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THE EFFECT OF MATERIAL MOISTURE CONTENT AND CHAMBER DIAMETER ON COMPACTION PARAMETERS OF MEADOW GRASS

Summary

This paper presents the results of analyses determining the effect of meadow grass compaction conditions on process parameters and agglomerate strength. The experiments were performed with the use of the ZWICK Z020/TN25 universal strength tester and a closed compression die assembly with three diameters of chamber: 12 mm, 15 mm and 18 mm. The correlations between material density in the chamber and agglomerate density, agglomerate compaction, compaction work, the coefficient of material susceptibility to compaction, the mechanical strength of the agglomerate and the moisture content of meadow grass were determined for three diameters of chamber. Compaction parameters were determined by the moisture content of meadow grass and the diameter of the compression die chamber. Material with a higher moisture content was more susceptible to compression in the die chamber, and the produced agglomerates were characterized by lower mechanical strength.

***Key words**: agglomeration, meadow grass, compaction parameters*

WPŁYW WILGOTNOŚCI MATERIAŁU I ŚREDNICY KOMORY NA PARAMETRY ZAGĘSZCZANIA TRAWY ŁĄKOWEJ

Streszczenie

Przedstawiono wyniki badań nad określeniem wpływu warunków zagęszczania trawy łąkowej na parametry procesu i wytrzymałość aglomeratu. W badaniach wykorzystano maszynę wytrzymałościową ZWICK typ ZO2O/TN25 oraz zespół prasujący z matrycą zamkniętą o trzech średnicach komory 12 mm, 15 mm i 18 mm. Określono zależności pomiędzy gęstością materiału w komorze i aglomeratu, stopniem zagęszczenia aglomeratu, nakładami pracy na zagęszczanie, współczynnikiem podatności materiału na zagęszczanie oraz odpornością mechaniczną aglomeratu a wilgotnością trawy dla trzech średnic komory. Wykazano, że parametry zagęszczania w różnym stopniu zależą od wilgotności trawy łąkowej i średnicy komory matrycy. Zwiększenie wilgotności polepsza podatność materiału na zagęszczanie oraz pogarsza jakość aglomeratów pod względem ich wytrzymałości.

***Słowa kluczowe**: aglomerowanie, trawa łąkowa, parametry zagęszczania*

1. Introduction

The growing interest in biomass for energy purposes spurred new research into the production of solid biofuels by pressure agglomeration (pelletizing and briquetting). Continued research into pressure agglomeration of plant material is needed because the processed material is highly diverse and innovative solutions for machine design and operation are drivers of technological progress [1].

Solid biofuels (pellets, briquettes) are manufactured mainly from forestry waste, timber processing waste, farming waste (including the straw of cereal and oilseed crops) and energy plants (including the common osier, Virginia fanpetals, Jerusalem artichoke and perennial grasses) [2-4]. Those plant resources are characterized by low density and low calorific value (per unit of volume), and they are difficult to transport in unprocessed form [2]. Low density materials have to be transformed into agglomerates by pressure compaction. The compaction process and product quality have to be analyzed in detail to determine process parameters such as compaction work and the material's susceptibility to compaction. The above parameters expand our knowledge of agglomeration processes. Research results indicate that the physical and chemical attributes of raw material influence agglomeration effectiveness and the quality of the final product [5-8]. Compaction pressure parameters are determined by the moisture content of plant material [9, 10] and process conditions, including chamber size and sample weight [11, 12]. The results of analyses investigating the effect of chamber diameter and material moisture content on the compaction parameters of wheat straw are presented in this study [13]. This article is part of ongoing research aiming to determine the effect of process conditions on the compaction of plant material.

2. Research objective

The objective of this study was to determine the effect of the moisture content of meadow grass and the diameter of the compression die chamber on compaction parameters and agglomerate quality.

3. Materials and methods

The experimental material was meadow grass supplied by a private farm in Góry (Markuszów municipality). The material was ground in the ML 500 grinding machine with a 4 mm mesh screen. The average diameter of ground particles, determined based on standard PN-89/R-64798 in the SASKIA Thyr 2 sieve shaker with a set of screens with mesh opening of 1.0, 0.8, 0.63, 0.4 and 0.2 mm, was 0.5 mm. The moisture content of processed material ranged from 10% to 18% (at intervals of 2 ±0.2%).

The experiment was performed with the use of the ZWIC ZO2O/TN25 strength tester and a closed compression die assembly in accordance with the methodology presented in [14]. Three dies with chamber diameter *d* of 12, 15 and 18 mm were used to compact grass samples of 1, 2 and 3 g, respectively. The ratio of sample height to sample diameter in the chamber was roughly identical before compaction and during maximum compaction in the chamber. Cylinder (compacted material) temperature was 20°C, and piston speed was 10 $\text{mm}\cdot\text{min}^{-1}$. The compaction process was continued until compaction force F_{max} reached 20 kN. For the above compaction force, the maximum specific piston pressure reached 117 MPa (d = 12 mm), 114 MPa (d = 15 mm) and 77 MPa (d = 18 mm). 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 maximum material density in the chamber ρ_c and total compaction work L_c. The coefficient of susceptibility to compaction k_c ($k_c = L_c'\cdot(\rho_c\text{-}\rho_n)^{-1}$ was calculated, where: $L_c' = L_c\cdot m^{-1}$ – specific compaction work, m – weight of material sample, ρ_n – initial bulk density of raw material. Agglomerate density after 48 of storage (ρ_{a1}) was determined.

The mechanical strength of the agglomerate was determined in a compression (Brazilian) test with the use of the ZWICK Z020/TN2S strength tester (piston speed 10 $\text{mm}\cdot\text{min}^{-1}$). The agglomerate was compressed along the perpendicular axis until damaged and maximum breaking force F_n was computed. Mechanical strength σ_n [MPa] was calculated from the following formula [15]:

$$\boldsymbol{\sigma_n = \frac{2\cdot F_n}{\pi\cdot d_a\cdot l}} \tag{1}$$

where: d_a – agglomerate diameter [mm], l – agglomerate length [mm], F_n – breaking force [N].

4. Results

The correlations between compaction parameters, the mechanical strength of the agglomerate and the moisture content (*w*) of compacted material were determined for every chamber diameter with the use of regression equations. The resulting regression lines and the values of the coefficient of determination R^2 are shown in Figures 1-7.

Figure 1 and Figure 2 indicate that linear regression equations adequately describe the correlation between the maximum material density in the chamber (ρ_c), agglomerate density (ρ_{a1}) and grass moisture content for every chamber diameter. An increase in moisture content from 10% to 18% leads (at the same maximum value of compaction pressure) to an increase in material density in the chamber (ρ_c), probably due to higher material plasticity, and an increase in packing density of particles. An increase in moisture content resulted in a drop in agglomerate density ρ_{a1}. The highest values of densities ρ_c and $\square_{a1}$ were reported for the smallest chamber diameter d=12 mm. For this chamber and at a moisture content of 10% to 18%, the value of ρ_c was determined in the range of 1.85 $\text{g}\cdot\text{cm}^{-3}$ to 1.88 $\text{g}\cdot\text{cm}^{-3}$ and the value of ρ_{a1} in the range of 0.83 $\text{g}\cdot\text{cm}^{-3}$ to 0.75 $\text{g}\cdot\text{cm}^{-3}$. Material compacted in a chamber with the largest diameter d = 18 mm was characterized by the smallest density values: from 1.65 $\text{g}\cdot\text{cm}^{-3}$ to 1.69 $\text{g}\cdot\text{cm}^{-3}$ for ρ_c and from 0.75 $\text{g}\cdot\text{cm}^{-3}$ to 0.66 $\text{g}\cdot\text{cm}^{-3}$ for ρ_{a1}.

Changes in agglomerate density are validated by agglomerate compaction S_{za} values (Fig. 3) which characterize storage-induced changes in agglomerate density relative to the initial density of raw material. Agglomerate compaction S_{za} decreases with an increase in the analyzed material's moisture content for every chamber diameter, which indicates that the agglomerate is less compressed upon its exit from the die chamber and that agglomerate density decreases with an increase in moisture content. The highest agglomerate compaction S_{za} was reported for grass with a moisture content of 10% compressed in a chamber with diameter d = 12 mm (agglomerate density is approximately 6 times higher in comparison with the initial density of raw material).

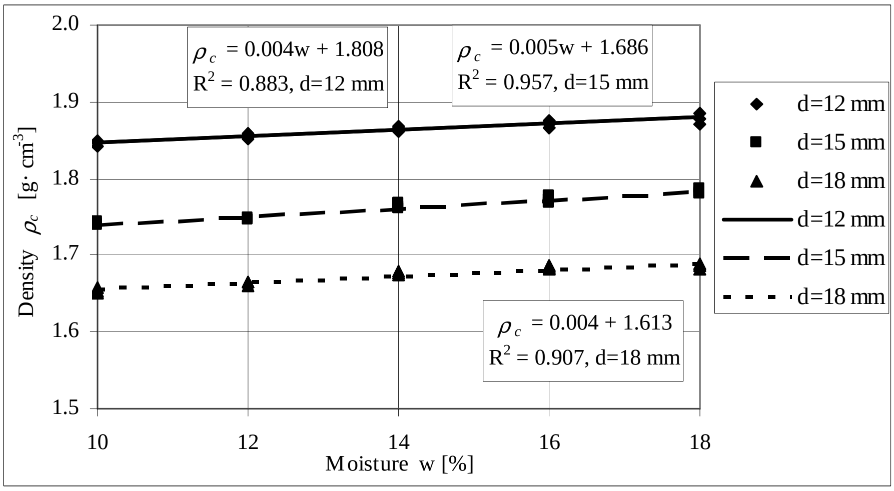

Fig. 1. Correlation between material density in the chamber ρ_c and moisture content w of processed material for three diameters of chamber d

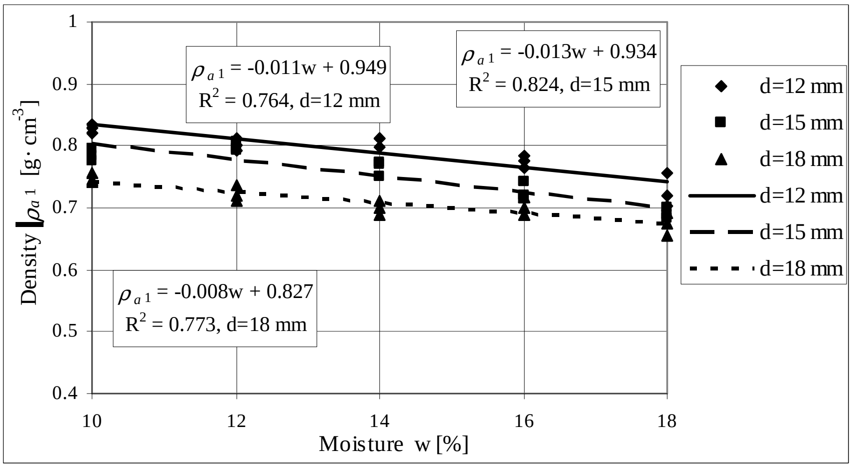

Fig. 2. Correlation between agglomerate density ρ_{a1} and moisture content w of processed material for three diameters of chamber d

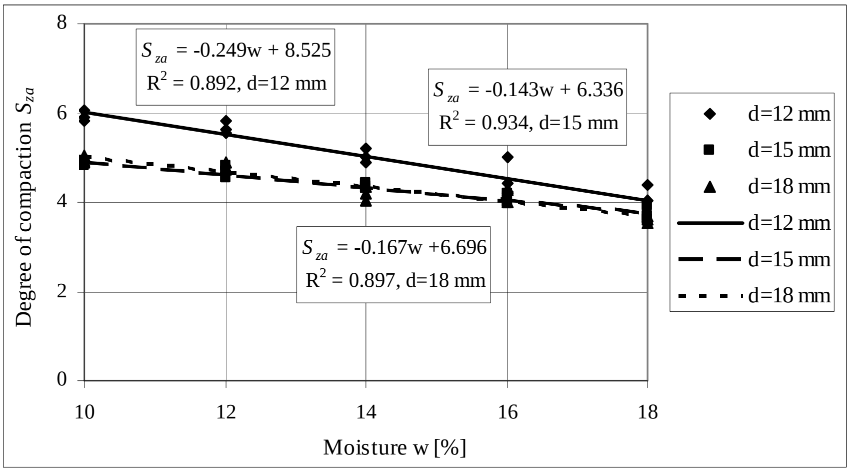

Fig. 3. Correlation between degree of agglomerate compaction S_{za} and moisture content w of processed material for three diameters of chamber d

An increase in the material's moisture content decreases compaction work L_c for every analyzed chamber diameter (Fig. 4). Compaction work L_c ranged from 74 J for *d*=18 mm (*w* = 10%) to 24 J for *d*=12 mm (*w* = 18%). The highest compaction work values were reported for material compressed in a chamber with diameter *d*=18 mm. Specific compaction work L_c' (Fig. 5) was determined in the range of 43 J·g^{-1} for *d*=12 mm (*w* = 10%) to 14 J·g^{-1} for *d*=18 mm (*w* = 18%). With an increase in the examined material's moisture content, the changes in specific compaction work L_c' (Fig. 5) were similar to those observed for compaction work L_c (Fig. 4). The highest values of specific compaction work L_c' were reported for grass samples processed in a chamber with the smallest diameter of 12 mm.

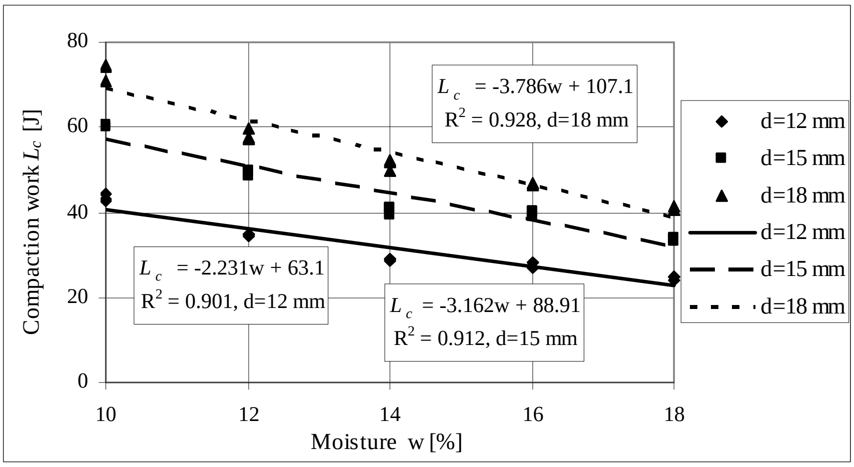

Fig. 4. Correlation between compaction work L_c and moisture content w of processed material for three diameters chamber d

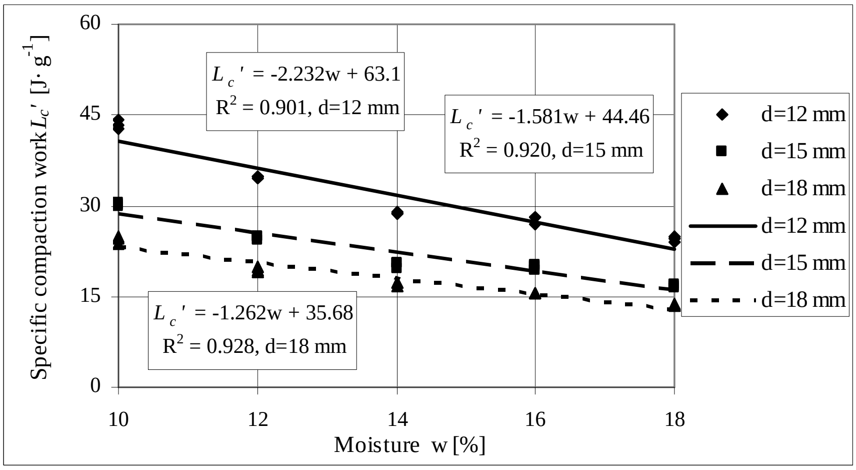

Fig. 5. Correlation between specific compaction work L_c' and moisture content w of processed material for three diameters of chamber d

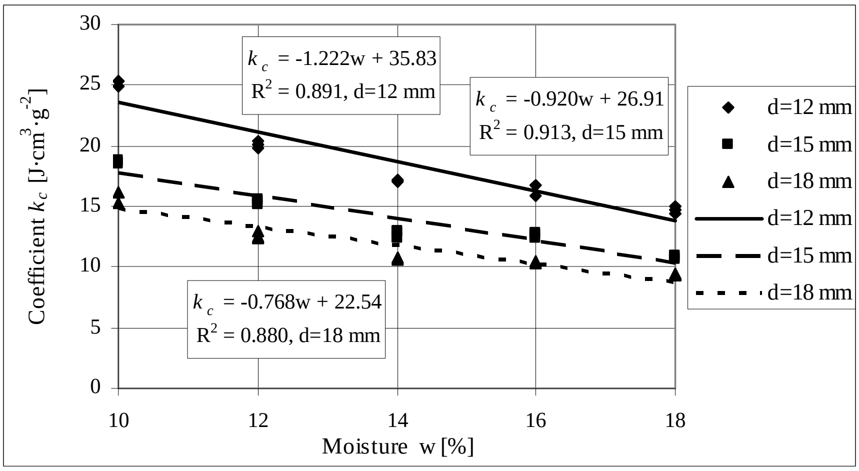

Fig. 6. Correlation between coefficient of susceptibility to compaction k_c and moisture content w of processed material for three diameters of chamber d

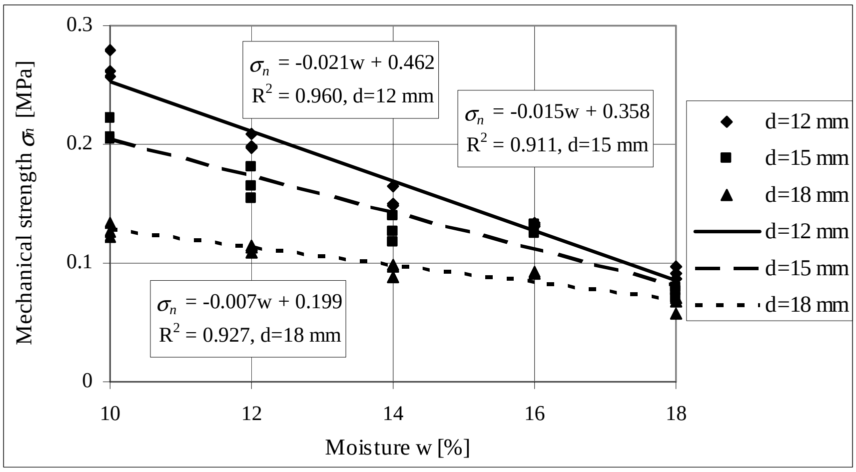

Fig. 7. Correlation between the mechanical strength o$_n$ of agglomerate and moisture content w of processed material for three diameters of chamber d

At a higher moisture content (*w*), the compacted material is probably characterized by greater plasticity, and its susceptibility to compaction grows, as demonstrated by lower values of the coefficient of susceptibility to compaction k_c (Fig. 6). At every moisture content level, the highest values of k_c were reported for grass compressed in a chamber with *d* = 12 mm, and the lowest values – for *d*=18 mm. For *d* = 12 mm (*w* = 18%), the minimal value of k_c was determined at 15 J·cm^3·g^{-2} and the maximum value at 25 J·cm^3·g^{-2}. For *d* = 18 mm, the value of k_c decreased from 16 J·cm^3·g^{-2} to 9 J·cm^3·g^{-2} as the material's moisture content increased from 10% to 18%. Similarly to other materials subjected to compaction analyses [9, 10, 13], the value of k_c (Fig. 6) observed in this study fluctuated with an increase in moisture content.

An increase in moisture content leads to greater expansion of the analyzed material and lowers the mechanical strength of the resulting aggregate. The results of a strength test indicate that with an increase in moisture content, the mechanical strength of aggregates decreases for all chamber diameters (Fig. 7).

The highest mechanical strength values were reported for grass compressed in a chamber with the diameter of 12 mm, and the lowest values – for chamber diameter of 18 mm. Mechanical strength σ_n (Fig. 7) was determined in the range of 0.28 MPa for d = 12 mm (moisture content w = 10%) to 0.06 MPa for d = 18 mm (moisture content w = 18%). Similar variations in the values of mechanical strength (Fig. 7) and agglomerate density (Fig. 2) were observed subject to the material's moisture content and chamber diameter. Grass compacted in a chamber with the smallest diameter at the maximum specific pressure produced agglomerates characterized by the highest density and the highest mechanical strength (Fig. 5). This process requires the highest specific compaction work, and it could be very energy consuming (Fig. 5). In a study of wheat straw, similar variations in compaction parameters and mechanical strength were reported with changes in moisture content and chamber diameter [13].

5. Conclusions

1. The moisture content of meadow grass and the diameter of the compression die chamber had a significant effect on pressure compaction parameters and the mechanical strength of the resulting agglomerate.
2. An increase in the analyzed material's moisture content from 10% to 18% led to an increase in the maximum material density in the compression chamber (ρ_c) and a decrease in: agglomerate density (ρ_{a1}), compaction work L_c), specific compaction work (L_c’) and degree of agglomerate compaction (S_{za}).
3. Materials with a higher moisture content are more susceptible to compaction. The produced agglomerates are characterized by a higher degree of expansion and lower mechanical strength (σ_n).
4. The use of a compression die chamber with a larger diameter decreases material density in the chamber (ρ_c), agglomerate density (ρ_{a1}), specific compaction work (L_c’) and agglomerate compaction (S_{za}). Agglomerates compressed in a chamber with the smallest diameter are characterized by higher mechanical strength.

6. References

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