THEORETICAL MODELING OF BONDING CHARACTERISTICS AND PERFORMANCE OF WOOD COMPOSITES. PART III. BONDING STRENGTH BETWEEN TWO WOOD ELEMENTS

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(Received January 2007)

ABSTRACT

The bonding characteristics between two wood elements (strands) were investigated using experimental and modeling approaches. Based on the mechanism of surface contact and resin coverage, the model predicted the apparent bond strength as a function of compaction ratio, resin content, and transverse tensile strength of wood. Experimental tests were conducted to determine the resin coverage and apparent bond strength of two overlapped aspen (*Populus tremuloides*) strands under uniform and random resin distributions. The model was validated by close agreement between the predictions and the experimental results. The results showed that the optimum compaction ratio should be between 1.25 and 1.30 for the maximum contact and apparent bond strength. Further densification would induce damage to wood and inhibit final bonding performance. The apparent bond strength was proved to be related to resin content through the direct impact of resin area coverage. The results also suggested that one could save resin consumption by reducing spot thickness and increasing spot number or coverage.

Keywords: Wood composites, modeling, bonding strength, wood strands, compaction ratio, resin distribution.

INTRODUCTION

Bonding strength in wood composites is developed through hot-pressing, during which wood elements intimately contact each other and are bonded together with wood resins. An appropriate pressure, which is critical to form intimate contact between the wood elements, generally makes the wood elements 50 to 80% denser in wood composites due to the porous nature of wood. It has been shown that panel density, which is proportional to the degree of wood densification, has significant influence on the bonding strength (Humphrey 1991; Schulte and Fruhwald 1996; Jin and Dai 2004). High bonding strength usually demands high panel density, but high density also means high cost and other undesirable properties of panels, such as low dimensional stability. An optimum strategy is needed to minimize the panel density while maintaining good bonding properties in the manufacturing of wood composites.

Resin application is another issue that is closely related to the bonding strength. The con-

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tacted wood elements do not form any measurable bond without coated resin coverage on the surface. Resin type, content, distribution, and curing are generally identified as the main variables that affect the bonding properties (Meinecke and Klauditz 1962; Lehmann 1970; Hill and Wilson 1978; Youngquist et al 1987; Kamke et al 1996). It is clear, for example, a uniform distribution of small resin spots produces the best properties for a given resin content, and of course the bonding strength increases with resin content. However, it is not clear how to achieve more uniform resin distribution in practice, and the option of increasing resin content is easier but always costly. Understanding the relationship between parameters of resin application and bonding properties is needed for optimizing the processing of resin coating.

In the preceding papers of this series, an analytical model and a computer simulation model have been first developed to predict the contact between constituent elements as a function of mat densification, wood density, and element dimensions (Dai et al 2007a). Also an analytical model and a computer simulation model have been developed to predict the random resin distribution as a function of wood density, element dimensions, and resin characteristics (Dai et al 2007b). The main objective of this study was to develop an analytical model to characterize the bonding strength between two strands associated with wood densification and resin coverage. Experimental investigations were conducted to determine the bonding strength of aspen (*Populus tremuloides*) strands and its correlations with the transverse tensile strength of aspen strands, resin distribution, and wood densification. The model was validated by comparing the model-predicted results with the experimental results. Finally, typical predicted effects of resin content and wood densification on the bonding strength were presented and discussed.

ANALYTICAL MODELING

Concepts and assumptions

Two resinated strands are overlapped and bonded under the combination of pressure, temperature, and time. The applied pressure allows intimate contact to be formed between the wood strands, while the temperature is needed to accelerate resin curing and to soften wood. The wood strands are usually densified as a by-product of hot-pressing. The bond performance of wood composites is commonly evaluated by internal bond (IB) strength, namely, the tensile strength perpendicular to strand surfaces. While other factors such as resin wetting (Hse 1972), resin curing (Humphrey and Ren 1989), and wood surface properties (Marian 1962) can affect bonding, the model here will capture only two basic mechanisms: resin distribution and surface contact. From the viewpoint of analytical modeling, resin distribution and interface contact are probably the most essential variables that need to be first considered. The establishment of such a model can then open a door to the integration of other variables such as resin wetting and curing. Specifically the model will be based on the following three general assumptions:

1. Resin is perfectly cured after resinated strand areas reach their intimate contact positions. This means that bonding strength depends only upon resin coverage and wood contact, and is independent of such factors as curing process and wood surface contamination.
2. The tensile strength of cured resin polymer is significantly greater than that of wood in perpendicular-to-grain loading. The localized bond failures always occur in the wood substrates rather than in the resin/wood interface, or the bulk of resin (Marra 1983).
3. Wood has a deterministic strength, which means that bonding strength is reached if the localized stresses reach the allowable transverse tensile strength of wood.

General relationship between apparent bond strength and resin bonding strength

As shown in Fig.1, similar to the internal bond strength of composite panel, the apparent bond strength $[\sigma]_{AB}$ between two discretely bonded wood strands is defined as:

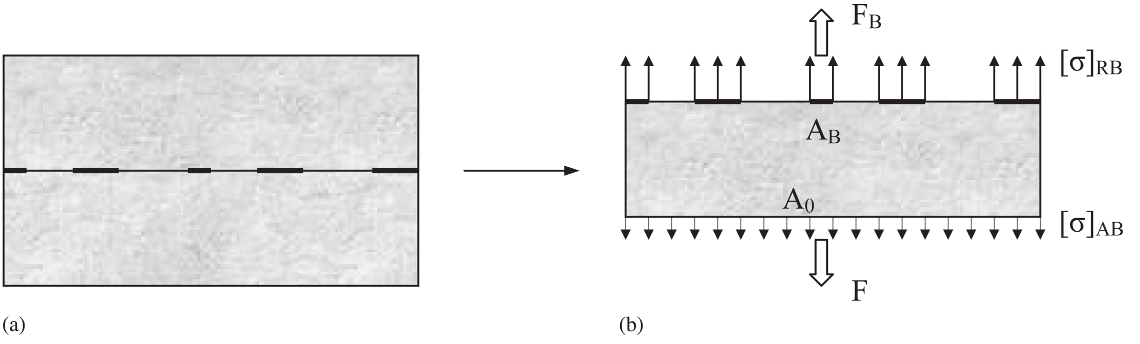

FIG. 1. Illustration of bond interface between two strands discretely bonded with a wood resin (thick dot lines in the interface represent resin spots).

$$[\sigma]_{AB} = \frac{F}{A_0}, \quad (1)$$

where F is the maximum allowable force applied on the strand surfaces to break the bond, and A_0 is the surface area of a strand given by the product of strand length and width.

Following the law of equilibrium, the external force F equals the bond force F_B, which is the resin bond strength $[\sigma]_{RB}$ multiplied by the resin bonded area A_B, or:

$$F = A_B[\sigma]_{RB}. \quad (2)$$

The bonded area is governed by the strand surface contact area and the resin area coverage, or:

$$A_B = R_{a2}A_C, \quad (3)$$

where A_C is the contact area between two strands and R_{a2} is the resin area coverage between two overlapping strands. Combining Eqs. (3), (2), and (1), we establish a general relationship between the apparent bond strength of the two overlapping strands and resin bond strength, relative contact area, and resin area coverage:

$$[\sigma]_{AB} = \beta R_{a2}[\sigma]_{RB}, \quad (4)$$

where $\beta = A_C/A_0$, is the relative contact area. Equation (4) clearly reveals that the apparent bond strength is proportional to resin bond strength, relative contact area, and resin area coverage.

Relative contact area β

Despite its more or less flat appearance, a machined wood strand surface is very rough at the scale of bonding. The roughness, which can be caused by the machining process and the inherent anatomic characteristics, prevents potential bond sites from intimate contact without pressure. Even under pressure, the contact area is only 0.1% of the surface area for hard materials such as metal (Greenwood and Tripp 1970–1971). For soft materials such as wood, compression can lead to greater localized deformations between the contacting surfaces, and hence enlarge the contact area. The compaction ratio C_r of a wood strand is defined by

$$C_r = \frac{\tau_0}{\tau}, \quad (5)$$

where τ_0 is the initial thickness of the strand, and τ is the thickness of the strand after pressing.

Assume the increment rate of contact area with the strand compression ($dA_C/d(\tau_0 - \tau)$) is proportional to the non-contact area ($A_0 - A_C$), or:

$$\frac{dA_C}{d(\tau_0 - \tau)} = c_0(A_0 - A_C), \quad (6)$$

where c_0 is a coefficient, which is governed by the surface roughness. The value of c_0 and thus the rate of contact development should decrease with increase of surface roughness.

Also assume that there is no contact between the strands before pressing, or: $A_C = 0$, when

$\tau = \tau_0$. Rewriting and integrating Eq. (6), we can obtain the following analytical solution for strand relative contact area β (or: A_C/A_0) as a function of the strand compaction ratio C_r (or: τ_0/τ):

$$\beta = 1 - e^{c_s\left(\frac{1}{C_r}-1\right)}, \quad (7)$$

where c_s is a modification of c_0, or $c_0\tau_0$, which is again related to the surface characteristics of wood strands including cellular structure and surface roughness.

Resin area coverage R_{a2}

Both uniform and random resin distributions need to be modeled here to define the resin coverage for the printed strands (Smith 2003) and the blended strands. For the random distribution, the resin area coverage R_a^r was defined in the previous paper (Dai et al 2007b):

$$R_a^r = 1 - \exp\left(-\frac{\varphi\tau_0\rho_s R_c}{2(1+MC)\tau_r\rho_r R_{solids}}\right), \quad (8)$$

where τ_0, τ_r were the thickness of strand and resin spot, respectively, ρ_s, ρ_r were the density of wood strands and resin mix, respectively, MC was the moisture content of wood strands based on oven-dry weight, R_c was the resin content based on oven-dry weight, and R_{solids} was the resin solids content.

It is worth noting that an enlargement factor φ is introduced in Eq.(8). During this study, we found that resin spots and hence area coverage significantly increased after hot-pressing, while the increase in resin area coverage may be generally caused by resin flow. Further studies are being conducted to examine the enlargement factor as a function of pressing pressure, temperature, and time. The results will be published in a separate paper.

In the case of printed strands, resin spots are uniformly distributed on strand surface without overlapping. The relationship can be obtained simply by converting the total resin mass into the area coverage R_a^u, or:

$$R_a^u = \frac{\varphi\tau_0\rho_s R_c}{2\tau_r\rho_r(1+MC)R_{solids}}. \quad (9)$$

Equations (8) and (9) describe the resin area coverage on one strand surface. For either the random distribution or the uniform distribution, the total interfacial resin coverage between two contacting strands should always be greater than the resin coverage of one strand. Assuming independent resin distributions, the total coverage should follow the role of probability addition. The general equation for calculating the total interfacial resin coverage R_{a2} in a pressed two-strand assembly is then given by:

$$R_{a2} = 2R_a - R_a^2. \quad (10)$$

Resin bonding strength $[\sigma]_{RB}$

According to the literature (e.g. Marra 1983), an adhesive-wood bond can be generally modeled as a chain of five rings. Each ring sequentially represents the bulk wood 1, the adhesive-wood interface 1, the bulk adhesive, the adhesive-wood interface 2, and the bulk wood 2. The bonding strength is therefore controlled by the weakest of the five components. For simplicity, it is assumed that the bond fails either in adhesive or wood. The preliminary test results have shown that the bonds mostly failed in the weak wood surface. This finding is consistent with the literature, which has reported that wood is weakened near the surfaces due to machining (Stehr and Johansson 2000). Furthermore, the compression should cause more damage to wood surfaces than bulk wood because of stress concentration around the contacting surfaces. The damage seems to increase with compression. It is therefore further assumed that the resin bonding strength is controlled by the transverse tensile strength of wood (more precisely, the strength of the weakened strand surfaces). The resin bonding strength/wood strength $[\sigma]_{RB}$ is related to the compaction ratio C_r through the following equation:

$$[\sigma]_{RB} = C_r^a[\sigma]_w, \quad (11)$$

where $[\sigma]_w$ is the wood tensile strength before pressing, and α is the exponential factor related to wood characteristics of compression.

EXPERIMENTAL

Raw materials

Aspen (*Populus tremuloides*) used in this study was made from sliced veneers with 0.81-mm thickness and 6% moisture content based on oven-dry weight. The veneers were cut into 25.4-mm-wide strips with the grain direction parallel to the long edge of the strips. A liquid phenolic resin (Cascophen LP02, Hexion Specialty Chemicals) with a solids content of 55% was used as a wood adhesive.

Strands under perpendicular-to-grain loading

Aspen strips were cut into 25.4-mm by 25.4-mm square strands. Two wood strands were overlapped together without resin and hot-pressed using a mini press. The pressing temperature was set at 200°C and pressing time was 60s under various compaction ratios. The thickness of each pressed strand was measured. The strand was glued to aluminum blocks from both surfaces with a hot-melt adhesive. The tensile strengths perpendicular-to-grain of 100 strands were then tested using an Instron material testing machine. The loading speed for this test was set at 0.5 mm/min.

Resin application using a printing system

Aspen strips were coated with resin droplet arrays using a modified flexographic printing technique (Smith 2003). The flexographic printing process is commonly used to produce newspaper and other printed materials. In this application, a liquid resin was applied to a patterned elastomeric material, called printing-plate. Then wood strands were hand-pressed against the printing-plate, and the resin wetted and transferred to the strands. The surface of the printing-plate is composed of a multitude of raised dots, whose diameter and local density determine the printed image. With this technique, the resin was uniformly coated on the wood surface as spot arrays. The resin coverage and spot size depend on both the diameter and local density of the dots.

Resin application using a regular blender

Aspen strips were cut into 25.4-mm by 76.2-mm rectangular strands. A total of 300 rectangular strands were mixed with 10 kg air-dried and screened commercial aspen strands. The mixed strands were blended with various levels of phenolic resin. The blender and the atomizer were run at 22.2 rpm and 16000 rpm, respectively. The strands were blended on the same batch sequentially with different resin contents. After each stage of adding phenolic resin, some resinated rectangular strands were retrieved from the blender at a given target resin content.

Sample assembly and test

The resin-coated aspen strands using the printing system or the regular blending system were further cut into 25.4-mm by 25.4-mm square strands. Two strands were overlapped to form an assembly and then pressed with a mini press. The pressing temperature was set at 200°C and pressing time was 60s. Preliminary tests showed that the glueline temperature reached 200°C around 5 to 10s. The final thickness for the assembly was controlled with a thickness stop. The tests were repeated to produce bonded assemblies with treatments of various compaction ratios and resin contents. Each treatment was tested with 10 replicates.

The apparent bond strength of strands was tested with the method for internal bond strength test according to ASTM D1037 using an Instron material testing machine. The loading speed for this test was set at 0.5 mm/min.

Resin area coverage measurement

Twenty resinated square strands were selected and heated on wire racks in an oven at 175°C for 20 min for resin area coverage measurement using the GluScan image analyzer (Groves 1998 and 2000; Dai et al. 2007b). After calibrating the camera system, five images were taken from the resin-coated surface. All images were analyzed for individual and average resin area coverage.

TABLE 1. *Initial parameters applied in the model.*

Wood strand		PF resin	
Thickness (mm)	0.81	Density (kg/m^3)	1200
Density (kg/m^3)	400	Solids content (%)	55
MC (%)	6	Spot thickness* (random) (mm)	0.030
$[\sigma]_w$ (MPa)	3.0	Spot thickness* (uniform) (mm)	0.015
α	−0.28	c_S	10.0

* Spot thickness was estimated from fitting data to the model.

Measurement of resin area coverage change due to hot-pressing

The coated aspen strips using the printing system were cut into 25.4-mm by 25.4-mm square strands. The strands were divided into two groups, each of which included 10 strands. One group was directly subjected to resin area coverage measurement, while another group was subjected to hot-pressing, and then to resin area coverage measurement. The resin area coverage change was obtained by comparing the resin area coverage before and after hot-pressing. For hot-pressing, two coated wood strands were overlapped together, but isolated with a Teflon film and pressed using the mini press. This isolation prevented the two pressed strands from bonding. As the resin spots were impregnated only by one strand due to the use of Teflon film, the resin area coverage after hot-pressing was probably overestimated. The hot-pressing conditions were the same as those applied for the bonded samples.

RESULTS AND DISCUSSION

Model validations and implications

Input parameters.—Table 1 lists the input parameters applied in the model. These parameters were obtained through experimental measurements. The resin spot thickness was evaluated from Eq. (8) for randomly coated (blended) strands or Eq. (9) for uniformly coated (printed) strands. The resin area coverages at various resin contents were experimentally measured and fitted into the equations by which the resin spot thickness could then be estimated. While efforts were made to control the materials and testing conditions, variations were observed both with wood and resin. The resin spot thickness for the blended strands was noticeably greater than that for the printed strands. This is because the resin spots were hand-pressed during the resin printing on the strand surface.

Effect of hot pressing on transverse tensile strength of wood strands.—The tensile strength under perpendicular-to-grain loading was measured for the control and hot-pressed strands. The measured results were compared with the predictions as shown in Fig. 2. The tensile strength of aspen strands showed large variability, and a decreasing trend with compaction ratio. It was also noted that failures occurred in or near the strand surface, indicating that the transverse tensile strength was governed by the strength of weakened surface. Increased compression probably led to further damage in the surface, particularly those areas around the peaks. Interestingly, the strength seemed to drop faster at the early stage of compression (1.0 to 1.25 C_r) and level off towards the higher compression. The speculation is also that the loss might vary with pressing conditions—particularly temperature, moisture content, and time. Further work is needed to quantify these rela-

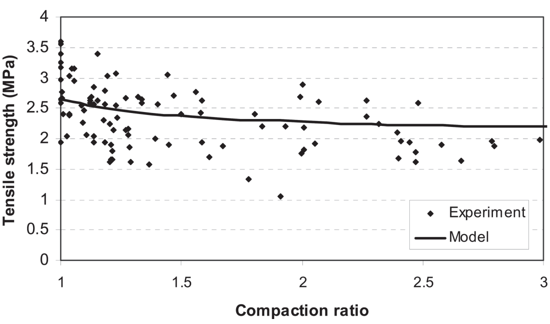

FIG. 2. Variation of wood tensile strength perpendicular-to-grain with compaction ratio.

tionships. Here, our main goal was to quantify the relationship between transverse strength and compaction ratio under a specific testing condition for the purpose of bond modeling. To this end, Eq. (11) seemed to fit the experimental data very well (Fig. 2). The tensile strength of this group of aspen strands was generally lower than 3 MPa, which should be the upper bound of the apparent bond strength of bonded assemblies according to our model.

Model validation for uniformly coated strands.—Figure 3 shows comparison of the modeling and experimental results on the variation of apparent bond strength with compaction ratio at the resin content of 1.95%. The experimental data generally agreed well with the model predictions. The apparent bond strength increased quickly with compaction ratio at the beginning. It reached the maximum around at the compaction ratio of 1.25. Further compression of wood did not significantly affect the apparent bond strength. Instead, it resulted in a slight decrease in apparent bond strength due to the wood strength loss at high compression. It was noted that a small delay of the predicted apparent bond strength occurred at the beginning of hot-pressing (compaction ratio from 1 to 1.05). This was probably attributed to the delay of the relative contact area with compaction ratio, which will be discussed later in this paper.

The variation of apparent bond strength with compaction ratio at the resin content of 1.17% (Fig. 4) gave the same trend as that at the resin content of 1.95% (Fig.3). The predicted result also showed good agreement with the experimental data. The maximum value of apparent bond strength was located in the same compaction ratio range (around 1.30). The difference was that the apparent bond strength at the same compaction ratio decreased as the resin content was decreased from 1.95% to 1.17%.

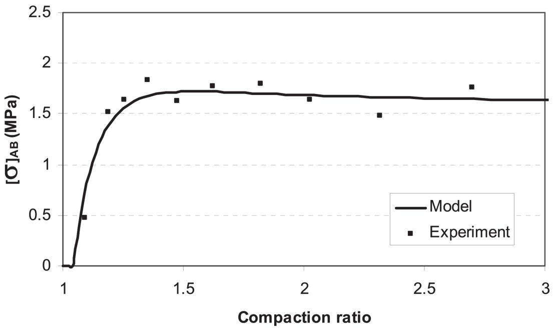

FIG. 4. Apparent bond strength varying with compaction ratio at the resin content of 1.17%.

The effect of resin content on apparent bond strength is shown in Fig. 5. Again the model predictions agreed well with the experimental data. Note that the relationship between the apparent bond strength and the resin content was not linear. Particularly, the apparent bond strength increased more quickly with resin content at low resin contents than at high resin contents. This was because high resin contents caused resin spots to overlap, which then slowed down the build-up of resin area coverage. It was the resin area coverage, not the resin content that had a more direct effect on, or a linear relationship with, the apparent bond strength.

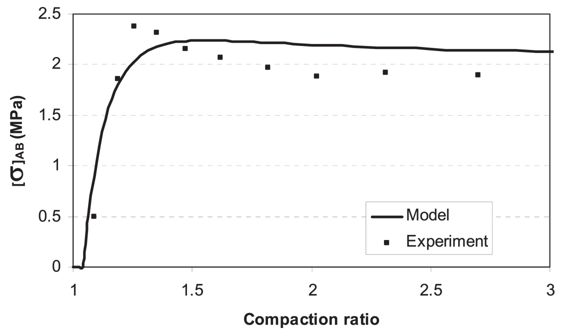

FIG. 3. Apparent bond strength varying with compaction ratio at the resin content of 1.95%.

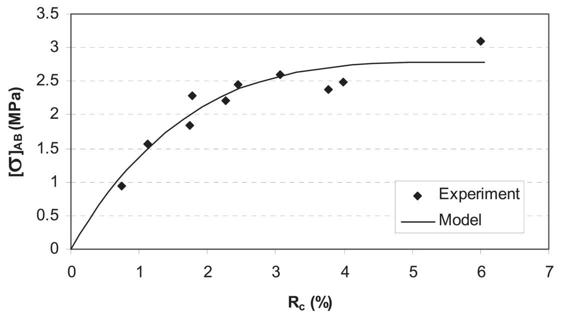

FIG. 5. Variation of apparent bond strength with resin content (compaction ratio: 1.35).

The variation of resin area coverage with resin content for the printed strands is shown in Fig. 6a. With the uniform resin distribution, the resin area coverage was linearly correlated with the resin content after the printing processing, regardless of resin content. The hot-pressing process, however, caused resin to flow within the plane of the strand surface, and hence enlarged the resin area coverage. The lateral resin flow was in fact so significant that it caused resin spots to overlap and altered the linear relationship to nonlinear one (Fig. 6b). The lateral resin flow behavior is believed to be affected by many factors including pressing pressure, temperature, species, and resin type. Further investigation on these parameters is underway, and the results will be published in a separate paper.

Comparing bonding performance between uniformly coated strands and randomly coated strands.—Figure 7a shows the apparent bond strength varying with resin content. At a given resin content, the apparent bond strength of uniformly coated strands was higher compared to randomly coated strands by the regular blending system. The resin printing system used in this study is capable of uniformly coating thin resin spot arrays on wood surface without overlap and hence obtaining a high resin area coverage with a low resin content. Blending systems commonly used in industry randomly spray resin spots on wood surface with a certain degree of overlap, resulting in lower resin area coverage. Figure 7b depicts the apparent bond strength against resin area coverage. It was clear that there was little or no difference in bonding performance between the two resin distributions. This result confirmed that the bonding performance was directly controlled by the resin area coverage instead of the resin content. The thickness of the resin spots seemed to have little or no effect on the bonding strength, given by the fact that the printed resin spots were much thinner than the blended resin spots.

Figure 8 shows the resin area coverage versus the resin content for both the uniform resin dis-

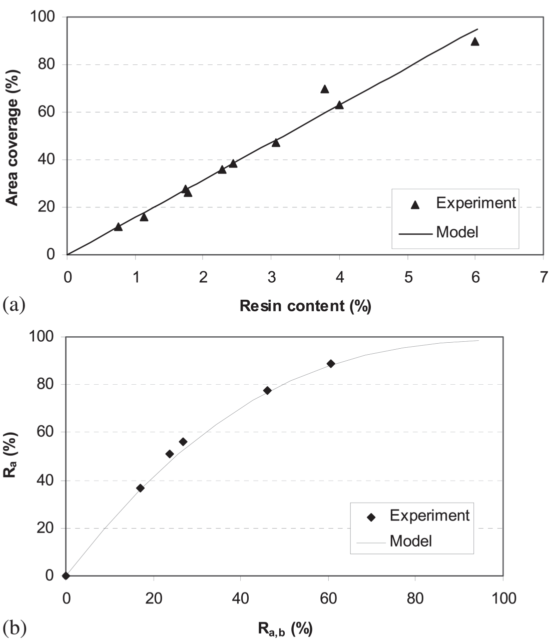

FIG. 6a. Relationship between resin area coverage and resin content for the uniformly coated strands. FIG. 6b. Changes of resin area coverage due to resin flow during hot-pressing ($R_{a,b}$ and R_a represent resin area coverage before and after hot-pressing, respectively).

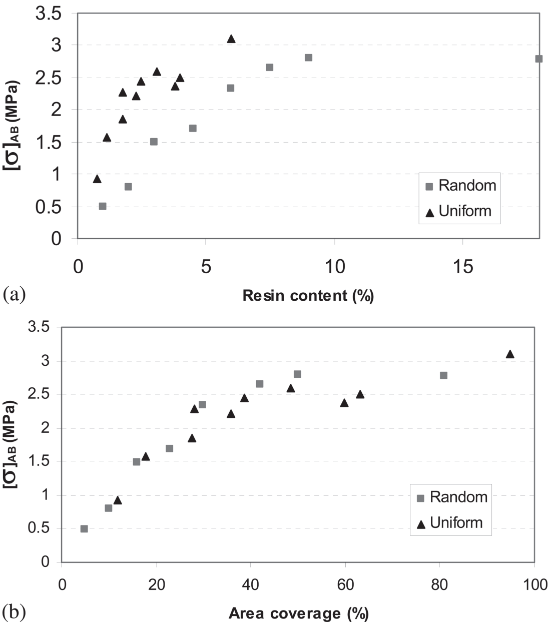

FIG. 7a. Comparison of apparent bond strength varying with resin content between the uniform and random resin distributions. FIG. 7b. Comparison of apparent bond strength varying with resin area coverage between the uniform and random resin distributions.

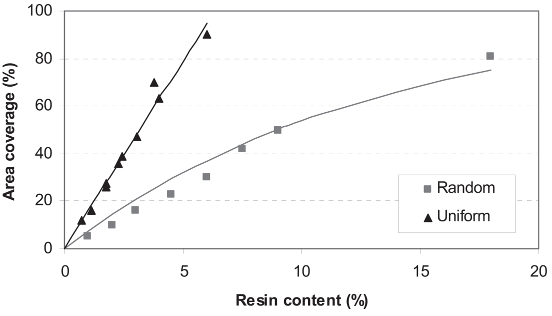

FIG. 8. Comparison of resin area coverage varying with resin content between the uniform and random resin distributions (dots represent experimental data, and lines represent modeling results).

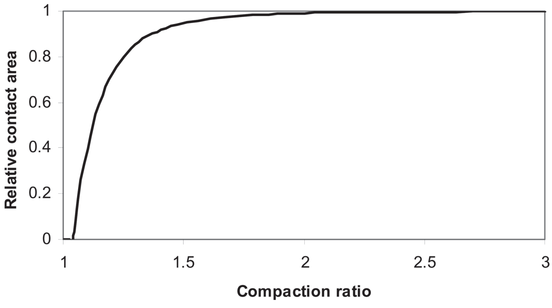

FIG. 9. Predicted effects of compaction ratio on relative contact area.

tribution (the printing system) and the random resin distribution (the blending system). The experimental results seemed to closely follow the model predictions by Eq. (8) for the random distribution and by Eq. (9) for the uniform distribution. The former followed an exponential relationship while the latter followed a linear one. Another difference was that at any given resin content, the printing system produced significantly higher resin area coverage primarily due to thinner resin spots and secondly due to more uniform distribution. This result suggested that one could maximize resin area coverage and hence bonding performance by manipulating resin spot thickness and/or resin distribution.

Typical predicted results

A series of results related to bonding performance between wood strands can be predicted by the model. These modeling predictions are helpful to understand the bonding process and characteristics of wood composites.

Relative contact area (β).—Figure 9 shows the predicted effects of compaction ratio on the relative contact area. Generally speaking, the relative contact area exponentially increased with compaction ratio after a slight delay at the beginning of pressing. This delay was attributed to the effect of surface roughness of wood strands similar to that of veneer (Wang et al 2006). If the surface roughness was best characterized by a random variation of peaks and valleys, neither the peaks nor the valleys should represent any significant portion of the surface area. At the onset of pressing, the contact area was only attained from the peaks. The contact area therefore did not significantly increase until the peaks were eliminated or deformed. It also revealed that the relative contact area β reached a critical level of 80% at the compaction of 1.25. Further compression led to a substantially less increase of the relative contact area.

Resin area coverage (R_a) for random distribution.—The relationship between resin area coverage and resin content is shown in Fig. 10. An exponential relationship between resin area coverage $R_{a,b}$ (before pressing) and resin content R_c was observed for one strand. The total area coverage $R_{a2,b}$ for two overlapped strands was greater than that on one strand, but less than twice because of the occurrences of resin spot overlapping, particularly at high resin contents. After hot-pressing, the resin spots were spread,

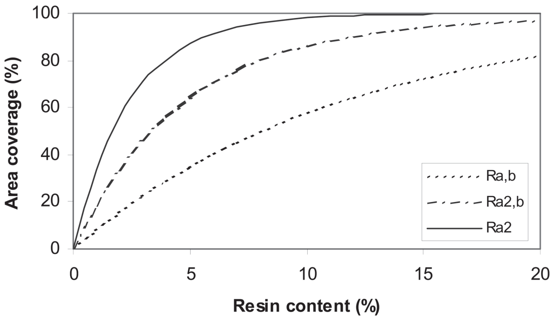

FIG. 10. Prediction of relationship between resin area coverage and resin content for the random resin distribution.

which enhanced the resin area coverage. The enhancement of area coverage appeared to be greater at lower resin contents than at high resin contents due to the phenomenon of spot overlapping. It is worth noting that the total resin area coverage R_{a2} after hot-pressing reached 70% and 87% at the resin contents of 3% and 5% respectively. Further increase in resin content only led to a slight increase in the total resin area coverage.

Relative bonded area (A_B/A_0) for the random distribution.—Figure 11 illustrates the advancement of A_B/A_0 with compaction ratio at various resin contents. The relative bond area increased significantly with compaction ratio at low compaction ratios, and reached 80% of the maximum value at the compaction ratio of 1.25 for a given resin content. In addition, the maximum relative bond area increased with resin content, but slowed down at high resin contents. The maximum relative bond area reached 0.7 and 0.87 as the resin content reached 3% and 5% respectively. Further increase in resin content only gave insignificant effects on the relative bond area.

Bonding strength ($[\sigma]_{AB}$) for the random distribution.—The effect of compaction ratio on the apparent bond strength at various resin contents is shown in Fig. 12. A close relationship between the apparent bond strength and the relative bond area was observed (Figs. 11 and 12) except that the apparent bond strength leveled off, and even slightly decreased with compaction ratio after it reached the maximum value. The decrease in apparent bond strength was induced by the decrease in wood strength due to strand compression. Further increase in compaction ratio after it reached 1.25 to 1.30 would not increase the bond area significantly but weaken wood strength, resulting in the decrease of apparent bond strength. Note that the value of wood strength applied to predict the apparent bond strength was increased around 10% from the wood strength shown in Fig. 2. This was to compensate for the enforcement effect due to resin penetration.

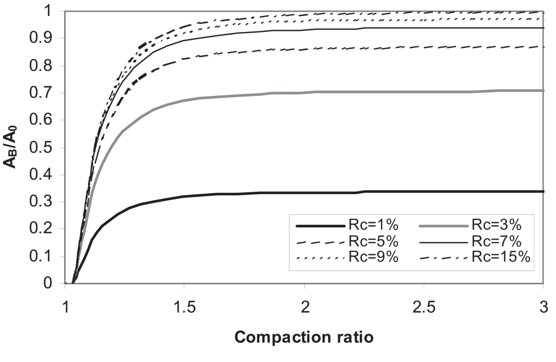

FIG. 11. Predicted effects of compaction ratio on relative bond area at various resin contents for the random resin distribution.

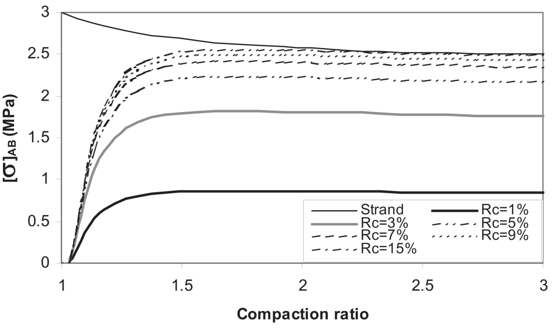

FIG. 12. Predicted effects of compaction ratio on apparent bond strength at various resin contents for the random resin distribution.

SUMMARY AND CONCLUSIONS

The bonding characteristics between two wood (aspen) strands were investigated using experimental and modeling approaches. Based on the mechanism of surface contact and resin coverage, the model predicted the apparent bond strength as a function of compaction ratio, resin content, and transverse tensile strength of wood. Experimental tests using a printing technique and a regular blender were conducted to determine the resin coverage and the bonding strength of two overlapped aspen strands under uniform and random resin distributions. The strand assemblies were also pressed using a mini press to determine the effect of compaction ratio on the bonding strength development. The main conclusions are the following:

1. The model predictions agreed well with the experimental results for both the uniform resin distribution and the random resin distribution. The apparent bond strength between wood strands was governed, in a complex and nonlinear manner, by compaction ratio, resin content, resin distribution, and transverse tensile strength of wood.
2. The compaction ratio of aspen strands should be between 1.25 and 1.30 to yield optimum bonding performance. Such a compaction ratio meant maximum surface-to-surface contact and minimum damage to wood.
3. The apparent bond strength was affected by resin content through the direct effect of resin area coverage. Within the range of this study, resin spot thickness did not seem to be a factor, suggesting that one could save resin usage by reducing spot thickness and increasing spot number or coverage.
4. Hot-pressing appeared to induce significant resin spread, enlarging the size of resin spots and hence the final resin coverage for bonding.
5. The transverse tensile strength of wood (strand) set the upper bound for the maximum bonding strength. High compression seemed to damage the wood cells and slightly weaken the wood strength.

ACKNOWLEDGMENTS

Forintek Canada Corp. would like to thank its industry members, Natural Resources Canada (Canadian Forest Service), British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Quebec, Nova Scotia, New Brunswick, Newfoundland and Labrador, and the Yukon Territory, for their guidance and financial support for this research. Financial support from NSERC through an industrial research fellowship is also gratefully acknowledged.

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