the authors suggested that redrying as high as 160°F (71°C) might be successfully used without adversely affecting allowable design stresses (Winandy *et al.,* 1985).

Mitchell and Barnes (1986) found that mean MOR was reduced 11 and 13 percent for small, clear specimens of CCA Type A treated Southern Pine (0.3 lb/ft^3 (4.8 kg/m^3)) when redried at maximum dry-bulb temperatures of 190°F and 240°F (88°C and 116°C), respectively. Mean toughness was reduced 12 and 22 percent when redried at 190°F and 240°F (88°C and 116°C), respectively. Using a three-parameter Weibull model fit to their data (64) specimens per treatment-redrying combination), they cautioned that estimated 5th percentile for MOR might be reduced even more than the mean values. For example, redrying at 190°F and 240°F (88°C and 116°C), reductions of 17 and 18 percent, respectively, in the estimated 5th percentiles were found.

Small wet-bulb depression temperatures, used during the initial hours of post-treatment kiln drying to increase heat transfer and inhibit premature drying that detracts from CCA fixation, were shown to be less critical than maximum dry-bulb temperature (Boone *et al., 1995).* Wet-bulb depression temperatures ranging from a 5°F (3°C) to 35°F (19°C) depression during the first 12 h of kiln redrying were found to have no significant differential effect on bending properties of Southern Pine and Western hemlock 2 by 4's when maximum dry-bulb temperatures were limited to <165°F (<74°C) (Boone *et al.,* 1995). However, this work did show that the ensuing leachability of the CCA-preservative was significantly altered.

In summary, waterborne preservative retention, preservative type, or species treated were not shown to be as important as maximum dry-bulb redrying temperature. The literature clearly shows that redrying temperature of waterborne preservative-treated material is critical and must be limited in AWPA standards, or else an across-the-board design adjustment factor would be needed in engineering design standards for waterborne preservative-treated lumber. As a result of these consistent strength effects from elevated redrying temperatures, the AWPA Subcommittee T-2 imposed in 1989a limitation on post-treatment kiln-drying temperature of 190°F (88°C) in Standard C-2 (AWPA 1994). In 1991, that limit was lowered to 165°F (74°C) in Standards C-2 and C-22. The reasons for these latter restrictions are discussed in a following section in this paper on the interactive effects of initial kiln-drying with post-treatment drying.

Size of Material

Although initial studies used small, clear specimens, the size and grade of material used during pretreatment, treatment, and post-treatment processing are also critical.

Two matched studies evaluated commercially graded No. 2, CCA-treated Southern Pine 2- by 6-in. (38- by 152-mm) and 2- by 4-in. (38- by 89-mm) lumber treated with CCA Type C (0.4 or 0.6 lb/ft^3 (6.4 or 9.6 kg/m^3)) and either air dried or kiln dried after treatment at 160°, 190°F, or 240°F (71°C, 88°C, or 116°C) (Winandy and Boone, 1988; Winandy, 1989). Few differences were noted between the two widths of nominal 2-in.- (38-mm-) thick lumber.

Generally, larger-sized material, specifically larger thicknesses, appear to have less strength reduction than the smaller-sized material. Recalling that preservative treatments usually only penetrate the treated material to a depth of 0.25 to 2.0 in. (6 to 51 mm), depending on species and other factors, the differential size-effect is probably a function of the surface-to-volume ratio of each product. For example, at comparable retention levels, poles and piles are generally reduced in strength far less than lumber, which in turn, is reduced in strength less than small specimens (Barnes and Winandy, 1986, 1989; Winandy, 1988).

Grade *of Material*

Barnes and Mitchell (1984) noted that although MOE was not affected, the estimated design stresses in bending (F_b) for No. 1 and better Southern Pine 2 by 6 lumber (38 by 152 mm) were reduced 1.5 to 2 times the average values when treated to 0.3 lb/ft^3 (4.8 kg/m^3) with CCA Type A, then redried using either a conventional (190°F (88°C)) or high-temperature (240°F (116°C)) schedule. They showed that F_b was reduced by 14 percent when redried at 190°F (88°C) and 19 percent at 240°F (116°C). The authors also found a direct correlation between the results of their small-scale tests (Mitchell and Barnes, 1986) and tests of 2 by 6's (Barnes and Mitchell, 1984).

Knuffel (1985) found that the maximum crushing strength of short sections of CCA-treated South African pine were reduced in the lower tails of the distributions more than were the mean values for both visual- and machine-stress rated grades. In addition, the reduction in mean maximum crushing strength and design stress in compression parallel-to-grain (F_c) tended to be greater for the higher grades of lumber. The South African lumber grades studies were V-5, V-7, and V-10, which correspond fairly well with the North American lumber grades of No. 2, No. 1, and Select Structural, respectively (USDC, 1994). These maximum crushing strength results appear to agree with the bending strength results of Barnes and Mitchell (1984).

Studies using No. 2 grade, Southern Pine 2 by 4's and 2 by 6's 6 found no differences between untreated No. 2 grade controls and CCA-treated lumber in the lower tails of the bending strength distributions below the 25th to 40th percentile (Winandy and Boone, 1988, Winandy, 1989). Thus, for the lower grades of lumber, CCA treatment did not appear to significantly reduce F_b (Winandy and Boone, 1988; Winandy, 1989) or F_c (Knuffel, 1985).

Most interestingly, Winandy and Boone (1988) and Winandy (1989) noted that as redrying temperature increased, higher redrying temperatures caused CCA-induced strength loss to occur in a lower percentile range of the bending strength distribution when compared to lower temperatures. They noted that the initial percentile level at which CCA effects first began to appear seemed to increase as grade increased. Later, in comparing these results with the work of Barnes and Mitchell (1984) and Knuffel (1985), a theory based on material quality was proposed in which the lower strength pieces of the lower grades were unaffected by CCA treatment, but the higher strength pieces of the lower grades and all pieces in the higher grades were somewhat reduced in strength (Winandy, 1991). Thus, the impact of CCA-treatment can be thought of as a quality-dependent phenomenon when comparing different grades or rank-order or percentile dependent within a single-grade distribution.

Product Type

Recent research on the effects of CCA treatments on nominal 2- by 10-in. (38-by 235-mm) scaffold planks made from Southern Pine laminated veneer lumber has shown that while average bending strength was not affected, the estimated 5th-percentile values were reduced (Woodson, 1985) when using ASTM D245 (ASTM, 1994), Reductions in design values for laminated veneer lumber of 10 percent for F_b, F_t, and F_v and by 5 percent for F_c and MOE were suggested, Thus, the magnitude of the CCA effect on strength for laminated veneer lumber conforms quite closely to CCA effects previously noted for the higher grades of solid-sawn lumber. Coincidentally, the magnitude of this CCA effect on laminated veneer lumber was similar to that using creosote treatments (Kimmel *et al.,* 1994)

The effects of waterborne preservative treatments on plywood seem comparable to lumber (Countryman, 1957; Lee, 1985; Khouadja *et al.,* 1991). In comparing the effects of CCA treatment and redrying on plywood to published results for lumber at comparable levels of retention and redrying, Khouadja *et al., (1991)* concluded that redrying limits for plywood should probably not exceed 160°F (71°C).

Fiber-based composite products seem to be reduced in strength to a slightly greater degree than lumber (Adams *et al.,* 1981). This effect in fiber-based composites may be more a function of internal bond damage caused by waterborne-preservative-treatment induced swelling than chemical hydrolysis. However, further studies are necessary to fully delineate this thought.

Initial Kiln-Drying Temperature

The susceptibility of a product to CCA-induced strength reduction also depends upon the severity of pretreatment processing factors (Winandy and Barnes, 1991). This effect may be related to the natural resistance of the wood species and size combination being considered for thermal degradation in pretreatment processing. Although initial kiln drying of Southern Pine lumber at 212°F to 240°F (100°C to 116°C) for short durations apparently has little effect on its structural properties (Koch, 1976; Yao and Taylor, 1979), it does result in more degradation of the cell wall than drying at lower-temperature kiln schedules (Thompson and Stevens, 1976). Subsequent preservative treatment and redrying of material initially dried at high temperatures causes additional hydrolytic degradation.

Initial kiln drying at 235°F (113°C) resulted in slightly larger reductions throughout the entire bending and tensile strength distributions than did initial kiln drying at 196°F (91°C) when subsequently treated with CCA (Barnes *et al* ., 1990, Winandy *et al.*, 1992). Because most Southern Pine lumber is initially kiln dried at high temperatures, the implications of these results are significant. If initial kiln-drying temperature is unlimited and redrying temperatures as high as 190°F (88°C) were maintained in AWPA standards, reduction of allowable design values would be required (Winandy and Barnes, 1991). In response to these results, AWPA in 1991 lowered its redrying temperature limit for solid-sawn lumber and timber from 190°F (88°C) to 165°F (74°C) in Standards C-2 and C-22 (AWPA, 1994).

Incising

Incising is a pretreatment mechanical process in which small slits (i.e., incisions) are punched in the surface of the wood product to improve preservative penetration and distribution in difficult-to-treat species. Incising reduces strength (Perrin, 1978); however, it is generally agreed that this strength loss is beneficial in the long-run because the increase in treatability provides a substantial increase in biological performance.

Incising is performed in conjunction with preservative treatment. Therefore, incising effects are a result of the combined effects of preservative treatment and incising, Most incising patterns induce some strength losses and the magnitude of this effect is related to the size of material being incised and the incision depth and density (i.e., number of incisions per unit area). In $\leq$ 2-in. ($\leq$ 50-mm) lumber, incising and preservative treatment induced losses in MOE of 5 to 15 percent and in static strength properties of 10 to 30 percent (Kass, 1975; Lam and Morris, 1991).

In huger materials, lower incision density and greater incision depth are often used. Incising at an incision density of $\leq 140/ft^2$($\leq 1500/m^2$) and 0.75-in. (19-mm) depth reduced strength by 5 to 20 percent when applied to creosoted timbers or tie stock (ByranL 1953; Harkom and Rochester, 1930; Harkom and Alexander, 1931; Luxford, 1926; Rawson, 1927; Schrader, 1945; Watkins and Wilson, 1920). Chudnoff and Goytia (1967) found a similar reduction in strength of 15 percent with posts. Little effect on Douglas-fir poles were found with 19-mm-deep, slit-like incisions, but increasingly larger reductions in pole strength were noted from 8 to 23 percent when evaluating 4-in. - (100-mm-) deep radial incisions, 0.5-in.- (12-mm-) diameter borings to l/2-pole diameter deep, and 0.5-in. - (12-mm-) diameter thru-borings, respectively (Graham *et al.,* 1969). Nunomura and coworkers found little strength loss on timbers ≥ 5 in. (≥ 125 mm), but noted that with smaller sizes incision density increased from 95 to 560/ft^2 (1,000 to 6,000/m^2), strength reductions increased up to 20 percent (Nunomura *et al.*, 1982; Nunomura and Saito, 1983). Strength reductions of 15 to 20 percent were reported when incision density increased from 70 to 380/ft^2 (750 to 4000/m^2) or when incision depth increased from 0.4 to 0.75-in. (10 to 19 mm) (Kass, 1975). Further, as incision density or depth increased, embrittlement occurred because energy-related mehanical properties, such as WML, were shown to be reduced by as much as 50 percent. Peyresaubes (1985) reported that as the same incising density was applied to progressively smaller sizes, strength reduction increased.

In the first study of high density incising, Banks (1973) reported strength reductions of 15 percent when evaluating knife incising at a density of 800/ft^2 (8500/m^2). During the past 10 years, the most intensive research on the effects of micro-knife incising has been carried out at Forintek-Canada. Several unpublished Forintek-Canada Ltd. projects indicate that incising of nominal ≤ 2-in. (≤ 50-mm) material could induce significant reductions in strength, especially when incision density exceeded 950/ft^2 (10,000/m^2). In a recent study, double-density knife-incising at a density of >950/ft^2 (>10,000/m^2) was shown to reduce MOE by 5 percent and strength by 15 percent (Lam and Morris, 1991).

DESIGN MODIFICATIONS

This literature review of the preservative - treated effects on wood shows that the majority of studies evaluated bending properties. Our knowledge of treatment effects on other properties is limited and based primarily on inference of bending data to these other properties.

During the past decade, several AWPA standards have incorporated post-treatment temperature limits on maximum dry-bulb temperature in an effort to preclude adjustments in the engineering design process. Thus, AWPA-processing limits serve as a means of avoiding design stress adjustments by engineers. As a result, few modifications in the engineering design process are currently required if material is treated with waterborne preservatives under AWPA standards (1994). Today, the only adjustment in standard design procedures for waterborne preservative-treated materials in the United States involves a restriction on impact loading of marine-treated material. However, several potentially important revisions are being considered. These revisions include a design adjustment for incising, in-service temperature, in-service moisture content, and short-term load duration, and each is reviewed in the following sections.

Incising

In 1989, the Canadian Standards Association (CSA, 1989) adopted a 10-percent reduction in MOE and a 30-percent reduction in all strength properties for dry-use conditions and a 5-percent reduction in MOE and a 15-percent reduction in strength properties for wet-use conditions. These latter incising factors for wet-use conditions are applied in addition to the traditional wet-use service factor which recognizes that green lumber is not as strong as dry lumber. The U.S. Design Guide has not adopted incising factors (AFPA, 1991), but is studying the problem through a task group that may soon make a recommendation for the use of incised and treated wood in engineered applications. Until more information is available, the limited technical literature supports a 10-percent reduction in MOE and a 20- to 25-percent reduction in dry-use allowable design stresses (F_b, F_t, F_c, F_v) for nominal 2-in.- (50-mm-) thick lumber and a 0-to 10-percent reduction for thicker material. The wet-use adjustment would probably be less.

In-Service Temperature

The effect of four waterborne preservatives on the toughness of four softwood species were evaluated during a 24-year exposure in a cooling tower (Baechler *et al.*, 1966; Gjovik *et al.*, 1972)[4].

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[4] Bendtsen, B. A. and L. R. Gjovik. 1990. Evaluation of waterbome-preservative-treated cooling tower slats after 24 years of exposure. Personal communications. USDA Forest

No changes in toughness between species or waterborne preservatives were noted during the four evaluations during the 24-year exposure at $\leq$ 120°F ($\leq$ 49°C). Comparable results were reported for impact bending strength (Pechman and Aufsess, 1968) and compression parallel-to-grain strength (Wazny and Krajewski, 1992) after near-room temperature exposures for up to 5 years. The effects of CCA Type C on MOR after high temperature exposures of 60 and 160 days at 150°F (66°C) and 75-percent relative humidity were recently evaluated (Winandy, 1994). Results indicated that CCA treatment accelerated the thermal degradation of bending strength when compared to matched untreated lumber. These results indicate that for waterborne-preservative-treated lumber, the design adjustment factor for in-service exposure temperature (currently based on the factor for untreated lumber), might need to be lowered for waterborne-preservative-treated material exposed between 125°F to 150°F (52°C to 66°C).

In-Service Moisture

Recall that published design values (AFPA, 1991) apply to material dried <19 percent maximum (and 15 percent average). If the design engineer anticipates that untreated wood will be exposed to moisture content $\geq$ 19 percent, design values are adjusted (i.e., modified) by applying the wet-use service factor (C_M of 0.85 for MOR and 0.9 for MOE (Table 1). A recent study evaluated the influence of moisture content on the effect of CCA-treatments on bending strength (Winandy, 1995a). This study found that the difference in the effect of changing moisture content on MOE seldom exceeded 5 percent when compared to untreated material. Thus, the application of the traditional C_M factor based to untreated and CCA-treated material appeared acceptable for estimating the effects of moisture content on MOE. However, a distinct negative effect on MOR was noted when tested at 10-percent moisture content. Thus, it would appear that applying the traditional C_M factor for untreated material to the higher grades of CCA-treated material <5-percent moisture content is unwarranted.

Previous work concluded that few species-related, preservative chemical-related, or chemical retention-related differences existed. It was also concluded that material quality factors (such as grade) and processing factors (such as redrying and initial kiln-drying temperature) were critical. This new work (Winandy, 1995a) is in agreement with the previous work in that the moisture content-influenced strength effect is related to grade. For green material, the traditional CM factor for MOR of untreated wood seemed to adequately describe CCA-treated bending strength for all grades (Table 1). Further, based on results from previous studies of No. 2 grade lumber tested at 12-percent moisture content, use of a C_M factor of 1.0 (i.e., no adjustment) for No. 2 grade, waterborne-preservative-treated lumber also seemed acceptable. However, for No. 1 and better grade, waterborne-preservative-treated material at moisture content $\leq$ 15 percent, these recent data support the need for a modified C_M factor of 0.9 on F_b (Table 1). Such a modification for the C_M factor is proposed.

Load Duration

Reductions are currently not required in allowable design stresses (10-year loading) for lumber treated with waterborne preservatives (AFPA, 1991). However, reductions in energy-related properties are usually about 1.5 to 2 times those reported for static strength properties. This then leads to the only exception in the design standards (AFPA, 1991) for preservative-treated material, that being the design engineer can not modify (increase) allowable design stresses when considering impact-type loading for material treated to marine retention levels with waterborne preservatives,

When the possibility of a design adjustment factor for the long-term loading portion of the duration-of-load (C_D) phenomenon was evaluated for CCA Type C-treated, No. 2 grade, Southern Pine 2 by 4's, Soltis and Winandy (1989) found that changes in a treated-materials performance under extended dead loading occurred at or above the 40th percentile of the static strength distribution. However, they concluded that because design stresses were derived for estimated 5th-percentile values, the existing C_D factor for untreated lumber could be applied to treated material exposed to long-term loading.

The performance of treated wood to impact

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loading sceneries was a different story. A recent study showed significant differences in bending strength related to short-term ramp loads between No. 1 and better untreated and CCA-treated Southern Pine 2 by 4's (Winandy, 1995b). The bending strength of CCA-treated lumber exhibited less short-term time-dependent increase in strength than did matched untreated 2 by 4's. Most importantly, the lower strength CCA-treated specimens consistently failed to exhibit time-dependent strength increases when compared to matched untreated material. These results infer that existing North American design guidelines for duration-of-load adjustments under impact loading sceneries for CCA-treated lumber, which are based on untreated lumber, should not be applied. Further, this report suggested that applicability of the load-duration factor for dynamic wind/earthquake loads, which in North America are assumed to last for $\leq$ 600 s (AFPA, 1991), to CCA-treated material appeared questionable because of the consistent lack of strength increase exhibited in the lower tails of the bending strength distribution between time-to-failure of 300 to 600 s and 30 to 60 s. Accordingly, Winandy (1995b) proposed that the traditional load-duration curve (AFPA, 1991) for untreated lumber should be modified when load-duration factors are applied to CCA-treated lumber (Fig. 1). Such a modification for short-term portion of the C_D factor is proposed.

CONCLUSIONS

Waterborne-preservative treatments were shown to generally reduce the mechanical properties of wood. The effects of waterborne preservatives on mechanical properties were shown to be directly related to several key wood material factors and pretreatment, treatment, and post-treatment processing factors. The key factors included preservative chemistry or chemical type, retention, post-treatment drying temperature, initial kiln-drying temperature, grade of material, and incising (if required). Each factor was reviewed and shown to have the potential of influencing the effects of the treatment on mechanical properties. Finally, the interactive nature of the processing and chemical factors was shown. Thus, it is evident that these factors must always be considered when attempting to define the effects of waterborne preservatives on mechanical properties.

LITERATURE CITED

Adams, R.D., S. Matteer, G.P. Krueger, [and others]. 1981. Composite wood material utility poles. Report No. EPRI-EL-1745, Electric Power Research Institute, Palo Alto, CA.

AAFPA. 1991. National Design Specification for Wood Construction. American Forest and Paper Association, Washington, DC. 125 p..

ASTM. 1994. The ASTM Book of Standards. American Society for Testing and Materials, Philadelphia, PA.

AWPA 1994. The AWPA Book of Standards. American Wood Preservers' Association, Woodstock, MD.

Anderson, T.C., Inwards, R.D., Leach, R.M., [and others]. 1993. A proposal for standardization of ammoniacal copper citrate: Submitted to AWPA Committee P—4 and the General Preservatives Committee. Osmose Wood Preserving, Inc., Buffalo, NY.

Archer, K.J., Jin, L., Preston, A.F., [and others]. 1992. ACQ: proposal to AWPA to include ACQ in AWPA Treatment Standards. Chemical Specialties, Inc., Charlotte, NC.

Baechler, R.F., Bendtsen, B.A., Roth, H.R. 1966. Preservative treatment of cooling tower slats. Heating, Piping, & Air Conditioning 38(4):121–123.

Banks, W. B. 1973. Preservative penetration in spruce. Timber Trades J. 285:51–53.

Bariska, M., Pizzi, A., and Conradie, W.R. 1988. Structural weakening of CCA-treated timber. Holzforschung 42(5):339–345.

Barnes, H.M. 1985. Effect of steaming temperature and CCA retention on mechanical properties of Southern Pine. Forest Prod. J. 35(6):31–-2.

Barnes, H.M. and Mitchell, P.H. 1984. Effects of post-treatment drying schedule on the strength of

CCA-treated Southern Pine dimension lumber. Forest Prod. J. 34(6):29–33.

Barnes, H.M. and S. Moore. 1987. The effects of post-treatment drying schedule on the modulus of elasticity of CCA-treated Southern Pine dimension stock using nondestructive methods. IRG/WP/3413, Stockholm, Sweden.

Barnes, H.M. and Winandy, J.E. 1986. The effect of seasoning and preservatives on the properties of treated wood. Proc. of the Am. Wood Pres. Assn. 82:95–105. Barnes, H.M.; Winandy, J.E. 1989. Mechanical properties of CCA-treated Southern Pine after post-treatment kiln-drying. Document No. IRG/WP/3543. IRG Secretariat. Stockholm, Sweden

Barnes, H.M., Lyon, D.E., Zahora, A.R., and Muisu, F. 1993. Strength properties of ACQ-treated Southern Pine lumber. Proc. Am. Wood Pres. Assn. 89: 51–60.

Barnes, H.M.; Winandy, J E.; Mitchell, P.H. 1990. The effect of initial and post-treatment drying temperature on the bending strength of CCA-treated Southern Pine. J. Inst. Wood Sci. 11(6):222–230.

Becker, H. 1966. Chemical and technical properties of modern wood preservative for building construction (A review of the literature). Seifen-Ole-Fette-Wachse 92(26):991–1009. (Ger.) (translation by Library, Environment Canada, Ottawa, No. OOENV-TR-1200, 1976).

Bendtsen, B.A., Gjovik, L.R., Verrill, S.P. 1983. Mechanical properties of longleaf pine treated with waterborne salt preservatives. USDA Forest Service Res. Pap. FPL–434. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison WI.

Betts, H.S. and Newlin, J.A. 1915. Strength tests of structural timbers treated by commercial wood-preserving. USDA Bull. No. 286. Washington, DC.

Boone, R.S., Winandy, J.E., and Fuller, J.J. 1995. Effects of redrying schedule on preservative fixation and strength of CCA-treated lumber. Forest Prod. J. 45(3).

Bryant, B.S. 1953. Effect of incising on the bending strength of crossarms. Forest Prod. J. 3(6):47–48, 88.

Burmeister, A. 1970. Long-term effect of wood preservatives on physical and mechanical wood properties. Holz als Roh– und Werkstoff 28(12):478–485 (Ger.).

Burmeister, A. and Becker, G. 1963. Investigations on the influence of wood preservatives on the strength of wood. Holz als Roh– und Werkstoff 21(10):393–409 (Ger.).

Chemical Specialties, Inc., 1994. ACQ Type D: proposal to AWPA Technical Committees to include ACQ Type D in AWPA Standards: P5, C1, C2, C15, C9, and M6. Charlotte, NC.

Chudnoff, M. and Goytia, E. 1967. The effect of incising on drying, treatability, and bending strength of posts. Res. Pap. ITF–5, Rio Piedras, PR: U.S. Department of Agriculture, Forest Service.

Countryman, D. 1957. Effect on plywood strength of preservative treatment. Laboratory Rep. No. 74. Douglas-fir Plywood Association, Tacoma, WA.

CAS. 1989. Standard 086.1M: Code on engineering design in wood. Canadian Standards Association, Rexdale, Ontario, CANADA.

Dahlgren, S. and Hartford, W. H. 1972. Kinetics and mechanisms of fixation of Cu-Cr-AS wood preservatives Holzforschung 26:62-66.

Evans, P.D., Beutel, P., Hoggett, A.J., and Stodart, D.M. 1991. The impact bending strength of slash pine after preservative treatment. Holz als Roh– und Werkstoff 49:270.

Fox, R.F., Pasek, E.A. DeShan, P.N.[and others]. 1994. Copper Azole Wood Preservatives: Proposal to AWPA Preservatives Committees to include copper Azole in AWPA Standard: P5. Hickson Corp., Conley, GA.

Gjovik, L.R., Bendtsen, B.A., Roth, H.G. 1972. Condition of Preservative-treated cooling tower slats after 10-year Service. Forest Prod. J. 22(4):35–40.

Graham, R.D., Miller, D.J.; and Kunesh, R.H. 1969. Pressure treatment and strength of deeply perforated Pacific Coast Douglas-fir poles. In: Proc. Am. Wood Pres. Assn. 65th Annual Meeting. American Wood Preservers' Association, Woodstock, MD. 234241.

Gregory, D.S. 1915. Strength tests of structural timber treated with commercial preservatives. U.S. Dept. Agriculture, Bull. No. 186.

Harkom, J.F. and Alexander, J. B. 1931. Strength tests of creosoted Douglas-fir railway ties. Dept Interior Canada, Forest Service Circ. No. 29. Ottawa, Ontario, Canada.

Harkom, J.F. and Rochester, G.H. 1930. Strength tests of creosoted Douglas-fir railway beams. Dept Interior Canada, Forest Service Circ. No. 28. Ottawa, Ontario, Canada.

Hatt, W.K. 1906. Experiments on the strength of treated timber. USDA Forest Service, Circ. No. 39, Washington, DC. p. 31.

Hatt, W.K. 1927. Effects of steaming on wood. American Railway Engineers Association Bull. 295:1164–1186.

Hesp, T. and Watson. R.W. 1964. The effects of water-borne preservatives applied by vacuum pressure methods on the strength properties of wood. Wood 29(6):5O–53.

Hunt, G.M. 1915. Temperature changes in wood under treatment. Proc. of the Am. Wood Pres. Assn. 11:85–89.

Kass, A.J. 1975. Effect of incising on bending properties of redwood dimension lumber. Res. Pap. FPL–RP–259. Madison, WI: U.S. Department of Agriculture, Forest Service. Forest Prod. Lab.

Kim, G.H. 1991. The effects of drying schedules on the bending properties of lodgepole pine dimension lumber treated with CCA. Mokchae Konghak 19(2):65–71.

Kimmel, J.D., Janowiak, J.J. Baileys, R.T., and Merrick, P. 1994. Characteristics of creosote-treated LVL materials. Forest Prod. J. 44(5):49–53

Khouadja, A., Barnes, H.M., and Lyons, D.E. 1991. Properties of CCA-treated Southern Pine plywood after redrying. Proc. Am. Wood Pres. Assn. 87:82–99.

Knuffel, W.E. 1985. The effect of CCA preservative treatment on the compression strength of South African structural timber. Holzforschung und Holzverwertung 37(5):96–99.

Koch, P. 1976. Strength of Southern Pine lumber dried at high temperatures. Proc. Research conference on high-temperature drying effects on mechanical properties of softwood lumber; February 25–26. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 38–49.

Koukal, M., Bednarlik, V., and Medricka, S. 1960. Effect of PCP and NaPCP on increasing the resistance of waterproof plywood to decay and on its physical and mechanical properties. Dres. Vysk. 5(1):43–60. (trans. by US Dept of State for USDA Forest Products Laboratory Trans No. 1962–102).

Kozlik, C.J. 1968. Effect of kiln-drying temperature on the strength of Douglas-fir and hemlock dimension lumber. Oregon State University, Forest Research Laboratory Rep. No. D-11. 20 p.

Lacey, W.S. 1983. Tests at Philadelphia Electric Company demonstrate that CCA treated distribution poles are not brittle. Proc. of the Am. Wood Pres. Assn. 79:179–182.

Lam, F., and Morris, P.I. 1991. Effect of double-density incising on bending strength of lumber. Forest Prod. J. 41(9):43–47.

Lebow, S.T. 1992. Interactions of ammoniacal copper zinc arsenate (ACZA) wood preservatives with Douglas-fir. Ph.D Thesis. Dept. Forest Products, Oregon State University, Corvallis, OR. 112 p.

Lee, A.W.C. 1985. Effect of CCA-treating and air-drying on the properties of Southern Pine lumber and plywood. Wood Fiber Sci. 17(2):209–213.

Loubinoux, B., Malek, H., Joly, J.P., and Kilbertus, G. 1992. Interaction of quaternary ammonium salts with wood: influence of cation and anion structure on fixation and leaching. Forest Prod. J. 42(10):55–58.

Luther, B. 1921. The effect of zinc chloride process of preservation on the strength of structural timber. Proc. Am. Wood Pres. Assn. 17:89–114.

Lutomski, K. 1976. Effect of treatment conditions using hot-cold method of inpregnating pine wood with water solutions of salts on static bending strength. Zesz. Probl. Postepow. Nauk. Rohl. Z. 178:143–152.

Luxford, R.F. 1926. Effect of perforations on the strength and treatment of Douglas-fir. Masters Thesis. Dept. Civil Eng., Univ. of Minnesota. St. Paul, MN.

Luxford, R.F. and MacLean, J.D. 1951. Effect of pressure treatment with coal-tar creosote on the strength of Douglas-fir structural timbers. Rep. No. D179. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI.

MacLean, J.D. 1927. Steam treatments: Report to Committee 8-1. Proc. Am. Wood Pres. Assn. 23:189–195.

MacLean, J.D. 1951. Rate of disintegration of wood under different heating conditions. Proc. Am. Wood Pres. Assn. 47:155–168.

MacLean, J.D. 1952. Preservative treatment of wood by pressure methods. U.S. Department of Agriculture Ag. Handb. No. 40. Madison Wı. 160 p.

MacLean, J. D. 1953. Effects of steaming on the strength of wood. Proc. Am. Wood Pres. Assn. 49:88–112.

McIntyre, C.R., Stokes, D.K., Freeman, M.H., and Arsenault, R.D. 1994. Copper Dimethyldithiocarbamate (CDDC): proposal to AWPA Subcommittees T-1, T-2, and T-7 to include CDDC in AWPA Standards: C1, C2, C15, C16, C17, C24, C25, and M6. ISK Biosciences, Memphis, TN.

McMillen, J.M., and Drow, J.T. 1956. Effect of kiln drying on the strength of red oak pressure treated with waterborne preservatives. Unpub. rep. to Bureau of Ships, U. S. Navy, under Contract No. BUSHIPS/1700.S-537-July 1, 1955. Washington, DC.

Mickelwright 1990. Wood preservation statistics. Proc. Am. Wood Pres. Assn. 86:258–272.

Mitchell, P.H. and Barnes, H.M. 1986. The effect of drying schedule on the clear wood strength of Southern Pine treated with CCA-Type A. Forest Prod. J. 33(6):53–58.

Nishimoto, K.S. and Inoye, Y. 1955. On the properties of treated wood. Wood Res. Bull., Wood Res. Inst., Kyoto Univ. No. 14:527–536.

Nunomura, A. and Saito, M. 1983. The effects of incising on the strength and preservative penetration of the lumber of softwood—Part II. J. Hokkaido For. Prod. Res. Inst., 378:12–16.

Nunomura, A., Saito, M., and Kasai, A. 1982. The effects of incising on the strength and preservative penetration of the lumber of Hokkaido softwood—Part I. J. Hokkaido For. Prod. Res. Inst. 371:12–14.

Ostmeyer, J.G. 1987. Chemical and mechanical evaluation of Southern Pine wood treated with chromated copper arsenate. Ph.D Thesis, Auburn University, Auburn, AL.

Ostmeyer, J.G., Elder, T.J., Littrell, Taterchuk B.J., and Winandy, J.E. 1988. Spectroscopic analysis of Southern Pine treated with chromated copper arsenate. I. X-ray photoelectron spectroscopy (XPS). J. Wood Chem. and Technol. 8(3):413–439.

Ostmeyer, J.G., Elder, T.J., and Winandy, J.E. 1989. Spectroscopic analysis of Southern Pine treated with chromated copper arsenate. II. Diffuse reflectance Fourier transform infrared spectroscopy (DRIFT). J. Wood Chem. and Technol. 9(1):105–122.

Pechman, H., and Aufsess, H. 1968. On the influence of various wood preservatives on the impact bending strength of beech, pine, and spruce. Holz als Roh. und Werkstoff 26(12):454–62.

Perrin, P.W. 1978. Review of incising and its effects on strength and preservative treatment of wood. Forest Prod. J. 28(9):27-33.

Peyresaubes, R. 1985. Incising of refractory timbers as an aid to effective preservation, J. Inst. Wood Sci. 10(4):170–177.

Rawson, R.H. 1927. The influence of incising and creosote treatment on 6 by 12 Douglas-fir beams. Proc. Am. Wood Pres. Assn. 23:203–213.

Resch, H. and Parker, R. 1982. Strength and stiffness of preservative-treated marine piles. Wood and Fiber 14(4):310–319.

Ruddick, J.N.R. 1979. Nitrogen content of ACA-treated wood. Mater. Org. 14(4):301–311.

Schrader, O.H. 1945. Tests on creosoted laminated beams, Eng. News-Record 135(20):80–83.

Shibamoto, T. and Inoue, S. 1962. Studies on waterborne wood preservatives (IX): Properties of treated wood with a preservative of flour-chrome-arsenic-phenol mixture type. Bull. Tokyo Univ. For. No. 56:349–380.

Siemon, G.R. 1981. Effect of C.C.A.—Preservative treatment on bending strength of small clear specimens of high-temperature-dried and air-dried Caribbean pine. Tech, Pap. No. 27. Department of Forestry, Queensland, Australia.

Soltis, L.A.; Winandy, J.E. 1989. Long-term strength of CCA-treated lumber. Forest Prod. J. 39(5):64–68.

Terentjev, V. 1972. Effect of KM-5 preservative on the mechanical properties of wood. Derev. Prom. 21(8):15-16.

Thompson, W.S. 1964 Effect of preservative salts on properties of hardwood veneer. Forest Prod. J. 14(3):124–128.

Thompson, W.S. and Stevens, R.R. 1976. Influence of thermal treatments on the mechanical properties of wood: A review of research at Mississippi Forest Products Laboratory. Proc., Research conference on high-temperature drying effects on mechanical properties of softwood lumber; February 25-26. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 81–100.

Thunell, B. 1941. Statens Provoningsanstalt. Stockholm (In Swedish). trans. by H. Becker 1966 Seifen-Ole-Fette-Wachse (Soaps Oils Fats Waxes) 92(26):991–1009.

USDC. 1994. American Softwood Lumber Standard PS-20-94. U.S. Department of Commerce., National Institute for Standards and Technology, Gaithersburg, MD. p. 25.

Watkins, J.R. and Wilson, T.R.C. 1920. Tests of perforated and unperforated Douglas-fir sticks—Creosoted and natural. Unpub. rep. U.S. Department of Agriculture, Forest Service. Forest Products Laboratory, Madison, WI.

Wazny, J., Krajewski, K.J. 1987. Untersuchungen uber den einfluss von holzschutzmitteln auf die druck- und biegefestigkeit des kiefernholzes. Holztechnologie 28(5):239–243. (ger.)

Wazny, J., Krajewski, K.J. 1992. Long-term effect of CCA and NaPCP preservatives on the compression strength of Radiata pine sapwood. Holzforschung 46(6):533–535.

Williams, A.D. 1986. Effect of preservative treatment on the hardness of Southern Pine posts. Proc. Am. Wood Pres. Assn. 82:231–237.

Wilson, T.R.C. 1930. The effect of creosote on strength of fir timbers. Timberman 31(8):50–56.

Wilson, T.R.C. and Bateman, E. 1921. Results of some tests on the effect of zinc chloride on the strength of wood. Proc. Am. Wood Pres. Assn. 17:80–88.

Winandy, J.E. 1988. Effects of treatment and redrying on the mechanical properties of wood. IN: Wood protection techniques and the use of treated wood in construction. M. Hamel ed. Forest Products Research Society Madison WI. 54–62.

Winandy, J.E. 1989. The effects of CCA preservative treatment and redrying on the bending properties of 2 by 4 Southern Pine lumber. Forest Prod. J. 39(9):14–21.

Winandy, J.E. 1991. Impact of preservative and fire-retardant treatment on allowable design stresses. Wood Design Focus 2(1):14–16.

Winandy, J.E. 1994. Effects of long-term elevated temperature on CCA-treated Southern Pine lumber. Forest Prod. J. 44(6):49–55.

Winandy, J.E. 1995a. The effect of moisture content on the strength of CCA-treated lumber. Wood Fib. Sci. 27(2).

Winandy, J.E. 1995b. The Influence of time-to-failure on the strength of CCA-treated lumber. Forest Prod. Jour. 45(3).

Winandy, J.E., Barnes, H.M. 1991. The influence of initial kiln-drying temperature on CCA-treatment effects on strength. Proc. Am. Wood Pres. Assn. 87:147–152.

Winandy, J.E., Boone, R.S. 1988. The Effects of CCA preservative treatment and redrying on the bending properties of 2 by 6 Southern Pine lumber. Wood Fib. Sci. 20(3):50–64.

Winandy, J.E., Barnes, H.M.; Mitchell, P.H. 1992. The effect of initial and posttreatment drying temperature on the tensile strength of CCA-treated Southern Pine. J. Mater. Civil Eng. 4(3):240–251.

Winandy, J.E., Bendtsen, B A., and Boone, R S. 1983. The effect of time-delay between CCA preservative treatment and redrying on the toughness of small clear specimens of Southern Pine. Forest Prod. J. 33(6):53–58.

Winandy, J.E., Boone, R.S., and Bendtsen, B.A. 1985. The interaction of CCA preservative treatment and redrying: effects on the mechanical properties of Southern Pine. Forest Prod. J. 35(10):62–68.

Winandy, J.E., Boone, R.S., Gjovik, L.R., and Plantinga, P.L. 1989. The effects of ACA and CCA preservative treatment and redrying: effects on the mechanical properties of small clear specimens of Douglas-fir. Proc. Am. Wood Pres. Assn. 85:106–118.

Wood, M.W., Kelso K.C. Jr., Barnes, H.M. and Parikh, S. 1980. Effects of the MSU process and high preservative retentions on Southern Pine treated with CCA–Type C. Proc. Am. Wood Pres. Assn. 76:22–37.

Woodson, G.E. 1985. Evaluation of mechanical properties of laminated scaffold plank. Project No. 85-1. School of Forestry, Louisiana Tech University, College of Life Sciences, Ruston, LA.

Yao, J.; Taylor, F. 1979. Effect of high-temperature drying on the strength of Southern Pine dimension lumber. Forest Prod. J. 29(8):49–51.

Zahora, A.R., Richardson, N.G., Jin, L.[and others]. 1991. ACQ: proposal to AWPA to include ACQ in AWPA Standard P5. Chemical Specialties, Inc., Charlotte, NC.

Zarudnaya, G.I., Katayev, O.A., and Filipov, A.E. 1980. Dependence of the strength of preserved wood on density and absorption. Lesnoi Zhurnal 1980(1):53–55. (translation by D. Pronin, Dec. 1981, USDA Forest Products Laboratory, Madison, WI).

SESSION CHAIRMAN YEADON: Thank you, Jerry.

Our next speaker is Mark Wright, project engineer with New York State Electric & Gas Corp. He manages the distribution pole maintenance program in upstate New York. He's worked for New York State Electric & Gas for 15 years. He's a 1979 graduate of the State University of New York, College of Environmental Science and Forestry, Syracuse; with a Masters Degree in Science and Wood Products Engineering from the same college in 1992, working on the project that is described in this paper.

Over the 15 years of his employment, Mark has taken part in research conducted in cooperation with many universities and having to do with utility wood pole management. The title of Mark's paper is, "Performance of Utility Pole Strength Prediction Techniques."

Table 1—Proposed service-use modification factors (C_M) for various in-service moisture content levels of CCA-treated lumber to predict strength loss for treated lumber for all grades except as noted (Winandy, 1995a).

Service moisture content (percent)	Untreated C_M factor		CCA-Treated C_M factor	
	MOE	F_b	MOE	F_b
>19	0.9	0.85	0.9	0.85
≤19	1.0	1.0	1.0	0.9[a] 1.0[b]
≤12	1.0	1.0	1.0	0.9[a] 1.0[b]

[a] No. 1 and better grade.

[b] No. 2 grade.

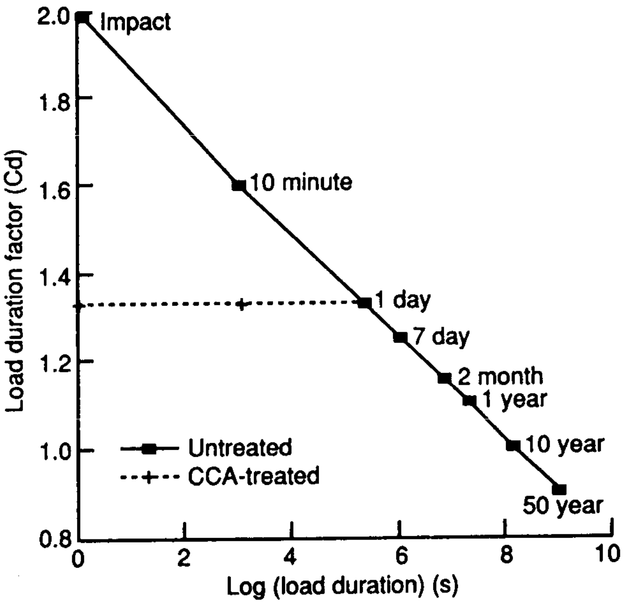

Figure 1. Proposed revision of short-term dynamic load-duration factors (C_D) for CCA-treated lumber (Winandy, 1995b).

PROCEEDINGS

Ninety-First Annual Meeting

of the

AMERICAN WOOD-PRESERVERS' ASSOCIATION

Marriott Marquis Hotel
New York, New York
May 21-24,1995

VOLUME 91

AMERICAN WOOD-PRESERVERS' ASSOCIATION
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