EFFECTS OF KNIFE JOINTING AND WEAR ON THE PLANED SURFACE QUALITY OF NORTHERN RED OAK WOOD

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ABSTRACT

Jointing is a technique to obtain 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 that becomes negative with workpiece motion relative to the cutterhead and as the cutting edge wears. Jointed knives may crush cells on the planed surface and affect the quality and performance of wood for end uses. We evaluated the gluing properties of northern red oak planed surfaces that had been planed using one of three jointed land widths, over four levels of knife wear. Under these cutting conditions, surface roughness significantly influenced gluability more than cellular damage. In sum, gluing performance was positively affected by knife wear, and no variation in gluing performance among the jointed land widths studied existed. In samples after accelerated aging, the effects of wear on gluing were more pronounced, with an improvement in gluing performance, associated with an increase in surface roughness and permeability with increased knife wear. These results suggest a jointed land of 1.2 mm as the maximum allowable width for planing red oak wood prior to gluing. Also, the planed surface gluability of this wood may be enhanced using a knife with the rake face recession of 332 μm and the clearance face recession of 438 μm, which results in a surface roughness of 40 μm R_{max}.

Keywords: Planing, knife jointing, wear, gluing properties, northern red oak.

INTRODUCTION AND BACKGROUND

Jointing is a common practice applied to peripheral knife planers to produce an equal cutting circle for all knives mounted in a cutterhead. An abrasive stone is passed over the knife edges as the cutterhead turns at its normal cutting speed. Any projecting knife edge is ground back, ensuring that all the edges lie in a common cutting circle. Thus, each knife can work in a uniform manner taking chips of equal thickness (Dunsmore 1965; Hoadley 2000). Jointing makes knife edges more wear-resistant, and it is sometimes wrongly repeated as a sharpening process.

The grinding action forms a jointed land on the cutting edges where width varies according to the initial knife projection from the cutterhead with respect to the other knives. The nominal knife clearance angle returns to 0 degrees in such a manner that during planing the face of the land causes perpendicular compression as well as friction on the wood surface. These forces normally should 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

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friction than surfaces machined with unjoined knives. Although greater cutting forces are involved with jointing, a positive or negative effect on gluing may result, depending on the species of wood (Hernández and Naderi 2001).

Damage on the surface and subsurface of wood plays an important role on the gluing performance (River and Miniutti 1975; Jokerst et Stewart 1976; White and Green 1980; Murmanis et al. 1983; Caster et al. 1985; Hernández 1994; Hernández and Naderi 2001; Hernández and Rojas 2002). The type and level of damage can affect subsequent transformation processes or even the performance of the final product (Stewart and Crist 1982). A poorer glueline performance has been associated with the presence of damaged cell layers on the glued wood surface (River and Miniutti 1975; Jokerst and Stewart 1976). In general, crushed cells may obstruct adhesive penetration (Caster et al. 1985). Superficial crushed cells are a result of high cutting forces generated by knives during the planing operation (Jokerst and Stewart 1976). Hernández and Naderi (2001) reported that the depth of the crushed cell layer increased as the width of the jointed land of knives increased. Therefore, there should be a maximum jointed land width with this jointing technique where the cutting efforts continue to result in a good quality surface.

Hoadley (2000) suggested that a very narrow land (0.25 mm) can be used without any loss in quality because the area of zero clearance is very small. Koch (1985) and the ASTM D 1666 (1987) indicate that the maximum jointed land width before re-sharpening should be 0.8 mm. Dunsmore (1965) recommended a maximum of three or four jointings, with a final jointed land width up to 1.2 mm. However, Hernández and Naderi (2001) suggested that the maximum allowable width for the jointing operation depends on the wood species. They found that sugar maple had permanent damage to the wood surface and consequently, the gluing performance decreased as the jointed land width increased. For red oak, there was no apparent cell damage and gluing performance was improved as jointed land width increased. This was associated with an increase in the permeability of the wood. However, planing tests in this earlier study were carried out with freshly sharpened knives only. Hernández and Naderi (2001) concluded that information was needed on interactions among anatomical wood structure, jointed land width, and knife wear.

In addition to jointed land width, acceptable limits of knife wear for planing wood need to be established. However, few data are available on the interaction between jointing and wear. In general, differences in gluing properties have been reported among wood species (Hernández and Naderi 2001) and data are required for different wood species.

This work evaluated the planed surface quality of northern red oak wood as a function of jointed land width and knife wear. Four wear levels of three jointed land widths were tested. The gluing shear performance was evaluated at constant hygrothermal conditions and after exposing surfaces to an accelerated aging treatment.

MATERIALS AND METHODS

Testing materials

Northern red oak (*Quercus rubra* L.) wood, a ring-porous hardwood, commonly applied indoors was tested. Prior to testing, the commercial air-dried lumber was stored in a conditioning room at 60% relative humidity (RH) and 20°C for 6 months. At the end of this period, the average moisture content (MC) was 10%. Eighty boards, 63 mm wide, 20 mm thick, and 2,220 mm long, were selected and prepared for planing tests. The boards were separated into four groups of twenty, with each group to be subjected to a specific wear level. Each board was cross-cut into three matched sections 550 mm long, and these were assigned for testing to a specific jointing level. This meant that a total of twelve subgroups of twenty specimens each were tested. Each section underwent a planing treatment and was then 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 at the assigned wear levels with a Weinig Unimat 23EL moulder. The feed rate was set to give 20 knife marks per 25 mm of length and the cutting depth was adjusted to remove 1 mm of wood in one pass. The cutting circle radius was 75 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 45 and 25 degrees, respectively. After jointing, these angles became 70 degrees for the knife angle and 0 degrees for the clearance angle. The rake angle was 20 degrees. The sharp knives were jointed with a silicon carbide/aluminum oxide abrasive stone at two specific jointed land widths, 0.4 and 1.2 mm. A third group of boards was planed with an unjointed knife, and was considered as having a 0-mm jointed land width. One knife was successively worked up to reach four wear levels for each of the three jointing levels. Thus, the process began with a planing test by a freshly sharpened knife followed by other planing tests after 500 m, 1,000 m, and 3,000 m of planing. To generate wear, two-hundred ninety knot-free pieces of northern red oak wood 75 mm wide by 25 mm thick and of varying lengths were planed under the same cutting conditions as during the planing treatment itself. After this planing treatment, the boards were crosscut to form pairs that were subsequently glued together to form a laminated block.

The pairs of boards were glued using a carpentry white adhesive (polyvinyl acetate), with a glue consumption of 810 g per square meter. A 0.4 MPa clamping pressure was applied for 45 min as recommended by the adhesive manufacturer.

Finally, the laminated blocks were machined to correct for any misalignment from sliding 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 samples were prepared from each laminated block. A total of 40 samples from each group was 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 (1994).

Conditioning treatments

The samples were prepared under constant conditions of 60% RH and 20°C, and half were tested under these conditions. The other half were subjected to accelerated aging, where samples were immersed in distilled water for 6 h, resulting in an average MC of about 27%. They were then oven-dried at 40°C for 18 h. This soaking-and-drying cycle was repeated twice. Finally, all samples were conditioned at 60% RH and 20°C to reach their initial 10% equilibrium MC.

Glueline tests

Samples were evaluated according to the ASTM D 905 standard (1994) with a universal testing machine fitted-out with a gluing shear fixture. The crosshead speed was 5 mm/min. Cross sections of the samples and load at failure were recorded, and the average gluing shear stress was calculated. The percent wood failure was then independently estimated by two technicians. The statistical analysis of the results was performed using multivariate and univariate analysis of variance.

Microscopic evaluation

Small blocks with about 0.8 cm^2 of transverse area, including the glueline, were removed from the laminated block for scanning electron microscopy (SEM). A surface on the end-grain perpendicular to the planed surface was carefully cut with a razor blade. The blocks were then desiccated with phosphorous pentoxide over two weeks, mounted onto standard aluminium stubs with silver paint, and coated with gold-palladium in a sputter-coater.

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

Planing length (m)	Jointed land (mm)	Edge recession[1]		Cutting forces[2]	
		Rake face (μm)	Clearance face (μm)	F_n (n/mm)	F_p (n/mm)
0	0.0	122 (8)[3]	83 (4)	6.3 (0.3)	48.9 (1.8)
	0.4	0 (0)	0 (0)	11.1 (0.5)	57.8 (2.8)
	1.2	79 (17)	62 (7)	11.9 (0.7)	59.3 (2.9)
500	0.0	167 (7)	136 (6)	8.1 (0.3)	51.8 (2.2)
	0.4	107 (9)	104 (6)	12.8 (0.4)	57.2 (1.7)
	1.2	175 (8)	192 (9)	16.5 (0.8)	59.6 (2.0)
1000	0.0	193 (8)	172 (9)	8.9 (0.4)	50.8 (1.7)
	0.4	138 (9)	135 (10)	13.2 (0.8)	55.6 (2.1)
	1.2	246 (5)	217 (8)	16.5 (1.0)	56.1 (1.7)
3000	0.0	258 (10)	215 (9)	10.1 (0.6)	49.9 (1.7)
	0.4	208 (10)	174 (10)	16.0 (0.6)	52.8 (1.7)
	1.2	332 (10)	438 (17)	16.3 (0.9)	50.3 (2.5)

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

Electron micrographs of four representative subsurfaces were taken for each of the twelve cutting conditions. The depth of damage and glueline thickness at five systematically chosen points from each SEM micrograph were evaluated. Surface roughness was estimated from the micrographs from the Rmax index.

Wear measurements

A resin molding technique was applied to make replicas of the three type M-2 high speed steel knives from the experiments. Seven equally spaced cross-sections were taken along the cutting edge area from each replica. 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 samples 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 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 to the normal and parallel directions. The feed speed was 280 mm/min with a chip thickness of 1 mm. The nominal rake angle was 20 degrees; however, the knife geometry would have varied according to the wear level. During each test, the cutting forces were recorded with a computer and a data acquisition card, set at 16 readings per second. The minimum, average, and maximum cutting forces for each test were determined from these data.

RESULTS AND DISCUSSION

Wear

The quality of sharpening prior to the planing treatment was not uniform for the freshly sharpened knives (Table 1). For this reason, wear values after planing treatments were adjusted by subtracting observed wear at 0 m of planing. Knife wear on the rake and clearance faces increased as the jointed land width and the planing length increased. The edge reces-

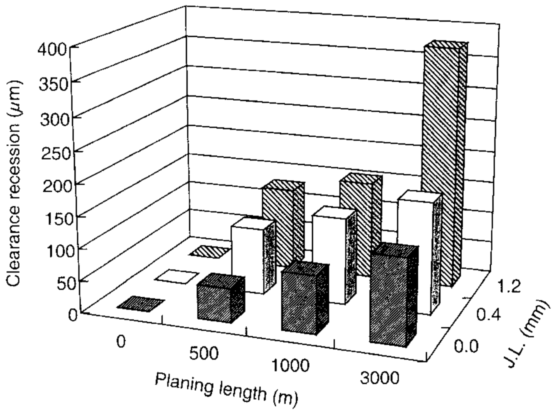

Fig. 1. Edge recession over the knife clearance face as a function of the planing length for three levels of jointed land width (J.L.).

sion was similar on both rake and clearance faces of the knives. The adjusted edge recessions on the clearance face as a function of planing length and jointed land width are given in Fig. 1. In general, the increase in wear was high between 0 and 1,000 m of planing. Afterwards, wear increased at a slower rate up to 3,000 m of planing. The wear pattern on the rake face was similar to that on the clearance face. Kirbach and Bonac (1982) also reported that wear characteristically follows two stages, an initial rapid and progressive stage followed by a second slower stage wear that tends to level off. We found a similar trend in the wear process.

The wear could be attributed principally to simultaneous chemical and mechanical actions (Hillis and McKenzie 1964; Krilov 1986). The friction generated between the knife rake face and the chips produced and between the clearance face and the new wood surface could provoke a mechanical erosion. This action would generate high temperatures and pressures in the cutting area and on the tool edge (Stewart 1989). For the jointed knives, the contact area between the clearance face and the new wood surface depended on the jointed land width, due to the zero clearance falling to negative during the cut. This response was not seen in the unjointed sharpened knife. As jointed land width increased, the magnitude of the friction force and the temperature would increase, increasing wear. This phenomenon could also occur between the rake face and the wood chips, being influenced principally by the rake angle and the chip thickness (Stewart 1991). In this study, chip thickness remained constant and the rake angle probably decreased given that recession on the rake face occurred. The high temperatures during cutting could also have favored chemical attack by extractives (tannic acid) increasing knife wear (Krilov 1986; Stewart 1989).

Cutting forces

Cutting forces were measured under conditions of experimental orthogonal slow-cutting rather than under practical peripheral cutting. Although experiments at low cutting speeds could be done at practical working speeds (McKenzie 1960), it would not be possible to analyze the negative clearance angle due to the feeding action during peripheral planing. The variation in the average orthogonal cutting forces of northern red oak was greater than that reported by Hernández and Rojas (2002) for sugar maple wood tested under similar conditions. This variation was also greater for the normal component (average C.V. 22%) compared to the parallel component (average C.V. 17%) of cutting forces (Table 1). The higher variation for red oak wood could be attributed to its ring-porous structure. The minimum and maximum values of cutting forces (not shown) were also highly variable and generally associated with earlywood and latewood regions, respectively.

The cutting force in the parallel component was greater than the normal component (Table 1). Generally, for all knives the normal cutting force (F_n) increased as the planing length increased. The increase in normal force was greater between 0 and 500 m of planing. Afterwards, normal cutting forces increased at a slower rate up to 3,000 m of planing. The parallel cutting forces for jointed knives decreased as the planing length increased. For the unjointed knife, the parallel cutting forces showed no

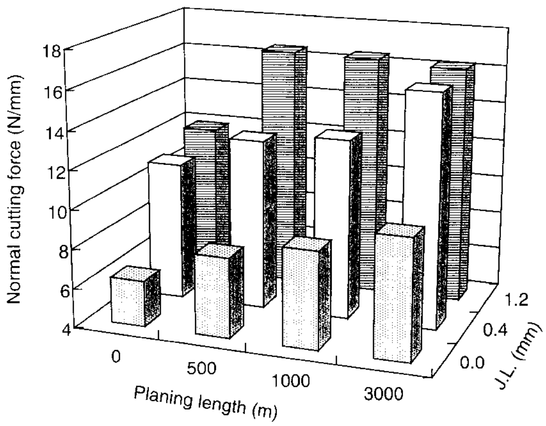

Fig. 2. Normal orthogonal cutting force from knives as a function of the planing length for three levels of jointed land width (J.L.).

apparent change as the planing length increased. The normal force component was therefore more sensitive to changes in wear compared to the parallel force component. The normal force increased 47% over 0 to 3,000 m of planing, while the parallel force decreased 7% (jointed lands pooled). Similar results were reported by Stewart (1991), Huang (1994), and Hernández and Rojas (2002) while studying the effect of the cutting length on the forces in wood machining processes. The increase in the normal force due to wear should be greater in peripheral planing since the negative clearance angle produced is greater.

The normal (F_n) and parallel cutting forces (F_p) tended to increase with increasing jointed land width (Table 1). The normal tool force

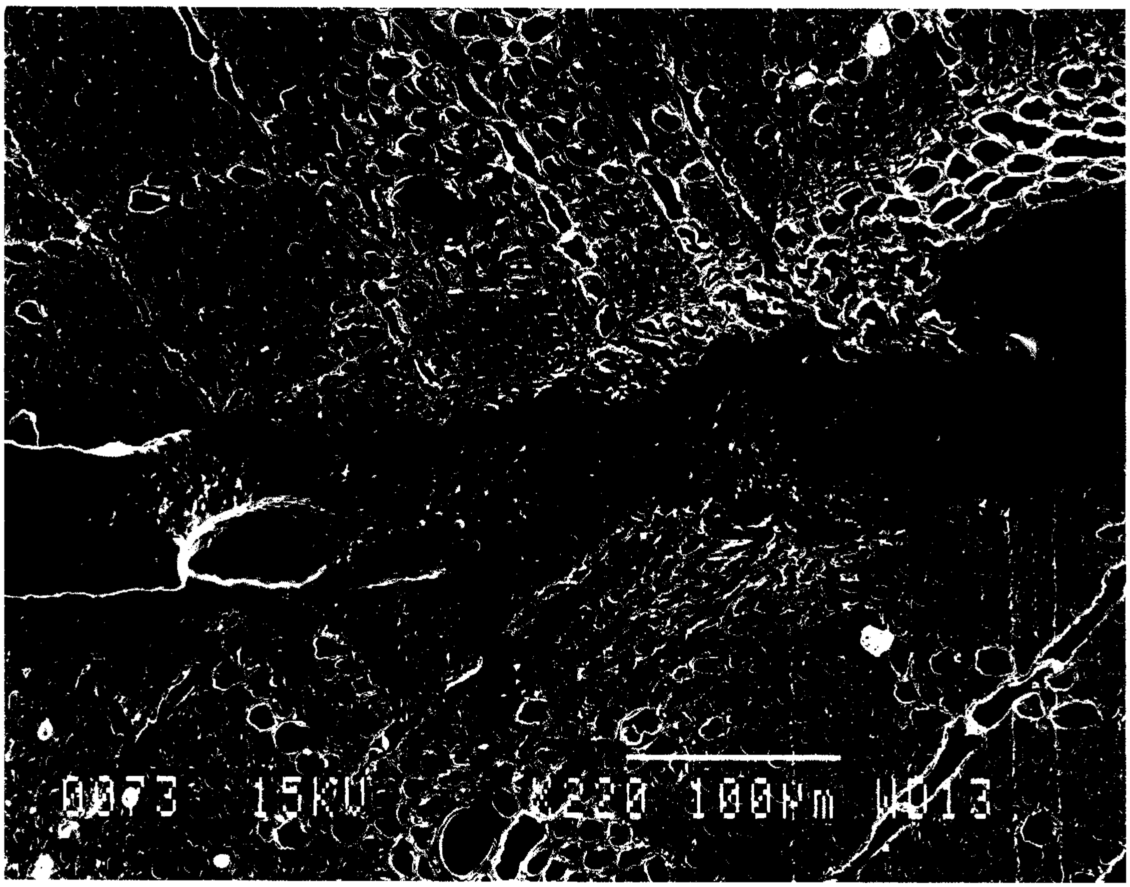

Fig. 3. Maximum damage noted during planing northern red oak wood with a knife having 1.2-mm jointed land width and 3000 m of planing.

was also more sensitive to jointing than the parallel tool force. The normal force increased 85% from 0 to 1.2 mm of jointed land width, while the parallel force increased 12% (planing lengths pooled). In general, the normal cutting force increased sharply from 0 to 0.4 mm of jointed land width (Fig. 2). The rate of increase of this force decreased slightly at 1.2-mm jointed land width, even though the edge recession continued to increase (Table 1). This was similar to the effect of jointing on orthogonal cutting forces reported by Hernández and Rojas (2002). As with wear, given that the clearance angle increases negatively, then increases in the normal force due to jointing should be greater in peripheral planing.

This analysis indicates that normal cutting forces are a good index of tool wear and jointing. This index can be used to evaluate tools and wood species in other jointing situations.

SEM analysis of transverse glueline faces

Crushed and collapsed cells were observed near or at the glueline in transverse sections of the SEM samples. However, the type and severity of surface damage were different from those earlier reported for planed surfaces of sugar maple (Hernández and Rojas 2002). In fact, damage to red oak surfaces was less, with no layer of severely crushed cells. In this study, damaged cells were seen mostly in thin-walled longitudinal parenchyma, vasicentric tracheids, and vessel tissues, while thick-walled fibers were affected only occasionally (Fig. 3). Differences in damage due to cell-wall thickness have been reported previously (White and Green 1980; Caster et al. 1985; Zink-Sharp et al. 1999). River and Miniutti (1975) found almost no damage on the surfaces of red oak latewood and only moderate damage in earlywood after cutting with saw, planer, and jointer machines. We found that the depth of the most severely crushed regions in four typical specimens for each planing condition was a function of the planing length and jointed land width (Fig. 4). In general, the surface damage was more severe as the jointed land width and wear increased.

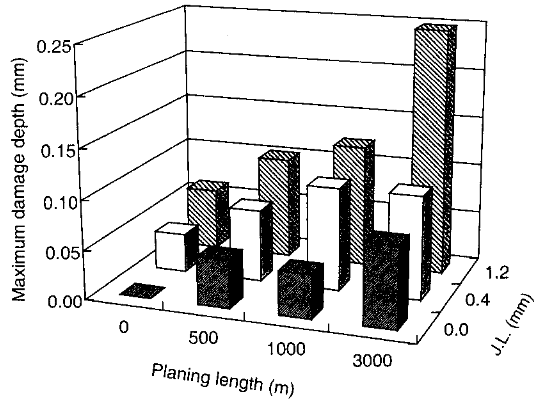

Fig. 4. Maximum depth of damage during planing northern red oak wood as a function of planing length and jointed land width (J.L.)

The freshly sharpened unjointed knife produced surfaces virtually free of damage (Fig. 5). However, the damage increased sharply up to 500 m of planing and then more slowly from 500 to 3,000 m. The damage was 0.05 mm and 0.08 mm thick after 500 and 3,000 m of planing, respectively.

When the two jointed knives were sharpened, surfaces were little damaged (Fig. 6) but as jointed land width increased, damage increased up to 0.06 mm deep at 1.2 mm of jointed land width (Fig. 4). The damage increased at a slower rate for both the jointed knives as planing length increased (Fig. 4). The damaged area varied between 0.07 mm and 0.10 mm thick at 500 m of planing, and increased to a range between 0.10 and 0.25 mm at 3,000 m of planing (Fig. 4). Typical damages under these cutting conditions are shown in Figs. 3 and 7.

The damage also tended to increase for all planing lengths as the jointed land increased from 0- to 1.2-mm width (Fig. 4). This result could be explained by the increase in the normal peripheral forces when planing with jointed knives. A similar behavior was reported for sugar maple wood by Hernández and Rojas (2002).

As expected, the roughness of planed sur-

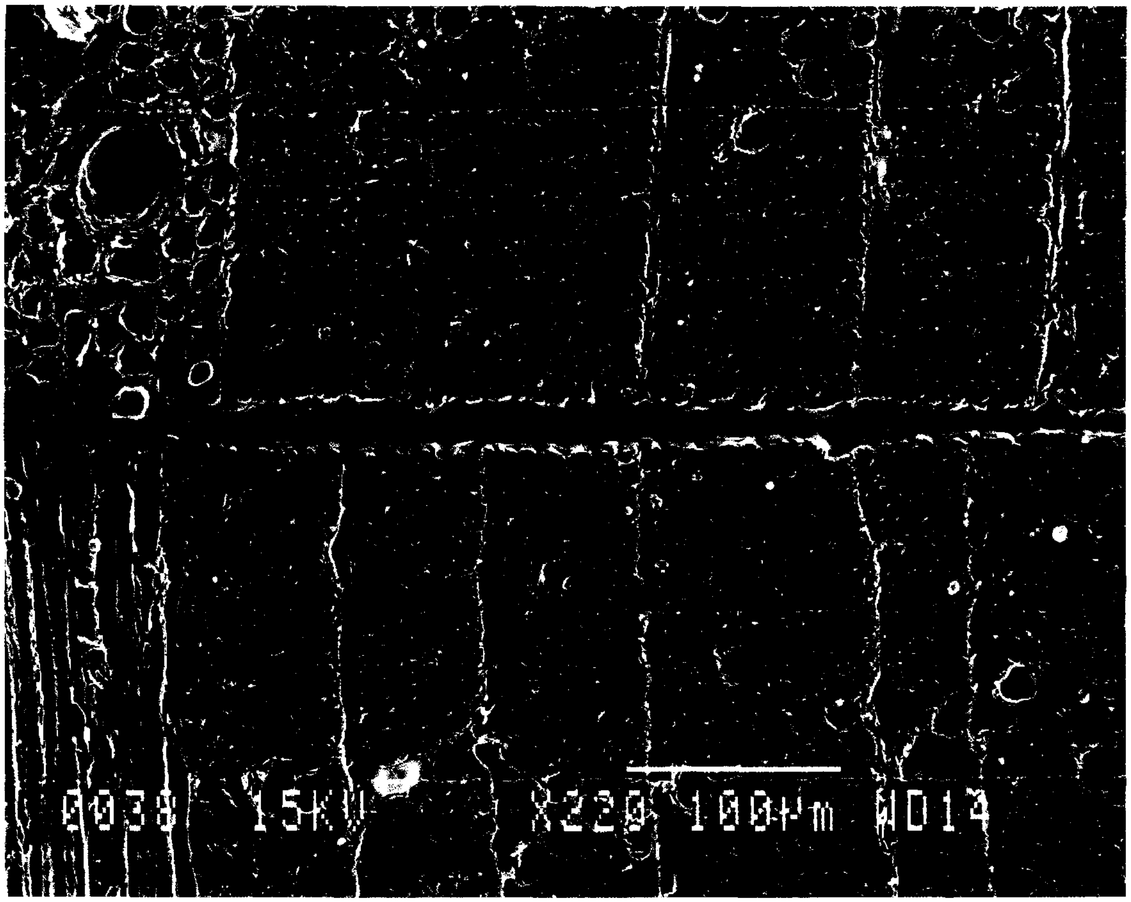

Fig. 5. No damage visible during planing northern red oak wood with a knife without jointing nor wear.

faces was directly related to the wear profiles of the unjointed and jointed knives, and the surface roughness increased significantly as planing length increased. Surface roughness was not affected by the differences in jointed land width within each planing length (not shown). The increase in roughness was greatest between 0 and 1,000 m of planing and increased at a slower rate up to 3,000 m of planing. Glueline thickness was also strongly affected by the surface roughness. Peaks in rough surfaces prevented uniform contact between faces during clamping, resulting in thicker gluelines.

Jokerst and Stewart (1976) as well as Stewart and Crist (1982) suggested that the severity of damage to the surface and subsurface is associated with the magnitude of normal cutting forces. We confirmed that there was a statistically significant linear correlation between the normal orthogonal cutting force and the depth of the damage produced by planing. Even when all planing lengths and jointed lands were pooled, the normal tool force effect accounted for 58% of the total variation in the depth of the damage. This force and the surface roughness were also significantly correlated. On the other hand, no significant correlations existed between the parallel orthogonal force and the two surface quality variables.

Gluing shear strength

Average values for the apparent gluing shear strength and the percent wood failure for

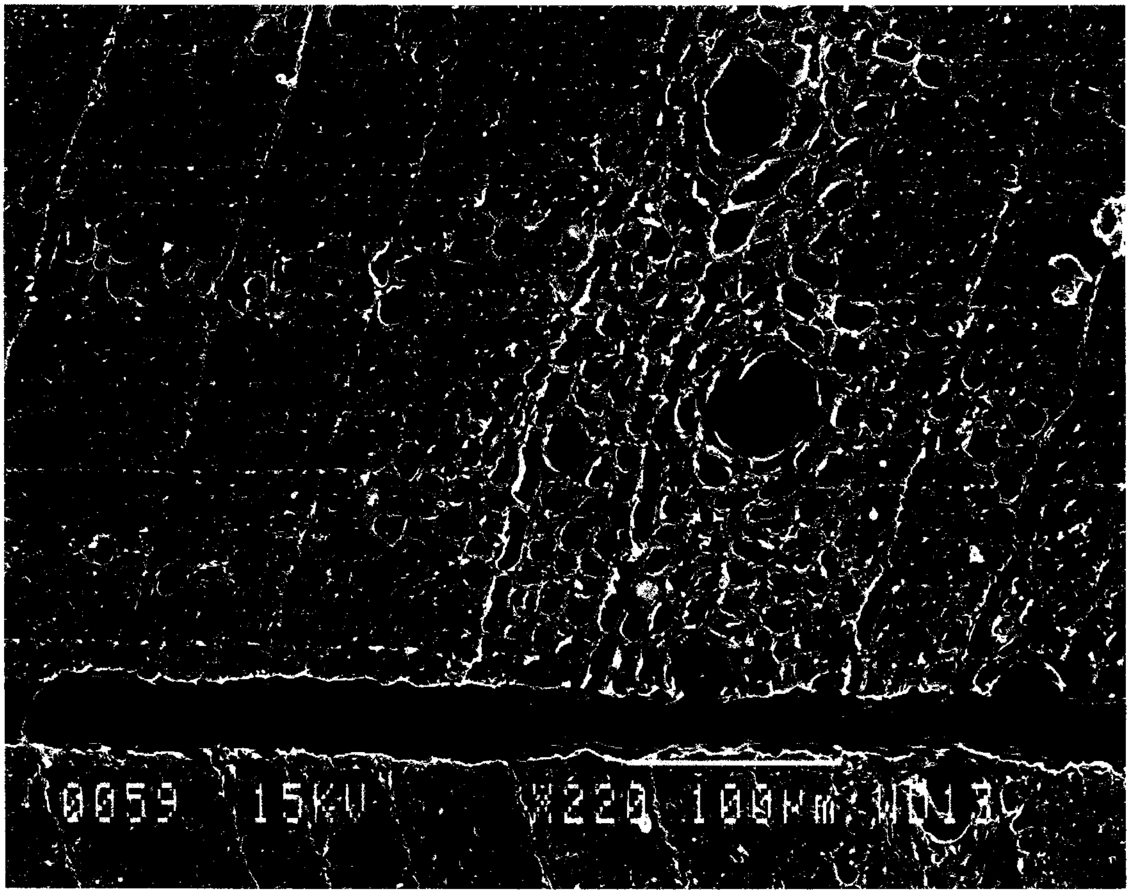

Fig. 6. Little damage noted during planing northern red oak wood with a sharpened knife having 1.2 mm of jointed land width.

the four planing lengths, three jointed land widths, and the two conditioning treatments are given in Table 2. Means were compared with the least-squares means statement from the SAS General Linear Models procedure at 95% confidence levels (SAS Institute 1988). Under constant hygrothermal conditions, the gluing performance of red oak wood was not significantly affected by the different jointing and wear processes. In contrast, the gluing shear strength and percent wood failure decreased after the accelerated aging treatment. The decrease in gluing shear strength was least pronounced as the planing length increased, and after aging, on average, gluing strength was 50%, 37%, 32%, and 26% lower for 0, 500, 1,000, and 3,000 m of planing, respectively (jointed lands pooled). The trend in percent wood failure was similar. The moisture saturation and subsequent drying cycles in the wood may have produced internal stresses related to swelling and shrinkage. These stresses would reduce the gluing shear strength and wood failure by increasing the number of microfailures, particularly in the cell walls at the surface and subsurface of wood. As a result, the effects of wear on gluing performance were evident after the accelerated aging treatment. Several authors have reported reduced gluing performance in wood after accelerated aging (Jokerst and Stewart 1976; Murmanis et al. 1983; Caster et al. 1985; Hernández 1994; Hernández and Naderi 2001). The aging treatment results are probably more representative

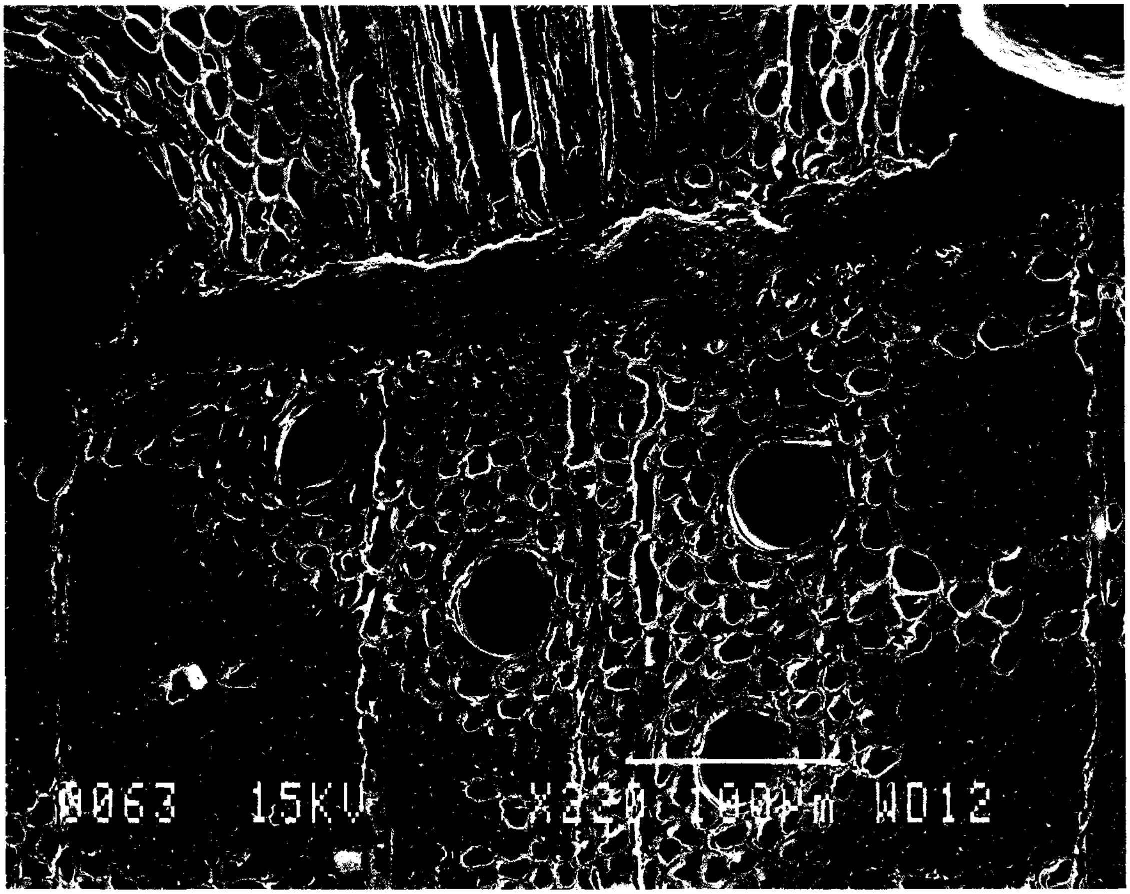

Fig. 7. Typical damage occurred during planing northern red oak with a knife having 0.4-mm jointed land width and 500 m of planing.

of the gluing performance of wood under normal working conditions.

After the severe soak-dry treatment, the gluing shear strength significantly increased as wear progressed. The influence of wear was different for red oak, a ring-porous wood, compared to sugar maple, a diffuse-porous wood (Hernández and Rojas 2002). Between 0 and 500 m of planing, the gluing shear strength greatly increased for all three jointed land widths (Fig. 8). Between 500 and 3,000 m of planing, the gluing shear strength continued to increase but at a slower rate. The overall increase in shear strength due to wear was about 39% (jointed lands pooled). In general, the trend in percent wood failure was similar. The increase in gluing performance due to wear appears to be associated to the surface roughness. We found a statistically significant polynomial correlation between the gluing shear strength and the surface roughness. When all planing lengths and jointed lands were pooled, the variation in roughness accounted for 84.5% of the total variation in the gluing shear strength (Fig. 9). The actual wood surface available for gluing was greater for rougher surfaces, and the glueline was thicker since the adhesive filled the troughs in the surface caused by the worn knives. Related to gluing shear strength, the percent wood failure was also highly correlated with surface roughness. Surface roughness variation accounted for 90.1% of the total variation in percent wood failure (all cutting conditions pooled).

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

Planing length (m)	Jointed land (mm)	Constant conditions[1] SS (MPa)	Constant conditions[1] WF (%)	After conditioning[1] SS (MPa)	After conditioning[1] WF (%)
0	0.0	18.2 (0.5)[2] A[3] a	65 (4) A a	8.4 (0.9) A a	31 (3) A a
	0.4	18.4 (0.4) A a	65 (5) A a	9.6 (1.2) A a	35 (4) A a
	1.2	18.8 (0.4) A a	55 (5) B a	9.6 (1.3) A a	34 (3) A a
500	0.0	19.3 (0.5) A a	81 (3) A b	10.9 (1.2) A b	40 (4) A b
	0.4	18.8 (0.4) A a	80 (3) A b	12.5 (1.1) A b	49 (3) B b
	1.2	18.9 (0.5) A a	77 (3) A b	12.6 (1.2) A b	48 (4) AB b
1000	0.0	18.7 (0.3) A a	81 (3) A b	12.6 (1.0) A bc	44 (3) A b
	0.4	18.1 (0.4) A a	86 (2) A b	13.2 (1.1) A b	63 (4) B c
	1.2	18.2 (0.3) A a	85 (2) A bc	11.7 (1.1) A b	50 (3) A bc
3000	0.0	17.6 (0.3) A a	84 (2) A b	13.2 (0.7) A c	58 (3) A c
	0.4	17.0 (0.4) A a	87 (2) A b	12.3 (1.0) A b	58 (4) A c
	1.2	17.5 (0.3) A a	87 (2) A c	12.9 (1.0) A b	58 (4) A c

[1] Means of twenty replicants.
[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% 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.

The increase in roughness may have enlarged the actual surface available for adhesive penetration and for mechanical linkages at the wood-glue interface, resulting in a more resistant glueline. However, optimal gluing performance of red oak may have already been reached (Figs. 8 and 9). Higher planing lengths and surface roughness could lead to declining gluing performance.

On the other hand, adhesion penetration may have increased as planing length increased. The permeability in the transverse direction of wood appears to be increased by the wear process, with resulting higher adhesive penetration. Compression rolling treatment increases permeability in several woods (Cech 1971; Günzerodt et al. 1988). Cutting forces generated during planing, particularly the normal cutting force, increased as the planing length increased (Fig. 2). Permeability of red

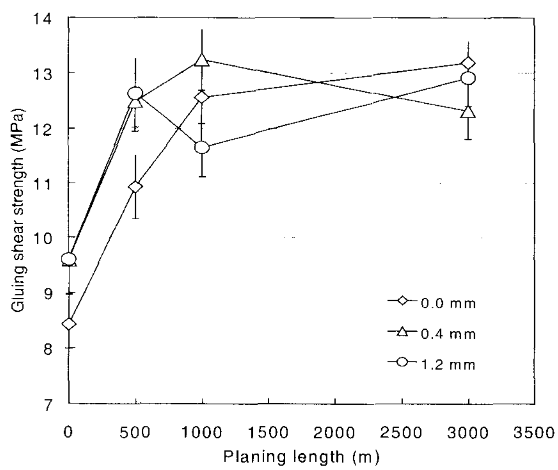

Fig. 8. Gluing shear strength as a function of planing length for three levels of jointed land for samples that had undergone an accelerated aging treatment.

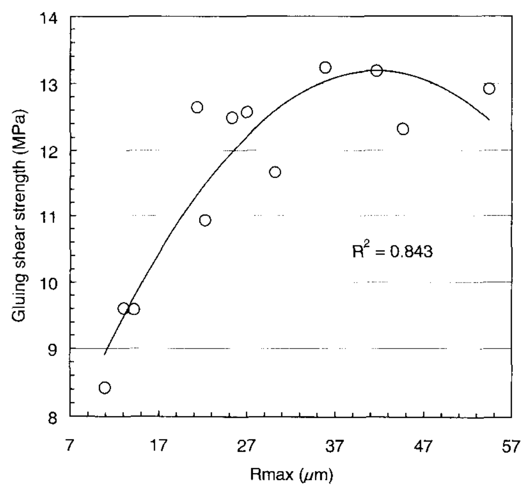

Fig. 9. Variation in gluing shear strength as a function of surface roughness.

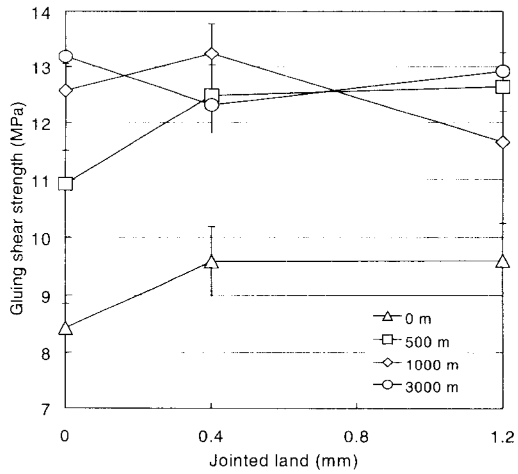

Fig. 10. Gluing shear strength as a function of jointed land width for four levels of planing length for samples that had undergone an accelerated aging treatment.

oak, especially latewood, may have been increased by an analogous mechanism with glue penetrating via paths opened up in the latewood to reach sound cells where mechanical attachments were available.

Therefore, under the given cutting conditions in this study, gluing properties of red oak were enhanced by a surface with 40 μm R_{max} roughness (Fig. 9) resulting from a 1.2-mm jointed land width knife, 0.33-mm rake face recession and 0.44-mm clearance face recession (Table 1). Such increases in gluing performance could be expected to progress up to an optimal planing length, after which the effect of knife wear would become negative.

The effect of jointing on the gluing shear strength measured after accelerated aging is shown in Fig. 10. In general, there was no significant variation in gluing shear strength among the different jointed land widths. The trend in percent wood failure was similar. Therefore, the increase of the jointed land up to 1.2-mm width for planing had no effect on gluing performance in red oak wood.

In this study we used a rake angle of 20 degrees, which is 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 damage produced by knives. However, the probable increase in wood permeability due to the normal cutting force could be reduced. The method suggested by Stewart (1977) predicts that cutting forces that result from sharpened unjointed knives with a rake angle of 27 degrees could be optimal for producing 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 rate 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

The peripheral planing with sharpened unjointed knives generated surfaces and subsurfaces of red oak wood with little damage. However, slight damage increased with increasing jointed land width and planing length. Damage was mostly in thin-walled longitudinal parenchyma cells, vasicentric tracheids, and vessel cells, while thick-walled fibers were relatively undamaged. The maximum depth of this damage was positively correlated with the magnitude of the normal cutting force. Knife wear also increased as the jointed land and planing length increased, and this process was similar on both the rake and clearance faces of knives. The normal cutting force increased with wear and jointing. Within the wear and jointed land width levels studied, gluability was more sensitive to surface roughness than to cellular damage. The increase in surface roughness from increased planing length, caused a corresponding increase in the gluing shear strength and percent wood failure of glued specimens. The effects on these properties were evident in specimens having undergone an accelerated aging treatment. In contrast, no significant variation in gluing performance of red oak wood existed among the three jointed land widths studied. The results suggest a jointed land of 1.2 mm as a maximum allowable width for planing this wood. Also, a surface roughness of 40 μm R_{max}, produced by knives with 332 μm of rake face recession and 438 μm of clearance face recession, could be suggested as maximum limit for positively affecting the planed surface quality of red oak for gluing.

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