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The effect of pressure on the compaction parameters of oakwood sawdust enhanced with a binder

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Summary. This paper presents the results of analyses investigating the effect of specific piston pressure (45 to 113 MPa) and the addition of a calcium lignosulphonate binder (0 to 20%) on the compaction parameters of oakwood sawdust. The experiments were performed with the use of the ZWICK Z020/TN2S universal strength tester and a closed compression die assembly. An increase in pressure led to an increase in material density in the compression chamber and agglomerate density (by 16% on average), and it more than doubled the mechanical strength of the agglomerate. Higher compaction pressure increased the demand for compaction energy by 104%, on average. The addition of binder contributed to agglomerate density and increased the mechanical strength of the agglomerate by 33%, on average.
Key words: compaction, pressure, binder, calcium lignosulphonate, sawdust, biomass.

INTRODUCTION

Solid biofuels manufactured from plant biomass are the main resource in the renewable energy industry [4, 6, 15, 20]. Energy biomass comprises timber processing waste, including sawdust. Those plant resources are characterized by low density and low calorific value (per unit of volume), and they are difficult to transport, store and feed to boilers in unprocessed form [1, 2]. Biomass density has to be increased to make this raw material more suitable for energy production. This is achieved by briquetting or granulating bulk material in the process of pressure agglomeration [5, 13, 21].

In laboratory analyses of the agglomeration process, raw material is compacted in a closed compression chamber with a piston. Process parameters, including energy consumption and raw material's susceptibility to compaction, are determined. Changes which take place in the material during compaction and the quality of the final product have to be closely monitored. The compaction process and agglomerate quality are determined by process parameters as well as by the physical and chemical properties of the compacted material [5, 7].

Compaction pressure (specific piston pressure) significantly affects the compression process and the quality of the resulting agglomerate [3, 11, 14, 17]. Inadequate pressure settings can lead to wasteful energy consumption, and they may lower the strength characteristics of the agglomerate. According to the authors' previous research [8], the use of lignin binders containing calcium lignosulphonate may offer a partial solution to the above problem. Lignin has adhesive properties, and it binds raw material components to improve agglomerate stability and quality [12, 16, 19, 22]. The resulting agglomerates are characterized by greater density and higher mechanical strength which, in turn, lowers energy intensity of the compaction process, decreases storage requirements and facilitates agglomerate transport.

The objective of this study was to determine the effect of specific piston pressure on the compaction parameters of oakwood sawdust containing various quantities of calcium lignosulphonate.

MATERIALS AND METHODS

The experimental material was oakwood sawdust supplied by a sawmill in the Lublin area. The material was obtained by cutting oakwood with a wooden saw with 22.2 mm tooth pitch. The granulometric composition of sawdust was determined in accordance with standard PN-EN 15149-2:2011 using the SASKIA Thyr 2 laboratory sieve. The bulk density of raw material was described in line with standard PN-EN 15103:2010.

A binding agent (calcium lignosulphonate) was added to material samples with 12% moisture content in the amount of 1% and 2%. Material without the added binder served as a control sample.

The pressure compaction methodology was described in the authors' previous study [9]. The experiment was performed with the use of the Zwick Z020/TN2S strength tester with a closed compression die assembly and a computer-controlled system for monitoring compaction parameters. Test parameters were as follows: chamber diameter – 15 mm, cylinder (compacted material) temperature – 20ºC, piston speed – 10 mm·min^{-1}. Sawdust was compressed at five values of the maximum compaction force: 8, 11, 14, 17 and 20 kN, which corresponded to the following compaction pressure parameters: 45, 62, 80, 96 and 113 MPa. Every compaction process was performed in three replications.

The results were plotted on a compaction curve showing the correlation between compaction force and piston speed. The curve was used to determine process parameters: maximum material density in the chamber *ρc*, total compaction effort (*Lc* = *L·m*$^{-1}$, where : *L* – compaction effort, *m* – weight of material sample). The coefficient of material's susceptibility to compaction *kc* was calculated from the following formula:

$$k_c = \frac{L_c}{(\rho_c - \rho_n)} \ ((\mathrm{J \cdot g^{-1}})/(\mathrm{g \cdot cm^{-3}})), \qquad (1)$$

where:
ρn – initial density of raw material in the compression chamber, g·cm^{-3}; *Lc* – specific compaction effort, J·g^{-1}.

Agglomerate density after 48 h of storage (*ρa*) was determined. The degree of material compaction in the chamber *Szm* and the degree of agglomerate compaction *Sza* (volume reduction) were calculated as the ratio of densities *ρc* and *ρa* to raw material density in the compression chamber *ρn* (*Szm*= *ρc*. *ρn*$^{-1}$, *Sza*= *ρa*. *ρn*$^{-1}$).

The mechanical strength of the agglomerate was determined in a compression test with the use of the ZWICK Z020/TN2S strength tester (piston speed 10 mm·min^{-1}). An agglomerate with diameter *d* and length *l* was compressed along the perpendicular axis until damaged, and maximum breaking force *Fn* was computed. Mechanical strength *σn* [MPa] of the agglomerate was calculated from the following formula [10, 18]:

$$\sigma_n = \frac{2 \cdot F_n}{\pi \cdot d \cdot l} \ (\mathrm{MPa}). \qquad (2)$$

The correlations between binder content and moisture content of the examined material and compaction parameters were analyzed statistically in the STATISTICA application at the significance level of α_i = 0.05. Regression equations describing the correlations between compaction and pressure parameters at various binder content levels are shown in Figures 2-5. A regression analysis revealed that the observed correlations can be described by quadratic equations of the second degree or linear equations.

RESULTS

BASIC PHYSICAL PARAMETERS OF THE ANALYZED MATERIAL

An analysis of the granulometric composition of material (Fig. 1) revealed that particles with the size of 0.4 to 1.6 mm were the predominant fraction.

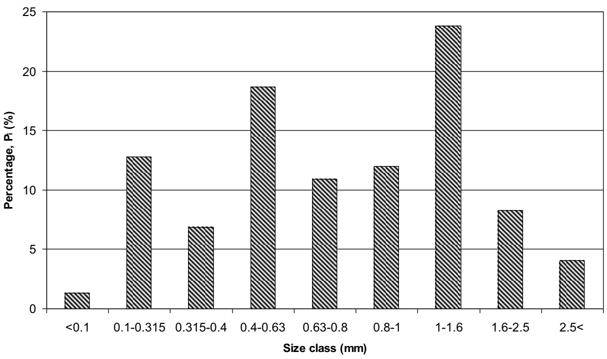

Fig. 1. Particle size distribution (P_i) of the studied raw material

Particle size distribution of the analyzed material was conducive to pressure agglomeration.

The average bulk density of raw material with 12% moisture content was determined at *ρn*= 0.297g·cm^{-3}.

RAW MATERIAL DENSITY IN THE COMPRESSION CHAMBER AND AGGLOMERATE DENSITY

The results presented in Figure 2 indicate that the initial density of raw material in the compression chamber *ρc* increased with a rise in pressure at all binder content levels *zl*. The greatest increase in agglomerate density *ra* was observed in the pressure range of 45–80 MPa. Further pressure increase had no effect on agglomerate density. The highest values of the analyzed parameters were reported for sawdust with the highest binder content, and the lowest – for control material.

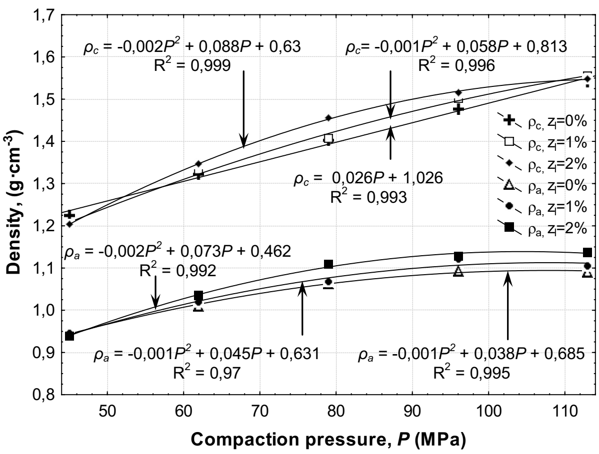

Fig. 2. Correlation between material density in the chamber (*ρc*), agglomerate density (*ρa*) and compaction pressure (*P*) at various binder content levels (*zl*)

In the pressure range of 45–113 MPa, the density of material with 2% binder content was determined in the range of 1.21 g·cm^{-3} to 1.55 g·cm^{-3} for parameter *ρc* and 0.92 g·cm^{-3} to 1.11 g·cm^{-3} for parameter *ra*. The applied binder had the greatest effect on sawdust density within the pressure range of 62– 96 MPa.

DEGREE OF AGGLOMERATE COMPACTION

An analysis of the degree of raw material compaction in the chamber and agglomerate compaction after storage point to a significant increase in compaction values with an increase in compaction pressure (Fig. 3). Under the pressure of 113 MPa, the maximum material compaction in the chamber *ρc* was 5.3 times higher on average in comparison with initial density of raw material *ρn* regardless of its binder content. The addition of binder had the most significant impact on the analyzed parameter within the pressure range of 62–96 MPa.

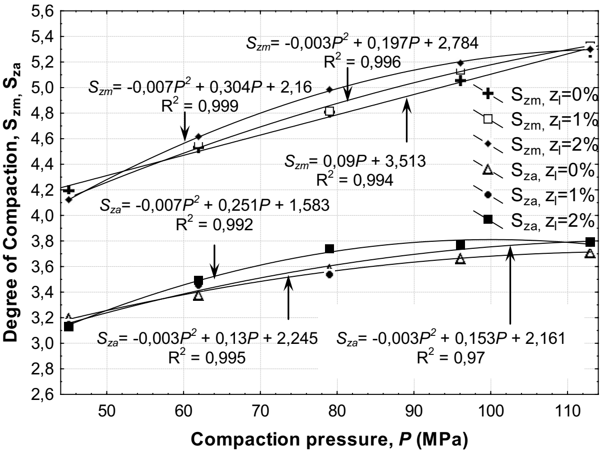

Fig. 3. Correlation between the degree of material compaction *(Szm)*, agglomerate compaction (*Sza*) and compaction pressure (*P*) at various binder content levels (*zl*)

The highest degree of agglomerate compaction *Sza* was reported in sawdust with 2% binder content compressed under the pressure of 80, 96 and 113 MPa (no significant differences in the values of *Sza* were observed under the above pressure settings). Agglomerate density was approximately 3.7 times higher in comparison with the initial density of raw material. Similarly to the reported changes in the value of *ra*, the highest increase in agglomerate compaction was observed in the pressure range of 45–80 MPa in all studied samples.

COMPACTION EFFORT AND SUSCEPTIBILITY TO COMPACTION

The correlations between specific compaction effort *Lc*, coefficient of susceptibility to compaction and compaction pressure *P* are presented in Figure 4. Within the entire range of examined values, the analyzed parameters increased with a rise in compaction pressure. Such a trend was observed in all examined samples. The value of *Lc* was determined in the range of 42.61 to 99.55 $J \cdot g^{-1}$, and the value of *kc* – from 23.01 to 40.11 $(J \cdot g^{-1}) \cdot ((g \cdot cm^{-3}))^{-1}$. The highest values of the analyzed parameters were noted at the maximum compaction pressure (113 MPa) in samples with the highest binder content (2%). This suggests that binder application increases the coefficient of friction between material particles and between particles and the walls of the compression chamber, leading to an increase in compaction effort and the coefficient of susceptibility to compaction (Fig. 4).

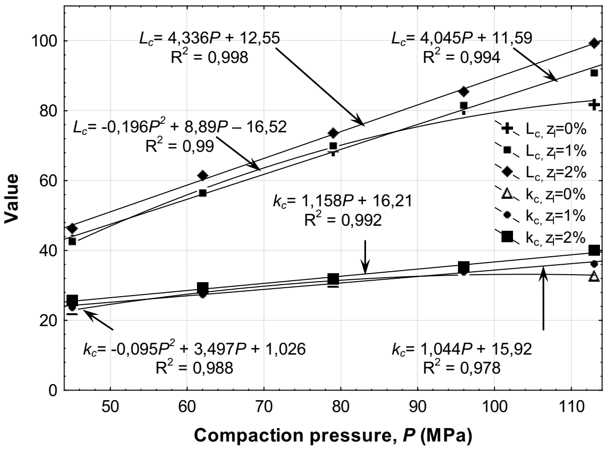

Fig. 4. Correlation between compaction effort (*Lc*), coefficient of susceptibility to compaction (*kc*) and compaction pressure (*P*) at various binder content levels (*zl*)

MECHANICAL STRENGTH OF THE AGGLOMERATE

In all the analyzed samples, the mechanical strength of agglomerate *σn* increased with a rise in compaction pressure within the range of 45–96 MPa (Fig. 5). A pressure increase to 113 MPa in material samples with 1% and 2% binder content did not lead to a noticeable increase in the mechanical strength of the agglomerate. An insignificant increase in the value of *σn* was noted only in control material. Mechanical strength values were determined in the range of 0.85 to 2.31 MPa. The agglomerate produced from sawdust with 2% binder content under the pressure of 96 and 113 MPa was characterized by the greatest mechanical strength.

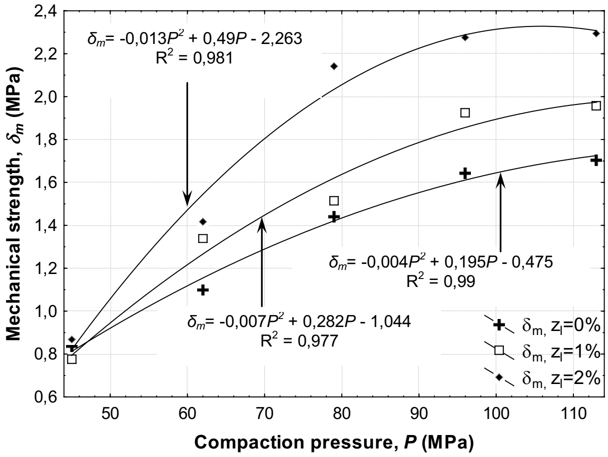

Fig. 5. Correlation between mechanical strength of agglomerate *(δm)* and compaction pressure (*P*) at various binder content levels (*zl*)

Greater variations in the value of *σn* were reported with an increase in pressure in the range of 45 to 96 MPa due to different binder content of the examined material. Under compaction pressure of 96 MPa, the mechanical strength of material with 2% binder content was 44% higher on average in comparison with control.

CONCLUSIONS

The following conclusions can be drawn from the results of the study:

1. The density of material in the compression chamber, including samples with and without the addition of binder, increased by 18% on average with a rise in compaction pressure. An increase in density within the examined range of values also contributed to an average 16% increase in agglomerate density. The addition of binder had the most significant impact on density within the pressure range of 62–96 MPa.
2. The degree of material compaction in the compression chamber increased by 24% on average within the entire range of tested pressure parameters. The degree of agglomerate compaction increased by 23% on average only within the pressure range of 45–96 MPa.
3. Specific compaction effort and the coefficient of susceptibility to compaction increased with a rise in compaction pressure values. The average increase in the former parameter reached 104% and in the latter – 80%. The addition of binder decreased the analyzed material's susceptibility to compaction.
4. An increase in compaction pressure within the analyzed range of values led to an average 104% increase in the mechanical strength of the agglomerate. In material with 2% binder content, the value of σn increased by 33% on average.

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WPŁYW CIŚNIENIA NA EFEKTYWNOŚĆ ZAGĘSZCZANIA TROCIN DĘBOWYCH Z DODATKIEM LEPISZCZA

Streszczenie. Przedstawiono wyniki badań nad określeniem wpływu jednostkowego nacisku tłoka (od 45 do 113 MPa) i dodatku lepiszcza w postaci lignosulfonianu wapnia (od 0 do 2%) na parametry zagęszczania trocin dębowych. Zagęszczanie przeprowadzano przy wykorzystaniu maszyny wytrzymałościowej Zwick typ ZO2O/TN2S i zespołu prasującego z matrycą zamkniętą. Stwierdzono, że wraz ze wzrostem ciśnienia rośnie gęstość materiału w komorze i gęstość aglomeratu (średnio o 16%) oraz ponad dwukrotnie zwiększa się odporność mechaniczna produktu. Zwiększanie ciśnienia zagęszczania w badanym przedziale, powoduje wzrost zapotrzebowania na energię zagęszczania średnio o 104%. Wykazano, że dodatek lepiszcza zwiększa gęstość aglomeratu oraz powoduje wzrost jego odporności mechanicznej przeciętnie o 33%.

Słowa kluczowe: zagęszczanie, ciśnienie, lepiszcza, lignosulfonian wapnia, trociny, biomasa.