Effect of Incising on Flexural Properties of Nominal 4 by 6-Inch Douglas-Fir

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Abstract

Incising is an essential preprocessing method to ensure lumber from difficult-to-treat wood species can achieve chemical loadings during pressure treatment that will allow commodities to perform in ground contact or critical infrastructure applications. National Design Specifications in the United States require engineers to include a strength reduction for incised lumber, but these reductions are based on data collected on 2-in (51-mm) nominal-thickness lumber. Little work has been done to measure the impact of incising on lumber with a larger cross-section. This exploratory study measured the effect of incising on modulus of rupture (MOR) and modulus of elasticity (MOE) of nominal 4 by 6-in (102 by 152-mm) Douglas-fir lumber. Lumber pieces ranked and matched by vibrationally measured MOE were tested edgewise by a four-point bending test according to ASTM D4761. A total of 48 incised and nonincised test specimens were included in the final analysis. Incised MOR values were 11.5 percent lower than nonincised pieces ($P < 0.05$ analysis of variance). MOE values were 2.5 percent lower for incised pieces compared with nonincised pieces, but the difference was not statistically significant ($P > 0.05$). Ranking paired incised and nonincised specimens showed that the divergence between the two categories was greatest in specimens with lower MOR values. The coefficient of variation for MOR values was high for both incised (32.4%) and nonincised (26.6%) samples and a more uniform data set would provide better confidence for resolving differences between them. This work provides a useful preliminary comparison in structural performance of incised and nonincised lumber.

Incising is required in the American Wood Protection Association standards for preservative treatment of Douglas-fir and many other thin sapwood species (AWPA 2023). The process exposes more permeable end grain to fluid flow, resulting in improved penetration to the depth of the incision and longer service life (Anderson et al. 1997). There is, however, no specific incising standard currently. The original incisors were designed for heavy timbers and used large, widely spaced teeth since there was little concern about the final appearance of the treated product. Previous studies found that for large timbers (>150 to 250 mm) these low-incision density patterns generally had little effect on mechanical properties (Luxford and Zimmerman 1921, 1923; Luxford 1926; Rawson 1927; Harkom and Rochester 1930; Harkom and Alexander 1931; Schrader 1945; Bryant 1953). Although these incisors are still used for industrial products, the emergence of markets for preservative-treated dimension lumber in Canada and the western United States led to the development of several incisor designs that used much finer teeth at much closer spacings to reduce the visual impact of the process. The intensity of the patterns led to concerns about the effects of such a large cross-sectional area being damaged and a series of studies were undertaken to more closely define the effects of incising on flexural properties of the final product.

Most of the recent studies on the impact of incising on wood strength have evaluated nominal 2-in (38-mm)-thick

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lumber (Perrin 1978; Morrell et al. 1998; Winandy and Hernandez 1998; Winandy and Morrell 1998; Winandy et al. 2020, 2021, 2023). These studies led to the inclusion of an incising design factor (C_i) in the National Design Specification (NDS) that called for a blanket modulus of rupture (MOR) reduction for incised wood. Although this was a simple solution to the problem, it ignored the variations in incising patterns as well as lumber dimensions. Previous studies have shown that the impacts of incising can be predicted by calculating the loss in cross-sectional area for a given member and incising pattern (Winandy and Hernandez 1998; Hernandez and Winandy 2005; Winandy and Cheung 2017; Winandy et al. 2020, 2021). This allows a user to estimate a reduction factor for a given incising pattern on a specific timber size. This is important since incising is mostly a surface effect that would be mitigated by increasing dimensions (Winandy et al. 2018). Thus, the effect of the same incising pattern and depth on a nominal 2-in (38-mm)-thick board would be much greater than on a nominal 4-in (89-mm) member. This is mitigated slightly by the increased chemical penetration requirement from 10 mm in lumber <125 mm thick to 13 mm in thicker lumber/timbers, but the overall impact of incising on strength should decrease with increased dimensions.

The ability to calculate factors for a given incising pattern is attractive, but this requires prior knowledge of the specific material being used on a project and this information may not always be available. The development of an incising design factor for thicker materials would allow specifiers to require incising for commodities in a specific size class. The primary objective of this study was to perform a preliminary assessment of the impact of a single type of incising pattern on flexural properties of nominal 4 by 6-in (89 by 140-mm)-thick Douglas-fir lumber. A secondary but broader objective was to evaluate incised material larger in size than the more intensively studied 2-in-thick lumber (for which effects have been quantified) but smaller than timber (>5-in thickness) for which predictive models and NDS agree are less likely to be affected by incising. This study provides a preliminary comparison of how well NDS design factors for incising reflect strength values for nominal 4 by 6-in lumber.

Materials and Methods

One-hundred-ten pieces of recently cut nominal 4 by 6-in (89 by 140-mm) by 12-ft (3.67-m)-long Douglas-fir lumber were obtained from a mill near White City, Oregon. The samples were acoustically tested using a Metriguard E-computer (Metriguard Technogies Inc. Pullman, Washington) to determine an E-rating so the incised and nonincised populations would consist of E-matched pairs. The samples were E-rated without drying to uniform moisture content because of the need for immediate on-site access to the incisor that was used in this study. The lumber with the five lowest and five highest E-ratings were removed from the test. The remaining 100 timbers were sorted into two groups of 50 pieces each with similar modulus of elasticity (MOE) values. One group of 50 pieces was incised on a RJH Proto-Mac model RJH-T16X16-BA (Corvallis, Oregon) incisor to a depth of 11.1 mm and a density of 7,930 incisions/m^2. The lumber was stickered under cover and air dried for about 9 months.

The nominal 4 by 6-in lumber was then tested to failure edgewise in four-point loading applied at the third point using a span-to-depth ratio of 18:1 and a loading rate of 38 mm/min according to the procedures described in ASTM Standard D4761. Load and deflection were continuously recorded. The linear portion of the resulting curve was used to calculate MOE, whereas ultimate load was used to calculate MOR. Failure mode was noted and a 50-mm-long section was cut from near the failure zone to determine moisture content at time of testing and the density of each specimen. The samples were weighed, then oven dried at 104 C for 24 to 48 hours before being reweighed. The difference between initial and final mass was used to calculate moisture content at time of testing. Dimensions of each specimen were measured and density was calculated using the oven-dried mass of each piece. These data were used to ensure that the two populations had similar density values. A total of 48 incised and 50 nonincised samples was evaluated. Excessive warping on two nonincised samples precluded testing. As a result, incising effects were only compared on 48 matched samples. The data were subjected to a single-factor analysis of variance ($\alpha = 0.05$).

Results and Discussion

Moisture contents of incised and nonincised lumber at the time of testing averaged 9.32 and 9.18 percent, respectively. Incising was associated with a statistically significant 11.5 percent ($P \leq 0.046$) decrease in average MOR over the entire MOR distribution (Fig. 1). The average difference in MOE of incised lumber was 2.5 percent less than that of nonincised lumber, but this difference was not significant. Incising is known to reduce the strength properties of lumber proportionally to the loss in section due to wood loss from incisions and damage beneath the wood extending over 2 mm into wood beneath the incisions (Winandy et al. 2021). This study showed that this level of damage was sufficient to reduce the structural properties of nominal 4 by 6-in lumber. The original intent was to compare incised-to-

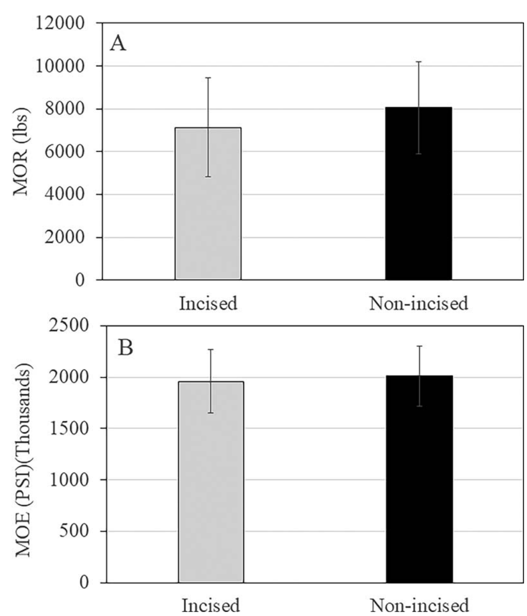

Figure 1.—(A) Effect of incising on modulus of rupture (MOR) and (B) modulus of elasticity (MOE) of nominal 4 by 6-in Douglas-fir timbers. Values represent means of 48 nonincised and 48 incised samples; error bars represent 1 SD.

nonincised ratios of MOR or MOE from pre-E matched pairs from two green (high moisture content) pre-E-rated boards. After air drying, the incised-to-nonincised ratio of MOE values for paired incised and nonincised values were extremely variable, ranging from 0.7 to almost 1.5 when analyzed on the basis of the E-sorting done on green lumber (Fig. 2). This disparity suggests that the initial E-sorting was not successful in parsing E-matched pairs into incised and nonincised populations. This may have resulted in random assignments of stronger pieces to the nonincised population, which could have contributed to the higher average MOR value.

Measuring MOE using transverse vibration is well established and is well correlated with MOE and MOR measured using static bending tests (Franca et al. 2018, 2019; Uzcategui et al. 2023). However, moisture content can complicate the measurement of MOE using transverse vibration. Although some studies have shown good correlations between green MOE measured by transverse vibration and dry MOE measured in static bending (Halabe et al. 1995), moisture content does play a role in how transverse stress waves are propagated through lumber, particularly below 50 percent moisture content (Gerhards 1975). Moisture content variation among green 4-by-6s sorted using transverse vibration may have resulted in inaccurate MOE-based pairings that contributed to differences in MOR in the two populations. There was no opportunity in this test to dry lumber before E-sorting in this study because of limited access to incising equipment.

As an alternative analytical method, the raw MOE and MOR data for the nonincised and incised boards were rank sorted on the basis of their tested MOR for MOR pairs and MOE for MOE pair, then analyzed in rank order as 48 MOR-matched pairs without regard to the initial E-rating. The ratios of nonincised to incised MORs and MOEs were then compared.

The 48 paired MOE ratio values were similar (ideal ratio = 1) except for the three weakest paired boards (Fig. 3). The incised-to-nonincised ratio for MOR, however, showed a distinctive trend across the 48-pair distribution. MOR ratios (incised to nonincised) in the lower quartile (at or below the

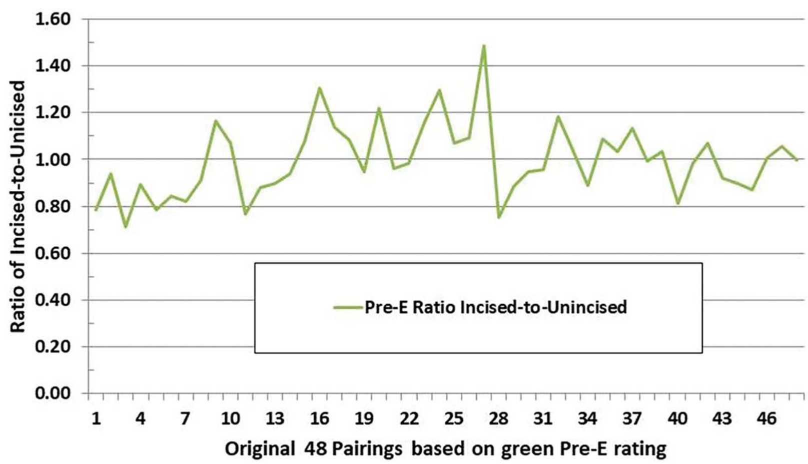

Figure 2.—Ratios of modulus of rupture and modulus of elasticity for nonincised and incised Douglas-fir timbers cut from E-rated timbers showing the high variability in ratios on the basis of green pre-E ratings.

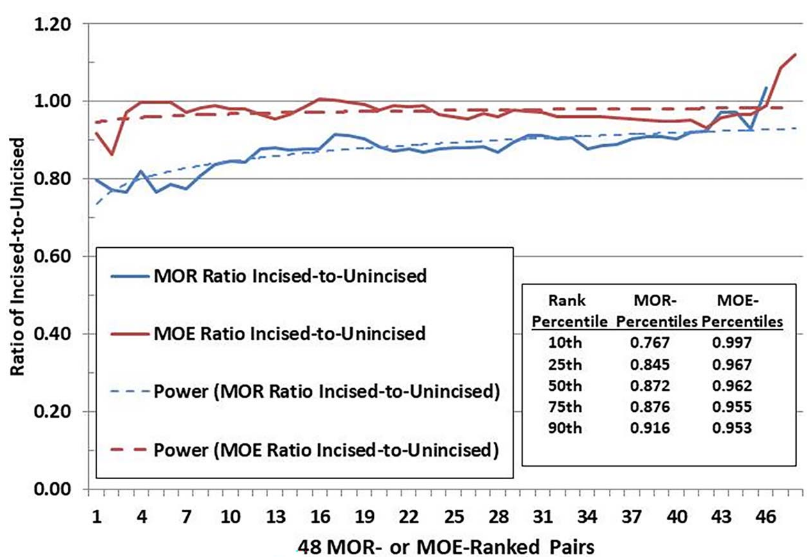

Figure 3.—Modulus of rupture (MOR) and modulus of elasticity (MOE) ratios for matched nonincised and incised nominal 4 × 6-in (89 × 140-mm) Douglas-fir lumber subjected to four-point loading when pairing was based on ranked order of the actual MOR or MOE values.

25th percentile, i.e., ranks 1 to 12 of 48) of the MOR distribution averaged about 0.80, whereas MOR ratios above the lower quartile (above the 25th percentile, i.e., ranks 13 to 48) averaged about 0.90 (Fig. 3).

Although this is only a preliminary assessment, these results clearly support the current engineering design adjustment factors for incised lumber in the NDS (American Wood Council 2024). However, viewing these data across the entire MOR distribution results clearly showed that >75 percent of 4-by-6 test materials experienced only about a 10 percent reduction in MOR. The lack of true E-matching in this study probably accounts for these differences in MOR effect across the MOR distribution. Thus, these results seem to indicate that although the NDS adjustment C_i factor of 0.80 is clearly applicable for nominal 2-by, and other predictive models have indicated that no C_i factor is required for timbers, further study of the effects of incising on full-size nominal 4-by material might support a C_i of 0.85 to 0.90 for these dimensions.

Conclusions

Incising had little practical effect on MOE of nominal Douglas-fir 4 by 6-in (89 by 140-mm) lumber but did significantly reduce MOR. MOR effects varied greatly across the MOR distribution but were more pronounced at the lower range of the MOR distribution (≤25th percentile). These results support the current NDS adjustment factors, but study on E-matched, full-length nominal 4 by 6-in (89 by 140-mm) lumber would eliminate some uncertainties in this data set.

Acknowledgments

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