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# Properties of pellets made of agglomerated pine and spruce sawdust with the addition of wheat bran

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**Abstract:** The effect of the addition of 10%, 15% and 20% wheat bran to pine and spruce sawdust on the kinetic strength, bulk density and specific density of the conglomerate pellet was determined. It turned out that with an increasing proportion of wheat bran in the sawdust mixture, there was a gradual increase in specific density compared to that of pellets agglomerated from wood sawdust alone. At a 20 per cent share of wheat bran, there was a 7 per cent increase in the kinetic strength of pellets obtained from both types of sawdust. Slight fluctuations in the bulk density of the pellets occurred with a change in the proportion of wheat bran. The share of wheat bran ranging from 10% to 20% in the absolutely dry sawdust mixture did not decrease the calorific value. The significant decrease in calorific value of 13% was mainly due to the increase in moisture content to 12% of the sawdust-wheat bran mixture.

*Keywords:* pellets, pine sawdust, spruce sawdust, wheat bran, calorific value, calorific heat

## INTRODUCTION

There is currently a great deal of research involving the use of lignocellulosic biomass as an alternative energy source. Converting biomass into fuel pellets by agglomeration is considered to be an efficient and simple way of obtaining a compacted fuel (Silva et al. 2022). Its use has a significant impact on reducing the consumption of natural gas and LPG and other fossil fuels (Thabuot et al. 2015, Asamoah et al. 2016, Schnürer et al. 2018, Ifa et al. 2020, Nagarajan et al. 2021, Suryani et al. 2022).

Biomass for the production of conglomerates, mainly comes from agricultural crops and food production, as well as many other sources related to, for example, the wood industry, pulp and paper industry and disposal and recycling. Traditionally, wood biomass has been used to produce pellets (Briggs et al, 1999, Karampinis et al. 2012). One of its important characteristics is its good combustibility, resulting from its high lignin content, which is also responsible for the cohesion of the pellets obtained (Karampinis et al. 2012, Bućko et al. 2012, Wróbel 2019). The lignin content in coniferous wood, e.g. Scots pine, ranges from 26.2÷31.4%, and in common spruce wood it ranges from 27.3% to 28.4% (Prosiński, 1984). The effect of the compaction process is also influenced by the density of the wood. At higher values, there is additional energy consumption in the agglomeration process.

If the compaction process is not suitable, binders, usually derived from other types of biomass, are used as an aid. The use of additional binders has the effect of extending the shelf life and achieving the correct transport strength of the pellet (Hare et al. 2011, Zhang et al. 2018). Effective natural binders mainly include starch-containing products. The addition of 0.3 % to 1.5 % starch to wood sawdust has been shown to extend the life of the matrix and reduce the temperature of the pelletisation process by 15% as well as energy consumption (Zhang et al. 2018). Due to the high price of starch, other natural waste materials with similar properties are being sought. Among these are cereal bran, which, in addition to its use for food and feed purposes, is a cheap and easy-to-process raw material with high biological activity. (Harasym 2010, Obuchowski et al. 2013). The cohesive properties of bran are due to its starch and protein content. On average, the starch content ranges from 20.3% to 22.5% and the protein content is about 13% relative to the bran dry matter (Briggs et al. 1999, Kaprelyants et al. 2019). It has been found, for example, that the addition of rye bran facilitates the pelleting process and reduces energy consumption, but adversely affects the heat of combustion and ash content (Zając et al. 2011).

In compaction technology, important properties of raw materials include the fineness and dimensions of the resulting particles (Narra et al. 2012). Previous research shows that particles with dimensions of 1÷2 mm, have an adequately developed surface area and bonding strength (Tumuluru et al. 2011, Flizikowski et al. 2016, Rahaman et al. 2017, Amrullah et al. 2020, Zawiślak et al. 2014).

The main parameters for assessing pellet quality include physical properties such as specific density and bulk density, which affect the combustion heat and calorific value. Their height, in addition to the chemical structure of the biomass from which the conglomerate is formed, depends significantly on the moisture content. During the combustion process, due to the consumption of a large amount of heat to evaporate water, the calorific value of the pellets decreases (Carroll et al. 2012, García-Maraver et al. 2011). The low moisture content of the agglomerated raw material increases the calorific value, bringing energy, economic and environmental benefits (Kamińska 2011).

Related to transport and storage costs are the kinetic strength of the pellets. Adequate kinetic strength ensures that the shape of the granules is maintained and limits the formation of excessive dust. Technical parameters including compaction method, moisture content, type of raw material used and admixtures that improve cohesion determine the kinetic strength of the conglomerate (Rynkiewicz 2007, Zawiślak et al. 2010).

Numerous densification methods are currently being developed worldwide, depending mainly on the origin and specific characteristics of the biomass (Harasym 2010, Zhang et al. 2018, Obi et al. 2022). There are also analyses of the properties of different types of binders and their effects on the agglomeration process (Rawat et al. 2021, Silva et al. 2022).

The aim of this study was to determine the effect of the addition of wheat bran to pine and spruce sawdust on the combustion heat and calorific value, as well as on the main physical properties of the pellets produced.

## MATERIALS AND METHODS

### *Materials*

The wood material used to produce pellets was pine and spruce sawdust produced during cross-cutting on a circular saw mill of lumber with a moisture content of approximately 12÷14%. Both types of sawdust contained no bark. The bran used was a by-product obtained from industrial milling of wheat.

The test materials were characterised by determining: fractional composition, moisture content, combustion heat and calorific value.

The determination of the fractional composition was carried out in accordance with PN-R-64798:2009 using a Multiserv Morek shaker with a set of 7 sieves with mesh sizes: 4.0, 2.0, 1.0, 0.5, 0.25, 0.125 and 0.063 mm. After sieving the material, the mass remaining on each sieve was weighed to the nearest 0.01 g. The result of the weighing was the percentage of the given fraction in the mixture.

The measurement of the moisture content of sawdust and wheat bran was carried out in accordance with PN-EN ISO 18134-1:2015-11 using an Axis AGS laboratory weighing machine with a measurement accuracy of 0.001 g. Three samples were made for each material and the arithmetic mean was calculated together with the standard deviation.

The determination of the heat of combustion and calorific value was carried out in accordance with standard PN-ISO 1928:2020-05 using a KL-12Mn calorimeter manufactured by Precyzja-Bit Company. The measurement consisted of burning a material sample in a calorimetric bomb in an oxygen atmosphere under increased pressure. The course of the temperature change determined in this way was the basis for automatic calculation by the programme (Calorimeter User Manual) of the combustion heat and calorific value. The test was carried out on 5 samples of absolutely dry moisture content, taken from pine sawdust, spruce sawdust, wheat bran, as well as mixtures of these sawdusts with bran. Once the heat of combustion and calorific value for the dry test material had been determined, the calorific value at a moisture content of 12% was converted (Obidziński 2010).

*Pellets production*

An industrial machine 39-1000 from KAHL was used to make the pellets, using a die with an area of 3850 $cm^2$ and a hole diameter of 8 mm. The pressing pressure was 100 MPa. The materials for the pellets consisted of pine sawdust alone, spruce sawdust and mixtures of these with 10%, 15% and 20% wheat bran. Each time, 30 kg of wood sawdust and an appropriate weight of wheat bran equal to their share in the mixture were prepared to make pellets. A Steinberg Systems SBS-PF panel scale was used for weighing. The homogeneity of the mixtures was ensured by mixing the ingredients in stages with an electric mixer.

*Pellet testing*

Testing of the basic properties of the pellets included determination of kinetic strength, specific density and bulk density. Tests were carried out on 24 hours cooling after pellets were made in the pelletiser.

To determine the kinetic strength of the pellets, the Holmen NHP100 tester (Thomas et al. 1996) and the guidelines of the subject standard PN–EN ISO 17831-1:2016-02 was used. The pellets were kept in the tester chamber for 60 s. At the end of the test, the pellets were sieved through a sieve. Three repetitions were made for each type of pellet. The kinetic strength of the pellets $P_{dx}$ was calculated from the following relationship:

$$P_{dx} = \frac{m_1}{m_o} \cdot 100\ (\%)$$

where:
$P_{dx}$ – kinetic strength of pellets (%)
$m_o$ – mass of the sample before the test (kg)
$m_1$ – mass of the sample after the test (kg).

The next pellet property tested was the specific density. The volume of the pellets was determined by measuring their length and diameter. This was measured to an accuracy of 0.01 mm using a calliper. The granules were then weighed on an OHAUS AX324 balance. The specific density of the granules was calculated using the formula:

$$\rho_g = \frac{m_g}{V_g}\ \ (kg/m^3)$$

where:
$\rho_g$ – density of the obtained pellets ($kg/m^3$),
$m_g$ – mass of the obtained pellets (kg)
$V_g$ – volume of the obtained pellets ($m^3$)

The result was the arithmetic mean of the 10 measurements together with the standard deviation.

The bulk density of the granules was determined in accordance with EN ISO 17828: 2016. The test consisted of filling a metal vessel of 850 cm$^3$ above the level of its edge with granules and levelling the surface with a metal scraper. The vessel together with the granules was then weighed. The bulk density $p_n$ was calculated from the relationship:

$$\rho_n = \frac{m_p}{V_n} \quad (kg/m^3)$$

where:
$\rho_n$ – bulk density (kg/m$^3$)
$m_p$ – test mass (kg)
$V_n$ – volume of the measuring glass (m$^3$)

A Radwag WLC 1/A2/C/2 balance was used to measure the weight of the sample. The result was the arithmetic mean of the 3 measurements together with the calculated standard deviation.

## RESULTS OF TESTS ON THE PROPERTIES OF WOOD MATERIAL AND WHEAT BRAN

The fractional composition of the test material in the form of pine and spruce sawdust and wheat bran is presented in Fig. 2. In the analysed mixtures, the largest share, amounting to more than 40%, was represented by fractions remaining on the sieve with 0.5 mm mesh size in the case of pine sawdust and wheat bran, and spruce sawdust on the sieve of 1.0 mm.

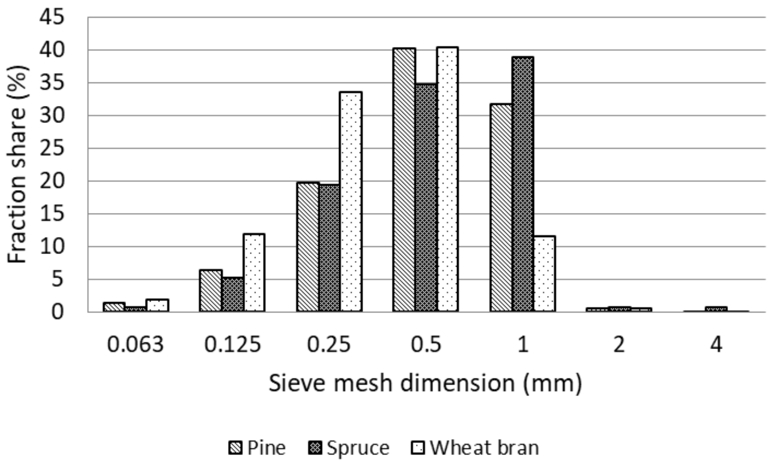


Fig. 2. Granulometric distribution of pine and spruce sawdust and wheat bran

The fractions remaining on the sieves with 0.25 mm, 0.5 mm and 1.0 mm mesh size accounted for more than 90% in the pine and spruce sawdust mixture and more than 85% in the wheat bran mixture.

Table 1. Moisture contents of pine and spruce sawdust and wheat bran

| Moisture Content (%) | |
|---|---|
| Pine sawdust | 12.22 |
| | 0.15* |
| Spruce sawdust | 11.94 |
| | 0.11* |
| Wheat bran | 12.60 |
| | 0.07* |

*Standard deviation

As a result, the wood sawdust and wheat bran mixtures were characterised by a very similar fractional composition. The moisture content of pine sawdust, spruce sawdust and wheat bran averaged 12% and had a small standard deviation for each type of material (Table 1). The analysis of the energy properties of the tested materials shows that absolutely dry pine sawdust (0%) showed the highest heat of combustion of 23.24 MJ/kg and a calorific value of 21.70 MJ/kg (Table 2). Spruce sawdust and wheat bran had a 3% lower calorific value and heat value than pine sawdust (Table 2). The differences for both properties were equal to 0.70 MJ/kg. The increased moisture content of up to 12% wood sawdust and bran had a significant effect on the properties tested. There was a clear decrease of 13% in the combustion heat and calorific value (Table 2).

Table 2. Mean heat of combustion and calorific value of sawdust pine, spruce and wheat bran with 0% and 12% moisture content

| Kind of material | Heat of combustion (MJ/kg) | | Caloric Value (MJ/kg) | |
|---|---|---|---|---|
| | Moisture content | | Moisture content | |
| | 0% | 12% | 0% | 12% |
| Pine sawdust | 23.24 | 20.39 | 21.70 | 18.80 |
| Spruce sawdust | 22.53 | 19.84 | 21.00 | 18.18 |
| Wheat bran | 22.55 | 19.70 | 21.02 | 18.20 |

Having the values of the heat of combustion determined on the basis of the conducted tests in the absolutely dry state and with a moisture content of 12% (Table 2) of pine sawdust, spruce sawdust and wheat bran, the calorific values of mixtures of wood sawdust with different proportions of wheat bran were calculated (Table 3).

On the basis of the results obtained, it was found that the calorific value of mixtures of wood sawdust with bran in an absolutely dry state and at a moisture content of 12% was slightly lower than or equal to that determined for wood sawdust alone (Table 3).

Table 3. Calorific value with 0% and 12% moisture content of sawdust pine, spruce and wheat bran and mixtures of pine sawdust and spruce sawdust with wheat bran

| Mixture of sawdust with wheat bran | | Caloric Value (MJ/kg) | |
|---|---|---|---|
| | | Moisture content | |
| | Share wheat bran | 0% | 12% |
| Pine sawdust | 10% | 21.63 | 18.74 |
| | 15% | 21.59 | 18.71 |
| | 20% | 21.56 | 18.68 |
| Spruce sawdust | 10% | 21.00 | 18.18 |
| | 15% | 21.00 | 18.18 |
| | 20% | 21.00 | 18.18 |

The share of wheat bran in the sawdust mixtures had no significant effect on the calorific value compared to the effect of moisture content. In the case of a mixture of pine sawdust and bran with 0% moisture content, there is a slight decrease in its value, which is 0.07 MJ/kg with a 100% increase in the bran share. A mixture of spruce chips, regardless of the proportion of bran, shows a constant calorific value of 21.00 MJ/kg. At a moisture content of 12%, there is a decrease in the calorific value of the sawdust/ bran mixture compared to the absolutely dry condition. With an increasing proportion of bran in the pine sawdust mixture, a slight downward trend in calorific value was found. Its value was unchanged in mixtures of spruce sawdust with bran (Table 3).

ANALYSIS OF THE PROPERTIES OF THE PRODUCED PELLETS

The structure, colour and gloss of the pellets obtained depended on the type of sawdust and the proportion of wheat bran (Figs. 3 and 4). Pellets made only from pine sawdust were characterised by a length of about 15 mm, numerous cracks and a glossy surface with a light yellow colour (Fig. 3A).

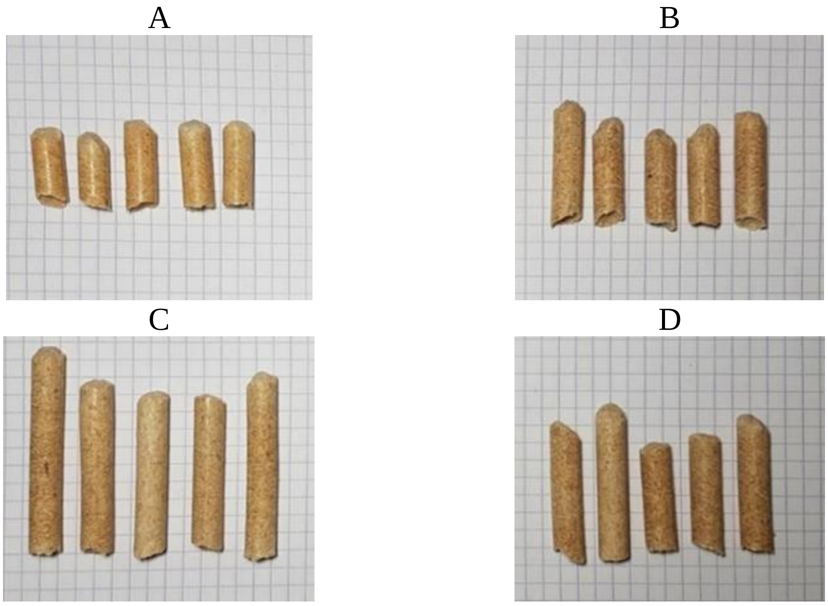


Fig. 3 Pine pellets with 0% (A), 10% (B), 15% (C) and 20% (D) wheat bran share (Braun 2021)

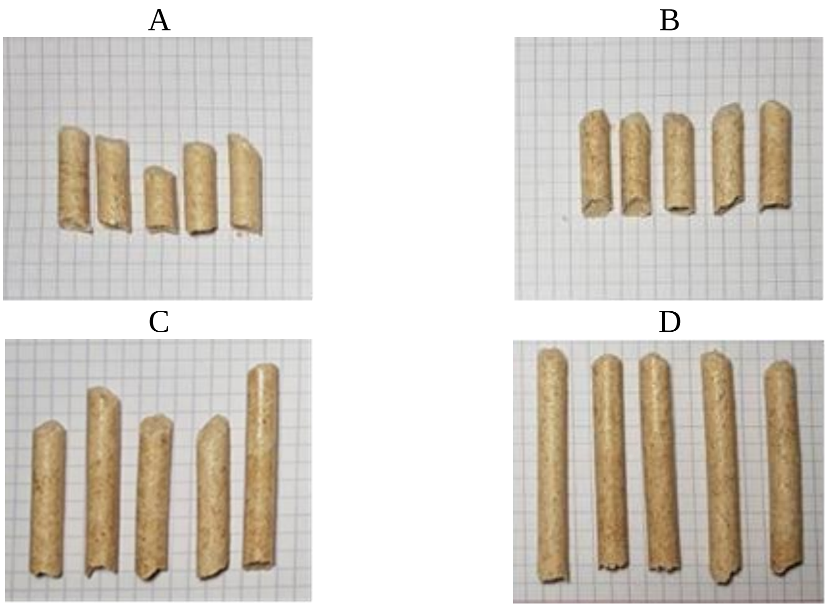


Fig. 4. Spruce pellets with 0% (A), 10% (B), 15% (C) and 20% (D) wheat bran share (Braun 2021)

Increasing the proportion of wheat bran in the pine sawdust mixture resulted in a gradual elongation of the particles and a reduction in the number and size of surface cracks (Fig. 3B). At 15% bran share, particle length reached 60 mm (Fig. 3C). A further increase up to 20% in the bran proportion resulted in a decrease in length and a darker colour, with few small cracks on the surface of the pellets (Fig. 3D).

Increasing the proportion of wheat bran in the pine sawdust mixture resulted in a gradual elongation of the particles and a reduction in the number and size of surface cracks (Fig. 3B). At 15% bran share, particle length reached 60 mm (Fig. 3C). A further increase up to 20% in the bran proportion resulted in a decrease in length and a darker colour, with few small cracks on the surface of the pellets (Fig. 3D).

Pellets made from spruce sawdust were short and very light with many surface cracks (Fig. 4A). The proportion of bran resulted in an increase in particle length (Fig. 4B), the dimension of which at 15% was between 30 mm and 40 mm (Fig. 4C) and at 20% around 70 mm (Fig. 4D). Increasing the bran content led to a smoother surface with a darker colour and loss of gloss.

Based on the study, it was found that a higher bulk density of 695 kg/m$^3$ was achieved by pellets made by conglomeration of pine sawdust (Table 4), and a lower density of spruce sawdust.

Table 4. Bulk density, specific density and kinetic strength of pellets made from pine and spruce sawdust at 0%, 10%, 15% and 20% wheat bran

| Mixture of sawdust with wheat bran | Share wheat bran | Bulk density (kg/m$^3$) | Pellets density (kg/m$^3$) | Kinetic strength (%) |
|---|---|---|---|---|
| Pine sawdust | 0% | 695<br>4* | 1272<br>21* | 97.63<br>0.15* |
| | 10% | 711<br>6* | 1347<br>14* | 98.17<br>0.33* |
| | 15% | 644<br>7* | 1357<br>15* | 99.27<br>0.06* |
| | 20% | 698<br>6* | 1366<br>17* | 99.47<br>0.12* |
| Spruce sawdust | 0% | 640<br>3* | 1249<br>30* | 95.50<br>0.85* |
| | 10% | 680<br>7* | 1329<br>30* | 96.54<br>0.64* |
| | 15% | 646<br>4* | 1332<br>15* | 99.44<br>0.15* |
| | 20% | 620<br>6* | 1337<br>14* | 99.37<br>0.15* |

*Standard deviation

The share of wheat bran in the pine sawdust conglomeration influenced slight variations in density. Only with a 15% share of bran, the density decreased by more than 50 kg/m$^3$, compared to the other pellet types made from mixtures of bran and pine sawdust.

Conglomerate made from a mixture of spruce sawdust with 10% bran, obtained the highest density of 680 kg/m$^3$. Its density was 6% higher than the pellet obtained from spruce sawdust alone. Increasing the proportion of bran up to 15% was associated with a 5% decrease in density, and at 20% the density reduction was 9% (Table 4).

From the analysis of the specific density of the pellets, it can be seen that it depends not only on the type of sawdust, but especially on the amount of wheat bran (Table 4). The specific density of pellets made from pine sawdust was 1272 kg/m$^3$ and from spruce sawdust 1249 kg/m$^3$. As the bran content increased, there was an increase in the density of the pellets. With the highest bran share of 20% in the mixture of pine and spruce sawdust, the difference in pellet density was about 90 kg/m$^3$.

For both types of sawdust, there was a gradual increase in kinetic strength with increasing wheat bran content. The lowest strength was found for pellets made from pine and spruce sawdust only, at 97.63% and 95.50%, respectively (Table 4).

The improvement in the kinetic strength of the pellets with 20 per cent bran in the pine sawdust mixture was nearly 2 percentage points, and spruce sawdust by 4 percentage points. Pellets made from pine sawdust with wheat bran achieved kinetic durability above 98%. Spruce sawdust agglomerate with 15% and 20% wheat bran had a kinetic durability above 99%. In terms of kinetic durability, both types of pellets at this share of wheat bran satisfy the requirements of class A1 according to ISO 17225-2:2021 and ENplus.

## CONCLUSIONS

Based on the study of the effect of the share of wheat bran, in a mixture of pine and spruce sawdust, on the properties of the pellets produced, it was found:

1. With an increasing share of wheat bran in a mixture of pine and spruce sawdust, there was a gradual increase in specific density compared to that of pellets agglomerated from wood sawdust alone.

2. The addition of wheat bran to wood sawdust resulted in a significant increase in pellet length. In the case of a pine sawdust conglomerate with 15 per cent bran, the pellet length was 60 mm, and in the case of spruce sawdust with 20 per cent wheat bran, the pellet length was 70 mm.

3. The bulk density of the pellets changed slightly with increasing share of wheat bran in the wood sawdust mixture. Increasing the share of wheat bran in the spruce sawdust mixture resulted in a decrease in bulk density of about 9%. The bulk density of pellets obtained from a mixture of pine sawdust and bran fluctuated slightly. The highest decrease in bulk density of more than 50 $kg/m^3$ was observed for the pellets agglomerated with 15% share of bran in the pine sawdust mixture.

4. Increasing the proportion of wheat bran in the wood sawdust mixture resulted in an increase in the kinetic strength of the pellets. A 1 percentage point increase in kinetic strength occurred at a wheat bran share of 10%. A further increase in the proportion of bran to 20% in a mixture of spruce and pine sawdust led to an increase in kinetic strength of 5 and 1.5 percentage points, respectively, compared to pellets produced without bran.

5. The share of wheat bran from 10% to 20% in the dry mixture of pine and spruce sawdust did not influence the lowering of the calorific value of the mixtures. The moisture content of the sawdust and bran mixtures had the greatest effect on the calorific value. Changing the moisture content of the mixtures from absolutely dry to 12% resulted in a 13% reduction in calorific value.

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**Streszczenie:** *Właściwości pelletu aglomerowanego z trocin sosnowych i świerkowych z dodatkiem otrębów pszennych*. Określono wpływ dodatku, w ilości 10%, 15% i 20% otrębów pszennych do trocin z drewna sosnowego i świerkowego, na wytrzymałość kinetyczną, gęstość nasypową i gęstość właściwą konglomeratu w postaci pelletu. Okazało się, że wraz ze zwiększającym się udziałem otrębów pszennych w mieszaninie trocin miał miejsce stopniowy wzrost gęstości właściwej w porównaniu z gęstością pelletu aglomerowanego z samych trocin drzewnych. Przy 20% udziale otrębów pszennych stwierdzono zwiększenie o 7% wytrzymałości kinetycznej pelletu otrzymanego z obu rodzajów trocin. Nieznaczne wahania gęstości usypowej pelletu wystąpiły wraz ze zmianą wielkości udziału otrębów pszennych. Udział otrębów pszennych wynoszący od 10% do 20% w absolutnie suchej mieszaninie trocin nie wpłynął na obniżenie wartości opałowej. Znaczny spadek wartości opałowej równy 13% wynikał głównie ze wzrostu wilgotności do 12% mieszaniny trocin z otrębami pszennymi.

*Słowa kluczowe:* pellet, trociny sosnowe, trociny świerkowe, otręby pszenne, wartość opałowa, ciepło spalania

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