EFFECT OF KNIFE WEAR ON THE GLUABILITY OF PLANED SURFACES OF RADIATA PINE

Cecilia Bustos A.†*

Assistant Professor

César Moya L.

Assistant Professor
Departamento de Ingeniería en Maderas
Universidad del Bío-Bío
Concepción, Chile

Justo Lisperguer M.

Professor
Departamento de Química
Centro de Polímeros avanzados (CIPA)
Universidad del Bío-Bío
Concepción, Chile

Eduardo Viveros M.

Former Undergraduate Student
Universidad del Bío-Bío
Concepción, Chile

(Received October 2009)

Abstract. The objectives of this study were to evaluate the effect of knife wear on the gluability of planed surfaces of radiata pine. A conventional process was used to plane samples to four lengths: 200; 10,000; 20,000; and 30,000 m. Cutting-edge recession was measured on the clearance surface of the planing knife for each length. The gluing properties of the planed surfaces were determined for each of the four levels of knife wear using polyvinyl acetate and emulsion polymer isocyanate adhesives. The results showed that the greatest amount of cutting-edge recession on the clearance surface was 65 μm after 30,000 m of planing. The tensile shear strength (TSS) of the lap-joint glue line decreased with knife wear from increased planing. However, TSS was generally greater than the minimum prescribed by the BS EN 204 standard. The effect of knife wear on TSS was more significant after accelerated aging of the glued samples.

Keywords: Planing, knife wear, gluing properties, radiata pine.

INTRODUCTION

The wear of wood-machining tools can be defined as the process that makes a usable tool inappropriate for continued use (Klamecki 1979). The major wear mode is associated with the rounding off of the cutting edge (Sarwar et al 2004, 2005). The change in edge geometry because of wear leads to an increase in cutting forces that also affects the quality of the finished surface and the dimensional accuracy of the work piece. In secondary wood manufacturing, performance and reliability of tools are key to efficient and profitable manufacturing processes as well as for quality finished products. Because finished surface quality is affected by knife-edge geometry, knowledge of the extent of knife wear indicates not only knife condition, but also product quality. The acquisition of knife wear data during processing can serve as input in the control of the planing process, more specifically as the basis for determining timely changes in knives or process conditions.

* Corresponding author: cbustos@ubiobio.cl
† SWST member

The performance of glue bonds is intimately related to wood-surface characteristics (Jokerst and Steward 1976). The preparation of wood surfaces before gluing typically involves machining such as knife or abrasive planing that can cause mechanical damage to wood cells (Hernández and De Moura 2002; Hernández and Rojas 2002; Bustos et al 2004; Kamke and Lee 2007), which can affect the strength of bonded joints. Inferior adhesively bonded joint performance has been related to damaged surfaces from machining (River and Miniutti 1975; Murmanis et al 1986; Kutscha and Caster 1987; Reeb et al 1998; Stehr and Östlund 2000; Hernández and Naderi 2001; Hernández and De Moura 2002; Hernández and Rojas 2002; Singh et al 2002). Hernández and Naderi (2001) reported that planing by peripheral cutting causes permanent damage to the surface and subsurface for different wood species, even with newly sharpened knives. Scanning electron microscopy (SEM) of wood surfaces has shown that the extent and depth of the damaged layer increases with joint width and consequently glued joint strength decreases. Singh et al (2002) studied the effect of planing on the microscopic structure of radiata pine (Pinus radiata) wood cells in relation to the penetration of polyvinyl acetate (PVA) adhesive. Observations by SEM and light microscopy suggest that dull knife-planed surfaces are likely causes of weaker glue bonding because of shallow glue penetration and damage to wood cells.

Using fluorescence microscopy, Murmanis et al (1983) showed that morphological differences exist in bonded wood specimens with regard to the surface machining process. Knife planing gave much smoother surfaces than abrasive planing at the cellular level, but these differences did not seem to affect bond strength. Reeb et al (1998) studied finger-joint quality obtained after 4, 6, and 32 h of knife wear. As knife wear increased with time, the crushed-cell zone in the finger joints increased in depth, and the joint surfaces became rougher and more irregular.

The objective of this work was to determine the gluability of radiata pine planed surfaces as a function of knife wear. Four wear levels were tested by planing lengths of 200, 10,000, 20,000, and 30,000 m. The gluing tensile shear aging performance was determined for two nonstructural adhesives, PVA and emulsion polymeric isocyanate (EPI).

MATERIAL AND METHODS

Plantation-grown radiata pine from the Bío-Bío Region of Chile was used. A total of 4.5 m^3 of commercial kiln-dried flat-sawn boards 50-mm thick by 100-mm wide and of varying lengths were selected. The boards were conditioned at 20°C and 60% RH to achieve a 12% equilibrium MC.

The boards were surfaced with a SCM molder. Feed rate was set for 20 knife marks per 25 mm of length, and the cutting depth was adjusted to remove 1 mm of wood in each pass. The cutting circle radius was 60 mm. One of the three knives of the cutter head was set for cutting. The knife and clearance angles for the freshly sharpened knives were 45° and 25°, respectively. The planing test began with a freshly sharpened knife that was exposed to 200, 10,000, 20,000, and 30,000 m of planing.

After each planing treatment, the boards were cross-cut to form pairs that were glued together to form lap-joint specimens for tensile shear strength (TSS) and microscopy. The final dimensions of the samples were 10-mm thick ($2 \times c$) by 20-mm wide (b) by 150-mm long (L) (Fig 1). The lap joints were glued with PVA and EPI according to the recommendations provided by the manufacturer, Akzo Nobel. The technical characteristics of these adhesives are shown in Table 1. A single-face adhesive application was made by hand with a brush at 250 g/m^2. Clamping pressure of 0.4 MPa was applied for 4 h followed by conditioning at 20°C and 65% RH for about 24 h to permit adhesive cure. A total of 60 samples for each type of adhesive was selected to evaluate the effect of knife wear on the glue line TSS after exposure to the three accelerated aging treatments described in Table 2.

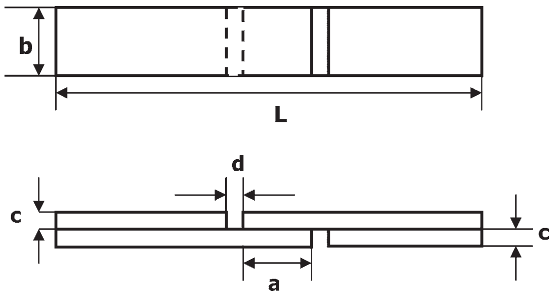

Figure 1. Tensile shear strength test sample (a = 10 mm, b = 20 mm, c = 5 mm, d = 3 mm, L = 150 mm).

Table 1. Characteristics of the adhesives.

Type of adhesive	Solid content (%)	Brookfield viscosity (mPa·s)	pH	Hardener (%)
PVA	48	2500	4.8	5
EPI	55	12000	7.0	10

PVA, polyvinyl acetate; EPI, emulsion polymer isocyanate.

Table 2. Accelerated aging treatment used following the BS EN 204 and 205 standards.

Accelerated aging procedure	Treatment conditions
D1 (Control)	Conditioned 7 da in standard atmosphere (20 ± 2°C and 65 ± 3% RH)
D2	Conditioned 7 da in standard atmosphere, 3 h in cold water, and 7 da in standard atmosphere
D3	Conditioned 7 da in standard atmosphere and immersed 4 da in cold water

Glue Line Tensile Shear Tests

The samples were prepared according to British Standard BS EN 205 (BSEN 1991b), which describes the lap-joint geometry and the test for TSS. The tests were done with a universal testing machine (Instron model 4468, 50 kN capacity) fit with a lap-shear test fixture. The loading speed was 50 mm/min and was continued until a fracture or separation occurred on the sample surface. TSS (σ, MPa) was calculated using the maximum load (P_{max}) and bonding surface of the sample (A) according to:

$$\sigma = \frac{P_{\max}}{A} = \frac{P_{\max}}{a \times b} \quad (1)$$

where a is the length (10 mm) and b is the width (20 mm) of the glued face.

Accelerated Aging

Accelerated aging was performed according to British Standard BS EN 204 (BSEN 1991a), which defines the durability classes of nonstructural adhesives (D1, D2, D3), the conditioning sequence, and the minimum values of adhesive strength for each class. The aging cycles correspond to durability classes under different environmental conditions. Durability class D1 is for interior applications, for which the temperature occasionally exceeds 50°C. D2 is for interior applications with occasional short-term exposure to running water or water of condensation. D3 is for interior applications with frequent short-term exposure to running or condensed water and exposure to high RH.

Table 2 shows the different accelerated aging treatments used. The samples were prepared under constant conditions of 20°C and 60% RH. Twenty samples were tested for each treatment.

Microscopic Evaluation

Small blocks of about 70 mm^2 in the transverse plane that included the glue line were cut from the specimens for light and epifluorescence microscopic analysis for EPI and PVA, respectively. The blocks were sliced with a microtome to prepare the surface. Micrographs of representative surfaces were taken for each type of adhesive and for the four knife wear levels to determine the depth of wood cell damage.

Knife Wear Characterization

The intersection between the rake face and the clearance face of the cutting tool generates an infinitely small radius known as initial wear radius (ρ_0) for new or freshly sharpened tools. As the cutting tool interacts with wood, the initial wear radius becomes greater until it reaches a maximum value (ρ_{max}) after which the tool is no longer usable. Wear of wood cutting tools depends metal type, processing time, wood density, and MC, expressed as (Petkov 1992:

$$\Delta_\rho = f(\gamma_\Delta, t, d, MC) \quad (2)$$

where Δ_ρ = wear–radius variation, γ_Δ = wear increment by length of wood processed, t = time of cutting, d = wood density, and MC = MC.

The wear–radius variation can be defined by:

$$\Delta_\rho = \rho_{max} - \rho_0 \quad (3)$$

Petkov (1992) also defines the wear–radius variation as:

$$\Delta_\rho = \frac{A_\mu tg(\frac{\beta}{2})}{1 - \sin(\frac{\beta}{2})} \quad (4)$$

where A_μ = horizontal edge retraction and β = knife angle.

Thus, the maximum wear–radius can be expressed as:

$$\rho_{max} = \rho_0 + \frac{A_\mu tg(\frac{\beta}{2})}{1 - \sin(\frac{\beta}{2})} \quad (5)$$

Figure 2 shows the angles of the cutting tool interacting with wood. Planer and veneer knives have just one cutting edge with a single set of rake and clearance angles.

Wear Measurements

For planing length, wear measurements were made with a stereoscopic microscope, and larger areas of the knife were analyzed using 20× magnification. Three equally spaced knife sections were taken along the cutting-edge area. The retraction (A_μ) was measured on the clearance surface (Fig 3). The wear–radius variation was determined using Eq 4.

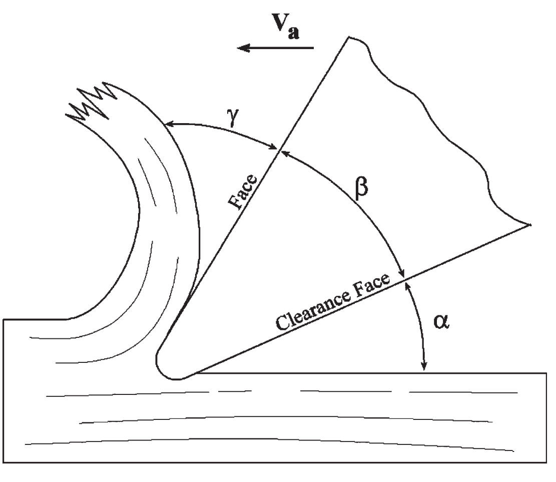

Figure 2. Angles defined by a cutting tool in a work piece (V_a = feed speed, γ = rake angle, α = clearance angle, β = knife angle).

Statistical Analysis

A factorial design of three factors (3 × 2 × 4) was carried out, the first factor (aging treatment) at 3 levels, the second (adhesive) at 2 levels, and the third (planing length) at 4 levels. A total of 24 treatment combinations were then analyzed by a completely randomized analysis of variance (ANOVA) using Statgraphics Plus (1994) software. The total sample size was 408 with at least 15 replicates per treatment combination.

RESULTS AND DISCUSSION

The overall results of the ANOVA performed on TSS data are shown in Table 3. The ANOVA showed a significant interaction between the accelerated aging procedure and planing length (p value = 0.0145). Significant differences of TSS were found between the D2 and D3 accelerated aging procedures (Fig 4). Thus, under constant hygrothermal conditions (D1), the gluing performance of radiata pine wood was not significantly affected by the different wear levels.

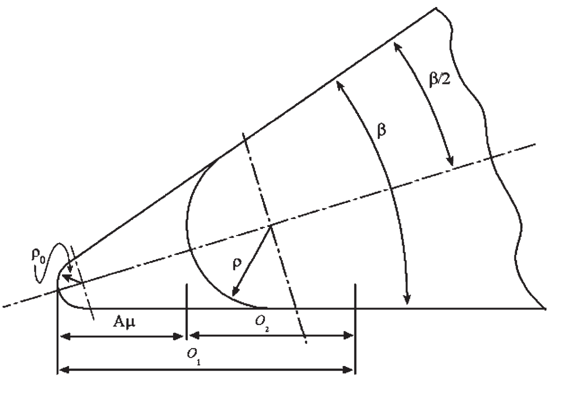

Figure 3. Knife parameters for wear measurements (ρ_0 = initial wear radius, ρ = wear radius, Aμ = horizontal edge retraction, O_2 = partial wear retraction, O_1 = total wear retraction).

Table 3. Summary of analysis of variance results on tensile shear strength.

Source	df[a]	Sum of squares	Mean square	F ratio	*p* value
Main effects					
Aging treatment	2	3626.8	1813.4	57.5	0.0000
Adhesive type	1	214.2	214.2	6.8	0.0095
Planing length	3	1204.3	401.4	12.7	0.0000
Interactions					
Aging treatment × adhesive type	2	4.4	2.2	0.07	0.9331
Aging treatment × planing length	6	508.3	84.7	2.7	0.0145
Adhesive type × planing length	3	19.8	6.6	0.2	0.8900
Aging treatment × adhesive type × planing length	6	134.2	22.4	0.7	0.6424
Residual	384	12109.2	31.5		
Total	407	17664.8			

[a] Degrees of freedom.

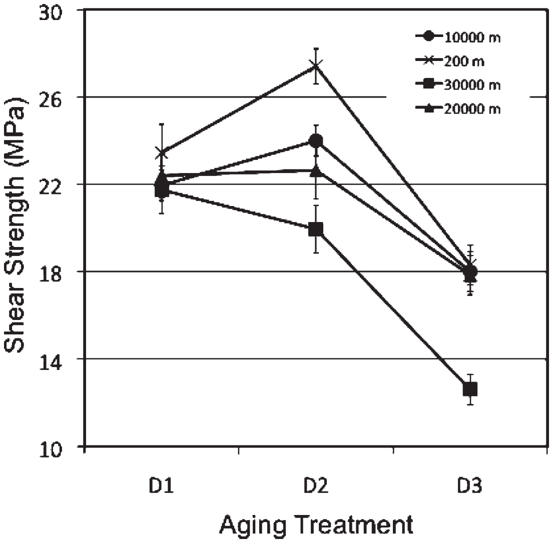

Figure 4. Average tensile shear strength as a function of accelerated aging treatment at three levels of planing length.

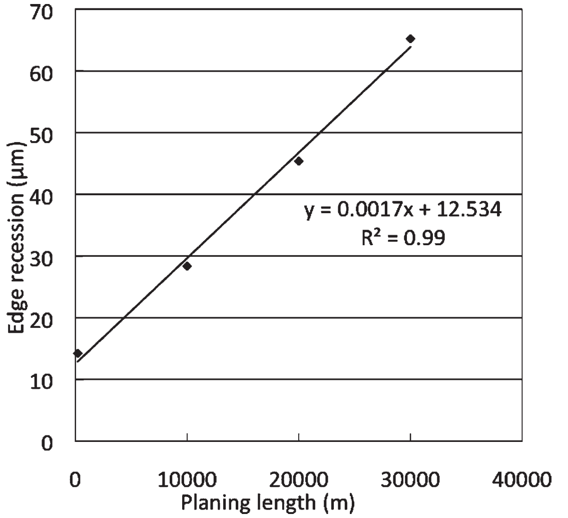

Figure 5. Effect of planing length of radiata pine lumber on knife wear.

In contrast, TSS decreased after the accelerated aging procedures D2 and D3. This could be because of the weakening of the lap joints after swelling and shrinkage of the samples exposed to varying hygrothermal conditions. The interactions between adhesive type and planing length and adhesive type and aging treatment were not significant.

These results are in agreement with those of Hare and Kutscha (1974) who examined adhesive penetration and shear strength of spruce plywood bonded with phenol-formaldehyde adhesive. Drying technique and influence of the aging treatment were parameters in that study. They noted deeper penetration into veneer that had more severe surface damage (cell-wall fractures). This condition was associated with low shear strength. Hernández and De Moura (2002), Hernández and Rojas (2002), and Kamke and Lee (2007) also found that stresses could reduce gluing shear strength by increasing the number of wood microfailures, especially in the cell walls at the surface of the wood.

Figure 5 shows the resulting wear-radius obtained after planing radiata pine lumber for 200, 10,000, 20,000, and 30,000 m. As expected, wear increased as the planing length increased, causing dulling of the cutting edge. It is interesting that a

Table 4. Average tensile shear strength (MPa) of lap joints of radiata pine lumber at different levels of planing length after accelerated aging treatments.

Accelerated aging procedure[a]	Planing length (m)								BS EN 204 requirement
	200	10,000	20,000	30,000	200	10,000	20,000	30,000	(MPa)
	Polyvinyl acetate				Emulsion polymer isocyanate				
D1 (control)	22.0 (5.2)[b]	21.6 (3.1)	21.5 (6.4)	21.5 (7.6)	24.9 (8.3)	22.3 (4.9)	22.2 (5.2)	22.0 (5.2)	10
D2	27.1 (3.7)	24.0 (3.8)	22.0 (7.0)	17.5 (3.9)	27.7 (5.1)	24.0 (4.1)	23.3 (8.1)	22.4 (7.2)	8
D3	17.5 (5.1)	17.1 (5.7)	16.9 (4.9)	12.32 (4.6)	19.1 (5.2)	18.9 (5.8)	18.8 (5.9)	12.9 (3.4)	2

[a] D1, D2, D3: accelerated aging procedure described in Table 2.
[b] Standard deviation.

rapid initial increase in wear-radius occurred in only 200 m of planing causing a knife cutting-edge recession of about 14 μm. Knife edge recession continued to increase at a constant rate with planing length. A linear relationship was found between knife edge recession and planing length with a coefficient of determination of 0.99.

A summary of test results on the influence of planing length on TSS is given in Table 4. Results showed that TSS obtained for both PVA and EPI are above the minimum requirement of the BS EN 204 standard. The average TSS of the lap-joint specimens was over 20 MPa for the three accelerated aging procedures. The results also show a slight decrease of TSS when planing length increases. This could be caused by damage of the wood surface from knife wear.

Microscopic analysis of transverse sections of the samples showed that the thickness of the glue line for both PVA and EPI adhesives was greater for samples planed for 30,000 m than those for 200 m. Crushed and collapsed cells were observed near or at the surface of the samples at the glue line (Figs 6 and 7). In general, surface damage was more severe as planing length increased. Similar results were found by Kamke and Lee (2007) who established that the penetration of the adhesive increases when cell damage is greater. Tracheids away from the glue line had a normal appearance. However, tracheids near and at the glue line were damaged for planing lengths greater than 20,000 m. Therefore, as planing length increased, knife wear caused damage to

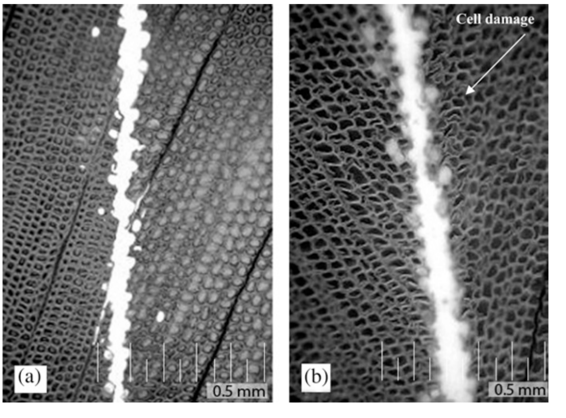

Figure 6. Epifluorescence micrographs of lap-joints of radiata pine glued with polyvinyl acetate adhesive after (a) 200 m of planing and (b) 30,000 m of planing. Magnification: 10×.

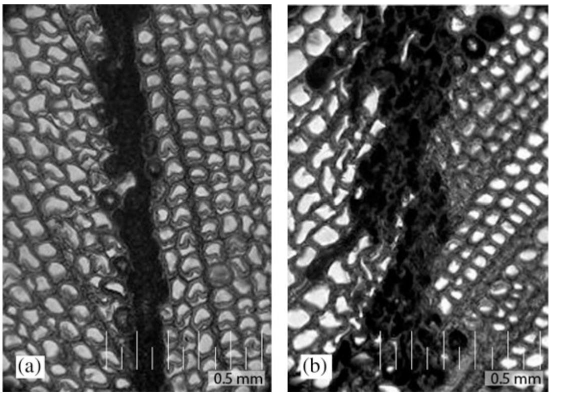

Figure 7. Micrographs of lap joints of radiata pine wood glued with an emulsion polymer isocyanate adhesive after (a) 200 m of planing and (b) 30,000 m of planing. Magnification: 20×.

the surface and subsurface wood cells. These results are in agreement with Reeb et al (1998) who reported that as knife wear progresses, the adherent surfaces become rougher and irregular. Kamke and Lee (2007) also showed that the cells in the damaged region can be weaker, thus increasing the potential for failure of the bond. These authors also mentioned that wood processing such as planing, flaking, sanding, and other mechanical surface preparation techniques can cause minute failures in the wood cells.

CONCLUSIONS

Knife wear increased 14-65 μm as planing length increased 200-30,000 m. Microscopic analyses showed increased cell damage and thicker glue lines as planing length increased for both PVA and EPI. The lap joints of radiata pine, planed at four wear levels, showed glue line TSS values over the minimum required by the BS EN 204 standard. TSS decreased significantly with planing length and the resulting knife wear. The influence of knife wear on the glue line TSS was more pronounced after the two accelerated aging treatments tested, but the TSS remained above the minimum required by the BS EN 204 standard.

ACKNOWLEDGMENTS

We are grateful to the Research Direction of the Universidad del Bío-Bío for funding this research through Project 060512 3/R. We also thank the technical staff of the Departamento de Ingeniería en Maderas at Universidad del Bío-Bío and Laboratorio de Materiales Compuestos for their support.

REFERENCES

BSEN (1991a) British Standard EN 204. Non-structural adhesives for joining of wood and derived timber products. European Standard. London British Standard Institution, UK.

BSEN (1991b) British Standard EN 205. Test methods for wood adhesives for non-structural applications. Determination of tensile shear strength of lap joints. European Standard. London British Standard Institution, UK.

Bustos C, Hernández RE, Beauregard R, Mohammad M (2004) Influence of machining parameters on the structural performance of finger-jointed black spruce. Wood Fiber Sci 36(3):359-367.

Hare DA, Kutscha NP (1974) Microscopy of eastern spruce plywood gluelines. Wood Sci 6(3):294-304.

Hernández RE, De Moura LF (2002) Effects of knife jointing and wear on the planed surface quality of northern red oak wood. Wood Fiber Sci 34(4):540-552.

Hernández RE, Naderi N (2001) Effect of knife jointing on the gluing properties of wood. Wood Fiber Sci 33(2): 292-301.

Hernández RE, Rojas G (2002) Effects of knife jointing and wear on the planed surface quality of sugar maple wood. Wood Fiber Sci 34(2):293-305.

Jokerst RW, Steward HA (1976) Knife—versus abrasive-planed wood: Quality of adhesive bonds. Wood Fiber Sci 8(2):107-113.

Kamke FA, Lee JN (2007) Adhesive penetration in wood—A review. Wood Fiber Sci 39(2):205-220.

Klamecki BE (1979) A review of wood cutting tool wear literature. Holz Roh Werkst 37(7):265-276.

Kutscha P, Caster RW (1987) Factors affecting the bond quality of hem-fir finger-joints. Forest Prod J 37(4):43-48.

Murmanis L, River B, Stewart H (1986) Surface and subsurface characteristics related to abrasive-planing conditions. Wood Fiber Sci 18(1):107-117.

Murmanis N, River BH, Stewart H (1983) Microscopy of abrasive-planed surfaces in wood-adhesive bonds. Wood Fiber Sci 15(2):102-115.

Petkov P (1992) Wood cutting (Рязане на дървесината). University of Forestry. Ed. Земиздат. Sofia. Bulgari. 335 pp.

Reeb JE, Karchesy JJ, Foster JR, Krahmer RL (1998) Finger-joint quality after 4, 6, and 32 hours of knife wear: Preliminary results. Forest Prod J 48(7/8):33-36.

River B, Miniutti V (1975) Surface damage before gluing-weak joints. Wood Wood Proc 80(7):35-38.

Sarwar M, Persson M, Hellbergh H (2004) Wear of high speed steel bi-metal bandsaw blade when cutting Avesta Polarite 17-7 stainless steel in the As-cast State. Materials Science Forums. Vols. 471-472. Trans Tech Publications, Switzerland. Pages 431-437.

Sarwar M, Persson M, Hellbergh H (2005) Chip formation mechanisms in bandsaw metal cutting. *In* Proc 18th International Conference on Production Research, Salerno, Italy.

Singh AP, Anderson CR, Warnes JM, Matsumura J (2002) The effect of planing on the microscopic structure of *Pinus radiata* wood cells in relation to penetration of PVA glue. Holz Roh Werkst 60(5):333-341.

Statgraphics Plus (1994) Version 7.1; Users guide reference. Statistical Graphics Manugistics Group Inc, Rockville, MA.

Stehr M, Östlund S (2000) An investigation of the crack tendency on wood surfaces after different machining operations. Holzforschung 54(4):427-436.