CHAPTER 7

Finite element simulation and empirical model

7.1 Introduction

Biomass or municipal waste is compressed, or densified, into pellet form for easy handling, transportation and storage. Densification process is a compression process that transforms losses biomass into highly density biomass by applied stress (Mani, Roberge, Tabil, & Sokhansanj, 2003). Strength and other mechanical properties of densified pellet can be increased with its density (Selig & Doman, 2015). The densification mechanism can be explained by compaction model as described in Chapter 6.

Behavior of densified biomass under densification process is nonlinear. As described in Chapter 6, the constitutive model is normally used for representation of material behavior under the compression process. In this chapter, the constitutive model is integrated with finite element software. Finite element simulation of the densified process can also be applied to other production process of pellet such as using rolling machine.

Several compression models (as mentioned in Chapter 2) were fitted to the pressure-volume and pressure-density which can analyze the compression to the characteristics of materials. This research selected the Kawakita-Ludde model which can describe the compression behavior of material including initial porosity and yield strength of the compact.

The equation for compaction behavior of Kawakita and Ludde (1971) as Equation 7.1.

$$\frac{P}{C} = \frac{1}{ab} + \frac{P}{a} \qquad (7.1)$$

Where $C = \frac{V_0 - V}{V_0}$

C is the volume decreasing, V_0 is the initial volume, V is the net volume of power underpressure P, and a, b are the constant of powder characteristic which can be determined from the linear relation of $\frac{P}{C}$ and P. The constant a is acted as the initial packing of sample, and $\frac{1}{b}$ is relation of the yield strength or cohesive forces of powder particles. Ooi et.al. (2013) and Adapa (2009b) et.al. used Kawakita and Ludde equation to explain the compression behavior which provided an excellent fit curve.

7.2 Finite element model

7.2.1 Model geometry and mesh

The geometry of die, piston and mixture of plastic waste and corn stover was constructed and mesh using LS-PrePost® 4.3. LS-DYNA finite element code was used to simulated the densification process of the mixture. Material behavior of the mixture was represented by nonlinear material model as presented in the material library of LS-DYNA. The piston and die were assumed to be rigid bodies made of steel since their stiffness are too high comparing with that of the mixture. Axisymmetric shell elements were used for modelling the die, piston and mixture. According to the experiment as described in Chapter 6, inside diameter of the die is 80 mm, initial height of the mixture is 107.27 mm. The mixture was represented by 120 shell elements.

7.2.2 Boundary conditions and loading

Axisymmetric shell element was represented the model simulation. Axial and radial directions are concerns. The mixture is free to move in axial and radial directions, while the die is fixed in both direction. The piston is fixed in radial direction and is free to move axially. Load curve corresponding to the load measure by UTM is applied to the element edges of the piston. The contact surfaces between mixture and die and mixture and piston are modelled by automatic surface-to-surface contact algorithm in LS-DYNA. Friction coefficient between surfaces are 0.24 which was taken from the work of Stanley and Darrel (2015).

7.2.3 Material model for the mixed plastic waste and corn stover

The mixture of plastic waste and corn stover was modelled as homogeneous material using material soil and foam with *MAT_SOIL_AND_FOAM keyword. Selected pairs of the pressure in compression process and the corresponding volumetric strain as shown in Figure 7.3 were inserted into LS-DYNA keyword in order to represent the material behavior of the mixture as experimental measure and described in Chapter 5.

7.3 Result and discussion.

7.3.1 Empirical model.

The experiment data from charpter 5 found that the best condition is at the ratio of plastic waste and corn stover at 55:45%w/w, 75°C preheating temperature, 10% moisture content, 0.5 – 1 mm. of particle size and pressure of 150 MPa. Mixed plastic waste and corn stover, mixed plastic waste and corn stover are compressed at this condition with universal testing machine, Instron. And the empirical model can define as $\frac{P}{C} = \frac{1}{ab} + \frac{P}{a}$. The Kawakita and Ludde equation was studied to describe for particle rearrangement and compression behavior. Table 7.1 showed the result of constants a, and R^2 value. It has been observed that Kawakita-Ludde model gave the best fit model and R^2 value for all 3 samples. Figure 7.1 showed the graph of P/C versus P. The constant a and b were calculated from the relation of linear equation. The constant a represents the initial packing while b represents the resistance to compaction. Thus $\frac{1}{b}$ represents the yield strength of compact (Adapa, Tabil, & Schoenau, 2009a) or cohesive forces of powder particles (Ooi et al., 2013). The constant a from table 7.1 shows that the highest initial packing value was corn stover (0.7648) followed by mixed plastic waste (0.7253) and mixed plastic waste (0.6452). The highest initial packing value of corn stover can be related to its highest density. The highest parameter 1/b or yield strength of compact was observed for corn stover (3.3356) followed by mixed plastic waste and corn stover (1.8006) and mixed plastic waste (0.6452).

Table 7.1: The result of constants a and b, and R^2 value for all 3 samples which are obtained from Kawakita-Ludde model.

Materials	Constants		Density (g/cm^3)	R^2 Value
	a	1/b		
Corn stover	0.7648	3.3356	1.1540	0.9999
Mixed plastic waste and corn stover	0.7253	1.8006	1.0231	0.9999
Mixed plastic waste	0.6452	1.3176	0.8699	0.9999

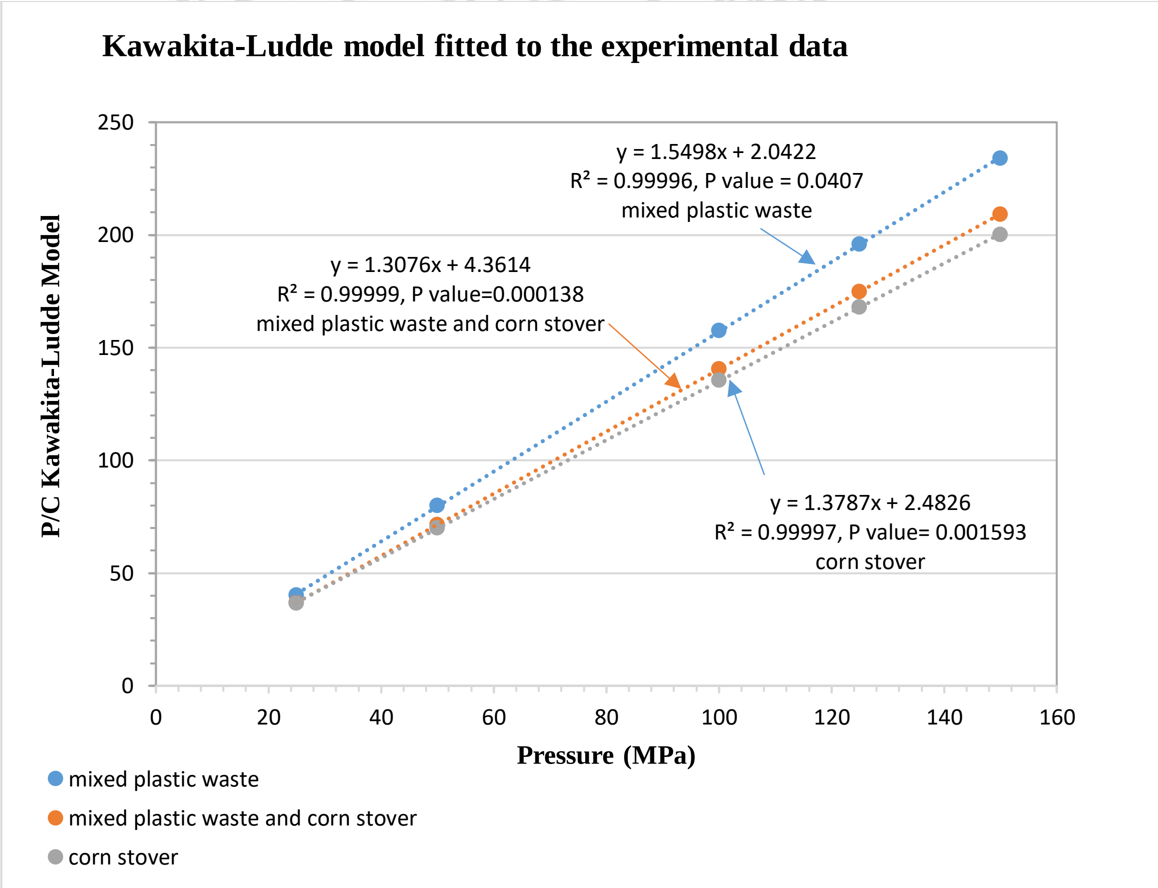

Fig. 7.1: The relation of P/C versus P fitted to the experiment data which obtained from Kawakita-Ludde model

The highest yield strength can be related to its highest density. Smaller value of $\frac{1}{b}$ let to small cohesive forces. The compressibility of mixed plastic waste was higher than of corn stover and, mixed plastic waste and corn stover. Because of the particle rearrangement and the volume changes. It can be explained that corn stover was found strongest inter-particle bonding.

7.3.2 Finite element simulation

Finite element analysis of this research is used the LS-DYNA software for simulate the compression process. The condition of compression was the instron experimental data and the constitutive model from chapter 6. This finite element model assume that material is homogenous and isotropic compressible continuum as the research of Tie-Li Ye (2012). The compaction pressure were considered to 150 MPa. The cylindrical die has a 8 mm diameter. The material filling height at the initial was 107.27 mm as measured from the experiment. The material model used axisymmetric quadrilateral elements. The material model used Mat_Soil_Foam keyword. The result of distribution of compressive stress and density at 10, 25, 50, 100, and 150 MPa are showed as figure 7.2 to figure 7.6.

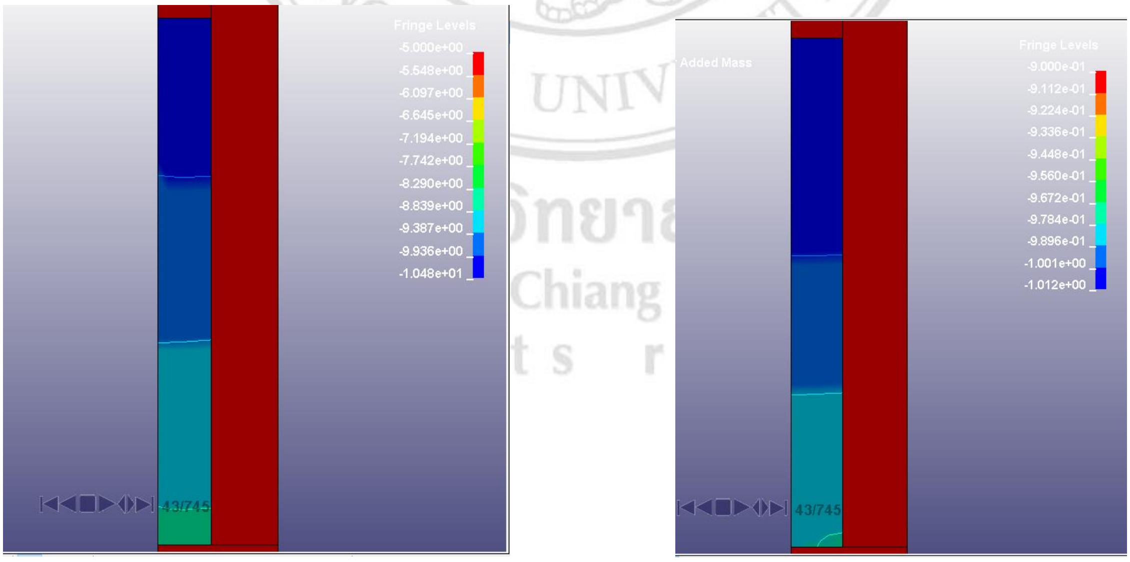

Figure 7.2: Distribution of compressive stress (left) and density (right) at 10 MPa.

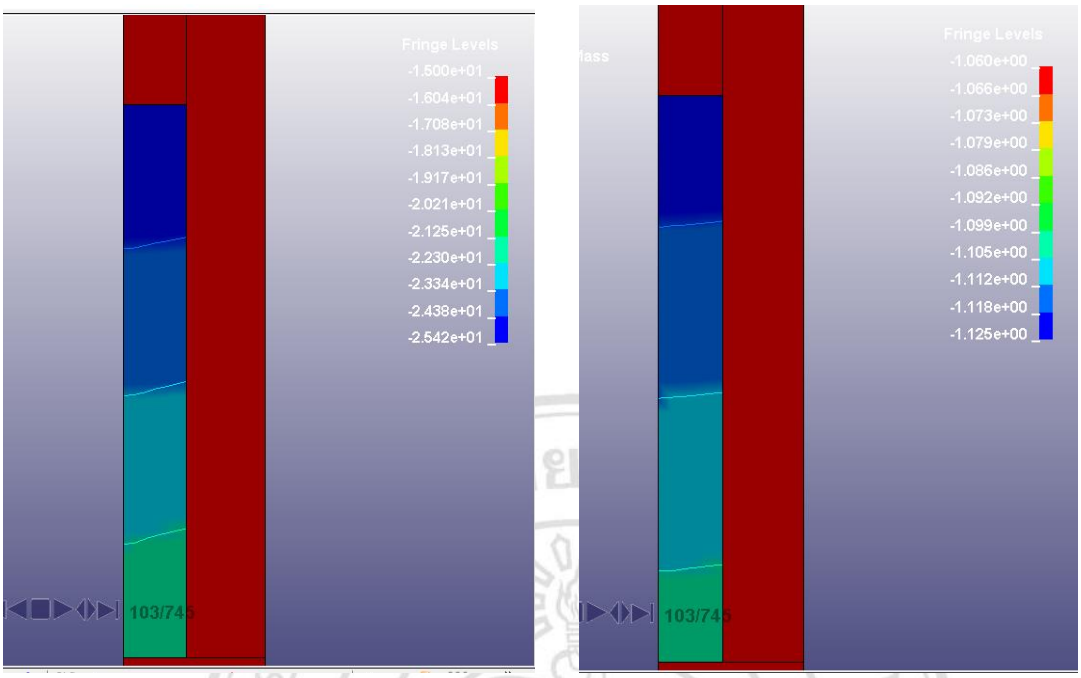

Figure 7.3: Distribution of compressive stress (left) and density (right) at 25 MPa.

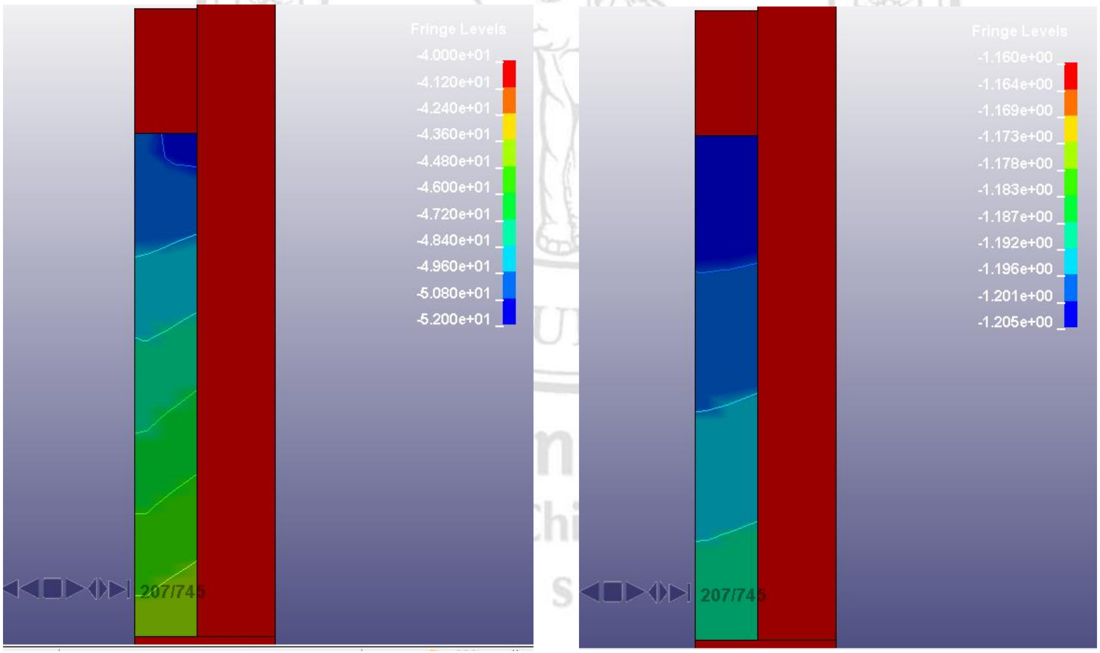

Figure 7.4: Distribution of compressive stress (left) and density (right) at 50 MPa.

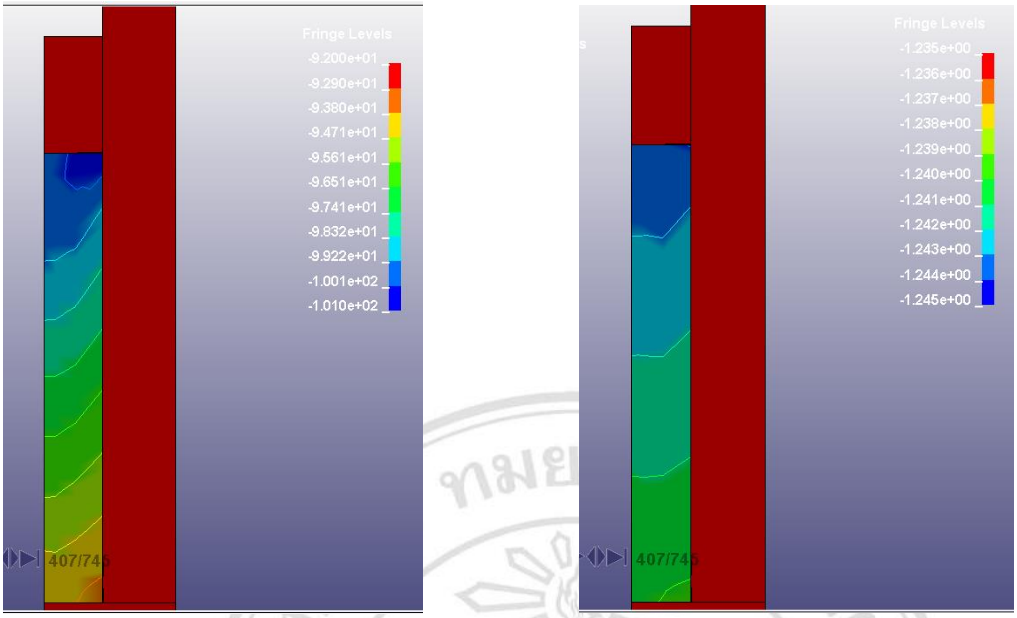

Figure 7.5: Distribution of compressive stress (left) and density (right) at 100 MPa**.**

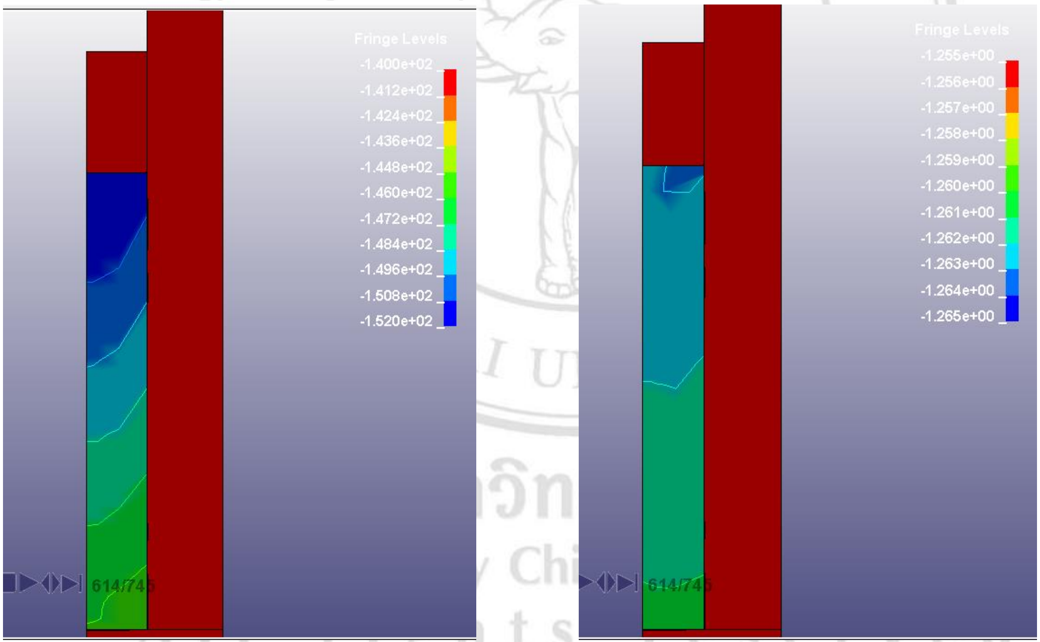

Figure 7.6: Distribution of compressive stress (left) and density (right) at 150 MPa.

The density and compaction pressure curve result shows a good agreement between simulation data and experiment data at the lowest compaction pressure and the highest compaction pressure. The curve result is shown in Figure 7.8. And the density contour plots for 25, 50, 75,100, 125 and 150 MPa are shown in Figure 7.7.

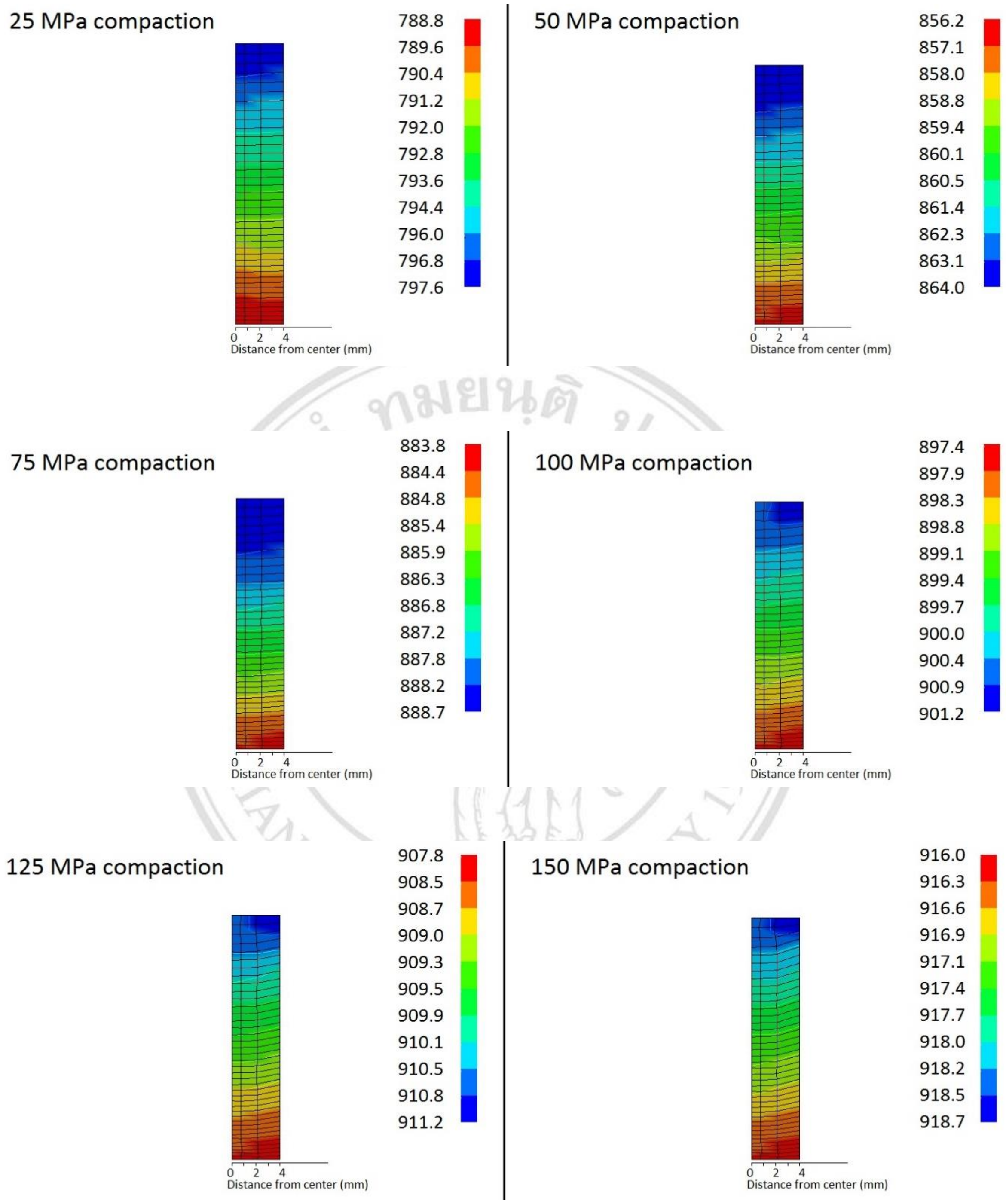

Figure 7.7: Density contour plots for 25, 50, 75,100, 125 and 150 MPa.

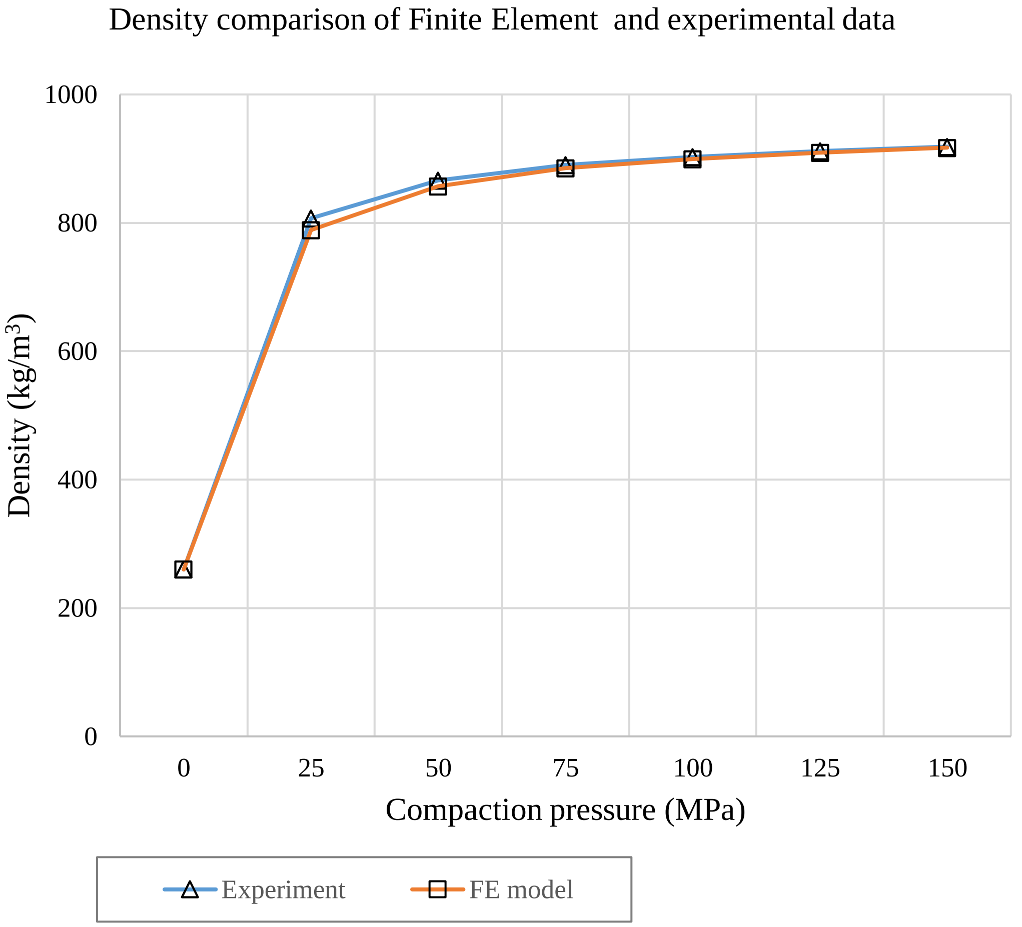

Figure 7.8: Comparison of density from FE simulation to experimental data.

7.4 Conclusion

The compression behavior of corn stover, mixed plastic waste and corn stover, and mixed plastic waste can be explained by compression model. It can be fitted to the pressure-volume and pressure-density data. The compaction characteristics of corn stover, mixed plastic waste and corn stover, and mixed plastic waste at 10% moisture content, 75°C preheating temperature, and 0.5 – 1 mm of particle size were studied by pressure level of 25-150 MPa. The model of Kawakita-Ludde model provides an excellent fit curve with R^2-value of 0.99 for all materials. The result found that corn stover had the highest of initial packing and cohesive forces of powder particle. Therefore, the strongest pellet was corn stover followed by mixed plastic waste and corn stover, and mixed plastic waste. The simulation of finite element of mixed plastic waste and corn stover pellet can represent the density distribution of pellet and also showed relation of density with compaction pressure. The curve of density and compaction pressure result shows a good agreement between simulation data and experiment data at the lowest compaction pressure and the highest compaction pressure.

7.5 References

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