FRICTION PROPERTIES OF PELLETS MADE OF WOOD AND STRAW

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Abstract. The aim of the work was to obtain knowledge of the friction properties of materials subjected to pressure agglomeration (wood pellets and straw pellets). The frictional properties of the tested materials were evaluated by: the angle of internal friction and the effective internal friction angle of pellets, uniaxial shear strength, material flowability coefficient and the cohesion value of the material. Wooden pellet has a higher strength on uniaxial compression average of 36.2 kPa than the pellet made of straw, approximately of 31.3 kPa. Based on the flowability index, it was found that straw and wood pellets are easily flowing ($4 < ff_c < 10$). The values of the internal friction angles were higher for biomass made of wood than from straw, and were 50.02º and 35.17º, respectively. Pellets made of straw were more cohesive materials (approximately 8000 Pa) than the pellets made of wood (approximately 6600 Pa).

Keywords: pellets, friction properties, cohesion, material flowability.

Introduction

The quality of densified products must meet the consumer requirements and market standards. Therefore, densified products must withstand the rigors of handling and transportation [1].

Loose materials, which include pellets, have certain mechanical properties such as: looseness, compressibility and flowability. They depend on the properties of the material such as: the shape and surface of the particles, structure of the bed and the strength of cohesion and adhesion [2-3]. These parameters allow to determine the conditions, under which the pellet ceases to be a bulk material and does not behave as a solid, but liquid [4-5]. In contrast to liquids, loose materials form dumps, which is caused by the fact that the static angle of internal friction is greater than zero. The flow mechanism of bulk materials is characterized by the fact that they can transfer shear stresses at rest. Cohesion forces between the particles are observed in cohesive materials, while these forces are notobserved in bulk materials [6].These properties play an important role in the process of loading and unloading, transporting and storage of pellets. Knowledge of the mechanical properties of granular biomass is important for the design and efficient operation of equipment for handling, storing, and processing such materials [7-9].

One of the popular and standardized methods of flowability determination is the direct shear test originally proposed by Jenike [10]. It enables the measurement of the shear strength of the material in static conditions under external load. According to the Jenike's theory of flow, the values obtained from shear tests determine the flow characteristics of the tested material and flowability parameters of loose materials with sufficient accuracy for practical application.

For this reason, the aim of this work was to obtain knowledge of the friction properties of materials subjected to pressure agglomeration (wood pellets and straw pellets). The shear tests could be a useful tool for estimation the shear resistance of wood and straw biomass for comparison of different lots of materials delivered for storage or processing.

Materials and methods

Tested materials were wood and straw pellets with a diameter of 8 mm. Wood pellets were purchased from the Barlinek company. According to the manufacturer's declaration, they were made of 30 % from sawdust from deciduous trees and 70 % from sawdust from coniferous trees. Straw pellets were produced by Lootor Ltd. from wheat straw. The friction properties of pellets and their physical properties were determined before the tests.The results are summarized in Table 1.

The flowability test was carried out in accordance with the Eurocode 1 standard [11]. The tests of the internal friction angle were carried out on the modernized stand for compaction of plant material (Fig. 1).

The compaction of plant material, ejection and insertion of the drawer and bottom of the cylinder were automated.A sample of the material was poured into the cylinder of the measuring chamber with a diameter of 332 mm and a height of 335 mm.In the used apparatus, shear stresses are forced by mutual displacement of the lower and upper rings..The displacements of the lower cylinder ring and the compaction disc were recorded using the FT 80 RLA sensor oflaser displacement from SensoPart. The shearing force and consolidation force were recorded using the CL21 force sensor from ZPWN Marki.The measurements were made after pre-consolidation of 50 kPa until a constant density of the samples was obtained. The shear measurements were carried out at a pressure of 25 kPa, 37.5 kPa and 50 kPa, at a mutual ring sliding speed of 15 mm·min^{-1}. All measurements were made in triplicate.

Table1

Physical properties of pellets used for tests

Parameter	Wood pellets	Straw pellets
Pellet density, kg·m^{-3}	1213	1151
Bulk density, kg·m^{-3}	671.1	587.5
Durability, %	98.31	94.66
Moisture content, %	3.53	8.52
Calorific value, kJ·kg^{-1}	16785	13786

Fig. 1. **View of test bench to determine angle of internal friction. 1 – sensor ofmaterial displacement by compacting piston, 2 – sensor of cylinder displacement 3 – sensorof compacting force, 4 – sensor of oil pressure in the actuator, 5 – sensorof shear force**

On the basis of the obtained results, it was possible to draw two Mohr`s circles by using two normal stresses, σ_1 – the major principal stress at steady state flow called the major consolidation stress, and σ_c – unconfined yield strength of the sample [12]. With these values a plot of σ_1 against σ_c was obtained, and it was used to characterize the flowability of the granular material (Fig. 2).

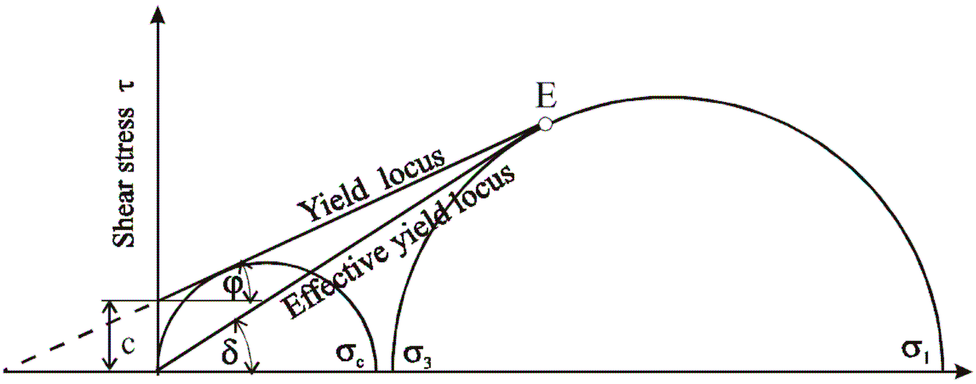

Fig. 2. **Yield locus and effective yield locus [12]**

Flowability function as a relationship of the strength for uniaxial compression σ_c to the major principal stressσ_1 allows to classify loose materials in four categories in terms of their resistance shown to gravity flow: very free flowing, free flowing, average flowing and poor flowing.It was calculated from the formula:

$$ff_c = \frac{\sigma_1}{\sigma_c} \tag{1}$$

where ff_c – flowability, (dimensionless),
σ_1 – major principal stress, MPa,
σ_c – strength to uniaxial compression, MPa.

The values of the effective angle of internal friction and the angle of internal friction were determined based on the following relationships:

$$\varphi_e = \frac{\tau_{\sigma r}}{\sigma_r} \tag{2}$$

$$\varphi_C = \frac{\tau_{\sigma r} - \tau_{0.5\sigma r}}{0.5\sigma_r} \tag{3}$$

where φ_e – effective angle of internal friction, °,
φ_c – angle of internal friction, °,
σ_r – consolidation stress, MPa,
$\tau_{\sigma r}$ – shear stress at consolidation stress σ_r, MPa,
$\tau_{\sigma r}$ – shear stress at consolidation stress $0.5\sigma_r$, MPa.

The statistical analysis of the results was conducted using the computer program Statistica v.13.5.

Results and discussion

The results of the research in straw and wood pellets, regarding determination of the internal friction and flow friction parameters, are shown in Fig. 3, 4 and 5.

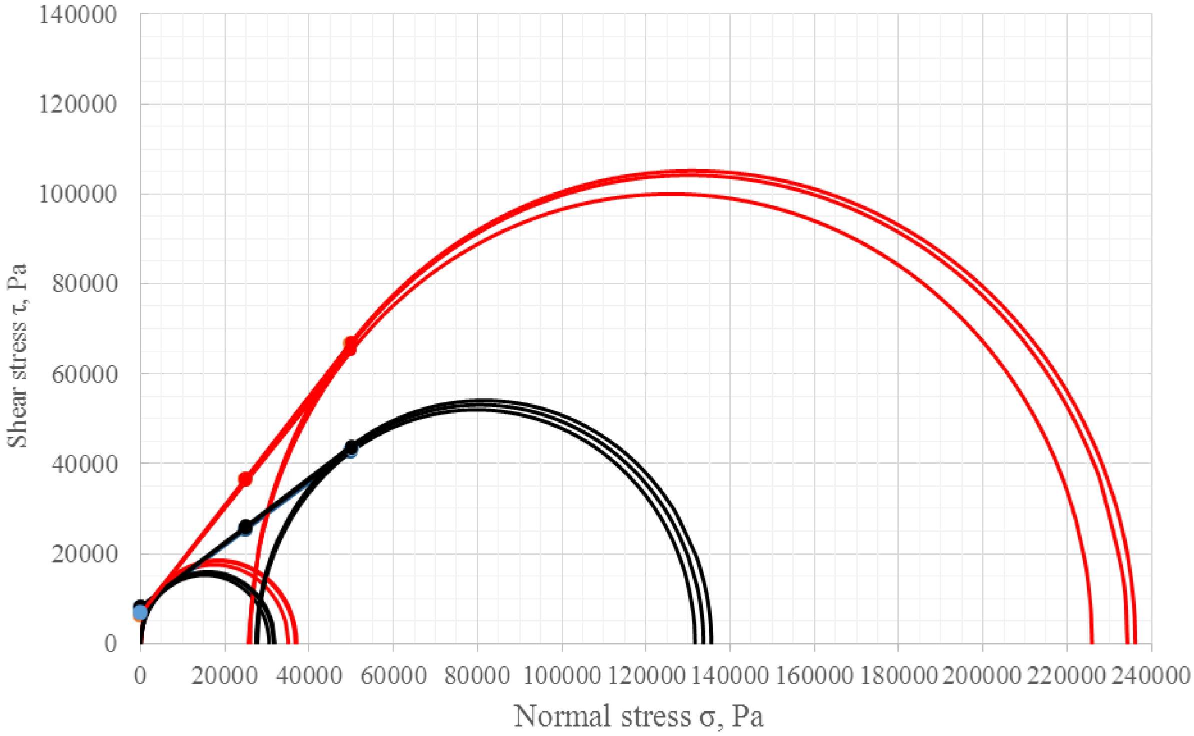

Fig. 3. **Linear flow conditions for two types of pellets**

All examined parameters differed statistically significantly at the confidence level of 0.05, depending on the type of the material. It was found that wood pellets were characterized by higher values of plasticity.Higher strength to uniaxial compression was shown by wood pellets on average about 36.2 kPa, while for straw pellets it was lower by approx. 15 %.

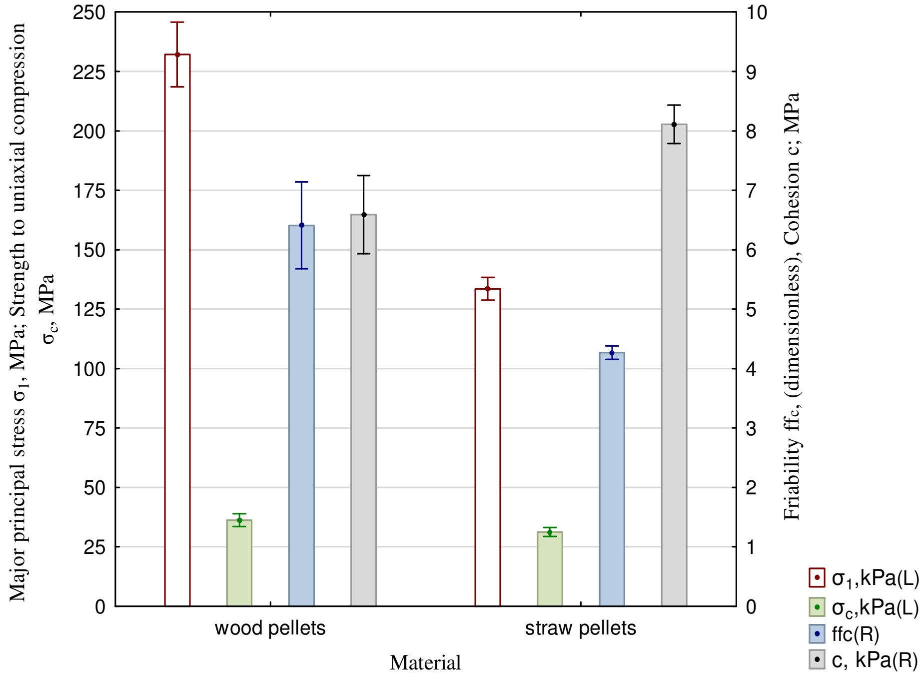

Fig. 4. **Friction parameters depending on type of pellets**

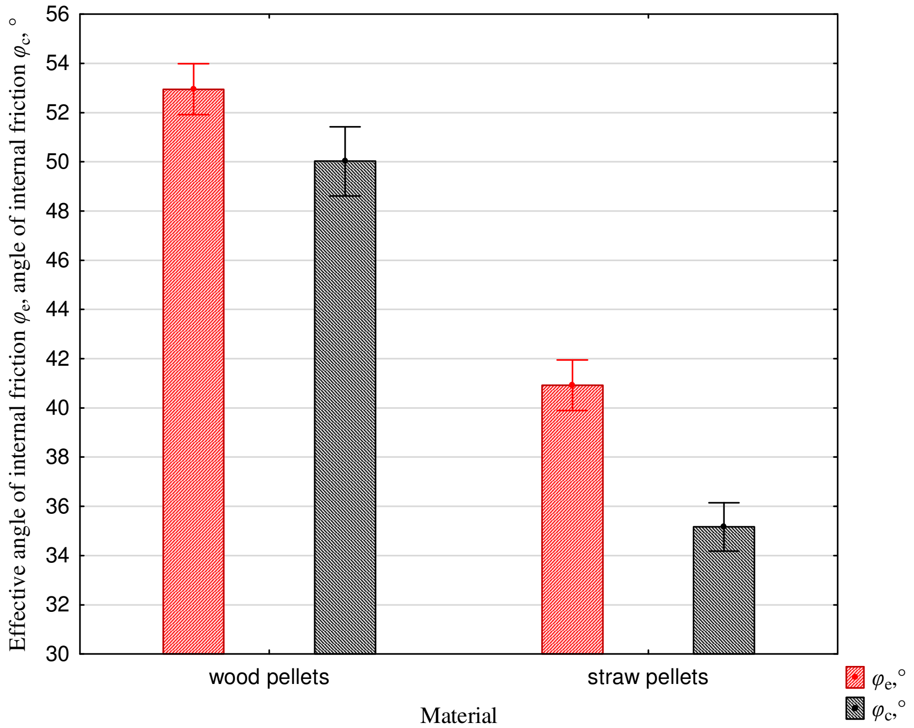

Fig. 5. **Angle of internal friction and effective angle of internal friction depending on type of pellets**

The straw pellet was a more cohesive material (about 8000 Pa) compared to wood pellets (about 6600 Pa). The higher value of the effective angle of internal friction for wood pellets (50.02º), compared to straw pellets (35.17º), indicates a rapid increase in cohesion in loose materials during consolidation.The factors that favor greater packing of particles in the agglomerate can be the external forces, causing the movement of particles, which is an intrinsic process during storage or forced in the transport process.

Straw pellets were characterized by a lower flowability of approx. 4.25, and thus they can be included to more cohesive materials, compared to wood pellets (flowability rate about 6.4). Both, pellets made of wood and straw, can be included to the group of easily flowing materials. That kind of material is referred to easily flowing, when the ff_c value is in the range of 4-10 [13; 14]. The flowability of the material has an impact on the material movement characteristics during the technological processes. Biomass compared to conventional fuels is less susceptible to flow material according to many authors [15-17].

Conclusions

1. Experimental methods for determining the mechanical properties should take into account the specifics of the tested materials. In case of pellets, a long distance to reach the conditions of steady flow was observed.
2. Wood pellets showed higher resistance to uniaxial compression, and it was approximately 36.2 kPa, while for straw pellets it was approximately 31.3 kPa.
3. The flowability indexes indicate that straw and wood pellets are easily flowingmaterials ($4 < ff_c < 10$). The value of the internal friction angle was higher for the wood biomass (50.02°) and lower for the biomass from straw (35.17°).

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