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THE EFFECT OF PRELIMINARY PROCESSING ON COMPACTION PARAMETERS OF OILSEED RAPE STRAW

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Summary. This study determines the effect of the moisture content (10% to 22%) and fractionation degree (d_{sr}=0.95 and d_{sr}=1.94 mm) of oilseed rape straw on compaction parameters under model conditions. The straw's susceptibility to compaction and the quality of the resulting briquettes were analyzed. Straw density increased with a rise in moisture content, whereas the density of the agglomerated product decreased after removal from the press die. Lower energy demand was reported during the compaction of finely ground material (average of 27.02 $J \cdot g^{-1}$) throughout the entire moisture content range. The average difference in energy demand reported at various moisture content levels reached 36%. A higher degree of straw fractionation reduced energy consumption by 14% on average.

Key words: compaction, briquetting, moisture content, degree of fractionation, oilseed rape straw.

INTRODUCTION

The achievement of stringent targets of renewable energy schemes requires the use of biofuels produced from residual crop materials. Straw shows considerable promise as crop residue biomass fuel. The straw of nearly all cereal grain species and oilseed rape can be used for energy generation. The growing demand for alternative energy sources supports productive management of oilseed rape straw which is usually chopped and incorporated into the soil through plowing.

Straw is a difficult material to handle in comparison with other energy carriers. Straw is a non-homogenous material with a lower calorific value, in particular per unit volume [3]. For this reason, straw has to be compacted into briquettes under pressure [11]. Compaction significantly reduces the cost of handling and transporting plant biomass for the needs of energy generation.

According to various research studies, the moisture content [5, 14, 15, 16, 17, 20] and fractionation degree of the processed material [1, 13] significantly affect the agglomeration of solid biofuels. Those parameters impact the compaction process [7, 9, 12, 18, 19] as well as the quality of the resulting product [2, 4, 6, 10]. Oilseed rape straw is characterized by a moisture content of 30% to 40% upon harvesting. Only wilted and dried straw can be processed, which implies that harvested straw has to be left in the field for several to more than ten days. Due to specific moisture content requirements, straw harvest dates have to be adapted to the needs of the compaction process (to eliminate additional drying or hydration of the processed material).

The objective of this study was to determine the values of parameters during the compaction of straw characterized by a different moisture content and degree of fractionation.

MATERIALS AND METHODS

The experimental materials comprised oilseed rape straw harvested in 2010. The material was ground in a H-950 hammer mill equipped with ϕ 3 and 9 mm sieves. The particle size distribution of the studied material was described to determine the average size of the produced fractions. Particle size distribution was determined in accordance with the Polish Standard PN-89/R-64798 using the SASKIA Thyr 2 laboratory screen and a set of sieves with the following mesh size: 6, 2, 2.5, 1.6, 1.0, 0.5, 0.315 and 0.1 mm. The screening time was two minutes. After screening, the produced fractions were weighed on WPE 300 scales with the precision of $\pm 10^{-2}$ g. The average size of fractionated particles (fractionation module) was calculated using the following formula:

$$d_{sr} = \frac{\sum_{i=1}^{i=n} h_i \cdot P_i}{100}, \tag{1}$$

where: d_{sr}- average particle size, mm; h_i- average mesh size of two adjacent sieves, mm; P_i- fractionated residue in sieve, %; n- number of sieves.

The average size of particles fractionated in a sieve with a 4 mm mesh was 0.95 mm, and the size of material passed through a 12 mm mesh sieve was 1.94 mm.

The parameters of the straw compaction process were determined for raw material with moisture content in the range of 10% to 22% (in steps of 3% +/-0.2%). Straw was brought to the desired moisture level through hydration. The quantity of added water was determined based on the following formula:

$$M_w = M_1 \frac{W_2 - W_1}{100 - W_2}, \tag{2}$$

where: M_w – weight of added water, g;
M_1 – weight of material sample, g;
W_1 – moisture content of material sample, %;
W_2 – required moisture content of material sample, %.

The samples were stored for 24 h in tight containers to evenly distribute moisture throughout the material.

The compaction process was analyzed according to the methodology proposed by Laskowski and Skonecki [8]. The mechanical properties of straw samples were observed using the Zwick Z020/TN2S tensile test machine. The samples were compacted in a pressing unit with a closed die. The compaction chamber had a diameter of 15 mm, cylinder (material) temperature was 20ºC, and piston speed was 10 mm·min^{-1}. Straw samples were compacted until the achievement of a working load equal to 20 kN. Compaction pressure was 114 MPa.

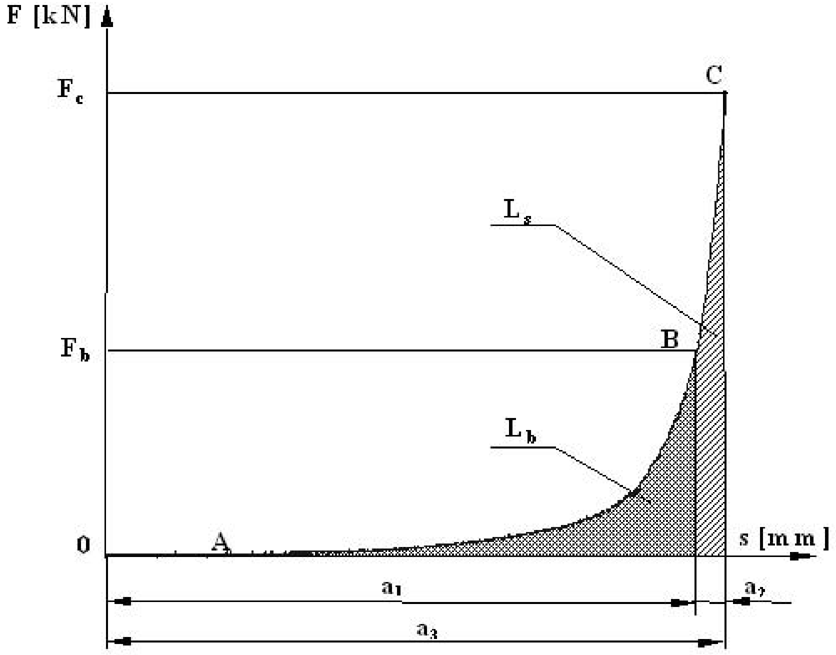

Fig. 1. Compaction characteristics: a_1–compaction, a_2-compression, a_3–pressing (Laskowski and Skonecki 2001)

The results of the analysis were used to develop a curve demonstrating the correlation between compaction force *F* and piston displacement *s*

(Fig. 1). Every compaction process was performed in three replications. The values of maximum material density in compaction chamber g_z and total compaction effort L_c were determined from the compaction curve. The above values were used to calculate the coefficient of material susceptibility to compaction k_c ($k_c = L_p \cdot (g_z - g_s)^{-1}$, where: $L_p = L_c \cdot m^{-1}$ – unitary compaction effort, *m* – weight of material sample, g_s – initial density of loose material. The agglomeration density of the resulting briquette was determined directly after removal from chamber g_a.

Briquette hardness was determined using the following formula:

$$T_a = \frac{F_n}{l}, \tag{3}$$

where: T_a – agglomeration density, N•cm^{-1},
F_n – maximum breaking force, N,
l – briquette length cm,

Mechanical properties were investigated using the ZWICK Z020/TN2S tensile test machine (piston speed of 10 mm·min^{-1}). The briquette was compressed transversely to the axis until breaking point, and maximum breaking force F_n was determined.

RESULTS AND DISCUSSION

The effect of moisture content on material density in the compaction chamber is illustrated in Figure 2.

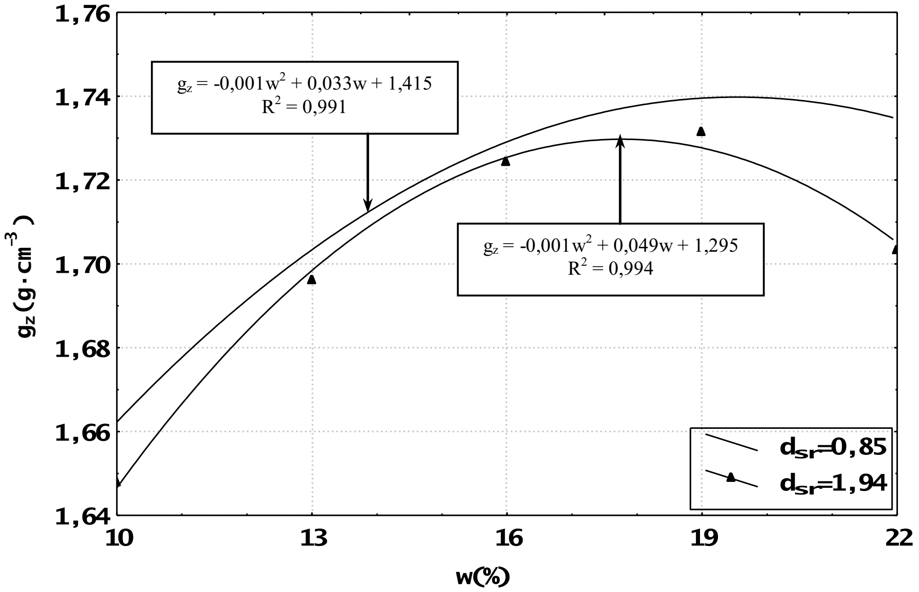

Fig. 2. Correlation between material density in the chamber (gz) and moisture content (w) at various degrees of fractionation (dsr)

The value of the studied parameter increased with a rise in the moisture content of samples characterized by a lower degree of fractionation within the entire range of tested values. Variation was determined in the range of 1.66 to 1.73 g·cm^{-3}. As regards the sample with d_{sr}=1.94 mm, the highest density (1.73 g·cm^{-3}) was noted at a moisture content of 19%. The analyzed parameter was characterized by the smallest variation (due to the effect of the degree of fractionation) at the moisture content of 13% to 19%.

The changes in agglomerate density after removal from the compaction chamber are presented in Figure 3. The highest density values were reported at 10% moisture content, and the lowest – at 22% moisture content for both the analyzed degrees of fractionation. Briquettes produced from material with d_{sr}=0.85 mm were marked by lower expansion. Product density reached 1 g•cm^{-3} at moisture content in the range of 10% to 13%. Agglomerates produced from material with d_{sr}=1.94 mm and a moisture content of 22% were characterized by the lowest density (0.71 g•cm^{-3}).

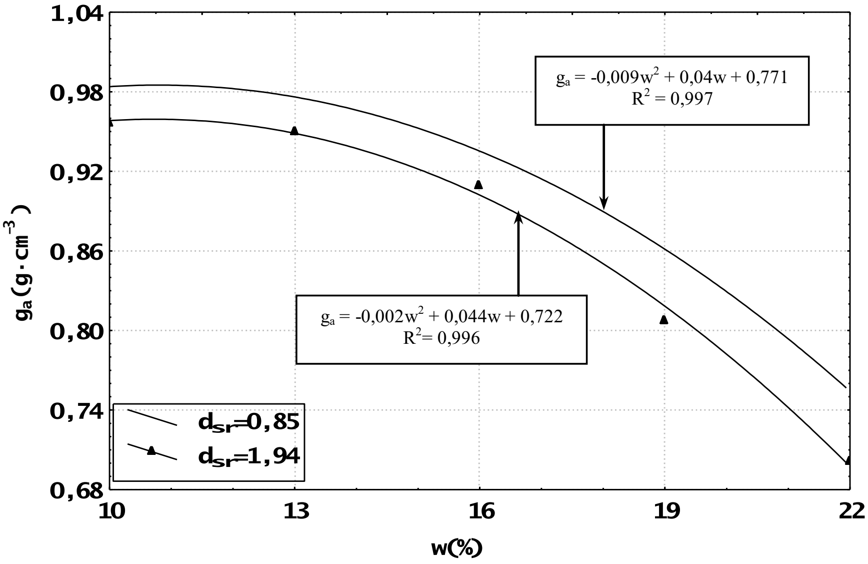

Fig. 3. Correlation between agglomerate density (g_a) and moisture content (*w*) at various degrees of fractionation (d_{sr})

Figures 4 and 5 demonstrate than an increase in the material's moisture content leads to higher susceptibility to compaction. It can be assumed that a higher moisture content increases the material's plasticity, thus reducing the amount of energy required for its compaction.

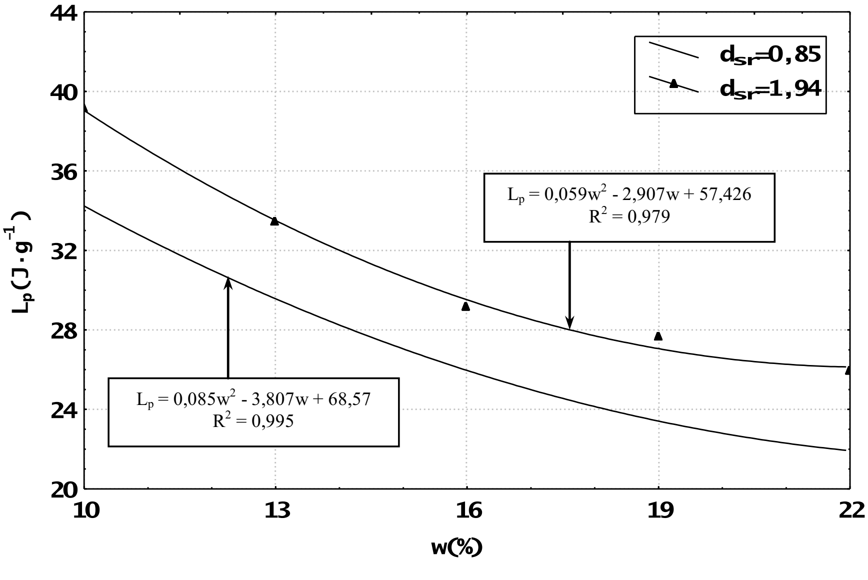

Fig. 4. Correlation between unitary compaction effort (L_p) and moisture content (*w*) at various degrees of fractionation (d_{sr})

The value of the unitary compaction effort (Fig. 4) for the studied materials ranged from 21.43 to 39.15 J•g^{-1}. The highest value of parameter L_p was reported for the sample with d_{sr}=1.94 mm, agglomerated at 10% moisture content. The analyzed parameter reached the lowest value for the material with d_{sr}=0.85 mm and moisture content of 22%.

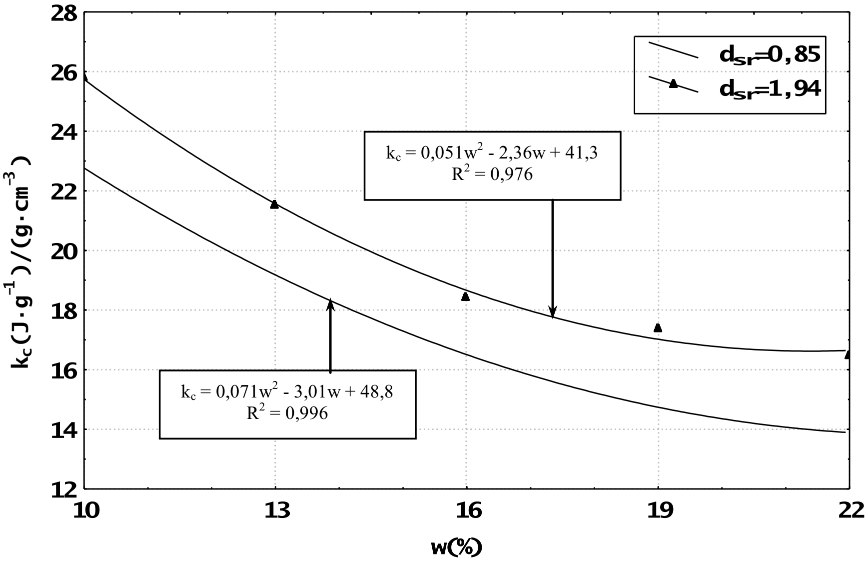

Fig. 5. Correlation between coefficient (k_c) and moisture content (w) at various degrees of fractionation (d_{sr})

Similar correlations were observed in respect of the coefficient of susceptibility to compaction which ranged from 13.51 $(J\cdot g^{-1})\cdot((g\cdot cm^{-3}))^{-1}$ to 25.81 $(J\cdot g^{-1})\cdot((g\cdot cm^{-3}))^{-1}$ (Fig. 5).

As regards the unitary compaction effort and coefficient k_c, an increase in moisture content did not level out the differences resulting from the effect of fractionation degree. The reported differences ($p>0.05$) remained constant throughout the entire range of variation in moisture content.

The results of agglomerate hardness measurements (Fig. 6) indicate that the mechanical strength of the studied materials decreased with a rise in moisture content.

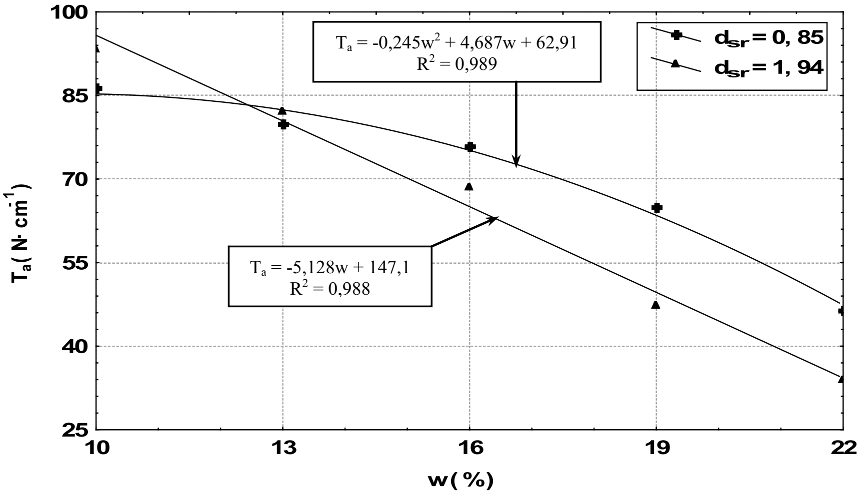

Fig. 6. Correlation between agglomerate hardness (T_a) and moisture content (*w*) at different degrees of fractionation (d_{sr})

Agglomerates produced from material with d_{sr}=1.94 mm were characterized by both the highest (93.32 N·cm^{-}1) and the lowest (33.84 N·cm^{-1}) hardness. An inversely proportional correlation was determined between moisture content and parameter T_a. In products obtained from material with d_{sr}=0.85 mm, the dynamics of decrease in hardness values increased beginning with the moisture content of 13%.

CONCLUSIONS

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

1. The highest increase in material density in the compaction chamber was observed at the moisture content of 10% to 16%. Within the above range, the average increase in the studied parameter's value was 4.2%. A further increase in moisture content (subject to the degree of fractionation) did not result in significant changes in density (d_{sr}=0.85 mm) or led to a drop in density (d_{sr}=1.94 mm).
2. After removal from the compaction chamber, briquette density (regardless of the degree of fractionation) reached the highest values at 10% moisture content, while the lowest values were reported for the moisture content of 22%. Agglomerates produced from material with d_{sr}=0.85 mm were marked by lower expansion. The average difference resulting from the effect of fractioning degree was 3.3%.
3. An increase in the material's moisture content contributed to higher susceptibility to compaction. The average drop in the unitary demand for compaction energy (at the moisture content from 10% to 22%) was 44%, and the drop in coefficient k_c reached 44.7%.
4. An increase in the material's moisture content within the investigated range led to a decrease in agglomerate hardness. The average drop in hardness values reached 48% in materials with d_{sr}=0.85 and 79% in materials with d_{sr}=1.94 mm.

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WPŁYW WARUNKÓW OBRÓBKI WSTĘPNEJ NA PARAMETRY PROCESU ZAGĘSZCZANIA SŁOMY RZEPAKOWEJ

Streszczenie. Przedstawiono wyniki badań nad określeniem wpływu wilgotności (od 10 do 22%) i rozdrobnienia (d_{sr}=0,95 i d_{sr}=1,94 mm) słomy rzepakowej na parametry procesu aglomerowania w warunkach modelowych. W szczególności wyznaczono podatność surowca na zagęszczanie oraz jakość uzyskiwanych aglomeratów. Stwierdzono, że wraz ze wzrostem wilgotności, rośnie gęstość materiału w komorze zagęszczania, natomiast gęstość produktu po wyjęciu z matrycy maleje. Wykazano, iż w całym zakresie wilgotności, niższe zapotrzebowanie energii występuje podczas zagęszczania materiału o wyższym stopniu rozdrobnienia (średnio 27,02 $J\bullet g^{-1}$). Przeciętna różnica w wielkości tego parametru, wynikająca z oddziaływania stopnia wilgotności wynosi 36%. Natomiast zwiększenie rozdrobnienia pozwala zredukować energochłonność procesu średnio o 14%.

Słowa kluczowe: zagęszczanie, brykietowanie, wilgotność, stopień rozdrobnienia, słoma rzepakowa.