EFFECTS OF INCISING ON LUMBER STRENGTH AND STIFFNESS: RELATIONSHIPS BETWEEN INCISION DENSITY AND DEPTH, SPECIES, AND MSR GRADE

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ABSTRACT

This report describes the relationship of incising-induced strength loss in bending as a function of preservative treatment and incising pattern, density, and depth of penetration for various machine-stress-rated (MSR) grades of full-size 2 by 4 Douglas-fir, Hem-Fir, and Spruce-Pine-Fir (South) dimension lumber. This study may represent a worst-case "incising effects" scenario: although the incising patterns and depths selected for study represent commonly used industrial practices. the incising process itself was performed on dry lumber, which is not the standard practice of the treating industry. As we had expected on the basis of Canadian results, incising affected bending properties. such as modulus of elasticity, modulus of rupture, and work to maximum load. Our results show that the combined incising-preservative effect on mean property values for lumber incised in the dry condition prior to treatment was in the range of a 0 to 10% loss in modulus of elasticity, 15% to 25% loss in modulus of rupture, and 30% to 50% loss in work to maximum load. The effect on properties at the lower end of the distribution, such as the allowable stress design value F_b was equal to or less than that on mean properties for the three species groups evaluated. While these results specifically apply to only MSR-graded standard 38-mm- (nominal 2-inch-) thick lumber and to lumber incised in the dry condition prior to treatment. they do imply that the new U.S. design adjustments for C_i in modulus of elasticity of 0.95 and F_b of 0.85 may not be sufficient for incised and treated material used in dry in-service conditions.

Keywords: Incising, preservative, treatment, mechanical properties, lumber, Douglas-fir, Hem-Fir, Spruce-Pine-Fir (South), MSR, grade.

INTRODUCTION

Difficult-to-treat (refractory) species must be incised prior to preservative treatment to meet minimum penetration and retention requirements for preservative-treated wood (AWPA 1997). Incising is a pretreatment process in which small incisions or slits are punched into the wood. Incising increases preservative retention and penetration during the treating process by increasing the amount of exposed, easily penetrated end-grain and by increasing the side-grain surface area. While incising has been used since the 19th century, the process appears to have developed casually with little consideration given to optimizing the process to maximize pre-

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servative penetration and minimize strength loss. For example, while U.S. Treating Standards (AWPA 1997) require incising, they do not define or recommend what type, how deep, or how many incisions are required. Generally, it appears that the more effective an incising pattern is in achieving preservative penetration, the more it reduces strength (Kass 1975; Perrin 1978; Winandy et al. 1995).

Incising effects result from the combined effects of preservative treatment and incising-related mechanical damage to the wood. While a majority of chemical effect studies have utilized non-incised, chromated copper arsenate (CCA)-treated pine, a number of studies have dealt with the effects of incising on the more difficult-to-treat species. A recent comprehensive review of this literature on incising effects concluded that most incising patterns induce strength losses, but this effect is highly related to material size and incision depth and density (that is, number of incisions per unit area) (Winandy et al. 1995). Throughout the 1980s, intensive research on the effects of micro-knife incising was carried out at Forintek-Canada Ltd. Several unpublished Forintek-Canada reports indicated that incising of 38-mm-thick (nominal 2-in.-thick) materials could induce significant reductions in strength, especially when incision density exceeded 10,000 incisions/m^2 (1,000 incisions/ft^2). In 38-mm-thick (nominal 2-in. -thick) materials. incising and preservative treatment induced 5% to 15% loss in modulus of elasticity (MOE) and 10% to 30% loss in static strength properties (Kass 1975; Lam and Morris 1991; Perrin 1978). For less dense patterns (5,000-8,000 incisions/m^2 (500-800 incisions/ft^2)), more shallow incisor depth, thicker material ($\geq$ 140 mm thick (nominal $\geq$ 6 in. thick)), and perhaps 90-mm (nominal 4-in.) material, the effects of incising would probably not be as great as the recommended incising adjustment (C_i) factors (Winandy et al. 1995).

As a result of these findings, the Canadian Standards Association (CSA 1989) adopted a 10% reduction in MOE and 30% reduction in other strength properties for dry-use conditions and a 5% reduction in MOE and 15% reduction in other strength properties for wet-use conditions. These wet-use incising factors are applied in addition to the traditional wet-use service factor, which recognizes that green lumber is not as strong as dry lumber. In the United States, the new 1997 National Design Specification for Wood Construction (NDS) (AF&PA 1997) recommends an allowable stress design adjustment factor (C_i) for treated and incised lumber. The NDS-recommended C_i factor imposes a 5% reduction in MOE and 15% reduction in allowable design stress in bending (F_b) for both dry and green material.

The most appropriate theory to predict strength loss from incising was originally proposed by Luxford and Zimmerman (1923). This theory holds that the effect of the incising process is directly related to the change in section modulus induced by incising. In other words, the effect of depth of incision is quadratic, while the effect of density of incision is linear. This approach was supported by nondestructive evaluations of MOE (Narayanamurti et al. 1963). The data presented in this report will eventually be used by the authors to develop predictive strength loss models that will verify or refute the "reduced section modulus" theory of Luxford and Zimmerman.

OBJECTIVES

The objectives of our study were to assess:

1. the effects of incising, specifically incision density and incision depth, on mean bending strength for each species and throughout the bending strength distribution for some species;
2. the influence of material quality (grade) on incising-related strength effects;
3. the interaction between commonly used preservative treatments and incising-related strength effects; and
4. the comparative effects of treatment, in-

cising density and depth, and strength between species as related to adjustments in allowable stress design (AF&PA 1997).

EXPERIMENTAL

Experimental design

The variables were assessed using three populations of lumber representing two MSR grades of the commercial species groups Hem-Fir, Douglas-fir, and Spruce-Pine-Fir (south).

The Hem-Fir study evaluated the effects of preservative treatment and lumber grade with various incising parameters, such as incision density and depth. In this study, we compared the mean effects of two levels of preservative treatment, two machine-stress-rated (MSR) grades, two incising densities, and two incising depths. We also evaluated the interactions between these factors. This study employed a 2^4 factorial design (treatment, grade, density, depth) with separate untreated, unincised controls at each MSR grade (Table 1). Sample size was approximatley 36 specimens per factor.

The Douglas-fir study specifically looked at the effects of lumber grade, incising parameters, and, to a limited extent, effects of incising and treatment throughout the bending strength distributions. In this study, we examined the mean effects of one preservative treatment as it related to two MSR grades, two incising densities, and two incising depths. This study employed a 2^3 factorial design (grade, density, depth) with separate untreated, unincised controls and treated, unincised controls for each MSR grade (Table 1). Sample size was approximately 55 specimens per factor for the 1800f/1.8E MSR grade and 60 specimens per factor for the 2400f/2.OE MSR grade.[2]

The Spruce-Pine-Fir (SPF) (South) study specifically examined preservative treatment and grade as they relate to distributional effects. In this study, we looked at the mean effects of two preservative treatments and two MSR grades. This study employed a 2^2 factorial design (pattern, grade) with separate untreated, unincised control at each MSR grade (Table 1). Sample size was approximately 66 specimens per factor.

Material

Nominal 2-by 4-inch[3] (standard 38- by 89-mm) lumber of three Pacific Northwest species groups was studied: Hem-Fir, which contained both western hemlock *(Tsuga heterophylla)* and true firs *(Abies* spp.); coastal Douglas-fir *(Pseudotsuga menziesii* var. Franco); and Spruce-Pine-Fir (South) (SPF (South)), which predominantly contained Englemann spruce *(Picea engelmannii)* but also contained a small amount of lodgepole pine *(Pinus contorta).* Coastal Douglas-fir is defined in ASTM D1760 (ASTM 1996a) as Douglas-fir grown west of the summit of the Cascade Mountains. These three species groups represent the most commercially important woods that are incised and treated in the United States. We had originally hoped to decrease treatment variability in the Hem-Fir group by obtaining Hem-Fir predominantly consisting of western hemlock grown in the Coast mountain range. However, because of current harvesting restrictions across the Pacific Northwest, we were able to obtain only MSR-graded Hem-Fir from a mill on the west slope of the Cascade range. The material appeared to contain nearly 80% western hemlock and 20% true fir. The SPF (South) was primarily Engelmann spruce from Eastern Washington State, again obtained in an attempt to decrease variability in treatment. However, no attempt was made to identify individual specimens with respect to separating species within the three tested commercial species groups. To limit staining and inhibit

[2] MSR grades are sorted by edgewise MOE and referred to by their assigned F_b and MOE values. Thus, an MSR grade of 1800f/1.8E infers design stress in flexure of 12.4 MPa (1,800 lb/in.^{2}) and MOE of 12.4 GPa (1.8 × 10^6 lb/in.^{2}).

[3] Hereafter called 2 by 4.

TABLE 1. *Mean effects of various treatments and incising patterns on bending properties.* [a]

Species	Grade	Incision Density (/m^2)	Incision Depth (mm)	Treatment	P_{max} (kN)	MOR (GPa)	MOE (MPa)	WML (kJ/m^3)	MC (%)	Specific gravity
Hem-Fir	1650f/1.5E	7,000	5	CCA	9.8	11.7	49.7	32.5	13.0	0.430
			9–11	CCA	7.6	11.4	38.1	18.6	12.9	0.432
			5	ACZA	9.4	13.3	49.2	28.0	12.9	0.433
			9–11	ACZA	7.3	11.8	37.4	20.7	12.7	0.437
		8,500	5	CCA	9.5	11.9	47.8	25.2	12.7	0.434
			7	CCA	9.3	12.1	47.2	29.2	13.0	0.423
			5	ACZA	9.5	12.9	49.0	32.1	13.1	0.439
			7	ACZA	9.8	13.2	51.0	31.0	13.2	0.435
		0	0	UNT	11.0	12.9	55.2	42.3	11.7	0.422
	2400f/2.0E	7,000	5	CCA	12.5	15.6	63.1	56.1	12.9	0.473
			9–11	CCA	9.7	13.7	48.8	37.9	13.0	0.484
			5	ACZA	13.0	16.6	67.2	55.6	12.8	0.470
			9–11	ACZA	10.1	16.1	51.5	32.1	12.7	0.491
		8,500	5	CCA	13.5	15.9	69.1	48.7	12.4	0.483
			7	CCA	12.9	15.8	66.0	48.5	12.2	0.483
			5	ACZA	13.2	17.2	67.9	58.9	13.1	0.488
			7	ACZA	12.1	17.5	62.7	49.8	13.1	0.483
		0	0	UNT	15.0	17.3	75.5	89.6	11.4	0.473
Douglas-fir	1800f/1.8E	7,000	5	ACZA	8.8	13.5	44.2	26.5	12.7	0.463
			7	ACZA	6.2	11.4	30.5	23.1	12.9	0.452
Douglas-fir	1800f/1.8E	8,500	5	ACZA	9.0	14.2	45.8	23.6	12.6	0.460
			7	ACZA	8.5	13.0	43.1	21.0	13.1	0.459
		0	0	ACZA	11.3	15.5	55.9	34.2	11.6	0.456
			0	UNT	11.0	15.3	56.6	34.1	13.3	0.461
	2400f/2.0E	7,000	5	ACZA	9.2	16.2	64.6	57.3	12.8	0.522
			7	ACZA	12.4	14.5	46.6	32.4	12.9	0.522
		8,500	5	ACZA	11.4	18.0	63.4	34.3	12.4	0.518
			7	ACZA	14.5	16.0	58.3	38.0	12.8	0.517
		0	0	ACZA	14.7	18.5	75.2	53.4	11.7	0.513
			0	UNT	0	18.1	73.1	53.8	12.6	0.520
SPF (South)	1650f/1.5E	7,000	7	CCA	7.6	11.6	39.3	19.9	12.2	0.435
			7	ACQ-B	6.4	9.8	33.0	19.7	12.3	0.428
		8,500	5	CCA	8.2	11.5	41.8	20.8	12.3	0.427
			5	ACQ-B	7.7	11.8	39.6	23.5	12.4	0.430
		0	0	UNT	9.4	12.1	48.2	31.7	11.5	0.419
	2250f/1.9E	7,000	7	CCA	9.6	13.8	49.4	28.8	12.0	0.470
			7	ACQ-B	8.9	12.4	45.6	28.5	12.5	0.469
		8,500	5	CCA	11.5	14.0	60.0	38.7	12.5	0.471
			5	ACQ-B	10.1	13.2	51.4	30.7	12.9	0.462
		0	0	UNT	13.0	15.2	66.4	55.0	11.9	0.473

[a] Conversion factors for English units of measurement: 1 kN = 225 lbf/in.^{2}; 1 GPa = 1.45×10^5 lbf/in.^{2}; 1 MPa = 145.0 lbf/in.^{2}; 1 kJ/m^3 = 0.145 in.·lbf.

fungal growth, all materials were kiln-dried to ≤ 19% prior to shipping to the Forest Products Laboratory (FPL).

At FPL, all material was equilibrated to constant weight in 23°C (74°F) and 65% relative humidity conditions. All material was then nondestructively evaluated full-span for MOE using a transverse-vibration DynaMoe apparatus.[4] For each species group, all specimens were ranked from lowest to highest MOE and then assigned to experimental groups in a systematic manner that ensured

[4] The use of trade or firm names in this publicantion is for reader information and does not imply endorsment by the U.S. Department of Agriculture of any product or service.

equal proportions of high, medium, and low MOE specimens in each group.

Incising

Incision depth was either 5 mm (0.2 in.) or 7-10 mm (0.3-0.4 inch); incision density was 7,000 or 8,500 incisions/m^2 (660 or 800 incisions/ft^2) (Table 1). These depths and pattern densities were selected to be representative of common practice in the North American treating industry for standard 38-mm-thick (nominal 2-in. -thick) dimension lumber. Modified chisel-type teeth were used for the 7,000-incisions/m^2 (660-incisions/ft^2) pattern and knife-like teeth for the 8,500-incisions/m^2 (800-incisions/ft^2) pattern.

All lumber was incised in the dry condition, which is not the common industry practice. The most common practice is to incise "S-grn" (surfaced green) material. Another commonly incised material is known as "kiln-wet," a nonstandardized term for fall-down lumber that is sorted from kiln-dried lumber when such material does not meet the $\leq$ 19% moisture content limit of "S-dry" material. We decided to use dry lumber to avoid biodegradation of green lumber because the overall process was conducted over a 3-year period: material was shipped from Oregon to Madison, *E* -rated and sorted into groups, returned to Oregon for incising and treatment, and finally shipped back to Madison for mechanical tests. However, using dry lumber increased the amount of damage from incising. We especially noted such damage in the first four groups of Hem-Fir incised with the 7,000/m^2 (660/ft^2) pattern to a depth of 10 mm (0.4 inch). Thus, to prevent further incising damage associated with dry wood, we chose to incise all remaining groups designated for the 7,000/m^2 (660/ft^2) pattern to a depth of 7 mm (0.3 inch) (Tables 2 and 3). The incision-related damage somewhat limits interpretation of these data because the "effect" of deeply incising dry wood cannot be considered truly representative of commercial practice.

Treatment

Selected lumber specimens were treated at a maximum moisture content of 19% before preservative treatment with ammoniacal copper or ammoniacal copper zinc arsenate (ACZA) (Douglas-fir), ACZA or CCA-Type C (Hem-Fir), or ammoniacal copper quat (ACQ)-Type B or CCA-Type C (SPF (South)) (Table 1). The cycles were full-cell treatment using a –82 kPa (24-in.-Hg) vacuum followed by 0.8 MPa (120 lb/in.^{2}) pressure. Total treating cycle time was approximately 3 h. After treatment, the 3.6-m (12-ft) 2 by 4 lumber was stickered and stored outdoors under cover for 30 days (temperature >7°C (>45°F)) to allow chemical fixation to proceed. This period also allowed for some post-treatment air-drying. Each specimen was analyzed for preservative penetration and retention. Preservative penetration was measured using conventional chemical indicators, and retention was measured using X-ray fluorescence spectroscopy (AWPA 1997). Retention generally conformed to AWPA standards, but penetration was less consistent. The retention and penetration analysis was previously reported in depth (Anderson et al. 1997).

After completing post-treatment air-redrying to about 19% to 25% moisture content, each 3.6-m (12-ft) lumber specimen was cut into 1.8-m (6-ft) halves. Although we did not reevaluate the grade of each stick, it is reasonable to assume that the *E* -based grade did not diminish for any group. One stick was randomly designated for shear testing, which will be discussed in a subsequent report. The other half of each specimen was shipped to FPL. There, all material was equilibrated to constant weight at 23°C (74°F) and 65% relative humidity prior to mechanical evaluation in flexure.

Mechanical testing

Each 1.8-m- (6-ft-) long 2 by 4 shipped to FPL was mechanically tested in edgewise bending using third-point loading (ASTM

TABLE 2. *Effects of various treatments and incising patterns across bending strength distribution.*

Species	Grade	Incision Density (incisions/m²)	Incision Depth (mm)	Treatment	MOR percentile (MPa) 10th	25th	50th	75th	90th
Hem-Fir	1650f/1.5E	7,000	5	CCA	35.8	44.0	47.2	51.8	63.5
			9–11	CCA	26.5	30.5	39.0	46.3	50.3
			5	ACZA	38.0	41.7	47.5	57.2	61.4
			9–11	ACZA	22.6	29.6	36.9	45.9	49.4
		8,500	5	CCA	34.4	40.9	47.1	54.5	62.8
			7	CCA	33.0	41.1	49.3	53.1	58.3
			5	ACZA	36.0	38.7	50.8	57.5	59.8
			7	ACZA	39.1	43.3	51.0	59.6	64.0
		0	0	UNT	36.2	43.1	54.6	66.3	71.9
	2400f/2.0E	7,000	5	CCA	45.7	53.9	65.7	70.4	75.0
			9–11	CCA	34.6	38.5	49.0	60.2	64.3
			5	ACZA	51.5	60.3	69.9	71.9	78.0
			9–11	ACZA	34.6	44.2	55.4	60.7	65.2
		8,500	5	CCA	56.8	63.7	71.9	75.2	78.8
			7	CCA	51.1	58.3	67.8	74.1	77.9
			5	ACZA	57.8	62.5	68.0	72.1	79.9
			7	ACZA	42.2	56.7	63.4	70.7	76.5
			0	UNT	51.7	65.7	76.4	86.6	93.8
Douglas-fir	1800f/1.8E	7,000	5	ACZA	30.5	34.8	43.7	52.1	57.3
			7	ACZA	14.5	22.2	28.7	38.9	46.7
		8,500	5	ACZA	28.3	34.9	44.9	53.8	62.7
			7	ACZA	29.7	32.7	41.0	50.8	60.4
		0	0	ACZA	37.3	45.0	52.6	64.7	76.2
			0	UNT	36.6	43.6	52.8	73.6	77.8
	2400f/2.0E	7,000	5	ACZA	47.9	54.7	62.8	76.2	82.6
			7	ACZA	27.3	36.3	45.8	58.4	66.2
		8,500	5	ACZA	39.4	53.9	62.7	74.8	83.7
			7	ACZA	38.6	49.5	59.5	67.7	74.9
		0	0	ACZA	54.3	64.4	76.5	85.7	95.7
			0	UNT	53.7	63.6	73.9	81.5	92.4
SPF (South)	1650f/1.5E	7,000	7	CCA	26.6	32.6	38.1	46.9	55.5
			7	ACQ-B	20.4	25.9	33.3	39.0	45.5
		8,500	5	CCA	30.3	33.4	42.2	48.5	52.6
			5	ACQ-B	28.4	32.6	37.8	46.7	52.2
		0	0	UNT	30.4	36.7	42.7	59.8	69.2
	2250f/1.9E	7,000	7	CCA	35.5	39.2	49.7	58.8	67.3
			7	ACQ-B	35.2	40.0	45.6	50.9	56.1
		8,500	5	CCA	45.5	48.8	61.5	67.6	75.2
			5	ACQ-B	33.9	42.8	51.3	58.9	66.7
		0	0	UNT	48.3	56.8	67.2	78.0	83.5

1996b). The span-to-depth ratio was 17:1 tested over a 1.5-m (60.0-in.) span. Rate of loading was 25 mm (1 in.) per minute, with failure almost always occurring within 30 to 90 sec. Modulus of elasticity, modulus of rupture (MOR), and work to maximum load (WML) were calculated from total load (P_{max}) and mid-point deflection data. Moisture content and specific gravity at test were also evaluated from a 25-mm (1-in.) full-size wafer cut from an undamaged section near the failure zone.

RESULTS AND DISCUSSION

A series of significant interactions between the four main factors (treatment, grade, density, and depth) of the Hem-Fir, Douglas-fir,

TABLE 3. *Experimental results of analysis of covariance (CV = specific gravity for bendinng strength.* [a]

Hem-Fir 2400f/2.0E

CCA	ACZA	ACZA	CCA	CCA	ACZA	ACZA	CCA	UNT
7,000	7,000	8,500	7,000	8,500	8,500	7,000	8,500	
10	10	7	5	7	5	5	5	

Hem-Fir 1650f/1.5E

ACZA	CCA	CCA	CCA	ACZA	ACZA	CCA	ACZA	UNT
7,000	7,000	8,500	8,500	8,500	7,000	7,000	8,500	
10	10	7	5	5	5	5	7	

Douglas-fir 2400f/2.0E

ACZA	ACZA	ACZA	ACZA	ACZA	UNT
7,000	8,500	8,500	7,000	0	
7	7	5	5	0	

Douglas-fir 1800f/1.8E

ACZA	ACZA	ACZA	ACZA	ACZA	UNT
7,000	8,500	8,500	7,000	0	
7	7	5	5	0	

SPF-South 2250f/1.9E

ACQ-B	CCA	ACQ-B	CCA	UNT
7,000	7,000	8,500	8,500	
7	7	5	5	

SPF-South 1650f/1.5E

ACQ-B	CCA	ACQ-B	CCA	UNT
7,000	7,000	8,500	8,500	
7	7	5	5	

[a] Covariance for bending strength (MOR) by species and MSR grade for treatment, incising density, and incising depth. Groups having shared lines are not significantly different ($\alpha < 0.05$).

and SPF (South) studies preclude simple discussion of any main effects independently of other factors. The effects of preservative treatment, incising density, and incising depth on two MSR grades of Hem-Fir, Douglas-fir, and SPF (South) are presented by species group. Individual summary discussions of preservative, grade, and species effects follow.

Hem-Fir study

This study compared the mean effects of two preservative treatments, two MSR grades, two incising densities, and two incising depths. It also looked at the interaction of these factors. The results of bending tests for the 18 groups of Hem-Fir specimens are shown in Table 1. Nonparametric percentile estimates of the bending strength data are given in Table 2. The reductions in most mean mechanical properties between similar incision patterns and incision depths showed few significant differences between each other (Table 3). Generally, except for the 7.000-incisions/m^2 (660-incisions/ft^2) pattern incised to a depth of 9 to 11 mm (0.35 to 0.43 in.), the incising effect for both MSR grades was in the range of 0-10% loss in MOE and 8%- 17% loss in MOR for the 5- and 7-mm (0.2- and 0.3-in.) incising depths (Table 1); however, the 2400f/2.0E grade experienced 35%-45% loss in WML, while the 1650f/1.5E grade experienced only 20%–40% loss.

Note that for the 7,000-incisions/m^2 (660-

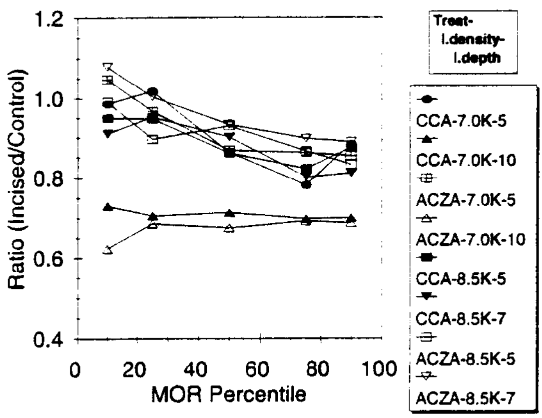

FIG. 1. Effects of various treatment, incising density, and incising depth on bending strength percentiles of 1650f/1.5E Hem-Fir.

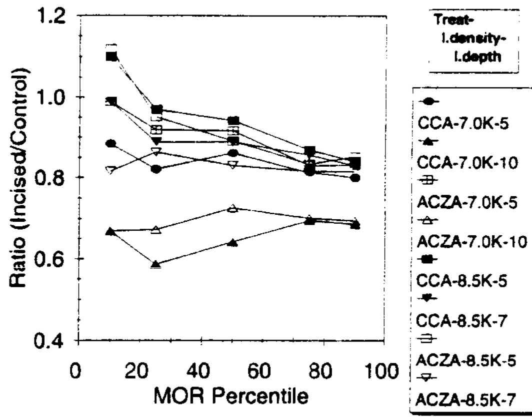

FIG. 2. Effects of various treatment, incising density, and incising depth on bending strength percentiles of 2400f/2.OE Hem-Fir.

incisions/ft^2) pattern incised to a depth of 9 to 11 mm (0.35 to 0.43 inch), the reductions in MOE, MOR, P_{max} and WML were about double that of any other incising density-depth pattern. The Hem-Fir lumber suffered more visible surface deterioration and damage to mechanical properties from deep incising (9 to 11-mm (0.35 to 0.4-in.)) with the 7,000/m^2 (660/ft^2) pattern compared to any other incision density-depth combination. This result may be related in part to our decision to incise dry lumber prior to treatment. Incising dry wood (moisture content $\leq$ 1970) is not standard practice within the treating industry. The increase in surface deterioration might also be related to the frequent ring-shake-related tendencies of both western hemlock and true firs (Meyer and Liney 1968). Finally, the increase in surface deterioration might be related to the particular chisel-like tooth geometry used in the 7,000 incisions/m^2(660 incisions/ft^2) pattern-insertion of those types of teeth to <5 mm (<0.2 in.) was not much different in its effect on strength than was the effect of the knife-like teeth of the 8,500 incisions/m^2(800 incisions/ft^2) pattern. However, incising with the 7,000/m^2(660/ft^2) pattern to a depth $\geq$ 7 mm ($\geq$ 0.3 in.) induced unacceptably large reductions in strength. At this depth, each incision clearly exhibited "crow's feet" at the outer edges of each end of the incision. The other patterns, even the 7,000/m^2(660/ft^2) pattern incised to a depth 55 mm ($\leq$ 0.2 in.), did not cause this secondary tearing of wood fiber. In our opinion, the secondary tearing of fiber at the edges of each incision was a symptom of incising wood that was too dry. Comparable incising of green Hem-Fir reportedly does not result in the same magnitude of surface damage.

The effect of incising on the bending strength distribution relative to that on a matched untreated, unincised control for each treatment-density-depth combination is shown for 1650f/1.5E Hem-Fir and 2400f/2.OE Hem-Fir in Figs. 1 and 2, respectively. Recalling that the Hem-Fir study had only ~36 specimens/group, incising generally caused a 30% loss in strength for both MSR grades incised to a 10-mm (0.4-in.) depth. For both MSR grades of Hem-Fir material incised to 5- or 7-mm (0.2 or 0.3 in.), the strength reduction ratio consistently decreased with increasing percentile level.

Douglas-fir study

This study specifically looked at the effects of one preservative treatment (ACZA, the most common waterborne preservative used with Douglas-fir), two MSR grades, two incising densities, and two incising depths. The

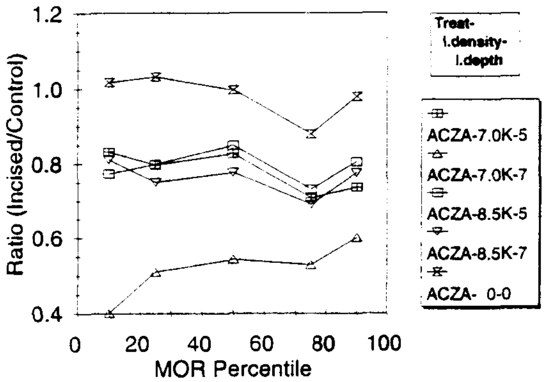

FIG. 3. Effects of various treatment, incising density, and incising depth on bending strength percentiles of 1800f/1.8E Douglas-fir.

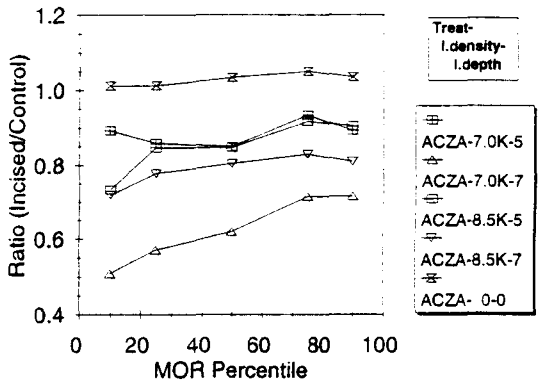

FIG. 4. Effects of various treatment, incising density, and incising depth on bending strength percentiles of 2400f/2.OE Douglas-fir.

results of the bending tests for the 12 groups of Douglas-fir specimens are shown in Table 1, and nonparametric percentile estimates of the bending strength data are given in Table 2. Again, as with the Hem-Fir specimens, note that the reduction in MOE, MOR, P_{max}, and WML for the 7,000 incisions/m^2(660 incisions/ft$_2$) pattern incised to 7 mm (0.3 in.) were much greater than those of the other incising density-depth patterns. Except for the 7,000/m^2(660/ft^2) pattern incised to 7 mm (0.3 in.), the incising effect was generally in the range of 0–15% loss in MOE, 12%-20% loss in MOR, and 30%-35% loss in WML (Table 1). However, the resulting reductions from various incising density-depth combinations on mechanical properties clearly indicate that depth of incision is the critical parameter in determining the effect on mean MOR, especially for high-density species-grade combinations like the 2400f/2.OE Douglas-fir (Table 3).

The effect of incising on the bending strength distribution relative to that for a matched untreated, unincised control for each treatment-density-depth combination is shown for Douglas-fir 1800f/1.8E and 2400f/2.0E in Figs. 3 and 4, respectively. Except for the 7.000 incisions/m^2(660 incisions/ft^2) pattern incised to 7 mm (0.3 in.), the effect of incising on the 1800f/1.8E Douglas-fir lumber was more stable across the entire bending strength distribution than was the effect on Hem-Fir, averaging a reduction of about 20% ± 5% (Fig. 3). For the 2400f/2.0E Douglas-fir lumber, the effect of incising was stable to slightly decreasing across the entire bending strength distribution as percentile level increased (Fig. 4). It was also slightly more variable, averaging about 20% ± 10% reduction (Fig. 4). For both MSR grades incised with the 7,000/m^2(660/ft^2) pattern to 7 mm (0.3 in.), the effect of incising on bending strength generally resulted in a 40% to 60% loss in strength (Figs. 3-4).

The Douglas-fir lumber suffered far less visible surface deterioration than did the Hem-Fir because it did not experience the same level of surface tearing. However, reduction in mechanical properties from deep incising (7 mm (0.3 in.)) with the 7,000/m^2(660/ft^2) pattern was even greater than that experienced with the Hem-Fir. Both the 7,000/m^2(660/ft^2) and 8,500/m^2(800/ft^2) patterns incised to 7 mm (0.3 in.) did significantly greater harm to strength than did the same incision density patterns incised to the more shallow $\leq$ 5 mm ($\leq$ 0.2 in.) depth (Table 3).

The AWPA standards are often interpreted to “require” incising to a full depth of 10 mm (0.4 in.) for lumber that will be treated. In our opinion, this interpretation of AWPA standards should not be encouraged and any language promoting such to control incising-in-

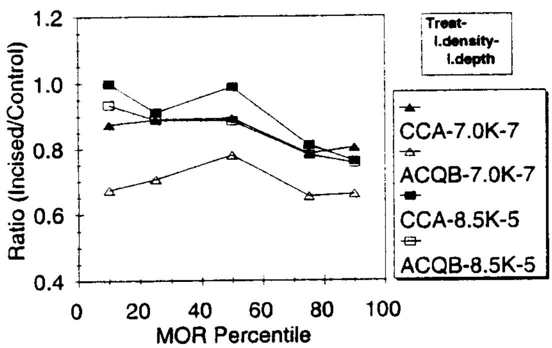

FIG. 5. Effects of various treatment, incising density, and incising depth on bending strength percentiles of 1650f/1.5E Spruce-Pine-Fir (South).

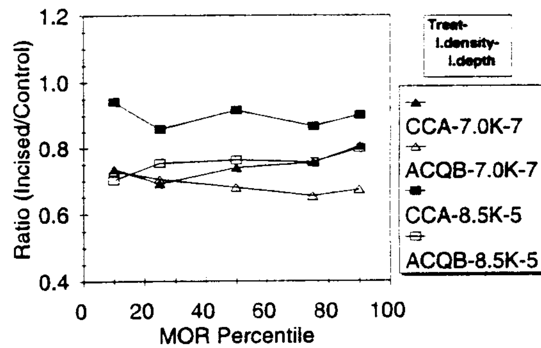

FIG. 6. Effects of various treatment, incising density, and incising depth on bending strength percentiles of 2250f/1.9E Spruce-Pine-Fir (South).

duced strength loss should be changed, at least when incising dry Hem-Fir and Douglas-fir standard 38-mm- (nominal 2-in.-) thick lumber.

SPF (South) study

This study specifically looked at the effects of two preservative treatments and two MSR grades as they are commercially processed using the low-density incising pattern incised to 7 mm (0.3 in.) and the high-density incising pattern incised to the shallower depth (5 mm (0.2 in.)). The results of the bending tests for the 10 groups of SPF (South) specimens are shown in Table 1. Nonparametric percentile estimates of bending strength data are given in Table 2. The effects on mechanical properties of either incising pattern studied with SPF (South) were generally less than those for comparably E-matched Hem-Fir (Table 1).

The effect of incising on the bending strength distribution relative to that for a matched untreated, unincised control for each treatment-density-depth combination is shown for SPF (South) 1650f/1.5E and 2250f/1.9E in Figs. 5 and 6, respectively. The negative effects of incising for the lower grade (1650f/1.5E) of SPF (South) generally increased across the entire bending strength distribution (Fig. 5) in a manner somewhat similar to that of its sister E-matched grade of 1650f/1.5E Hem-Fir (Fig. 1). For the higher grade of SPF (South) (2250f/1.9E), the effect of incising was fairly consistent across the entire bending strength distribution, ranging from –10% to –30% depending on the treatment-incising pattern (Fig. 6).

When comparing the effects of the deeply incised (7-10 mm (0.3-0.4 in.)), 7,000 incisions/m^2 (660 incisions/ft^2) patterns, the SPF (South) lumber suffered even less visible surface damage than did the Douglas-fir and far less visible deterioration than did the Hem-Fir. This may reflect the softer texture of SPF (south).

We had originally hoped that differences in either the incising patterns or the treatments would not be found significant. This would have allowed us to combine similarly treated or incised groups (i.e., 2 @ 66 = 132 specimens), which would have allowed additional statistical power to analyze distributional effects. However, the groups could not be combined because of significant differences, and this additional in-depth analysis was not possible (Table 3).

Preservative effects

There were few significant differences between the mean effect of the two preservatives (CCA and ACZA) in the Hem-Fir study at any matched incising density-depth combination (Table 3). Unincised Douglas-fir treated with ACZA showed no significant differences from its *E* -matched unincised, untreated control for both MSR grades (Table 3). The results from these two species groups correspond to results of several previous studies that showed that waterborne preservatives have little effect on strength except when the material is exposed to impact loads (Winandy 1995a) or loaded at very dry conditions such as ≤ 10% moisture content (Winandy 1995b).

On the other hand, there were several significant differences in the SPF (South) study between the mean effect of the two preservatives (CCA and ACQ-Type B) at matched incising density-depth combinations (Table 3). These SPF (South) data imply that the effect of ACQ-Type B treatment on strength properties may be greater than that of ACZA or CCA. We postulate that the relative increase in the strength effect for ACQ-Type B compared to ACZA may be related to the increased reactivity of the quaternary ammonium component of ACQ-Type B.

Grade effects

The *E* -values of lumber assigned to an MSR grade are usually considered to be less variable than those under visually assigned grade rules. For example, the assigned coefficient of variability in E for MSR grades is 11%, compared to 25% for visually assigned grades (Brown et al. 1997).[5] Because MSR grades generally tend to exhibit less variability than do visually assigned grades, the distributional--wide implications of the results reported in this study should be specifically considered to apply to only MSR-graded lumber. Thus, while some inference can be made to grades assigned under visual rules, that inference is certainly not unequivocal.

Few differences were found between the incising-related effect for the two MSR grades of Hem-Fir (compare Fig. 1 to 2). The lower grade Douglas-fir (1800f/1.8E) experienced slightly greater reductions in strength than did the matched higher grade Douglas-fir (2400f/2.0E). Both grades of CCA-treated SPF (South) lumber suffered less-to-almost equivalent strength loss as did the nearly-grade-matched CCA-treated Hem-Fir and Douglas-fir lumber. In general, few gross differences related to grade within each species grouping were noticeable. The single exception was that while the effect of incising on strength was generally consistent across the bending strength distribution for the higher grade SPF (South) and both grades of Douglas-fir, the effect generally increased for the lower grade SPF (South) and both grades of Hem-Fir. This might imply that any species- or grade-related incising effect on strength may be just as likely to be related to wood specific gravity in that the effect increases, then reaches a threshold, as wood specific gravity increases.

Species effects

No practically important species-related differences in the incising effect were noted after comparing each grade of comparably incised material (Table 4). Note that for both the higher MSR grades (DF 2400f/2.0E. HF 2400f/2.0E, SPF 2250f/1.9E) and lower grades (DF 1800f/1.8E, HF 1650f/1.5E, SPF 1650f/1.5E), the groups incised with similar incising patterns generally exhibited similar responses in strength from incising. All the heavily incised groups, regardless of species groups. were lowest in strength; whereas the moderately incised groups were intermediate in strength. and the unincised groups were generally highest in strength. Although some significant differences exist between comparably incised material, we believe that those differences reflect inherent species/specific gravity differences rather than differential incising effects between species.

Modeling

Based on the overall mechanical property results described in this report, the develop-

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[5] Specifically, reported coefficient of variation (COV) is reduced throughout the lower tail of these strength distributions. However, COV in the upper ranges depends on which grades are pulled above the MSR or VSR grade in question.

TABLE 4. *Results of analysis of covaiance (Cv = specific gravity)* cotrasting *similar grades of comparably incised and treated groups for all species groups.* [a]

Higher grade

DF	SPF	HF	HF	SPF	SPF	DF	SPF	HF	SPF	HF	DF	DF	HF
ACZ	ACQ	CCA	ACZ	CCA	ACQ	ACZ	CCA	ACZ	UNT	CCA	UNT	ACZ	UNT
660	660	660	660	660	800	800	800	800	0	800	0	0	0
7	7	10	10	7	5	5	5	5	0	5	0	0	0

Lower grade

DF	SPF	HF	HF	SPF	SPF	SPF	DF	HF	HF	SPF	DF	DF	HF
ACZ	ACQ	ACZ	CCA	CCA	ACQ	CCA	ACZ	CCA	ACZ	UNT	ACZ	UNT	UNT
660	660	660	660	660	800	800	800	800	800	0	0	0	0
7	7	10	10	7	5	5	5	5	5	0	0	0	0

[a] Groups having shared lines are not significantly different ($\alpha < 0.05$).

ment of a predictive incising-effects model based on preservative treatment, grade, incising density, and incising depth is now underway. This work will evaluate the applicability of the reduced section modulus theory (Luxford and Zimmerman 1923).

CONCLUSIONS

Bending properties (modulus of elasticity (MOE), modulus of rupture (MOR), and work to maximum load (WML)) of dry 38-mm- (nominal 2-inch-) thick lumber appeared to be affected by incising at levels consistent with those previously reported. This series of studies showed that the combined incising-preservative effect on average dry property values was in the range of 0-10% loss in MOE, 15%-25% loss in MOR, and 30%-50% loss in WML. For lower specific gravity species, incising-preservative exerted less of an effect on lower tail properties, such as F_b, than on mean properties. However, for higher specific gravity species like Douglas-fir and higher grade SPF (South), the effects of incising and treatment on lower tail properties were comparable to mean effects and often exceeded a 25% loss in MOR. While new NDS design adjustment factors (C_i) for *E* of 0.95 and F_b of 0.85 may be sufficient for green material, these results—which specifically apply to MSR-graded standard 38-mm- (nominal 2-inch-) thick lumber and to lumber incised in the dry condition prior to treatment-specifically imply that those same design adjustments may not be sufficient for incised and treated Douglas-fir and SPF (South) 2 by 4 material used in dry in-service conditions.

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