UNIVERSITY OF BC
WOOD SCIENCE DEPARTMENT

Development of Thick MPB Strand Based Wood Composites

Year 2 Report

by

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EXECUTIVE SUMMARY

This three year study aims at generating fundamental knowledge needed to develop new MPB strand based thick wood composites. Year 2 of this project used modeling and experimental approaches to examine

1) the fundamental properties of adhesive-wood fibre interaction,
2) the in-plane permeability and gas flow in thick strand composites,
3) modeling of the pressing process and influence of pressing on the gas permeability, and
4) creep and load duration response of thick MPB strand based wood products.

For the adhesive interaction, a small humidity chamber unit for the UBC DMA equipment has been assembled and successfully tested to measure the interaction between the MPB fibre and the adhesive.

A permeability test jig was built during Year 2 to allow measurement of in-plane permeability of gas flow of formed mat under out-of-plane pressure. Preliminary tests to debug the apparatus have been initiated.

Production of prototype thick MPB strand composites was initiated during Year 2. The UBC three-dimensional hot pressing-consolidation model was calibrated against test results measured from the processing of the thick boards. Image scanning of the thick strand based composite products was undertaken to analyze the strands' orientation. Tests to determine the stiffness and internal bond of the boards were also performed.

PROJECT RATIONALE

A large volume of MPB wood can be utilized in oriented strand board products. Timber licenses for MPB OSB production have been tendered and one new facility for MPB OSB production is proposed to be established. The plant is expected to consume approximately one million m^3/year of MPB fibre. In the market place for OSB, the all time high pricing of OSB has passed and a soft North American housing market is anticipated for the next few years. This fact, coupled with the new increased production capacity of OSB coming on stream, makes it critical that mills consider new alternative value-added product lines that have the attributes to expand their use into low-rise commercial and multi-family residential markets to reduce the impact of cyclical decline of the residential market on their operation. The solution may be to develop new value-added strand based structural products from this resource.

This type of product is ideal to complement the conventional oriented strand board (OSB) product because

1) the production technology of making conventional OSB can be expanded to make the thicker product;

2) the availability of additional product line can create marketing flexibility and can reduce risk associated with producing only panel type product, and

3) the price structure of engineered wood products tends to be more stable than commodity OSB.

Patented technology for producing thick strand based wood products was created in Canada, by MacMillan Bloedel, to produce commercial structural composite lumber products such as Parallam and Timberstrand. New technologies are currently being developed in Europe to produce thick panels in OSB mills. As the chemical structure of lodgepole pine wood is altered by the MPB attack, new knowledge must be developed to allow fuller understanding of the pressing and adhesion properties of MPB wood and its influence on one of the most important properties of structural wood composites, namely creep and load duration.

PROJECT FINDINGS AND ACHIEVEMENTS FOR YEAR 2

Modeling of thick strand-based composites

During the second year of this project, the major focus was experimental. Typical MPB logs used for OSB were obtained from Ainsworth Lumber (Fig. 1) MPB wood strands were cut from MPB logs from the Prince George area supplied by Ainsworth.

Fig. 1 Typical MPB log used for the study

MPB strands were manufactured at Carmanah Technologies facilities using a disc strander (Fig. 2). The strands were manufactured to the following target size: 175 mm (7”) length, 25mm (1”) width and 1mm (0.04”) thickness.

Fig. 2 MPB log stranded using Carmanah's disc strander

Based on oven dry weight, the average density of the MPB strands measured about 375 kg/m^3 (23.4 pcf). In comparison, the density of Aspen strands obtained from Ainsworth's mill in Grand Prairie AB measured 400 kg/m^3 (25 pcf).

As shown in Figure 3, the two types of MPB boards pressed and manufactured at UBC were:

Small size (250mmx250mmx45mm) Aspen and MPB boards
Large size (750mmx750mmx40mm) Aspen and MPB boards

The Aspen strands were obtained from the Ainsworth's Grand Prairie OSB mill. PF resin was used as the bonding agent.

Fig. 3 Large and small MPB boards processed at UBC

Preliminary validation of a newly developed hot pressing - consolidation model was initiated and will continue throughout the 3rd year of the project. Some preliminary results are shown below in Figures 4 and 5.

Figure 4. highlights the internal temperature which is measured and modeled in the centre of the face and core layers of the MPB small trial boards (250x250x45 mm).

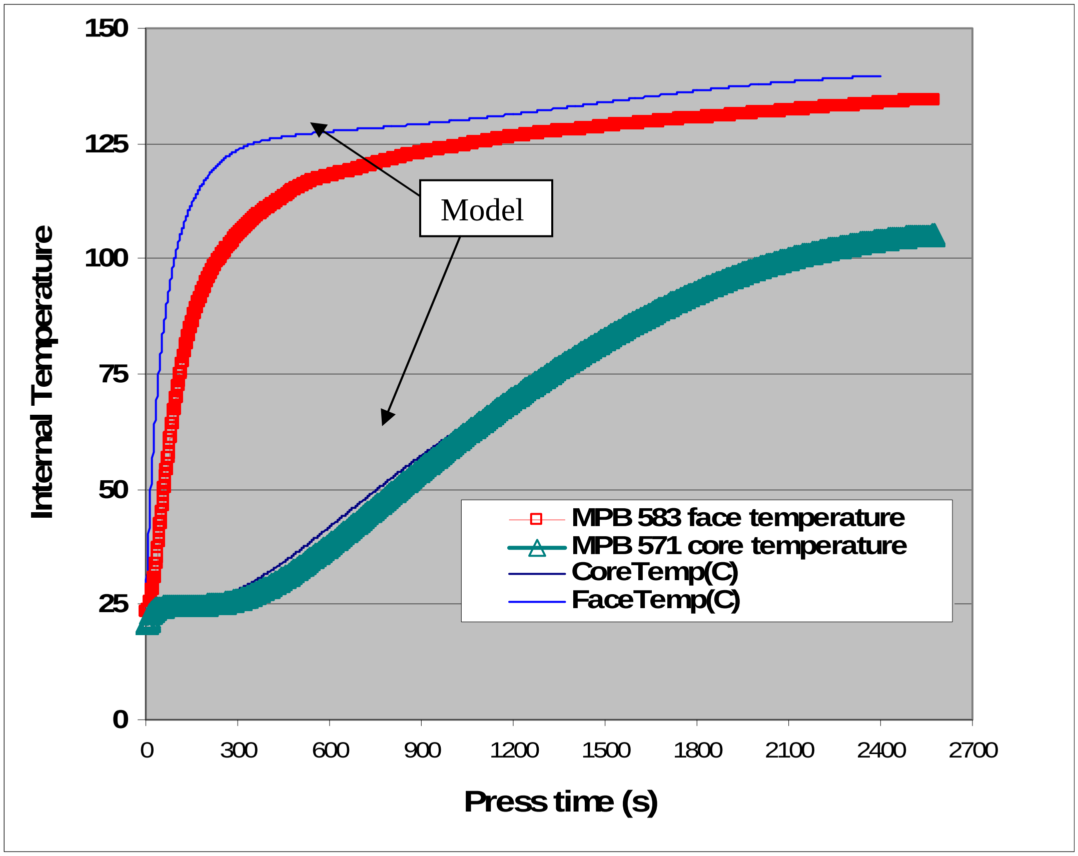


Fig..4. Model (Face Temperature and Core Temperature) - internal temperature during hot pressing compared to 2 experimental MPB strand small boards with respective densities of 573 kg/m^3 and 581 kg/m^3

Figure 5. illustrates the internal temperature measured in the centre core of thick strand mats using aspen and BKP strands. Individual board density was measured at 610 kg/m^3 and 550 kg/m^3 respectively for MPB and aspen thick strand composite boards.

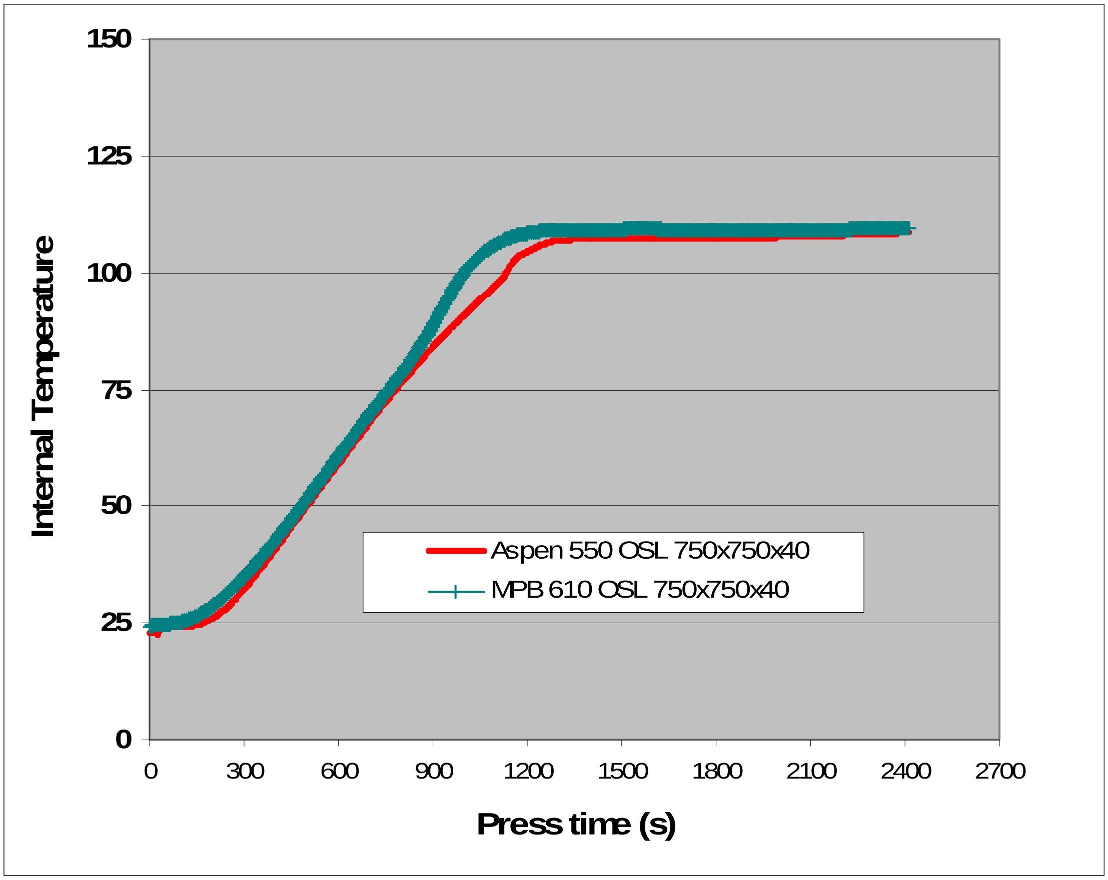


Fig.5. Internal core temperature during hot pressing of large MPB and Aspen strand boards

As an engineered wood product, one of the key properties of a thick strand based composite is it's structural response under long term loading (creep).

Creep is the time-dependent increase of deformation of material under a constant stress and is an important material characteristic because it can lead to structural failure from either excessive deformation or collapse. As creep can lead to collapse, load duration is another important material characteristic. The deterioration of strength under continued application of constant stress is called duration-of-load effect, which transitions to failure after a given time. This failure or rupture, under long-term loading, is termed creep-rupture (Laufenberg, 1988), which is used to describe the combined phenomena of duration-of-load (DOL) and creep.

All wood-based composite products are susceptible to creep and duration of load effects noted previously. Thus, in-service stiffness characteristics must be known and controlled to limit the component's creep deformation. It is important to quantify the load duration effect to ensure reliability throughout its full intended service life.

Based on a literature review, it appears the phenomenon of creep-to-rupture is a continuous process. Previous performance models used to treat the effects of duration-of-load and creep separately. As for creep modeling, researchers studied the creep behavior from the perspective of constitutive relationship, so that the models would give the description of the time-dependent deformation, i.e. strain versus time. While for duration-of-load modeling, most models put emphasis on the "final point", namely how long the structural component can be sustained under given load. Hence the researchers cared about predicting the time to failure rather than the specific process of deformation, and thus the results were given in terms of stress ratio versus time-to-failure.

In order to investigate the serviceability and structural safety of thick strand-based wood composites made from MPB killed lumber, a unified approach to describe the creep-rupture behavior is proposed in this project, wherein a strain-based damage accumulation model incorporates the viscoelastic constitutive relationship. The distinctive advantage of a damage accumulation model is that it permits the prediction of damage produced by an arbitrary random load sequence and its convenient usage in reliability-based design formats. Based on the research work of Foschi (Foschi and Yao, 1986; Foschi, 1989), a strain-based damage accumulation model is proposed, as shown in Eq. (1).

$$\frac{d\alpha}{dt} = A\dot{\varepsilon} + B\dot{\varepsilon} \cdot \alpha \tag{1}$$

Three types of rheological models, i.e., 3- and 4-element and 5-parameter model (Pierce and Dinwoodie, 1977, 1979, 1985; Dinwoodie et al., 1990), will be investigated to describe the constitutive relationship. The choice of creep models should be based on the balance between model complexity and accuracy.

For 3-element model:

$$\varepsilon(t)=\frac{\sigma_a}{\sigma_s}\left[\beta_1+\beta_2\left(1-e^{-t/\beta_3}\right)\right] \tag{2.1}$$

$$\dot{\varepsilon}=\frac{\sigma_a}{\sigma_s}\cdot\frac{\beta_2}{\beta_3}\cdot e^{-t/\beta_3} \tag{2.2}$$

For 4-element model:

$$\varepsilon(t)=\sigma_a\left[\frac{1}{k_0}+\frac{\left(1-e^{-t/\tau_1}\right)}{k_1}+\frac{t}{\eta_0}\right]=\frac{\sigma_a}{\sigma_s}\left[\beta_1+\beta_2\left(1-e^{-t/\beta_3}\right)+\beta_4 t\right] \tag{3.1}$$

$$\dot{\varepsilon}=\frac{\sigma_a}{\sigma_s}\cdot\left(\frac{\beta_2}{\beta_3}\cdot e^{-t/\beta_3}+\beta_4\right) \tag{3.2}$$

The 5-parameter model is actually a modified 4-element model, with the viscous flow term being a non-linear function of time.

$$\varepsilon(t)=\sigma_a\left[\frac{1}{k_0}+\frac{\left(1-e^{-t/\tau_1}\right)}{k_1}+\frac{t^{\beta_5}}{\eta_0}\right]=\frac{\sigma_a}{\sigma_s}\left[\beta_1+\beta_2\left(1-e^{-t/\beta_3}\right)+\beta_4 t^{\beta_5}\right] \tag{4.1}$$

$$\dot{\varepsilon}=\frac{\sigma_a}{\sigma_s}\cdot\left(\frac{\beta_2}{\beta_3}\cdot e^{-t/\beta_3}+\beta_4\beta_5 t^{\beta_5-1}\right) \tag{4.2}$$

When the damage state variable reaches unity, failure occurs. Formulae of time-to-failure for such different load cases as constant load, ramp load and experimental load have been derived and given in Eqs. (5.1) ~ (5.3) respectively.

$$\frac{1}{B}\ln\left(1+\frac{B}{A}\right)=\frac{\sigma_a}{\sigma_s}\left[\beta_2\left(1-e^{-T_c/\beta_3}\right)+\beta_4 T_c^{\beta_5}\right] \tag{5.1}$$

$$1=\frac{A}{B}\left[\exp\left(B\left(\frac{K_s}{\sigma_s}\left[(\beta_1+\beta_2)T_s-\beta_2\beta_3\left(1-e^{-T_s/\beta_3}\right)+\frac{\beta_4 T_s^{\beta_5+1}}{(\beta_5+1)}\right]\right)\right)-1\right] \tag{5.2}$$

$$\frac{1}{B}\ln\left(\frac{A+B}{A+B\alpha_c}\right)=\frac{\sigma_a}{\sigma_s}\left[\beta_2\left(1-e^{-(T_f-t_a)/\beta_3}\right)+\beta_4\left(T_f-t_a\right)^{\beta_5}\right] \tag{5.3}$$

(where $\alpha_c=\alpha(t_a)=\frac{A}{B}\left[\exp\left(B\left(\frac{K_s}{\sigma_s}\left[(\beta_1+\beta_2)t_a-\beta_2\beta_3\left(1-e^{-t_a/\beta_3}\right)+\frac{\beta_4 t_a^{\beta_5+1}}{(\beta_5+1)}\right]\right)\right)-1\right]$)

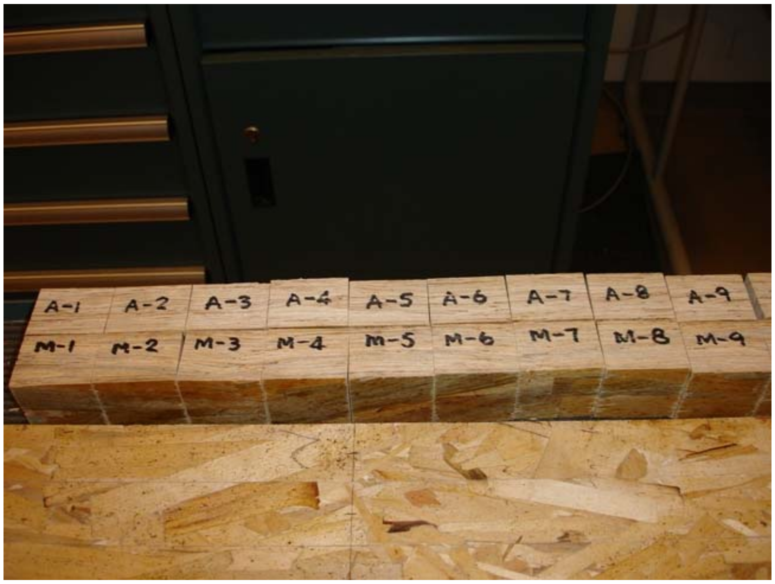
Correspondingly the number of cycles to failure for fatigue load case is given in Eq. (5.4)

$$N_f = \frac{\varphi_N - \varphi_0}{C_0} = \frac{\ln(A+B) - \ln A}{C_0} \tag{5.4}$$

Meanwhile, the unified model proposed in this project can be compared with other promising methods, including the damaged viscoelastic material theory proposed by Nielsen (Nielsen, 1986, 2000, 2005) and strain energy approach (Fridley et al., 1992). It should be noted that both methods considered creep behavior in their modeling with different failure criteria defined. In Nielsen's theory, it defines that failure occurs when the rate of crack growth reaches infinity; while in the strain energy approach, it defines that when strain energy density reaches its critical value, failure occurs. Actually both methods coincide in nature with the approach proposed in this project except that different failure criteria are applied. In this project we assume that the damage state variable being unity corresponds to failure.

An outline for the experimental program to validate the unified creep and load duration model has also been developed during year 2. The experimental program that will be carried out during the 3rd year of this study will include short term bending tests and long term creep-rupture bending tests. The influence of loading rate will also be investigated.

Image scanning of the thick strand based composite products was undertaken to analyze the strands' orientation. Tests to determine the stiffness and internal bond of the boards were also performed. Test samples are shown in Figure 6.



a. Internal Bond samples

b. Bending samples

Fig. 6. MPB and Aspen strand composite samples for internal bond and bending tests.

Third-point edge bending tests were conducted to determine the MOE of the thick oriented strand-based lumber. Results are summarized in Table 1. It can be noted that the average MOE for MPB composite lumber is at a satisfactory level. Results for the internal bond tests, performed to determine the internal bonding strength (IB) of the composites, are summarized in Table 2. One can note that the properties of the MPB boards were slightly higher than the Aspen board. Direct comparison of the results is not appropriate because the specimens were made at different density. Furthermore the MPB strands obtained from the lab scale strander at Carmanah seem to be of higher quality than the Aspen strands obtained from an OSB mill. For example the average thickness of the Aspen and the MPB strands was about 0.6 mm (0.024”) and 1.1 mm (0.044”), respectively.

Based on the information gained during the preliminary experiments, the blending and pressing method of thick composites has been validated to make sure that future specimens can be manufactured following similar procedure. The test apparatus for the long-term creep-rupture bending test (a steel frame) will be designed to accommodate multiple specimens to be tested simultaneously considering the limited available space of chamber room.

Table 1. Stiffness of MPB and Aspen thick strand boards

	Average MOE (GPa)	Board density Kg/m^3
MPB	9.7	610
Aspen	7.1	550

Table 2. Internal Bond results for MPB and Aspen thick strand boards

	Average IB (MPa)	Board density Kg/m3
MPB	0.22	610
Aspen	0.15	550

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Permeability Test Jig

The gas flow within strand composite mats during pressing is one of the key parameters that controls the development of gas pressure during the pressing process. If excessive pressure is built up before adequate bond strength can be developed failure of the bond within the mat (blow) can result. This is one of the most critical issues facing the manufacturing of thick strand based material.

To address this issue and understand and quantify the effective in-plane permeability of gas flow of thick MPB strand composites under out-of-plane pressure, a test jig was built during the past year. After successfully building the jig (figure 7), preliminary testing and debugging of the permeability jig have been conducted.

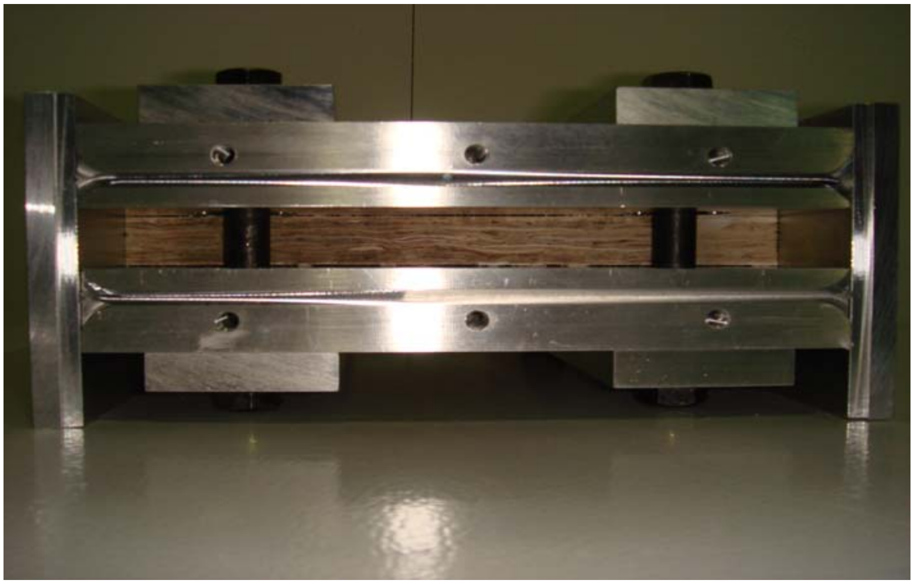

Fig.7. Permeability jig front view.

Fibre – Adhesives interaction

To measure and quantify the fibre-adhesive interaction in wood-based composites interactively, which is influenced by the temperature and moisture effects, a small humidity chamber unit for the UBC DMA[1] was assembled and tested.

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[1] **DMA or Dynamic mechanical analysis** is a technique used to study and characterize materials. It is most useful for observing the time dependence behavior and properties of materials**.**

Figure 8 illustrates the tan δ DMA results for the various levels of attack and locations within a tree for samples conditioned at 11.5% moisture content. All other data (total of 144 tests) exhibited similar graphs. Two distinctive transitions are observed on the curves with intensity below 0.1. The tan δ peaks of both transitions showed variations between levels of attack, based on the stage of attack or location within the tree. The transitions exhibited almost the same broadness interval. The lower temperature (second transition temperature) is related to methylol groups associated with lignins and xylans. However, as the xylan composition is only <8 % of the total hemicelluloses, lignin would be the only major source for methylol groups. Thus any difference observed in the second transition would imply a probable difference in lignin structure. The higher temperature (first transition) has been discussed as the glass transition temperature of lignin in the presence of moisture. As these samples had an 11.5% moisture content, the transitions may be assigned to the glass transition of water plasticized lignin. Therefore, any difference in the transition temperature suggests some changes of lignin structure.

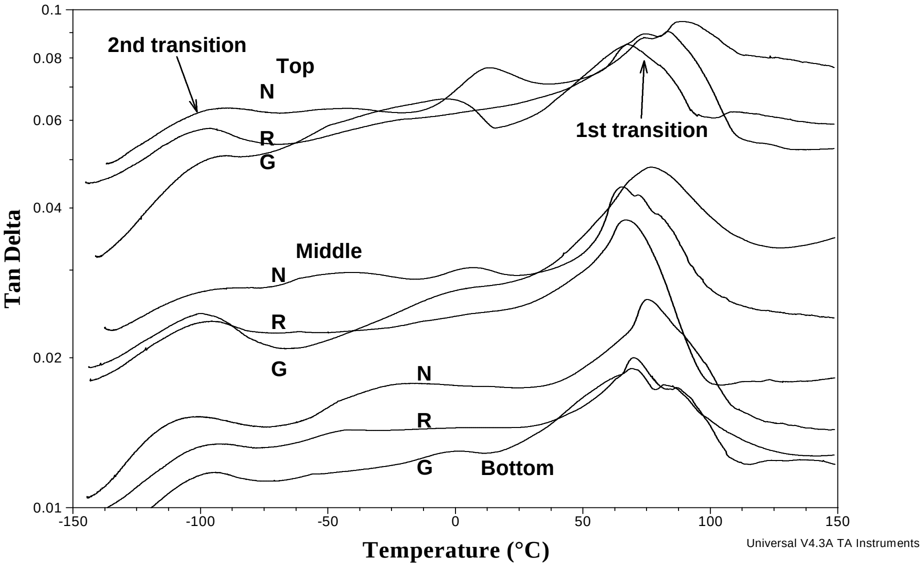

Fig.8. DMA (Tan δ curves) analysis of MPB wood

ANOVA analysis of the DMA data showed some differences between these samples. Tables 1 and 2 show the result of the ANOVA analysis. The analysis reveals that only some of the transition temperatures have significant differences (95% level of confidence).

Table 1 exhibits significant differences for the first transition of the top of tree samples and the second transition of the middle part of the tree samples.

Table 2 shows differences for the first transition between red and grey stages of attack, as well as with the second transition of the green attack stage.

Table 3. ANOVA analysis of MPB DMA data based on tree position; analysis of 1st and 2nd transition temperature differences (11.5% moisture content)

Degree of freedom : 2 (between groups), 6 (within groups), 8 (total) F critical = 9.55						
Source Analysis Factors	1st transition temperature			2nd transition temperature		
	Top	Middle	Bottom	Top	Middle	Bottom
F calculated	112.7	19.22	1.62	0.47	551.66	0.60
Probability	**0.002**	0.190	0.270	0.580	**0.0001**	0.670

Table 4. ANOVA analysis of MPB DMA data based on stage of attack; analysis for 1st and 2nd transition temperature differences (11.5% moisture content)

Degree of freedom : 2 (between groups), 6 (within groups), 8 (total) F critical = 9.55						
Source Analysis factors	1st transition temperature			2nd transition temperature		
	Green	Red	Gray	Green	Red	Gray
F calculated	1.29	51.64	41.85	123.69	0.88	10.47
Probability	0.390	**0.005**	**0.006**	**0.001**	0.500	0.044

A statistical analysis of the results obtained from dynamic mechanical analysis (DMA) of MPB attacked wood was conducted. The results revealed some significant differences between the 1^st and 2^nd transition temperatures in the tan delta curves of wood specimens conditioned at 60% humidity and 20ºC; proposed to be the effect of variations in structure and composition between trees and within a tree rather than levels of attack. DMA analysis on completely dry specimens did not show any significant differences between the 1^st and 2^nd transition temperatures in the tan delta curves.

CONCLUSIONS

The following conclusions can be drawn from the activities undertaken during the second year of this project:

- Preliminary simulations of the internal temperature during the hot pressing of thick strand based composites using the UBC hot pressing – consolidation model indicate a good correlation with the experimental manufacturing of Aspen and MPB thick strand boards.

- Prototype thick MPB strand boards were successfully manufactured at the UBC lab using a press schedule developed from simulations.

- The framework for the duration of load model and analysis of thick strand based wood products has been successfully set and developed. An experimental program for long term creep and rupture will be performed in year three to validate the model.

- Results from the DMA analysis on completely dry specimens revealed no significant chemical or structural differences between MPB attacked lodgepole pine samples at different stages since-attack.