MECHANICAL PROPERTIES OF ENERGY CROPS

Aivars Kakitis, Imants Nulle, Dainis Ancans
Latvia University of Agriculture
aivars.kakitis@llu.lv; imants.nulle@llu.lv; dainis.ancans@llu.lv

Abstract. The article presents the investigation of 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. The investigation of the compressive properties of hemp (*Cannabis sativa* L.) stalk was carried out in the Laboratory of Mechanics of the Latvia University of Agriculture. Three hemp varieties, Bialobrezskie, Futura 75, Santhica 27, were used in the compression experiment. Depending on the hemp variety the axial compressive strength varies from 19.5 MPa to 32.1 MPa, but the lateral compressive strength varies from 1.32 MPa to 1.55 MPa. The calculated energy consumption for hemp cutting to sizes less than 7 mm was >15 $kJ \cdot kg^{-1}$ whereas for the size 50 mm it was just 2 $kJ \cdot kg^{-1}$. The density of the arranged reed and hemp stalk particles increases recommended in standards 1000 $kg \cdot m^{-3}$ and reaches the value 1185 $kg \cdot m^{-3}$ for the arranged hemp stalk particles with the length 150mm and briquetting pressure 212 MPa. The specific briquetting energy of coarse chopped arranged reed and hemp stalk particles varies from 51.61 $kJ \cdot kg^{-1}$ to 67.23 $kJ \cdot kg^{-1}$. In comparison the fine chopped reed particle briquetting energy gives the maximum specific energy 40 $kJ \cdot kg^{-1}$. The splitting force of the hemp stalk briquettes reaches 122.37 $N \cdot mm^{-1}$.

Keywords: biomass, hemp, biomass briquettes, briquetting energy, strength.

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. 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 from a 1 hectare plantation. It is estimated that cultivation of 1 ha of hemp absorbs about 2.5 tons of CO_2, which contributes significantly to the lessening of the greenhouse effect [1]. Hemp with its rich leafage suppresses weeds, and leaves left on the soil after harvesting, improve the soil structure [2].

In 2009 in Latvia about 200 ha are planted with hemp. To successfully develop the industry, the need to sow hemp is at least 1 000 ha [3]. The Latvian association of industrial hemp plans to reach this number in 2011. The Latvia University of Agriculture provides growing experiments with two varieties: variety Bialobrezskie for fibre production and local hemp Purini for seed, which has been grown in Latvia for 200 years [4].

The goal of the investigation is to establish the compressive properties of hemp stems, energy of briquetting and durability of briquettes made in cold briquetting process. Compression strength tests were carried out to obtain the strength of hemp stalks in axial and lateral directions. The obtained maximal stress values further should be used for modelling of the briquetting process.

The other experiment was carried out to obtain the necessary density and durability of hemp briquettes of larger biomass particles by arranging them. The orientation of stalks had to promote binding by the pressing operation. It is generally agreed that biomass material of 6-8 mm size with 10-20 % powdery component (<4 mesh) gives the best results [5]. But the calculated energy consumption for hemp cutting to the mentioned size was >15 $kJ \cdot kg^{-1}$ whereas for the size 50 mm it was just 2 $kJ \cdot kg^{-1}$ (data from no published investigations of our colleagues Kronbergs E., Kronbergs A., Siraks E. – 2011), therefore, from the position of cutting energy efficiency the large particles (stems) of hemp are recommendable for briquetting.

Briquetting energy is important to reduce the total energy demand for industrial production of briquettes. Therefore the briquetting energy of the arranged reed and hemp stalk particles with different length and different briquetting pressures was experimentally stated.

Materials and methods

Compressive behaviour of stalk biomass is important for the design of biomass processing machines, shredders, briquetting press, etc. Expanding of hemp production in the world and Latvia leads to increasing of hemp stalk usage for energy purposes. The investigation of compressive properties of hemp (*Cannabis sativa* L.) stalk was carried out in the Laboratory of Mechanics of the Latvia University of Agriculture. Three hemp varieties, Bialobrezskie, Futura 75, Santhica 27, were used in the compression experiment. The air-dried hemp had the average moisture content approximately 10 % at the time of the compression tests. The stems were cut into short 20 mm specimens. As the hemp stem is hollow, special attention was paid to ensure smooth cutting without any breakage of the hollow stem wall. Because of the small size of the specimen, buckling of specimen under compression was not expected.

The compression tests were performed using universal testing equipment Zwick for the lateral compression test, and GUNT for the axial compression test. Zwick materials testing machine TC-FR2.5TN.D09 has the force resolution 0.4 %, displacement resolution 0.1 µm and the maximal testing force 2.5 kN.

GUNT 20 materials testing machine has the force resolution 1 %, displacement resolution 10 µm and the maximal testing force 20 kN.

The hemp stem inner and outer diameters were measured using digital microscope Keyence VHX-100K with resolution 1 µm.

During the compressive test, a specimen was placed on the sample holder with the desired orientation (either axial or lateral) and compressed by the compression rod at constant speed. At a certain point the specimens broke, mainly because of the stem wall being collapsing. The load-displacement curves were obtained by special software of the testing machines. Further the obtained data were imported in *Excel* datasheets and compressive stress diagrams were calculated (Fig. 1). The maximum compressive load was defined as the peak of the load-displacement curve.

Treating the hollow hemp stem as a tube the maximum stress was determined using the following equations:

- for axial compression

$$\sigma_{\max} = \frac{4 \cdot F_{\max}}{\pi \cdot \left(D^2 - d^2\right)} \tag{1}$$

- for lateral compression

$$\sigma_{\max} = \frac{F_{\max}}{l \cdot \left(D - d\right)}, \tag{2}$$

where $\sigma_{\max}$ – maximum compressive stress, MPa;
$F_{\max}$ – maximum load, N;
D, d – outer and inner diameter of stem, mm;
L – length of specimen, mm.

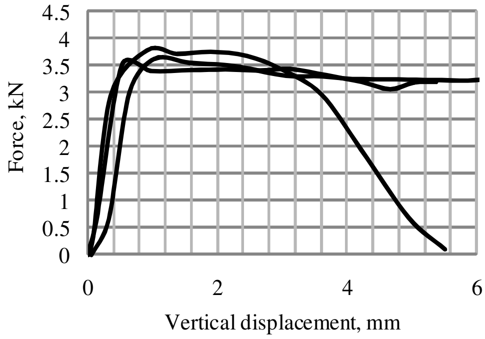

Fig. 1. **Typical compressive load-displacement curves of hemp stem**

Briquettes of reed and hemp stalks were tested experimentally. The length of the reed stalks was 30, 60, 150 and 300 mm and of the hemp stalks – 150 and 300 mm. The experiments were carried out with arranged reed and hemp stalks.

Stalk material particles with certain length were arranged in a closed die as it is described in [6]. The arranged particles were located in the direction of longitudinal axe of the die. The displacement between the ends of the particles in different layers was approximately from 5 to 15 mm. The particles were slightly compacted in the arranging process to obtain the same mass of material for every rerun. After arranging the particles were compacted by the hydraulic press with the maximum pressure 158 MPa and 212 MPa. The diameter of the briquettes was 36 mm. The length, diameter of briquette and weight were measured and the density of the briquettes was calculated. The pressing force and displacement of the piston were measured using load cell and LVDT displacement transducer. For data acquisition virtual instrument ADC 212 and software Picolog were used.

The total briquetting energy *E* was represented by the area underneath the entire load-displacement curve, Fig. 2. The calculation of the energy *E* is done according to equation (3):

$$E=\left[\left(\frac{F_2+F_1}{2}\right)\Delta z+\left(\frac{F_3+F_2}{2}\right)\Delta z+\ldots+\left(\frac{F_n+F_{n-1}}{2}\right)\Delta z\right], \tag{3}$$

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

Specific briquetting energy was calculated for every briquette by equation:

$$E_s=\frac{E}{m}, \tag{4}$$

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

The mechanical strength of the briquettes is characterized by the force necessary for their destruction [7; 8]. The briquette of circular cross section was placed on the support plate of the testing machine and the compression force *F* was applied to the briquette in the direction perpendicular to the briquetting direction as shown in Fig. 3. This force is gradually increased until the briquette disintegration and splitting.

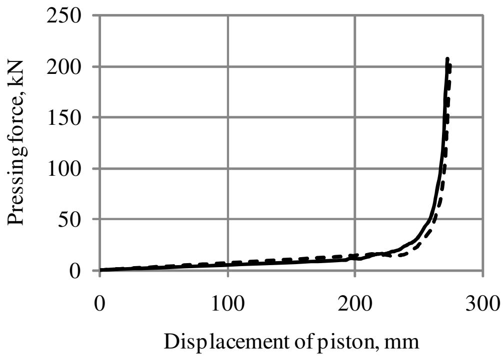

Fig. 2. **Typical briquetting force-displacement curves of hemp stem, particle length 150 mm**

The destruction force intensity was investigated for 11 samples of each composition. The obtained force-deformation diagrams (Fig. 4) 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 varies 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 diameter 36 mm varies from 34 to 85 mm.

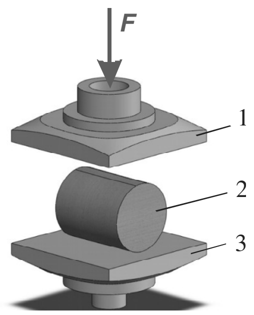

Fig. 3. **Scheme of compression:**
1 – compression plate; 2 – briquette;
3 – support plate

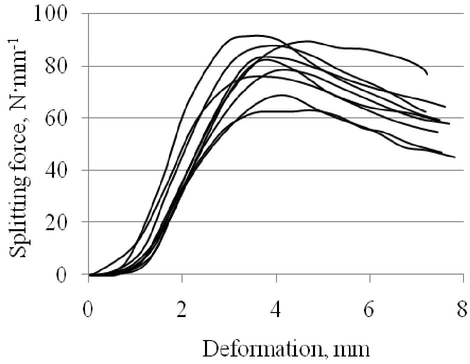

Fig. 4. **Force – deformation diagram for not flattened reed stalks, 300 mm length**

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

$$F_s = \frac{F}{L}, \tag{5}$$

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

Results and discussion

The scope of investigation was to find the compressive durability of hemp stems in axial and lateral compression. The obtained values of the compressive strength further will be used for theoretical modelling of the briquetting process of coarse chopped biomass particles. The mean values of axial stress of hemp varieties varied from 19.5 MPa (Bialobrzeskie) to 26.4 MPa (Santhica 27) (Fig. 5). The obtained value of axial stress is approximately the same as for the hemp variety Alyssa [9].

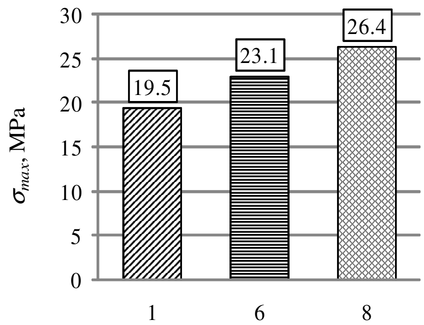

Fig. 5. **Axial compressive strength for different hemp varieties:** 1 – Bialobrzeskie; 6 – Futura 75; 8 - Santhica 27

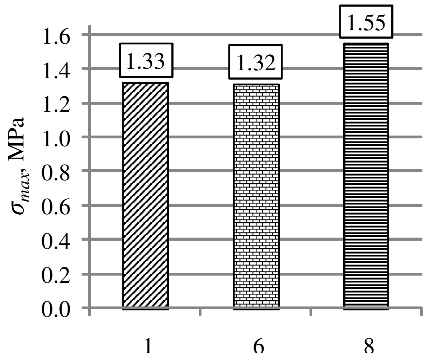

Fig. 6. **Lateral compressive strength for different hemp varieties:** 1 – Bialobrzeskie; 6 – Futura 75; 8 – Santhica 27

The values of lateral strength were much smaller than those for axial compression. The lowest lateral stress was shown by the hemp variety Futura 75, but the maximum of lateral strength was obtained for the variety Santhica 27.

In previous experiments it was stated that increasing of the 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 the material is unarranged in the closed die before cold briquetting. Arranging particles in the closed die parallel to the longitudinal axe of the die significantly increases the density and durability of briquettes.

The experiments were carried out in a closed die with two briquetting pressures – 158 MPa and 212 MPa. The obtained density of the briquettes increases recommended in standards 1000 kg·m^{-3}

(Fig. 7). The briquetting pressure slightly affects the density of the briquettes - increasing of the briquetting pressure increases the density of briquettes. The maximum density of the briquettes was stated for hemp stalk with particle length 150 mm (Fig. 7).

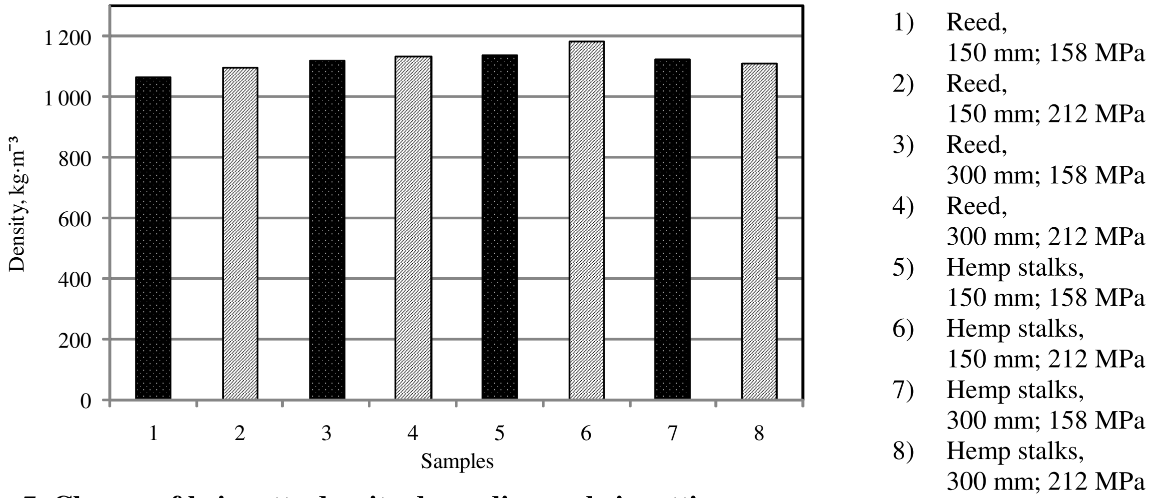

Fig. 7. **Change of briquette density depending on briquetting pressure and particle length for reed and hemp stalks**

Increasing of the particle length arranged in the briquetting cylinder changes the briquetting energy. To establish the dependence of the briquetting energy on the briquetting parameters experimentally the specific briquetting energy for reed and hemp stalk particles was stated (Fig. 8).

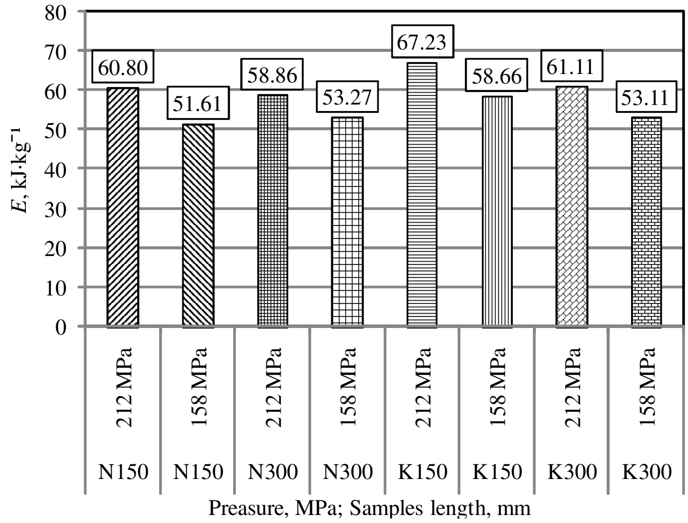

Fig. 8. **Briquetting energy of arranged reed and hemp stalk particles, N – reed, K – hemp**

Decreasing of the briquetting pressure decreases the briquetting energy. The maximum specific briquetting energy 67.23 $kJ \cdot kg^{-1}$ was shown by the hemp stems with the particle length 150 mm and the briquetting pressure 212 MPa. These briquettes showed the maximum density 1185 $kg \cdot m^{-3}$. The specific briquetting energy of the reed particles varies from 51.61 $kJ \cdot kg^{-1}$ to 60.80 $kJ \cdot kg^{-1}$, but hemp stalk particles showed the specific briquetting energy from 53.11 $kJ \cdot kg^{-1}$ to 67.23 $kJ \cdot kg^{-1}$.

The splitting force for briquettes with the diameter 36 mm was stated for different particle length of reed and hemp stalks with two briquetting pressures (Fig. 9). Increasing of the pressing force increases the specific splitting force of all briquettes. The splitting force of the hemp stalk briquettes is significantly greater then the specific splitting force of the reed particle briquettes. The specific splitting force of the hemp stalk briquettes is approximately from 20 % to 50 % greater than the specific splitting force of the reed briquettes. For comparison, industrially produced wood and pure peat briquettes were tested using the same method. The specific splitting force for the wood briquettes reaches 38 $N \cdot mm^{-1}$ and this value can be taken as a base for comparison of the experimentally made briquettes. The pure peat briquettes showed the splitting force 55 $N \cdot mm^{-1}$.

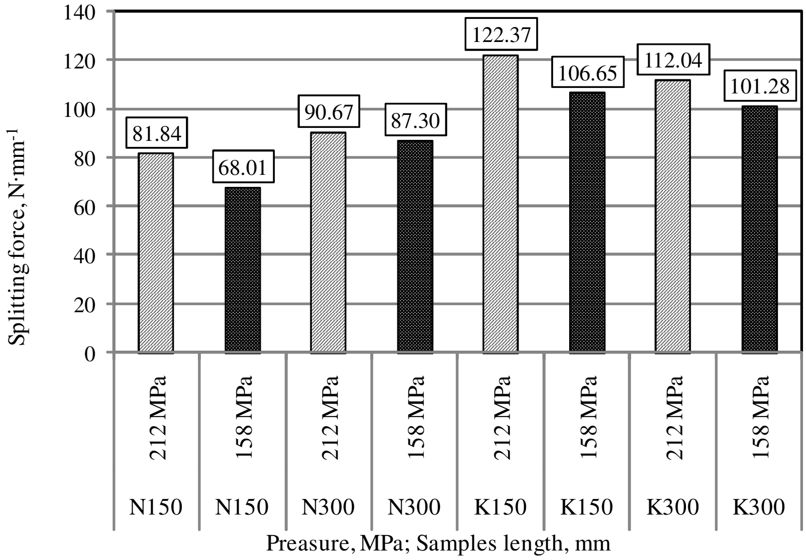

Fig. 9. **Specific splitting force of reed and hemp stalk particles, N – reed, K – hemp**

Conclusions

1. Depending on the hemp variety the axial compressive strength varies from 19.5 MPa to 26.4 MPa, but the lateral compressive strength varies from 1.32 MPa to 1.55 MPa.
2. The density of the arranged reed and hemp stalk particles increases the recommended in standards 1000 $kg \cdot m^{-3}$ and reaches the value 1185 $kg \cdot m^{-3}$ for the arranged hemp stalk particles with the length 150 mm and the briquetting pressure 212 MPa.
3. The specific briquetting energy of coarse chopped arranged reed and hemp stalk particles varies from 51.61 $kJ \cdot kg^{-1}$ to 67.23 $kJ \cdot kg^{-1}$. In comparison, the fine chopped reed particle briquetting energy gave the maximum specific energy 40 $kJ \cdot kg^{-1}$.
4. The specific splitting force of the hemp stalk briquettes is approximately from 20 % to 50 % greater than the specific splitting force of the reed briquettes and it reaches the value 122.37 $N \cdot mm^{-1}$. It considerably exceeds the specific splitting force of the industrially produced wood briquettes – 38 $N \cdot mm^{-1}$.

References

1. Mankowski J., Kolodziej J. Increasing Heat of Combustion of Briquettes Made of Hemp Shives [online]: [viewed 2011.01.20.]. Available at: http://www.saskflax.com/documents/fb_papers/67_Kolodziej.pdf
2. Poiša L., Adamovics A., Jankauskiene Z., Gruzdeviene E. Industrial hemp as a biomass crop [online]: Innovation and technology transfer [online] [20.01.2011]. Available at: http://www.ramiran.net/ramiran2010/docs/Ramiran2010_0155_final.pdf
3. Ulme A., Strazds G., Freivalde L. Latvian Renewable Ecological Raw Materials as Conducive Factors of Sustainable Spatial Development // Scientific Journal of RTU. 14. series., Ilgtspējīga telpiskā attīstība. - 1. vol. (2010), pp 62-66.
4. Poiša L., Adamovics A., Jankauskiene Z., Gruzdeviene E. Industrial hemp as a biomass crop [online]: Innovation and technology transfer [online] [20.01.2011]. Available at: http://www.ramiran.net/ramiran2010/docs/Ramiran2010_0155_final.pdf
5. Grover P.D., Michra S.K. Biomass briquetting: Technology and practices. Bangkok: FAO Regional Wood Energy Development Programme in Asia, 1996. 48 p.
6. Kakitis A., Nulle I., Ancans D. Stalk material orientation in biomass composite briquettes. In: Trends in Agricultural Engineering 2010. Proceedings of 4th International Conference held in Czech University of Life Sciences Prague, Faculty of Engineering. Prague, 2010, pp. 285-290.
7. Plištil D., Brožek M., Malaták J., Hutla P. (2005): Mechanical characteristics of standard fuel briquettes on biomass basic. Research in Agricultural Engineering, 51: pp. 66-72.
8. Brožek M., 2001. Briketování nekovového odpadu. In: Sborník z mezinárodní konference XIV Diamatech.Krakow, Univerzita Radom: pp. 84-87.
9. Compressive properties of Hemp (Cannabis sativa) stalks, Md. Majibur Rahman Khan, Ying Chen, Claude Lague, Hubert Landry, Qingjin Peng, Wen Zhong. (2010) Biosystems engineering 106, pp. 315-323.