MECHANICAL DURABILITY OF BRIQUETTES MADE OF ENERGY CROPS AND WOOD RESIDUES

Tatiana Ivanova, Michel Kolarikova, Bohumil Havrland, Lubos Passian
Czech University of Life Sciences Prague
ivanova@ftz.czu.cz

Abstract. Briquettes from biomass seem to be promising, rapidly growing and high quality source of biofuel and challenge to fossil fuels. Briquettes' mechanical quality, first of all mechanical durability, is very important parameter from the viewpoint of transportation and the other manipulations, it describe the visual appearance of briquettes, which has impact on their market price. The present research paper is focused on determination and comparison of mechanical durability of briquettes produced from selected energy crops. Biomass of high yielding annual and perennial crops such as miscanthus, giant reed, giant knotweed, sweet sorghum and industrial hemp, which may be perspective source of renewable energy in appropriate areas, was briquetted in the pure state or as mixture with wood biomass. Totally twenty tree kinds of briquettes was produced by hydraulic piston press and its mechanical durability was then determined according to European standards for solid biofuels. Addition of wood residues in the form of wood savings and wood sawdust increased the durability in most of the materials.

Keywords: biomass, briquetting, mechanical durability, moisture content.

Introduction

Production of briquettes and pellets from biomass is energy and economically demanding, however, the popularity of their use greatly increased in recent years that show significant advantages of these fuels. These forms of fuel are considered to be the fuels of the future due to their low moisture content, high calorific value, low ash content, easy handling and environmentally friendly impact [1]. In addition, briquetting improves characteristics of biomass for handling, transporting, storage and combustion [2; 3]. Due to the above-mentioned qualities, fuel briquettes are highly competitive as compared with other fuels, and fuel briquettes market is rapidly expanding [1; 4-6].

Biomass is one of the most suitable materials for briquetting. The briquettes can be produced from agricultural and forestry wastes, biomass of energy crops and short-rotation trees [1]. Generally, it is essential to support all forms of biomass production. It is necessary to use all wood and forest residues and simultaneously to utilize the surplus agricultural land for cultivation of energy crops [7].

Fast developing market of solid biofuels puts high requirement on their quality. In addition to physical and chemical parameters, mechanical parameters of solid biofuels such as mechanical durability are very important.

Mechanical durability simply expresses how dense the briquette is, and how well it is formed. The mechanical durability is the measure of the resistance of densified fuels towards shocks and/or abrasion in consequence of transport and handling processes [8]. Mechanical durability depends on [9]: 1. Used material and its structure, especially size of the input fraction; 2. Compaction pressure: with increasing pressure mechanical durability of the briquettes increase. But also according to [1], when using too high pressure the produced briquette is although quality and hard, but too much energy is spend; 3. Material moisture content.

The moisture content of the raw material is basic input parameter for pressing process and its significantly influent the quality of briquettes. If the moisture content exceeds the level of 20 %, the biomass will not compress to required size in a pressing chamber and briquette will crumble [4; 10]. It is possible to distinguish the optimal and critical moisture values. The optimum moisture content of input raw material is between 4 - 10 % when the best mechanical properties of briquettes are attained. However, for some sorts of raw materials the upper limit of moisture is a 6-8 %. The critical moisture content is such at which the formation of briquettes is still possible, but crack failures usually appear on their surface and the briquettes lose their market value. The critical amount of water is within 10 - 15 % [1; 4; 6]. Moisture of briquettes depends mainly on the initial moisture of raw material and it changes during the briquetting process, when the temperature increases by compression, some amount of moisture evaporates. High moisture content of briquettes leads to their bed consistency, increased number of crumbles, low energy value [11] and consequently low price [4].

Materials and methods

The tested material was biomass of two kinds of miscanthus (*M. sinensis* L. and *M. x giganteus* L.*),* giant reed (*Arundo donax* L.), giant knotweed (*Reynoutria* x *bonemica* L.), hemp (*Canabis sativa* L.) and sweet sorghum (*Sorghum bicolor* (L.) Moench). The brief description of selected energy crops is as follow:

Miscanthus is perennial grass with C_4 photosynthesis native to East Asia, which can grow up to 3-4 m height and yield in average 15-25 t·ha^{-1} of dry matter (DM) [1; 12; 13]. Knotweed is perennial 2-4 m height shrub-like C_3 grass originated from Asian temperate zone [13]. It is aggressive invasive crop [14] with biomass yield about 13.2-21.4 t·ha^{-1} DM [15]. Giant reed is perennial 8-9 m height C_3 grass, which nowadays widely dispersed into all subtropical and warm-temperate areas of the world [16]. It has high biomass production in average 35 - 40 t·ha^{-1}DM and great adaptability to marginal land [1; 17]. Industrial hemp is annual fibre plant originated from Western Asia and India, which can grow at higher altitudes [18]. Its great benefit is an ability to create over 10 t·ha^{-1} DM yield within 140 days [1]. Sweet Sorghum is an annual herbaceous C_4 plant originated from Africa, but also used in the America and Asia [13]. It can produce about 54-69 t·ha^{-1} of wet biomass containing sweet juice [19].

The above-mentioned energy crops were cultivated in experimental plots in the Czech Republic, only sweet sorghum biomass (stalks after juice extraction) was brought from Moldova. All the biomass sources were dried out by natural way to the moisture content below 12 %.

Dry biomass was ground (disintegrated) by hammer mill 9FQ-40C (Pest Control Corporation; grinding mill input – 5.5 kW). The biomass of miscanthus species was ground with two different hammer mill screen sizes (3.8 mm and 8 mm) the other materials were ground using the screen size 3.8 mm. All these biomass sources were also enriched with other components – waste biomass in the form of wood sawdust and wood shavings with initial moisture less than 13 %; biomass of energy crops and wood biomass was weight and mixed in the ratio 1:1. As a result the following mixtures of raw materials were prepared for further process of briquetting (see Table 1).

Table 1

Composition of mixtures of raw materials prepared for briquetting

Material	Fraction size, mm	Additive	Ratio
M. sintesis	3.8	–	–
M. sintesis	3.8	+ wood sawdust	1:1
M. sintesis	3.8	+ wood shavings	1:1
M. sintesis	8	–	–
M. sintesis	8	+ wood sawdust	1:1
M. sintesis	8	+ wood shavings	1:1
M.x giganteus	3.8	–	–
M.x giganteus	3.8	+ wood sawdust	1:1
M.x giganteus	3.8	+ wood shavings	1:1
M.x giganteus	8	–	–
M.x giganteus	8	+ wood sawdust	1:1
M.x giganteus	8	+ wood shavings	1:1
Giant reed	3.8	–	–
Giant reed	3.8	+ wood shavings	1:1
Giant reed	3.8	+ wood sawdust	1:1
Giant knotweed	3.8	–	–
Giant knotweed	3.8	+ wood sawdust	1:1
Giant knotweed	3.8	+ wood shavings	1:1
Sweet Sorghum	–	–	–
Sweet Sorghum	–	+ wood shavings	1:1
Sweet Sorghum	–	+ wood sawdust	1:1
Hemp	3.8	–	–
Hemp	3.8	+ wood shavings	1:1

The briquetting was carried out by hydraulic piston briquetting press BrikStar model 50-12 (Briklis), which allows to produce briquettes of diameter 65 mm and length 30-50 mm.

Determination of moisture content (*w*): the moisture content of bio-briquettes (as well as moisture contents of raw materials during the drying) was determined according to the ČSN P CEN/TS 14774-1 using the oven drying method. The material was dried out within 5-8 hours at 105 ºC in the oven MEMMERT 100-800 (Schwabach) and the following formula was then applied:

$$w = \frac{m_w - m_d}{m_w} \cdot 100\,\% \,, \tag{1}$$

where m_w – total mass of wet material, g;
m_d – dry matter mass of the dried material, g.

Determination of mechanical durability (*DU*): the mechanical durability of produced bio-briquettes was determined according to the standard EN 15210-2. The mechanical durability of bio-briquettes was tested by specific abrasion drum, there briquettes' samples were rotated at 21±0.1 revolutions per min for 5 min. Five simples of each mixture of about 2 kg (±0.1 kg) each was prepared and tested. The mechanical durability (*DU*) was calculated using the following formula:

$$DU = \frac{m_A}{m_E} \cdot 100\,\% \,, \tag{2}$$

where m_E – mass of pre-sieved briquettes before the drum treatment, g;
m_A – mass of sieved briquettes after the drum treatment, g.

Results and discussion

The moisture content of raw biomass materials just before the briquetting as well as moisture content of produced bio-briquettes is presented in the Table 2.

Table 2

Moisture content of selected biomass and produced bio-briquettes

Biomass sources	Biomass moisture content, %	Composition of briquettes	Briquettes moisture content, %
M.x giganteus	10.6	*M.x giganteus 1**	7.3
		M.x giganteus 2	7.5
		M.x giganteus 3	7.4
M. sintesis	9.4	*M. sintesis 1*	8.2
		M. sintesis 2	7.3
		M. sintesis 3	6.5
Giant knotweed	10.2	Giant knotweed 1	8.5
		Giant knotweed 2	10.6
		Giant knotweed 3	7.7
Giant reed	10.7	Giant reed 1	3.9
		Giant reed 2	8.4
		Giant reed 3	9.0
Hemp	11.3	Hemp 1	7.3
		Hemp 2	7.2
Sweet Sorghum	10.5	Sweet Sorghum 1	7.7
		Sweet Sorghum 2	7.3
		Sweet Sorghum 3	7.9

* 1 – briquettes made from single biomass source;
2 – combined briquettes made of biomass source + wood sawdust (1:1)
3 – combined briquettes made of biomass source + wood shavings (1:1)

The results of mechanical durability of the tested briquettes are shown in the Fig. 1.

From 23 different mixtures three mixtures had very high results of mechanical durability more than 95 % (*M. x gigantheus* (screen 8 mm) + wood sawdust 1:1; pure hemp briquettes; sweet sorghum + wood shavings 1:1).

Most of the mixtures – 13 samples, showed very good results above 90 % (*M. x giganteus* (screen 3.8 mm) + wood sawdust 1:1; pure *M. x giganteus* (screen 8 mm); *M. x giganteus* (screen 8 mm) + wood shavings 1:1; *M. sinensis* (both screen 3.8 mm and screen 8 mm) + wood sawdust 1:1 and *M. sinensis* (screen 8 mm) + wood shavings 1:1 as well; pure giant knotweed briquettes and mixture of giant knotweed + wood shavings and the same samples in case of giant reed; hemp briquettes made of mixture with wood sawdust; pure sweet sorghum as well as sweet sorghum + wood sawdust).

Briquettes produced from pure *M. x giganteus* and pure *M. sinensis* biomass crushed by the screen size 3.8 mm and also their mixtures with wood shavings in the ratio 1:1 had the values of mechanical durability just slightly below 90 % (above the value of 88.5 %).

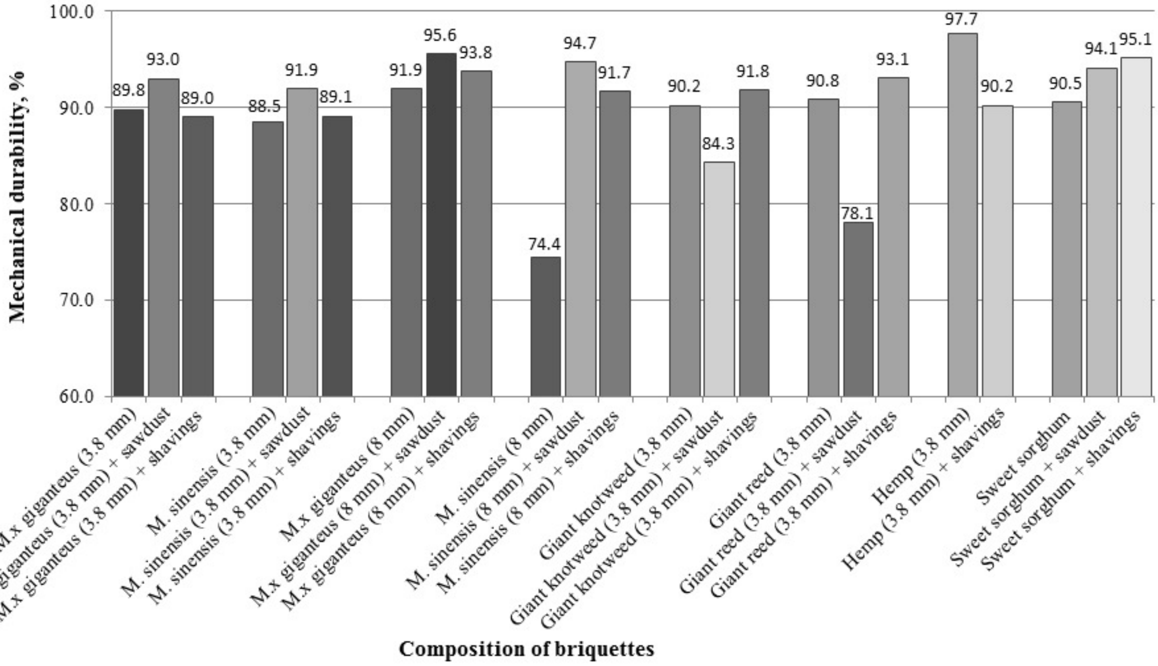

Fig. 1. **Comparison of the mechanical durability of produced bio-briquettes**

Comparing the results of two different kinds of miscanthus (see Fig. 1) it is visible that the mechanical durability of the pure as well as combined briquettes based on *M. sinensis* and *M. x giganteus* crushed through the screen diameter 3.8 mm is very similar. The mechanical durability of the briquettes based of these plants crushed by screen size 8 mm is generally better, except of briquette made of pure *M. sinensis* biomass. Probably the reason is in the higher moisture content comparing to the other mixtures (see Table 2), but the probability is very low due to imperceptible differences. The fact that briquettes produced from miscanthus biomass crushed through screen size 8 mm show better results in contrast to briquettes made of the same materials crushed through screen 3.8 mm is very positive, because the energy consumption during the crushing to bigger particles is considerably lower. It should be also mentioned that *M. x giganteus* gives higher biomass DM yields as almost twice in comparison to the yields of *M. sinensis* (according to own experience and results of other authors). This is another fact that makes *M. x giganteus* more perspective for energy use, but in should be taken into account that requirements of these plants to climate conditions are little different (according to [1; 13; 20] in terms of zoning, *M. sinensis* is the most suitable for Northern Europe, *M. x giganteus* for Central Europe).

The behaviour (change of weight) of single briquettes during the drum treatment on the example of the less and the most durable types of briquettes is illustrated in the Fig. 2 and Fig. 3.

The big difference between briquettes' weight before and after drum treatment and due to it creation of significant amount of abrasion is very well depicting on the Fig. 2. It is also visible that thee briquettes were totally beaked in this case. In comparison there was almost no change in briquettes' weight in case of the most durable type of briquettes (see Fig. 3).

From the viewpoint of mechanical durability the briquettes from hemp biomass belong to very high quality solid biofuels (category DU95.0 according to EN 14961-1).

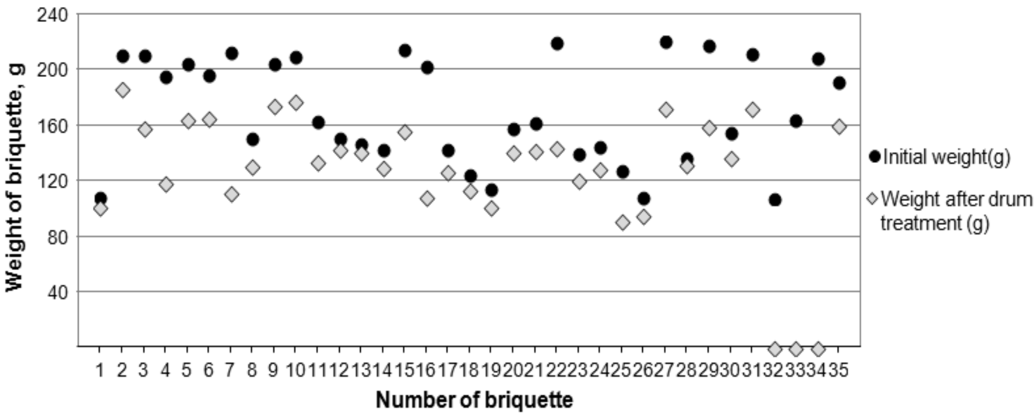

Fig. 2. **Mechanical durability of pure *M. sinensis* briquettes**

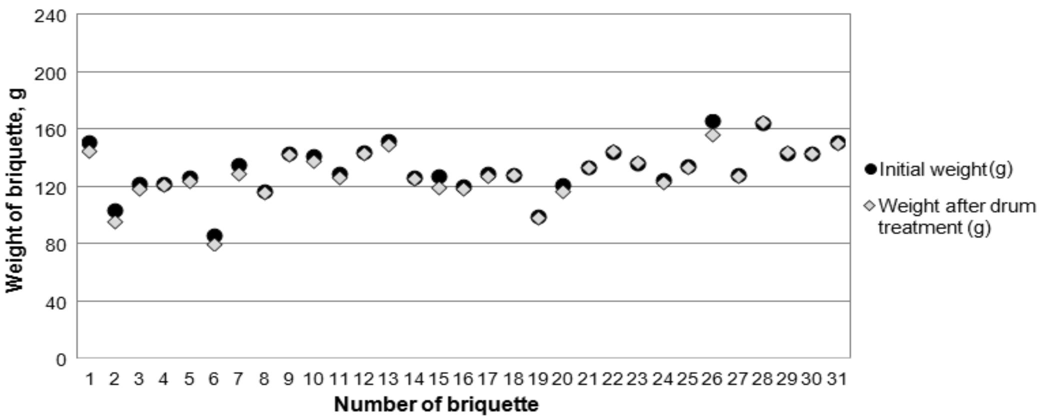

Fig. 3. **Mechanical durability of pure hemp briquettes**

Conclusion

Generally, the mechanical quality of briquettes produced from selected energy crops expressed by mechanical durability is good. The durability of briquettes based on pure biomass of energy crops like miscanthus, giant reed, giant knotweed, sweet sorghum range about 90 %. According to experimental results it could be concluded that the durability of briquettes may be improved by addition of wood residues.

The best results of mechanical durability (97.7 %) were achieved in hemp briquettes. In contrast with all other types of briquettes where durability was increasing with addition of wood biomass, pure hemp briquettes are more durable. It can be explained by the briquettes structure - better connection of fibrous material particles. Very good results of mechanical durability also show the briquettes made of sweet sorghum waste biomass, which could be successfully used for solid biofuels production after the juice extraction.

Material moisture content should be taken into account within the briquetting process as it has a big impact on the final quality of produced briquettes.

Acknowledgements

The study was supported by Internal Grant Agency of the Faculty of Tropical AgriSciences, Czech University of Life Sciences Prague in the framework of research grant number 20145029.

References

1. Ivanova T. Research of Energy Plants Processing to Solid Biofuels. Dissertation thesis. Czech University of Life Sciences Prague, Prague, 2012, 122 p.
2. Plíštil D., Brožek M., Malaťák J., Roy A., Hutla P. Mechanical characteristics of standard fuel briquettes on biomass basis. Research in Agricultural Engineering, vol. 51, 2005, No 2, pp. 66-72.

3. Wilaipon P. Physical characteristics of maize cob briquette under moderate die pressure. American Journal of Applied Sciences, vol. 4, 2007, No 12, pp. 995-998.
4. Pobedinschi V., Havrland B., Muntean A., Vrancean V., Kandakov A., Ivanova T. Практикум по дисциплине: Заготовка и переработка сельскохозяйственной продукции и биоотходов (Manual for the Subject: Preparation and Processing of Agricultural Produce and Bio-wastes). Powerprint, Chisinau – Prague, 2009, 162 p. (In Russian).
5. Kotlánová A. Testování biomasy a výrobků z biomasy (pelet a briket) určených ke spalování. CZBiom, 2009. (In Czech). [online] [15.02.2009]. Available at: http://biom.cz/cz/odborne-clanky/testovani-biomasy-a-vyrobku-z-biomasy-pelet-a-briket-urcenych-ke-spalovani.
6. Havrland B., Pobedinschi V., Vrancean V., Pecen J., Ivanova T., Muntean A., Kandakov A. Biomass processing to biofuel. Powerprint, Prague – Chisinau, 2011, 86 p.
7. Petříková V. Nedostatek biomasy. CZBiom, 2011. (In Czech). [online] [14.03.2011]. Available at: http://biom.cz/cz/odborne-clanky/nedostatek-biomasy.
8. Alakangas E., Wiik C., Lensu T. CEN 335 – Solid biofuels, Feedback from market actors, EUBIONET report – VTT Report VTT-R-00430-07, Jyväskylä, 2007, 71 p.
9. Mani S., Tabil L.G., Sokhansanj S. Effects of compressive force, particle size and moisture content on mechanical properties of biomass pellets from grasses. Biomass and Bioenergy, vol. 30, 2006, pp. 648-654.
10. Plíštil D., Hutla P., Roy A. Briketování odpadů z dendromasy a zjištění mechanických parametrů briket. CZBiom, 2005. (In Czech). [online] [14.02.2005]. Available at: http://biom.cz/cz/odborne-clanky/briketovani-odpadu-z-dendromasy-a-zjisteni-mechanickych-parametru-briket.
11. Heneman P. Change in humidity of solid biofuels. Research in Agricultural Engineering, vol. 50, 2004, No 2, pp. 61-65.
12. Clifton–Brown J.C., Stampel P.F., Jones M.B. Miscanthus biomass production for energy in Europe and its potential contribution to decreasing fossil fuel carbon emissions. Global Change Biology, vol. 10, 2004, No 2, pp. 509-518.
13. Havrland B., Ivanova T., Lapczynska-Kordon B., Kolarikova M. Comparative Analysis of Bio-Raw Materials and Biofuels. Engineering for rural development, May 23-24, 2013, Jelgava, Latvia. Available online: http://tf.llu.lv/conference/proceedings2013/Papers/100_Havrland_B.pdf.
14. Gerber E., Krebs Ch., Murrell C., et al. Exotic invasive knotweeds (*Fallopia* spp.) negatively affect native plant and invertebrate assemblages in European riparian habitats. Biological Conservation, vol. 141, 2008, No 3, pp. 646-654.
15. Strašil Z., Kára J. Study of knotweed (*Reynoutria*) as possible phytomass resource for energy and industrial utilization. Research in Agriculture Engineering, vol. 56, 2010, No 3, pp. 85-91.
16. Lewandowski I., Scurlock J.M.O., Lindvall E., Christou M. The development and current status of perennial rhizomatous grasses as energy crops in the US and Europe. Biomass and Bioenergy, vol. 25, 2003, pp. 335-361.
17. Pilu R., Bucci A., Badone F. C., Landoni M. Giant reed (*Arundo donax* L.): A weed plant or a promising energy crop? African Journal of Biotechnology 11(38), 2012. pp. 9163-9174.
18. Prade T., Svensson S.E., Andersson A., Mattsson J.E. Biomass and energy yield of industrial hemp grown for biogas and solid fuel. Biomass and bioenergy, vol. 35, 2011, No 7, pp. 3040-3049.
19. Almodares A, Jafarinia M, Hadi M R. The effectes of nitrogen fertilizer on chemical compositions in corn and sweet sorghum. American-Eurasian. Journal of Agriculture and Environment Sciences, vol. 6, 2009, No 4, pp. 441-446.
20. Strašil Z. Základy pěstování a možnosti využití ozdobnice (*Miscanthus*). Metodika pro praxi. Výzkumný Ústav Rostlinné Výroby - VÚRV, Praha, 2009, 48 p. (In Czech).