

EFFECT OF KNIFE JOINTING ON THE GLUING PROPERTIES OF WOOD

Roger E. Hernández†

Professor

and

Nader Naderi

Former Ph.D. Graduate Student

Département des Sciences du Bois et de la Forêt

Université Laval

Québec, Canada, G1K 7P4

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ABSTRACT

Jointing is a common practice required to produce the same cutting circle for all knives mounted in a cutterhead of a peripheral knife planer. This practice also is sometimes used wrongly to refresh slightly dulled knives. Initially the jointed land at the cutting edge has a 0 degree clearance angle, which becomes negative with the workpiece motion relative to the cutterhead and as the cutting edge wears. The jointing operation potentially could crush a thin layer of the planed board and affect the wood quality and performance. The gluing properties of sugar maple, red oak, and spruce woods were evaluated using four jointed land widths. A wider jointed land affected the surface quality and resulting gluing shear strength differently depending on anatomical differences of the specific woods. The effect of knife jointing was more pronounced where the moisture content of the samples had fluctuated.

Keywords: Planing, knife jointing, gluing properties, sugar maple, red oak, spruce.

INTRODUCTION AND BACKGROUND

The peripheral milling planer is the most common machine in the wood industry for planing wood surfaces. This machine removes single chips from a workpiece by the intermittent engagement of knives mounted on the periphery of a rotating cutterhead.

The final step of knife installation on the cutterhead is the jointing operation, where an abrasive stone is passed along a rotating cutterhead, slightly touching all knife edges. Any projecting knife edge is ground back, ensuring that all the edges lie in a common cutting circle. Thus each knife takes a chip of equal depth with each revolution of the cutterhead (Hoadley 1980). The area or joint appearing next to the cutting edge of the knife is called the "land." As the knives become dull, joint-

ing is sometimes wrongly repeated as a sharpening process.

Apart from the jointing operation, previous work has shown that there are crushed cells and checks on the surface and subsurface of the workpiece (Stewart and Crist 1982; Murmanis et al. 1983; Reeb et al. 1998). Several researchers have reported differences in surface quality, especially in presence of moisture changes and even in specimens prepared under laboratory conditions using sharp knives (River and Miniutti 1975; Jokerst and Stewart 1976; Edvardsen 1993; Hernández 1994; Naderi and Hernández 1999). The occurrence of this damaged layer has been attributed to the normal component of cutting forces that exceed the perpendicular-to-the-grain compression strength, and consequently crushes and breaks wood cells.

Wood surface properties could also be affected by the heat produced during cutting due

† Member of SWST.

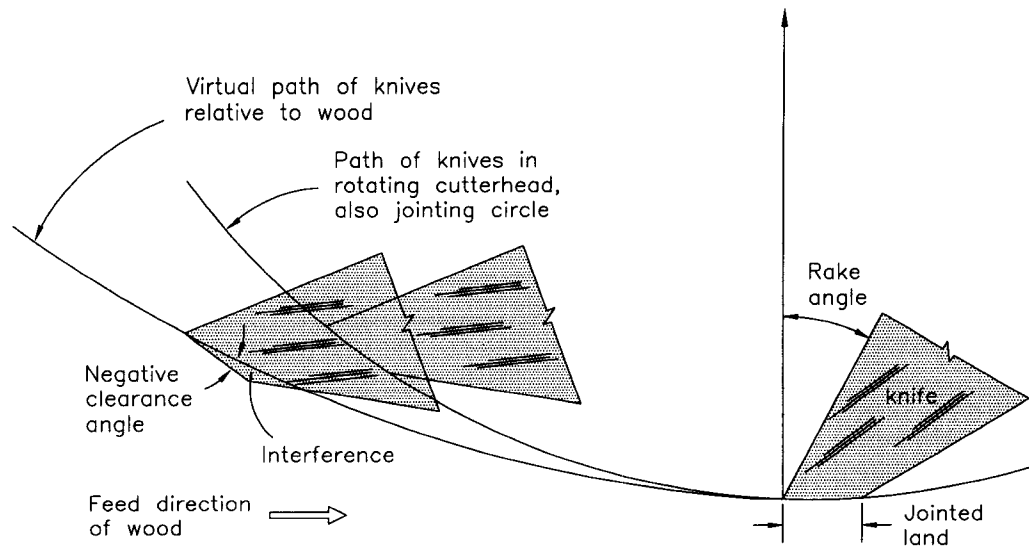


FIG. 1. Schema of the action of a jointed knife on the cutting circle (from Hoadley 1980).

to friction between the tool edge and the wood surface. A superficial burned layer often occurs on a planed board when feeding is stopped for a moment during peripheral planing. Dull knives can also leave burned layers on the planed surface. Stewart (1989) reported that temperatures may approach or even exceed 800°C near or at the tool edge when cutting wood. Due to the low thermal conductivity of wood, this temperature can be thought of as a local heat treatment, and could alter the properties of the surface and subsurface layer.

The jointed land produced on the knife edge after jointing has a nominal clearance angle of 0 degree. However, because of the feeding action and wear at the cutting edge, this angle can become negative during cutting (Fig. 1). This negative clearance angle means that the machined surface is subjected to a greater crushing and friction than a surface planed using unjointed knives. Consequently, the superficial damage produced should be more pronounced for jointed planing than for unjointed planing.

The advantage of jointing is principally to form the same cutting circle, where all the knives take a chip of equal depth. According

to Dunsmore (1965), this operation is the only way to form a common cutting circle for all the knives. Jointing allows several intermediate sharpenings without removing knives from the cutterhead and reduces down-time (Jones 1994). Jones (1994) also indicated that an uneven or wide jointed land has adverse effects upon the planed surface quality. A wide jointed land that results after several re-jointings causes an increase in friction between that land and the workpiece. Davis (1942) cautioned that jointing should not be repeated too frequently between grindings. Hordern (1958) reported that after three or four re-jointings, the jointed land will project farther from the axis of the cutter block than that of the cutting edge (Fig. 1). As a result, the wood surface will be more crushed and heated compared to a sharp unjointed knife. Hoadley (1980) noted that a very narrow land, (0.25 mm) will not create problems because the area of zero clearance is very small. Wengert (1988) and ASTM D 1666 (1987) state that the maximum allowable jointed land width before re-sharpening should be 0.8 mm. Earlier Dunsmore (1965) recommended a maximum of three or four re-jointings, within which the land width must not exceed 1.2 mm. These varied recommen-

dations for a maximum allowable jointed land indicate a need for more precise information on the effects of jointing under specific cutting conditions.

A cutting edge with a wide jointed land will pound and rub the wood surface rather than make a clear cut. When jointed land width increases, the normal cutting force increases and may cause deeper superficial damage and a lower surface quality. The objective of this study was to evaluate the planed surface quality as a function of the knife jointed land. Three wood species and four jointed land widths were evaluated. The gluing shear performance was evaluated at constant hygrothermal conditions and after exposing surfaces to an accelerated aging treatment.

MATERIALS AND METHODS

Testing materials

Sugar maple (*Acer saccharum* Marsh), red oak (*Quercus rubra* L.), and spruce (*Picea sp.*) woods were studied. Sugar maple and oak are diffuse-porous and ring-porous hardwoods, respectively, and mostly have indoor applications. White spruce is a softwood more often used in outdoor applications. Commercial air-dried lumber was stored in a conditioning room at 65% relative humidity (RH) and 20°C for 4 months. Boards 63 mm wide by 20 mm thick and 450 mm long were then processed. After processing, these boards were divided into four matched groups for each species.

Specimen preparation

Each group was surfaced with a specific jointed land knife using a conventional cabinet knife planer. The feed rate was set to give 34 knife marks per 25 mm of length, and the cutting depth was adjusted to remove 1 mm of wood in one pass. The radius of the cutting circle was 50.5 mm. One of the three knives on the cutterhead was set for cutting. The knife angle and the clearance angle for the freshly sharpened knives before jointing were 60 and 15 degrees, respectively. After jointing, these angles became 75 and 0 degrees, respec-

tively. The rake angle was therefore 15 degrees. Jointing normally is performed when knives are rotating at the operational speed. In the present study, the fresh sharp knives were jointed using a sharpening machine prior to being mounted in the cutterhead. This procedure enabled us to ensure three specific values of jointed land width (0.5, 1, and 2 mm wide). A fourth group of samples was planed with an unjointed knife, and was considered as having 0-mm jointing width. After planing, pairs of longitudinal adjacent boards were matched; these pairs would be eventually glued together. Each matched pair was assigned to one of the four jointed land widths. Since the length of the initial lumber was not sufficient to select a complete set of matched specimens for one replicate, the sample matching process and the analysis of the results were adapted so that a balanced incomplete block statistical design could be applied. Finally, for each species, there were four groups with 15 pairs of replicates each. Subsequently each pair was glued, forming a laminated block.

Taking into account the end-use of the species, the oak and maple samples were glued with a carpentry white adhesive (polyvinyl acetate), and the spruce samples were glued with a phenolresorcinol-formaldehyde adhesive. The white glue consumption was 400 g per m² and a pressure of 0.4 MPa was applied for 45 min. The resorcinol-phenol formaldehyde consumption was 480 g per m², and a pressure of 0.8 MPa was applied over 6 h. These conditions followed the technical recommendations supplied by the adhesive manufacturer.

Finally, the laminated blocks were machined to eliminate misalignment due to sliding during the gluing process. The final dimensions of the laminated block were; 50 mm wide, 38 mm thick, and 450 mm long. Two gluing shear specimens were selected from each laminated block. A total of 30 specimens from each group were selected to evaluate the effect of knife jointing on the gluing strength after exposure to two hygrothermal conditions. The gluing shear test samples were machined according to the ASTM D-905 standard

(1994). Small blocks for all species and jointed lands were also cut from the laminated block for analysis by scanning electron microscopy (SEM).

Conditioning treatments

During and after sample preparation, the 65% RH and 20°C conditions were kept constant. Half of the specimens were tested under these conditions. The other half were subjected to an accelerated aging treatment. This treatment varied depending on the type of glue. For white glue, maple and oak samples were exposed over distilled water for 25 days. Gain in MC of the samples at this point was about 8%. Spruce samples glued with a phenol resorcinol adhesive were subjected to an accelerated aging procedure given in the CSA 0112.7-M standard (1977). Briefly, the samples were first soaked in boiling water for 4 h, then oven-dried at about 60°C for 20 h; then the samples were again immersed in boiling water for 4 h. After the respective aging treatments, all three sample types were conditioned at 65% RH and 20°C to reach their initial equilibrium moisture content.

Glueline tests

Specimens were evaluated according to the ASTM D 905 standard with a universal testing machine fitted-out with a gluing shear fixture. The crosshead speed was 0.38 mm/min. Cross sections of the specimens and load at failure were recorded, and the average gluing shear stress was calculated. The percent wood failure was also evaluated by independent examinations by two technicians. The statistical analysis of the results was with a balanced incomplete block design.

Microscopic evaluation

Small blocks with about 1 cm² of transverse area, including a glueline, were removed from gluing shear specimens for examination by SEM. The blocks were prepared for SEM with a razorblade by carefully cutting a surface on the end-grain perpendicular to the planed sur-

face. They were then desiccated, mounted onto standard aluminium stubs with silver paint, redesiccated, and coated with gold in a sputter-coater. Electron micrographs of representative subsurfaces were taken for all combinations of cutting conditions.

RESULTS AND DISCUSSION

The average values for the apparent gluing shear strength and the percent wood failure for the three species, for the four jointed land widths, and the two conditioning treatments are given in Table 1. The influence of the jointing operation on the gluing behavior depended on the wood and glue.

At constant hygrothermal conditions, sugar maple wood showed higher gluing shear strength when the knife for planing was not jointed. The effect of jointing was statistically significant at the 5% probability level. Strength decreased when jointed knives did the planing. At 0.5 mm of jointed land width, the gluing shear strength decreased 14%. A similar shear strength was obtained at 1 mm of jointed land and decrease was 18% when the jointed land was 2 mm. Crushed and damaged cells were observed near or at the glueline in transverse sections of the specimens (Figs. 2 and 4). However, the severity of damage was variable within each jointed land set (compare Figs. 2 with 3). The variation in surface damage within a given machining condition for sugar maple wood has been previously reported (Murmanis et al. 1986). However, in general, as jointed land of knives increased in width, the crushed cell layer increased in thickness. The maximum thickness observed for this layer varied from about 0.1 mm for unjointed knives (Fig. 2) up to 0.3 mm for knives having 2 mm of jointed land width (Fig. 4). Beneath the surface, longitudinal cells were locally quite severely crushed, and in some cases rays were bent or broken (Fig. 4). Where jointed knives produced severe cells crushing on the surface, the glue did not penetrate through the crushed layer to sound wood. In fact, glue penetration was at

TABLE 1. Apparent average shear stress (SS) and percent wood failure (WF) for sugar maple, red oak, and spruce planed under four jointed lands and two conditioning treatments.

Wood species	Jointed land (mm)	Constant condition ¹		After conditioning ¹	
		SS (MPa)	WF (%)	SS (MPa)	WF (%)
Sugar maple	0	20.1 (0.3) ² A ³	2 (2) A	16.7 (0.3) AB	9 (5) A
	0.5	17.2 (0.3) B	6 (5) A	17.2 (0.3) A	14 (6) A
	1	17.3 (0.3) B	0 (0) A	16.5 (0.4) AB	9 (4) A
	2	16.5 (0.3) B	0 (0) A	16.3 (0.2) B	3 (2) A
Red oak	0	13.7 (0.5) A	16 (3) A	13.8 (0.6) A	22 (10) A
	0.5	14.3 (0.4) A	23 (8) A	14.6 (0.4) AB	39 (9) AB
	1	15.8 (0.4) B	25 (6) A	15.3 (0.4) B	45 (10) AB
	2	15.6 (0.2) B	67 (8) B	15.4 (0.3) B	55 (9) B
Spruce	0	11.5 (0.2) A	50 (9) AB	7.6 (0.2) A	33 (8) A
	0.5	11.4 (0.3) A	40 (7) A	7.7 (0.3) AB	32 (9) A
	1	11.2 (0.3) A	73 (6) B	8.3 (0.2) B	33 (8) A
	2	11.2 (0.3) A	62 (7) AB	8.3 (0.3) B	35 (10) A

¹ Values represent means of fifteen replicates.

² Values in parentheses represent one standard error of the mean.

³ Means within a column followed by the same letter are not significantly different at the 5% probability level. Comparison is done for each wood separately.

a minimum at 2-mm jointed land planed surfaces and increased for unjointed knife-planed surfaces. Consequently, the bonding mostly occurred in this damaged region where the cells had already been broken and crushed. River and Miniutti (1975) have also noted the negative effect of surface machining on yellow-poplar, a wood having a homogeneous anatomical structure similar to sugar maple. These researchers identified two types of glue-line failure; first, a deep wood failure that follows the grain, which represents a typical case of strong joints between well-machined sur-

faces; second, the failure may take the form of a shallow wood failure in joints. River and Miniutti (1975) felt that this type of failure was the result of damage to the wood during machining, and damaged wood does not provide a solid base for gluing. We found that the glue-line was regular and very thick in sugar maple samples (Fig. 4) and failure occurred at the wood surfaces, as indicated by the percent wood failure values (Table 1). This demonstrates that gluing adhesion was within an already damaged superficial layer.

After exposing maple to the moisture sorp-

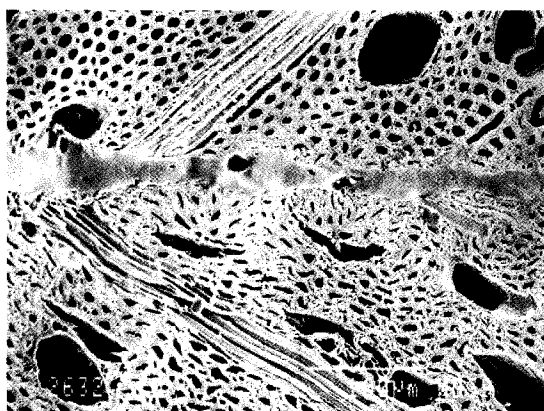


FIG. 2. Sugar maple, maximum damage, unjointed knife-planed specimen (SEM micrograph).

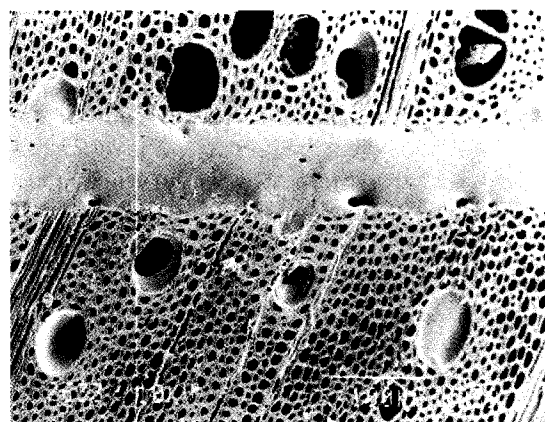


FIG. 3. Sugar maple, minimum damage, unjointed knife-planed specimen (SEM micrograph).

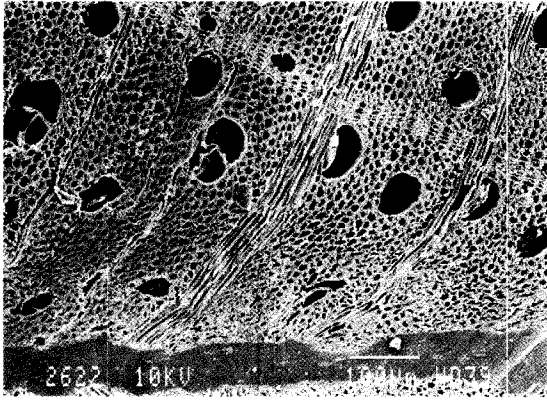


FIG. 4. Sugar maple, maximum damage, 2-mm jointed knife-planed specimen (SEM micrograph).

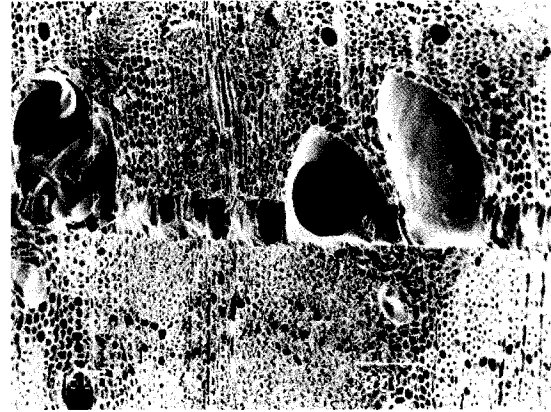


FIG. 5. Red oak, undamaged cells at bondline surface, unjointed knife-planed specimen (SEM micrograph).

tion cycle, the gluing shear strength of samples planed with unjointed knife decreased significantly 17% (Table 1). Failure occurred again mostly in the superficial layer, which showed that glue did not penetrate sufficiently deep to reach undamaged fibers. Even for unjointed knives, the superficial layer was subjected to crushing and breakage during planing but to a lesser degree than for the jointed knives. Figure 2 shows damaged fibers on the surface of the bottom half of the specimen. Our previous work (Hernández 1994) indicated that a surface machined with oblique planing had 10% higher gluing shear strength compared to a peripheral unjointed knife-planed surface. During moisture changes, the crushed cells tend to swell and shrink more than intact cells, which consequently alters the properties of the superficial layer. In this case, the gluing shear strength after moisture cycling for jointed knife-planed specimens was similar to the gluing shear strength in samples treated under constant conditions. The adhesion was apparently mainly at the damaged superficial layer and being practically already at a minimum and was not altered after a moisturizing and drying cycle. Lowering the glue viscosity and increasing the clamp pressure could probably increase glue penetration and improve the gluing shear strength if sound cells could be reached.

The gluing shear strength for oak specimens

was lower than for sugar maple specimens (Table 1). The influence of the jointing operation was different for red oak, a ring-porous wood, than for sugar maple, a diffuse-porous wood. At constant conditions, the specimens planed with the unjointed knife showed a low gluing shear strength of 13.7 MPa. This property increased gradually as the jointed land increased. At 2 mm of jointed land width, the gluing shear strength increased 14% compared to using the unjointed knife. River and Minutti (1975) reported almost no damage on the surfaces of red oak latewood and only moderate damage in earlywood after cutting with saw, planer, and jointer machines.

Figures 5 and 6 are typical micrographs of red oak surfaces planed at two of the four jointed lands. We found either no apparent or very few crushed cells below the surface of wood, irrespective of the jointed land used for planing. Gluelines in oak had an even thickness and were narrow compared to sugar maple gluelines (compare Figs. 4 and 6). Even earlywood cells with large vessels at the surface kept their original shape (Fig. 6). In this wood, several vessels at and near the surface were filled with adhesive, forming effective bonding attachments (Figs. 5 and 6). Good adhesive penetration and bonding between undamaged cells existed. The proportion of wood failure in red oak samples confirmed



FIG. 6. Red oak, very slight damage near to the vessels filled by adhesive is noted, 2-mm jointed knife-planed specimen (SEM micrograph).

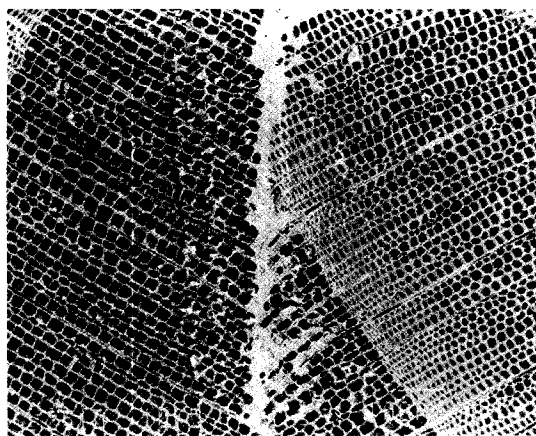


FIG. 7. White spruce, no damage observed at bondline surface in earlywood and latewood, unjointed knife-planed specimen (SEM micrograph).

that glue penetration was high. Wood failure increased as the jointed land width increased, passing from 16% for 0-mm jointed land to 67% for 2-mm jointed land. These results indicate that the surface and subsurface of samples did not exert an exclusive influence on gluing for this wood. This contrasts with the sugar maple samples with a very low proportion of wood failure and is further evidenced that the lower glue penetration in maple wood was due to its dense and homogeneous structure, which forms a layer of crushed cells.

After the conditioning treatment, gluing behavior of the red oak samples was similar to that under constant conditions (Table 1). Shear stress and percent wood failure increased as the knife land width increased. Furthermore, no decrease of the gluing shear stress after conditioning as noted for sugar maple wood occurred. Breaks in cell walls and consequent weakening caused by moisture changes during the aging treatment did not occur and demonstrate that the effect of the jointing on gluing behavior of oak was not affected as much by the production of crushed cells. The percent of wood failure in oak also showed that adhesive penetration was adequate. Wood failure increased from 22% for samples planed with unjointed knives to 55% for samples planed with 2-mm jointed width knives and indicated that the adhesive penetration may

have actually increased as jointed land width increased. The permeability in the transverse direction of wood appears to be increased by the jointing operation, with resulting higher adhesive penetration. Previous reports have shown that a compression rolling treatment increases the permeability in several wood species (Goulet et al. 1968; Cech 1971; Günzerodt et al. 1988). Cutting forces generated during planing, particularly the normal cutting force, increased as the jointed land width of knives increased. Permeability of red oak could have been increased by an analogous mechanism, and a slight compression produced by the feeding cylinders of the planer may have mimicked a compression rolling treatment.

At constant hygrothermal conditions, the gluing performance of spruce was not affected by the jointing process (Table 1). Given the low density of this wood, the normal forces developed during planing should be considerably less than those produced with sugar maple and red oak. Therefore, gluing would have taken place mostly between sound cells. Glue penetration was good, as indicated by the percent wood failure values. Surfaces planed with unjointed knives were generally undamaged, with a resulting thin glueline (Fig. 7). Hernández (1994) had earlier shown that spruce sur-

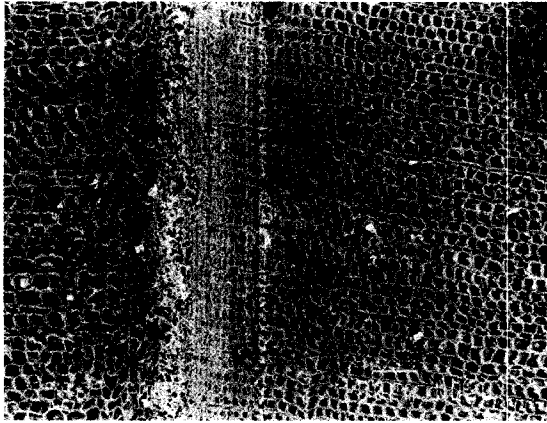


FIG. 8. White spruce, latewood cells relatively undamaged at the bondline (right), earlywood cells very crushed at the bondline (left), 2-mm jointed knife-planed specimen (SEM micrograph).

faces appeared to be unaffected by unjointed knife planing. However, there were crushed and broken cells in surfaces planed with jointed knives. A typical example corresponding to a 2-mm jointed knife-planed glueline is shown in Fig. 8. As noted for sugar maple wood, the damage was variable within each jointed land set. This variation was greater for spruce, which has a heterogeneous anatomical structure. Damage occurred almost exclusively on earlywood cells, which have thin cell walls and large lumina (Fig. 8). Where the layer of crushed cells was great, the glueline was generally thicker (Fig. 8). For the most part, latewood cells retained their normal appearance for all jointed lands. This damage pattern in spruce was similar to other heterogeneous woods, such as Douglas-fir (Jokerst and Stewart 1976; Murmanis et al. 1983; Murmanis et al. 1986) and southern pine (Jokerst and Stewart 1976).

After the severe soak-dry treatment, the gluing shear strength of spruce specimens decreased about 30% from its original value (Table 1). This treatment affected the glueline as the percent wood failure decreased from an average of 56% for the controls to 33% for the treated samples. This meant that the effect of jointing was more evident since failures in

the glueline increased. Crushed and broken cells and cracks within the cell walls produced during planing were magnified by a soak-dry treatment as noted by Murmanis et al. (1983). However, surfaces planed with jointed knives exhibited higher gluing shear strength compared to surfaces planed by unjointed knives, even though the presence of crushed cells was greater as jointed land width increased. The effect of jointing on gluing performance of spruce surfaces apparently depended on the morphological features of the wood element implicated during gluing. Better gluing occurred between latewood cells, which were less damaged or not damaged by the action of jointed knives. The amount of latewood influenced adhesion in spruce. Undamaged surfaces of earlywood cells also glued favorably. On the other hand, regions of crushed cells principally in earlywood failed to glue well. As the jointed land increased, the normal cutting forces had a greater impact on the superficial layer. This could cause a negative effect on earlywood cells (crushing action), but could be compensated by a positive effect on latewood cells. A suggested for red oak, permeability of wood, especially latewood, could be increased by the jointing. Glue may penetrate more via paths opened up in latewood and reach sound cells, where better mechanical or chemical attachments were available. A slight compression rolling induced by the feeding cylinders of the planer could have also aided this treatment. Compression rolling increases the permeability of white spruce (Goulet et al. 1968) and sitka spruce (Günzerodt et al. 1988). In an analogous manner, the increase of the jointed land width for planing had an overall positive effect on gluing performance in spruce.

The planing process produced variable wear on the knife edges from the different wood species, which corroborates the different effects of jointing on each species studied. Wear occurred even though each knife was cutting for a limited length, only to plane the final pass. The edge sharpness after planing was evaluated by measuring the force required for a knife to cut a 0.32-mm diameter fishing line.

A detailed description of this method is given by Huang (1994). This force was measured for 2-mm jointed knives. The cutting force was 3.8 N for the spruce sample knives, 5.6 N for oak sample knives, and 8.5 N for maple sample knives. This indicates that smaller cutting forces were generated by spruce, intermediate forces by red oak, and the highest forces by sugar maple wood. Changes in knife geometry due to wear were therefore more important when planing sugar maple. A negative clearance angle or a smaller rake angle may have increased the negative effect of jointing on sugar maple wood surfaces. The positive effect of jointing found for red oak and spruce using relatively freshly sharpened jointed knives may eventually be eliminated as wear occurs. The maximum admissible jointed land width should be determined according to the wood species. Experiments at different wear levels are also needed. Varying rake angle, diameter of the cutting circle, and cutting depth are other factors that need to be considered. The compression rolling action of the existing infeeding system should also be known. Given these individual uncertainties, general recommendations could be misleading and further investigations are required.

CONCLUSIONS

Significant differences exist among the three species studied. Results for sugar maple revealed that wood planed by peripheral cutting even with fresh sharp knives is subjected to high normal forces and friction that cause permanent damage in the surface and subsurface of wood. The amount and depth of this damaged layer increased with the width of the jointed land. Consequently, the gluing performance decreased as jointed land width increased. For red oak, no apparent damage in the form of broken and crushed cells occurred. Gluing performance was enhanced for red oak as jointed land increased. This was associated with an increase in the permeability of this wood. For spruce, gluing performance was slightly improved as the jointed land in-

creased. Therefore, the maximum allowable width for the jointing operation should be considered for each wood species separately. The interactions among the anatomical structure of wood, the jointed land width, and wear of knives are important factors that need to be studied more.

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