



AGGLOMERATION OF ACACIA MANGIUM BIOMASS

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Abstract. The aim of this study was to analyze the effects of temperature (T), moisture content (MC) and particle size (x) on *Acacia mangium* biomass and also to find the optimal conditions of the densification process for producing tablet with high density. *Acacia mangium* biomass was compressed in load cell by hydraulic piston press with 25 mm diameter. Effect of independent variable, including temperature (20 °C to 120 °C), moisture content conditions (5.1 wt.% and 18.1 wt.% in the case of $x < 1$ mm, and 5.3 wt.% in the case of $x < 2$ mm) were investigated. The results showed that at constant pressure, increasing temperature (T) resulted in higher density of tablets and also increasing moisture content resulted in higher density of tables. Tablets made from raw material with smaller particle size have lower strength than those made from material with larger particle size.

Keywords: agglomeration, tableting, *Acacia mangium*, spring-back ratio.

Classification numbers: 3.4.1; 2.3.1; 2.8.2

1. INTRODUCTION

Biomass is planned to represent 17.2 % of the planned European heating and cooling mix and 6.5 % of electricity consumption in 2020 [1]. The Finnish Pöyry Industry consulting company has predicted growth in global pellet production capacity up to 46 million tonnes by 2020 [2]. Biomass is an important source of energy in Vietnam and it is one that the country is well endowed with. It is estimated that approximately 90 % of domestic energy consumption in rural areas is derived from biomass such as fuel wood, agricultural residues (e.g. rice straw and husks) and charcoal. Moreover, biomass fuel is also an important source of energy for small industries located mainly in rural areas [3].

In tropical Asia, the *Acacia mangium* (*A.mangium*) is a fast growing species, which can maintain active growth during the dry season and is used for reforestation [4, 5]. *Acacia mangium* species was first introduced into Vietnam in the 1960s [6, 7]. It is a fast grown species and very adaptable to different soil types on degraded sides and hills. *Acacia mangium* wood is diffuse-porous with mostly solitary vessels and tolerance of very poor soils. It is playing an increasingly important role on sustainable commercial supply of wood products. Due to its good physical properties, *A.mangium* is a potential and suitable source as a raw material for the production of particleboard with excellent dimensional stability [8].

Agglomeration is the mechanical process, in which the particle size of solid disperse materials (bulk materials, fine particles of slurry) is increased by bonding forces between the particles [9]. Agglomeration has three main types: pressure agglomeration (briquetting, extrusion, tableting, pelletizing), growth agglomeration, and sintering. In this paper pressure agglomeration is introduced especially for biomasses.

2. THEORETICAL BACKGROUND

2.1. Pressure agglomeration principle

During pressure agglomeration, new, enlarged entities (tablets, briquettes, etc.) are formed by applying external forces to particulate solids in more or less closed dies that define the shape of the agglomerated product (Figure 1) [10].

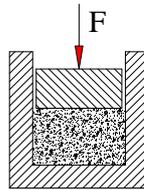


Figure 1. Pressure agglomeration.

2.2. Compressibility

Compressibility is the ability of the powder to deform under pressure (1) [11].

$$\rho = f(p_{\max}) \quad (1)$$

where ρ is agglomerate density, p is tableting pressure.

Compressibility of biomass (C_m) with normal pressure was determined using the following equation (2) [12, 13].

$$C_m = \left(\frac{V_i - V_f}{V_i} \right) \cdot 100 = \left(1 - \frac{\rho_{bi}}{\rho_{bf}} \right) \cdot 100 \quad (2)$$

where V_i is the initial volume of biomass (m^3), V_f the final volume of biomass at desired consolidating pressure (m^3), ρ_{bi} the initial bulk density of the biomass (kg/m^3) and ρ_{bf} is the final bulk density of the biomass at desired consolidating pressure (kg/m^3).

Johanson's equation can take two forms:

$$\frac{\rho}{\rho^*} = \left(\frac{p}{p^*} \right)^{1/\kappa} ; \quad \frac{F}{F_o} = \left(\frac{V_o}{V} \right)^\kappa \quad (3)$$

where κ is compressibility factor, ρ is agglomerate density, p is tableting pressure, F is tableting force, V is tablet volume and p^* , ρ^* , F_o and V_o are reference values (if surface perpendicular to force and mass of tablet are constant) [14].

Liu and Wassgren [15] modified the Johanson model 1965 [16] for improved relative density predictions

$$\frac{p}{P_{\text{initial}}} = \left(\frac{\eta}{\eta_{\text{initial}}} \right)^k \quad (4)$$

where η_{initial} is the inlet relative density, P_{initial} is the corresponding pressure according to the fit data, k is fitting constant and η the powder's relative density.

A compress equation was proposed by Panelli and Filho (2001), given as:

$$\ln \frac{1}{1-\rho_r} = A\sqrt{p} + B \quad (5)$$

where ρ_r is the relative density of compact, A is a parameter related to densification of the compact by particle deformation and B is a parameter related to powder density at the start of compression [17].

2.3. Influence of the temperature and moisture content

The influence of the briquetting temperature and moisture content have been described in several studies reported in literature. A recent study conducted by Xia Zhang et al. [18] has shown that optimal temperatures for water hyacinth pellet density were 100.4°C and 104.3°C, respectively. According to Arnavat et al. [19] the single pellet press was used to find the optimum moisture content and die operating temperature for pellet production. A friction increase was seen when the die temperature increased from room temperature to 60 - 90°C for most biomass types, and then a friction decrease when the die temperature increased further.

3. EXPERIMENTAL

3.1. Materials



Figure 2. *A.mangium* sawdust with particle size < 2 mm; (left) optical camera; (right) optical microscope: Zeiss AXIO Imager.M2m.

An 8 years old *A.mangium* was chosen as raw material for our experiments. It originated from Quang Ninh, Viet Nam. It was dried for around one month (from harvesting to

agglomeration) and after coarse size reduction ($x < 10$ mm) ground using a cutting mill (Retsch SM2000) in one step (screen size 2 mm) and in two steps (screen sizes: 2 mm, 1 mm). Biomass was stored at room temperature (25 °C), in closed plastic bags. The moisture contents (MC) and bulk density of *A. mangium* biomass were determined to be 5.1 wt.%, 143 kg/m³ for the case of particle size $x < 1$ mm, and 5.3 wt.%, 133 kg/m³ ($x < 2$ mm). Raw material *A. mangium* sawdust is shown in Figure 2. It can be observed that *A. mangium* sawdust is a homogeneous material.

3.2. Apparatus

The hydraulic piston press (Figure 3) was designed and produced by the University of Miskolc. The press is supported by a pump motor unit with a pressure limiter and a heat-able load cell (20...140 °C). The maximum force is 200 kN, and the maximum velocity of the piston feed-rate is 30 mm/s. The measuring of the piston position is done with an incremental encoder.



Figure 3. Hydraulic piston press.

3.3. Experimental procedure

The hydraulic piston press with diameter 25 mm was used for two different kinds of tests and each tablet was made by the compression of 3 g sawdust. Applied pressures on the surface of tablets were 50, 100, 150, 200, 250 and 300 MPa, with different temperatures.

In the first test, the applied temperatures were 20, 60, 100 and 120 °C with 5.1 wt.% and 18.1 wt.% in the case of $x < 1$ mm, and 5.3 wt.% in the case of $x < 2$ mm).

In the second test, spring-back ratio experiments were carried out with particle size < 2 mm, the applied temperatures were 20, 60, 100 and 120 °C.

The spring-back ratio (SBR) of a tablet can be determined by the following equation

$$\text{SBR} = \frac{H_t - H_{tp}}{H_{tp}} 100\% \quad (6)$$

where H_t is the height of the produced tablet and H_{tp} is minimum height of the tablet under pressure.

The quality of tablets can be described easily by their density. The diameters and heights of the tablets product were measured by Vernier caliper (a tablet can be extended after

agglomeration). The mass was measured and density was calculated for each test. The minimum height of tablets under pressure was measured by the incremental distance measurement method.

The determination of tablet strength was carried out by the known falling test method. In this test, tablets were released by freefall from a height of 2 m onto a concrete floor repeatedly until they broke. The falling number is the number of falls the sample survived undamaged. In each experiment three tablets were tested. This method was used to compare tablet strength at different conditions.

4. RESULTS AND DISCUSSION

4.1. Tablet density

Tablets produced by processes with different parameters are shown in Figure 4. The tablet density values are recorded as an average of three measurements with particle size < 1 mm (MC = 5.1 wt.%) and also with particle size < 2 mm (MC = 5.3 wt.%).

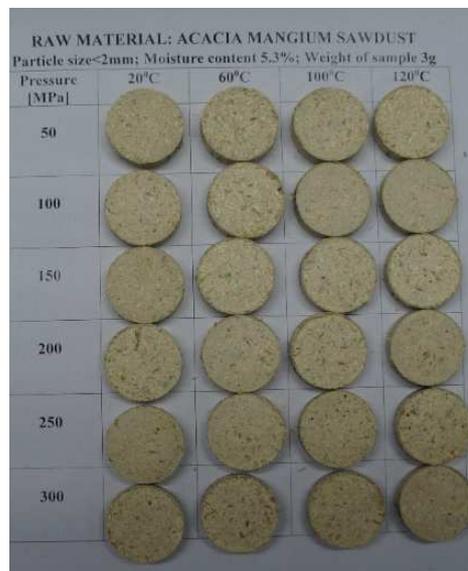


Figure 4. Tablets made from particle size < 2 mm.

Figure 5 (left) shows the pressure-density values and the fitted Johanson curves in the case of $x < 1$ mm raw material at 20, 60, 100 and 120 °C. Table 1 shows the values of the constants of the fitted curves, coefficient of determination (R^2), residual mean square (σ) and calculated deviation (V_s). Results for particle size < 2 mm are introduced in Figure 5 (right), and Table 2.

Tablets compressed at lower pressure have lower densities. If pressure, moisture content and particle size are kept constant, an increasing temperature resulted in higher tablet density (in the case of $x < 2$ mm raw material on 100 MPa the tablet densities: 1017 kg/m³ (T = 60°C) and 1123 kg/m³ (T = 100 °C)). The reason for that can be increasing temperature results in lower spring-back ratio. Tablets made from raw material with larger spring-back ratio had higher heights and lower densities.

If pressure, temperature and particle size are kept constant, an increasing moisture content resulted in higher tablet density. The reason for that can be increasing moisture content results in lower spring-back ratio.

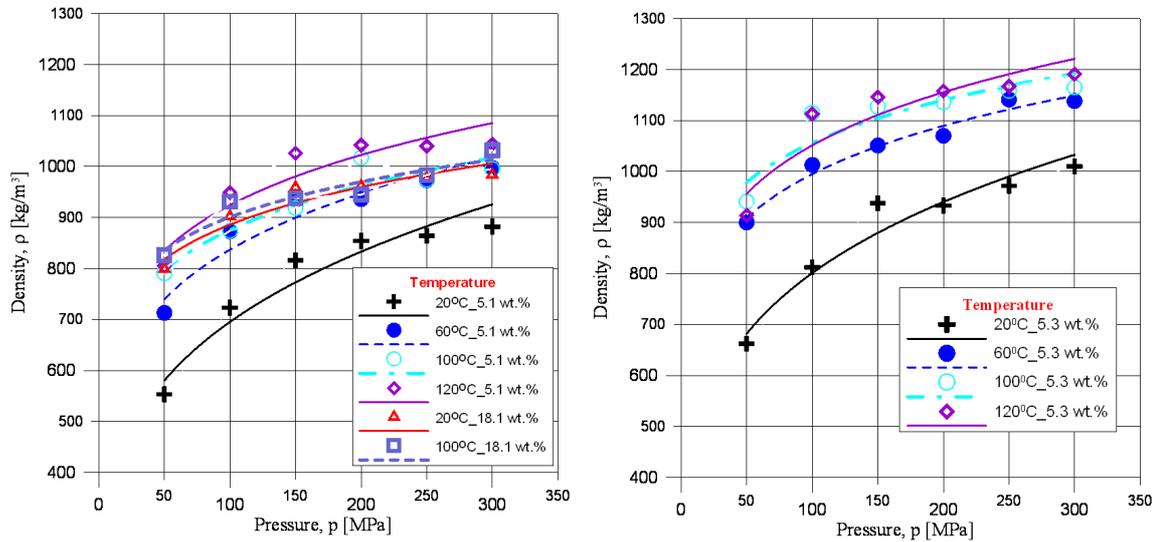


Figure 5. Compressibility data for biomass with different temperature; (left) particle size < 1 mm; (right) particle size < 2 mm.

Tablets made from material particle size < 2 mm have higher density than tablets made from particle size < 1 mm, at constant pressure, temperature and moisture content (in the case of pressure 250 MPa, T = 120 °C, the tablet densities 1040 kg/m³ (x < 1 mm, MC = 5.1 wt.%); 1167 kg/m³ (x < 2 mm, MC = 5.3 wt.%).

The spread deviation values (V_s) of fitted Johanson's equations were calculated (Table 1) and they have a value smaller than 2.19 %. At the same moisture content, increase in temperature results in higher constants α and κ .

Spread deviation values (V_s) are calculated and it has a value smaller than 1.4 %. The processes were well described by the applied Johanson functions on each temperature.

Table 1. Constants of Johanson's equation ($\rho = \alpha \cdot p^{1/\kappa}$) for different temperature (x < 1 mm).

Temperature (°C)	Moisture content [wt.%]	Constant α	Constant κ	Spread deviation: V_s Coefficient of determination: R^2 Residual mean square: σ
20	5.3	209.4651	3.8	$R^2 = 0.9355$; $\sigma = 0.0025$; $V_s = 1.8$ %
60	5.3	369.1054	5.6	$R^2 = 0.9285$; $\sigma = 0.0013$; $V_s = 1.2$ %
100	5.3	467.4657	7.3	$R^2 = 0.9112$; $\sigma = 0.0009$; $V_s = 1.2$ %
120	5.3	471.2722	6.8	$R^2 = 0.8833$; $\sigma = 0.0015$; $V_s = 1.4$ %
20	18.1	520.8847	8.7	$R^2 = 0.9222$; $\sigma = 0.0006$; $V_s = 2.1$ %
100	18.1	550.0913	9.3	$R^2 = 0.9130$; $\sigma = 0.0005$; $V_s = 2.19$ %

Table 2. Constants of Johanson's equation for different temperature ($x < 2$ mm).

Temperature (°C)	Constant α	Constant κ	Spread deviation: V_s Coefficient of determination: R^2 Residual mean square: σ
20	275.6347	4.3	$R^2 = 0.9506$; $\sigma = 0.0015$; $V_s = 1.4$ %
60	544.2687	7.6	$R^2 = 0.9710$; $\sigma = 0.0002$; $V_s = 0.6$ %
100	636.6259	9.1	$R^2 = 0.8284$; $\sigma = 0.0013$; $V_s = 1.3$ %
120	561.5390	7.3	$R^2 = 0.8474$; $\sigma = 0.0018$; $V_s = 1.4$ %

4.2. Spring-back ratio

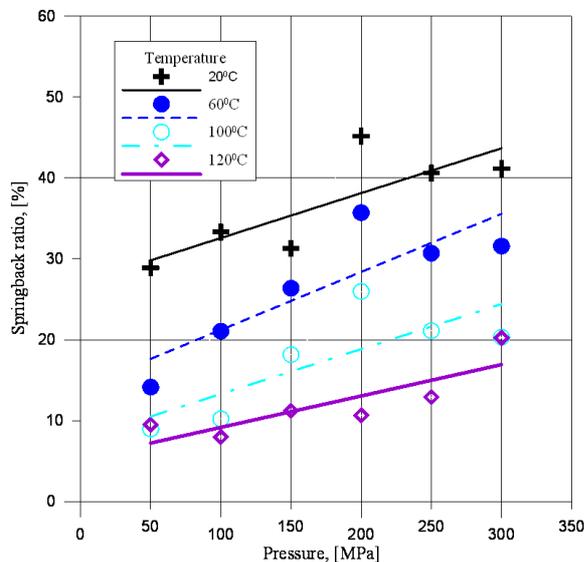


Figure 6. Relationship between pressure, spring-back ratio and temperature (Particle size < 2 mm).

This relationship can be described by the linear function: $SBR = c p + d$. Increasing of pressure with same temperature resulted in higher SBR, where the constants c , d are a function of temperature. Tablets made from raw material with higher temperature had lower spring-back ratio (at the same pressure, moisture content and particle size). In the case of $T = 120$ °C less than 20 % SBR was measured. Tablets made at 20 °C temperature had 28.8 % to 41.6 % SBR depending on pressure, in the examined pressure range.

4.3. Struof tablets

The cross sectional surfaces of tablets were investigated with an optical microscope (Zeiss AXIO Imager.M2m), as shown in Figure 7. The tablets made at pressure 250 MPa ($T = 20$ °C) had more space between particles (porosity is higher) than the tablets made at pressure 250 MPa ($T = 100$ °C), with the same moisture content of 5.3 wt.% and particle size < 2 mm. The reasons for that generally, increasing temperature resulted in lower swelling, thus lower porosity of the tablet at constant pressure, particle size and moisture content.

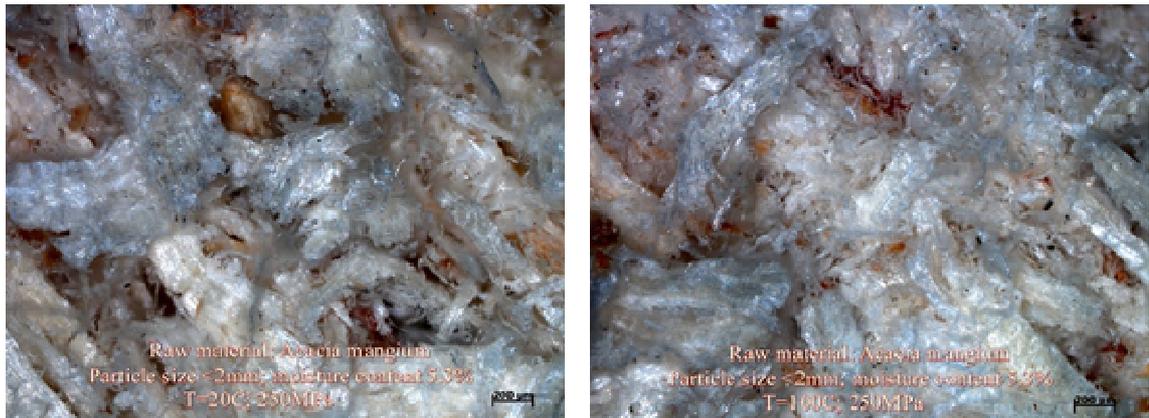


Figure 7. Cross sectional surface of tablets (optical microscope: Zeiss AXIO Imager.M2m).

4.4. Tablet strength

Falling number values in the case of $x < 1\text{ mm}$ and $x < 2\text{ mm}$ raw materials are shown in Figure 8 as a function of temperature on different pressures. Increasing temperature resulted in higher tablet strength at the same pressure and particle size, and also increasing moisture content resulted in higher tablet strength at the same pressure, temperature and particle size.

Tablets made from raw materials $x < 2\text{ mm}$ form tablets with higher strength (falling number: 27 at 250 MPa and $120\text{ }^\circ\text{C}$), than tablets made from $x < 1\text{ mm}$ biomass (falling number: 14.6 at 250 MPa and $120\text{ }^\circ\text{C}$), if moisture content and pressure are kept constant. The reason for this can be more intensive binding in the case of larger particles ($x < 2\text{ mm}$).

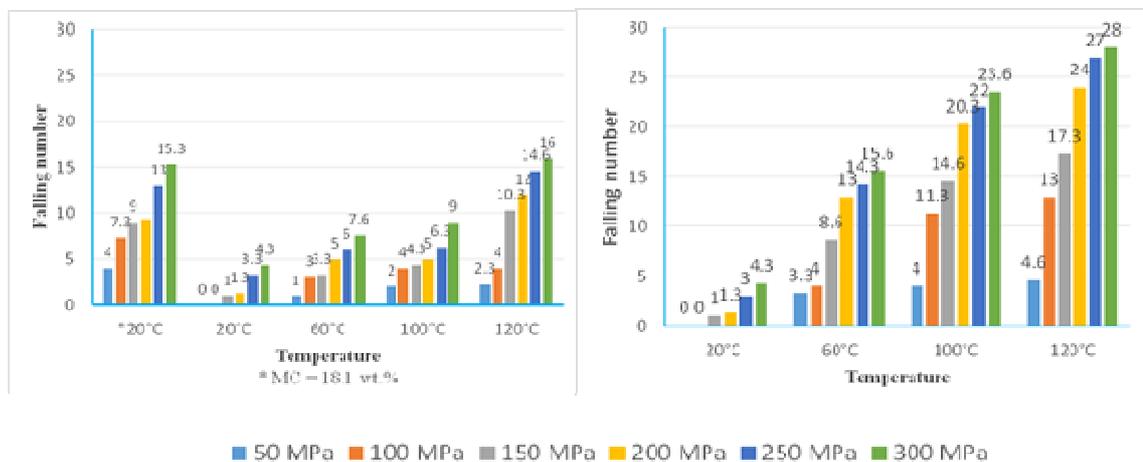


Figure 8. Relationship between falling number, temperature and pressure;

(left) Particle size $< 1\text{ mm}$, MC = 5.1 wt.% (except first data); (right) Particle size $< 2\text{ mm}$, MC = 5.3 wt.%.

5. CONCLUSIONS

This paper has presented tools and methods to evaluate the effect of temperature, pressure, particle size and moisture content on tablet density in the case of *A.mangium* sawdust. The

description of the processes is essential in order to determine the optimal production parameters. While the Johanson functions describes the processes well (at 60 °C temperature in the case of $x < 1$ mm raw material $V_s = 1.2$ %, using $x < 2$ mm raw material $V_s = 0.6$ %).

If pressure, moisture content and particle size are kept constant, increase in temperature results in higher density of tablets. Also an increasing moisture content resulted in higher tablet density when pressure, temperature and particle size are kept constant.

Increasing moisture content resulted in higher tablet strength at the same pressure, temperature and particle size. Also increasing temperature resulted in higher tablet strength at the same pressure, moisture content and particle size.

Tablets made from material $x < 2$ mm have higher strength than those made from $x < 1$ mm biomass when temperature and pressure are kept constant.

The experimental method can be used for other materials as well, to determine the optimal conditions of pressure, temperature and particle size during an agglomeration process. Results showed that moisture content is one of the most important parameters during agglomeration process of biomass, and it is necessary to investigate these more detailed in further. The drying time of the biomass can have also an important role during agglomeration.

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