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The effect of binder addition on the parameters of compacted poplar wood sawdust

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Abstract. The study discusses the results of tests investigating the effect of binder addition (calcium lignosulphonate, 0% to 20%) and moisture content (10% to 22%) on the parameters of compacted poplar wood sawdust. The susceptibility to compaction of the studied material, changes in material density and the mechanical strength of briquettes were analyzed. The addition of a binding agent increased compaction effort by 15.4% and briquette density – by 37% on average. Binder addition in the examined range resulted in an approximately 7-fold increase in the mechanical strength of briquettes at all analyzed moisture content levels.

Key words: compaction, briquetting, binding agents, calcium lignosulphonate, poplar wood sawdust.

INTRODUCTION

The growing demand for solid biofuels [2, 16] supports the management of various types of by-products from the wood processing industry. Wood shavings, chips, bark, sawdust and wood powder account for 20÷30% of the initial mass of wood intended for processing. Most of those materials are characterized by problematic structure, low bulk density and low energy density, which is why they have to be processed into pellets or briquettes [5, 9, 10, 11].

Sawdust is a valuable raw material for the production of compacted biofuels. The particle size distribution of sawdust is generally suitable for pressure compaction without the need for further disintegration [1]. Sawdust from the wood of both coniferous and deciduous trees is used in the production process. Waste and by-products originating from various tree species have different lignocellulose composition. The most important consideration in the compaction process is lignin content whose average share in deciduous trees is 5% lower than in coniferous trees. Lignin is a natural binder which aggregates briquettes [18, 19, 20]. Sawdust from various tree species is often mixed in the production process to level out its lignin content. The above prevents technological problems, and it gives end products the required mechanical strength [3].

The above problem can also be solved by using organic and synthetic binders [12, 15]. Those compounds bind comminuted components (by acting like glue), thus improving the stability and quality of briquettes. As a result, the mechanical strength of briquettes is improved and the amount of energy required for the production process is reduced. Lignin binders are the most effective solution for compacting biological materials. They contain calcium and sodium lignosulphonates, processed starch and fatty acids. Lignin binders are used at various doses which generally do not exceed 3% of the material's weight. In line with the applicable regulations, the content of lignin binders in the production of solid biofuels should not exceed 2%. The discussed binders do not have a negative impact on biofuel combustion because they are burned in their entirety without producing additional ash, and they are completely neutral for the environment.

Binders improve material viscosity and lower its sensitivity to moisture, which supports the briquetting of materials with a higher moisture content without the risk of disintegration. This is an important consideration because sawdust from furniture and carpentry plants contains 10% to 20% of water on average. Sawdust from wet wood processed in sawmills is characterized by 50% moisture content, and it has to be dried to achieve a suitable moisture level for compacting [4, 8, 13, 17].

In view of the above, the objective of this study was to determine the values of pressure compaction parameters characterizing poplar wood sawdust with different moisture content levels and various quantities of a calcium lignosulphonate binder.

MATERIALS AND METHODS

The experimental material was poplar wood sawdust from a sawmill in the Lublin area. Sawdust was dried in accordance with the requirements of standard PN-EN 14774-1:2010, to achieve a moisture content in the range of 10% to 22% (every 3% +/-0.2%). The required moisture content was determined using an equation for mass change over time based on the following dependence:

$$m_1 = m_0 \left(\frac{100 - w_0}{100 - w_1}\right)(\mathrm{g}) \quad (1)$$

where: m_0 – initial mass of material, g; m_1 – mass of material after drying, g; w_0 – initial moisture content of material, %; w_1 – moisture content of material after drying, %.

The binding agent (calcium lignosulphonate) was added to material samples with a various moisture content in the amount of 0.5%, 1%, 1.5% and 2%. Material without the binder served as the control.

The particle size distribution of sawdust was determined in accordance with standard PN-EN 15149-2:2011 using the SASKIA Thyr 2 laboratory sieve. The density of sawdust with a different moisture content was determined in bulk state according to standard PN-EN 15103:2010.

The material was subjected to pressure compaction in line with the method proposed by Laskowski and Skonecki [6] using the Zwick Z020/TN2S tensile test machine equipped with a pressing unit and a closed die with a cylinder (compaction chamber) diameter of 15 mm. Test parameters were as follows: mass of material sample – 2 g, cylinder (compacted material) temperature - 20°C, piston speed - 10 mm·min^{-1}, maximum unit piston pressure – 114 MPa. Every compaction process was performed in three replications.

The results were used to develop a curve illustrating the correlation between compaction force and piston displacement. The values of maximum material density in compaction chamber ρ_c and total compactive effort L_c were determined based on the characteristic points of the compaction curve. The coefficient of material susceptibility to compaction k_c was calculated:

$$k_c = \frac{L_c'}{(\rho_c - \rho_n)} \ ((\mathrm{J{\cdot}g^{-1}})/(\mathrm{g{\cdot}cm^{-3}})) \quad (2)$$

where: ρ_n – initial material density in compaction chamber, g·cm^{-3}; L_c' – unitary compactive effort, J·g^{-1}.

The density of the resulting briquettes was determined after 48 hours of storage ρ_a.

The compaction degree of the analyzed material in the chamber S_{zm} and the compaction of the resulting briquette S_{za} were determined as the quotient of density ρ_c and ρ_a, and initial density in the compression chamber ρ_n ($S_{zm} = \rho_c \cdot \rho_n^{-1}$, $S_{za} = \rho_a \cdot \rho_n^{-1}$). The degree of briquette expansion S_{ra} was calculated as the quotient of density ρ_a and ρ_c ($S_{ra} = \rho_a \cdot \rho_c^{-1}$) to evaluate the decrease in briquette density caused by turning expansion.

The mechanical strength of a briquette δ_m was determined in the Brazilian compression test [7, 14] using the Zwick Z020/TN2S tensile testing machine (with piston speed of 10 mm·min^{-1}). A briquette with diameter d and length l was compressed transversely to the axis until breaking point, and maximum breaking force F_n was determined. Mechanical strength δ_m was calculated using the following formula:

$$\sigma_n = \frac{2F_n}{\pi\, dl} \ (\mathrm{MPa}) \quad (3)$$

The correlations between the binder content, the moisture content of the examined material and compaction parameters were analyzed in the STATISTICA program at a significance level of $\alpha_i = 0.05$. The form of the equations was selected by reverse stepwise regression. The significance of regression coefficients was determined by Student's t-test. Model adequacy was verified using Fisher's test.

RESULTS

BASIC PHYSICAL PROPERTIES OF MATERIAL

The results of the density of sawdust with different moisture content are presented in Table 1. The obtained data indicate that the bulk density of material in the analyzed range decreased by around -20% with an increase in moisture content.

Table 1. Correlation between the bulk density of material *(ρ_s)* and moisture content *(w)*

w (%)	10	13	16	19	22
$\rho_s (g{\cdot}cm^{-3})$	0.142	0.137	0.132	0.122	0.114

The results of the particle size distribution of sawdust are presented in Figure 1. Particles measuring 1 to 1.6 mm had the highest percentage share of the analyzed samples, therefore, the material's granulometric composition was appropriate for pressure compaction.

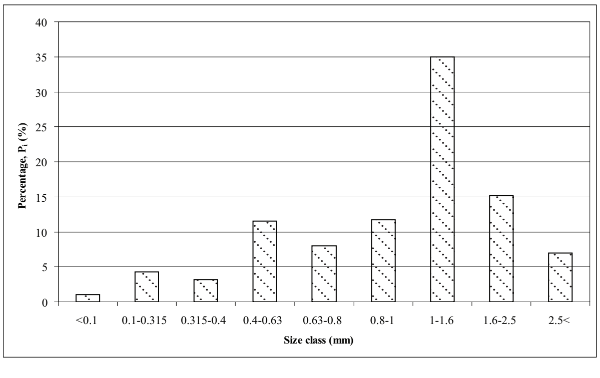

Fig. 1. Particle size distribution (P_i) of the studied material

Multiple regression equations describing the correlations between compaction parameters, the binder content and the moisture content of the experimental material are presented in Table 2. A regression analysis revealed that the studied correlations can be described by a quadratic equation of the second degree or a linear equation. The analyzed correlations are presented in Figures 2-6.

Table 2. Regression equations describing the correlations between density ρ_c, ρ_a, compactive effort L_c, coefficient k_c, degree of compaction S_{zm}, S_{za}, degree of expansion S_{ra}, mechanical strength δ_m and binder content Z_l and material moisture content w, and the values of determination coefficient R^2.

Parameter	Regression equation	R^2
Density of material in the chamber, ρ_c	ρ_c=–0.003Z_l^2–0.032Z_l+0.03w+ 0,001$Z_l w$+1.391	0.912
Briquette density after 48., ρ_a	ρ_a=–0.044Z_l^2–0.059Z_l– 0.002w^2+0.015$Z_l w$+0.837	0.943
Compactive effort, L_c	L_c=3.151Z_l–1.508w+63.89	0.911
Coefficient of susceptibility to compaction, k_c	k_c=0.982Z_l–0.607w+23.65	0.956
Degree of material compaction, S_{zm}	S_{zm}=–0.138Z_l+0.287w+8.290	0.923
Degree of briquette compaction, S_{za}	S_{za}=–0.369Z_l^2–0.61Z_l– 0.011w^2+0.135$Z_l w$+5.778	0.904
Degree of briquette expansion, S_{ra}	S_{ra}=–0.024Z_l^2–0.021Z_l+0.01w+ 0.008$Z_l w$+0.604	0.945
Mechanical strength of briquette, δ_m	δ_m=0.341Z_l–0.037w+0,875	0.973

DENSITY OF MATERIAL IN THE CHAMBER AND BRIQUETTE DENSITY

An analysis of the results shown in Figure 2 and regression equations (Table 2) indicated that an increase in binder dose resulted in an insignificant drop in the maximum density of material in the chamber. The above was observed at every moisture level, and a more profound decrease in maximum density was reported at a lower moisture content of 10% and 13%.

The variation of the analyzed parameter was determined in the range from 1.56 to 1.69 g·cm^{-3}. The highest density was observed in material samples with 22% moisture content.

Briquette density (after turning expansion – 48 h) increased from 0.62 (Z_l=0%; w=22%) to 1.07 (Z_l = 2%; w=13%) with the application of higher binder doses. The analyzed binding agent had the most significant impact on the density of briquettes made of material with a higher moisture content (19% and 22%). 1% and 2% addition of calcium lignosulphonate significantly reduced the effect of moisture content on the values of the examined parameter.

COMPACTIVE EFFORT AND SUSCEPTIBILITY TO COMPACTION

The application of higher binder doses probably increased the coefficient of friction between material particles and between particles and the walls of the compaction chamber. The above led to an increase in compactive effort and the coefficient of susceptibility to compaction (Fig. 3).

The value of parameter L_c for the analyzed samples ranged from 30.32 to 54.12 J, and the value of

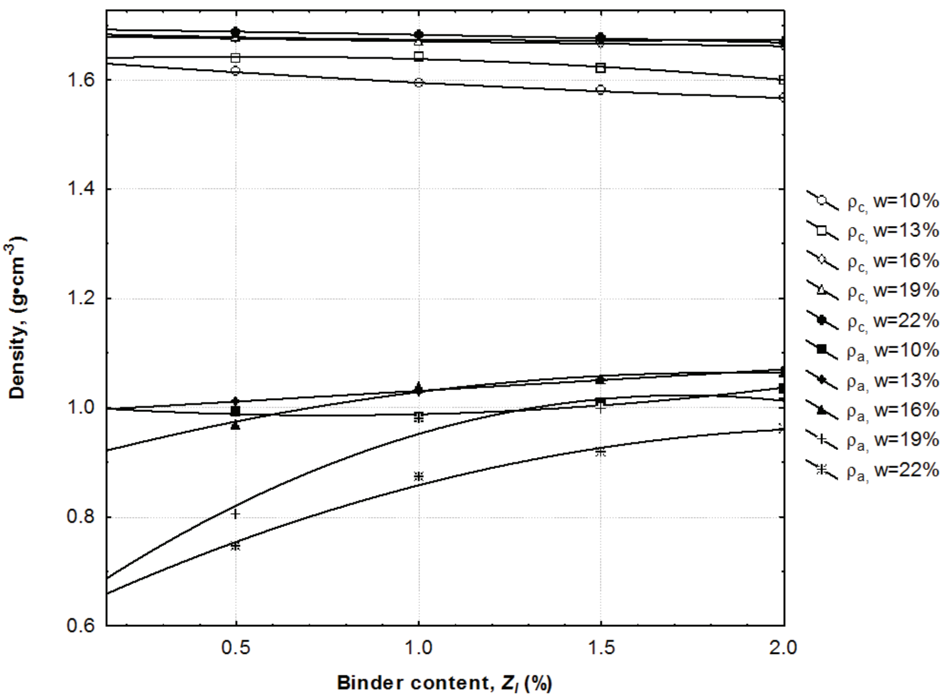

Fig. 2. Correlations between density of material in the chamber (ρ_c), briquette density (ρ_a) and binder content (Z_l) at different moisture content levels (w).

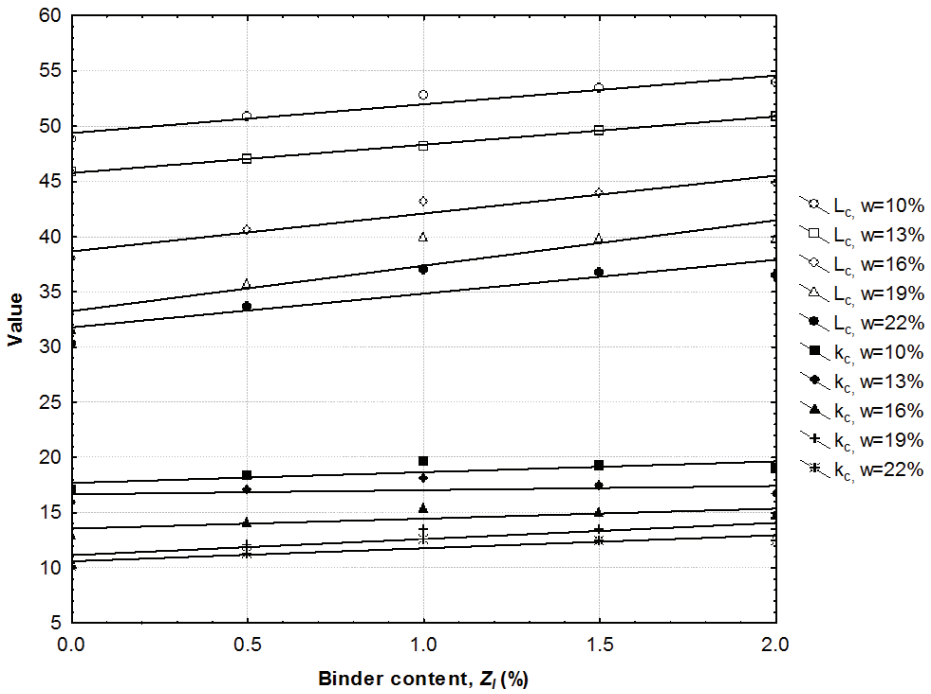

Fig. 3. Correlations between compaction effort (L_c), the coefficient of susceptibility to compaction (k_c) and binder content (Z_l) at different moisture content levels (w).

parameter k_c – from 10.82 to 20.02 $(J \cdot g^{-1}) \cdot ((g \cdot cm^{-3}))^{-1}$. The values of the studied parameters were highest for the maximum binder dose (2%) and the lowest moisture content (10%). The above indicates that sawdust with a higher moisture content and without the addition of a binding agent is more susceptible to compaction.

DEGREE OF BRIQUETTE COMPACTION AND EXPANSION

An analysis of the degree of material compaction in the chamber revealed that binder dose had an insignificant effect on the values of the studied parameter (Fig. 4).

On average, the maximum density of material in the chamber ρ_c was 13-fold higher than initial material

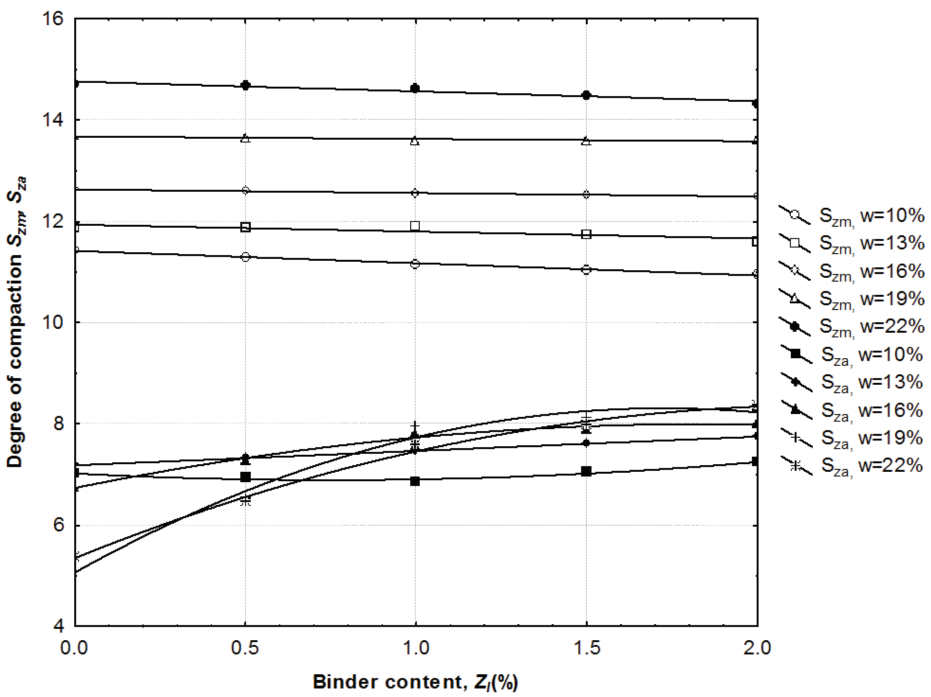

Fig. 4. Correlations between the degree of material compaction (S_{zm}), the degree of briquette compaction (S_{za}) and binder content (Z_l) at different moisture content levels (w)

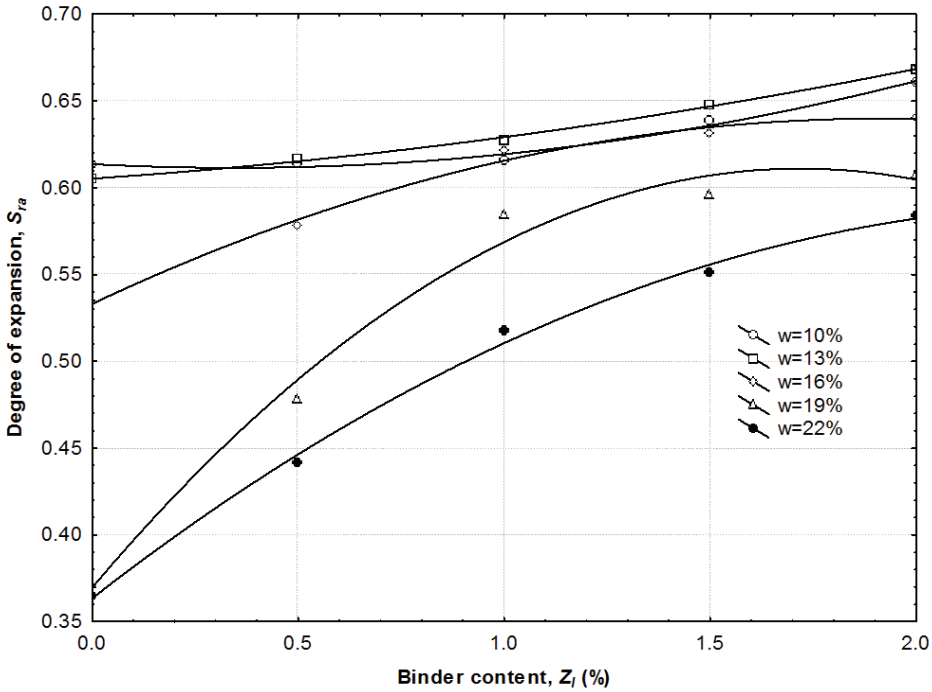

Fig. 5. Correlations between the degree of briquette expansion (S_{ra}) and binder content (Z_l) at different moisture content levels (w)

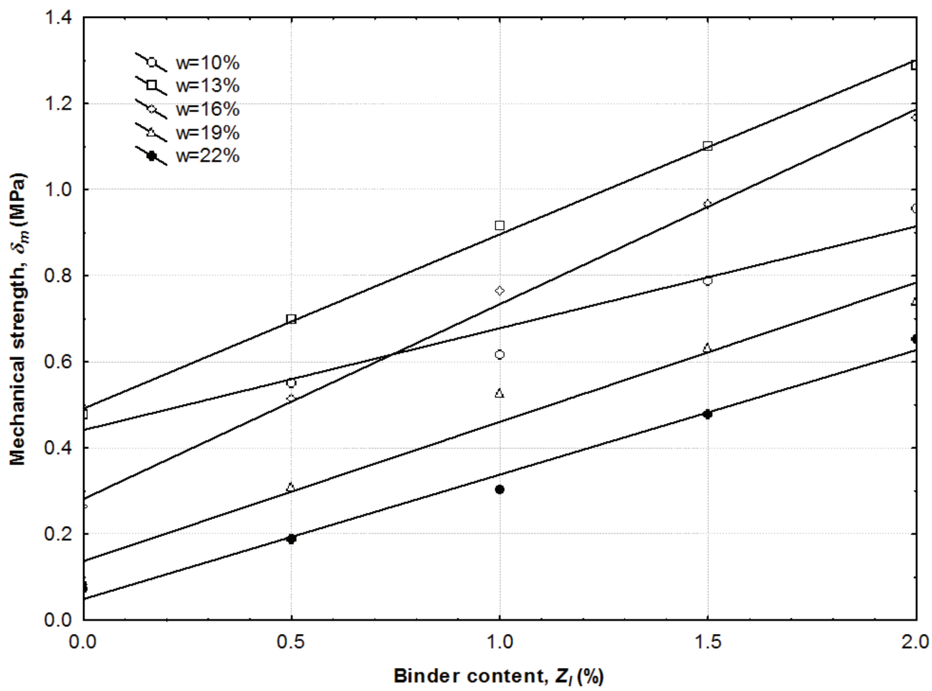

Fig. 6. Correlations between the mechanical strength of briquettes (δ_m) and binder content (Z_l) at different moisture content levels (w)

density ρ_n. The highest maximum density was reported in material samples with 22% moisture content.

The results of briquette compaction analysis (Fig. 4) indicated that the density of a stored product was around 5-fold higher than the initial density in samples with 22% moisture content and no binder to around 8-fold higher one in samples with 2% binder content and the same moisture content. Binder addition increased the density of products made of materials with a higher moisture content. The highest compaction values were noted in briquettes made of material with 19% and 22% moisture content with 1%-2% addition of binder.

The results of briquette expansion tests confirm the above observations (Fig. 5). In briquettes made of material with 19% and 22% moisture content, the addition of higher binder doses increased the analyzed parameter two-fold (from around 0.37 to around 0.6).

BRIQUETTE STRENGTH

The results of strength tests indicate that the mechanical strength of briquettes increased with the addition of a binding agent to poplar sawdust (Fig. 6).

Mechanical strength values were determined in the range of 0.07 to 1.29 MPa. The highest strength values were reported in briquettes made of sawdust with 13% moisture content, and the lowest – in products with 22% moisture content, at every binder dose. It should be noted, however, that 1.5% addition of the binder to material with 22% moisture content produces briquettes whose strength is identical to that of products made of pure sawdust with 13% moisture content.

CONCLUSIONS

The following conclusions can be formulated based on the results of this study:

1. The addition of a binding agent in the analyzed dose range decreased the maximum density of material in the compaction chamber by an average of -4.1%, and increased briquette density by an average of 37%.
2. Sawdust's susceptibility to compaction decreased with a rise in binder dose. Compaction effort (with a binder content of 0%-2%) increased by 15.4%, and coefficient k_c increased by 12.5%, on average.
3. The degree of briquette compaction and expansion increased with a rise in binder dose at every binder content level. The highest increase was reported in the material with 19-22% moisture content where parameter S_{za} increased by 56.6% and parameter S_{ra} – by 61.1%, on average.
4. An increase in binder content led to an approximate 7-fold rise in the mechanical strength of briquettes, regardless of the moisture content of the investigated material.

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WPŁYW DODATKU LEPISZCZA NA EFEKTYWNOŚĆ ZAGĘSZCZANIA TROCIN TOPOLOWYCH

S t r e s z c z e n i e. Przedstawiono wyniki badań nad określeniem wpływu dodatku lepiszcza w postaci lignosulfonianu wapnia (od 0 do 2%) i wilgotności (od 10 do 22%) na parametry procesu zagęszczania trocin topolowych. W szczególności wyznaczono podatność surowca na zagęszczanie, zmiany gęstości materiału oraz wytrzymałość mechaniczną aglomeratów. Stwierdzono, że wraz ze wzrostem dodatku lepiszcza, rośnie wartość pracy zagęszczania przeciętnie o 15,4%. Natomiast gęstość aglomeratu wzrasta średnio o 37%. Wykazano, iż dodatek lepiszcza w rozpatrywanym przedziale powoduje około 7-krotny wzrost wytrzymałości mechanicznej aglomeratów w odniesieniu do wszystkich analizowanych wilgotności surowca.

S ł o w a k l u c z o w e: zagęszczanie, brykietowanie, lepiszcza, lignosulfonian wapnia, trociny topolowe.