Chapter 6. Validation of the Transverse Compression Model

Summary

The connection between internal mat conditions and the final average vertical density profile was established, and the capabilities of the transverse compression model were demonstrated on a simulation run. The validation of the model among different pressing parameters is the focus of this chapter. The model predicted data were compared to experimental density profiles. Two experimental methods were applied; a continuous measurement of the density profile formation at three distinct locations through the thickness of the mat by an in-situ γ-ray device, and the measurement of the final vertical density profile of the panel by an x-ray scanning technique. The first approach gives insight into the formation of the vertical density profile during the press schedule, while the second technique provides more detailed data about the effect of the pressing parameters on the final vertical density profile of the panels. General trends in the change of the shape of the vertical density profile as a function of different pressing strategies (involving mat initial moisture content, panel final density, press platen temperature, press closing time) were adequately predicted by the model. However, the quantitative predictions require more refinements of the model parameters, most importantly a better understanding of the effect of temperature and moisture on the viscoelastic transverse compression properties of the flakes.

6.1 Introduction

The density of wood-based composite panels is not uniform in the thickness direction. A characteristic vertical density profile is formed, which is highly dependent on furnish properties, mat structure, and pressing conditions. The combined effect of the migrating heat and moisture within the mat severely reduces the compressive strength of the flakes perpendicular to the grain. The transient internal environment, combined with high compression pressure, forms the vertical density profile within the mat. The density profile of wood-based composites has a direct influence on all the relevant physical and mechanical properties of the finished panel. Some of the properties, most importantly the bending strength of the board, are significantly improved by a larger density gradient. Other properties, such as internal bond strength, interlaminar shear, and thickness swell, are adversely affected. Either a more pronounced or flat density profile is attainable by changing the pressing procedure. Therefore, the decision about production parameters is based on the required density profile of the panel. A large amount of data would need to be collected using different pressing conditions, to optimize the density profile of the board to meet end-use requirements. Developing such a database is time consuming, because it needs a considerable "trial and error" experimentation with the production process. A more rational approach is process modeling. A validated process model can predict the effect of production variables on the vertical density profile very quickly and efficiently. Only the production parameters identified by the simulation need to be tested experimentally, substantially reducing the time spent on research.

6.2 Background

The development of efficient production processes of wood-based composite materials based on extensive experimentation has been carried out over many years. It has been demonstrated by these experiments that there is a strong relationship between the vertical density profile and the final physical and mechanical properties of the board (Kelley 1977, Andrews 1998, Kawai and Sasaki 1986). Some of the properties, most importantly the bending strength, of the board are significantly improved by a steeper density gradient. The high density surface layer provides improved strength and stiffness to resist stresses imposed by in-plane bending. Because of the strong relationship between the vertical density profile and pressing parameters, an immense amount of information has been published on different pressing strategies to improve the final properties of the board (Stickler 1959, Andrews 1988, McFarland 1992, Heebink et al. 1972). The most fundamental experimental study was completed by Stickler (1959), who investigated the effect of press cycle, initial moisture content, and moisture distribution on the physical and mechanical properties of Douglas-fir flakeboards. The most influential parameters identified were initial mat moisture content, panel final density, platen temperature, and press closing time. The effect of these variables will be outlined in the context of the validation study.

During a typical pressing operation the mat includes moisture in the wood in a range of 5-7 %, and the addition of water-borne resin will further increase the moisture content. Occasionally, water is also sprayed on the surface of the panel to accelerate the vertical vapor flow, therefore accelerating the rate of temperature rise in the core of the mat. The moisture acts as a plasticizer, consequently the flakes densify, resulting in a more pronounced density gradient. Additionally, the ram pressure required to compress the mat to the target thickness is lower with increasing initial mat moisture content (Stickler 1959, Kamke and Casey 1988a, b). High mat moisture content results in a more pronounced density profile formation, effectively increasing the bending and tensile strength, and decreasing the internal bond, shear, and screw withdrawal characteristics of the board. Commonly, nonuniform moisture distribution is used in the industry to circumvent the adverse moisture effects on board properties, but retain the advantageous rapid heat transfer to the core.

Heebink and his colleagues (1972) in an extensive study examined the effect of various pressing parameters on the density profile formation. The investigated variables were wood species, particle geometry, board density, board thickness, moisture content and distribution, press time, press closing time, and platen temperature. They found that moisture content, moisture distribution, press closing time, and press platen temperature were the most important variables contributing to the vertical density formation, and all the other variables had only secondary effects. The density gradient was steepest when the moisture content of the surface was 15 % and the core layer 5 %. However, the gradient was relatively flat when the surface layer had a 5 % and the core a 15 % moisture content. These results agree with those reported by others. (Winistorfer and DiCarlo 1988, Strickler 1959, Andrews 1998).

Strickler (1959) in a comprehensive study investigated the influence of moisture content on the vertical density gradient formation. He assumed that a high moisture gradient forms during the pressing cycle in the case of high moisture content panels, and consequently the final density gradient is more severe. Although he did not measure moisture distribution within the mat, he could clearly prove that high surface layer moisture content increases the density of the surface layer while decreasing the density of the center layer. He concluded that, not only the initial moisture content, but also the moisture distribution can affect the vertical density distribution.

Andrews (1998) looked at the effect of moisture content on the maximum value of the density profile and the position of the density peak by subdividing the board into 5 layers. He clearly reinforced the previous findings that increasing moisture content enhances the vertical density gradient, and also demonstrated that the density peak actually moves closer to the surface.

The "steam shock" pressing method, based on the injection of hot steam into the mat, uniformly increases the moisture content and temperature of the interior of the mat, resulting in a more uniform density profile (Fharni 1956, Heebink et al. 1972, Geimer et al. 1975, Hata 1989a, b, c, d, 1993).

The information to an extent limited on the influence of panel final density and platen temperature on the vertical density profile. One reason might be their obvious effect on the shape of the profile. Stickler's (1959) test results showed that the density variation through the thickness of the board is more pronounced for higher target density boards. He supposed that the amount of moisture in high density boards is higher for the same moisture content, and therefore the distributed mass in the mat is also larger. Heebink et al. (1972) reported that the higher the platen temperature the faster the heat transfer towards the center of the board, and the maximum density peak is shifted towards the interior.

Geimer et al. (1975) investigating the effect of several production variables, also looked at the influence of panel thickness on the vertical density distribution. He found that thicker panels have steeper vertical density gradients. He postulated that the heat and moisture will reduce the compressibility of the thin boards more evenly through the thickness, resulting in a flatter density profile.

In a sense, the press closing time is the "heart" of the hot-pressing operation, the rest of the cycle allows the resin to cure and dissipates the steam so the board will not "blow" upon press opening. Furthermore, the press closing time is the production variable which is the easiest and quickest to adjust in a modern press without upsetting the press cycle (Smith 1982). Several reports concentrated on how board properties are related to press closing time (Suchsland 1962, Stickler 1959, Heebink et al. 1972). The press closing time does not influence the horizontal density distribution in the mat, consequently the average density of the mat will be the same with different closing times, but it has a critical effect on the vertical density profile formation.

Suchsland (1962) related the press closure rate to the time-dependent nature of the heat and mass transfer through the mat and their effect on the compressive strength of the flakes. Fast press closing will allow only the surface layer of the board to heat up, and the interior of the mat will be colder. This unequal temperature distribution will cause the reduction of the compressive strength of the surface layer, and this layer will be compressed the most, forming a large gradient in the vertical density profile. The slower the press closes to the final thickness of the panel, the more time is available for the center of the mat to attain higher temperature, resulting in more even temperature distribution. Therefore, the compressive strength of the flakes will be reduced evenly, and as the mat is compressed, the difference in density between the surface and the center of the board will be small. The press closing time is rarely increased in industrial press schedules, because the total press time determines the production capacity of the particleboard mill, and therefore the increased press closing time has an immediate and adverse effect.

Stickler (1959) found that rapid press closing results in high surface density and low core density. Plath and Schnitzler (1974) further improved the concept and showed experimentally that the press closing time not only influences the extent of the surface layer densification, but also the shape of the final density profile.

Both Geimer et al. (1975) and Heebink at al. (1972) confirmed that extremely rapid press closure time caused the highest density in the surface layer and a large vertical density gradient. As the press closing time was decreased the peak density moved towards the interior of the mat, and the gradient was less pronounced.

An original set of experiments completed by McFarland (1992) monitored the change of the density profile of aspen flakeboards in 16 vertical layers. The thin layers allowed a very accurate definition of the change in the shape of the vertical density profile. He clearly reinforced the previous findings that decreasing press closing time enhances the vertical density gradient, and also demonstrated that the density peak actually moves closer to the surface.

Andrews (1998) found that press closing time had the strongest influence on the face layer of a three-layer flakeboard. The density peak moved closer to the surface as press closure became faster, resulting in better bending characteristics of the board. This result was also demonstrated by Suchsland and Woodson (1987) in the case of medium density fiberboard (MDF). They also stated that a theoretical instantaneous press closing will not result in density profile development. This statement was based on cold pressing, obviously neglecting the plasticizing effect of heat and moisture. Suchsland and Woodson (1974) gave a schematic representation of the typical density profiles resulting from different closing strategies.

Smith (1988) further improved the concept that press closing time regulates the extent and the location of wood densification. He reported that the shape of the density profile is a function of the press closure rate, with a fast closing rate (30 s) causing "U-shaped", and a slow closing rate (100 s) causing "M-shaped" density profiles. He recommended fast press closing time because it provides denser face layers together with higher bending strength. However, he clearly neglected the adverse effect of fast press closing time on the internal bond strength of the board. He also claimed that the reduced face layer permeability will not cause a blow in the panel because the permeability of the less densified center of the mat is still high enough that internal steam pressure will not become excessive.

Wang and Winistorfer (2000) studied multi-step press closing strategies. Closing the press to certain positions and heating up the center layer before closing to the target position results in a more uniform density profile. Clearly, this is one more variable to affect the final density profile and the resulting mechanical properties of the board.

The above literature review indicates that production parameters affect the density distribution of the mat in the vertical direction. For research and quality control purposes direct and indirect methods were elaborated to determine the vertical density profile of composite panels. The resolution of the density profile measurement depends on the applied technique. Direct, gravimetric methods can provide only a limited resolution. The material is incrementally surface sanded or planed, and the volume and weight of the remaining specimen is determined providing a low resolution density profile. (Stevens 1978, Humphrey 1982). Several indirect, nuclear (Laufenberg 1986, Winistorfer et al. 2000, Wang and Winistorfer 2000a, 2000b), and x-ray (Nearn and Basset 1968, Steiner et al. 1978, Woodson 1977) techniques have been developed, and have become standard methods of analysis. Indirect methods use the attenuation characteristics of γ-rays or x-rays as they are transmitted through the material. Density measurement can be made to a resolution of 0.001 inch (Quintek Measurement Systems Inc. 1999). The density profile may be subdivided into zones, and the effect of pressing variables on the average density of the zones can be analyzed (Andrews 1998).

In addition, the shape of the density profile can be assessed with this technique. The advantages of the indirect measurement methods over the direct gravimetric method are that they are nondestructive, repeatable, faster, and more accurate (Winistorfer et al. 1986).

The techniques presented so far can determine the final density profile. The formation of the density profile during the pressing operation can be monitored with an in-press device described by de Paula (1992). The nuclear based method measures the attenuation of focused γ-ray beams emitted by an Cs^{137}radiation source at three distinct locations through the thickness of the material. The radiation sources are coupled with NaI crystal detectors, and a photo scintillation counting system. The sources and detectors move simultaneously with the press platens allowing their relative positions to remain at 25, 50, and 75 % through the thickness of the mat during the press cycle. The count readings are converted to density allowing the formation of the density profile to be monitored during the press closure and after the press reaches the target position. Using the in-press continuous density monitoring device, Winistorfer and Wang demonstrated that the density profile continues to change during the entire press cycle (Wang and Winistorfer 2000a, b, Winistorfer et al. 1998, 2000).

In spite of the considerable impact of pressing parameters on the density profile, the industry approach is mainly experimental, and only few attempts were made to predict it. The following study demonstrates the merit of the computational approach. The effects of pressing parameters on the density profile were clearly predicted by the developed model, and more refined material properties will allow quantitative predictions of the density profile formation.

6.3 Materials and Methods

6.3.1 In-situ Measurement of Mat Density

The in-situ vertical density formation measurements were completed in the Tennessee Forest Products Center, Knoxville, Tennessee in May, 1999. The Tennessee Forest Products Center has a hot-press equipped with an in-press, continuous, γ-ray density measurement apparatus as described by dePaula (1992). The device is based on the measurement of the attenuation of the intensity of radiation emitted by three γ-ray sources at different vertical locations through the mat. The movement of the three sources and detectors are synchronized with the movement of the hot platens, therefore their relative positions are always the same. Density measurements were obtained at top, middle, and bottom positions in the mat, representing distances from the bottom platen of 25, 50, and 75 % respectively. Figure 6.1. depicts the three in-press γ-ray sources.

Figure 6.1. The relative positions of the γ-ray sources mounted on the side of the hot press.

A Cs^{137} source, with photon energy of 663 keV, coupled to a NaI crystal detector and a photo scintillation counting system, were used during the radiation measurements. The determination of the density from the attenuated count rate (I) was based on the following relationship between the count rate before and after passing through the mat:

$$I = I_0 \, e^{-\mu_l \, t} \tag{6.1}$$

where

I = intensity of the radiation beam after passing through the material,

I_0 = intensity of the radiation beam before passing through the material,

t = sample absorbed thickness,

μ_l = linear attenuation coefficient.

The linear attenuation coefficient changes with the density of the absorber, and it can be derived as the product of the mass attenuation coefficient and the density of the absorber:

$$\mu_l = \mu_m \, \rho \, . \tag{6.2}$$

Substituting Eq. 6.2 into Eq. 6.1, the density of the absorber can be calculated as follows:

$$\rho = -\frac{1}{\mu_m \, t} \ln\left(\frac{I}{I_0}\right). \tag{6.3}$$

The mass attenuation coefficient (μ_m) was established through calibration experiments and has a value of 0.08238 cm^2 / g. The mass attenuation coefficient is not particularly material-sensitive, and therefore should not vary for most wood species. To calculate the density of the mat, air count data (I_0) were collected by executing the press schedules without positioning the mat in the press.

Thirty-six one-layer strand boards were manufactured among different pressing conditions to investigate the influence of production parameters on the vertical density profile formation. Strands from the face layer of OSB were obtained from a commercial OSB mill. The moisture content of the strands was 7 %. Liquid phenol-formaldehyde adhesive (45 % solids content) and powdered wax (100 % solid) were sprayed on the strands with a solids loading level of 7 % and 1% respectively. The strands were randomly hand-felted in a 457 x 457 mm (18 inch x 18 inch) forming box between two pieces of OSB panels. The strand mat between the panels was pre-pressed with 500 psi pressure. The compressed mat was fixed between the OSB panels at the compressed position by 4 screws at the corners. The loose edges of the mat were then trimmed with a bandsaw to a 406 x 406 mm (16 inch x 16 inch) dimension. The OSB panels were removed, and the strand mat was positioned on a metal caul plate. This special mat forming technique assured uniform edges and accurate dimensions of the mat, which was necessary for the accurate in-press radiation density measurements. The mat was compressed to a 19 mm (0.75 inch) target thickness in the laboratory hot press. The total pressing time was 360 s, which included the press closing time and a 40 s venting period. The initial opening of the press was 102 mm (4 inch).

The main objective of the experiment was to collect vertical density data using different compression parameters. Two different final panel densities (609, 673 kg/m^3 or 38, 42 lb/ft^3), three different press closing times (30, 45, 60 s), and two different platen temperatures (175, 200 °C) were considered in the experimental design as it is summarized in Table 6.1.

Table 6.1. Experimental design for the γ-ray density measurements, indicating three replications per treatment.

Final Density (kg/m^3) (lb/ft^3)	Press Closing Time (s) 30		45		60	
	Platen Temperature (°C)					
	175	200	175	200	175	200
609 (38)	xxx	xxx	xxx	xxx	xxx	xxx
673 (42)	xxx	xxx	xxx	xxx	xxx	xxx

Three boards were compressed at each condition. Internal temperature and pressure data was collected in the vertical midplane of the board at the core and 75 % from the bottom of the board in two panels with the same measurement apparatus which was described in Chapter 3.3. The radiation attenuation of the γ-ray at three locations through the thickness of the mat was collected during the manufacture of the third board. The attenuation data was converted to density data according to Equation 6.3. Preheating of the bottom face of the mat during the press loading is unavoidable, which resulted in an asymmetric density profile. The model predictions were symmetric. Therefore the average of the top and bottom densities measured at probe location 25 and 75 %, and the middle density measured at probe location 50 % provided the data for comparison.

6.3.2 Measurement of the Final Density Profile

The final vertical density distribution of the panels was measured by a commercial x-ray density profiler (QMS Density Profiler, Model QDP-01X, Quintek Measurement Systems, Inc., Oak Ridge, Tennessee). The instrument is shown in Figure 6.2.

Figure 6.2. The QMS x-ray density profiler.

The profiler can collect density data through the thickness of a 50.8 x 50.8 mm (2 inch x 2 inch) specimen with 0.0254 mm (0.001 inch) increments. The profiler moves the specimens in a stepwise manner in front of a highly focused x-ray beam. The attenuation of the beam is measured as it passes through the material. The density calculations are based on Eq. 6.3, but the provided software automatically converts the attenuation data to density data. The mass attenuation coefficient (μ_m) was set to the manufacturer provided 0.2517 cm^2/g. The same boards were used for the final vertical density measurements as were used for the validation of the heat and mass transfer model (see Chapter 4.). After the edges of the boards were trimmed, 81 specimens were manufactured from the panels at each pressing conditions. The average of the 81 measurements was considered as the final vertical density profile of the board. The 2 inch x 2 inch specimens were equilibrated at 20 °C and 65 % relative humidity before the x-ray density scans. The model predicts the vertical density profile at 0 % moisture content. For direct comparison of the measured and predicted final density profiles, the experimental data was converted to 0 % moisture content. The model predicted density profiles are symmetric to the horizontal midplane of the board, therefore, only half of the profiles are depicted in the results. The experimental profiles showed a slightly asymmetric shape due to the unavoidable preheating of the bottom part of the mat during the press loading. Therefore, the data presented is the average of the top and bottom half of the density profile.

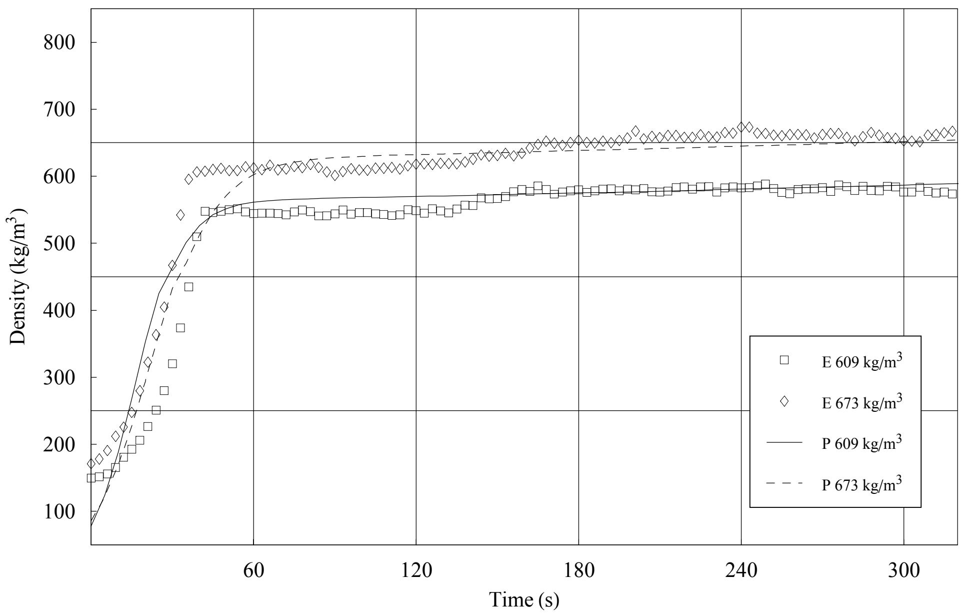
6.4 Results and Discussion

6.4.1 In-situ Density Measurements

Several general observations can be made from the results of the in-situ density monitoring experiments presented from Figure 6.3 to Figure 6.5. During the press closing time, all density curves reflect the rapidly increasing density of the mat as it is compressed to the target thickness which is most evident in Figure 6.5. This is the "uniform and nonuniform consolidation" stages of the vertical density profile formation (see Figure 5.16). Notice, that all the measured density plots show that the mat density continues to change after the press closure. Following the press closure the thickness of the mat is precisely controlled, therefore the average mat density would be constant after the press reached final position. The change of the density after press closure can be attributed to either the nonuniform relaxation of the material, or the influence of the migrating, escaping moisture on the density measurements (Winistorfer et al. 2000). It was verified experimentally that migrating moisture has an effect on the density readings, and the effect is more pronounced in the case of medium density fiberboard (MDF) than oriented strandboard (OSB) (Wang et al. 1999b). It was also demonstrated that the viscoelastic effects are far higher, than the moisture migration effects on the density measurements by comparing five layer OSB panels with and without Teflon separation among the layers. The Teflon did not let the moisture migrate between the layers, although the moisture still could escape towards the edges of the board. The influence of moisture migration on the measured vertical density of the mat was not accounted for in the comparison with the model results, which can explain part of the discrepancy between predicted and experimental results.

The measured density of the middle layer of the board declines after it reaches a peak value immediately after the press closure among all the different pressing conditions (Figure 6.3a, 6.4a, 6.5a). The face layer densities contrary to the middle layer densities, further increase after press closure (Figure 6.3b, 6.4b, 6.5b). This behavior pattern takes place during the time period after the press closing until approximately 120 s in the press schedule. The most probable explanation of the phenomena is the different relaxation rates of the mat due to differences in temperature and moisture content through the thickness. The largest temperature gradient exists between the surface and the core of the mat at this time during the compression. The higher temperature at the surface layers soften the wood flakes, providing lower compression modulus, and higher compaction. The slowly increasing temperature at the center is not high enough during this time period to plasticize the material, resulting in the springback of the flakes to counteract the densification of the surface layers. This period coincides with the third "surface layer consolidation" stage of the vertical density profile formation (see Figure 5.16).

a.)



b.)

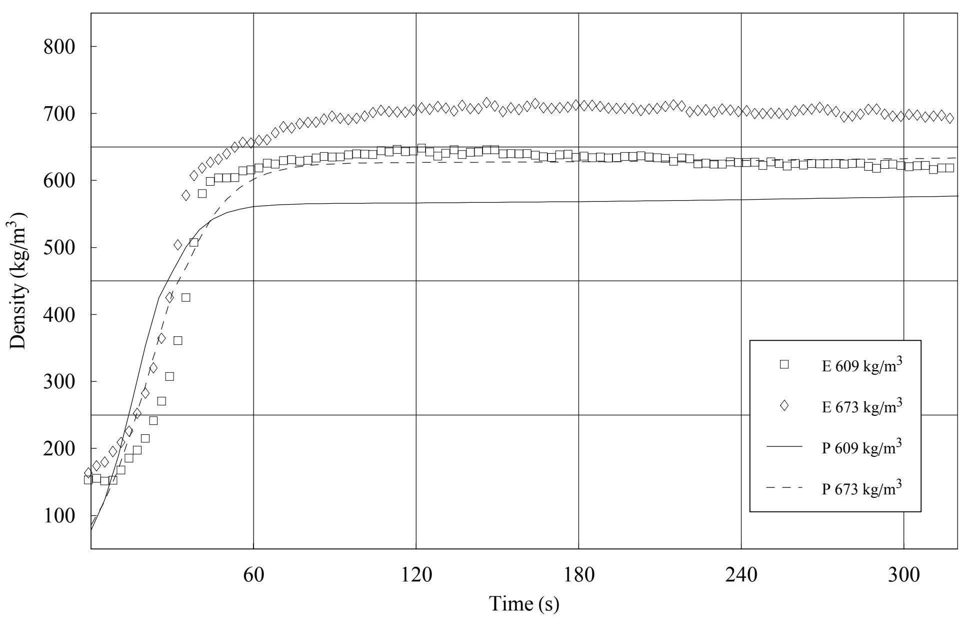
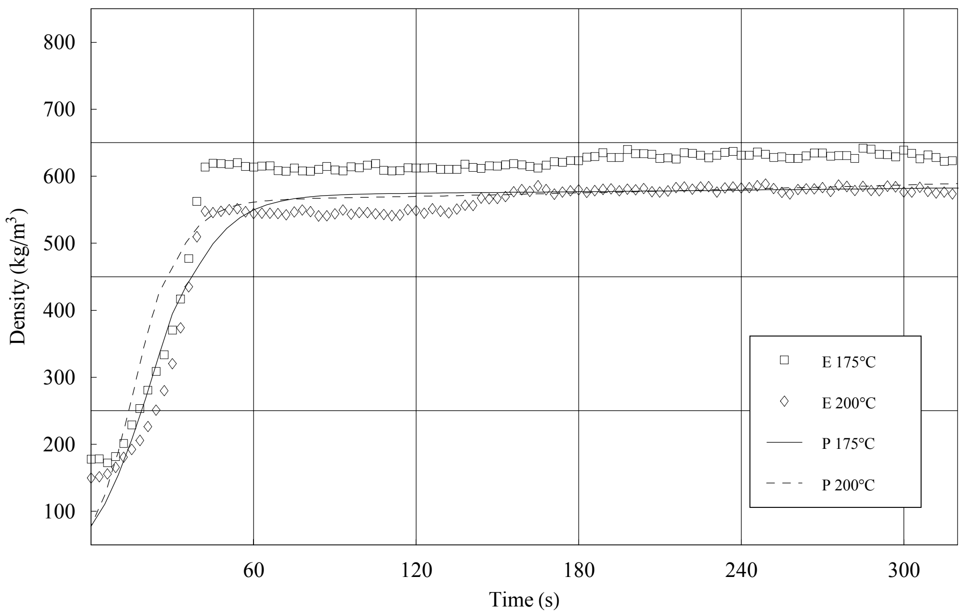


Figure 6.3. The effect of panel final density on the evolution of density at 50 % (a.) and 25 % (b.) locations in the mat during the press schedule. The two panel final densities were 609 kg / m^3 and 673 kg / m^3. The experimentally measured (E) and model predicted (P) data are overlaid.

a.)



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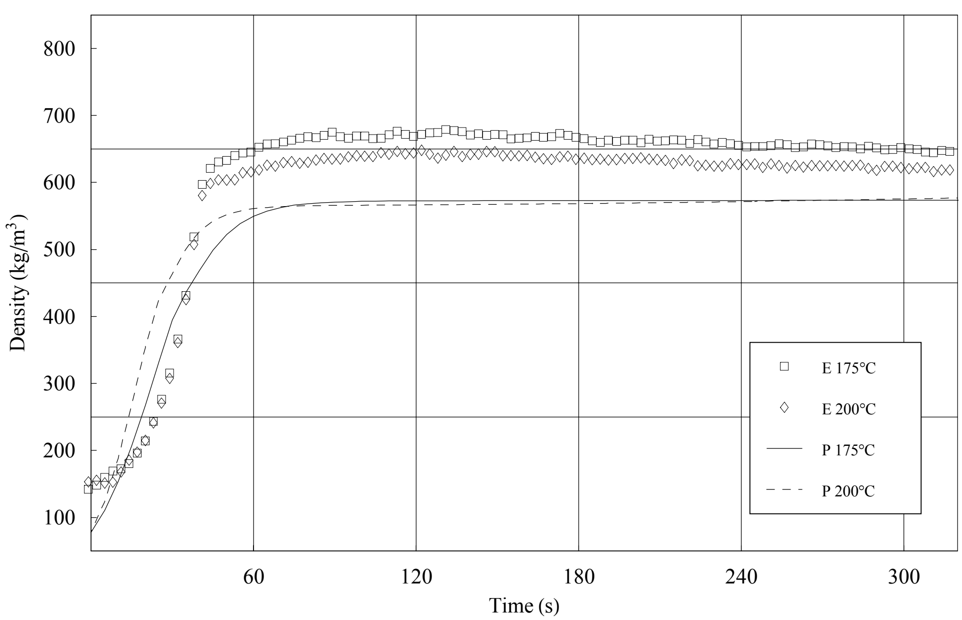
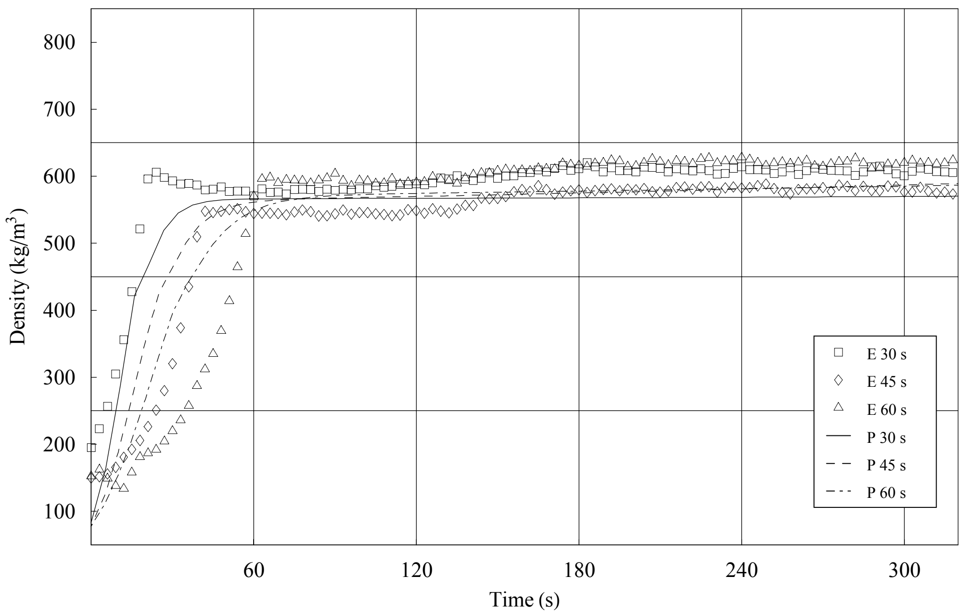


Figure 6.4. The effect of platen temperature on the evolution of density at 50 % (a.) and 25 % (b.) locations in the mat during the press schedule. The two platen temperatures were 175 °C and 200 °C. The experimentally measured (E) and model predicted (P) data are overlaid.

a.)



b.)

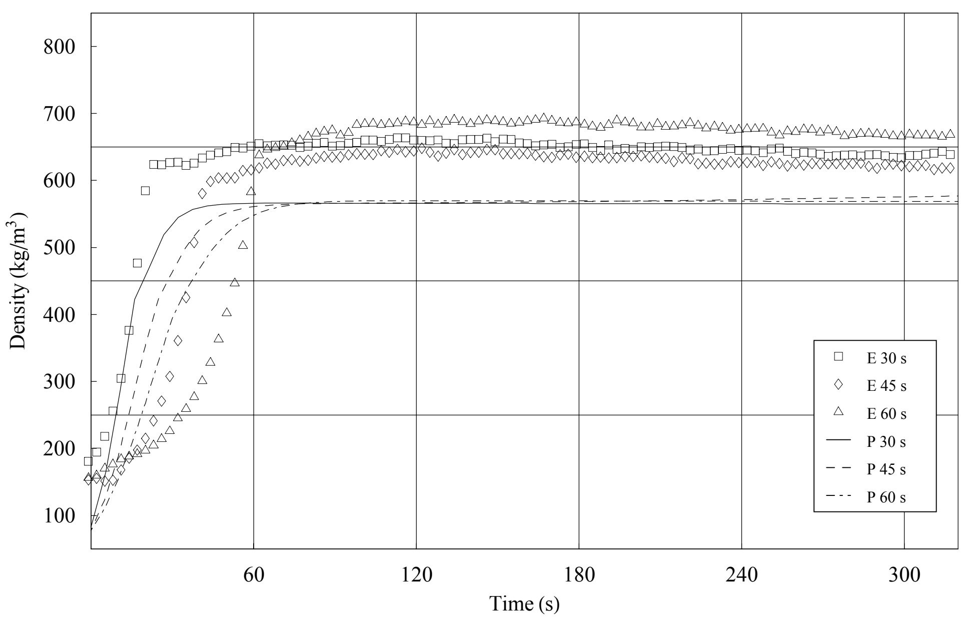


Figure 6.5. The effect of press closing time on the evolution of density at 50 % (a.) and 25 % (b.) locations in the mat during the press schedule. The three press closing times were 30 s, 45 s, and 60 s. The experimentally measured (E) and model predicted (P) data are overlaid.

The measured density in the middle of the board begins to rise as the core temperature of the mat increases, and the high temperature gradient between the middle and face layers diminishes. The experimental face layer density tends to level off between the period of 120 s and 180 s. The temperature, together with the moisture in the middle of the mat, continuously rise as hot vapor migrates vertically during this period. The combined effect of heat and moisture is that the flakes at the middle of the board are plasticized and start to consolidate as it is exhibited by the increasing densities at the 50 % probe locations (Figure 6.3a, 6.4a, 6.5a). The effect of high temperature and diminishing moisture content on the compressibility of the flakes oppose each other at the face layer, consequently the face layer densities tend to level off (Figure 6.3b, 6.4b, 6.5b). During the remainder of the press schedule, from 180 s till the beginning of the venting period, the densities at the middle layer show a steady behavior and the face layer densities slightly decline. This period is the "core layer consolidation stage" in the vertical density profile formation (see Figure 5.16)

The consolidation stage is well predicted among all the experimental conditions. Although the initial densities of the mat tend to be higher than predicted (Figure 6.3, 6.4, 6.5). The uncompressed thickness of the board will determine the initial average density during the calculations. The average of the measured uncompressed mat thicknesses was used as input during the simulations. The mat might consolidate between the thickness measurement and the loading of the press under the weight of the metal press platens, causing the discrepancy. The predicted peak pressures after the consolidation stage are showing good agreement with the experimental ones at the middle location (Figure 6.3a, Figure 6.4a, Figure 6.5a). This is not the case at the face location, where the measured density is higher in all instances (Figure 6.3b, Figure 6.4b, Figure 6.5b). A possible explanation of the difference is the location of the probes. Referring to Figure 6.6, where the final density profiles are shown, it is clear that the density predictions are good in the middle of the board (position 9.5 mm, probe location 50 %). However, at the 25 % probe location the predicted density is lower than the measured density. The predicted density curves become flat after the density rise not showing the effects analyzed previously at the measured density curves. Figure 5.15 depicts that the predicted density profile is flat between the middle of the board and at the 20 % probe location (~vertical position 4), and the profile is formed closer to the surface of the board.

6.4.2 Final Density Profiles

The results of the final vertical density measurements among different pressing conditions are summarized in Figure 6.6. The initial mat moisture content has an immense effect on the predicted density profiles. A larger amount of moisture migrates towards the core of the board with increasing moisture content, softening the flakes further from the surface. Therefore, the higher the initial mat moisture content, the lower the face density, and the higher the core density, as it is evident in Figure 6.6a. The influence of increasing moisture content on the experimental density profiles is not as pronounced as expected, although at 12 % moisture content pressing condition provided the steepest (largest difference among the surface, peak, and core density) density gradient.

The increasing final panel density has an apparent effect on both the experimental and predicted vertical density profiles, as it is shown in Figure 6.6b.

The influence of platen temperature on the final vertical density profile was large during the experiments as well as during the predictions. Examining Figure 6.6c it is obvious that higher temperatures will produce more pronounced density profiles, therefore larger differences exist among the surface, intermediate, and core locations of the material. The peak density also shifted towards the center with increasing platen temperature.

Increasing press closing time resulted in a flatter predicted vertical density profile (Figure 6.6d). The peak of the profiles moved towards the core of the mat, displacing the profiles inwards with increasing press closing time. This behavior was not evident in the measured data. The low measured density at the core at 80 s press closing time is the result of the inadequate curing of the resin at the middle of the board, which was evident after inspecting the test specimen following the completion of the test .

The temperature and moisture effects on the density profile formation are far more evident in the experimental results, than predicted by the model. Perhaps the omission of mechano-sorptive effects can explain the discrepancy. The relaxation modulus data collected by Wolcott (1989) were based on experiments in a steady environment. Unsteady moisture content conditions can enhance the creep or relaxation behavior of the material, resulting in a steeper density profile.

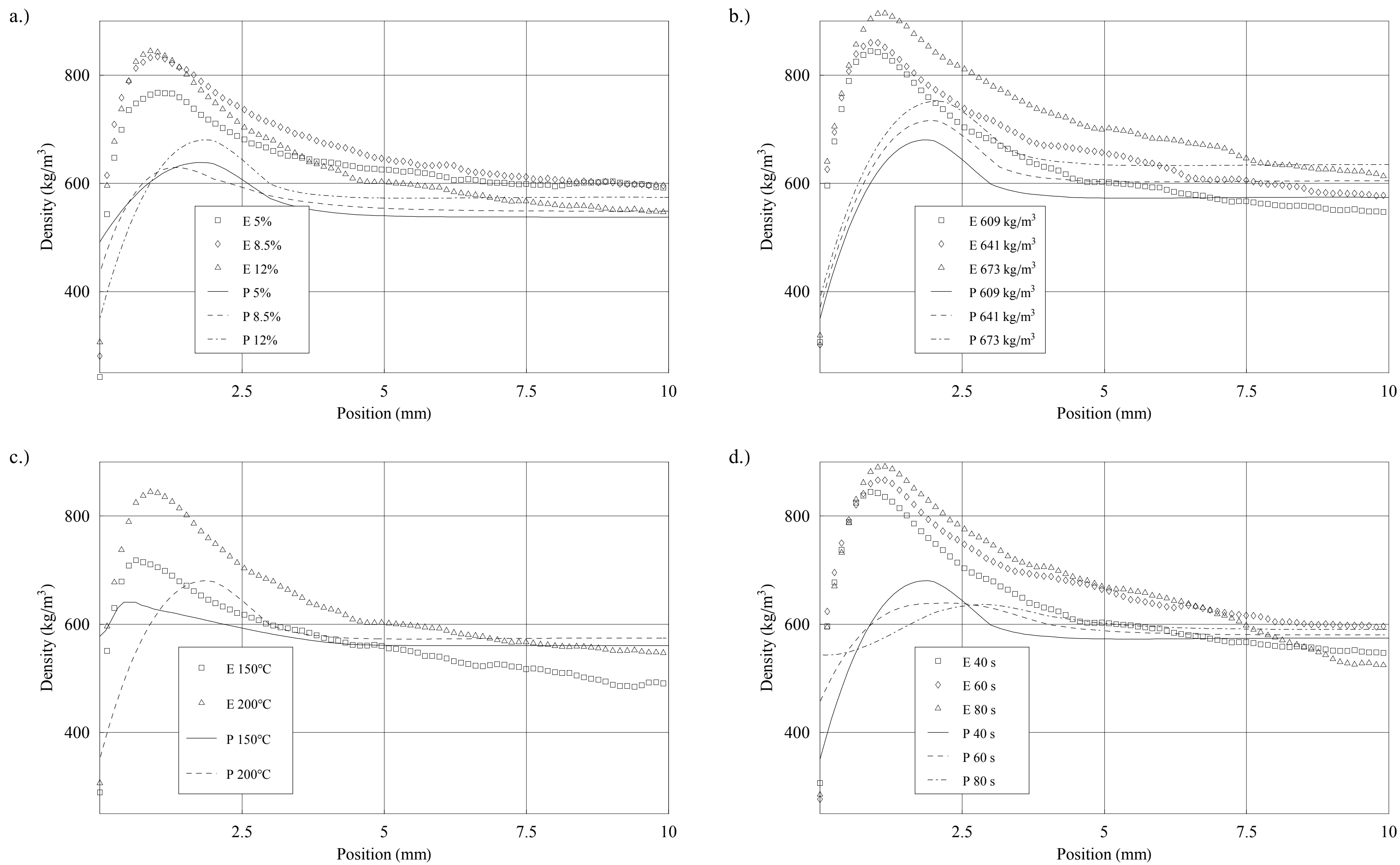


Figure 6.6. The effect of different mat characteristics and press schedules on the final vertical density profile. The final vertical density profile is depicted as function of mat initial moisture content (a.), board final density (b.), press temperature (c.) and press closing time (d.). The experimentally measured (E) and model predicted (P) data are overlaid.

6.5 Conclusions

The model predicted the general effects of production variables on the density profile formation qualitatively. The temperature effects on compression properties of the flakes in the model seem to be overestimated as the change of the press platen temperature provided the most pronounced difference in the predicted profiles. The trends of increasing initial mat moisture content on the density profile formation follow the experimentally observed trends. Changes in the relaxation modulus in the face and core of the mat were far more evident in the experimental results than predicted by the model. For quantitative predictions, more reliable data on the compression relaxation modulus of the flakes have to be determined experimentally.

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