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ASSESSMENT OF QUALITATIVE CHARACTERISTICS OF BRIQUETTES PRODUCED FROM SELECTED PLANT RAW MATERIALS

Summary

The paper presents results of research on quality characteristics of briquettes made from selected raw materials of plant origin. The following raw materials were used: corn straw, oat straw, and chamomile waste. Cereal straw was crushed using H 111/1 shredder equipped with a screen with a diameter of 20 mm. For the production of briquettes, a hydraulic piston briquetting machine of JUNIOR type from Deta Polska working at the pressure of 8 MPa, was used. The moisture, calorific value, granulometric composition, and compaction of raw materials as well as length, mass, bulk density and mechanical strength of the briquettes, were determined during the tests. Depending on the type of agglomerated raw material and its granulometric composition, the qualitative characteristics of briquettes varied. More advantageous features of briquettes were found in case of agglomeration of oat straw and chamomile waste, whereas less favorable for corn straw.
***Key words**: biomass, briquettes, physical properties, density, mechanical durability*

OCENA CECH JAKOŚCIOWYCH BRYKIETÓW PRODUKOWANYCH Z WYBRANYCH SUROWCÓW ROŚLINNYCH

Streszczenie

W pracy przedstawiono wyniki badań cech jakościowych brykietów produkowanych z wybranych surowców pochodzenia roślinnego. Do badań użyto następujących surowców: słomę kukurydzianą, słomę owsianą i odpady rumiankowe. Słomę zbóż rozdrabniano przy użyciu rozdrabniacza bijakowego H 111/1, wyposażonego w sita o średnicy otworów 20 mm. Do produkcji brykietów zastosowano hydrauliczną brykieciarkę tłokową typu JUNIOR firmy Deta Polska, przy ciśnieniu roboczym 8 MPa. Podczas badań określano wilgotność, wartość opałową, skład granulometryczny i stopień zagęszczenia surowców oraz długość, masę, gęstość objętościową i trwałość mechaniczną brykietów. W zależności od rodzaju aglomerowanego surowca oraz jego składu granulometrycznego badane cechy jakościowe brykietów były zróżnicowane. Korzystniejsze cechy brykietów, stwierdzono w przypadku aglomeracji słomy owsianej i odpadów rumiankowych, a mniej korzystne dla słomy kukurydzianej.
***Słowa kluczowe**: biomasa, brykiety, cechy fizyczne, gęstość, trwałość mechaniczna*

1. Introduction

Raw and waste materials of plant origin are the main source of renewable energy in Poland and represent a significant energy potential. These include by-products and waste from agriculture, forestry, horticulture and the agri-food industry. The use of renewable energy sources helps to increase the country's energy security and to improve the energy supply. Plant biomass is potentially the largest source of renewable energy in Poland [2, 4, 10]. The energy is usually obtained through solid incineration (direct combustion or co-combustion with coal) as well as in the form of liquid or gaseous fuels [3].

The use of biomass as a fuel in power systems can generate certain economic and environmental benefits. However, exclusively biomass-based installations may be unreliable due to fuel quality, instability of supplies and their large dispersion. Furthermore, biomass usually has a high humidity lowering its calorific value and low bulk density [7]. Therefore, some types of biomass need to be dried to obtain the desired combustion parameters and higher fuel energy value. Moreover straw is a fuel with strong hydrophilic characteristics and low milling properties [3, 9, 12].

The need to look for alternative fuels for the energy sector makes that there is a strong interest in using various types of plant biomass for these purposes [8]. New technological solutions using plant-origin fuels for energy production are also sought, as well as existing technologies for biomass production from agricultural, forestry and orchard production are improved. Moreover, the possibilities of growing different types of energy crops in the country are also explored [10].

The usefulness of plant raw materials for agglomeration depends on many factors, including: moisture content, granulometric composition, internal friction coefficient, temperature, flowability, etc. [11]. Chemical composition of plant materials is also important. Raw materials of plant origin usually contain cellulose, starch, proteins, resins, lignin, fats and waxes [19]. These substances during agglomeration are subject to various physical and chemical changes, that have a great influence on the course of the process. Also a proper material fragmentation and applied compaction pressure affect the density of briquettes as well as their durability [1, 6, 20].

The briquetting machines offered on the market differ mainly in their purpose for compaction of various types of plant materials (sawdust, straw, etc.). Depending on the compactor construction, briquettes of different shapes and sizes are obtained. Hence, the proper preparation of the raw material for briquetting, and in particular, its fragmentation have the decisive influence on the density of the agglomerate obtained. In order to obtain a high briquette density as well as to improve the filling degree of the compaction chamber in briquetting machines applied, the material needs to be crushed [13, 18].

The main parameters determining the quality of briquettes include primarily their density and mechanical durability. The quality of briquettes can be determined by their durability tests during the strength test. Briquettes with good qualities are those, for which mechanical durability is over 95% [17]. Its value is affected by the fragmentation degree and plant raw material compaction degree. Mechanical durability tests allow to compare the qualitative characteristics of briquettes produced from different raw materials under certain conditions. In practice, their durability depends to a large extent on the way they are transported and their actual load during transportation, unloading, storage or dispensing into the furnace [1, 5, 13].

Mechanical durability can also be a testimony to the quality of briquettes offered by manufacturers using different constructions and operating principles of briquetting devices. On the basis of these values, one can decide on the purpose of the briquette (e.g. for the fireplace or boiler, etc.). In the power industry, where plant fuels in compacted form are subject to combustion prior to the process, high durability is not necessary. On the other hand, when briquettes are to be used as a fuel in the fireplace, both quality and often the aesthetic features count. Such briquettes should be durable, not delaminated or disintegrated, and have a high density and durability, providing a long combustion time [5, 12].

The aim of the study was to analyze the quality characteristics of briquettes made from selected raw materials of plant origin in a hydraulic piston briquetting machine.

2. Material and methods

The following plant-origin raw materials were used to produce briquettes: corn straw, oat straw, and chamomile waste. Cereal straw was crushed using H 111/1 shredder powered by an electric motor of 7.5 kW and equipped with screen 20 mm in diameter.. Prior to agglomeration of plant raw materials, their relative humidity and calorific value were determined. For the briquetting of raw materials, hydraulic piston briquetting machine of type JUNIOR Deta Polska, was used. During the agglomeration process, a double feed hopper to the briquetting compaction chamber was applied.

Following items were determined during the study:

− relative moisture content of raw materials of drying and weighing method according to PN-EN 15414-3:2011 [14],

− calorific value of raw materials on the basis of calorimetric combustion heat using an isoperibolic type of calorimeter of Parr 6400 type, according to PN-EN 14918:2010 [15],

− granulometric composition of raw materials using laboratory shaker LPzE-4e, according to PN-EN 15149-2:2011 [16],

− bulk and shaken density of raw materials using a 50 dm^3 container and laboratory shaker LPzE-4e,

− measurements of the physical characteristics of briquettes, i.e. length, diameter and mass and on that basis their bulk density was calculated according to the formula (1):

$$\rho_o = \frac{4 \cdot 10^6 \cdot m}{\pi \cdot d^2 \cdot l} [kg \cdot m^{-3}] \quad (1)$$

where:

ρ_o – bulk density of a briquette [$kg \cdot m^{-3}$],
m – mass of a briquette [g],
d – diameter of a briquette [mm],
l – length of a briquette [mm],

− compaction degree of the raw material on the basis of bulk density and volume density of a briquette produced, according to the formula (2):

$$S_z = \frac{\rho_o}{\rho_n} \quad (2)$$

where:

S_z – compaction degree of a raw material,
ρ_o – volume density of a briquette ($kg \cdot m^{-3}$),
ρ_n – bulk density of a briquette ($kg \cdot m^{-3}$).

− mechanical durability of the briquettes in the testing bench was assessed in accordance with PN-EN 15210-2:2011 standard [17], and calculated according to the formula (3):

$$D_u = \frac{m_A}{m_E} \cdot 100\% \quad (3)$$

where:

D_U – mechanical durability of a briquette [%],
m_A – mass of briquettes after durability test [g],
m_E – mass of briquettes prior to durability test [g].

The results of the tested briquettes were subject to statistical analysis using variance analysis and Tukey's test. For this purpose, the Statistica ver. 13.1 software was applied and the significance level was assumed at $\alpha = 0.05$.

3. Results and discussion

Based on the obtained results, it was found that their moisture content ranged from 9.9% for chamomile waste to 11.7% for oat straw, while calorific value ranged from 16.3 $MJ \cdot kg^{-1}$ for oat straw to 17.1 $MJ \cdot kg^{-1}$ for corn straw (Table 1).

Table 1. Moisture content and calorific value of raw materials used for briquetting
Tab. 1. Wilgotność i wartość opałowa surowców stosowanych do brykietowania

Kind of material	Moisture [%]	Calorific value [$MJ \cdot kg^{-1}$]
Corn straw	10.6	17.1
Oat straw	11.7	16.3
Chamomile waste	9.9	16.7

Source: own work / Źródło: Opracowanie własne

Table 2 shows the results of granulometric analysis of raw materials used for the production of briquettes. The particle length depended on the nature of the raw material and its susceptibility to grinding. The highest mass of particles above 3.15 mm was noted for corn straw (85.2%), significantly lower for oat straw (46.3%) and the lowest for chamomile waste (19.5%). The smallest mass proportion of the dusty fraction (< 0.5 mm) was found for corn straw

(2.3%), slightly higher for oat straw (3.1%), and the largest for chamomile waste (8.1%).

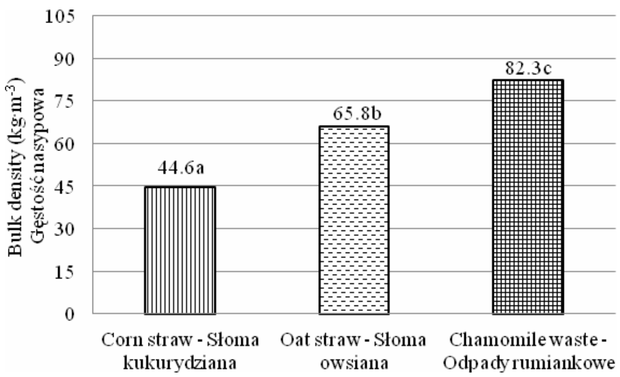
Table 2. Granulometric composition of raw materials used for the production of briquettes [%]

Tab. 2. Skład granulometryczny surowców użytych do produkcji brykietów [%]

Meshes of sieve [mm] / Kind of material	3.15	2.8	2.0	1.4	1.0	0.5	0.25	0.0
Corn straw	85.2	0.8	0.5	1.9	3.6	5.7	1.6	0.7
Oat straw	46.3	2.2	6.1	12.5	16.6	13.2	1.9	1.2
Chamomile waste	19.5	0.3	0.7	7.0	22.0	42.4	7.2	0.9

Source: own work / Źródło: Opracowanie własne

Figure 1 illustrates results of bulk density measurements of comminuted plant raw materials. The average bulk density amounted to 44.6 kg·m^{-3} for corn straw, to 65.8 kg·m^{-3} for oat straw, to 82.3 kg·m^{-3} for chamomile waste. There were statistically significant differences between the bulk density of all tested plant materials.



a, b, c – mean values marked with the same letter do not differ statistically significantly at the level α=0.05

Source: own work / Źródło: Opracowanie własne

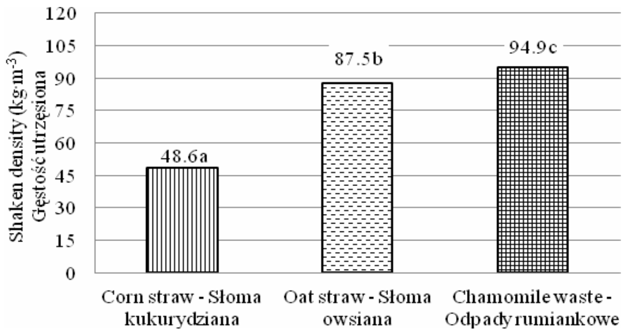
Fig. 1. Average bulk density of agglomerated raw materials

Rys. 1. Średnia gęstość nasypowa aglomerowanych surowców

Figure 2 shows the results of shaken density measurements of shredded plant materials. The average shaken density ranged from 48.6 kg·m^{-3} for corn straw and 87.5 kg·m^{-3} for oat straw to nearly 95.0 kg·m^{-3} for chamomile wastes. Also in this case, statistically significant differences were found between the shaken density of all tested plant materials.

Figure 3 presents results of length measurements of briquettes produced from tested plant materials. The average briquette length was 28.7 mm for corn straw and nearly 40 mm for oat straw to 43.1 mm for chamomile waste. The diameter of the obtained briquettes was constant and amounted to 50 mm. There were statistically significant differences between the length of briquettes produced from all examined plant raw materials.

Figure 4 shows the results of mass measurements of briquettes made from compacted plant raw materials. The lowest mass was obtained for corn straw briquettes (53.5 g), higher for oat straw (74.2 g) and the highest for chamomile briquettes (78.1 g). There were statistically significant differences between the mass of briquettes produced from corn straw and the mass of briquettes produced from oat straw and chamomile wastes. On the other hand, there were no statistically significant differences between the mass of briquettes from oat straw and the mass of briquettes made of chamomile waste.

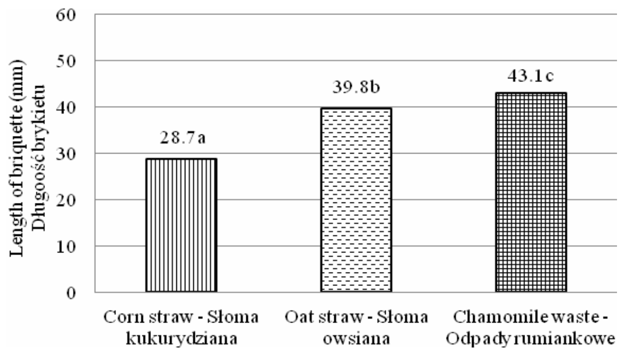


a, b, c – mean values marked with the same letter do not differ statistically significantly at the level α = 0.05

Source: own work / Źródło: Opracowanie własne

Fig. 2. Average shaken density of agglomerated raw materials

Rys. 2. Średnia gęstość utrzęsiona aglomerowanych surowców

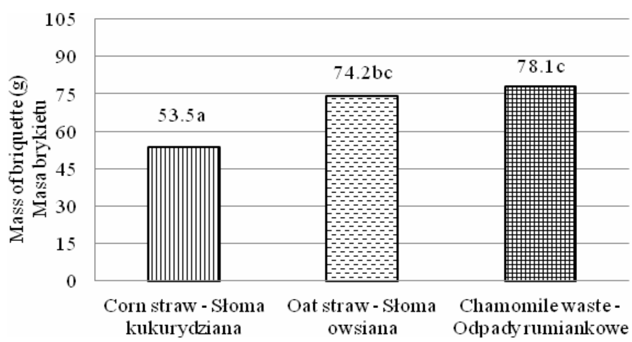


a, b, c – mean values marked with the same letter do not differ statistically significantly at the level α = 0.05

Source: own work / Źródło: Opracowanie własne

Fig. 3. Average length of briquettes depending on the type of raw material

Rys. 3. Średnia długość brykietów w zależności od rodzaju surowca



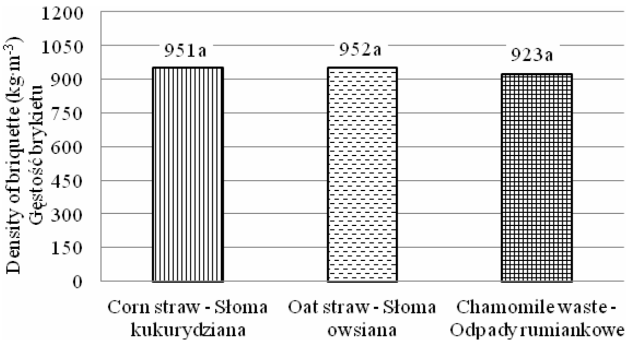
a, b, c – mean values marked with the same letter do not differ statistically significantly at the level α = 0.05

Source: own work / Źródło: Opracowanie własne

Fig. 4. Average mass of briquettes depending on the type of raw material

Rys. 4. Średnia masa brykietów w zależności od rodzaju surowca

Figure 5 illustrates results of briquette volume density studies of agglomerated raw materials. The lowest density was obtained for briquettes made of chamomile waste (923 kg·m^{-3}), while slightly higher for briquettes made of corn straw (951 kg·m^{-3}) and oat straw (952 kg·m^{-3}). There were no statistically significant differences between the volume density of briquettes produced from all tested plant materials.



a, b, c – mean values marked with the same letter do not differ statistically significantly at the level α = 0.05

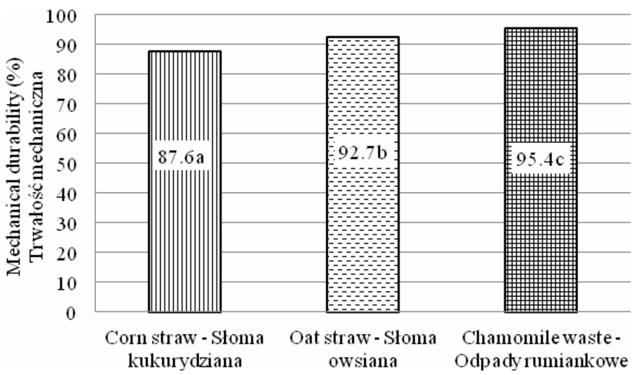
Source: own work / Źródło: Opracowanie własne

Fig. 5. Average density of briquettes depending on the type of raw material

Rys. 5. Średnia gęstość brykietów w zależności od rodzaju surowca

The compaction degree of plant materials depended on their diverse morphological structure (especially that of corn straw: stalks, leaves, panicles), fragmentation and bulk density. Due to worse grinding and low bulk density of corn straw, the density of its compaction was the highest and amounted to 21.3 on average. Better fragmentation and higher bulk density of oat straw caused that degree of its compactness was considerably smaller and amounted to an average of 14.5. At the same time, the smallest degree of compaction was recorded for chamomile waste (11.2).

Figure 6 shows results from mechanical durability tests of briquettes produced from plant raw materials used. The lowest mechanical durability characterized corn straw briquettes (87.6%), higher oat straw briquettes (92.7%), and the highest briquettes made of chamomile waste (95.4%). Statistically significant differences were found between durability of briquettes produced from all tested plant raw materials.



a, b, c – mean values marked with the same letter do not differ statistically significantly at the level α = 0.05

Source: own work / Źródło: Opracowanie własne

Fig. 6. Average mechanical durability of briquettes depending on the type of raw material

Rys. 6. Średnia trwałość mechaniczna brykietów w zależności od rodzaju surowca

4. Conclusions

Based on the analysis of the study results, following conclusions can be drawn:

1. Bulk and shredded densities of raw materials were affected by their fragmentation and granulometric composition. The lowest bulk density was found for corn straw (44.6 kg·m^{-3}), while for oat straw and chamomile waste from 1.5 to 2-fold higher.
2. Based on the studied parameters of raw materials, more favorable qualitative traits were found for briquettes made from oat straw and chamomile waste, whereas less favorable for corn straw briquettes.
3. Briquettes obtained from corn straw had the smallest length (28.7 mm) and mass (53.5 g), while those parameters were about 1.5 times higher for oat straw and chamomile briquettes.
4. The volume density of briquettes was at a similar level (from 923 to 952 kg·m^{-3}), and their mechanical durability amounted to 87.6% for corn straw briquettes, to 92.7% for oat straw and to 95.4% for chamomile waste.
5. Depending on the type of plant material used, fragmentation degree, granulometric composition, and bulk and shredded densities, produced briquettes differed statistically significantly in terms of their qualitative characteristics.

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