

EFFECT OF TIME FROM HARVEST TO AGGLOMERATION PROCESS OF HERBACEOUS MASS ON THE DENSITY AND HARDNESS OF BRIQUETTES

Marek Rynkiewicz, Petr Trávníček, Petr Junga

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Abstract

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The study presents the results about the density and hardness of the briquettes produced from barley straw, wheat and rapeseed straw and hay. 6-month and 18-month raw materials after harvest from the fields were used to the agglomeration, stored in stacks in the field. The study showed that the briquettes produced from 6-month material characterized by a greater density in the comparison with the 18-month material. The difference was $130.28 \text{ kg}\cdot\text{m}^{-3}$ for the hay briquette, whereas the difference was $58.14 \text{ kg}\cdot\text{m}^{-3}$ in the case of rape straw briquettes. Similar results were found for the hardness. All samples of briquette used for testing had longitudinal cracks, however transversal cracks were observed only on the briquettes produced from barley straw and hay.

biomass briquette, barley straw, hay, density

Briquetting is a process of pressure agglomeration of materials which under the knitting of external and internal forces are compressed, and the final product has specific, continuous geometric form (Grochowicz, 1998; Hejft, 2002). Briquettes produced from biomass are often used as a source of renewable energy. This is mainly from reason because these products have high density, which facilitates the storage and distribution, and is possible to obtain a larger amount of energy per unit volume.

Kaliyan and Morey (2009) stated that the agglomeration of biomass increases its density from $40\text{--}200 \text{ kg}\cdot\text{m}^{-3}$, where it is in the baled form, to $600\text{--}800 \text{ kg}\cdot\text{m}^{-3}$ when it is agglomerated. Wójcicki (2010) states that the calorific value of straw is $17 \text{ MJ}\cdot\text{kg}^{-1}$ and this value is relatively high. From the reason straw is often used for production of briquettes from biomass. For comparison, the calorific value of coal is $28 \text{ MJ}\cdot\text{kg}^{-1}$.

Herbaceous mass, which is obtained for energy purposes, is a heterogeneous material. This

material is contented from various crops, which have different humidity, size, form, density. It is recommended that the stored herbaceous mass suitable for briquetting was protected from rain.

Various species composition of briquetted herbaceous mass and its storage time from harvest until the agglomeration effect have on the physical properties of the final product in the form of briquettes. This allows performing a wide range of research on the physical properties of briquettes.

The aim of this study was to determine the effect of time from harvest to the agglomeration process of herbaceous mass on the density and hardness of briquettes.

MATERIALS AND METHODS

The study was performed with the briquettes, which are made from herbaceous biomass as follows: barley straw, wheat straw, rape straw and hay. Crops for agglomeration were harvested in 2009 and 2010 and stored in stacks in the field. The result

is a material that has been processed into briquettes at the turn of 2010/2011 was a 6 month, and from year prior to the production process – marked as 18 months.

In this study briquettes, for the survey was determined as follows:

- A6 – barley straw briquettes 6-month,
- A18 – barley straw briquettes 18-month,
- B6 – wheat straw briquettes 6-month,
- B18 – wheat straw briquettes 18-month,
- C6 – rape straw briquettes 6-month,
- C18 – rape straw briquettes 18-month,
- D6 – briquettes from straw 6-month,
- D18 – from straw briquettes 18-months.

Altogether 8 samples with different time of storing and different species diversity was tested to their density, hardness, and determining the kind of the cracks.

Moisture content of samples was performed in accordance with EN 14774-3:2009 and was calculated using the following formula:

$$M_{ad} = \frac{(m_2 - m_3)}{(m_2 - m_1)} \times 100, \quad (1)$$

M_{ad} ...humidity [%],

m_1 the mass of the empty dish (plus lid) [kg];

m_2 the mass of the dish (plus lid) with sample before drying [kg];

m_3 the mass of the dish (plus lid) with samples after drying [kg].

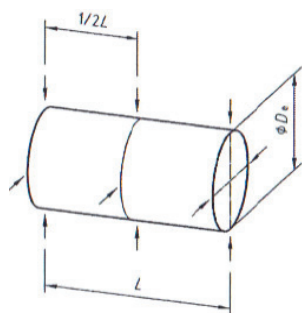
Briquette density was determined according to standard EN 15150:2011. For this purpose measurements of the length, diameter and weight for 3 samples of each type of briquette were made. Diameter measurement was performed 6 times, in accordance with Figure 1. Density was determined using the following formula:

$$\rho = \frac{m}{V_p}, \quad (2)$$

ρ briquettes density [$\text{g} \cdot \text{cm}^{-3}$],

mmass of the sample [g],

V_p volume of the briquette [cm^3], where:



1: Briquette diameter measurement points (EN 15150:2011)

$$V_p = \frac{D_{em}^2 \times \pi \times L}{4}, \quad (3)$$

Llength [cm],

D_{em} ...average value for 6 measurements of the diameter [cm].

ZGW-1 unit of DHN (Fig. 2) was used to measure the hardness. Examination consisted of exerting the force with head of hardness tester on a given briquettes sample. In the research was used mandrel with a rectangular base of 18 mm \times 6 mm. The load, at which the pellet was disintegrating, was a measure of its hardness in kg. The measurement was performed in triplicate for each batch of tested briquettes.



2: Hardness tester ZGW-1 used for tests

Type of cracks was determined by appearance. Cracks parallel to the axis of briquettes were determined as longitudinal cracks, and perpendicular to the axis was defined as transverse.

Briquette production line (from which research material was obtained) consisted of the following components: chipper, mill, tank dispenser and briquetting mixer of eccentrically-piston. Humidity of agglomerated materials ranged from 12 to 20 %. Mill sieve mesh was 8 mm. However, the briquetting press output diameter was 60 mm.

Statistical calculations

Statistical analysis was performed using Statistica and MS Excel. For tested parameters their compatibility with normal distribution was verified. Degradation studies were carried out using the Shapiro–Wilk test. The critical level for significance was $p = 0.05$. To check the homogeneity of variance Levene's test was used.

The significance of differences in average values of more than two populations with normal distributions and homogeneous variances verified using t-Student test. To verify the differences between the average values Tukey's test was used. Pearson's correlation coefficient was calculated for the parameters when at least one of them had different from the normal distribution (Stanisz, 1998).

RESULTS AND DISCUSSION

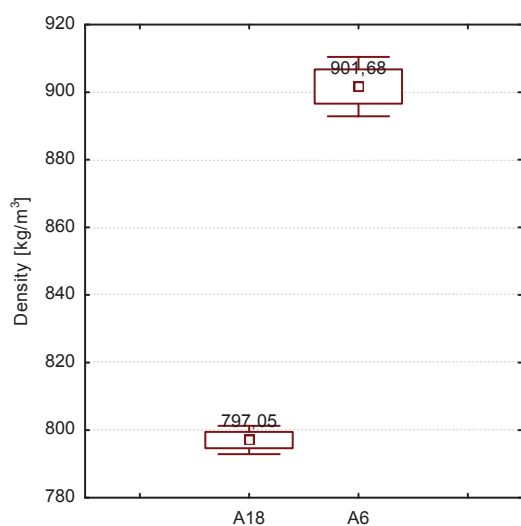
Humidity of tested samples of briquettes was from 4 to 6 %. Figs. 3–6 show the densities of tested briquettes depending on the species and time of storage of raw materials for briquetting (from harvest until they agglomerate).

Based on Figure 3, it can be concluded that the density of the briquettes from 6 months barley straw (A6) was greater than $104.63 \text{ kg}\cdot\text{m}^{-3}$, compared to the 18-month barley straw briquette ($797.05 \text{ kg}\cdot\text{m}^{-3}$). In the case of wheat straw briquette hardness difference between the 6 and 18 month straw was $70.88 \text{ kg}\cdot\text{m}^{-3}$. A similar phenomenon occurred in the case of rape straw (Fig. 5), while in the case of hay briquette difference between D18 and D6 sample obtained the highest value among the samples ($130.28 \text{ kg}\cdot\text{m}^{-3}$).

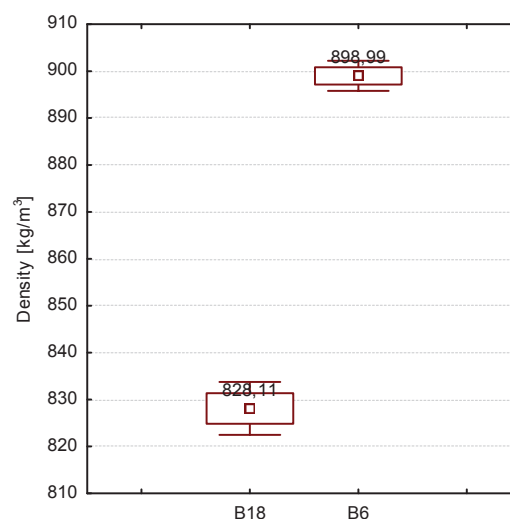
The statistical analysis showed statistically significant differences in the average densities of agglomerated materials depending on the time from harvest to their agglomeration

Density of agglomerated briquettes from 18 months raw materials (Fig. 7) obtained the highest value in the case of hay (D18) ($917.03 \text{ kg}\cdot\text{m}^{-3}$). On the other hand rape straw briquettes have the lowest density from all measured samples (C18) ($668.71 \text{ kg}\cdot\text{m}^{-3}$). The statistical analysis of variance ANOVA revealed statistically significant differences in the average density in group of briquettes from 18 months raw materials at $p < 0.05$. However, Tukey's test confirmed statistically significant differences between tested groups.

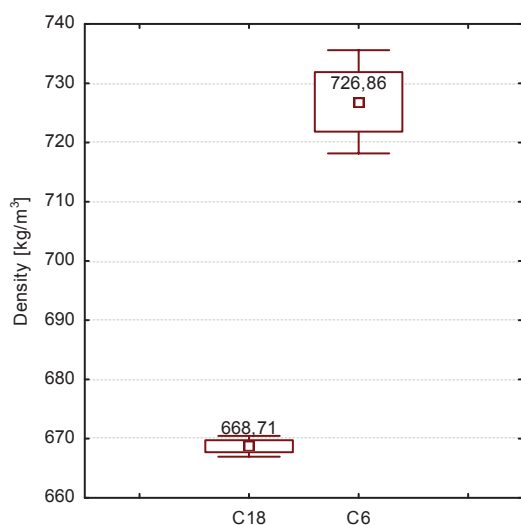
Hay briquettes from 6 month raw material have the highest density too. However, statistical analysis carried out with post-hoc Tukey's test, not only showed a statistically significant difference between



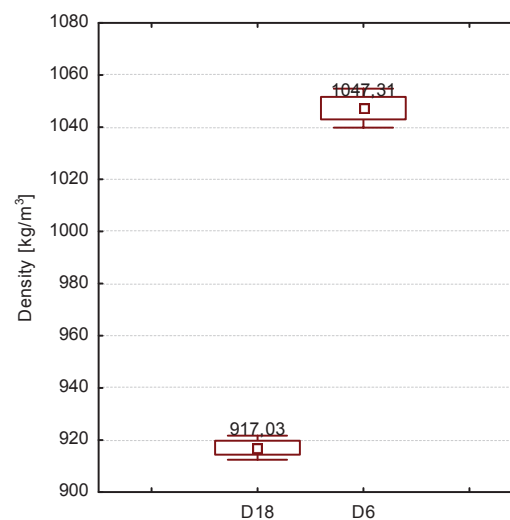
3: Density of briquettes from 18 and 6 months barley straw



4: Density of briquettes from 18 and 6-month wheat straw

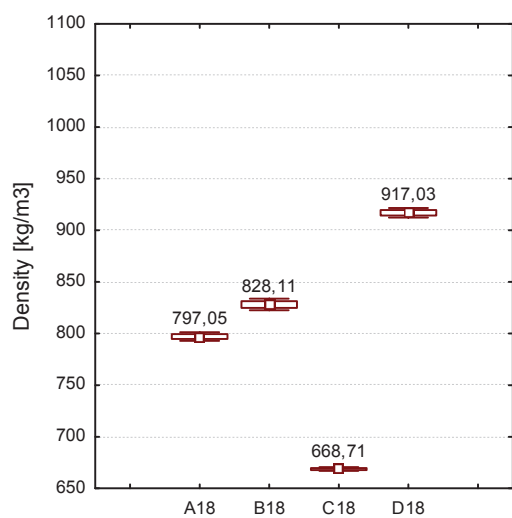


5: Density of briquettes from 18 and 6-month rape straw

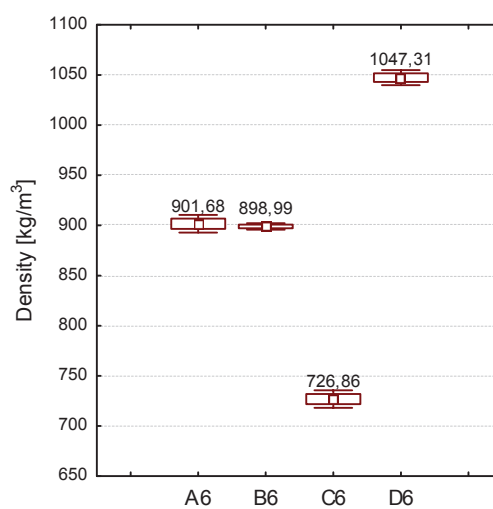


6: Density of briquettes from 18 and 6-month hay straw

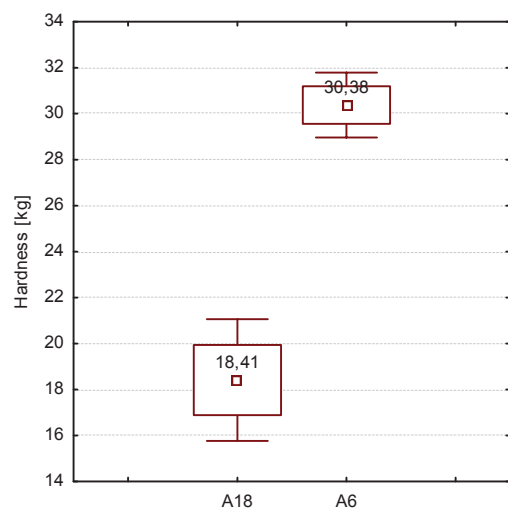
□ average average±standard error average±standard deviation



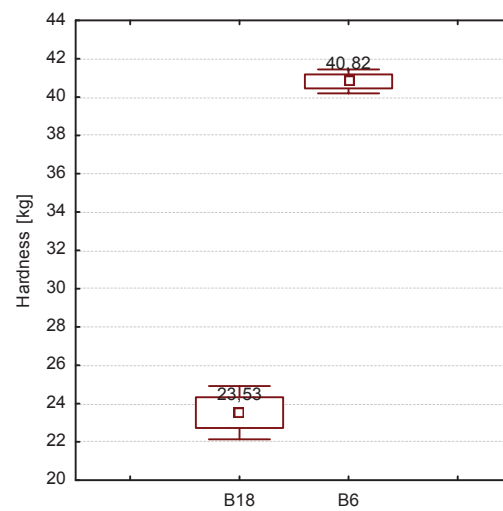
7: Density of agglomerated briquettes from 18 months raw materials.



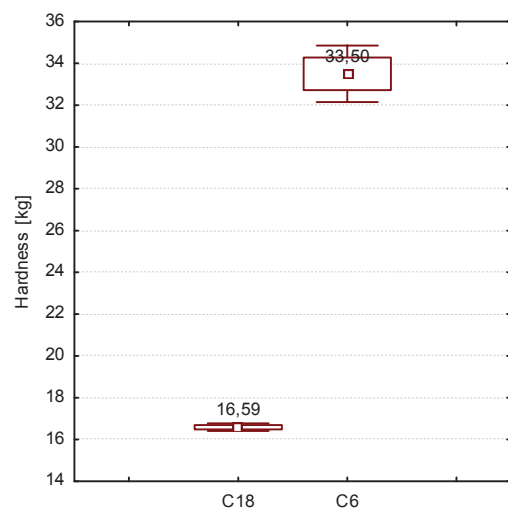
8: Density of agglomerated briquettes from 6 months raw materials



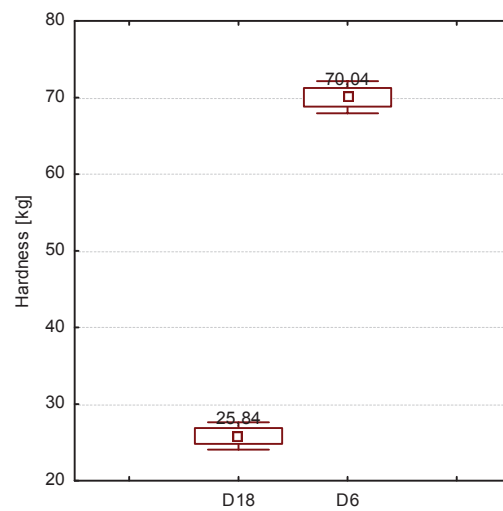
9: Hardness of briquettes from 18 and 6 months barley straw



10: Hardness of briquettes from 18 and 6 months wheat straw

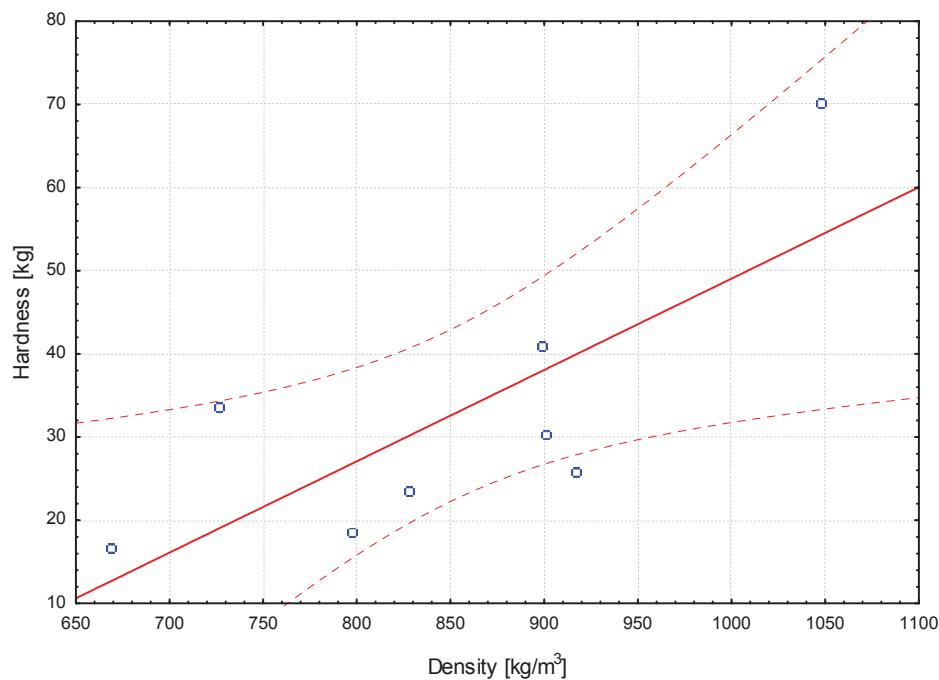


11: Hardness of briquettes from 18 and 6 months rape straw



12: Hardness of briquettes from 18 and 6 months hay

□ average average±standard error average±standard deviation



13: Linear regressions function of hardness depending on the density of the tested briquettes

the average values of the density of briquettes from barley (A6) and wheat (B6), which can be seen in Figure 8.

Figures 9-f 12 show hardness of tested briquettes depending on the species and time of storage of raw materials for briquetting, from harvest until they agglomerate. In the case of the 18-month barley straw briquette (A18) hardness was 18.41 kg and it was about 11.83 kg less than briquette from 6 month straw (A6).

The study showed a similar relationship for briquettes from other raw materials. The statistical analysis with Student's t-test revealed statistically significant differences between the average values of hardness of the briquettes from 6 to 18 monthly raw materials at $p < 0.05$.

Functional dependence of the density and hardness is given by equation:

$$y = 0.110x - 60.789,$$

where $r^2 = 0.5844$; $r = 0.7644$; $p = 0.0272$.

To the tested hardness depending on the density, the Pearson correlation coefficient obtained

I: Types of cracks observed in the studied briquettes

Component	Type of cracks	
	Transversal	Longitudinal
barley 18 (A18)	+	+
barley 6 (A6)	+	+
wheat 18 (B18)	-	+
wheat 6 (B6)	-	+
rape 18 (C18)	-	+
rape 6 (C6)	-	+
hay 18 (D18)	+	+
hay 6 (D6)	-	-

value when $r = 0.76$ at level of significance $p < 0.05$ indicating a very high correlation. A positive value of the slope of the regression line (0.110) indicates a positive linear correlation (Fig. 13).

From Tab. I is evident that only the 6-month hay briquettes (D6) have not transverse and longitudinal cracks. However, the longitudinal and transversal cracks were observed for the 6 and 18-month barley and 18-month hay.

SUMMARY

1. Samples of briquettes obtained from 6-months raw materials have a higher density compared to 18 months materials in the case of the same species.
2. The lowest density among the examined briquettes from 6 and 18 months materials had rape agglomerate, it means 668.71 and 726.86 $\text{kg}\cdot\text{m}^{-3}$.
3. Briquettes from 6 months material are characterized by higher performance of hardness in the comparison with briquettes agglomerated from older materials.

4. For tested briquettes was found relatively high correlation ($r = 0.76$) between the hardness and density.
5. Manufacturers to produce briquettes should obtain raw materials from current field production, eventually mixing of raw materials from the current year with previous years.

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Address

Dr inż. Marek Rynkiewicz, Department Construction and Use of Technical Equipment, West Pomeranian University of Technology in Szczecin, ul. Papieża Pawła VI/3, 71-459 Szczecin, Poland, Ing. Petr Trávníček, Ph.D., Department of Agriculture, Food and Environmental Engineering, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic, Ing. Petr Junga, Ph.D., Department of Agriculture, Food and Environmental Engineering, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic, e-mail: marek.rynkiewicz@zut.edu.pl., petr.travnicek@mendelu.cz, petr.junga@mendelu.cz