Chapter 7. Final Conclusions and Recommendations

7.1 Final Conclusions

A combined stochastic deterministic model has been developed to characterize the random mat formation and physical mechanisms during the hot-compression of wood-based composites. The model is based on the combination of several fundamental engineering principles, such as the heat and mass transfer of porous materials, the viscoelastic theory of polymers and the transverse compression behavior of cellular solids. The model predicts the horizontal and vertical density distribution, the internal mat environmental conditions and the extent of the cure of the adhesive during a conventional hot-pressing process. The model performed well among a wide range of pressing conditions. The validation of the model showed qualitative agreement between predicted and measured temperature, pressure and vertical density profiles, which suggest that the mechanisms included in the model do reflect those present during hot-compression. Quantitative predictions require further research which is addressed in the following section.

The predictions of the model complement each other logically. Changing pressing parameters have the expected effect on the internal temperature and gas pressure distributions. This includes the effect of parameters on the vertical gradient of temperature and the building up of pressure within the mat. Additionally, the vertical density profile follows a typical "M" shape, observed during the experimental studies. The discrepancy between predicted and measured density profiles was attributed to the reported data on the viscoelastic properties of the flakes which will be discussed in detail in the following section. The model also provides moisture content and adhesive cure profiles. The experimental collection of this information during the press schedule has not yet been solved. Therefore, simulation predictions on the spatial distribution of moisture in the mat can enhance our understanding of the migration of moisture during the hot-compression process. Furthermore, the variation of adhesive cure with changing pressing parameters can lead to the optimization of the hot-pressing process and the development of new adhesive systems.

A fundamentally new approach was used during the model development. The mechanisms of the manufacturing process have been integrated into one general model, allowing a view of the intensive interaction among the production parameters. For example, the geometry of the wood elements determines the structure of the mat, which will have an influence on the thermal conductivity and gas permeability. This in turn influences the temperature and moisture distribution of the mat. Furthermore, the horizontal distribution of the cumulative thickness of the flakes will determine the onset of consolidation at different locations in the mat, essentially linking the mat formation and the compression behavior of the mat. This integrated model provides a valuable development tool for the wood-based composite industry. Critical processing parameters can be identified, and their influence on the flake-adhesive system can be addressed without extensive experimentation. The properties of existing products can be improved. Innovative production technologies or new composites can be developed with the help of the model. The design of panels for specific end-use requirements is also viable. This requires the support of data on the properties of different raw materials, pressing and boundary conditions. A discussion of some of these issues follows in the next section.

7.2 Recommendations

After completing this research the author feels that the main focus of future research related to the modeling of the hot-compression of wood-based composites should be oriented toward the determination of the material physical properties. All the material properties necessary for the simulation model were obtained from the literature and the presented model is deficient in this regard.

The sensitivity study revealed that the model results are very sensitive to mat thermal conductivity and gas permeability. Therefore, a method for quick and reliable experimental determination of these transport properties during the consolidation of the mat is essential for improved quantitative predictions.

Accurate data on the hygroscopicity of different wood species above 150 °C is not available at the present time. A unified model, similar to the Hailwood-Horrobin equation, to describe the equilibrium moisture content of wood in the range of temperature and relative humidity conditions present during the hot-compression is necessary for more reliable model predictions.

As it was suggested above, the discrepancy between the measured and predicted vertical density profile occurred due to the master curve of the relaxation modulus used to describe the viscoelastic properties of the flakes. The master curve was determined with tension tests over a limited range of temperature and moisture conditions. Although it was a weak assumption that the viscoelastic behavior of wood in compression is similar to tension, it was necessary due to lack of more reliable data. The relaxation modulus of flake columns has to be determined with compression experiments. Additionally, the complex problem of the effect of strength development of the curing resin on the viscoelastic properties of the wood-adhesive system has to be addressed. Furthermore, the temperature and moisture dependence of the yield strain in the nonlinear strain function has to be investigated.

Finally, the resin cure properties depend upon many physical and chemical characteristics of the adhesive. Establishing a relationship among resin types and cure characteristics of different resins would widen the applicability of the model.

With the long term objective in mind to create a process simulation tool for innovative wood-based composite design, the following improvements of future models are suggested. A three-dimensional model for the compression of multi-layer composite structures has to be developed to realize the full potential of computer simulation. It requires a more efficient algorithm to solve the heat and mass transfer model in three spatial dimensions. Bound water and gas diffusion mechanisms have a secondary role in the moisture transfer. Their exclusion from a three-dimensional model may substantially reduce execution time, without considerably affecting model predictions. A fully three-dimensional model also needs the experimental determination of the direction dependent transport properties of the separate layers of the panel.

Research aimed to determine external heat and mass transfer coefficients of different boundary conditions should have high priority. Industrial pressing conditions use a screen at one side of the mat to eliminate the high internal pressures resulting in asymmetric boundary conditions. More realistic model predictions in this situation would have direct applicability in industrial production.

In recent years nontraditional production technologies, such as high frequency heating, steam injection, or continuous pressing, are gaining acceptance in wood composite production. The model, with certain modifications would be able to predict the internal environment and the density profile of multi-layer panels produced with one of these innovative technologies. The modular structure of the model allows easy inclusion of research advancements, and therefore the process simulation can be further refined.