INFLUENCE OF THE PARTICLE PARAMETERS ON THE PROPERTIES OF BIOMASS BRIQUETTES

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Abstract
In the handling and usage processes, sufficient density and durability of biomass (straw, reed and hemp stalk) briquettes should be provided. For the briquettes density standards determined the value ρ > 1.0 g·cm^{-3}. In the densification process, usually fine grinded particles are used, which significantly increases energy consumption for stalk material cutting. It is generally agreed that biomass material of 6-8 mm size with 10-20% powdery component (< 4 mesh) gives the best results. Calculated energy consumption for hemp stalk cutting to such size is > 12 kJ·kg^{-1}, but to the size of 100 mm – <1 kJ·kg^{-1}.
Calculated energy consumption for common reed cutting to sizes less than 3 mm was > 7 kJ·kg^{-1} but to the size of 20 mm – approximately 1 kJ·kg^{-1}. The goal of the investigation was to obtain the necessary density and durability of briquettes of larger biomass particles by arranging them. The orientation of the straw or reed or hemp stalks has to promote binding by the pressing operation. The article presents the investigation of straw, common reed and hemp biomass mechanical properties which influence the machine design and methods for biomass conditioning. The investigation of biomass briquetting energy and briquettes strength is also presented. Crushing force dependence on particle size for arranged structure briquettes was stated in laboratory experiments. The specific splitting force of arranged structure coarse chopped wheat straw and reed briquettes reached the value of 35 N·mm^{-1}. It is approximately the same as that of industrially produced wood briquettes. Splitting force of the hemp stalk briquettes reached 115 N·mm^{-1}. The density of the arranged reed and hemp stalk particles exceeds the recommended in the standards (1000 kg·m^{-3}) and reaches – 1185 kg·m^{-3} for the arranged hemp stalk particles with the length of 150mm and briquetting pressure – 212 MPa. The specific briquetting energy of coarsely chopped arranged reed and hemp stalk particles varied from 51.61 kJ·kg^{-1} to 67.23 kJ·kg^{-1}. For comparison, the finely chopped reed particle briquetting energy gave the maximum specific energy – 40 kJ·kg^{-1}. The splitting force of the hemp stalk briquettes reached 133.33 N·mm^{-1}.
Key words: briquette, hemp, straw, reed, solid biofuel, energy.

Introduction

The demand for different agricultural raw materials for biofuel production has increased in recent years, causing shortage of the traditional raw materials – sawdust and wood shavings. Biomass energy production can be realized only in accordance with ecosystem approach and good understanding of agricultural ecosystem function.

Growing of hemp, which is a good fibre, oil and biofuel resource, can be a good alternative source for energy producing. Hemp is a phytosanitary plant that enables its introduction into each crop rotation, practically after any plant. The yield of industrial hemp produces 10–15 tons of biomass per hectare plantation. It is estimated that cultivation of 1 ha hemp absorbs about 2.5 tons of CO_2, which contributes significantly to the lessening of the greenhouse effect (Mankowski J., Kolodziej J. 2008). Hemp with its rich leafage suppresses weeds, and leaves left on the soil after harvesting improve the soil structure (Poiša L. et al., 2010). In 2009, in Latvia about 200 ha were planted with hemp. To successfully develop the industry, the need to sow hemp is at least 1000 ha (Ulme A. et al., 2010). Latvia University of Agriculture provides growing experiments with two varieties: variety Bialobrezskie for fibre production and local hemp Purini, which has been grown in Latvia for 200 years, for seed (Poiša L. et al., 2010).

Particle size and shape are of great importance for briquetting. It is generally agreed that biomass material of 6-8 mm size with 10-20% powdery component (< 4 mesh) gives the best results (Grover P.D., Michra S.K. 1996). Calculated energy consumption for common reed cutting to that size was > 5 kJ kg^{-1}, but o the size of 20 mm – approximately 1 kJ·kg^{-1} (Kronbergs E., 2006; Kakitis A., 2004), whereas energy consumption for hemp stalk cutting to the size of 6 – 8 mm is > 12 kJ·kg^{-1}, and to the size of 100 mm – <1 kJ·kg^{-1}.

The goal of the investigation was to obtain the necessary density and durability of briquettes of larger biomass particles by arranging them. The orientation of straw or reed or hemp stalks had to promote binding by the pressing operation.

Theoretical analysis of briquetting process was stated before the experiments. If particles are inserted in the briquetting die without arranging, they lay down perpendicularly to the pressing direction. Pressing force

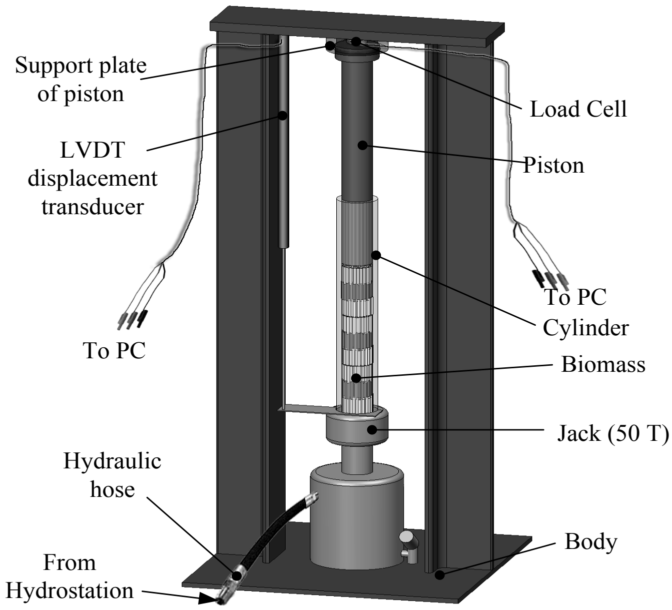


Figure 1. **Scheme of densification**

compacts the particles, but sharp adhesion between them does not occur because of the hard stalk particle surface. The reason is flattening of stalk material particles of the bonding surface area. To increase density and strength of briquettes it is necessary to maximize bonding surface area between the particles. Suitable arrangement of straw and reed particles in briquetting die allows changing deformation directions of particles. The stalk material curves and adhesion between particles increases.

As the pressing operation with oriented stalks was carried out on laboratory equipment, productivity of it was low. Therefore durability of briquettes has to be characterized by a different (not solid biofuel testing standard method) method where small amount of briquettes are sufficient. For laboratory experimental testing of briquettes crushing strength should be examined (Plištil D., et al., 2005).

Materials and methods

Compressive behaviour of stalk biomass is important for the design of biomass processing machines, shredders, briquetting press, etc. Hemp and reed stalks densification experiments were carried out by means of hydraulic press equipment in a closed die. To decrease briquetting energy, “cold” briquetting was carried out. It means that stalk material was pressured by piston in cylindrical closed die. Friction forces between biomass particles and inner cylinder wall did not increase energy consumption significantly because displacement of particles at large pressing force was small (Fig. 1).

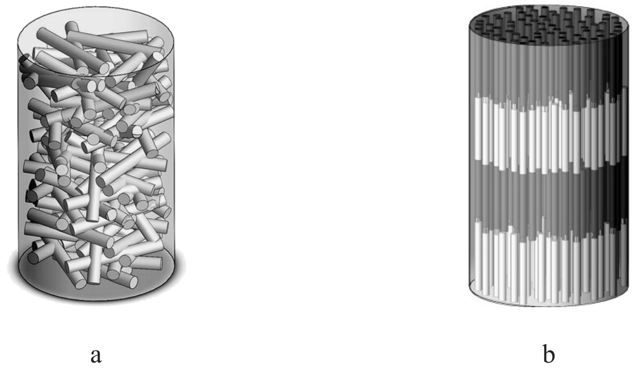
The length of reed and hemp stalks was 30, 60, 100, 150 and 300 mm. Experiments were carried out with unarranged reed and hemp stalks (length of particles was 30 mm), and with arranged reed and hemp stalks (length of particles was 60, 100, 150 and 300 mm).

Stalk material particles with certain length were arranged in a closed die as it is presented in Fig. 2b. The Arranged particles were located in the direction of longitudinal axe of the die. Overlapping of the ends of particles in different layers was 5 to 15 mm. Particles were slightly compacted in the arranging process to obtain the same mass of the material for every rerun. After arranging, the particles were compacted by hydraulic press with the maximum pressures in the closed die – 158 MPa and 212 MPa.

Length, diameter of briquette, and weight were measured. Density of briquettes was calculated on the basis of dimension measurement and weighing. For comparison, 30 mm length reed and hemp particles were placed in the briquetting die without arranging (Fig. 2a), and they were pressed with maximum pressure of 158 MPa and 212 MPa.

The pressing force and displacement of the piston were measured using load cell and LVDT displacement transducer. The load cell had force resolution of 1% of full scale, and the LVDT transducer had displacement resolution of 0.3 µm. For data acquisition, 24-bit virtual instrument ADC24 and software Picolog were used. As a result of the experiment, force_displacement curves were obtained (Fig. 3).

The total briquetting energy *E* was represented by the area underneath the entire load_displacement curve (Fig. 2). The calculation of the energy *E* was done according to equation (1):



a – unarranged, b – arranged

Figure 2. **Arrangement of stalk material in a closed die before briquetting**

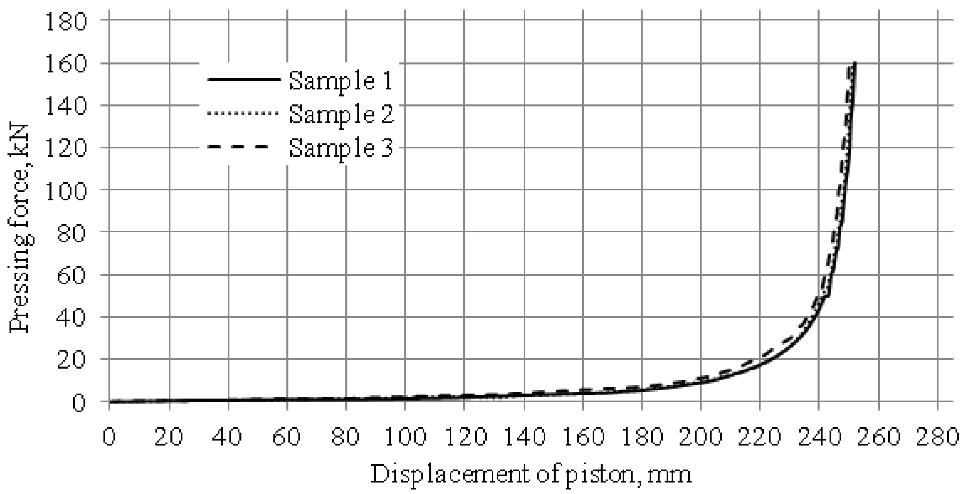


Figure 3. **Typical briquetting force_displacement curves of reed, particle length 150 mm.**

$$E = \left[\left(\frac{F_2 + F_1}{2} \right) \Delta z + \left(\frac{F_3 + F_2}{2} \right) \Delta z + ... + \left(\frac{F_n + F_{n-1}}{2} \right) \Delta z \right] , \quad (1)$$

where E is energy, kJ; F_1 – first data point, kN; F_2 – second data point, kN; F_n – nth data point, kN; Dz – displacement interval between data points.

Specific briquetting energy was calculated for every briquette by equation:

$$E_s = \frac{E}{m} , \quad (2)$$

where E_s is specific briquetting energy, kJ·kg^{-1}; m – mass of briquette, kg.

The destruction force was investigated for 11 samples of each composition. The obtained force_ deformation diagrams were analyzed for all kinds of the tested biomass, and the average crushing force was calculated.

The diameter of the briquettes produced in the experimental pressing device was 36 mm. The length of the briquettes varied according to the closed die filling capacity before pressing. It depends on the biomass stalk diameter, flattening, and density. The average length of the briquette varied from 34 to 85 mm.

To compare the durability of different length briquettes, the specific splitting force was calculated:

$$F_s = \frac{F}{L} , \quad (3)$$

where F_s – specific splitting force, N·m^{-1}; F – splitting force, N; L – length of briquette, mm.

Compression tests were carried out on GUNT testing equipment. GUNT 20 materials testing machine with force resolution 1% and displacement resolution 10 µm and the maximal force for testing is 20 kN.

Results and discussion

In previous densification experiments of chopped straw, common reed stalk material particles and compositions with additives it was stated that compositions of straw particles from two fineness groups (2 – 3 mm and < 0.5 mm) compacted with pressure 230 MPa, have density > 1.0 g·cm^{-3}, if fineness proportion (amount of particles < 0.5) exceeds 25%. Density of 1.0 g·cm^{-3} has been obtained in densification of the straw and reed stalk material particle compositions with peat, if peat proportion exceeds 20%.

Fine communition of stalk material significantly increases energy of grinding. It has been stated that increasing of particle length from 1 to 100 mm decreases the specific cutting energy up to 40 times. Roughly shredded straw or reed material does not provide the necessary density and durability of briquettes, if material is unarranged in the closed die before cold briquetting.

To increase density and strength of briquettes it is necessary to maximize the bonding surface area between the particles. Suitable arrangement of the straw and reed particles in the briquetting die allows changing deformation directions of particles. The stalk material curves and adhesion between particles increases (D. Ancans, et al., 2011).

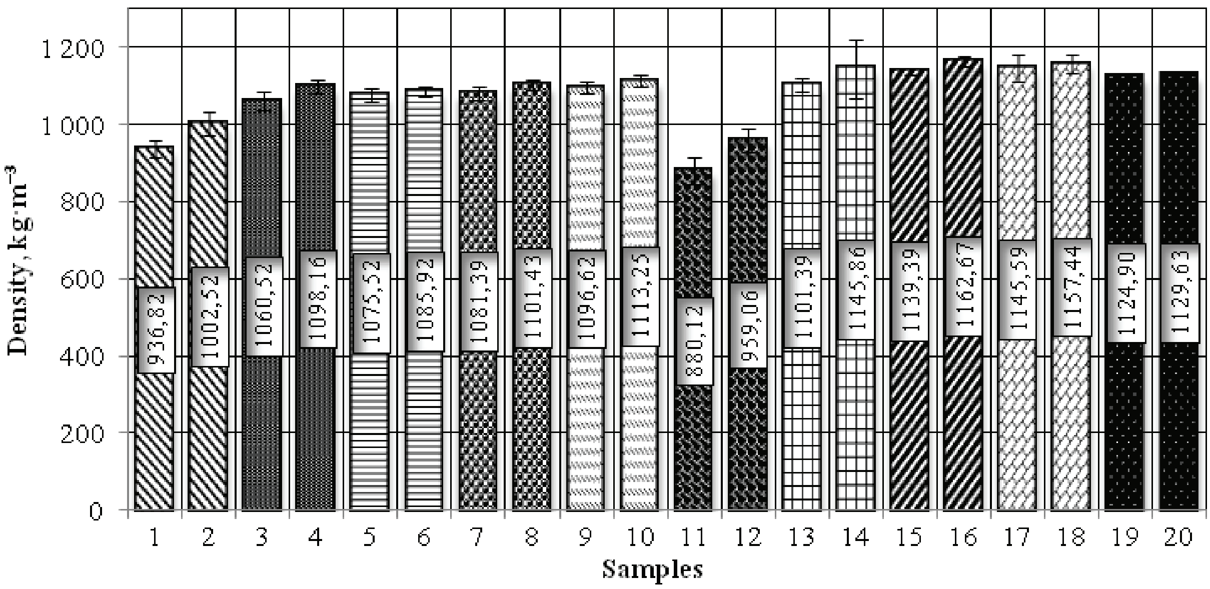
Results of the investigation of the briquettes density dependence on arranged particle size are presented in Fig. 4.

Density of arranged reed briquettes of the diameter of 36 mm varied between 1060 kg·m^{-3} (length of particles 60 mm) and 1113 kg·m^{-3} (300 mm).

Density of hemp stalk briquettes was 1162 kg·m^{-3} for particle length of 100 mm. Increase in the hemp particle length to 300 mm slightly decreased the density of briquettes. Results of the experiments showed that density of the briquettes recommended in the standards (1 g·cm^{-3}) was obtained for all lengths of arranged particles.

Decreasing of the briquetting pressure decreased the briquetting energy (Fig. 5). The maximum specific briquetting energy, 67.4 kJ·kg^{-1}, was obtained using the hemp stems with the particle length of 150 mm, briquette diameter of 36 mm, and the briquetting pressure of 212 MPa (specification in Fig. 5 – H150; 212 MPa). These briquettes showed the maximum density – 1157 kg m^{-3} (Fig. 4). The specific briquetting energy of the reed particles varied from 44.8 kJ·kg^{-1} to 59.3 kJ·kg^{-1}, but of hemp stalk particles – from 58.9 kJ·kg^{-1} to 67.4 kJ·kg^{-1}. Increasing of the length of reed particles from 30 to 300 mm increased the specific energy of briquetting 1.23 times. Increasing of the length of the hemp particles decreases the specific energy of briquetting.

Increasing of the pressing force increased the specific splitting force of all briquettes (Fig. 6). The specific splitting force of the hemp stalk briquettes was significantly by 20 to 50% greater than that of the reed particle briquettes.



1 Reed, 30 mm; 158 MPa
2 Reed, 30 mm; 212 MPa
3 Reed, 60 mm; 158 MPa
4 Reed, 60 mm; 212 MPa
5 Reed, 100 mm; 212 MPa
6 Reed, 100 mm; 212 MPa
7 Reed, 150 mm; 158 MPa
8 Reed, 150 mm; 212 MPa
9 Reed, 300 mm; 158 MPa
10 Reed, 300 mm; 212 MPa
11 Hemp stalks, 30 mm; 158MPa
12 Hemp stalks, 30 mm; 212 MPa
13 Hemp stalks, 60 mm; 158 MPa
14 Hemp stalks, 60 mm; 212 MPa
15 Hemp stalks, 100 mm; 158 MPa
16 Hemp stalks, 100 mm; 212 MPa
17 Hemp stalks, 150 mm; 158MPa
18 Hemp stalks, 150 mm; 212 MPa
19 Hemp stalks, 300 mm; 158MPa
20 Hemp stalks, 300 mm; 212 MPa

Figure 4. **Briquette density dependence on the length of particles**

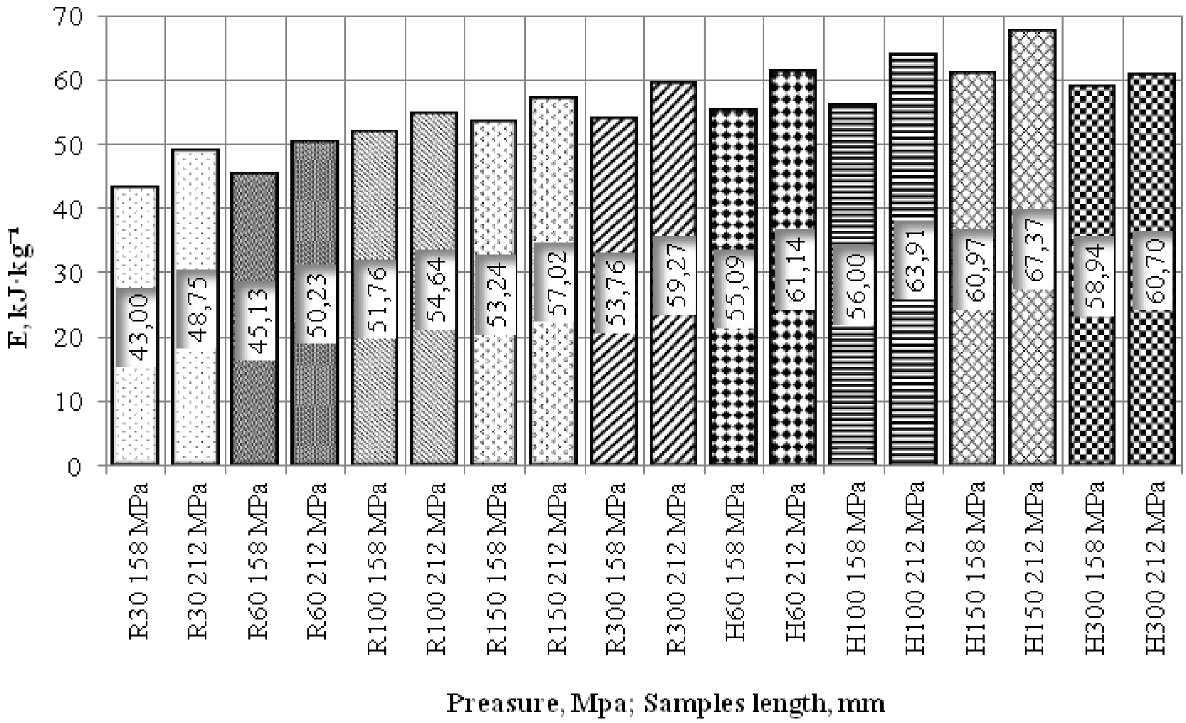


Figure 5. **Specific briquetting energy of briquettes**

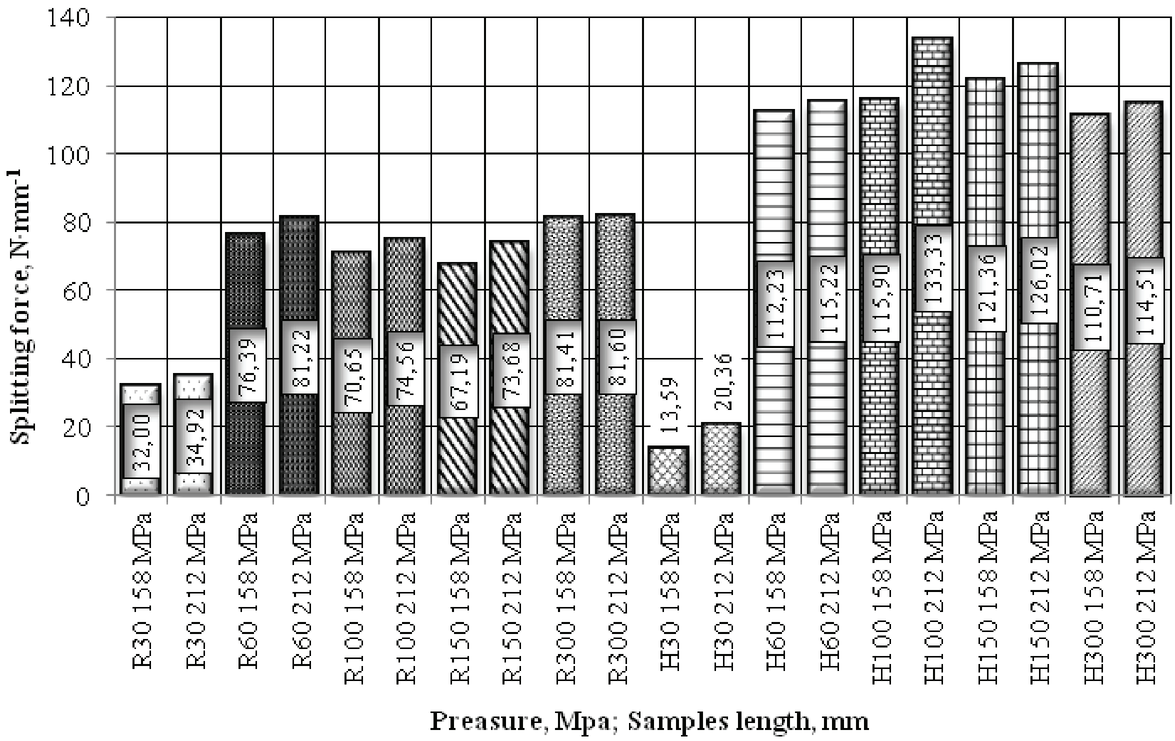


Figure 6. **Specific splitting force of briquettes**

For comparison industrially produced wood and unarranged reed briquettes were tested using the same method. Specific splitting force for industrially produced wood briquettes reached 38 $N \cdot mm^{-1}$, and this value can be taken as a base for comparison of experimentally made briquettes.

Dependence of the splitting force on the density of briquettes was evaluated from the

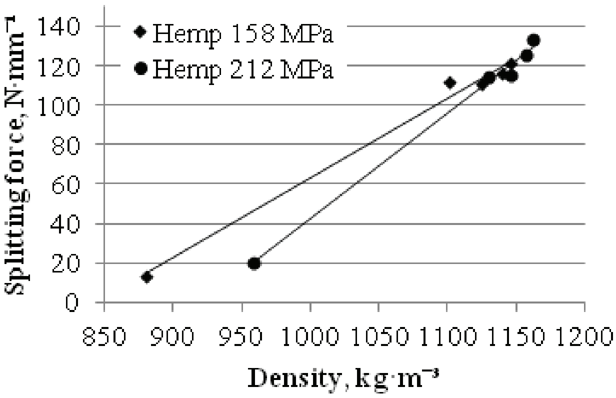


Figure 7. **Splitting force dependence on the hemp briquette density**

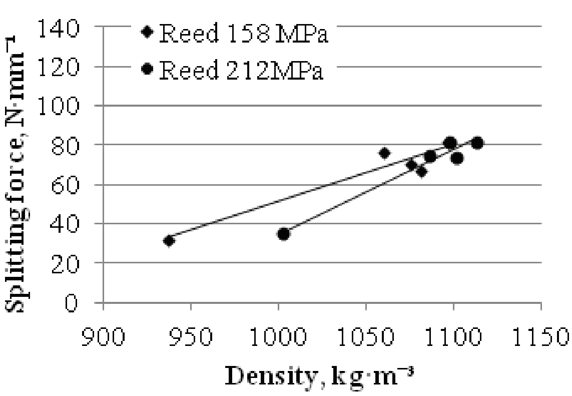


Figure 8. **Splitting force dependence on the reed briquette density**

results of experiments. Increasing of the density of briquettes increases durability of the briquettes for both tested biomass materials – reed and hemp (Figs. 7 and 8).

Conclusions

The density of the arranged reed and hemp stalk particles exceeded the recommended in the standards (1000 kg·m^{-3}) and reached the value of 1185 kg·m^{-3} for the arranged hemp stalk particles with the length of 150 mm and the briquetting pressure of 212 MPa.

The specific briquetting energy of coarsely chopped arranged reed and hemp stalk particles varied from 51.61 kJ·kg^{-1} to 67.23 kJ·kg^{-1}. For comparison, the finely chopped reed particle briquetting energy gave the maximum specific energy – 40 kJ·kg^{-1}.

The specific splitting force of the hemp stalk briquettes was 20 to 50% greater than the specific splitting force of the reed briquettes and reached the value of 133.33 N·mm^{-1}. It considerably exceeds the specific splitting force of the industrially produced wood briquettes – 38 N·mm^{-1}.

Arranged structure of biomass particles in briquetting die is recommended for significant increasing durability of stalk material briquettes.

New briquetting equipment is necessary to design for biomass particle arranging before pressing.

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