Hot Pressing of Wood-Based Composites: A Review

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Abstract

The hot-pressing process is a vital step in the manufacture of wood-based composites and directly affects the properties and quality of the final products. During hot pressing, the heat and mass transfer process interact with each other, coupling with the mechanical deformation process of wood-based composites under the high-temperature interaction. In addition, the curing of resin, although governed by the laws of chemical reactions, can result in the release or absorption of heat and water, which may, in turn, affect the heat and mass transfer process. Realizing its complex and coupling nature, many scientists have conducted long-term, multisided and multilevel studies to better understand hot pressing. This work reviews the development of wood composite hot pressing, including the heating methods of hot pressing, the mechanism of heat and mass transfer, the hot-pressing models, and the experimental testing of the internal environment. The shortage of current studies and potential directions for future research are also discussed.

Wood-based composites are usually manufactured by consolidating mats of resinated wood material (veneers, particles, or fibers) under heat and pressure for a certain period of time (Dai and Yu 2004). Owing to the difference of raw material elements, wood-based composites can be divided into two types, namely, veneer-based wood composites and non–veneer-based wood composites (Dai et al. 2005). Plywood was the first created wood-based composite, followed by particleboard and fiberboard (Shi 2011).

During the hot pressing of wood-based composites, heat transfer from an external heat source increases the temperature of the mat, and results in water evaporation, a gas pressure change, and moisture migration. Moisture migration also affects heat transfer. The hydrothermal effect softens wood material and thus facilitates mat densification. Conversely, the change in mat density can greatly affect the heat transfer and moisture flow (Dai and Yu 2004). In general, hot pressing wood-based composites involves the mechanical deformation of the mat, physical changes, and chemical reactions, which all interact with each other. Coupled with the raw material variability, it is very hard to essentially understand the hot pressing of wood-based composites. Since the 1950s, people have realized that the hot-pressing process for wood-based composites is very important and complex. To mitigate the associated confusion, many scientists have conducted several investigations. This article reviews and analyzes the research results related to the internal environment in the hot-pressing process of wood-based composites to provide reference points for further study.

Heating Methods for Wood-Based Composites

The heating methods for wood-based composites are mainly classified into contact heating and noncontact heating (Yu et al. 2004, Wei et al. 2014). Contact heating refers to a heating process in which the heat source transmits its energy to the platen via the media and the platen then heats the mat. Under the condition of heat and pressure, the resin can be allowed to cure after a period of time. The cured resin forms bonds between wood elements and thus creates integrated products. Heating is necessary not only to shorten the resin curing time, but also to soften the wood material, allowing a high degree of mat densification to be

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achieved under conditions of minimal pressure. The densities of the compressed panels are usually uneven and are characterized by high density in the surface layers and low density in the core. This vertical density distribution results from the temporal and spatial interactions between the mat pressure and the heat and mass transfer (Dai and Yu 2004). The hot-pressing process is clearly of great importance in governing the production and physical and mechanical properties of wood-based composites, which also affects energy consumption. The thicker the mat, the more time required for heating, and the corresponding energy consumption is greatly increased. Thus, contact heating is not suitable for heating thick wood-based composites.

The principle of noncontact heating, namely dielectric heating, can be described as follows. As a dielectric, wet material is put in the alternating electromagnetic field and generates heat energy via the constantly rotating friction of polar molecules. Noncontact heating mainly includes high-frequency (HF) heating and microwave (MW) heating (Pereira et al. 2004). HF and MW heating have been successfully used in industrial drying and heating. When heating or drying materials, HF is usually used to heat the absorbed water, and MW is used to heat liquid or capillary water (Pereira et al. 2004). The dielectric heating used in the wood industry has a 60-year history. Based on modern technology and equipment, the use of dielectric heating for wood drying and bonding has an obvious advantage in terms of efficiency. According to the retrieved literature, many studies investigate the dielectric drying of wood and curing of resin. In the HF heating of wood-based composites, the platens of the press are also the plates of an HF electric field. The pressed mat generates energy to increase the temperature and resin curing due to the effect of the HF electric field. HF heating can be used for preheating or hot pressing of wood-based composites, which can shorten the heating cycle and reduce the hot-pressing temperature. Moreover, it makes the manufacturing of thick panels in a short period of time possible (Malony 1989). Owing to the insufficient understanding of a coupling effect between the HF electric field and wood-based composites, the technology has not been reasonably used in the manufacture of wood-based composites. Fiberboard made by HF heating, instead of with the contact hot pressing, has better machinability and coating abilities, higher dimensional stability and internal bonding, and improved edge screw-holding strength and hardness. Because of its more uniform vertical density profile (VDP), the final product has slightly lower bending strength and stiffness. However, the information regarding the use of dielectric heating in the manufacture of wood-based composites is relatively insufficient (Fahey 1976, Wooden and Stevens 1977, Pereira et al. 2004), and this technology has not been applied on a large scale (Wang, X. M. 2007).

In addition, researchers have tried other new heating methods, such as steam-injection hot pressing. During steam-injection hot pressing, high-temperature saturated steam is sprayed vertically from the mat surface to the core. The rapid movement of the steam greatly improves the efficiency of heat transfer (Wang and Liu 1995, Xu et al. 2000). Thus, this type of heating is more suitable for thick panels.

Heat and Mass Transfer Mechanism of Wood-Based Composites during Hot Pressing

On the basis of previous research, Thömen (2000) described the heat and mass transfer of wood-based composites during contact heating (as shown in Fig. 1). The mat came into close contact with the hot platen and was heated via heat conduction. With the surface temperature of the mat rising, the absorbed water existing in the cells or in the resin began to evaporate. Water evaporation first caused a gap pressure increase in the outermost layer, which then formed a pressure gradient, thereby bringing a steam flow with heat. When the steam flow came into contact with the cooler layer of the mat, some water vapor condensed and then released heat. Owing to the incensement of moisture content (MC), the temperature of the cooler layer rose rapidly. Until the MC of this layer reached the maximum, heat by conduction from the surface of this layer started to evaporate water. In this way, the layers of evaporation and condensation gradually moved back to the core. With the heat and moisture transferring from the surface to the core, the temperature and gas pressure developed in the plane, resulting in the escape of heat, water vapor, and air from the edge of the mat.

However, the hot-pressing process is not only a phenomenon of heat and mass transfer, but it also combines with wood deformation under high temperatures and a chemical reaction of the resin in the specific internal environment of mat. Thus, a variety of different physical changes and chemical changes are intertwined in a complex way. Dai and Yu (2004) described this complex process of the contact heating of wood-based composites, as shown in Figure 2. Figure 2 shows the heat and mass transfer of wood-based composites during contact heating. The core of this process was based on the law of mass and energy conservation for predicting mat environmental conditions, such as temperature and MC. As for contact heating, heat conduction and convection were viewed as the two most important heat transfer methods, and the relation of gas flow and thermodynamics determined the gas flow velocity and pressure. Resin curing also affected the heat and mass transfer through heat generation or absorption (water generation or consumption resulted from resin curing). Following the physics principles, the mat environmental conditions were controlled externally by press operating parameters and internally by mat properties. While the mat was pressed under heat and pressure, both the mechanical

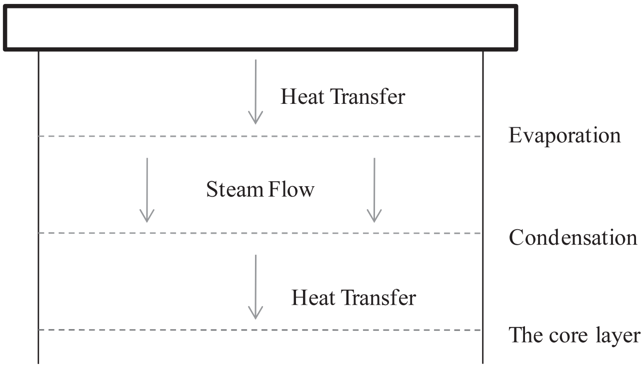

Figure 1.—Evaporation and condensation process during contact hot-pressing (adapted from Shi 2011).

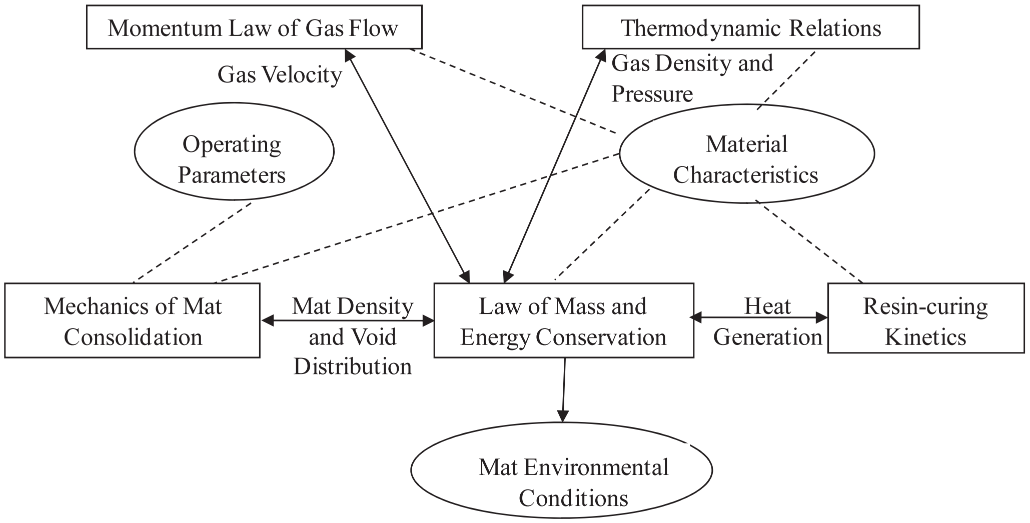

Figure 2.—Heat and mass transfer process of wood composites during hot pressing (reprinted with permission from Dai and Yu 2004).

deformation process and the heat and mass transfer process interacted with each other. Heat and moisture softened the material and thus facilitated mat densification. Conversely, the change of mat density significantly affected the heat and mass transfer. Wood-based composites were hydrophilic and porous and thus the heat transfer inevitably caused the flow of moisture, or vice versa. In addition, the curing of resin, although governed by the laws of chemical reactions, resulted in the release or absorption of heat and water, which may in turn have affected the heat and mass transfer. The bonds formed between the resin and wood elements also had an effect on the mat deformation behavior, particularly springback during and after pressing (Dai et al. 2000).

As for contact hot pressing, Bowen (1970) noted that 76 percent of the energy came from the hot platen, 2 percent from the heat released because of compression, and 22 percent from the exothermic reaction of curing resin (Bowen 1970). However, Humphrey and Bolton (1989a) argued that Bowen had overestimated the heat released during resin curing. To simplify the model, Shi (2011) proposed that the hot platen is the only source of heat.

The HF heating is special in that, because of the coupling effect of the dielectric properties of the mat and electromagnetic energy, electromagnetic energy is converted into heat, i.e., the so-called inner heat source (Shin 1998). The following formula is thus used (Wei et al. 2014):

$$\Phi = \omega \varepsilon_0 \varepsilon_r'' E^2 = 5.56 \times 10^{-11} f \varepsilon_r'' E^2 \qquad (1)$$

where Φ is the absorption of the unit volume of material power (W/m^3 or J/m^3, s); ω is the angular frequency (rad/s), $\omega = 2\pi f$; f is the radiation frequency (Hz); ε_r'' is the relative dielectric loss factor; and E is an effective electric field intensity (V/m).

Generally, there are three types of heat transfer, namely, heat conduction, convection, and radiation. Dielectric heating is considered the fourth type of heat transfer (Koumoutsakos 2001). When the temperature gradient exists in the mat, heat transfer occurs. During contact hot pressing, the hot platens provide heat to the cold mat, and heat conduction is the main type of heat transfer (Humphrey 1982). However, in the HF electric field, owing to the different dielectric properties of wood and resin, the partial absorption of electromagnetic energy in the mat is different, which will lead to the temperature gradient. In addition, wood with anisotropic and inhomogeneous features also produce temperature differences (Hansson and Antti 2008); thus, heat conduction is still important in HF heating. The proportion of the mat's internal heat transfer by conduction was just controversial for different products (Thömen 2000, Yu et al. 2007). B. J. Wang (2007) calculated the proportion of heat conduction and convection along the thickness direction in the hot pressing of laminated veneer lumber (LVL) and found that the percentage of heat convection was only 1 percent. However, the contribution of heat convection was greater for non–veneer-based panels such as medium-density fiberboard (MDF) and particleboard owing to the difference in short and discontinuous elements. For heat radiation, it is the energy emission of the matter under a certain temperature. Generally speaking, heat radiation for porous media is more important at high temperatures. Chen and Churchill (1963) conducted a study of a dry glass bed. The results showed that heat radiation was only less important than heat conduction under the temperature of 200°C (Humphrey 1982). In fact, the temperature of the mat is generally below 200°C during hot pressing of wood-based composites. Therefore, energy transfer via heat radiation is very limited. Kollmann and Malmquist (1956) noted that heat radiation may be more obvious in the early stages after the press closed, whereas the density of the mat was as low as 0.20 to 0.30 g/cm^3 (Humphrey 1982). However, there are only a few seconds when the mat remains at a density of 0.20 to 0.30 g/cm^3 while compressed from the initial stage to the densified stage. Therefore, heat radiation in the hot-pressing process of wood-based composites should be neglected.

Because the hot-pressing process involves a mechanical process, a physical process, a chemical process, the interactions among these processes, and the variability of raw material, it is very hard to completely understand this process. More than 50 years ago, people realized that the hot-pressing process of wood-based composites was so complicated that a better understanding needed modeling of hot pressing.

Research Progress of the Hot-Pressing Modeling for Wood-Based Composites

In accord with the developmental sequence of wood-based composites, the hot-pressing simulation also started with plywood, followed by particleboard, and then fiberboard. However, there has not been much research performed on hot-pressing models for plywood. According to the published documents, B. J. Wang (2007) was the first to systematically study the characteristics of heat and mass transfer during the contact heating of veneer-based wood composites (plywood and LVL). Wang noted that permeability measured the ease with which fluids moved through a porous material under the influence of a pressure gradient. During the hot pressing of LVL, a panel's transverse (vertical) air permeability determined the degree of penetration and diffusion of hot gas. Wang studied the influence of the air permeability of the veneer and resin layer on the hot pressing of a panel. The results showed that compression was the most important factor affecting air permeability, followed by the veneer sapwood–heartwood composition, the glue spread level, and the degree of resin curing. With a compression ratio (CR) of 5 percent, veneer permeability decreased by 80 percent. When the CR was 23 percent, veneer permeability decreased by 93 percent (Wang et al. 2006). For veneer-based wood composites, compression is necessary to ensure that the veneers can bond with one another. A thickness control is generally used to achieve a target CR from 5 to 15 percent. Because of the wide application of low-grade wood for the manufacture of veneer-based wood composites, a higher CR is needed to achieve good bond quality and stiffness. Thus, heat convection along the thickness direction is restricted. In other words, when the veneer CR is more than 5 percent, heat convection can be ignored. On the basis of the laws of mass conservation, energy conservation, the momentum equation, and the ideal gas state equation, B. J. Wang (2007) established a one-dimensional numerical heat and mass transfer model for veneer-based wood composites during contact hot pressing and then verified the correctness of the model through several experiments.

On the basis of B. J. Wang's study (2007), Wei et al. (2014) considered the particularities of HF heating and established a one-dimensional model of LVL during HF heating. The HF hot-pressing mechanism of heat and mass transfer for LVL was thus preliminarily revealed.

Over the past few decades, tremendous efforts have been devoted to hot-pressing simulations of nonveneer-based wood composites (particleboard and fiberboard), resulting in various simulation models with different levels of complexity (Kelly 1977, Bolton and Humphrey 1994, Lenth and Kamke 1996, Carvalho et al. 2001, Dai and Yu 2004, Thömen and Humphrey 2006). In most cases, the responses of temperature, gas pressure, and MC have been addressed. Mat consolidation or deformation has been the focus of other studies (Dai and Steiner 1993, 1994a, 1994b, 1994c, 1997; Suo and Bowyer 1994; Lang and Wolcott 1996; Winistorfer and Yong 1996; Xu 1999; Dai et al. 2000; Clouston and Lam 2001; Dai 2001).

The hot-pressing models for particleboard have experienced a shift, moving from one dimension to two or three dimensions. The one-dimensional hot-pressing model represented an exploratory stage for early researchers, including Bowen (1970). Humphrey and Bolton (1989a) proposed a two-dimensional hot-pressing model on the basis of previous studies. In this model, they studied the heat and moisture transfer of cylindrical particleboard in the longitudinal and radial directions, considering the phase change of water in the mass transfer process. Simulations via modeling could predict the responses of temperature and steam pressure versus time in the mat, and simulations mostly agreed with the experimental results. However, in the process of deriving this model, because of the lack of relevant research, many parameters, such as the thermal conductivity coefficient and the permeability coefficient, involved in the process of heat and mass transfer, only referred to empirical values of solid wood, which undoubtedly affected the accuracy of the model's predictions. Later in the development of the model, people modified the heat and mass transfer model on the one hand and studied the parameters of the heat and mass transfer via modeling and experiments on the other. For example, von Haas et al. (1998) measured the permeability of pine particleboard and fiberboard with different densities. Later authors (Thömen 2000, Dai and Yu 2004) used the empirical formula for permeability versus density. Using the model to solve heat and mass transfer parameters (Dai and Steiner 1994a, 1994b) and porosity and permeability parameters (Dai and Yu 2004), researchers improved the model's precision by obtaining heat and mass transfer parameters via experiments and modeling. It is worth mentioning that Humphrey (1994) introduced the rheology model into the original hot-pressing model, which greatly improved the original model's prediction and made it possible to predict the vertical density of the panel. Subsequently, hot-pressing models such as those of Zombori et al. (2003) and Dai and Yu (2004) were essentially established on the basis of Humphrey's model.

The development of hot-pressing models for fiberboard surfaced relatively late, but it developed very rapidly on the basis of the hot-pressing models for particleboard, including some three-dimensional models of heat and mass transfer and rheology established by Carvalho and Costa (1998), Thömen (2000), and Carvalho et al. (2003). In those models of Carvalho and Costa (1998) and Carvalho et al. (2003), the evolution of the dependent variables with time and the horizontal and vertical profiles agreed qualitatively with experimental data. However, the polycondensation reaction and the prediction of the mat densification were not considered. For the model developed by Thömen (2000), important features added in the previous model (Humphrey 1982) were air as a component of the within-void gas mixture, molecular diffusion of vapor and air, and a structural model to predict the cross-sectional density profile. A three-dimensional grid in the Cartesian coordinate system was used instead of a circular one. Further, a strategy was developed and implemented to simulate continuously working presses. However, the kinetics of adhesive polymerization and associated bond strength development were not yet considered in this model.

On the basis of contact hot pressing of wood-based composites, Pereira et al. (2004) established a heat and mass transfer model for the HF heating of fiberboard and verified it by experiments, revealing the mechanism of HF hot pressing for fiberboard.

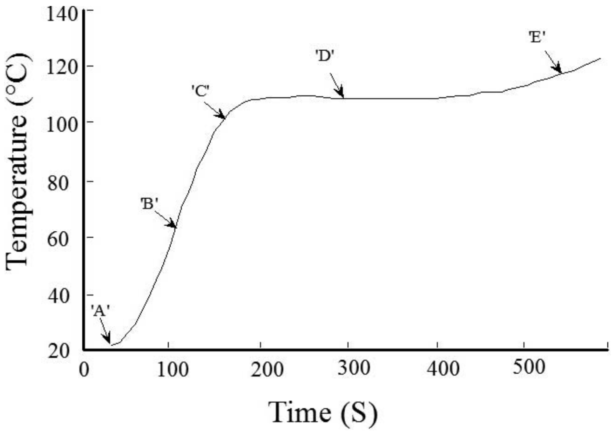

Figure 3.—Temperature curve of the core layer versus heating time (reprinted with permission from Bolton et al. 1989).

There are very few studies on the hot-pressing model of wood-based composites in China. Only studies such as Xie et al. (2003) and Wang (2008) established a one-dimensional heat conduction empirical model for the hot pressing of fiberboard, regardless of mass transfer. Bao (2006) used phenomenological theory to develop a one-dimensional heat and mass transfer statistical model for MDF hot pressing, but the differences between the model's output results and the experimental values were considerable. It was supposed that there was a major gap between China and developed countries in the hot pressing of wood-based composites.

Measurement of the Internal Environment of Wood-Based Composites during Hot Pressing

Measurement of the internal environment of wood-based composites during contact hot pressing

A quantitative understanding of the change rule of the mat's internal environment (temperature, humidity, and air pressure) is key in ensuring the quality of panels. Many scientists have attempted to measure the internal environment of wood-based composites during contact hot pressing using experimental methods. The basic idea was to use sensors to collect information of the internal environment.

Starting in the 1950s, some researchers, such as Maku et al. (1959), Strickler (1959), and Grasser (1962), began to measure temperature change of wood-based composites during contact hot pressing by inserting thermocouples into the mat. In the late 1980s, Hata (1994) studied the temperature distribution of particleboard during hot-platen pressing and steam-injection hot pressing by a similar method and found that the efficiency of steam-injection hot pressing was much higher than the hot-platen pressing. Notably, Humphrey and Bolton (1989b) not only studied the hot-pressing model for plywood but also obtained the temperature curve via experiments. On the basis of their research results, the core layer temperature of wood-based composites during contact hot pressing can be divided into five phases (Bolton et al. 1989) (Fig. 3): (1) very little change or almost no increase; (2) rapid increase; (3) slow heating; (4) very little change or almost no increase; and (5) gradual temperature rising.

On the basis of the experimental results, Humphrey and Bolton (1989b) further analyzed the effects of mat MC, panel density, hot-pressing temperature, and panel thickness on the temperature and gas pressure changes within the mat. (1) If the initial MC was higher, the temperature rose more rapidly in the second phase, but the increasing temperature slowed in the third and fourth phases. Therefore, the higher initial MC of the mat affected the temperature needed to cure resin in a relatively economic hot-pressing time. (2) There was higher panel density and slower heating speed in the second phase, longer times in the third and fourth phases, and a higher equilibrium temperature in the fourth phase. (3) Thinner panels led to faster temperature increases in the second phase and shorter times in the third and fourth phases, and a higher equilibrium temperature in the fourth phases.

Kamke and Casey (1988) proposed one way to measure the gas pressure changes inside the mat. Factors affecting internal pressure such as instrument design, sensor placement, initial MC, and platen temperature were studied. The results showed that a lower initial MC and platen temperature led to lower gas pressure inside the mat, and there were no other differences between the surface and core layer; when the mat's initial MC and temperature were higher, the gas pressure of the surface layer was higher in the initial stage. In addition, the gas pressure in the core layer showed no obvious change over a 2-minute period after press closure. In comparison with saturated vapor pressure under the same conditions, the gas pressure of the surface layer was far less. However, that of the core layer was similar to the saturated vapor pressure curve over a 4-minute period after press closure. Later, Humphrey and Bolton (1989b) established a theoretical model for the contact hot pressing of wood-based composites and developed an instrument for measuring the internal temperature and the pressure in the industrialized continuous process of MDF (Steffen et al. 1999).

Wang and Winistorfer (2000) and Wang et al. (2004) used the ray spectrum technology to measure the formation of VDP and moisture migration in the thickness direction during contact hot pressing. A more profound understanding about moisture migration in the contact hot pressing of wood-based composites was obtained.

Scientists in China have mainly focused on the experimental study of internal mat temperature. Liu and Cai (1992) tested the temperature response to the hot pressing of particleboard using a thermocouple; Zhang and Li (1993) examined the relationship between the internal MC, the moisture distribution, and the heat transfer rate inside the particleboard; and Liu et al. (1995) studied the effect of target density, thickness, platen temperature, initial MC of the mat, water spread using a steam hammer, and concentration of additives on the internal environment of particleboard. Previously, Xu and Hua (2002) studied the interior temperature distribution of waferboard; others studied the contact hot-pressing heat transfer of dry-process fiberboard (Xie and Chen 2005), particleboard (Xie and Niu 2005), and low-density particleboard (Xie and Liu 2005). Lin et al. (2004) studied the heat transfer speed of the veneer-based wood composites during contact hot pressing and found that moderately increasing platen temperature and MC of veneer could speed up the heat transfer. Lei (2006) investigated the internal heat transfer and temperature distribution of particleboard during contact hot pressing. Other similar studies are not discussed here.

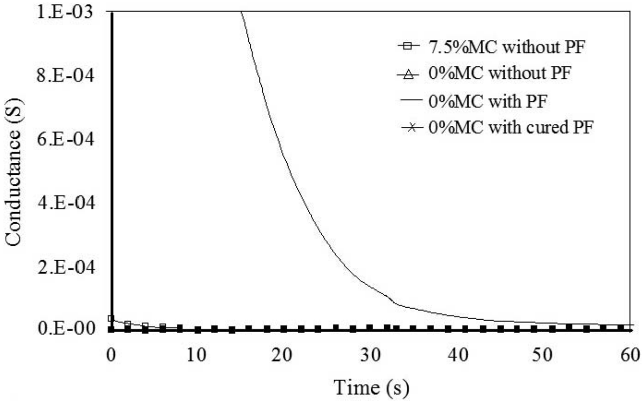

Figure 4.—Relationship between the mat conductance and the hot-pressing time at a temperature of 160°C. MC = moisture content; PF = phenolic resin (reprinted with permission from Sernek and Kamke 2007).

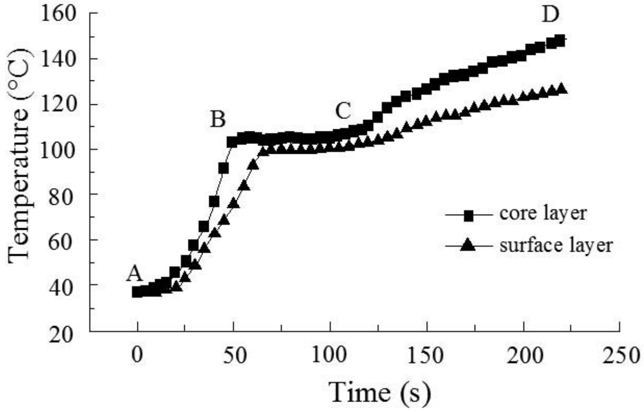

Figure 5.—Temperature distribution versus hot-pressing time along with the thickness direction of the mat (adapted from Wei et al. 2013).

In China, few experimental studies have been conducted on the internal MC change during contact hot pressing. Sun and Sa (1996) invented a temperature and humidity sensor to measure the MC in the mat during contact hot pressing, which was an early attempt in this field. Chen (2006) measured the mat's internal MC using a resistance moisture tester.

Measurement of the internal environment of wood-based composites during noncontact hot pressing

The noncontact hot pressing of wood-based composites includes HF hot pressing and MW hot pressing. As for the dielectric properties of wood, Torgovnikov (1993) conducted a systematic study. However, researchers have seldom studied the dielectric properties of resin. From its liquid state to solid state, resin experienced a complex process, including chemical reaction and phase change of water (evaporation) and wood absorption. Resin curing involved the same chemical reaction as prepolymers and syntheses (Odian 2004). Sernek and Kamke (2007) used a dielectric analysis to study the curing process of phenol resin in the continuous compression of a panel to prove that the change in the resin's dielectric properties resulted from resin curing rather than from moisture migration or other changes. Four groups of tests were designed. The first group tested two pieces of wet veneers with a MC of 7.5 percent and no resin, the second group tested two pieces of dried veneers with a MC of 0 and no resin, the third group tested two pieces of dried veneer with resin and a MC of 0, and the fourth group tested two pieces of dried veneers with cured resin and a MC of 0. Scattering field sensors were placed in between the veneers and then accessed through the inductance capacitance resistance (LCR) meter. Information on changes in the dielectric properties during the resin-curing process was obtained, as shown in Figure 4.

Owing to the particularity of HF heating, metal components were not allowed in the HF electric field because they would affect the distribution of the electric field and the heating uniformity and would have easily produced an electric spark. In addition, the HF electric field had an induction effect on the measuring instrument and even burned it out, which resulted in inaccurate test data. Thus, in HF hot pressing, special methods were needed for measurements of the mat's temperature, mainly using an alcohol thermometer, a thermocouple, and an optical fiber temperature meter (Wei et al. 2013). Using an alcohol thermometer, holes must be made in the resin layer, and the alcohol thermometer can then be inserted in the holes to measure the temperature, as once carried out by Lu (1986) and Yu (2007). With this method, the alcohol thermometer was not affected by the electromagnetic field, and the data were stable. However, the disadvantage of this method was its limited response and fragility. Therefore, it was not very suitable for measuring the temperature response during HF hot pressing. The method using a thermocouple was intermittent. When the mat was put into the press, the thermocouple was placed on the resin layer. However, the temperature measurement line was disconnected when opening the HF press. Once the HF press was closed, the temperature measurement line should be immediately connected to measure the temperature. This method was adopted by Wu (1990) and Chen et al. (2010). Obviously, its shortcoming was that the temperature cannot be continuously acquired. An optical fiber temperature sensor was not affected by the HF electromagnetic field, and it could accurately and continuously collect the mat's internal temperature. Wei (2014) used HF heating to manufacture straw-based particleboard, and the fluorescence optical fiber temperature sensor was used to measure the temperature response, as shown in Figure 5. The figure shows that a temperature difference existed within the mat along the thickness direction during HF heating, and the overall temperature distribution included a high temperature in the core layer and a low temperature in the surface layer. The heating process could be divided into three stages, namely, AB for rapid temperature rise, BC for water escape, and CD for slow temperature rise.

Wei et al. (2014) established a one-dimensional heat and mass transfer model of LVL during HF hot pressing and investigated the change rule of the mat's internal temperature using an optical fiber thermometer (Fig. 6). The experimental results and numerical simulation results were then compared (Fig. 7).

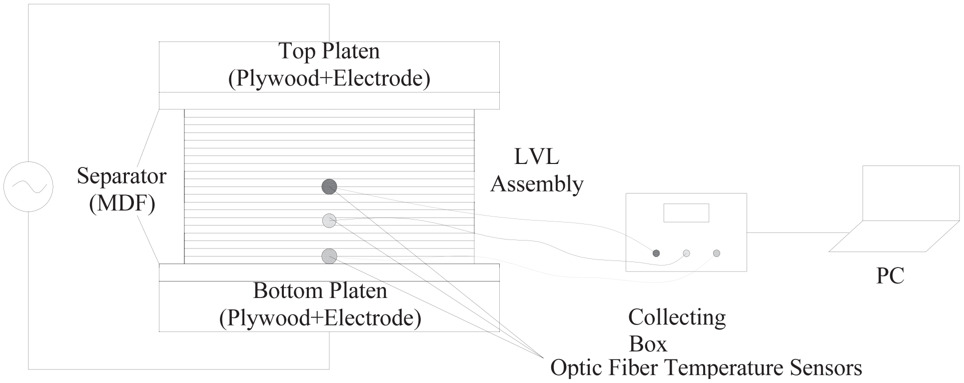

Figure 6.—Schematic representation of the laminated veneer lumber (LVL) panel of the high-frequency heating apparatus. MDF = medium-density fiberboard (reprinted with permission from Wei et al. 2014).

Conclusions and Suggestions

This article reviews the research progress in the field of the hot pressing of wood-based composites, including research about heating methods, mechanisms of heat and mass transfer, heat transfer and mass transfer models, and internal environment measurement of wood-based composites during hot pressing. Scientists in this field have insisted on conducting these studies and have obtained some remarkable results that have improved the understanding of the hot pressing of wood-based composites and offered considerable practical guidance. However, despite the considerable progress in this field of study, further research is still needed to better understand the hot pressing of wood-based composites.

1. The hot-pressing process of wood-based composites is dynamic. Heat and mass transfer combined with panel deformation, in addition to the porous properties of wood material and resin curing and the creep and springback characteristics of wood material, make the hot pressing of wood-based composites difficult to precisely predict. The current models for predicting temperatures are relatively accurate, but they are not accurate for the prediction of MC distribution and pressure change.
2. Resin cannot be ignored. For the sake of convenience, the influence of resin on contact and noncontact hot pressing is not always considered. In fact, this assumption can lead to errors between theoretical predictions and experimental results.

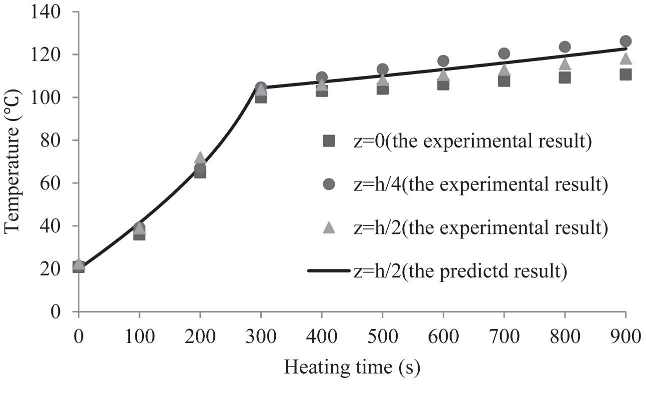

Figure 7.—Comparison of the experimental and numerical results (reprinted with permission from Wei et al. 2014).

3. For testing the internal environment of wood-based composites during hot pressing, the measurements for contact hot pressing have matured, but there are still blind spots for noncontact hot pressing.
4. Currently, the shortage of raw materials has caused enterprises to implement more sophisticated production practices and has also promoted the study of the hot pressing of wood-based composites that is more closely linked to actual production. It has also inspired future research to consider factors that have been previously ignored.

Acknowledgments

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