VENEER SURFACE ROUGHNESS AND COMPRESSIBILITY PERTAINING TO PLYWOOD/LVL MANUFACTURING. PART I. EXPERIMENTATION AND IMPLICATION

*Brad Jianhe Wang**†
Composites Research Scientist

*Chunping Dai**†
Group Leader

*Wood Composites Group
Forintek Canada Corp.
2665 East Mall
Vancouver, B. C.
Canada V6T 1W5

and

Simon Ellis†
Associate Professor
Department of Wood Science
The University of British Columbia
2935-2424 Main Mall
Vancouver, B. C.
Canada V6T 1Z4

(Received July 2005)

ABSTRACT

Extensive experiments were conducted to examine the transverse compression behavior of trembling aspen (*Populus tremuloides*) veneer at ambient and controlled temperature and moisture content (MC) environments, and the relationship between contact area, veneer surface roughness, and applied load. Based on the results, a novel method was developed to characterize surface roughness/quality of wood veneer in terms of its compression behavior. This method may have significant implication on both theory and practice. In theory, the general wood transverse compression theory needs to be revised to include four stages instead of the commonly defined three. The first stage, which has long been overlooked but is critically important, could be named "progressive contact." During this stage, the contact area increases nonlinearly with the load applied. It is this stage that reveals the interfacial contact of veneer-to-veneer or veneer-to-plate and the minimum veneer compression required for achieving adequate contact. With the inclusion of the first stage, the yield displacement also needs to be redefined. In practice, the method provides a fast and objective way of evaluating veneer surface roughness/quality for plywood/LVL manufacturing. Furthermore, the minimum compression required and yield displacement of wood veneer derived from its compressive load-displacement curve were found to be independent of temperature and MC, which helps benchmark material recovery in terms of veneer surface roughness/quality when manufacturing into quality plywood/LVL products. The method could also be applied to other wood composite elements such as wood strands.

Keywords: Compressibility, compression, contact area, laminated veneer lumber (LVL), load, material recovery, plywood, progressive contact, roughness, strand, surface quality, trembling aspen, veneer.

† Member of SWST.

Wood and Fiber Science, 38(3), 2006, pp. 535–545

INTRODUCTION

Wood is an anisotropic cellular material. Machined surfaces of wood composite elements such as veneers, strands, or fibers are rough to various degrees. Surface roughness affects wood composites manufacturing in which wood elements are consolidated to form intimate contact and then adequate bonding under heat and pressure with the least amount of resin.

Currently, surface roughness is evaluated by surface texture parameters defined in standards such as ASME Standard B46.1-2002 and ISO 4287-1997 (ASME 2003). Two main methods for surface roughness/quality measurement are conventional stylus profilometer and optical scanning. The conventional stylus profilometer is widely accepted as the most accurate contact-type roughness device for laboratory and off-line use, whereas the optical method is generally accepted as the most effective non-contact surface profilometer in quality and process control. To quantify surface roughness, two key parameters are generally used. One is the roughness average R_a, which is the arithmetic average of the absolute value of the profile height deviations recorded within the evaluation length and measured from the mean line. The other is the root mean square (RMS) roughness R_q, which is the RMS average of the profile height deviations taken within the evaluation length and measured from the mean line. However, R_a and R_q are derived from a single roughness profile based on a point measurement. Also, they are amplitude-based not spacing-based, hence they may not adequately characterize the surface roughness/quality of wood materials (Sandak and Tanaka 2003; Sandak et al. 2004). As shown in Fig. 1, the shape of the two profiles of veneer surface roughness is dramatically different but they have the same R_a. Neese et al. (2004) investigated whether traditional two-dimensional, amplitude-based measures for characterizing surface roughness can be used to predict percent wood failure and load at failure. It was determined that the only statistically significant relationship was between the loose-side roughness measurements and percent wood failure giving an R^2 of 0.68.

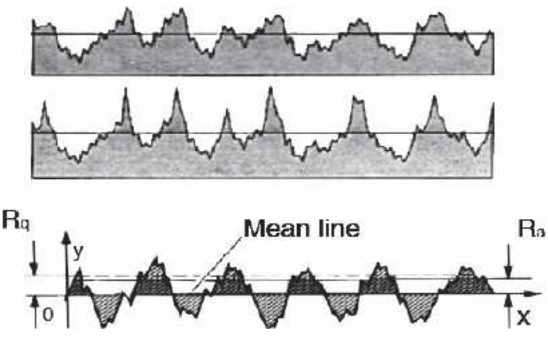

FIG. 1. Veneer surface roughness profiles and the two key roughness parameters.

At present, both methods are very slow (0.3 to 0.6 mm/s), tedious, and labor-intensive for assessing wood surface roughness/quality and are generally suitable for only small samples (8 to 15 mm in length). Since a single line measurement might deviate from the complete surface profile of wood due to its anisotropic nature, many line-scans need to be done to generate a three-dimensional surface map for an accurate assessment. Further, the data reduction process is rather complicated from the measured profile. As a result, these two methods are limited for an off-line and laboratory use and cannot yet be fully utilized for on-line applications. Although image methods have been used to measure veneer surface roughness at the production speed (about 0.5 m/s), the algorithm used, filter level, veneer vibration and variation of wood color might significantly affect the accuracy of roughness measurements (Faust 1987).

There is no commonly accepted quantitative parameter for characterizing surface roughness/quality of wood veneer or strand. No specific roughness measurement standard has been recommended and widely used in the wood industry (Fujiwara et al. 2004). In addition, the single and combined effects of the three veneer quality criteria, namely, surface roughness, thickness (average and variation), and lathe checks (depth and frequency), on required glue application and gluebond performance have not been systematically studied (Faust and Rice 1986; Faust and Rice 1987; Neese et al. 2004). Although the initial upward curvilinear stress-strain relationship was observed through compression tests of four wood species with different anatomical characteristics, it was speculated that this was probably due to the irregularities such as those caused by drying stresses in the wood specimen surface (Bodig 1965). Wolcott et al. (1989) examined the transverse compression behavior of small wood specimens and found that yield stress was not affected by specimen height, but an increase of specimen height resulted in a decrease of yield strain. They attributed these observations to surface roughness or non-parallelism of the specimen. Information is still lacking concerning how veneer surface roughness/quality affects veneer-to-veneer contact, compressibility, and material recovery.

The goal of this study was to improve the fundamental understanding of plywood/LVL manufacturing process. The specific objectives were: 1) to develop a new method to measure veneer surface roughness/quality; 2) to determine the relationship between veneer contact area, surface roughness, and pressing load; and 3) to determine the impact of veneer surface roughness/quality, temperature, and MC on minimum compression required for bonding contact. Through systematic transverse compression tests of trembling aspen (*Populus tremuloides*) veneer, a threshold load was established under which the transition from the initial nonlinear stage to the linear stage occurred. Then a concept of the minimum compression required was proposed for achieving adequate contact veneer-to-veneer or veneer-to-plate. After that, the correlation between veneer surface roughness and the minimum compression required was established. In addition, the relationship between contact area, veneer surface roughness, and the load applied was determined. Furthermore, the effect of veneer surface roughness, temperature, and MC on the minimum compression required and yield displacement was examined. Based on the results, a novel method was developed for characterizing veneer surface roughness/quality, and a revised wood transverse compression theory was proposed.

MATERIALS AND METHODS

Materials

One hundred and fifty 3.2-mm (1/8-in.)-thick rotary-cut aspen dried veneer sheets (1.2 × 1.2 m) were randomly selected from a mill in Eastern Canada and delivered to Forintek's Vancouver laboratory. The average veneer MC was about 3% on an oven-dry basis. Among them, 120 veneer sheets were visually separated into the three groups: smooth, medium rough, and rough. Ten 1.2- × 1.2-m veneer sheets were randomly selected from each group for cutting one hundred 30- × 30-mm veneer specimens. These 100 specimens from each group were marked and kept in plastic bags for compression tests. Before the tests, five-point veneer thickness, weight, length, and width of each specimen were measured to calculate veneer density.

One 1.2-m-long fresh trembling aspen log (30.5 cm in diameter) was acquired from the same mill. The log was sliced into 2.5-mm (1/10-in.)-thick veneer. Five sliced aspen veneer sheets (about 1.2 × 0.2 m) were randomly selected and then dried down to an average MC of 3% on an oven-dry basis.

Veneer surface roughness/quality assessment

To quickly evaluate veneer surface roughness/quality and compressibility, a novel method was developed to measure an averaged quality criterion over any given area. To demonstrate the new method, ten 30- × 30-mm specimens were randomly selected from each roughness group. At the ambient temperature (20°C), the compression tests of these thirty specimens were conducted on a universal Instron test machine in the transverse (thickness) direction at a load rate of 2 mm/min until the load reached the maximum (about 975 kg). This maximum load can ensure 30- × 30-mm specimens to reach a stage of cell-wall densification. Before starting the compression test, a load level of about 2.5 kg was applied to each 30- × 30-mm veneer specimen to create an initial contact between veneer and compression steel plates. In this way, the slack in the universal test machine can be largely eliminated. For each test, the load-displacement curve was recorded and then plotted. Based on these load-displacement curves, an average threshold load can be identified under which the transition of the load-displacement curves from a nonlinear stage to a linear stage occurs. The displacement measured prior to the linear elastic stage under the threshold load can be named the minimum compression required. For each specimen, the minimum compression required under the average threshold load and yield displacement were determined.

Accuracy of the method proposed for roughness measurement.—Five 30- × 30-mm veneer specimens were randomly selected from each of the three roughness groups. The surface roughness of these 15 veneer specimens was evaluated using a SJ-400 surface roughness tester, a stylus profilometer. The stylus of the tester traced the minute irregularities of the veneer surface by measuring vertical stylus displacement as the detector traversed the surface irregularities (Mitutoyo 2004). The roughness was evaluated across the grain on both tight and loose sides of each specimen. The overall veneer roughness parameter R_a was the square root of R_a at the tight side and R_a at the loose side. The overall veneer roughness parameter R_q was calculated similarly. After measuring veneer roughness, compression tests were conducted at the ambient temperature following the same method established to determine the minimum compression required and yield displacement for each specimen. Then the correlation between the R_a and R_q and the minimum compression required was established.

Relationship between the contact area veneer-to-veneer and the load applied.—Eight, ten, and twelve 30- × 30-mm specimens were randomly selected from each of the three roughness groups: smooth, medium rough, and rough, respectively. Then, the roughness of each specimen was measured on both sides using the SJ-400 tester. These specimens were paired for each of the three roughness groups. For each pair, a plywood phenol-formaldehyde (PF) glue (45% solids content) was uniformly spread onto the tight side of one veneer specimen at an application rate of 170 g/m^2 (35 lb/1000 ft^2). Parallel grain veneer-ply was generated by naturally stacking two veneer specimens in a loose-to-tight pattern. The assembly time was about 3 minutes. Before starting the compression test, a load level of about 2.5 kg was applied to 30- × 30-mm veneer specimens to create an initial contact for veneer-to-veneer and veneer-to-plate. At the ambient temperature, the compression test of each parallel veneer-ply was conducted in a load-control mode and stopped when the load reached a desired level from 20 to 220 kg. During the compression, glue was transferred from the tight side of one specimen to the loose side of the other, displaying the contact area (glue coverage map) when the parallel veneer-ply was brought into contact at varying load levels. After stopping compression, the thickness and weight of each parallel veneer-ply were measured to calculate its compression ratio (CR) and density. Then each parallel veneer-ply was carefully detached to determine the contact area. Subsequently, the correlation between the contact area and the load applied was established.

Relationship between the contact area veneer-to-plate and the load applied.—One 3.2-mm-thick 1.2- × 1.2-m dried aspen veneer sheet each was selected from the smooth group and rough group, respectively. Twenty-four 63.5- × 63.5-mm (2.5- × 2.5-in.) veneer specimens were cut from each sheet for compression tests at the ambient temperature. Before performing tests, the five-point veneer thickness, weight, length, and width were measured on each piece of veneer to calculate veneer density. A plywood phenol-formaldehyde (PF) glue was uniformly spread onto a smooth steel plate (125 × 125 mm) at an application rate of 170 g/m^2 (35 lb/1000 ft^2). The loose side of each veneer specimen was placed face-down on the glue-covered plate. Prior to the compression test, a load level of about 10 kg was applied to 63.5- × 63.5-mm veneer specimens. This load level was equivalent to the 2.5 kg applied to 30- × 30-mm veneer specimens for eliminating machine slacks and creating an initial contact between veneer and the steel plate. The compression tests were started in a load-control mode at a load rate of 2 mm/min and manually stopped when the load reached a desired target from 50 to 975 kg in order to establish the relationship between the contact area and the load applied. During the test, glue was transferred to the loose side of the veneer, displaying the contact area (glue coverage map) when veneer and the steel plate were brought into contact to various degrees. After completing the test, the veneer specimens were carefully removed from the plate. The thickness and weight of each veneer specimen were measured to calculate the CR and density. Using an image analysis software program, the glue coverage map of each specimen was taken and the contact area (in dark color) was evaluated in terms of the percentage of the specimen size. The correlation between the contact area and the load applied was established.

Sensitivity of the method proposed to veneer temperature and MC.—Sliced aspen veneer was chosen because the veneer surface was smooth and uniform and no lathe checks occurred in the veneer. This was done to minimize the effect of veneer density, surface roughness, thickness variation, and lathe checks. In total, two hundred 30- × 30-mm veneer specimens were cut from the five selective sheets (1.2 × 0.2 m): half were wrapped with the plastic bags to keep a MC level of 3% and the remaining half were left unwrapped for one week to achieve an average MC level of about 6% based on oven-dry weight at the ambient environment. The compression tests of these sliced veneer specimens were conducted using an apparatus with a temperature control. Before starting the compression test, a load level of 2.5 kg was applied to 30- × 30-mm veneer specimens to create an initial contact between veneer and compression steel platens. The apparatus can be affixed to the Instron test machine for compression tests. The tests were conducted at the following four temperature levels: 20°C, 50°C, 100°C, and 150°C. For each temperature level, ten specimens were compressed to a maximum load of about 650 kg. Since the threshold load changes with the temperature, an average threshold load was determined based on the ten load-displacement curves at each temperature level. The minimum compression required under the threshold load and yield displacement were evaluated for each specimen. The t-tests were conducted to compare the minimum compression required and yield displacements at different veneer temperature levels.

RESULTS AND DISCUSSION

A novel method to evaluate veneer surface roughness/quality

As an example, two 30- × 30-mm aspen veneer specimens (one smooth and the other rough) were selected. They had the same wood density (0.47 g/cm^3) and average MC (3%). Figure 2 shows the load-displacement curves of these two aspen veneer specimens. At the linear elastic stage, they displayed almost the same magnitude of slopes (compression MOE) but with different levels of delay in displacement, namely d_1 and d_2, prior to the linear elastic stage. This delayed elasticity at the early stage of compression is believed to be mainly caused by different levels of veneer surface roughness/quality. The threshold load required to identify the surface roughness/quality effect was also found to be species-dependent, but was consistent for one specific species. For 30- × 30-mm specimens at the ambient temperature and 3% average MC, this threshold load was about

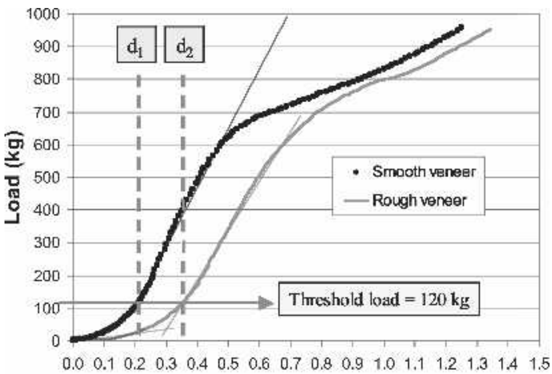

FIG. 2. Effect of veneer roughness/quality on compression indicated by the early stage load-displacement curve.

120 kg for aspen veneer and about 100 kg for white spruce and lodgepole pine veneer.

For viscous-elastic and porous materials like wood, nonlinear load-displacement relationship occurs at the early stage of the compression. It is proposed that by measuring displacement of wood veneer under transverse compression at a predetermined threshold load, veneer surface roughness/quality can be evaluated. Figure 3 shows the apparatus required for this method.

Accuracy of the method for veneer surface roughness measurement

The 15 specimens used for the roughness measurements appeared to have two density groups: low density (average 0.42 g/cm^3, ranging from 0.40 to 0.43 g/cm^3) and high density (average 0.52 g/cm^3, ranging from 0.51 to 0.53 g/cm^3). One aspen veneer specimen was out of the magnitude range of the roughness tester. Figure 4 shows the plots of the load-displacement curves for three typical veneer specimens with different levels of density and roughness. It can be seen that the optimum threshold load for 30- × 30-mm specimens was about 120 kg, and the effect of the veneer density was mainly revealed in the linear-elastic range with different slopes. Compared to the smooth veneer (small R_a), the rough veneer (large R_a) had larger displacement before the linear elastic range started.

For each of the 15 specimens, the displacement under the threshold load was derived from each load-displacement curve. Figure 5 shows that the correlation between the roughness parameters R_a and R_q and the displacement derived was very good with R^2 values of 0.87 and 0.85, respectively. This indicates that the displacement obtained under the threshold load is a good

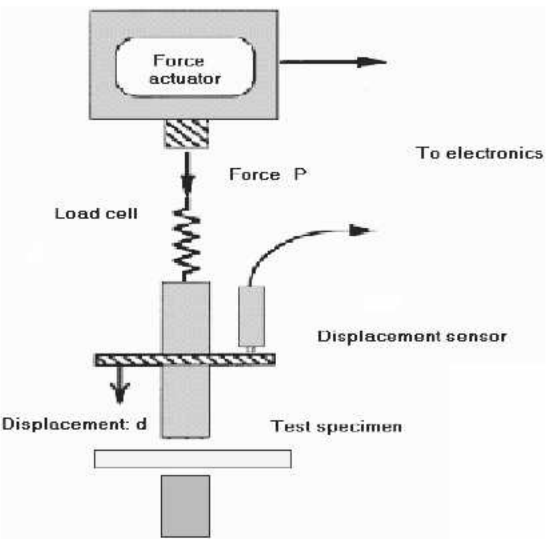

FIG. 3. Method for evaluating veneer surface roughness/quality and compressibility.

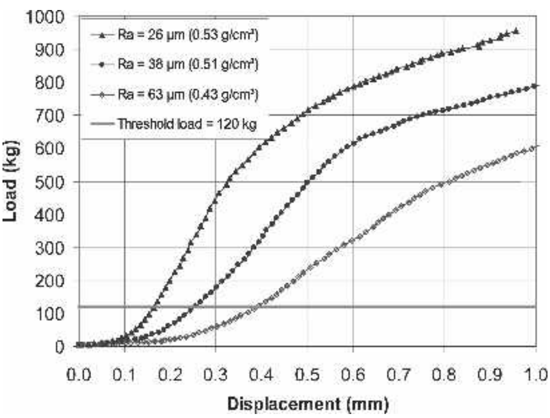

FIG. 4. Load-displacement curves for aspen veneer in terms of roughness and density.

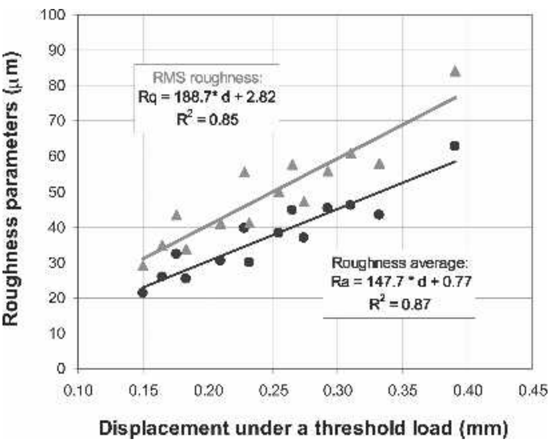

FIG. 5. The correlation between the two key roughness parameters and displacement under a threshold load.

indication of overall veneer surface roughness on an area averaging basis. Since the roughness measurement is taken with single compression, the method proposed is fast, reasonably accurate, and suitable for evaluating veneer surface roughness/quality. The variation unaccounted for the correlation is probably due to the two-dimensional nature of the stylus tracing measurement since the roughness parameters were derived from the single line measurement on each side of the veneer specimen. It is expected that the correlation could be further improved through multi-line measurements using the stylus profilometer.

The relationship between the contact area and the load applied

Veneer-to-veneer contact.—It was found that for glued aspen parallel veneer-ply samples (30 × 30 mm), the threshold load was about 105 kg, which was lower than 120 kg determined for unglued aspen veneer specimens (30 × 30 mm). This could be mainly due to the fact that the PF-coated specimens had a greater MC at the surface. The higher the MC, the lower the threshold load for determining the displacement to assess veneer surface roughness.

Figure 6 shows the three typical glue coverage maps indicative of the contact areas at the three different load levels for 30- × 30-mm aspen rough parallel veneer-ply samples. The higher the load applied, the larger the contact area. Figure 7 shows the relationship between the contact area and the load applied for the total 15 aspen parallel veneer-ply samples. The correlation between the contact area and the load applied followed a power or polynomial pattern, whereas the correlation between the non-contact area (100-contact area) and the load applied followed an exponential pattern. This result was in good agreement with that found from the paper-press contact during paper manufacturing (Provatas and Uesaka 2003). Under a small load from 20 to 40 kg, the difference in contact area between the smooth, medium rough, and rough veneer was relatively small. However, under a larger load, the smooth veneer seemed to have a larger contact area than the rough veneer. At a threshold load of about 105 kg, the contact area reached about 80%. Thus, about 80% of the effect of surface roughness or irregularities could be eliminated at the threshold load level.

a) 48% (40 kg) b) 78% (98 kg) c) 92% (210 kg)

FIG. 6. Measurement of the contact area in terms of the load applied for 30- × 30-mm aspen rough veneer.

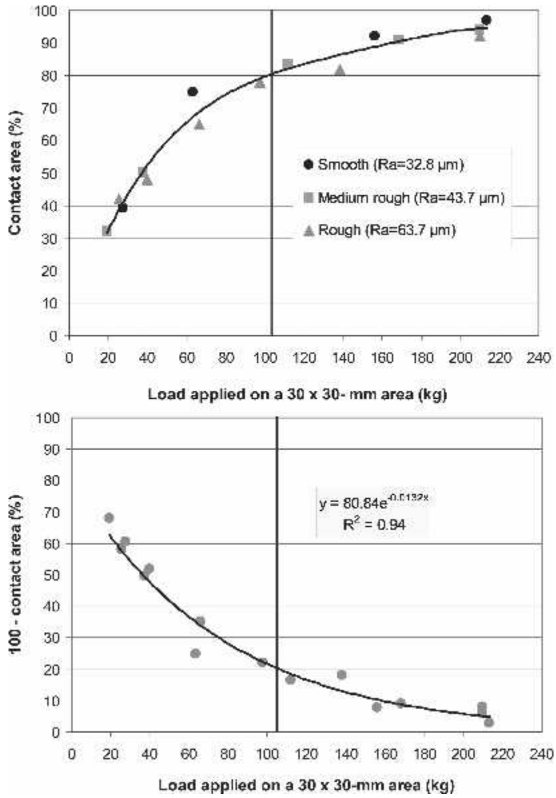

FIG. 7. The relationship between the contact area and the load applied for aspen parallel veneer-ply samples (upper: power or polynomial; bottom: exponential).

Veneer-to-plate contact.—As shown in Fig. 8, the correlation between the contact area and the

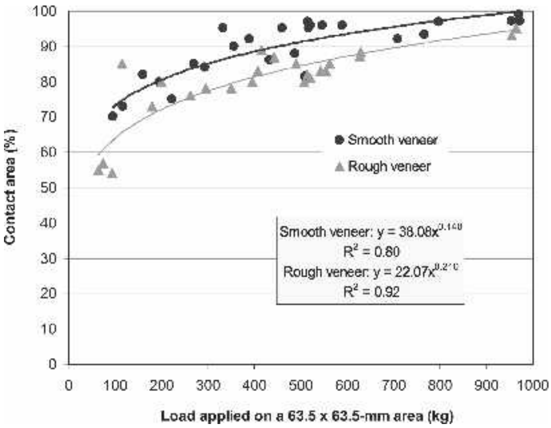

FIG. 8. The effect of veneer surface roughness on the contact area veneer-to-plate at different loads.

load applied was also good with a power pattern for both smooth and rough 63.5- × 63.5-mm veneer specimens. In general, at the same load, the smooth veneer had a higher contact area than the rough veneer. As shown in Fig. 9, the correlation between the contact area and the load applied was established for the combination of the smooth and rough veneer. For 63.5- × 63.5-mm veneer specimens, the contact area reached about 86% at a threshold load level of about 470 kg, which is equivalent in pressure to 105 kg established for 30- × 30-mm parallel veneer-ply samples. At their respective threshold loads, the contact area for the 63.5- × 63.5-mm veneer specimens was slightly higher than that for the 30- × 30-mm parallel-ply veneer samples. This is because the 63.5- × 63.5-mm veneer specimen was in contact with smooth surface of the plate. The plate can be conceived of as the veneer with a perfectly smooth surface. The results again demonstrate that for a given area, the threshold load determined from the load-displacement curves would eliminate the major effect of veneer surface roughness or irregularities to achieve a contact area equal to or greater than 80%. Since plywood products require a minimum 80% wood failure for quality assurance, it is believed that the displacement of wood veneer under the threshold load defines the minimum compression required to achieve adequate contact veneer-to-veneer or veneer-to-plate for bonding development. As a result, this minimum compression required not only reveals the roughness/quality and compressibility of wood veneer but also benchmarks the inherent material recovery when manufacturing into quality veneer panels.

Effect of temperature and MC on veneer compression behaviour

Figure 10 shows the load-displacement curves of the 30- × 30-mm, 2.5-mm-thick sliced aspen veneer specimens over a temperature range of

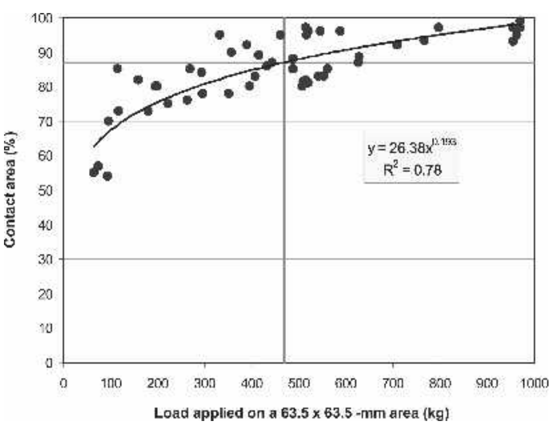

FIG. 9. The relationship between the contact area veneer-to-plate and the load applied for aspen veneer.

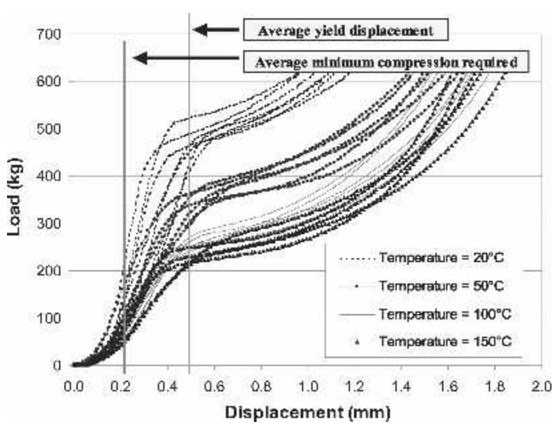

FIG. 10. The average minimum compression required and average yield displacement over a temperature range for 30- × 30- × 2.5-mm sliced aspen veneer.

TABLE 1. *Comparison of the minimum compression required (d_{min}) and yield displacement (d_{max}) at two temperatures for sliced aspen veneer.*

Comparison	d_{min} (T = 20°C)*	d_{min} (T = 150°C)**	d_{max} (T = 20°C)	d_{max} (T = 150°C)
Mean	0.230	0.217	0.494	0.490
Variance	0.0014	0.0008	0.015	0.020
Observations	10	10	10	10
Hypothesized mean difference	0		0	
df	9		9	
t Stat	1.31		0.06	
P (T ≤ t) one-tail	0.11	$t < t_{critical}$	0.48	$t < t_{critical}$
t critical one-tail	1.83		1.83	
P (T ≤ t) two-tail	0.22		0.96	
t critical two-tail	2.26		2.26	

Note: * d_{min} was derived at a threshold load of 120 kg.
** d_{min} was derived at a threshold load of 50 kg.

20° to 150°C. In general, the higher the temperature, the lower the threshold load required to achieve the minimum compression required. On average, it is this threshold load level, rather than the minimum compression required, that changes with the temperature of the veneer specimens. Table 1 summarizes the t-test results for comparison of temperatures of 20°C and 150°C. Note that the threshold load at 150°C was only about 50 kg as compared to about 120 kg at 20°C. Statistically, the results demonstrate that for this sliced aspen veneer, there was no significant difference in the minimum compression required and yield displacement between the two temperature levels ($p > 0.05$). Thus, it is believed that the minimum compression required and yield displacement are primarily dependent on veneer surface roughness and the cellular structure of the wood while the threshold load changes in relation to temperature and MC.

Figure 11 shows the effect of MC on the minimum compression required and yield displacement. The range between the minimum compression required and the yield displacement could be defined as the optimum range of veneer compression pertaining to plywood/LVL manufacturing. Overall, the temperature and MC mainly affected material compression MOE and the threshold load level required to achieve the required compression, but they did not affect the minimum compression required and the yield displacement for the range of MC and temperature tested. This phenomenon could also be explained by the modified Hooke's law as follows:

$$\sigma = \varphi(\varepsilon)\,\text{MOE}\,\varepsilon$$

where ε is the compression strain, σ is the applied stress (platen pressure), MOE is the veneer compression modulus of elasticity, which is the function of veneer density, MC and temperature, and $\varphi(\varepsilon)$ is the strain function. When veneer temperature and MC increase, the slope at the second stage (linear elastic) of the stress-strain curve becomes less steep, hence the compression MOE reduces. This will result in a reduced load or stress because the veneer is more easily compressed. However, in this case, the level of compression required to achieve adequate con-

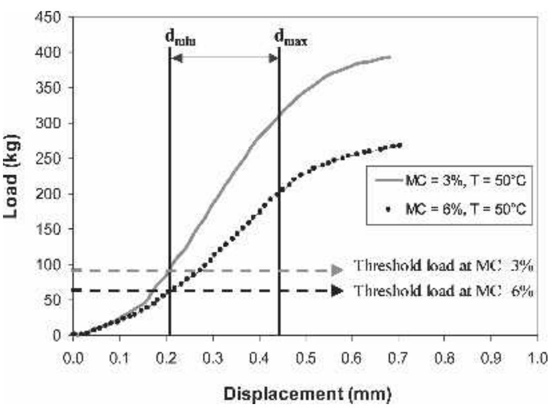

FIG. 11. The effect of MC on the minimum compression required (d_{min}) and yield displacement (d_{max}) of 30- × 30- × 2.5-mm sliced aspen veneer.

tact and cell-wall buckling or fracture would stay unchanged. The implication is that the minimum compression required of wood veneer can be measured at any combinations of temperature and MC as long as the threshold load is reexamined. Similarly, the yield displacement of wood veneer can be rigorously determined from the compression tests as long as the initial nonlinear stage for progressive contact is taken into account. In practice, it is more convenient to measure the minimum compression required (indication of surface roughness/quality) and yield displacement under the ambient temperature and oven-dry conditions.

Implications of initial roughness-induced progressive contact

The new method developed for evaluating veneer surface roughness/quality and compressibility has several implications on both theory and practice. In theory, the general wood compression theory needs to be modified. A load-displacement curve in compression for one 30- × 30-mm 3.2-mm-thick aspen veneer specimen is shown in Fig. 12. The revised wood transverse compression theory includes four stages instead of commonly defined three (Fukuyama and Takemura 1962; Wolcott et al. 1989; Ellis and Steiner 2002; Zhou and Dai 2005). The first stage may be referred to as "progressive contact" period, in which the contact area increases nonlinearly with the load applied. It is this stage that directly reveals the interfacial contact of veneer-to-veneer or veneer-to-plate and the minimum compression required for achieving adequate contact (equal to or greater than 80% of contact area). Furthermore, with the inclusion of the first stage, the yield displacement needs to be redefined.

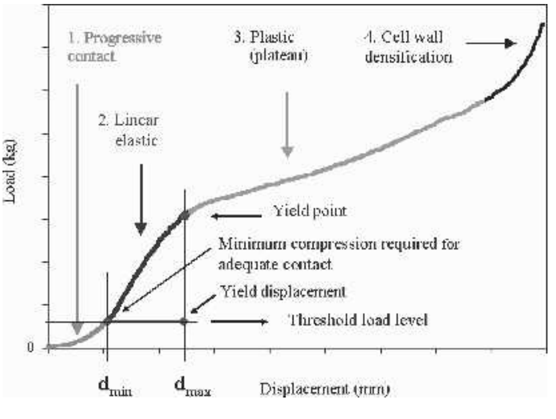

FIG. 12. Revised wood compression theory with four stages.

In practice, the method provides a fast and objective way of evaluating surface roughness/quality of wood veneer in terms of its compression behavior. For veneer-based wood composite products such as plywood and LVL, the implication is that the veneer is required to reach the critical compression level, namely the minimum compression required, to achieve the target 80% contact veneer-to-veneer for developing adequate bonding area while maximizing material recovery. In addition, in order to increase material recovery for manufacturing performance plywood/LVL products, there are constraints to avoid both veneer under-densification and over-densification. The optimum range of veneer compression seems to be between the minimum compression required and the yield displacement. Beyond the yield displacement, the cell walls of wood veneer start to buckle or fracture, which may result in reduced panel bonding strength and dimensional stability. Without inclusion of the initial stage of progressive contact, there would be no baseline to deal with the variation in wood surface roughness/quality. Since both the minimum compression required and yield displacement are independent of temperature and MC, the material recovery of wood veneer can be benchmarked with regard to its surface roughness/quality when manufacturing into quality plywood/LVL products.

SUMMARY AND CONCLUSIONS

A novel method was developed to characterize surface roughness/quality of wood veneer in terms of its compression behavior. Based on the concept of this method, the surface roughness/quality of wood veneer can be quickly assessed on an area basis. The method could also be applied to other wood composite elements such as wood strands.

Through extensive transverse compression tests under ambient and controlled temperature and MC environments for trembling aspen veneer, the relationship between contact area, veneer surface roughness, and the load applied was established. The critical importance of veneer surface roughness/quality on contact area was revealed as well. The results demonstrate that the general wood transverse compression theory needs to be revised to include four stages instead of the commonly defined three. The first stage, which has long been overlooked but is critically important, could be named "progressive contact." During this stage, the contact area increases nonlinearly with the load applied. It is this stage that directly reveals the interfacial contact of veneer-to-veneer during compression and the minimum compression required for achieving adequate contact. The results also indicate that the yield displacement needs to be redefined with the inclusion of the first stage. Furthermore, the results show that both the minimum compression required and yield displacement of wood veneer were independent of temperature and MC, which helps benchmark the material recovery of wood veneer with regard to veneer surface roughness/quality when manufacturing into quality plywood/LVL products.

ACKNOWLEDGMENTS

Forintek Canada Corp. would like to thank its industry members, Natural Resources Canada, and the Provinces of British Columbia, Alberta, Quebec, Nova Scotia, New Brunswick, Saskatchewan, and Newfoundland and Labrador, for their guidance and financial support for this research. The authors thank Mr. Francine Côté, Mr. Kevin Groves, and Mr. Peter Ens for their assistance in performing some of the tests.

REFERENCES

ASME Standard B46.1-2002. 2003. Surface texture (surface roughness, waviness, and lay). American Society of Mechanical Engineers, New York, NY. (Revision of ASME B46. 1–1995).

Bodig, J. 1965. The effect of anatomy as the initial stress-strain relationship in transverse compression. Forest Prod. J. 15(5):197–202.

Ellis, S., and P. Steiner. 2002. The behavior of five wood species in compression. IAWA Journal 23(2):201–211.

Faust, T. D. 1987. Real-time measurement of veneer surface roughness by image analysis. Forest Prod. J. 37(6): 34–40.

———, and J. T. Rice. 1986. Effects of veneer surface roughness on the bond quality of southern pine plywood. Forest Prod. J. 36(4):57–62.

———, and ———. 1987. Effects of a variable glue application rate strategy on bond quality and resin consumption in the manufacture of southern pine plywood. Forest Prod. J. 37(7/8):64–70.

Fujiwara, Y., Y. Fujii, and Y. Sawada. 2004. Assessment of wood surface roughness: Comparison of tactile roughness and three dimensional parameters derived using a robust Gaussian regression filter. J. Wood Sci. 50:35–40.

Fukuyama, M., and T. Takemura. 1962. The effect of temperature on compressive properties perpendicular to grain of wood. Journal of the J. Japan Wood Res. Soc. 8(4):170–176.

Mitutoyo. 2004. SJ-400—Surface Roughness Tester. User's Manual.

Neese, J. L., J. E. Reeb, and J. W. Funck. 2004. Relating traditional surface roughness measures to gluebond quality in plywood. Forest Prod. J. 54(1):67–73.

Provatas, N., and T. Uesaka. 2003. Modelling paper structure and paper-press interactions. J. Pulp Paper Sci. 29(10):332–340.

Sandak, J., and C. Tanaka. 2003. Evaluation of surface smoothness by laser displacement sensor I: effect of wood species. J. Wood Sci. 49:305–311.

———, ———, and T. Ohtani. 2004. Evaluation of surface smoothness by a laser displacement sensor II. Comparison of lateral effect photodiode and multielement array. J. Wood Sci. 50:22–27.

Wolcott, M. P., B. Kasal, F. A. Kamke, and D. A. Dillard. 1989. Testing small wood specimens in transverse compression. Wood Fiber Sci. 21(3):320–329.

Zhou, X., and C. Dai. 2005. Interaction of temperature and moisture content on flake compression. Proc. of the 7th Pacific Rim Bio-Based Composites Symposium. Volume II:116–125. Nanjing, P.R. China.