Effect of kiln drying on the hardness and machining properties of tamarack wood for flooring

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Abstract

The hardness, planing and moulding properties of tamarack wood from natural forests were evaluated on kiln-dried specimens following three types of drying schedules namely, high-temperature, elevated-temperature, and conventional drying. Hardness tests were conducted according to ASTM D 143 standard. The planing and moulding properties were evaluated according to ASTM D 1666-87 standard. Wood specimens were machined at 7% moisture content and the surface quality obtained was visually graded on a scale of 1 to 5 (excellent or defect-free to very poor). The maximum depth of torn grain produced by planing was also measured for eight cutting conditions. Hardness was positively related to wood density. Machining and hardness properties appeared not to be differently affected by the drying process. The wood of tamarack trees performed well in the planing and moulding processes. The best planing condition was obtained at 10° rake angle and twenty knife marks per 25.4 mm cutting length. The global analysis of properties indicated that tamarack wood is suitable for the fabrication of flooring products.

Keywords: Hardness, planning, moulding, drying, tamarack

Introduction and background

Tamarack is a larch species (*Larix laricina* (Du Roi) K. Koch) that grows from Maine to Minnesota, throughout much of Canada, and in Alaska. This species can live on poorly drained sites as well as on cool, moist, well drained soils. Tamarack is rarely found in pure stands. Black spruce, northern white cedar, balsam fir, paper birch, and red maple are common associates of tamarack in mixed stands (Mullins and McKnight 1981).

Tamarack wood is moderately hard and heavy, and yellowish to russet brown or occasionally reddish brown in color. The sapwood is whitish and narrow. The wood is fairly high in bending and compressive strength, and low in resistance to impact. It ranks high in hardness, second only to western larch among the Canadian coniferous species (Jessome 2000). Traditionally, tamarack has been mainly used as lumber in building construction, for railroad ties, mine timbers, poles, posts and piling, and pulpwood (Mullins and McKnight 1981). In the last decade, however, a new market niche developed throughout North America for tamarack rustic and classic solid wood floors. This new utilisation brought about a need for more research on the kiln drying, hardness, and machining properties of tamarack wood.

Hardness is currently a practical mechanical property used to assess the suitability of wood species for use as residential and commercial flooring (Wiemann and Green 2007). On the other hand, tamarack wood frequently contains spiral grain, which forces the kiln operator to take special precautions during the drying process to avoid warping, such as the application of top-load restraint and the use of a high-temperature schedule to take advantage of the plasticization effect of heat on wood. The presence of spiral grain combined to the hardness of this wood requires particular measures for its machining. For instance, tamarack wood is reported to show poor quality surface in planing, torn grain and raised grain being two of the typical defects observed when planing dried lumber. The moulding or shaping performance, however, seems to be high ranked (Lihra and Ganev 1999).

The influence of the drying treatment on the planing and moulding properties of wood has been the subject of only a few investigations (Hernández et al. 2001). Several studies, however, have been reported on the effect of the drying temperature on the hardness of wood. No significant effect of the drying temperature was noticed in the case of softwood species, namely for Scots pine (Sehlstedt-Persson 1995) and Norway spruce (Hansson and Antti 2006).

The objective of this study was to determine the hardness, planing, and moulding properties of tamarack wood from natural stands. The effect of three drying treatments on both hardness and machining properties was evaluated.

Material and methods

Logs of tamarack (*Larix laricina* (Du Roi) K. Koch) were milled into boards of 32 mm by 102 mm by 2.44 m. The logs were collected from trees coming from three different sites of the Beauce region, Quebec, Canada, characterized by mixed stands growing on poorly drained soils. The boards were dried in a 2.5 m^3 experimental kiln at Laval University using three treatments: a conventional schedule (dry-bulb temperature (T_{db}) between 66 and 82°C), an elevated-temperature schedule (T_{db} between 82 and 90°C), and a high-temperature schedule (T_{db} between 90°C and 115°C) with a top-load restraint of 7.5 kN/m^2 in each case. Each drying treatment was replicated twice. The elevated-temperature and high-temperature schedules started with a pre-steaming treatment of six hours. The three drying schedules were finished by an 18-hour long equalizing period and a 4-hour long conditioning treatment. The target final moisture content was 7%.

After drying, the boards selected for the planing tests were placed in a conditioning room set at 20°C and 40% relative humidity (RH) in order to keep a nominal equilibrium moisture content (EMC) of 7%. This EMC represents a suitable value for wood that will be processed for indoor applications. The average density based on the mass and volume at 7% moisture content (MC) was 598 kg/m^3.

Hardness test

The hardness test was conducted in accordance with the ASTM D 143 standard, except for the dimensions of the specimens. As the initial boards were thinner than the size required for the hardness test, specimens were prepared by face-gluing three 17-mm thick pieces together. Green et al. (2006) suggested that if two pieces must be used to obtain a desired thickness, the pieces should be glued together. Thus, these specimens had two gluelines. The gluelines were on the tangential faces when prepared from flatsawn boards, and on radial faces when prepared from quartersawn boards. Tests were then conducted on specimens that were 51 mm by 70 mm by 152 mm. The test set-up allowed continuous recording of load as a function of penetration depth of the standard 11.28 mm - diameter steel ball into the specimen. For each sample, two indentations were done for each side face and one indentation for each transverse face. All indentations occurred away from gluelines. The maximum applied load gave the value of the hardness.

Planing test

A total of 150 specimens were submitted to the planing test based on ASTM D 1666-87 standard (50 specimens per drying treatment). Specimen dimensions for this test were 25 mm x 102 mm x 910 mm. Before planing, a 25-mm long sample was cross-cut from each specimen in order to determine the density at 7% EMC (mass and volume at 7% MC).

The tests were performed with a cabinet planer using five rake angles, 10, 15, 20, 25 and 30 degrees. Knives were not jointed and were beveled on the rake face in order to modify the rake angle. In all cases, the clearance angle was 16 degrees. Knives were kept freshly sharpened during the tests. The feed rate was adjusted to obtain 20 knife marks per 25.4 mm of planing length with a cutterhead rotational speed of 3640 rpm. Three other tests were made to obtain 8, 12 and 16 knife marks per 25.4 mm length but with a 10 degree rake angle only. In all cases, the cutting depth was 1.6 mm. Half of the specimens for each drying treatment (25 specimens) were planed with the grain and the other half against the grain. Knives and tools were always kept in good cutting condition.

After planing, each specimen was visually assessed and classified on the basis of five quality grades (grade 1: excellent or defect-free; grade 2: good; grade 3: fair; grade 4: poor; and grade 5: very poor). Planing properties were expressed as the percentage of defect-free pieces.

The planing quality was also evaluated on a quantitative basis by measuring the depth of the torn grain produced. For each sample, the two deeper torn grains were measured, the first near a knot (between 0 and 10 mm from the knot), and the second one away from a knot area. Defects were measured with a Mitutoyo sensor of ± 0.001 mm accuracy equipped with a tip of 1.7 mm of diameter.

Moulding evaluation

To evaluate the surface quality of the flooring made from tamarack wood, a total of 358 kiln dried boards were submitted to a moulding process to fabricate tongue and groove flooring strips. A Weining Unimat 23EL moulder operating at 6000 rpm of rotation speed was used. The knife and rake angles for the freshly sharpened knives were 30 and 12 degrees, respectively. The feed speed was set at 18 knife marks per 25.4 mm length. The planed top face as well as the groove and tongue joint were then evaluated based on the quality criteria of the ASTM D 1666-87 standard. As the tongue was inserted into a corresponding groove to form a joint, the top face of each wood piece (including the joint) was evaluated in terms of absence or presence of defects. Flooring was visually examined and classified on the basis of five quality grades (grade 1: excellent or defect-free; grade 2: good; grade 3: fair; grade 4: poor; and grade 5: very poor).

Statistical analysis

A multiple analysis of variance (MANOVA) was carried out using the GLM procedure of SAS software (1990) to analyze the hardness properties. The use of the MANOVA is explained by the fact that there were, in this case, several dependent variables (hardness test performed on three surfaces). This procedure provides parameter estimates for generalized linear models including both fixed and random factors in the same model. Thus, drying treatments were considered as a fixed effect while other sources of variation were considered as random effects. Normality was checked with the Mardia test (which checks both distribution skewness and kurtosis). Furthermore, an analysis of variance was conducted using SAS software for planing tests. Data were analyzed as a split-split-plot design using the MIXED procedure (Littell et al. 1996). Univariate normality was carried out using the Kolmogorov-Smirnov test. For moulding analysis, means were compared with the Least-squares means statement from the SAS General Linear Models procedure at 95% confidence levels (SAS Institute 1998).

Results and discussion

Hardness properties

Table 1 shows a summary of mean hardness values for each loading direction with respect to the type of drying and orientation of the gluing plane. There was no significant difference between radial and tangential hardness, which is in agreement with previous work (Green et al. 2006). According to the latter authors, the primary reason to test both the radial and tangential faces is to ensure a more representative value for each specimen. Therefore, these values are averaged and tabulated as "side hardness" in Table 1. Moreover, no effect of the drying treatments was found on the hardness of wood. Similar conclusions have been reported in earlier studies on Scots pine (Sehlstedt-Persson 1995) and Norway spruce (Hansson and Antti 2006).

The MANOVA results showed that all interactions implicating the density, drying treatments and gluing were not significant for hardness properties. As the pieces of wood were face-glued to reach the right thickness, the gluing effect was analyzed, and no statistically differences in hardness related to the glueline orientation were observed. The results also showed that the density affected positively wood hardness. The relationship between these two parameters has been extensively documented in a number of studies (Green et al. 2006, Wiemann and Green 2007).

Hardness reached moderately high values in average from 3700 N on the side to 4445 N at the end, making this species an excellent wood for flooring. Jessome (2000) reported hardness values for tamarack at 12% MC. Based on these data, hardness values at 7% MC were estimated as being 3600 N side and 4200 N end (by assuming 30% of fiber saturation point (FSP) and a linear tendency of hardness variation from 0% MC to FSP). Hardness values obtained by our study resulted slightly higher that those obtained by Jessome (2000).

Table 1. Mean hardness values of tamarack wood as a function of the type of drying, glueline orientation and loading direction.

		Hardness (N) [2]			
		Load direction			
Type of drying[1]	Nominal plane of gluing	Radial	Tangential	Axial	n
HT	Tangential pieces	3586 (586)	3468 (647)	4033 (569)	30
ET		3888 (712)	3566 (731)	4163 (737)	27
CT		3829 (676)	3721 (588)	4318 (681)	29
HT	Radial pieces	3540 (484)	3544 (358)	4397 (649)	19
ET		3876 (705)	3812 (665)	4894 (605)	23
CT		3921 (541)	3644 (505)	4866 (821)	23
	Mean	(Side) 3700		(End) 4445	

[1]HT: High temperature, ET: Elevated temperature and CT: Conventional temperature
[2] Standard deviation within brackets

Planing properties

Results of the ANOVAs performed on the qualitative evaluation of planing data showed significant interactions between the grain direction with respect to planing and planing condition ($p < 0.0133$) and between drying treatment and planing condition ($p < 0.0024$). The multiple comparison analysis showed that grain direction with respect to planing condition strongly affected the quality of planed larch wood surfaces. However, the drying treatment did not affect the planing quality. The main defect observed after planing was the torn grain. As expected, when planing with the grain, many combinations of rake angles and feed speeds produced a satisfactory surface. In contrast, torn grain was often produced when planing against the grain. Raised and fuzzy grain defects were also observed, but to a lesser degree.

As expected, results of the mixed ANOVA procedure applied to the torn grain data produced during planing showed that knots had a strong effect on planing. The worst surface quality was obtained near the knots. However, as for the qualitative evaluation, results of the ANOVA did not show any significant difference among the drying treatments for all planing conditions studied. In a similar study, high-temperature drying did not affect the planing properties of white spruce wood as compared to conventional drying (Hernández *et al* 2001). Thus, the main results showed in Figures 1 to 4 hereafter are presented by pooling the values of the drying treatments.

Effect of rake angle on planing quality

As expected, the proportion of defect-free pieces increased as rake angle decreased from 30° to 15° (Figure 1). This proportion decreased when rake angle changed from 15° (36.7%) to 10° (34.7%), although, no statistically differences were found between them. Lihra and Ganev (1999) reported that tamarack had the lowest scores compared with sixteen other species studied by these authors. A 20-degree rake angle at 12 knife marks per 25.4 mm was recommended by Lihra and Ganev (1999) for this species. However, they classified the specimens on the basis of grade 1 and 2 resulting in 78% of defect-free and or good pieces. From this proportion, only 6% corresponded to defect-free pieces which should be considered as grade 1. Thus, considering only the grade 1 as evaluation criterion, better results were produced in our study than the previous one for the same wood species.

The effect of rake angle on the maximum depth of torn grain produced by planing larch wood is shown in Figure 2. In general, torn grain decreased as the rake angle decreased from 30° to 10° at 20 knife marks per 25.4 mm feed speed when measuring near the knots. The maximum depth of torn grain was minimum at 10° of rake angle (0.40 mm) followed by 15° of rake angle (0.51 mm). Thus, a rake angle of 10° appears to be the most suitable for producing a quality surface when planing natural forest larch wood. The zones near the knots were more sensitive to the effect of the rake angle. Torn grain was similar in surfaces far away of knots for all rake angle conditions studied. This means that there is a tendency to form a type I chip, according to the three basic chip types studied by Franz (1958). Hernández et al. (2001) suggested a 15° rake angle when planing white spruce from plantation forests. However, greater differences in the proportion of defect-free white spruce pieces were found for rake angles between 10° and 15°. Results showed that the quantitative criterion was a better method to evaluate the surface quality. Thus, based on the results obtained in this study, it is suggested a rake angle of 10° as the best condition for planing larch wood from natural forests.

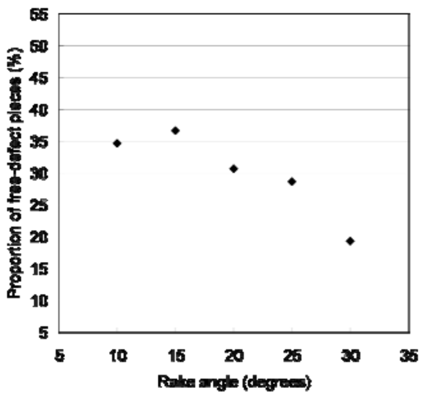

Figure 1.- Effect of the rake angle on the proportion of defect-free pieces for tamarack grown in a natural forest. Planing performed at 20 knife marks per 25.4 mm of feed speed and 1.6 mm of cutting depth

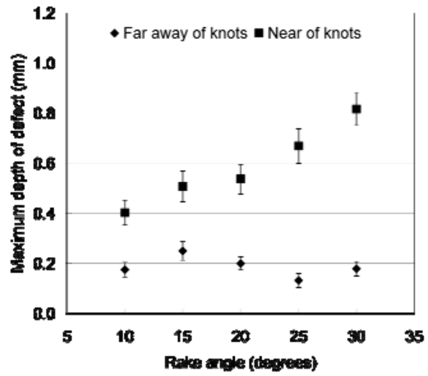

Figure 2.- Effect of rake angle on the maximum depth of torn grain for tamarack grown in a natural forest. Planing performed at 20 knife marks per 25.4 mm of feed speed and 1.6 mm of cutting depth (error bars indicate standard error of the mean).

Effect of feed rate on planing quality

The proportion of defect-free pieces increased with the number of knife marks per 25.4 mm of cutting length, reaching a maximum around 35% of defect-free pieces (Figure 3). On the other hand, the maximal depth of torn grain produced by planing also decreased as feed rate decreased (Figure 4). Thus, the best surface quality for larch wood from natural forest was obtained at 20 knife marks per 25.4 mm. Reduction in the maximum depth of torn grain was important, decreasing from 1.38 mm to 0.40 mm on average between 8 and 20 knife per 25.4 mm, and from 0.53 mm to 0.17 mm near and far away from the knots, respectively (Figure 4). A similar trend for white spruce from plantation forest was reported by Hernández et al. (2001). Results of Figures 3 and 4 also indicate that planing quality could be improved at higher number of marks per 25.4 mm length than those studied.

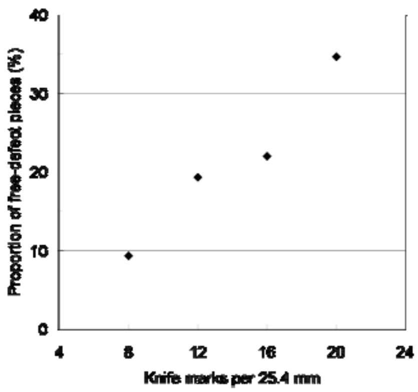

Figure 3.- Effect of the number of knife marks per 25.4 mm on the proportion of defect-free pieces for tamarack grown in a natural forest. Planing performed at 10° rake angle and 1.6 mm of cutting depth

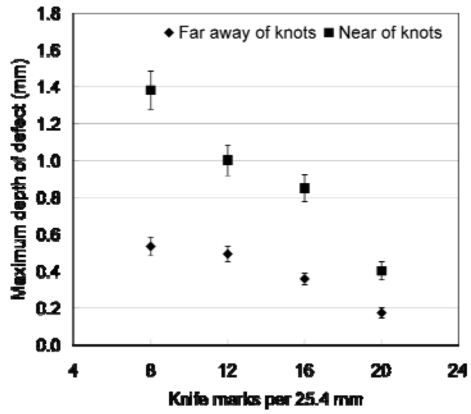

Figure 4.- *Effect of the number of knife marks per 25.4 mm on the maximum depth of torn grain for tamarack grown in a natural forest. Planing performed at 10° rake angle and 1.6 mm of cutting depth (error bars indicate standard error of the mean)*

The grain deviations associated with knots in tamarack natural wood produced deeper torn grain in comparison with the area far away from the knots. Similar results were obtained by Hernández et al. (2001) where the presence of knots significantly affected the planing of white spruce from plantation forest.

Moulding evaluation

Tamarack wood flooring was evaluated following the criteria from ASTM D 1666-87. The results produced by the three drying treatments are shown in Table 2.

Table 2. Proportion of defect-free strips of tamarack wood flooring for the three drying treatments studied

Drying treatment	% of free defects
High temperature	64[1] A
Elevated temperature	51[1] A
Conventional	87[1] A

[1] Means of 2 replicates
³ Means within a column followed by the same letter are not significantly different at the 5% probability level.

The proportion of defect-free pieces was not affected differently by the drying treatment. Thus, high-temperature, elevated-temperature and conventional drying treatments appeared to have a similar effect on the quality of specimens machined. However, additional replicates for each drying treatment should be performed in future studies to increase statistical confidence. It is confirmed that the moulding or shaping behavior of tamarack make this species suitable for high quality flooring products.

Conclusion

This research showed that tamarack wood grown in natural forest has a good performance for planing and moulding processes. The performance in planing tended to increase as rake angle and feed speed decreased. The best planing condition was obtained at 10° rake angle and 20 knife marks per 25.4 mm of feed speed. The analyses of variance performed on data showed that the three drying treatments studied did not affect differently the hardness properties as well as the quality of wood machined with the two cutting processes. Density positively affected the hardness properties of tamarack larch wood. The comprehensive analysis of density, hardness, planing and moulding properties showed that tamarack larch wood can be satisfactorily used for the fabrication of flooring products.

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