

## Evaluation of selected properties of briquettes from recovered paper and board

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### Abstract

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Worldwide increasing energy demand is today permanently covered by a majority of non-renewable energy sources, namely by coal, crude oil and natural gas. This causes the rapid decline of their reserves and the time gets near when they will be run out. Therefore in the last years the exploitation of renewable energy sources has been permanently preferred. One of alternative fuel forms is fuel on the basis of paper waste. In this paper the results of tests are published, which were carried out using six sorts of recovered paper and board (group and grade 1.05, 1.06, 2.02, 2.05, 2.07 and 2.08 according to CSN EN 643:2002), pressed into the form of briquettes. During the tests following briquettes parameters were watched: moisture content, ash amount, gross calorific value, length and diameter, weight, density, rupture force and mechanical durability. It was proved that briquettes made from recovered paper and board compared with briquettes from wood waste are of high density, high mechanical durability and for their rupture, relatively high force is necessary. But at the same time they have high ash amount and low gross calorific value.

**Keywords:** renewable energy sources; briquetting; mechanical durability; ash amount; rupture force; gross calorific value

Today the comfortable life is paid with the expressive consumption of energy in all its forms. The non-renewable energy sources reserves are limited and they exhaust. Nevertheless they supply about four fifths of energy consumption. In last decades the renewable energy sources have been preferred. One of alternative forms of fuel, made from renewable sources, is the fuel on the basis of paper waste. First of all it is recommended to recycle this raw material – to use it as a material (MCKINNEY 1995). However, in several last years there is a paper waste surplus on the world market and therefore the interest of specialized firms in this raw material decreases. Besides, not every paper waste is apt for recycling. For instance, chancery paper, exercise-book paper, magazine paper, newspaper, boxes,

cartoons or boards are suitable, whereas e.g. wet, greasy or otherwise polluted paper or coverings from paper and another material (e.g. paper coverings of Tetra Pak contain aluminium or polyethylene foil besides paper, too) are not suitable. Their energetic use has become an interesting alternative and it is certainly more suitable than the paper waste disposal. Besides, it is necessary to keep in mind that cellulose fibres progressively lose their original properties. The paper recycling can be therefore repeated only 5 or 6 times. Then the raw material is unusable (KUPSA 2009; TYMICH 2011; TYMICH, LEŠIKAR 2011).

The fuel briquettes are mostly of circular section, eventually of square, rectangular or hexagonal section with rounded corners. The briquettes size de-

depends above all on the used press type. Cylindrical briquettes are most often of 50 mm, 65 mm or 90 mm diameter; briquettes in form of blocks are usually of 100 × 150 mm section. The briquette length is proportional to the material quantity in the press chamber. The length of cylindrical briquettes is most often 0.5 to 1.5 of their diameter, that of block form briquettes about 65 mm (BASORE 1929; SHERIDAN, BERTE 1959; PLÍŠTIL et al. 2004). Besides the shape of briquettes the combustible materials are processed in the shape of pellets (PLÍŠTIL 2005; NOVÁKOVÁ, BROŽEK 2008; PUNKO, GAVRILOVICH 2009).

However, the briquetting technology is not limited only to non-metallic materials (BROŽEK, 2001a; BROŽEK, NOVÁKOVÁ 2009). It is used also for processing of chips resulting from metallic materials machining and it is either on the ferrous basis (steel, cast iron) or on the non-ferrous basis (BROŽEK 2001b, 2005). In this case, the waste volume reduction, handling facilitation or possibility of its use as recycled material are the main aims.

The briquettes mechanical properties are very important. They influence expressively for instance the storage ability. The author experimentally proved that at storage, the briquettes mechanical properties decrease (BROŽEK, NOVÁKOVÁ 2011; BROŽEK 2013b). The decrease depends above all on the storage conditions and storage time. The adequate mechanical properties level influences also the possible handling from their production, packing and sale to the incineration to the final user.

From the results of works published before (BROŽEK 2013a; BROŽEK, NOVÁKOVÁ 2013) it follows that briquettes made from recovered paper and board compared with briquettes from wood waste are of low moisture content, high density, high mechanical durability and for their rupture relatively high force is necessary. But at the same time they have high ash amount and low gross calorific value.

Other works studying the briquettes and pellets properties exist, too. But they engage in other materials than paper waste, primarily in briquettes made from wood waste (BASORE 1929; SHERIDAN, BERTE 1959; BROŽEK et al. 2012; BROŽEK 2013b), from energy plants (PLÍŠTIL et al. 2004, 2005; KAKITIS et al. 2010), or from alternative fuels (KOLÁŘOVÁ 2011). Their authors concentrate primarily on energy properties, but not on mechanical properties. Therefore the comparison of the results gained at the use of briquettes from paper waste is not possible owing to the tested materials dissimilarity.

## MATERIAL AND METHODS

In the Czech Republic the requirements of the briquettes properties are prescribed by the Directive of the Ministry of the Environment No. 14/2009. It requires the briquettes min. density of 900 kg/m<sup>3</sup>. The briquettes strength requirements are not prescribed. Nevertheless for operational reasons the adequate compactness is very important in order that at a common handling neither crumbling nor disintegration occur. The briquettes min. gross calorific value must be 17 MJ/kg, the total moisture content max. 10% wt. and the ash content max 1.5%.

However, the above mentioned Directive concerns briquettes made from wood waste, alternatively to wood waste with max. 20% of vegetable waste. Although it is a case of a different material, briquettes from paper waste are evaluated according to these technical requirements. In the Czech Republic the special technical requirements for briquettes from paper waste still do not exist.

The properties of briquettes made from six different sorts of recovered paper and board were watched (according to CSN EN 643:2002), namely old corrugated containers (group 1, grade 05), unsold magazines (group 1, grade 06), unsold newspapers (group 2, grade 02), sorted office paper (group 2, grade 05), white wood-free books (group 2, grade 07) and coloured wood-free magazines (group 2, grade 08). Before briquetting all samples were shredded using a shredder of cross cut 4 × 50 mm.

Ahead of briquetting the moisture content (according to CSN EN 14774-2:2010), ash amount (CSN EN 14775:2010) and gross calorific value (CSN EN 14918:2010) were determined.

Then the raw material was briquetted without other treatment using the briquetting press type "BrikStar CS 25" (Briklis, Malšice, Czech Republic; <http://www.briklis.cz/briketovaci-lis/cs/>) of 65 mm pressure chamber diameter. From each material at least 60 pieces of briquettes were made, which made it possible to carry out the measured values statistical evaluation.

The tests of briquettes mechanical properties were carried out according to the method used by author during several years for testing of briquettes made from different nonmetallic (BROŽEK 2001a, 2011, 2013a,b; BROŽEK et al. 2012) and metallic materials (BROŽEK 2001b; BROŽEK, NOVÁKOVÁ 2010). The method of operation is relatively sim-

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ple. Using the slide caliper the diameter and length of each briquette are measured. By weighing their weight is determined. Then the briquettes are placed between the plates of the universal tensile testing machine and continuously loaded till the briquette rupture. The method of operation is presented in Fig. 1. The test is finished at the briquette rupture, which is accompanied with the rapid load decrease. From the load indicator the max. load was noted down. In this way the test carried out enabled the individual evaluation of each briquette in the tested group. Its disadvantage is the high labour consumption.

By the above mentioned method the obtained values were mathematically evaluated. From diameter and length volume, with volume and weight density and from length and force for rupture, the destruction force needed per unit of length has been calculated. Using the unit of length the influence of briquettes different length is eliminated.

The determination of the mechanical durability of briquettes (according to CSN EN 14961-1:2010 and CSN EN 15210-2:2011) was the part of the tests carried out. The advantage of this test is the small time consumption (only 5 min/test). But the results can be influenced by one or a few poor quality briquettes in the tested group.

## RESULTS AND DISCUSSION

The results of the tests are presented in the following table and figures. Table 1 presents the properties of tested papers ahead of briquetting (moisture content, ash amount and gross calorific value).

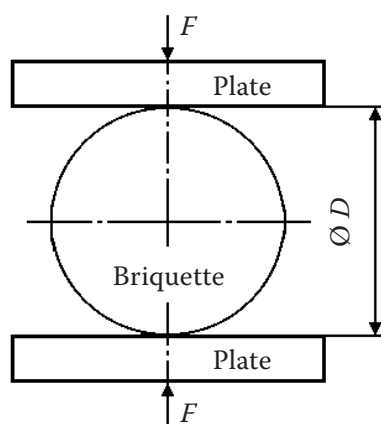


Fig. 1. Principle of the rupture test (BROŽEK et al. 2012)  
 $F$  – rupture force;  $D$  – diameter

Table 1. Properties of the tested papers

Sample designation	Moisture content (%)	Ash amount (%)	Gross calorific value (MJ/kg)
1.05	6.2	13.9	15,5
1.06	4.4	41.0	15.9
2.02	6.2	11.5	17.4
2.05	5.3	22.8	13.9
2.07	5.7	21.6	18.0
2.08	3.6	34.7	15.2

Figs 2a–2c present results of length, diameter, weight measurements, respectively. Fig. 2d contains results of calculated briquettes density and Fig. 2e presents results of rupture force measurements. Fig. 2f presents results of the briquettes mechanical durability. Fig. 3 demonstrates the relation between rupture force and density of all six tested materials. In figures the standard deviation is demonstrated by the line segments.

From the results presented in Table 1 it follows that the moisture content at all tested materials ranged in the relatively low level, from 3.6% (sample 2.08) to 6.2% (samples 1.05 and 2.02).

From the point of view of the ash amount (Table 1) between six tested materials the significant differences exist. The lowest ash amount was determined at the sample 2.02 (11.5%), the alike low at the sample 1.05 (13.9%). At the next two samples (2.07 and 2.05) the ash amount was higher than 20%, and at the sample 2.08 it higher than 30%. The highest ash amount was found at the sample 1.06, namely 41.0%.

The gross calorific values (Table 1) ranged from 13.9 (sample 2.05) to 18.0 (sample 2.07) MJ/kg. The values of three samples (2.08, 1.05 and 1.06) ranged from 15 to 16 MJ/kg; the value of the sample 2.02 was 17.4 MJ/kg. From this point of view only the sample 2.07 met the requirements.

From the results published in Fig. 2a it is evident that the average length of briquettes made from all six sorts of paper waste is in the relatively wide range from 30 mm (sample 2.05) to 49 mm (sample 2.08).

From the results published in Fig. 2b it is evident that briquettes made from all six tested materials enlarged their diameter compared to the diameter of the pressure chamber diameter (65 mm). The enlargement was relatively small and for all tested materials it ranged from 0.75 mm (samples 1.05) to 1.08 mm (sample 2.02).

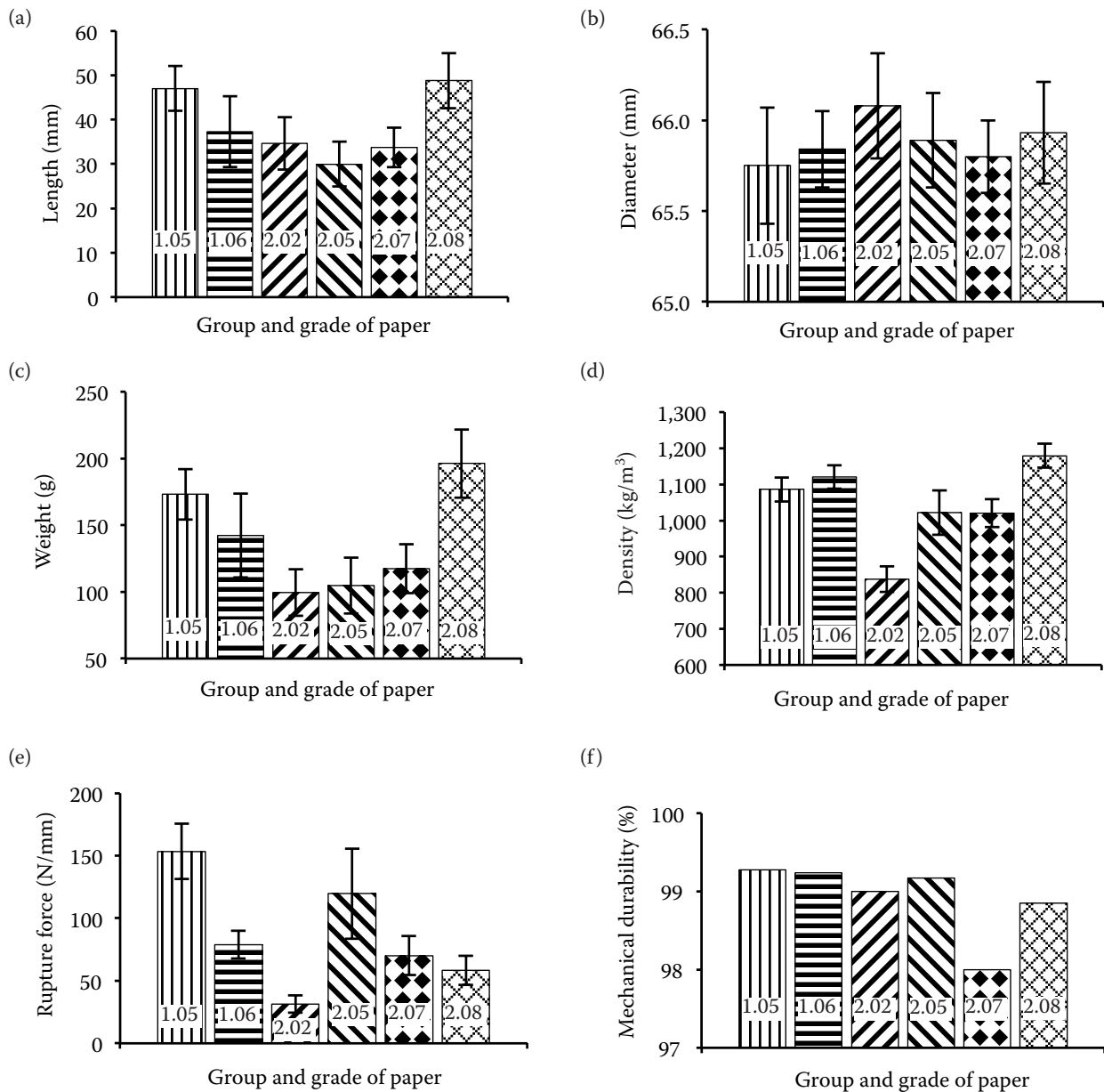


Fig. 2. Test results: (a) briquettes length, (b) briquettes diameter, (c) briquettes weight, (d) briquettes density, (e) rupture force for briquette destruction, (f) mechanical durability standard deviation is demonstrated by the line segments

From the results published in Fig. 2c it is evident that the briquettes weight ranged relatively widely from 99.0 g (sample 2.02) to 196.3 g (sample 2.08).

From the results presented in Fig. 2d it is evident that the briquettes density ranged relatively widely from 837.8 kg/m<sup>3</sup> (sample 2.02) to 1179.0 kg/m<sup>3</sup> (sample 2.08).

From the results in Fig. 2e it is evident that the rupture force of the briquettes made from paper ranged relatively widely from 32 (sample 2.02) to

153 N/mm (sample 1.05). From this point of view briquettes were not similar.

As it follows from Fig. 2f the mechanical durability of all briquettes was very high. The value of the mechanical durability of all tested briquette samples was not less than 98%. The mechanical durability of four samples (1.05, 1.06, 2.02 and 2.05) was even higher than 99%.

The graphical relationship between the briquettes rupture force and density is shown in Fig. 3. It is

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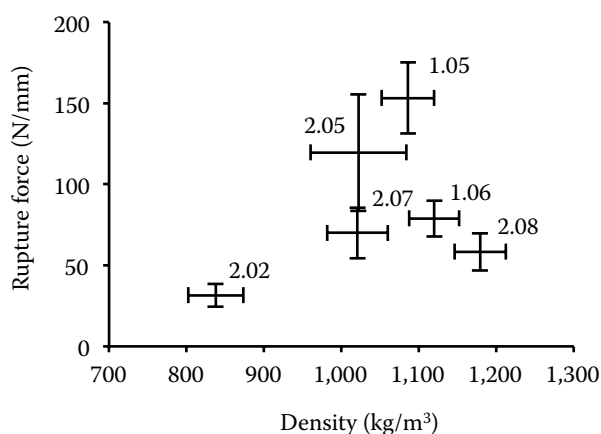


Fig. 3. Relationship between rupture force and density standard deviation is demonstrated by the line segments

evident that the highest density was determined at briquettes made from sample 2.08 (coloured wood-free magazines). The highest rupture force was determined at the briquettes made from the paper 1.05 (old corrugated containers).

From Fig. 3 it follows also that the properties of the briquettes made from five materials (1.05, 1.06, 2.05, 2.07 and 2.08) were relatively similar. The briquettes made from unsold newspapers (2.02) were a bit deviating. Nevertheless it is possible to state that also these briquettes accommodated the requirements on the mechanical properties.

## CONCLUSION

In the paper the results of briquettes mechanical properties are published. Briquettes were made from six sorts of recovered paper and board (according to CSN EN 643:2002), namely old corrugated containers (group 1, grade 05), unsold magazines (group 1, grade 06), unsold newspapers (group 2, grade 02), sorted office paper (group 2, grade 05), white wood-free books (group 2, grade 07), coloured wood-free magazines (group 2, grade 08). Before briquetting all samples were shredded using shredder of cross cut  $4 \times 50$  mm. These materials were pressed without any admixtures.

Ahead of briquetting the paper properties (moisture content, ash amount and gross calorific value) were determined. For briquetting the briquetting press type “BrikStar CS 25” of the pressure chamber diameter 65 mm was used. Briquettes were judged from several standpoints – length, diame-

ter, weight, density, mechanical durability and rupture force using plate-loading test.

After evaluation of all measured values it is possible to say that all briquettes made from six sorts of recovered paper and board are suitable from the user’s view. Briquettes technical parameters were objectively determined using the above mentioned tests, adopted from methods for testing of briquettes made from wood waste. Compared with briquettes from wood waste briquettes from paper waste are of considerably higher density, mechanical durability and rupture force. But gross calorific value of all sorts of paper waste is lower than gross calorific value of wood waste and contemporarily ash amount is many times higher.

The results of the tests carried out confirm that the energy utilization of paper and board waste is theoretically and practically possible. Nevertheless, it is desirable to prefer its utilization as a material, namely by recycling. Only in the case when recycling is not possible, e.g. owing to pollution, it is desirable to produce briquettes and incinerate these successively. But the situation is complicated by changes of paper and board waste prices on the world market. Sometimes there is the paper waste shortage, its need increases and successively its price increases, too. Probably in this period, the energy utilization of paper waste will not be requested. On the contrary in other periods there is surplus of paper waste, the need decreases and its price decreases very much, too. In this period the energy utilization of paper and board waste in form briquettes is the advantageous method of solution of the transient surplus of paper waste.

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