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Project No.: 2019

Computer Simulation Model of Hot-Pressing Process of LVL and Plywood Products

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April 2003

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.

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Notice

Summary

Laminated Veneer Lumber (LVL) and plywood are the two major veneer-based wood composite products. During LVL/plywood manufacturing, the hot pressing process is crucial not only to the quality and productivity, but also to the performance of panel products. Up to now, the numerical simulation of the hot-pressing process of LVL/plywood products is not available.

To help understand the hot-pressing process of veneer-based wood composites, the main objective of this study was to develop a computer simulation model to predict heat and mass transfer and panel densification of veneer-based composites during hot-pressing. On the basis of defining wood-glue mix layers through the panel thickness, a prototype finite-element based LVL/plywood hot-pressing model, VPress®, was developed to simulate, for the first time, the changes of temperature, moisture and vertical density profile (VDP) of each veneer ply and glueline throughout the pressing cycle. This model is capable of showing several important characteristics of the hot-pressing process of veneer-based composites such as effect of glue spread level, veneer moisture, density, platen pressure and temperature as well as pressing cycles on heat and mass transfer and panel compression. Experiments were conducted using several different variables to validate the model. The predicted temperature profiles of the veneer plies and gluelines (especially at the innermost glueline) by the model agree well with the experimental measurements. Hence, the model can be used to evaluate the sensitivity of the main variables that affect hot-pressing time (productivity), panel compression (material recovery) and vertical density profile (panel stiffness). Once customized in industry, the new model will allow operators to optimize the production balance between productivity, panel densification and panel quality or stiffness. This hot-pressing model is the first step in facilitating the optimization of the pressing process and enhanced product quality.

Acknowledgements

The authors wish to thank following project liaisons for their guidance during this work:

Nick Nagy, Canadian Plywood Association
Noel Grenier, Tembec Forest Products Group
Ralph Dawson, Riverside Forest Products
Dam Nguyen, Louisiana-Pacific Corp.
Rick Hiraoka, West Fraser Mills Ltd. (Alberta Plywood)

The senior author (Brad Wang) would also like to thank his Ph.D academic supervisor Dr. Simon Ellis, Wood Science Department, the University of British Columbia, for his guidance.

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To develop a hot-pressing simulation model to predict heat and mass transfer and panel densification of veneer-based composites during hot-pressing.

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3 Introduction

LVL and plywood are the two major veneer-based composite products. LVL is made by aligning and gluing multiple veneer plies in the product length direction. This unidirectional structure gives LVL higher specific stiffness (the ratio of bending stiffness to density) and specific strength (the ratio of bending strength to density) because of the smaller strength variation than sawn lumber and glulam beams. Due to these outstanding features, LVL has become one of the major engineered wood composite products. Its production in North America has grown significantly for specialized lumber, I-joist flanges, headers and beams with annual output close to 2 million m^3. By comparison, the traditional plywood industry is challenged to maintain profitability while the wood resource and quality decline and raw material prices increase. Like other wood composites, the hot pressing process is the final stage in LVL/plywood manufacturing where the layered structure is heated and compressed between two platens to create close contact and form bonds between veneer plies to become a solid piece. In the manufacturing processes of wood composite products, the hot-pressing schedules for non-veneer based products such as oriented strand board (OSB) and medium density fiberboard (MDF) are different from those for LVL/plywood products.

As shown in Figure 1, the hot pressing process of veneer-based composite products is to press a lay-up of multiple glued veneer plies under heat and pressure until the innermost glueline cures. Generally, instead of the four stages for OSB, only three distinct stages can be seen. At the first stage, the press is quickly closed to generate intimate contacts between veneer plies. By holding a constant pressure at the second stage until the innermost glueline temperature reaches the target, panel thickness decreases due to the coupled mechanism of hydro-thermo softening and creep (Wellons *et al* 1983), resulting in certain degree of densification. At the third stage, the panel is pressed under a predefined decompression cycle to avoid delaminations or blows during which the innermost glueline temperature continues to rise to cure the glue and springback results. During the hot-pressing process, drastic changes in heat, moisture, deformation and glue curing take place simultaneously within a period of the pressing cycle (Zavala 1986). The LVL/plywood manufacturing productivity or efficiency is mainly controlled by the time needed for the innermost glueline to reach a target curing temperature, and subsequent careful decompression cycle to suppress delaminations (blows) (Wang 2001a and Wang 2001b). Under a constant pressure, effective bonds are achieved sequentially from surface to core with a certain level of panel densification. Panel densification, affected by changes of temperature, moisture and viscoelastic behavior of each veneer ply during hot-pressing, contributes directly to the enhancement of panel stiffness (Wang 2001b). For fast growing or plantation species, target stiffness of LVL/plywood products is achieved with a fair amount of panel densification (Knudson and Wang 2002). Excessive densification, on the other hand, causes negative effects such as heavier products, material (thickness) loss and dimensional changes after unloading from the press or in service (Wellons *et al.* 1983). Therefore, LVL/plywood hot pressing is very critical not only to the product quality and productivity, but also to the product performance.

Over the past twenty years, tremendous efforts have been devoted to the hot-pressing simulation of wood composite products in order to understand and further optimize the manufacturing process (Bolton and Humphrey 1994; Carvalho *et al*. 1998; Dai 2001; Dai and Steiner 1993; Humphery and Bolton 1989; Lenth and Kamke 1996). Recently, a comprehensive OSB hot-pressing simulation model, MatPress®, was developed at Forintek to help industry to optimize the hot-pressing process (Dai *et al*. 2001). However, the main focus for hot-pressing simulation models has been placed on non-veneer based composites such as OSB and MDF. Realizing the importance of the LVL/plywood hot-pressing, it is surprising to learn of the very limited published information on the behavior of heat and mass transfer and manipulation of panel densification. More specifically, all research thus far on LVL/plywood hot-pressing has been qualitative in nature (Zavala *et al.* 1996). Recently at Forintek, veneer grading strategies for LVL/plywood products were extensively studied and a very good correlation between veneer stiffness and LVL edgewise bending stiffness was found (Dai and Wang 2000). Further, the hot-pressing behavior and strength properties of 13-ply aspen LVL and 5-ply Douglas-fir and spruce plywood were studied (Wang 2001a; Wang 2001b; Wang 2003). It was found that veneer stress grade and veneer moisture content were the two predominant factors that affected LVL stiffness and strength properties. In contrast, phenol formaldehyde glue spread and platen pressure were two key factors affecting hot-pressing time needed for the core to reach 105^0C (the target temperature to ensure full cure). The moisture in the glueline, normally exceeding that of the veneer (50% to 80% of total panel moisture), affected the rise of the innermost glueline temperature more apparently than the moisture in the veneer, which indicates that the glueline acts as a barrier of heat conduction during hot-pressing. Quantifying the heat and mass transfer behavior at or near the glueline zone is essential to understand the hot-pressing productivity or efficiency. Further, it was found that during hot-pressing, the gas was largely trapped inside the panel since gas pressure generally kept increasing during the decompression process of the press. All results indicated that: 1) the stiffness of LVL/plywood products is determined by the stiffness of individual veneer plies and the hot-pressing process; 2) the glueline is critical to the panel hot-pressing process and 3) a one-dimensional heat and mass transfer model is a good start to simulating the LVL/plywood hot-pressing process. To optimize the LVL/plywood manufacturing process, a quantitative understanding of the hot-pressing process of LVL/plywood products is important to enhance product quality and efficiency of the manufacturing process.

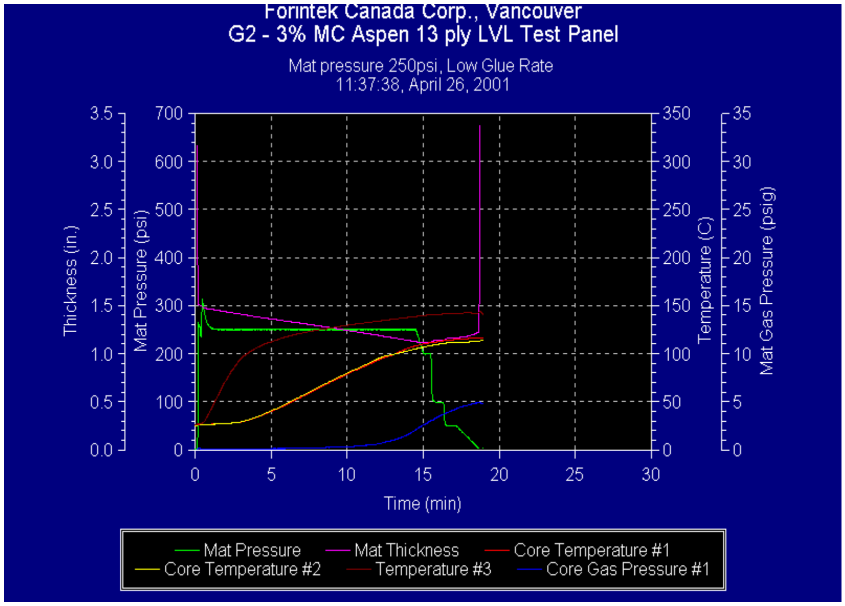


Figure 1: Typical pressing strategy of LVL

4 Modeling of LVL/Plywood Hot-Pressing Process

4.1 General hypothesis

To quantify the heat and mass transfer and panel densification of LVL/plywood products during hot-pressing, numerical approaches are needed and following assumptions are made:

- the heat conduction is predominant during hot-pressing;
- the glue solid material is incompressible;
- the thickness of veneer is infinitesimal compared to its length and width; therefore, the heat and mass transfer mainly occurs through-the-thickness;
- pressure control is the mode of the hot-pressing operation.

The current scope of this work is shown in Figure 2.

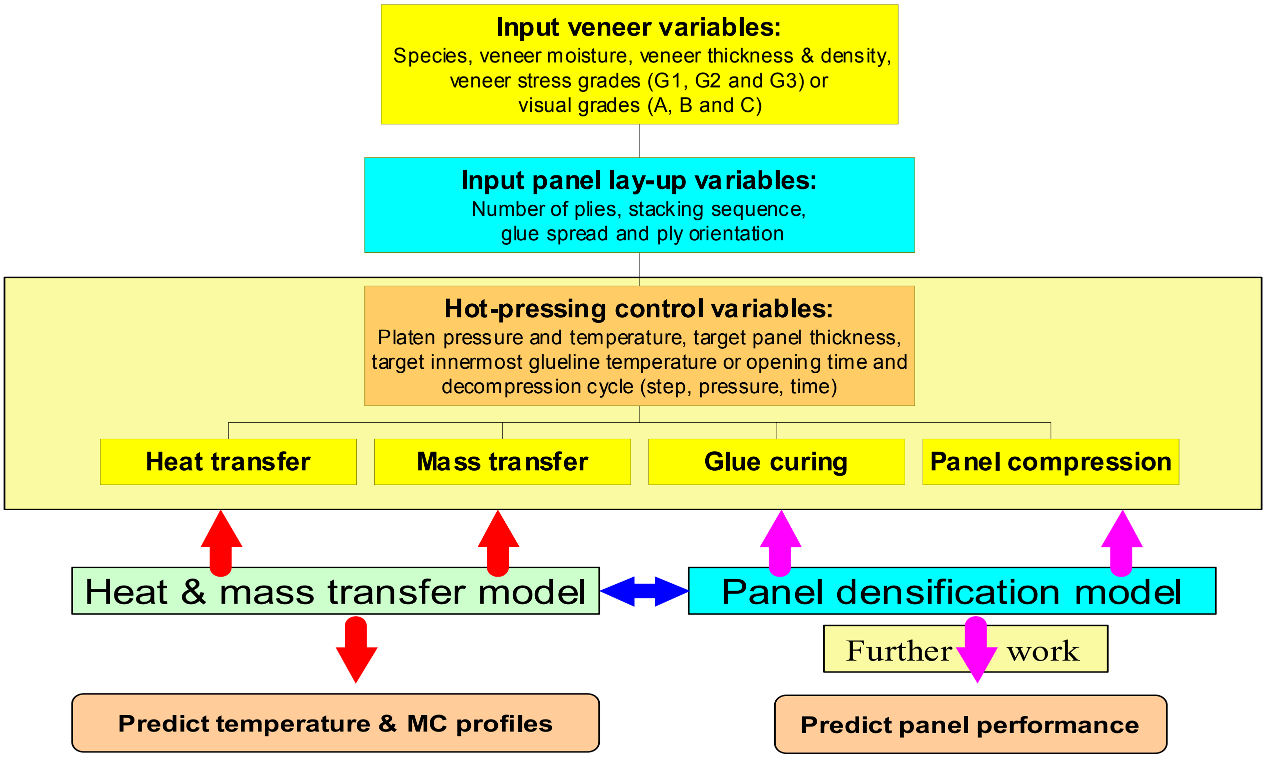
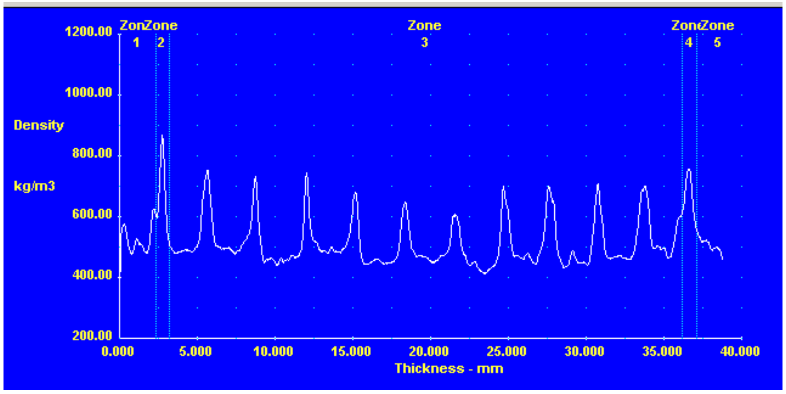


Figure 2: Schematic description of LVL/plywood hot-pressing simulation

4.2 Modeling of heat and mass transfer during hot-pressing

4.2.1 The definition of wood-glue mix layer

As stated, one of the keys to simulate hot-pressing process of veneer-based composites such as heat and mass transfer and compression behavior is to characterize the role of the glueline, an interfacial layer between two adjacent veneer plies. During the course of heat and mass transfer, the glueline effect cannot be ignored since moisture from the glue significantly affects the core temperature rise and, in turn, the hot-pressing time. Figure 3 shows a typical X-ray density profile (batch average) and an enlargement of the profile of one sample at the core of the 13-ply aspen LVL panel with the two peaks representing two glueline zones.



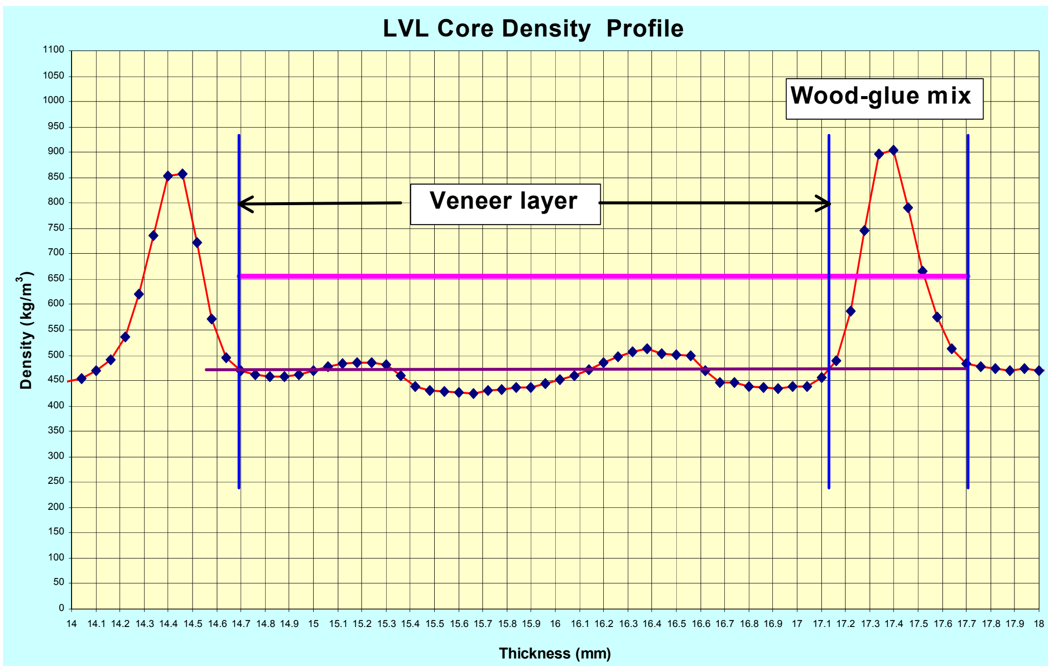


Figure 3: Typical LVL X-ray density profile

As shown in Figure 3, it can be assumed that there is no independent glueline or glue layer in the cross section of the panel. The portion of the veneer where glue penetrates can be included into the glueline. That is, the glueline consists of wood and glue. As shown in Figure 4, in the panel cross-section, the distinct glueline can be seen as a mixture of glue and partial wood, or simply called wood-glue mix. By defining a layer of wood-glue mix, the combined effect of veneer lathe checks or incision marks, roughness, thickness variation, glue penetration into the veneer ("wash in") and glueline irregularities can be combined.

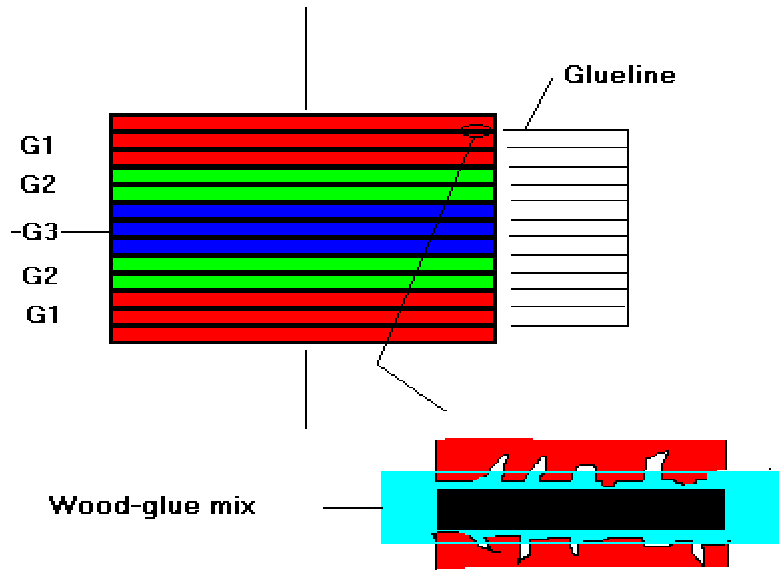


Figure 4: Defining glueline as wood-glue mix at the panel cross section

4.2.2 Model assumption

To simplify the development of a heat and mass transfer model, the following assumptions are made:

- each wood-glue mix layer is homogeneous and uniform along the glueline;
- the water produced by phenolic glue during its curing reactions is negligible;
- migration of the phenolic glue to the edge of panel ("squeezing-out") during pressing is negligible.

From Figure 4, it can be estimated that the thickness of the wood-glue mix layer is about 10 ~ 20% of veneer ply thickness (1/8"). After glue spreading, it was observed that the glue largely penetrated into the veneer ply due to the existence of open lathe checks and roughness. Therefore, LVL/plywood panels can be conceptualized as a chain series with alternative veneer and wood-glue mix layers, as shown in Figure 5. Each veneer layer is defined as the portion of veneer ply after deducting the partial wood included in the adjacent wood- glue mix layers. For the top and bottom veneer layers, only one side of partial wood needs to be deducted.

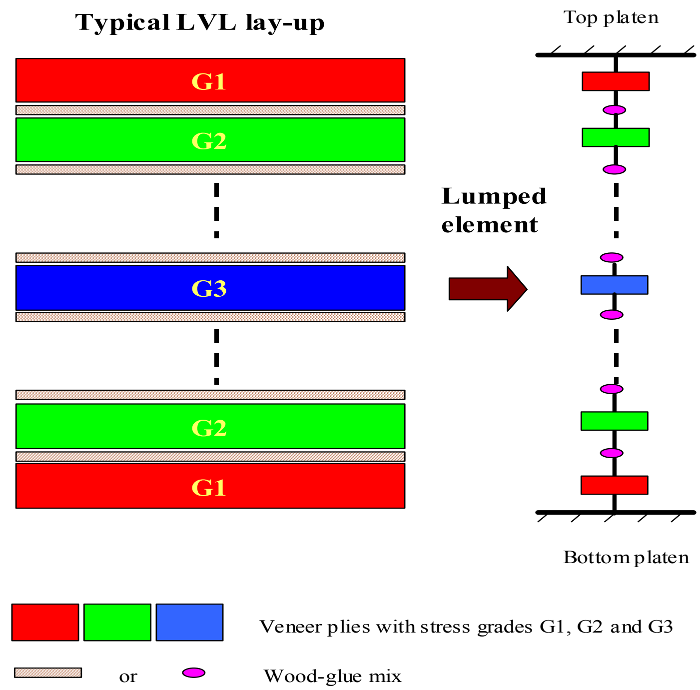


Figure 5: Conceptualizing a typical LVL lay-up as lumped elements

4.2.3 Energy balance during panel hot-pressing

4.2.3.1 Energy balance for the veneer layer

A lumped finite–element method was used to describe the heat and mass transfer behavior for veneer-based composites.

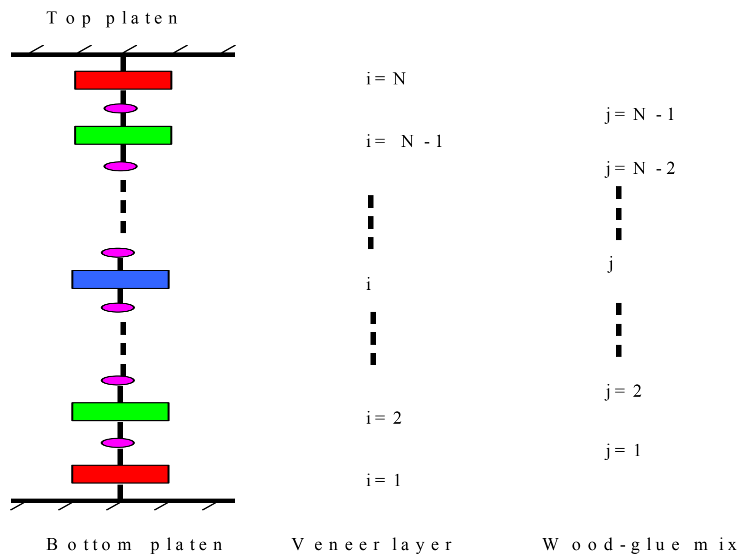


Figure 6: Meshing veneer layer and wood-glue mix through the panel thickness

As shown in Figure 6, the veneer layer number is the same as the number of veneer plies n (from 1 to n) for the panel lay-up; whereas the number of wood-glue mix layers is n-1. For the first veneer layer at the bottom, the energy obtained from the bottom platen and from first layer of wood-glue mix should contribute to the increase of temperature of the veneer layer in unit time. As such, without considering the effect of heat convection, the energy balance equation for the ith veneer layer can be established as:

$$k_{v,i}\frac{T_{m,i-1}-T_{v,i}}{0.5*(h_{m,i-1}+h_{v,i})}+k_{v,i}\frac{T_{m,i}-T_{v,i}}{0.5*(h_{v,i}+h_{m,i})}=\frac{d(C_{pv,i}\rho_{v,i}h_{v,i}T_{v,i})}{dt}$$

i= 1~ n

(1)

The Euler method can be used to solve a set of above n ordinary differential equations:

$$T_{v,i}^{k+1}=T_{v,i}^{k}+\frac{\Delta t}{C_{pv,i}^{k}\rho_{v,i}^{k}h_{v,i}^{k}}\left\{\frac{2k_{v,i}^{k}}{h_{m,i-1}^{k}+h_{v,i}^{k}}\left(T_{m,i-1}^{k}-T_{v,i}^{k}\right)+\frac{2k_{v,i}^{k}}{h_{m,i}^{k}+h_{v,i}^{k}}\left(T_{m,i}^{k}-T_{v,i}^{k}\right)\right\}$$

(2)

i= 1~ n

where the superscript k means the previous time and k+1 present time (the k ranges from 0 to required time), Δt is the time step, T_v is the temperature of the veneer layer, T_m is the temperature of the wood glue mix layer, C_{pv} is the specific heat of the veneer layer, ρ_v is the density of the veneer layer, h_v is the thickness of the veneer layer, h_m is the thickness of the wood glue mix layer and k_v is the heat conductivity of the veneer layer. On the right hand side, all the variables are assumed known. Notice that at k=0, $T_{v,1}^{0}$,

$T^0_{m,1}$, and $T^0_{v,1}$ are the ambient temperature. The equation (2) shows how to calculate the temperatures for n veneer layers, simultaneously when the boundary conditions such as top and bottom platen temperatures are known.

4.2.3.2 Energy balance for the wood-glue mix layers

During the hot-pressing process of veneer-based composites, the moisture from glue will not evaporate easily because the platen pressure is greater than the saturated steam pressure with regard to the given temperature inside the panel. That is, the majority of moisture in the wood glue mix layer normally remains in the liquid phase. Based on the law of energy conservation, without considering the effect of heat convection, the energy increase of the wood-glue mix layer is acquired from the two adjacent veneer layers. Therefore, for the ith wood-glue mix layer, we have

$$k_{v,i}\frac{T_{v,i}-T_{m,i}}{0.5*(h_{v,i}+h_{m,i})}+k_{v,i+1}\frac{T_{v,i+1}-T_{m,i}}{0.5*(h_{m,i}+h_{v,i+1})}=\frac{d(C_{pm,i}\rho_{m,i}h_{m,i}T_{m,i})}{dt} \quad (3)$$

i= 1~ n-1

Equation (3) can be solved as follows:

$$T^{k+1}_{m,i}=T^{k}_{m,i}+\frac{\Delta t}{C^{k}_{pm,i}\rho^{k}_{m,i}h^{k}_{m,i}}\left\{\frac{2k^{k}_{v,i}}{h^{k}_{m,i}+h^{k}_{v,i}}\left(T^{k}_{v,i}-T^{k}_{m,i}\right)+\frac{2k^{k}_{v,i+1}}{h^{k}_{m,i}+h^{k}_{v,i+1}}\left(T^{k}_{v,i+1}-T^{k}_{m,i}\right)\right\}$$

i= 1~ n-1 (4)

where the superscript k means the previous time and k+1 present time (the k ranges from 0 to required time), Δt is the time step, T_v is the temperature of the veneer layer, T_m is the temperature of the wood glue mix layer, C_{pm} is the specific heat of the wood glue mix layer, ρ_m is the density of the wood-glue mix layer, h_v is the thickness of the veneer layer, h_m is the thickness of the wood glue mix layer and k_v is the heat conductivity of the veneer layer. The superscript k means the previous time and k+1 present time. On the right hand side of the equation (4), all the variables are assumed known.

4.2.4 Mass balance during panel hot-pressing

4.2.4.1 Mass balance for the veneer layer

During hot-pressing, the mass of each veneer layer will increase due to the migration of moisture from the wood glue mix layer. The veneer density ρ_v, according to the definition, can be written as:

$$\rho_v=\frac{M_v}{V_v} \quad (5)$$

Here, M_v is the mass of veneer layer and V_v is the volume of veneer layer. Since the veneer density changes with the pressing time, we can take its derivative against the pressing time (t) as shown below:

$$\frac{d\rho_v}{dt} = \frac{d}{dt}\left(\frac{M_v}{V_v}\right) = \frac{1}{V_v}\frac{dM_v}{dt} + \left(-\frac{M_v}{V_v^2}\right)\frac{dV_v}{dt} \qquad (6)$$

Two factors are attributed to explain the density change for the veneer layer. One is the absorption of moisture from glue; the other is the volume change of veneer layer during pressing. On the right side of the equation (6), the first term represents the density change due to the change of veneer mass; the second term indicates the density change due to the change in the veneer layer volume from pressing. The differential equation for these two changes in veneer density can be expressed as

$$\Delta\rho_v = \Delta\rho_{v,m} + \Delta\rho_{v,v} \qquad (7)$$

$\Delta\rho_{v,v}$ can be derived based on the experimentation and modeling of panel densification. $\Delta\rho_{v,m}$ is an increase of moisture in the veneer layer which results from the decrease in moisture from the wood-glue mixture layer. The value can be derived from the mass balance equation of the wood-glue mix layer in the next section.

4.2.4.2 Mass balance for the wood-glue mix layer

The mass of the wood-glue mix is the sum of mass of both partial wood and glue. The latter also comprises glue solid and moisture. After spreading glue onto the veneer ply, a portion of moisture from glue is absorbed by the veneer ply. That is, before pressing, the moisture in the veneer ply has already increased. The other portion of moisture from the glue gradually migrates into the veneer layer during pressing. This forced migration can be expressed by the following modified Fick's Law:

$$\frac{dW\rho_m}{dt} = -K_{diff}\,(W\rho_m - W\rho_v) \qquad (8)$$

K_{diff} is defined as the effective diffusivity of moisture, and determined through experimentation. In the equation (8), $W\rho$ refers to the water potential or mass of water in unit space. In this unit space, water and wood from the veneer layer as well as glue solid co-exist.

$W\rho_v$, the water potential in the veneer layer, can be calculated as

$$W\rho_v = \rho_{veneer,dry} * MC \qquad (9)$$

In equation (9), $\rho_{veneer,dry}$ is the veneer dry density. For each veneer layer,

$$\rho_{veneer,dry,i} = \frac{\rho_i}{1+MC_i} \qquad (i = 1 \sim n) \qquad (10)$$

So equation (8) can be rewritten to be a difference equation as follows:

$$W\rho_{m,i}^{k+1} = W\rho_{m,i}^{k} - K_{diff} (W\rho_{m,i}^{k} - W\rho_{v,i}^{k}) \Delta t - K_{diff} (W\rho_{m,i}^{k} - W\rho_{v,i+1}^{k}) \Delta t \qquad (11)$$

In equation (11), the superscript k means the previous time and k+1 present time.

4.3 Modeling of panel densification during hot-pressing

During hot-pressing of veneer-based composites, the platen pressure is generally kept constant. Under this pressure, panel densification, or decrease of panel thickness, occurs. The first thickness reduction (strain ε_e) is due to the well-known hydro-thermo-softening resulting from the combined effect of veneer temperature and moisture on veneer compression modulus of elasticity (E); the second thickness reduction (strain ε_v) arises from the veneer viscoelastic (creep) behavior. The reduction of total panel thickness (strain change) is the sum of both as shown below:

$$\varepsilon_{total} = \varepsilon_e + \varepsilon_v \qquad (12)$$

Where ε_e is the strain change due to hydro-thermo-softening and ε_v is the strain change due to creep.

4.3.1 Panel strain due to hydro-thermo softening

Through transverse compression experiments, the stress and strain relationship of LVL/plywood panels at different moisture levels and temperatures can be established. An example of this relationship for 5-ply panel lay-up at ambient temperature is shown in Figure 7.

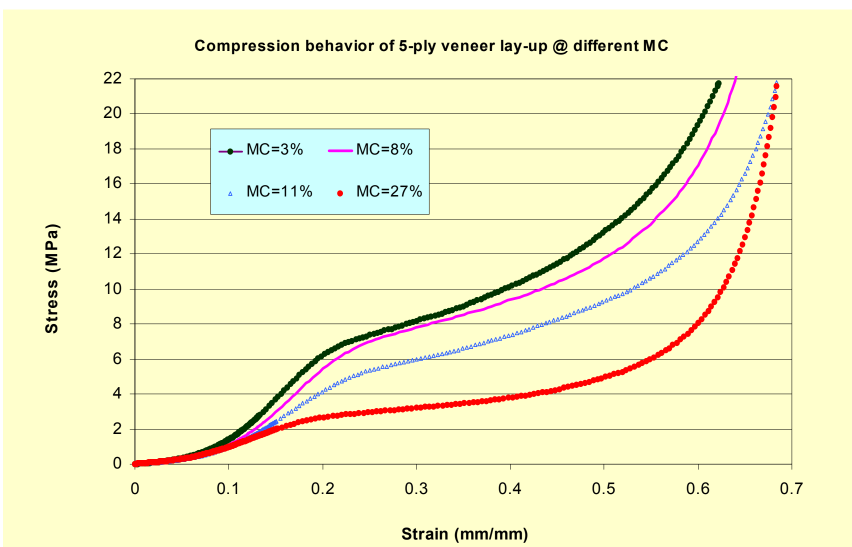


Figure 7: The stress-strain relationship of 5-ply panel lay-up

A modified Hook's law was used to obtain

$$\varepsilon_e = \sigma / (\varphi(\varepsilon) E) \quad (13)$$

Where ε_e is the compression strain, σ is the applied stress (platen pressure), E is the veneer compression modulus at a given veneer moisture and temperature, and $\varphi(\varepsilon)$ is the strain function. Under combined effect of moisture and temperature, veneer can be seen as a quasi-elastic material. Depending on the stage of compression, veneer behaves differently from elastic (strain within the yielding point) to elastoplastic (strain beyond the yielding point).

4.3.2 Panel strain due to creep

Under a constant platen pressure, veneer will display viscoelastic behavior (creep). For general viscoelastic materials, the basic constitutive equation between applied stress σ and strain ε according to the definition is:

$$\sigma = \mu \, d\varepsilon_v / dt \quad (14)$$

Where μ is the viscous coefficient of veneer determined by the experimental results reflecting the relationship between strain ε and the pressing time t, σ is the applied stress, ε_v is the viscous strain and t is the pressing time. The equation (14) is a one-order linear ordinary differential equation. To solve it, an initial condition is needed such that ε_v is equal to zero when time t is zero. So we can obtain the solution for the equation (14) as follows:

$$\varepsilon_v = \sigma / \mu * t \quad (15)$$

Therefore, in theory, the total strain at any pressing time can be expressed as follows:

$$\varepsilon_{total} = \sigma \, [\, 1 / (\varphi(\varepsilon) E) + 1 / \mu * t \,] \quad (16)$$

However, equation (16) is not easy to solve because E is the function of temperature and moisture, μ also changes with pressing time t and veneer density, and $\varphi(\varepsilon)$ needs to be determined by a series of veneer compression tests.

Recapping the following simple relationship for total strain:

$$\varepsilon_{total} = \frac{h_0 - h}{h_0} = \frac{V_0 - V}{V_0} = \frac{\frac{M}{\rho_0} - \frac{M}{\rho}}{\frac{M}{\rho_0}} = 1 - \frac{\rho_0}{\rho} \quad (17)$$

In equation (17), h_0, V_0 and ρ_0 are panel initial lay-up thickness, volume and density, respectively, and H, V, ρ and M are panel thickness, volume, density and mass at any pressing time t, respectively. The equation (17) reveals that the panel compression is affected by initial veneer or panel lay-up density. This is particularly true since panels constructed with higher density and/or lower moisture veneer are more difficult to be compressed. As an example, as shown in Figure 8, the relationship between applied stress (platen pressure) σ and veneer initial density ρ_0 and panel density ρ at ambient temperature can be established for veneer at different moisture contents.

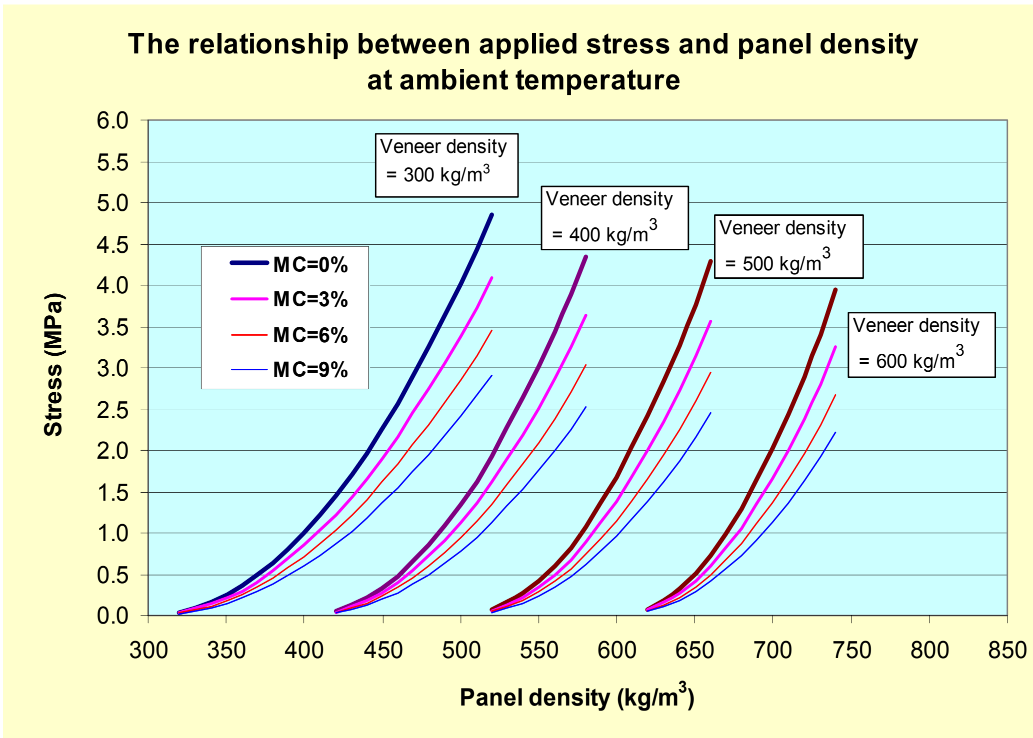


Figure 8: The relationship between applied stress and panel density

At ambient temperature, the relationship between applied stress and resulting density for each veneer ply was established as:

$$\sigma = C_0 \ \rho_{0,i}^{(1-MC_{0,i})} [\rho_i - \rho_{0,i}]^{m_0} \qquad (i = 1 \sim n) \qquad (18)$$

In equation (18), $MC_{0,i}$, $\rho_{0,i}$ and ρ_i are the veneer initial moisture, density and resulting density for ith veneer ply, respectively; and C_0 and m_0 are constant coefficients depending on veneer species. For spruce veneer, it was found that C_0 and m_0 are about 3.35 * 10^{-7} and 3.5, respectively, by fitting the data points with the equation (18) based on Figure 8. The effect of veneer temperature and moisture on change of veneer density during hot-pressing was reflected in the exponential coefficient m_0. Considering the combined effect of temperature and moisture, the m_0 should be modified as follows:

$$m_0 = m_{0,amb} \{1 - C_T \frac{T - T_{ini}}{T_{platen} - T_{ini}} - C_{MC} (MC - MC_0)\} \quad (19)$$

In equation (19), $m_{0,amb}$ is the exponential coefficient at ambient temperature; T, T_{ini}, T_{platen} are the veneer current temperature, initial temperature and platen temperature, respectively; and MC and MC_0 are the veneer current moisture and initial moisture, respectively. C_T and C_{MC} are the correction coefficients of temperature and moisture, reflecting the relative importance of temperature and moisture on changes of density. In this study, it was found that the effect of veneer moisture is more significant than the temperature, so C_T and C_{MC} were chosen as 0.4 and 2.0, respectively. Therefore, the density of each veneer ply at a given temperature and moisture can be written as:

$$\rho_i = \rho_0 + e^{\ln\{\frac{\sigma}{[C_0 \rho_{0,i}^{(1-MC_0)}]}\} / m_0 \{1 - C_T \frac{T_i - T_{ini}}{T_{platen} - T_{ini}} - C_{MC} (MC_i - MC_0)\}} \quad (20)$$

Based on equation (20), it can be seen that when the temperature and moisture of each veneer ply increase, the density of each veneer ply increases. Apparently, the temperature and moisture of each veneer ply at any pressing time can be known by solving the heat and mass transfer equations during hot pressing. Therefore, the veneer ply thickness change during hot-pressing can be calculated as:

$$h_i = mass_i / (S \rho_i) \quad (21)$$

In equation (21), $mass_i$ is the mass of each individual veneer ply and S is the area of panel pressed. At each time step, the total panel thickness can be written as:

$$h^k_{panel} = \sum_{i=1}^{n} h_i \quad (22)$$

In equation (22), n is total number of panel plies.

5 Development of VPress® Model

One of the main objectives of this project is to deliver a practical and user-friendly computer simulation model of conventional LVL/plywood hot pressing. As shown in Figure 9, the structure of the model is composed of two major components: a user interface and a finite difference method (FDM) solver. The user interface, as shown in Figure 10, defines all the inputs to run the model and allows the user to monitor the evolution of key parameters such as temperature, moisture, density, deformation and gas pressure at any time step. The FDM solver, which is the heart of the model, contains all the calculation algorithms described in Section 5. To solve the complex problem, a modular approach is used for the FDM solver. The pressing process is simulated by the consecutive execution of modules describing various physical, chemical and mechanical phenomena (i.e. heat and mass transfer, glue cure and densification). The modular nature of the proposed model allows for flexible incorporation of any changes that need to be implemented in the future.

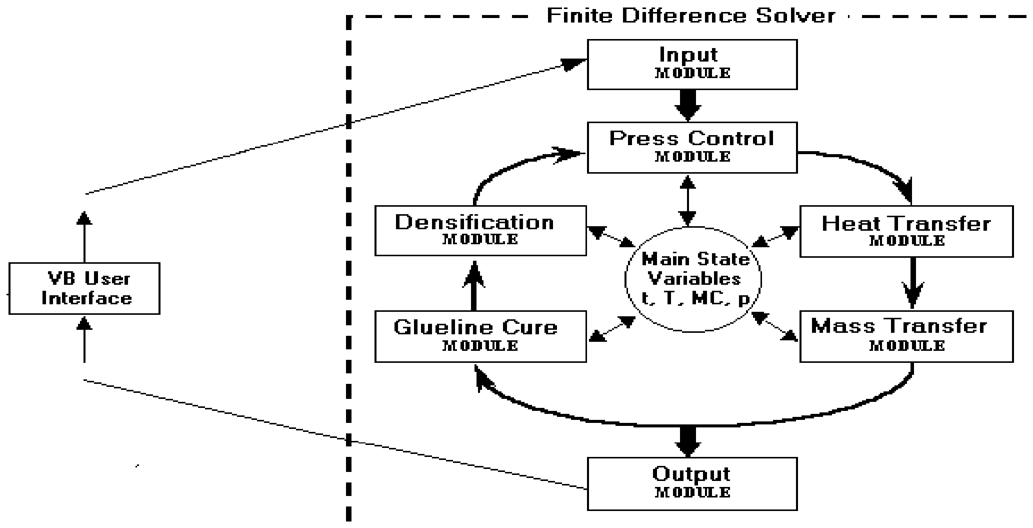
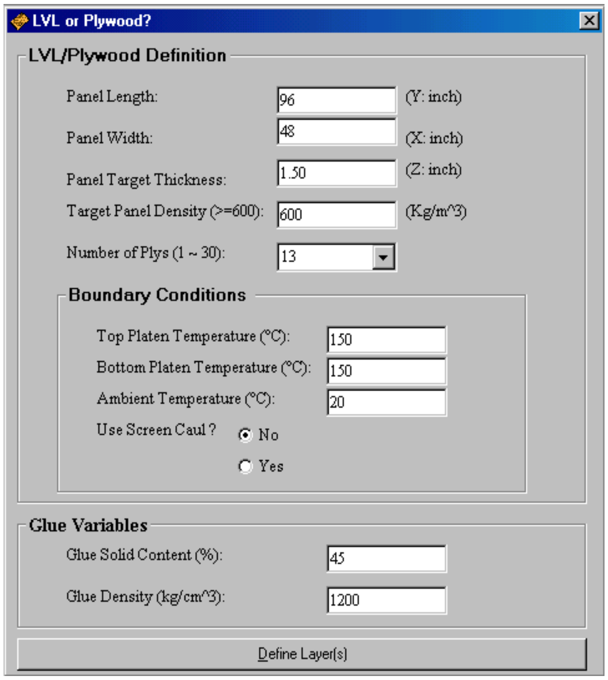
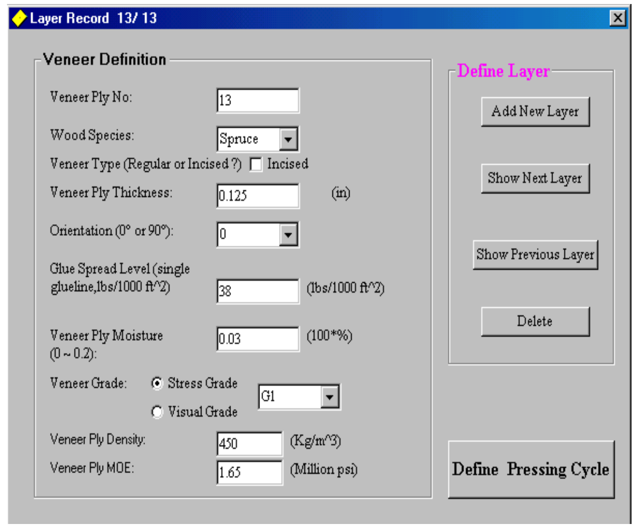


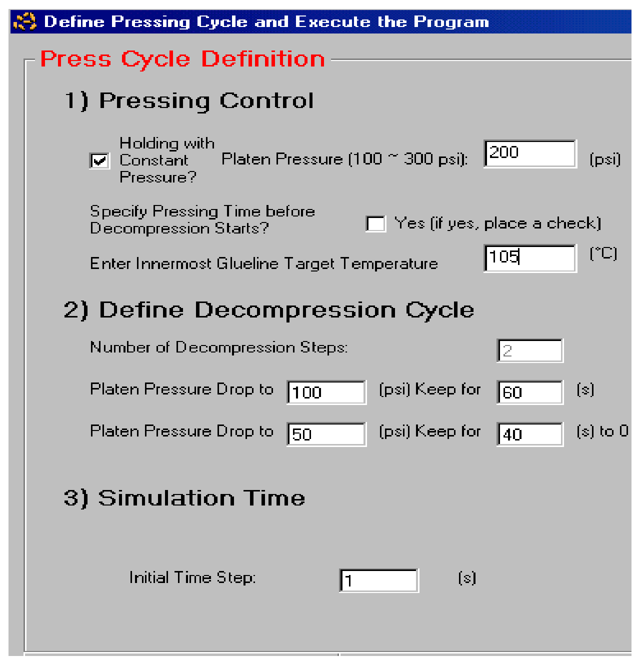
Figure 9: The structure of VPress® model

a) Variables defining panel



b) Variables defining each veneer layer





c) Variables defining pressing schedule

Figure 10: Input user interfaces of VPress® model

6 Typical VPress® Simulation and Validation

6.1 PressMan® plot

The first key feature of VPress® model is to present the real-time changes of multiple variables. An example is shown in Figure 11 with 13-ply Douglas-fir LVL. The predictable variables include the innermost glueline temperature, gas pressure and density, core veneer layer moisture and density as well as platen pressure and panel thickness.

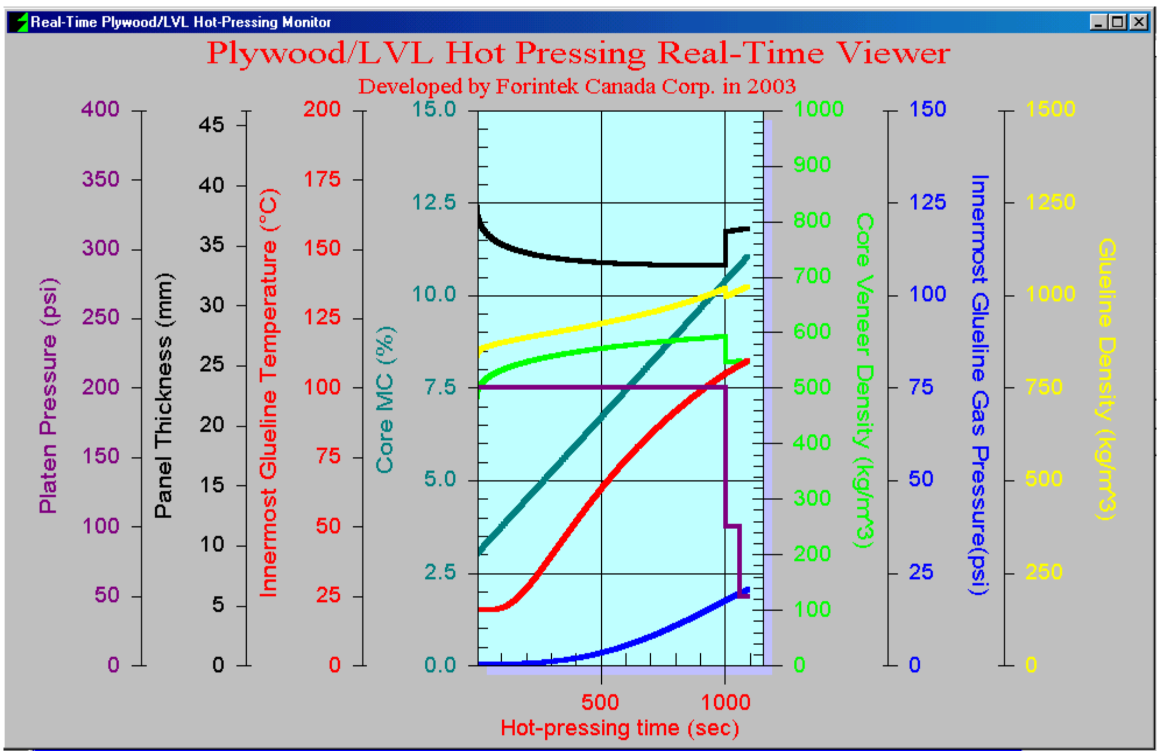


Figure 11: PressMan® plot for veneer-based wood composites

(the PressMan® was developed by Alberta Research Council)

6.2 Use of target glueline temperature to control hot-pressing process

The second key feature of the VPress® model is to predict the pressing time needed for the innermost glueline to reach a target temperature to cure the glue, and subsequently control the entire hot-pressing process. As shown in Figure 12, once users specify a target temperature for the innermost glueline of desired LVL/plywood products, the model runs to the required pressing time and then automatically switches to the pre-defined decompression cycle. This feature helps the users to conduct sensitivity studies of main variables on pressing time, in turn, productivity. The model also provides an option to use pressing time to control the pressing process before the decompression cycle starts.

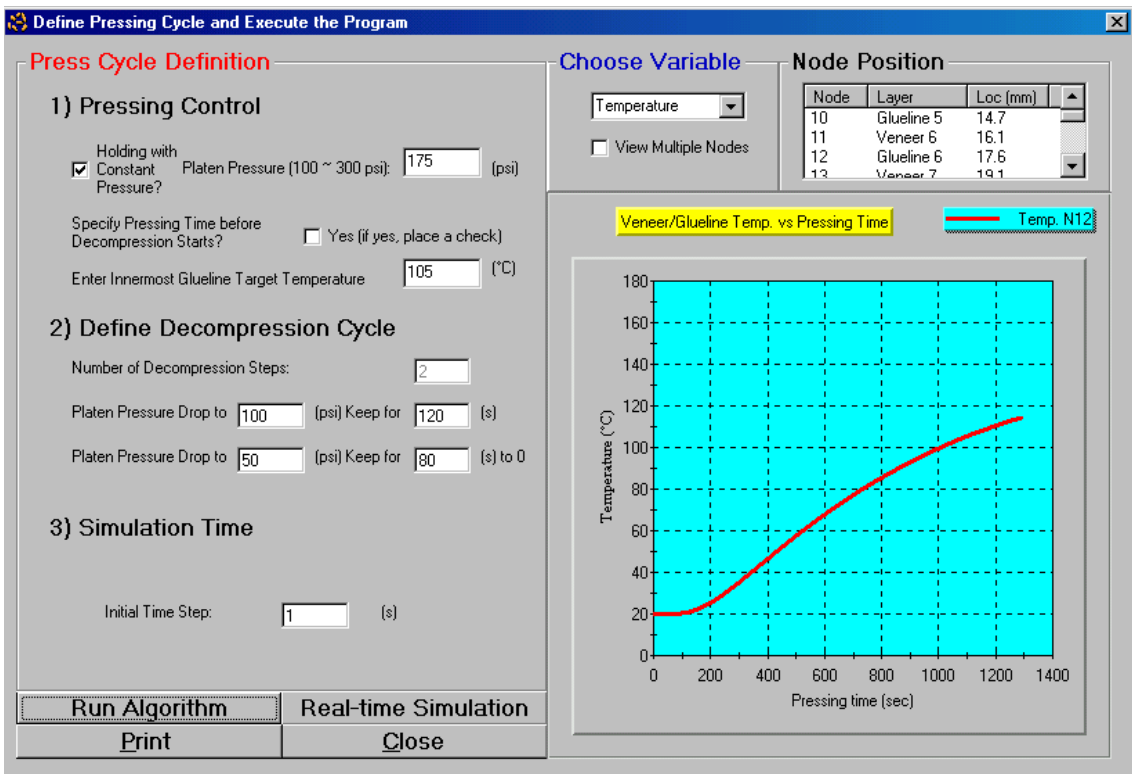


Figure 12: Use of target innermost glueline temperature to control pressing process

The model is also capable of predicting the temperature changes of different layers of veneer plies and wood-glue mixes (gluelines). As shown in Figure 13, the temperature rising curves of 13-ply spruce LVL at the second glueline (N4) and sixth glueline (innermost, N12) are predicted.

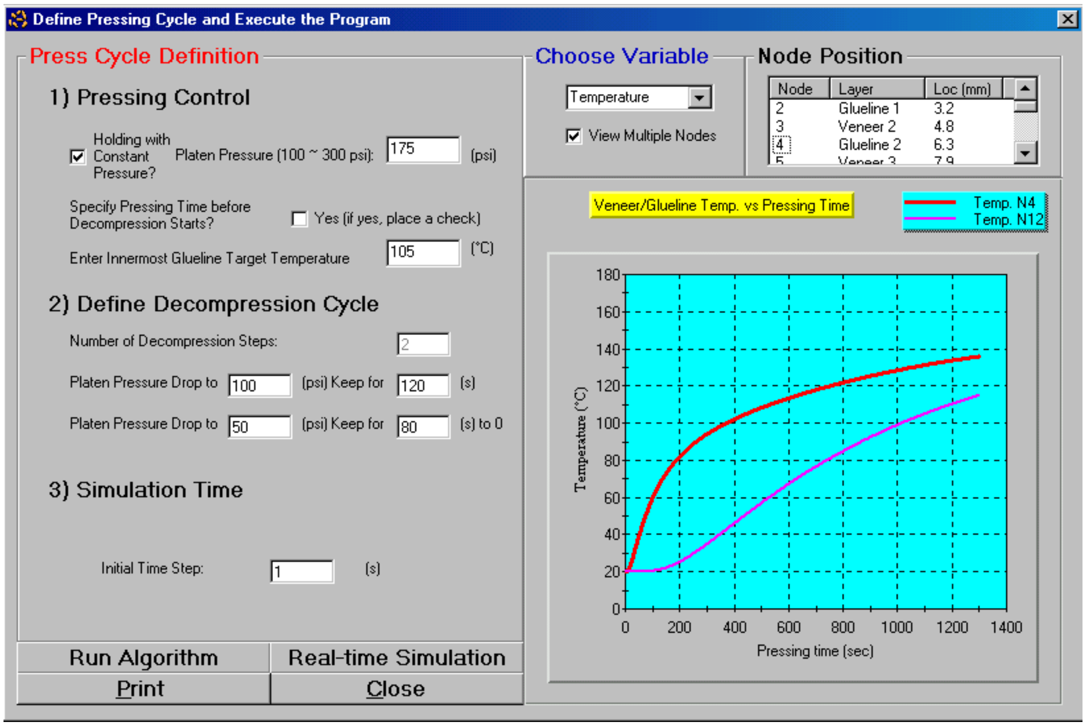


Figure 13: The temperature predictions of two wood-glue mix layers (innermost and one at two plies below the panel surface)

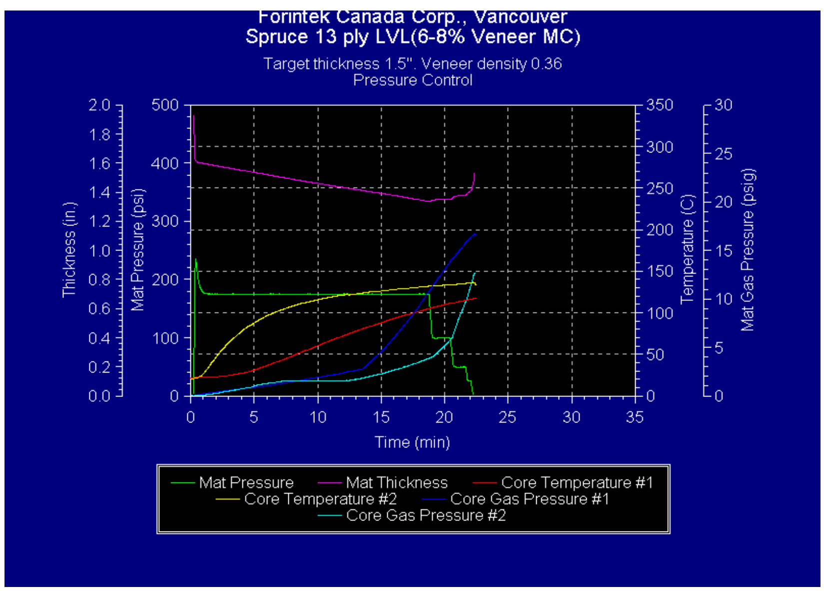


Figure 14: The actual temperature and gas pressure plots

To validate the results, more than one hundred 34”x 24” spruce veneer sheets were cut with an equilibrium moisture of about 6 ~8%. For each veneer sheet, the thickness, length, width and weight were measured. Veneer sheets were then sorted-out based on the density groups (high, medium, low and random). Seven LVL panels were prepared with different experimental variables. As an example, 13 veneer sheets were selected as the low density group with an average density of 0.36 g/cm^3 to make a 13-ply LVL panel. The glue spread was 35 lb/1000 ft^2 per single glueline (all the other conditions were the same as the VPress® input). During hot-pressing, the innermost glueline temperature and gas pressure were monitored by the PressMan® software. Figure 14 shows the PressMan® plot. Comparing Figure 13 with Figure 14, it can be seen that the model prediction of temperatures at gluelines (innermost and two plies below the surface) agrees well with the experimental temperature measurements. The other panels showed similar results.

6.3 Vertical density profile

Similar to other wood composites such as OSB and MDF, vertical density profile (VDP) has a drastic effect on stiffness and strength of LVL/plywood products. Examining density formation helps understand the mechanism of panel densification and effect of hot-pressing strategy on panel performance. Figure 15 shows the density profile (batch average) through the thickness of 13-ply spruce LVL with veneer density of 0.401 g/cm^3.

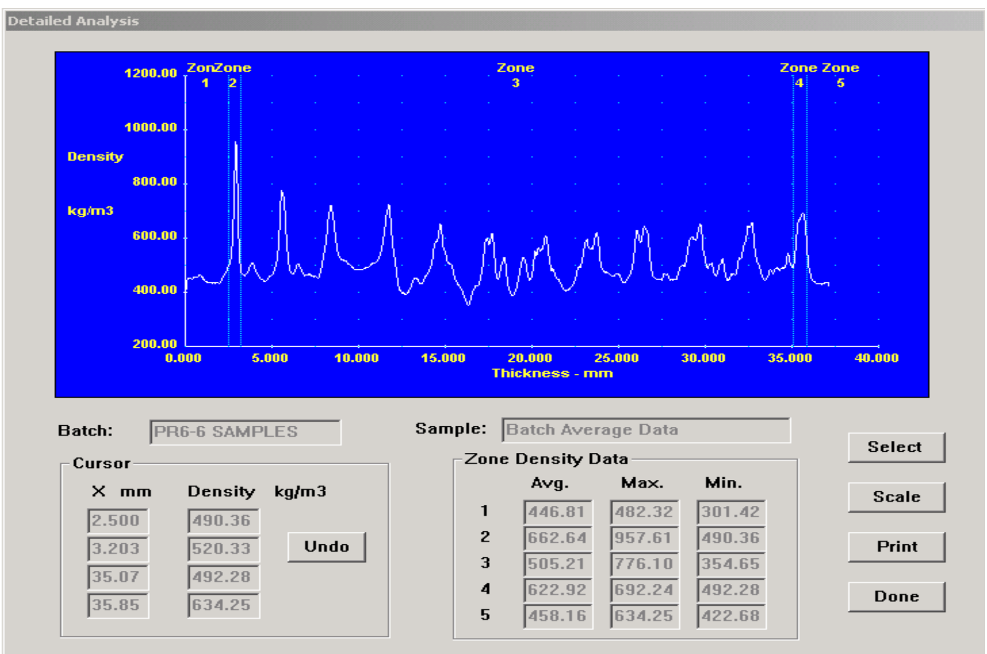
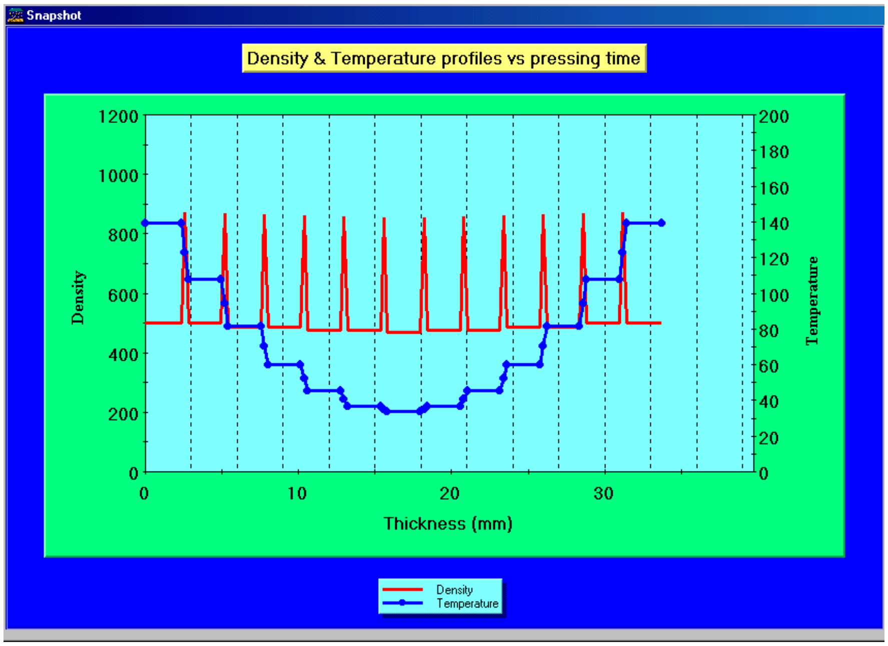
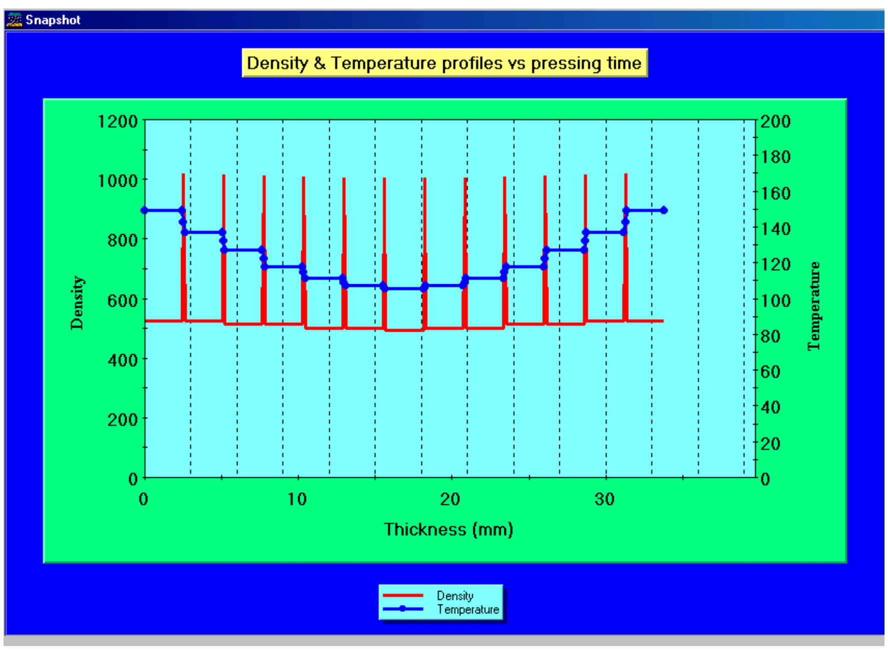


Figure 15: Density profile of 13-ply spruce LVL (batch average)



a) at 300 seconds



b) at 1100 seconds

Figure 16: Simulated density and temperature profiles with VPress®

Comparing Figures 15 and 16, it can be seen that the VPress® captures the trend of vertical density distributions with the same magnitude of peak density in the glueline. In reality, the glue penetration during pressing seems more significant than the model assumed. Due to this extended wood-glue mix zone, the peak density at the glueline appears to be smaller.

7 Conclusions

From this work, a prototype hot-pressing simulation model VPress® has been developed for the first time to simulate the heat and mass transfer and panel densification for veneer-based wood composites. By introducing wood-glue mix layers, the role and contribution of distinct gluelines to heat and mass transfer and panel deformation during hot-pressing was quantified. The simulation model can capture the trends of temperature, gas pressure, moisture and density during hot pressing. Specifically, the predicted temperature profiles of veneer plies and gluelines (especially at the innermost glueline) agree well with the experimental measurements. Hence, the model can be used to evaluate the sensitivity of the main raw material and manufacturing variables on hot-pressing time (productivity), panel compression (material recovery) and vertical density profile (panel stiffness). This hot-pressing model is the first step in facilitating the optimization of the pressing process and enhanced product quality.

8 Recommendations

However, the hot-pressing process of veneer-based products is very complex, involving many material variables, process variables and pressing control variables. To make the model prediction more accurate, it is deemed necessary to characterize 1) the time-dependent heat and mass transfer behavior of the glueline and 2) the heat and mass transfer and transverse compression behavior of basic element (veneer-ply) of veneer-based wood composites at different moistures, densities and glue spreads and elevated temperatures. To make the model more practical, efforts are needed to determine the effects of the hot-pressing process and resulting panel densification on panel quality and stiffness properties. Further work is needed to refine the algorithm with more available experimental data, and continue to upgrade the VPress® simulation model.

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