EFFECTS OF KNIFE JOINTING AND WEAR ON THE PLANED SURFACE QUALITY OF SUGAR MAPLE WOOD

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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. 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. Jointed knives could crush a thin layer of the planed board and affect the wood quality and performance. Sugar maple wood gluing properties were evaluated in samples that had been planed using one of four jointed land widths, each tested at four states of wear. With increased jointed land and planing length, the damage to the surface and subsurface of wood increased, but the gluing strength and percent wood failure decreased. The depth of this damaged layer was positively correlated with the magnitude of the normal cutting force. In samples where moisture content had fluctuated, the effects of jointing and wear on gluing were more pronounced. The results suggest that a jointed land of 0.9 mm may be used as maximum allowable width for planing sugar maple wood. Also, the planed surface quality of this wood may be negatively affected using a knife with 45 μm of rake face recession and 60 μm of clearance face recession, which results in a damaged layer 0.20 mm thick.

Keywords: Planing, knife jointing, wear, gluing properties, sugar maple.

INTRODUCTION AND BACKGROUND

One of the principal objectives of a mechanical process such as planing is to obtain an acceptable finished surface. The quality of planing depends on the wood characteristics, cutting tool geometry, and on the operational conditions of the machine. The quality level may be based on aesthetic or technical requirements and expressed in terms of damage caused to the wood surface during the planing process.

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

The final step in knife installation on the cutterhead is the jointing operation, where an abrasive stone is passed over the knife edges as they turn in the cutterhead. Any projecting knife edge is ground back, ensuring that all the edges lie in a common cutting circle. Thus, each knife will work in a uniform manner taking chips of equal thickness (Dunsmore 1965; Hoadley 2000). This forms a jointed land on the cutting edges where width varies according to the initial knife projection from the cutterhead with respect to the others. As the knives wear, jointing is sometimes wrongly repeated as a sharpening process. The nominal

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knife clearance angle returns to 0 degrees in such a way that during cutting the face of the land causes perpendicular compression as well as surface wood friction. These forces should normally increase with the increased jointing. The feeding action and wear at the cutting edge may also cause the clearance angle to become negative during cutting, reduce the rake angle, and further increase the normal component of the cutting forces. As a result, surfaces planed with jointed knives are subjected to greater crushing and friction than surfaces machined using unjointed knives. Although greater cutting forces are expected with jointing, a positive or negative effect on gluing shear strength may result, depending on the species of wood (Hernández and Naderi 2001).

Apart from the jointing operation, crushed cells and checks on the surface and subsurface of the workpiece exist (Stewart and Crist 1982; Murmanis et al. 1983; Reeb et al. 1998). Several researchers have reported differences in surface quality, especially with moisture changes and even in specimens machined under laboratory conditions with sharp knives (River and Miniutti 1975; Jokerst and Stewart 1976; Edvardsen 1993; Hernández 1994; Hernández and Naderi 2001). This damaged layer has been attributed to the normal component of cutting forces that in some cases exceeds the perpendicular-to-the-grain compression strength, and consequently crushes and breaks wood cells.

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

The principal advantage of jointing is to form an equal cutting circle, where all the knives take a chip of equal depth. This operation is the usual way to form a common cutting circle for all knives (Dunsmore 1965). Jointing allows several re-sharpenings without removing knives from the cutterhead and reduces down-time (Jones 1994). Jones (1994) also indicated that an uneven or wide jointed land adversely affects the planed surface quality. A wide jointed land that results from several re-jointings causes increased friction between that land and the workpiece. Davis (1942) cautioned that jointing should not be repeated too often between grindings. Hordern (1958) reported that after three or four re-jointings, the jointed land will project farther from the axis of the cutterhead than that of the cutting edge. As a result, the wood surface will become crushed and heated compared to wood planed with a sharp unjointed knife. Hoadley (2000) suggested 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 (1987b) both state that the maximum allowable jointed land width before re-sharpening should be 0.8 mm. Dunsmore (1965) also recommended a maximum of three or four re-jointings, within which the land width must not exceed 1.2 mm. However, Hernández and Naderi (2001) found that the maximum allowable width for the jointing operation should be determined separately for a given wood species. Sugar maple had permanent damage in the wood surface and subsurface and, consequently, the gluing performance decreased as the jointed land width increased. For red oak, no apparent cell damage existed, and gluing performance was enhanced as jointed land width increased. This was associated with an increase in the permeability of the wood. For spruce, gluing performance was slightly improved as the jointed land width increased. However, planing tests in this earlier study were carried out with freshly sharpened knives only. Hernández and Naderi (2001) concluded that the interactions among the anatomical wood structure, the jointed land width, and knife wear are important factors needing study.

The objective of this study was to evaluate the planed surface quality of sugar maple wood as a function of jointed land width and knife wear. Four wear levels of four jointed land widths were tested. We evaluated gluing shear performance at constant hygrothermal conditions and after exposing surfaces to an accelerated aging treatment.

MATERIALS AND METHODS

Testing materials

All tests were done with sugar maple (*Acer saccharum* Marsh) wood, a diffuse-porous hardwood that is commonly applied indoors. Commercial air-dried lumber was stored in a conditioning room at 60% relative humidity (RH) and 20°C for 4 months. Average moisture content (MC) was 12%. Eighty boards 63 mm wide by 20 mm thick and 2220 mm long were selected and prepared for planing tests. The boards were separated into four groups of twenty and, the groups were assigned to be subjected to a specific wear level. Each board was cross-cut into four matched sections 550 mm long, and these were assigned to a specific jointing level. This meant that a total of sixteen groups of twenty specimens each were tested. Each section underwent a planing treatment and then was sectioned to prepare a laminated block and a specimen for measuring cutting forces.

Specimen preparation

Each group was surfaced with a specific jointed land knife and wear level with a conventional cabinet knife planer. The feed rate was set to give 34 knife marks per 25 mm of length, and the cutting depth adjusted to remove 1 mm of wood in one pass. The cutting circle radius 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 were 60 and 15 degrees, respectively. After jointing, these angles became 75 degrees for the knife angle and 0 degrees for the clearance angle. The rake angle was 15 degrees. The sharp knives were jointed with a sharpening machine prior to mounting in the cutterhead, which meant we could obtain three specific jointed land widths (0.9, 1.8, and 2.7 mm wide). A fourth group of boards was planed with an unjointed knife, and was considered as having 0-mm jointing width. Each one of the four jointing levels was studied with a specific knife, which was successively worked up to reach four wear levels. Thus, the process began with a planing test performed with a freshly sharpened knife followed by other planing tests after 500 m, 1000 m, and 3000 m of planing. Three hundred forty pieces of sugar maple wood 75 mm wide by 25 mm thick and of varying lengths were planed to generate wear. This wear was under the same cutting conditions as during the planing treatment itself. After this planing treatment, the boards were cross-cut to form pairs that were subsequently glued together to form a laminated block.

The pairs of boards were glued with a carpentry white adhesive (polyvinyl acetate), with a glue consumption of 810 g per m^2. As recommended by the adhesive manufacturer, 0.4 MPa of pressure was applied for 45 min.

Finally, the laminated blocks were machined to correct for sliding that may have caused misalignment during the gluing process. The final dimensions of the laminated blocks were 50 mm wide, 38 mm thick, and 235 mm long. Two gluing shear specimens were prepared from each laminated block. A total of 40 specimens from each group were selected to evaluate the effect of knife jointing and wear on the gluing strength after exposure to two hygrothermal conditions. The gluing shear test samples were machined according to ASTM D 905 (1987a).

Conditioning treatments

The samples were prepared under constant conditions of 60% RH and 20°C. Half of the specimens were also tested under these conditions. The other half were subjected to accelerated aging. Specimens were exposed over distilled water for 30 days, and arrived at an average MC of about 21%. All specimens were then conditioned at 60% RH and 20°C for at least 45 days to reach their initial 12% equilibrium MC.

Glueline tests

Specimens were evaluated according to the ASTM D 905 standard (1987a) with a universal testing machine fitted-out with a gluing shear tool. The crosshead speed was 0.38 mm/min. Cross sections of the specimens, load at failure, and the estimated percent wood failure were recorded, and the average gluing shear stress was calculated. Statistical analysis of the results was done using multivariate and univariate analyses of variance.

Microscopic evaluation

Small blocks with about 0.7 cm^2 of transverse area, including the glueline, were cut from the laminated block for scanning electron microscopy examination (SEM). The blocks were prepared with a razor blade to carefully cut a surface on the end-grain perpendicular to the planed surface. The blocks were then desiccated, mounted onto standard aluminum stubs with silver paint, redesiccated, and coated with gold in a sputter-coater. Electron micrographs of three representative subsurfaces were taken for each one of the sixteen cutting conditions.

Wear measurements

A molding technique was applied to obtain replicas of the four type M-2 high speed steel knives used in the experiments. Black-colored resin (the knife) and white-colored resin (the mold) were employed. From each replica, four equally spaced cross-sections were taken along the cutting edge area. Micrographs of these cross-sections were taken with a digital camera mounted on the microscope and processed with an Adobe Photoshop 4 software and a Regent Instruments WinCell Pro 5.6d image analyzer. The edge recession from an ideally sharp edge was measured parallel to the rake and clearance faces of knives.

Cutting force measurements

Primarily radial oriented 7-mm-wide by 19-mm-thick and 75-mm-long specimens were taken from the matched sections to evaluate the effect of jointing and wear on the cutting forces. After each planing treatment, the normal and parallel components of the orthogonal cutting forces, 90°–0°, were measured. Knives were removed after planing from the planer and mounted on the column of a milling machine. A cross-ring dynamometer (King and Foschi 1969) was fixed to the feed table to measure the cutting forces. This dynamometer was calibrated by known forces applied at the normal and parallel directions. The feed speed was 28 cm/min with a chip thickness of 1 mm. The nominal rake angle was 15 degrees, even though the knife geometry should have varied according to the jointed land and wear level. During each test, the cutting forces were recorded with a computer and a data acquisition card, set at 25 readings per second. The minimum, average, and maximum cutting forces for each test were determined from this data.

RESULTS AND DISCUSSION

SEM analysis of transverse glueline faces

Crushed and damaged cells were seen near or at the glueline in transverse sections of the specimens. However, the severity of damage was variable within each jointed land set and planing length. The variation in surface damage within a given machining condition for sugar maple wood has been previously reported (Murmanis et al. 1986; Hernández and Naderi 2001). The thickness in the most severely crushed cell layer was measured in three typical specimens for each planing condition and was plotted as a function of the jointed land width and planing length (Fig. 1). In general, the surface damage was more severe as the jointed land width and the wear increased.

The freshly sharpened unjointed knife pro-

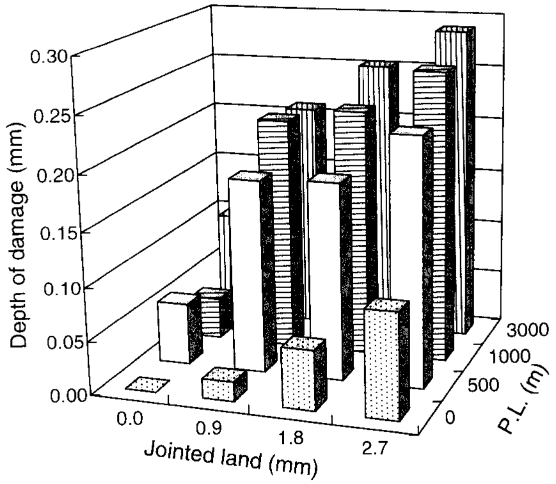

Fig. 1. Maximum crushed layer thickness during planing sugar maple wood as a function of planing length (P.L.) and jointed land width.

duced surfaces virtually free of damage (Fig. 2). However, as the planing length increased, a small amount of damage was seen. The damaged layer was 0.1 mm thick after 3000 m of planing.

When the three jointed knives were sharpened, they produced surfaces with little damage (Fig. 1), but damage increased as jointed land width increased up to 0.1 mm thick at 2.7 m of jointed land width (Fig. 3). However, once knives had planed 500 m of wood, the damaged layer increased drastically. Between 500 and 3000 m of planing, the damaged layer continued to increase but less severely (Fig. 1). The damaged area varied between 0.18 mm and 0.23 mm thick at 500 m of planing, and increased to between 0.21 and 0.29 mm at 3000 m of planing (Fig. 1). Typical damages for these cutting conditions are shown in Figs. 4 and 5.

On the other hand, the depth of damage increased as the jointed land increased from 0- to 0.9-mm width for all planing lengths. The damage continued to increase somewhat between 0.9 and 2.7 mm of jointed land width (Fig. 1).

The subsurface damage was in the form of crushed and deformed vessels and fibers and in certain cases, as broken and deviated rays (Fig. 5). As mentioned, the severity of this type of damage was more obvious as the planing length and the jointed land width increased. The damage that occurred on the planed surfaces from unjointed knives was light, and the adhesive was able to penetrate through the damaged surface layer (Fig. 2). On surfaces planed with jointed knives, the damage was more severe, especially with increased planing length. Nonetheless, the rate of damage increase decreased between 500 and 3000 m of planing. On these surfaces, no adhesive penetration through the damaged zone was found (Figs. 4 and 5). Jokerst and Stewart (1976) as well as Stewart and Crist (1982) suggested that the intensity of the damage to the surface and the subsurface is associated with the magnitude of the normal cutting forces. We found a statistically significant correlation between the normal cutting forces and the thickness of the damaged layer of the planed surface. Even when all cutting conditions were pooled, the normal tool force effect accounted for 33% of the total variation in the damaged layer depth.

Wear and cutting forces

The average results of knife wear and orthogonal cutting forces for each planing length and jointed land width are presented in Table 1.

Wear

Knife wear on the rake and clearance faces increased as the jointed land width and the planing length increased (Table 1). The edge recession was greater on the clearance face than on the rake face of knives. The difference in wear between the two faces was more pronounced as the planing length increased. Thus, the edge recession in the clearance face with respect to the rake face was, on average, 56%, 86%, and 120% greater for 500, 1000, and 3000 m of planing, respectively. Similar differences of wear between the rake and the clearance faces have been reported (Tanaka 1985; Stewart 1988; and Ali et al. 1990).

Relationships between the clearance reces-

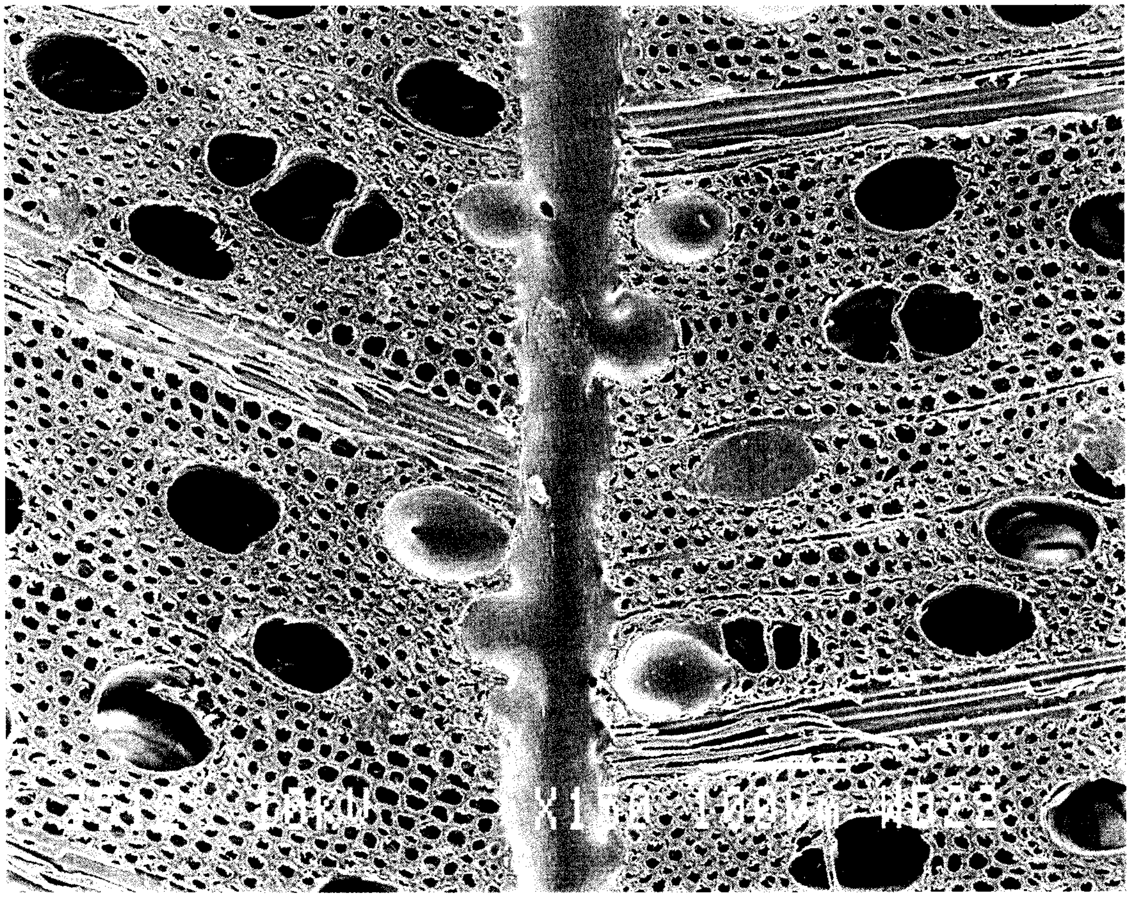

Fig. 2. No damage visible during planing sugar maple wood with a knife without jointing nor wear.

sion and the planing length for each jointed land width existed (Fig. 6). In general, the increase in wear was greater between 0 and 1000 m of planing. Afterwards, wear increased at a slower rate up to 3000 m of planing. The wear on the rake face reacted similarly to that on the clearance face. The variation in wear rate with respect to the cutting length has been reported earlier. Kirbach and Bonac (1977, 1982) found that wear characteristically followed two stages, a first rapid and progressive, then a second stage of slower wear that tended to level off. We found a similar trend in wear processes.

The wear could be attributed principally to a mechanical action, from the friction generated between the knife rake face and the chips produced, and between the clearance face and the new wood surface. This action would generate high temperatures and pressures in the cutting area and on the tool edge (Stewart 1989). Thus, for the jointed knives, the contact area between the clearance face and the new wood surface depended on the jointed land width, due to zero clearance, falling to negative during the cut. This response was not found in an unjointed sharpened knife. With the increase in jointed land width, the magnitude of the friction force and the temperature should increase, increasing wear. This phenomenon should also occur between the rake face and the wood chips, being influenced principally by the rake angle and the thickness of the wood chips (Stewart 1991).

TABLE 1. *Summary of the edge recession and the normal (F_n) and parallel (F_p) orthogonal cutting forces from four planing lengths and four jointed land widths.*

Planing length (m)	Jointed land (mm)	Edge recession[1] Rake face (μm)	Edge recession[1] Clearance face (μm)	Cutting forces[2] F_n (N/mm)	Cutting forces[2] F_p (N/mm)
0	0.0	0 (0)[3]	0 (0)	15.3 (0.4)[3]	82.0 (2.2)
	0.9	0 (0)	0 (0)	17.5 (0.6)	83.4 (2.5)
	1.8	0 (0)	0 (0)	18.8 (0.6)	85.2 (2.4)
	2.7	0 (0)	0 (0)	18.8 (0.7)	87.7 (2.9)
500	0.0	28 (2)	50 (6)	18.9 (0.5)	90.1 (2.3)
	0.9	40 (9)	60 (9)	23.2 (0.7)	84.4 (2.0)
	1.8	44 (4)	63 (3)	24.6 (0.8)	86.3 (2.1)
	2.7	82 (13)	125 (8)	22.7 (0.9)	87.4 (2.6)
1000	0.0	62 (0)	110 (5)	18.2 (0.3)	86.2 (1.8)
	0.9	83 (6)	126 (9)	25.4 (0.8)	83.4 (1.6)
	1.8	154 (14)	357 (21)	23.1 (1.0)	83.4 (2.3)
	2.7	333 (21)	605 (26)	27.1 (0.8)	89.8 (1.8)
3000	0.0	117 (9)	181 (14)	17.8 (0.4)	85.5 (1.7)
	0.9	162 (16)	425 (22)	28.4 (1.0)	84.9 (1.8)
	1.8	223 (12)	456 (13)	30.5 (1.0)	87.4 (1.9)
	2.7	516 (14)	1326 (28)	26.4 (1.2)	89.2 (1.9)

[1] Means of four replicates.
[2] Means of twenty replicates.
[3] Standard error of the mean in parentheses.

Cutting forces

Cutting forces were measured under orthogonal slow-cutting experiments rather than under practical peripheral cutting conditions. McKenzie (1960) indicated that experiments at low cutting speeds could be applied to cutting at practical working speeds. However, the negative clearance angle due to the feeding action during planing could not be analyzed. The cutting force was greater in the parallel component than in the normal component (Table 1). Generally, the normal cutting force (F_n) increased, while the parallel cutting force (F_p) showed no apparent change as the planing length increased. The normal force component was therefore more sensitive to changes in wear than the parallel force component. Stewart (1991) and Huang (1994), while studying the effect of the cutting length on the forces in the turning and planing processes, reported a similar behavior. An effect of the planing length on the normal tool force for each jointed land existed (Fig. 7). In general, normal cutting force increased up to 500 m of planing for unjointed knives. With respect to sharpened knives, this tool force increased 23%. The normal tool force remained constant for these knives between 500 and 3000 m of planing, even though the edge recession showed increasing values (Table 1). For the jointed knives, normal cutting force increased sharply up to 1000 m of planing and continued to increase slightly after this length. Thus, the force increased up to about 56% when compared to the sharpened knives. The increase in the normal force due to wear should be even greater in peripheral planing because the negative clearance angle produced should be greater.

On the other hand, the normal cutting force (F_n) increased, while the parallel cutting force (F_p) showed no apparent change as the jointed land increased (Table 1). The normal tool force was therefore more sensitive to the jointing than the parallel tool force. In general, the normal cutting force increased between 0 and 1.8 mm of jointed land width (Fig. 7). This force then remained constant or decreased slightly at 2.7 mm of jointed land, even though the edge recession continued to increase (Table 1). Furthermore, the effect of jointing on normal tool force increased as wear advanced. Thus, this force increased when knives were

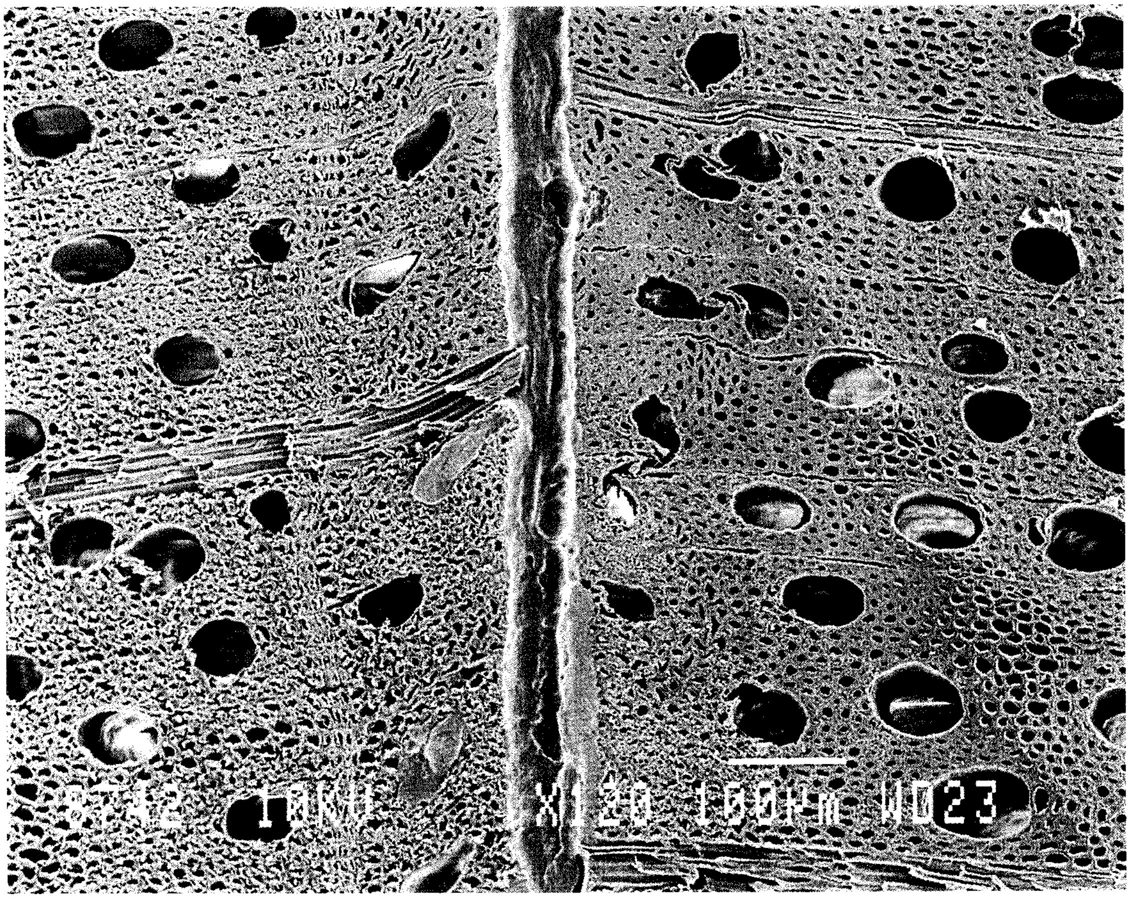

Fig. 3. Maximum damage noted during planing sugar maple wood with a knife having 2.7-mm jointed land width and freshly sharpened.

jointed (jointed lands pooled) on average 20, 24, 43, and 63% for 0, 500, 1000, and 3000 m of planing, respectively. As in the case of wear, given that clearance angle increases negatively, the increase in the normal force due to jointing should be even greater in peripheral planing.

Some cutting force values were more variable and did not appear to closely follow the general trend. A lower average chip thickness (0.8 mm instead of 1 mm) for the 1.8-mm jointed land width and 1000 m of planing cutting force test was due to a mistake. Other fluctuations may have been due to differences in initial tool sharpness or inherent differences in the tool or workpiece.

Gluing shear strength

As expected, the greater gluing shear strength values were observed for the knives without wear and at constant hygrothermal conditions (Table 2). Comparisons were made using the least-squares means statement from the SAS General Linear Models procedure—95 percent confidence level (SAS Institute 1988). A statistically significant effect of the jointing and knife wear on gluing behavior of sugar maple wood under constant conditions existed. Also the gluing strength decreased after the accelerated aging treatment. This decrease was about 7% for the sharpened knives and 5% for the worn knives. After the aging treatment, the effects of jointing and wear

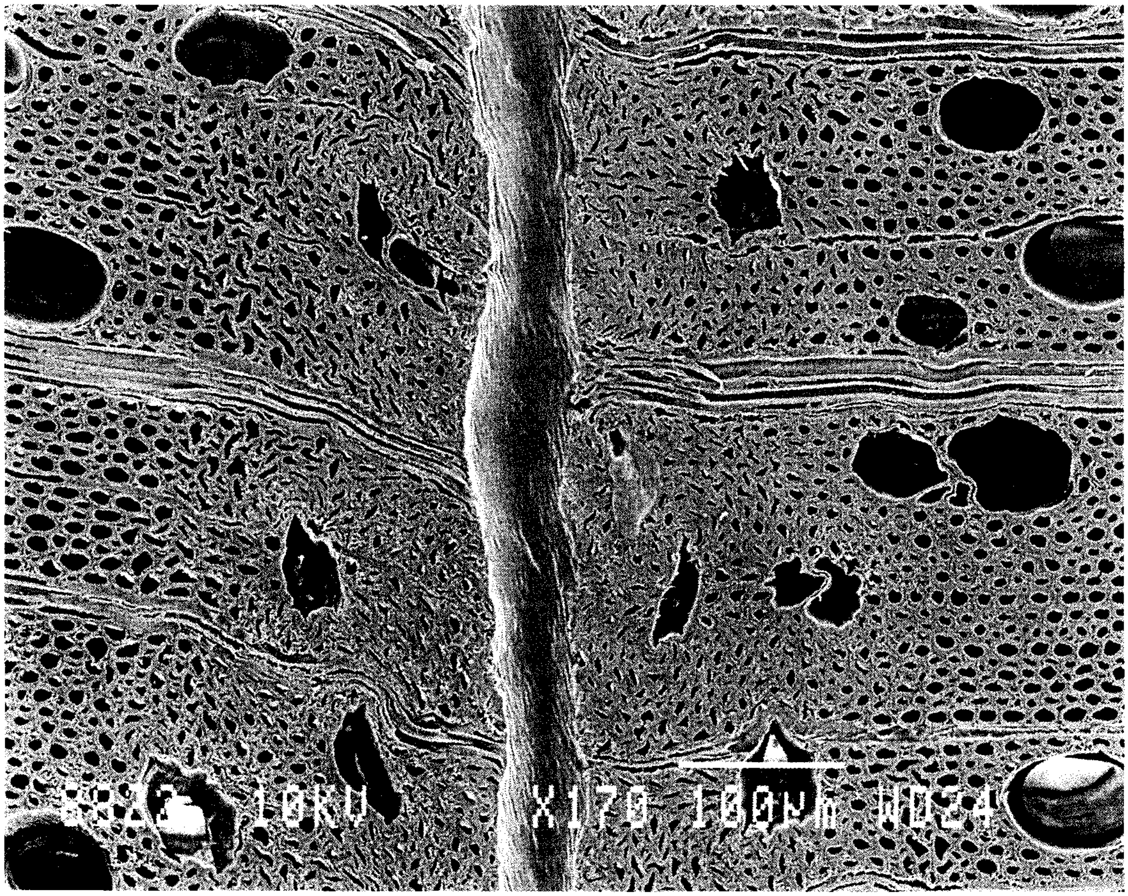

Fig. 4. Typical damage noted during planing sugar maple wood with a knife having 0.9-mm jointed land width and 500 m of planing.

were evident. For example, the effect of jointing on gluing shear strength was statistically significant for sharpened knives only after the aging treatment. The moisture saturation of wood and subsequent drying could have produced internal stresses related to swelling and shrinkage. These stresses would reduce the gluing shear strength by increasing the number of wood microfailures, particularly in the cell walls at the surface and subsurface of the wood.

The decrease in gluing shear due to jointing and wear was related to the variation in the normal cutting force. Statistically significant negative correlations existed between this tool force and, either the gluing shear strength or the percent wood failure. For the accelerated aging treatment, the normal tool force effect accounted for at least 40% of the total variation in gluing shear strength and 36% of variation in percent wood failure (all cutting conditions pooled). The effect of this tool force on gluing behavior was a result of the tissue damage at the surface and subsurface of the wood (Figs. 3–5).

Between 0 and 500 m of planing, the gluing shear strength greatly decreased for the four jointed land widths (Fig. 8). Between 500 and 3000 m of planing, no significant variation in gluing shear strength existed, except at 0.9-mm jointed land (Fig. 8). Thus, the overall decrease in shear strength due to wear was about 12% (jointed lands pooled). In general, the percent wood failure showed a similar be-

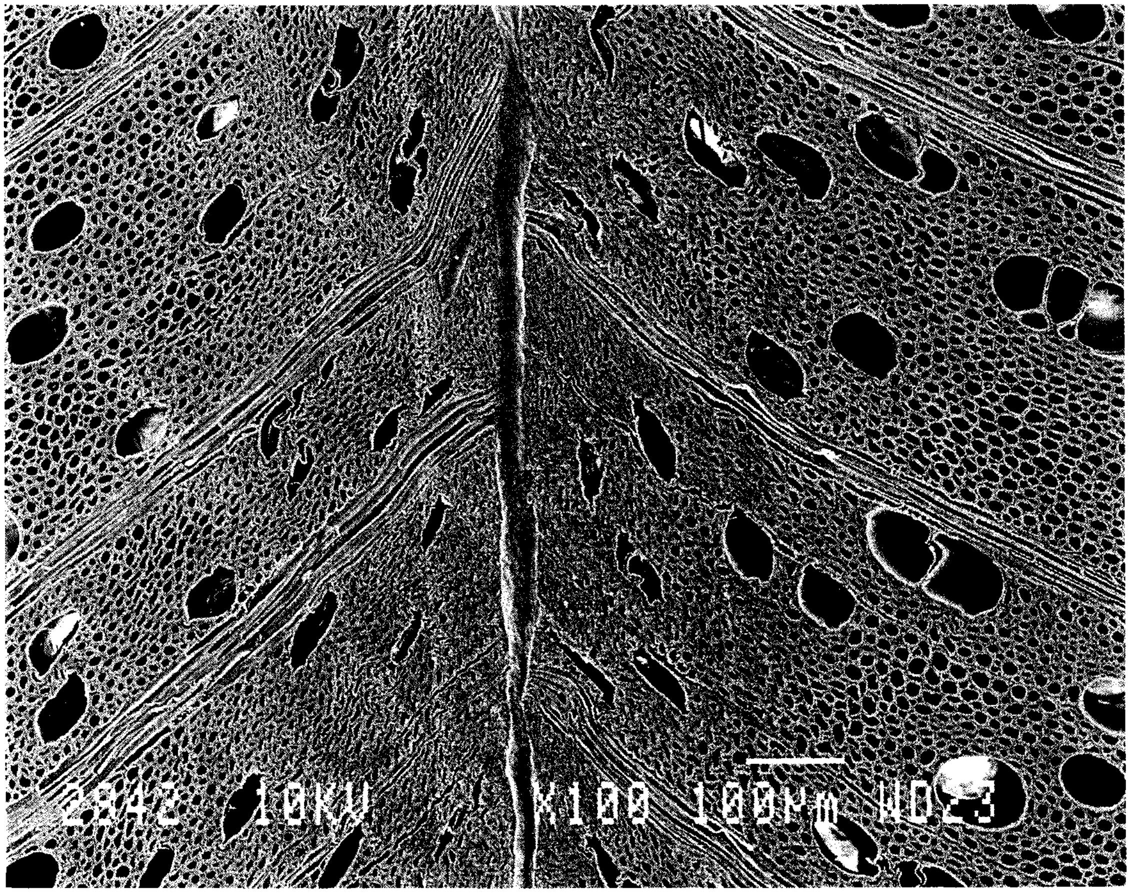

Fig. 5. Maximum damage noted during planing sugar maple wood with a knife having 2.7-mm jointed land width and 3000 m of planing.

havior and indicates that the adhesive penetration may have decreased as planing length increased. As previously mentioned, the damaged superficial layer of the wood increased rapidly up to 500 m of planing (Fig. 1). The gluing shear strength results are in good agreement with the idea that damage was caused to the wood cells by knives. Adhesion was primarily at the damaged layer, and since this adhesion was practically at a minimum at 500 m of planing, further planing caused little difference. Therefore, under the cutting conditions of this study, a damaged layer of 0.20 mm thick (Fig. 1), from a knife with 45-μm rake face recession and 60-μm clearance face recession (Table 1), was sufficient to negatively affect the planed surface quality of sugar maple wood.

The effect of jointing on the gluing shear strength measured after accelerated aging is shown in Fig. 9. A similar effect has been reported from freshly sharpened knives (Hernández and Naderi 2001). In general, no significant variation in gluing shear strength existed between the unjointed knives and those jointed at 0.9-mm jointed land. But, a statistically significant decrease in shear strength occurred for 1.8- and 2.7-mm jointed lands. The overall decrease in shear strength when jointing exceeded 0.9-mm width was about 8% (planing lengths pooled). In general, the percent wood failure showed a similar trend

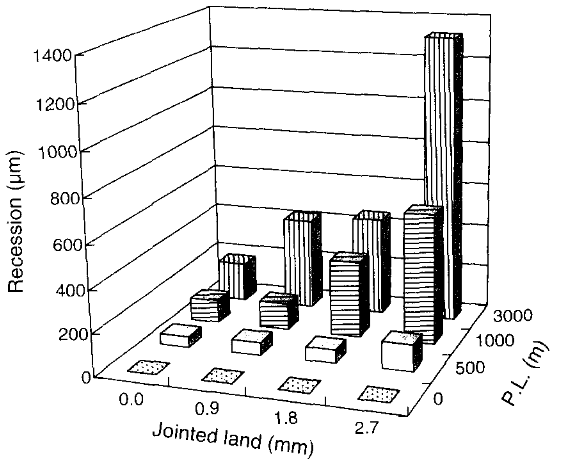

Fig. 6. Edge recession over the knife clearance face as a function of the planing length (P.L.) for four levels of jointed land width.

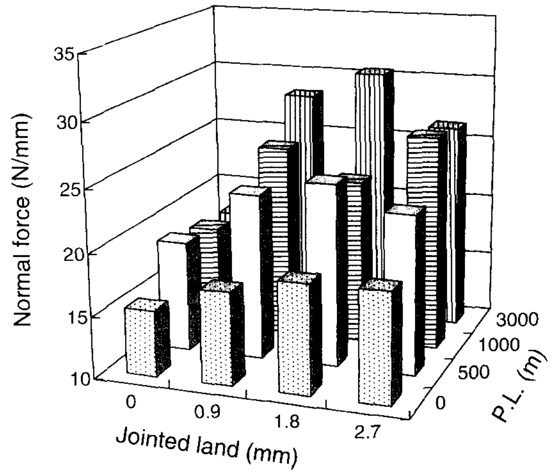

Fig. 7. Normal orthogonal cutting force from knives as a function of planing length (P.L.) for four levels of jointed land width.

even though its statistical significance was not established clearly. A jointed land of 0.9-mm width could serve as maximum allowable value for planing sugar maple wood.

The results of this study were obtained with a rake angle of 15 degrees common in the wood industry. The normal cutting force was relatively important even for sharpened unjointed knives. Increasing the rake angle, which decreases the normal cutting force, could reduce the damaged layer produced by knives, and result in improved gluing performance. The method suggested by Stewart

TABLE 2. *Average gluing shear strength (SS) and percent wood failure (WF) for four planing lengths, four jointed land widths and two conditioning treatments.*

Planing length (m)	Jointed land (mm)	Constant conditions[1]		After conditioning[1]	
		SS (MPa)	WF (%)	SS (MPa)	WF (%)
0	0.0	20.1 (0.5)[2] AB a[3]	45 (7) A a	20.2 (0.4) A a	34 (7) B a
	0.9	20.2 (0.8) AB a	19 (5) B a	19.7 (0.3) A a	47 (8) A a
	1.8	19.6 (0.6) B a	18 (3) B a	17.5 (0.4) B a	24 (6) C a
	2.7	20.6 (0.4) A a	20 (4) B a	17.7 (0.5) B a	24 (6) C a
500	0.0	18.0 (0.5) A b	24 (5) A b	17.0 (0.3) A b	18 (4) A b
	0.9	16.9 (0.5) B c	13 (3) B a	15.7 (0.3) B c	10 (2) B c
	1.8	16.4 (0.4) B bc	13 (4) B a	15.9 (0.4) B b	11 (2) AB a
	2.7	16.9 (0.4) B bc	16 (2) AB a	16.1 (0.4) AB b	19 (4) A a
1000	0.0	17.9 (0.4) A b	30 (7) A b	17.5 (0.4) A b	25 (6) A ab
	0.9	16.0 (0.4) C d	13 (4) B a	17.3 (0.3) A b	22 (4) A b
	1.8	17.1 (0.4) AB b	15 (2) AB a	15.4 (0.3) B b	16 (3) A a
	2.7	16.6 (0.4) BC c	17 (3) AB a	16.7 (0.6) A b	20 (5) A a
3000	0.0	18.0 (0.4) AB b	20 (4) A b	17.5 (0.3) A b	22 (5) A b
	0.9	18.7 (0.3) A b	18 (4) A a	17.7 (0.3) A b	16 (4) A b
	1.8	16.0 (0.3) C c	19 (5) A a	15.5 (0.3) C b	17 (3) A a
	2.7	17.6 (0.4) B b	21 (3) A a	16.5 (0.3) B b	16 (4) A a

[1] Means of twenty replicates.
[2] Standard error of the mean in parentheses.
[3] Means within a column followed by the same letter are not significantly different at the 5 percent probability level. Uppercase letters are for jointed land comparison and lowercase letters are for planing length comparison, for each planing length and jointed land separately.

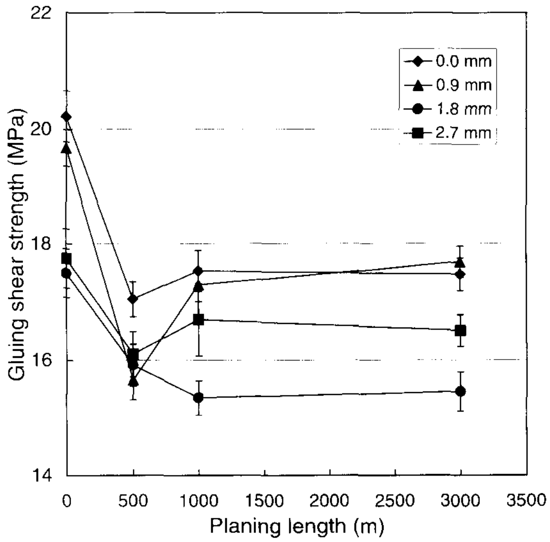

Fig. 8. Gluing shear strength as a function of planing length for four levels of jointed lands for samples that had undergone an accelerated aging cycle.

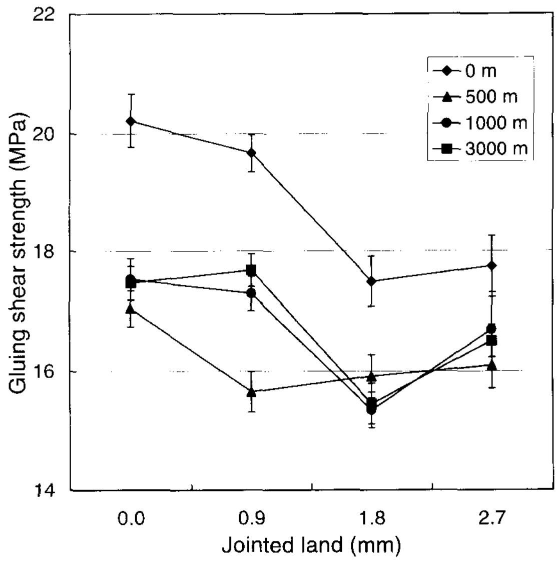

Fig. 9. Gluing shear strength as a function of jointed land width for four levels of planing length for samples that had undergone an accelerated aging cycle.

(1977) predicts from cutting forces that result from sharpened unjointed knives that a rake angle of 26 degrees could be the optimal to produce a satisfactory wood surface. Experiments at different rake angles are needed to verify this prediction. Other factors that need to be considered include the feed per knife, diameter of the cutting circle, and cutting depth. Given this lack of information, general recommendations could be misleading and further investigations are required.

CONCLUSIONS

We found that peripheral planing with sharpened unjointed knives generated the least damage in the surface and subsurface of sugar maple wood. However, the depth and severity of the damaged surface layer increased with increasing jointed land width and the planing length. The depth of this damaged layer was positively correlated with the magnitude of the normal cutting force. Knife wear also increased as the jointed land and planing length increased, but this was lesser on the rake face than on the clearance face of knives. The normal cutting force increased with wear. The damage in surfaces and subsurfaces of wood caused a corresponding decrease in the gluing shear strength and percent wood failure of glued specimens. The effects of these parameters on gluing were more pronounced in samples where the moisture content had fluctuated. The results suggest a jointed land of 0.9 mm as a maximum allowable width for planing sugar maple wood. Also, a damaged layer 0.20 mm thick, obtained using a knife with 45 μm of rake face recession and 60 μm of clearance face recession, appear to be sufficient to negatively affect the planed surface quality of this wood.

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