CUTTING ENERGY ASSESSMENT OF HEMP FIBRES

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Abstract. In recent years, there has been a growing interest for the use of natural materials in composite applications, where cellulose materials are reinforced in cement matrix. The result is an environmentally friendly low density building material, which gives high tensile and compressive strength and good heat and sound insulation properties. To use hemp fibre for cement reinforcement, it should be cut in the definite length of particles. The shapes of the cutting knives and counter knives were designed. Specific cutting energy was used as the main evaluation parameter. The experimentally obtained values for the mentioned hemp varieties of cutting properties and energy consumption using different cutting methods would be used for fibre cutter mechanism design. The main hypothesis for the cutter design is that the cutting method has to be used with minimum of energy consumption by reducing frictional forces to a minimum. During pilot studies the specific cutting energy change depending on the cutting speed for dry hemp and flax fibres was determined. Dry hemp fibre specific cutting energy is 170.4 $J \cdot m \cdot kg^{-1}$ at the blade rotation speed 3.1 s^{-1}. Increasing the blade rotation speed to 4.6 s^{-1}, the specific cutting energy decreases to 152.8 $J \cdot m \cdot kg^{-1}$.

Keywords: hemp fibre, cutter, foam gypsum.

Introduction

Hemp fibres are used in a wide range of products, including fabrics and textiles, yarns and raw or processed spun fibres, paper, carpeting, home furnishings, construction and insulation materials, car parts, and composites. In recent years, there is a growing interest for the use of natural materials in composite applications, where cellulose materials are reinforced in gypsum matrix. A result is an environmentally friendly low density building material, which can show high tensile and compressive strength, good heat and sound insulation properties. Foam gypsum is produced using gyps cohesive substance, manufacture of which is environmentally friendly and energy efficient [1]. A new energy saving composite building material – foam gypsum with fibrous hemp reinforcement is investigated at the Latvia University of Agriculture [2]. The foam gypsum was produced using the dry mineralization method mixing water, gypsum, surface active stuff (SAS), and adding hemp reinforcement. The fibre particle length used for foam gypsum reinforcement varies between 5 and 20mm. To use hemp fibre for foam gypsum reinforcement, it should be cut in a definite length of particles. There are several methods used for fibre cutting: knife and bedplate, squeeze reels with knife slash through, rubber covered squeeze rolls with protruding knives etc. [3]. The result of the research was developed and the method with a rotating knife and soft material support was patented [4]. Fibre is compressed between the rotary knife blade and the soft material support. When compressive stresses exceed the fiber rupture stresses, the material is being cut [5]. Specific cutting energy was used as the main evaluation parameter. The experimentally obtained values of cutting properties and energy consumption using different cutting methods would be used for the fibre cutter mechanism design. The main hypothesis for the cutter design is that the cutting method has to be used with minimum of energy consumption by reducing frictional forces to a minimum.

Materials and methods

Cutting energy was determined using the developed prototype of the cutting equipment (Fig. 1). To determine the cutting energy it is necessary to define the blade rotation torque and rotational angle. For torque and angle registration in a dynamic regime the measuring equipment MOUNTZ with a smart torque sensor was used (Fig. 2).

The obtained data were stored on a computer as the torque changes depending on the blade rotation angle (Fig. 3). Cutting energy is characterized by the area under the curve in Figure 3. The energy consumption of each operating cycle was determined applying the graphical integration method using a computer program Excel. The given method has been described in the previous publications [6]. To obtain the amount of energy that was consumed in the direct material cutting, of the total energy the idle energy and shearbar friction energy losses were subtracted. Idling energy losses were determined by running the machine at idle. The idle friction torque of at least 20 cutting cycles was determined and the average value of one cycle calculated, which corresponds to one blade shaft revolution. Considering that the material deformation cycle consists of several phases - fixation, compression and cutting, more precise result was obtained by subtracting the friction torque average value from the drive torque sum in the cutting cycle.

Fig. 1. **Equipment for fibre cutting**

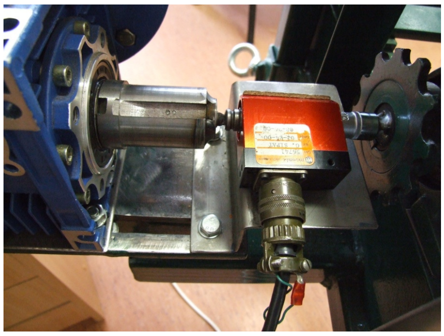


Fig. 2. **Torque sensor mounted on the equipment**

In order to assess the idle energy loss caused by shearbars, the energy that was consumed in overcoming friction between the blade and shearbar was calculated for each idle cycle (see Fig. 3). The loss of energy caused by shearbars was calculated using the graphical integration method of at least 20 idle cycles and the mean value was found.

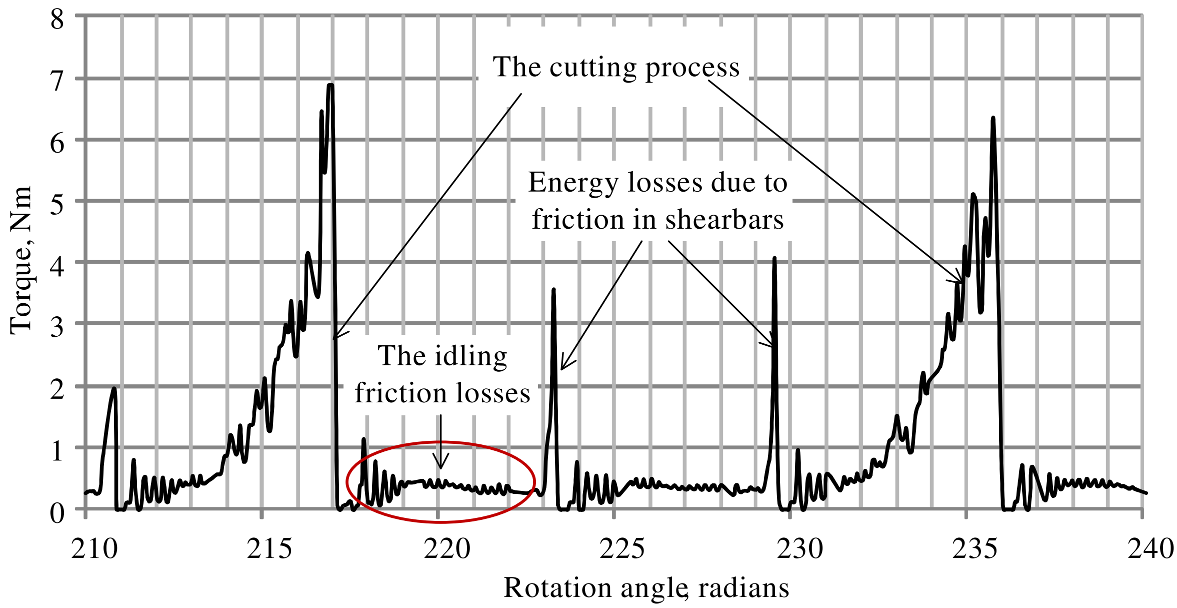


Fig. 3. **Torque variation in the cutting process**

To determine the cutting energy, the samples were prepared from flax and hemp fibres (Fig. 4 and 5). To determine the impact of various factors on the cutting process, the samples were wetted in water, and surface active substances used in the manufacture of foam gypsum. In order to assess the blade lateral surface friction effects, in some experiments, it was treated with the silicone oil.

For measurement data registration *MOUNTZ* torque gauge *Torque mate PTT* was used. The system provides an accuracy ± 0.5 % of full scale. The meter is equipped with a computer program that provides signal filtering and obtained calibration data registration in the computer. To measure the torque the smart sensor RTSX50i-A was used with a range of 565 cNm. The sensor non-linearity is ± 0.2 %. Interchangeability error does not exceed ± 0.3 %. Gauge bridge resistance is 350 Ω.

In order to determine the energy required for a certain amount of mass splitting, you need to know the specific shredding energy. Assuming that the total shredding energy E is proportional to the mass of the material and inversely proportional to the length of the comminuted particles, the total energy can be calculated using the formula:

$$E = \frac{E_s \cdot m}{\Delta l}, \tag{1}$$

where E_s – specific shredding energy, J·m·kg^{-1};
m – mass of the material, kg;
Δl – particle length, m.

Fig. 4. **Hemp and flax fibre test samples**

Fig. 5. **Hemp and flax stalks**

The specific cutting energy is calculated by the formula (1):

$$E_s = \frac{E_1 \cdot \Delta l}{m}, \tag{2}$$

where E_1 – one cut energy, J.

In order to evaluate the experimental samples the specific gravity or one meter mass μ of sample was determined:

$$\mu = \frac{m}{l}, \tag{3}$$

where m – mass of the sample, kg;
l – length of the sample, m.

Substituting in formula 2 the specific gravity of the sample, we obtain the expression of the specific cutting energy as follows:

$$E_s = \frac{E_{1av}}{\mu}, \tag{4}$$

where E_{1av} – average energy for one cut, J.

Results and discussion

Specific hemp fibre cutting energy was determined for air dry hemp fibres with various blade rotation speeds. Specific energy change depending on the blade speed is shown in Figure 6.

Increasing the angular velocity of the blade from 3.1 s^{-1} to 4.6 s^{-1} reduces the specific cutting energy by 12 %. Performing the regression analysis empirical relationship that describes the specific energy changes depending on the speed of rotation of the knife was established (equation 5):

$$E_s = e^{5.06 \cdot (\ln \omega)^{-0.011}}, \tag{5}$$

where ω – angular velocity of the blade, s^{-1}.

Increasing the angular velocity of the blade above 5 s^{-1} the specific cutting energy did not decrease significantly.

Hemp fibre wetting with water increases the specific shredding energy by 17.5 % to cut at the same speed (Fig. 7). The obtained experimental result confirms the previously developed cutting model, which explains the blade side friction dominant role in cutting energy development. In the previous experiments it was found that the wet fibre friction coefficient is significantly higher than the dry fibre friction coefficient [7]. The results obtained suggest that dry fibre cutting is cost-effective.

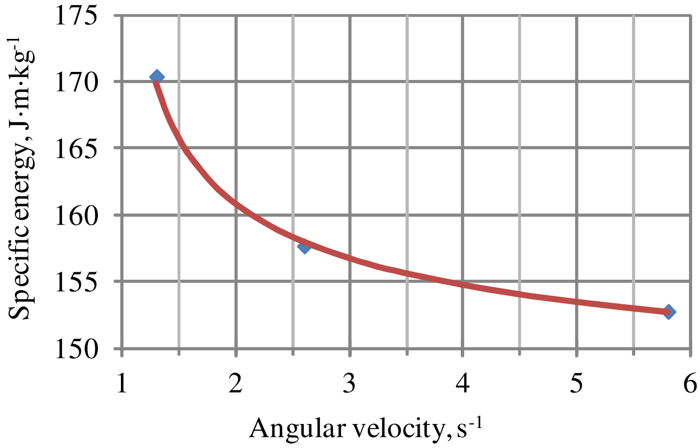
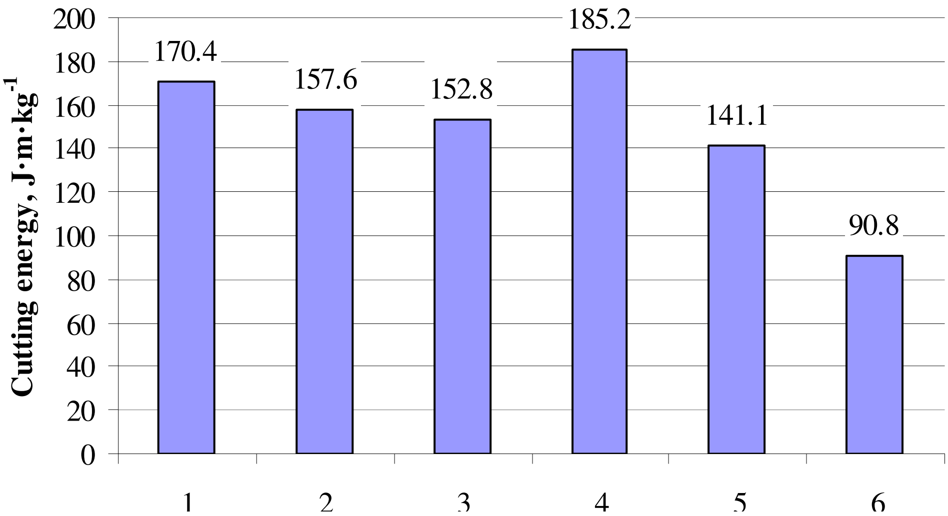


Fig. 6. **Hemp fibre specific cutting energy change depending on the angular velocity of the knife**



1	Dry rope, $\omega = 1.3$ s^{-1}	4	Wet rope, $\omega = 2.6$ s^{-1}
2	Dry rope, $\omega = 2.6$ s^{-1}	5	Rope soaked with SAS, $\omega =.6$ s^{-1}
3	Dry rope, $\omega = 5.8$ s^{-1}	6	Silicone oiled blade, $\omega = 2.6$ s^{-1}

Fig. 7. **Hemp fibre specific cutting energy**

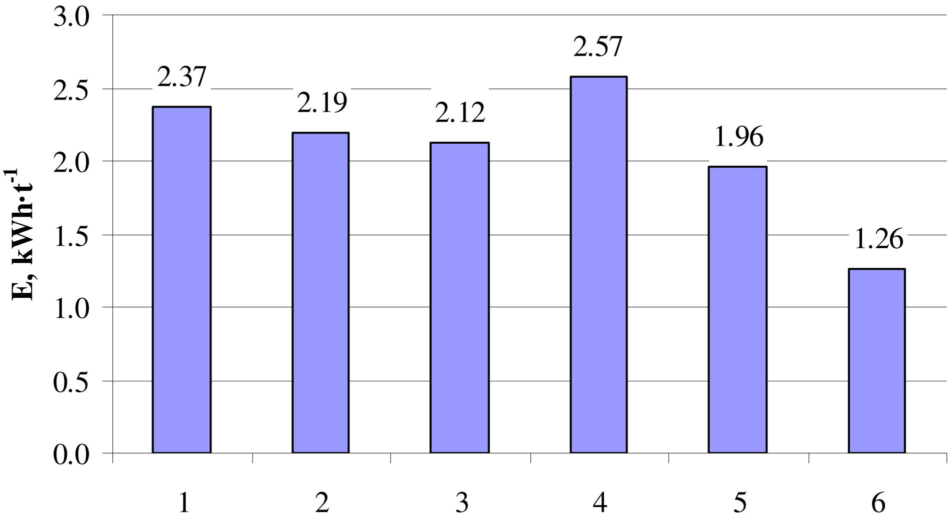
In order to produce foam-gypsum a surfactant is used, which promotes mass foaming. It means that fibre is moistened with a surfactant. To find the surfactant effect on fibre cutting, experiments were carried out with surface active substance soaked fibres. As a result, the substance lubricating effect on the cutting process was found. Surface active substance (SAS) promotes decreasing of the specific cutting energy by 10.5 % (see Fig. 7). We can conclude that fibre wetting with SAS before shredding is recommended.

To find the knife side friction impact on the cutting energy, experiments were made with silicone oil lubricated knife lateral surface. Silicone oil on the surface of metal forms a solid film, which significantly reduces the sliding friction force. The results showed that the specific cutting energy decreases 1.7x compared to dry fibre cutting (see Fig. 7). Comparing the results that were obtained at different cutting regimes, we concluded that in order to reduce the cutting energy blade lubrication with silicone oil or fibre wetting with surfactant (SAS) is recommended.

Total cutting energy required for 1 tonne of fibre shredding was calculated by the formula 1, assuming that the fibre is cut into 20 mm long particles (see Fig. 8). It can be seen that the cutting energy is directly proportional to the specific cutting energy. The cutting energy ranges from 1.26 kWh·t^{-1} (with silicone oil lubricated knife) to 2.57 kWh·t^{-1} (wet fibres).

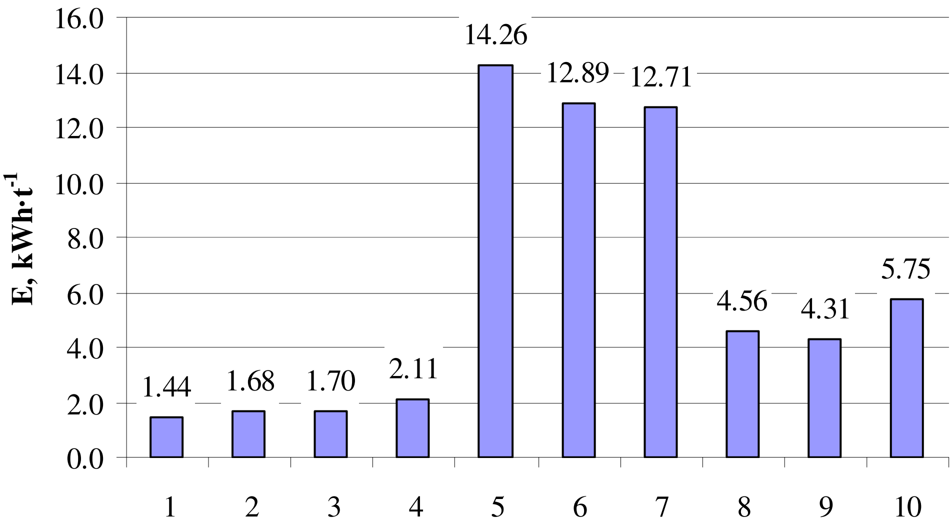
Hemp straw shredding energy is considerably larger than the hemp fibre shredding energy (Fig. 9). This is explained by much larger blade side friction compared to fibre cutting. The result of the experimental research confirms the results of the previously performed theoretical research [8].

Increasing the angular velocity of the blade, the cutting energy increases, but the stalk moisture does not significantly affect the cutting energy (Fig. 9).



1 Dry rope, ω = 1.3 s^{-1}
2 Dry rope, ω = 2.6 s^{-1}
3 Dry rope, ω = 5.8 s^{-1}
4 Wet rope, ω = 2.6 s^{-1}
5 Rope soaked with SAS, ω = 2.6 s^{-1}
6 Silicone oiled blade, ω = 2.6 s^{-1}

Fig. 8. **Cutting energy of 1 ton of hemp fibre splitting with a particle length of 20 mm**



1 Flax fibre, dry, ω = 2.3 s^{-1}
2 Flax fibre, dry, ω = 4.6 s^{-1}
3 Flax stalk, dry, ω = 4.6 s^{-1}
4 Flax stalk, wet, ω = 4.6 s^{-1}
5 Hemp stalk, dry, d = 6 mm, ω = 4.6 s^{-1}
6 Hemp stalk, dry, d = 6 mm, ω = 2.3 s^{-1}
7 Hemp stalk, wet, d = 6 mm, ω = 2.3 s^{-1}
8 Hemp stalk, dry, silicone oiled knife, d = 6 mm, ω = 4.6 s^{-1}
9 Hemp stalk, dry, silicone oiled knife, d = 6 mm, ω = 2.3 s^{-1}
10 Hemp stalk, dry, silicone oiled knife, d = 8 mm, ω = 2.3 s^{-1}

Fig. 9. **Shredding energy for 1 ton different fibre materials (Δl = 20mm)**

With silicone oil lubricated blade significantly reduces the shredding energy. Cutting energy of hemp straw with a diameter d = 6 mm decreases on average 3 times compared to dry blade cutting (Fig. 9).

The cutting energy is significantly affected by the hemp stalk diameter. Increasing the diameter of stalks from 6 mm to 8 mm, the cutting energy increases 1.3 times. (Fig. 9).

Experimentally also the energy of flax straw cutting was assessed. Diameter of flax stalks ranges from 2.5 mm to 3 mm. Average cutting energy for dry flax straw was 1.7 $kWh \cdot t^{-1}$, which is less than the hemp fibre cutting energy at the same mode. The cutting energy of moist flax straw increased by 24 % compared to the dry flax straw cutting energy. Flax fibre cutting energy is on average 1.44 $kWh \cdot t^{-1}$, which is significantly less than the hemp fibre cutting energy. Contrary to hemp fibres, increasing the cutting speed of flax fibres leads to the cutting energy increasing. The obtained results allow justify the main conditions of fibre material shredding technologies.

Conclusions

1. The specific cutting energy of dry hemp fibre is 170.4 $J \cdot m \cdot kg^{-1}$ (ω = 1.3 s^{-1}). Increasing the angular velocity of the knife, the specific cutting energy decreases and reaches 152.8 $J \cdot m \cdot kg^{-1}$ at $\omega = 4.6$ s^{-1}.
2. Fibre wetting with water increases the specific cutting energy by 17.5 %, while moistening with a surface active substance reduces the specific cutting energy by 10.5 % compared with the dry fibre cutting energy. A knife with silicone oil lubrication reduces the specific cutting energy 1.7 times.
3. The dry hemp fibre one tonne shredding energy (Δl=0.02 m) is in the range from 2.12 $kWh \cdot t^{-1}$ ($\omega = 4.6$ s^{-1}) to 2.37 $kWh \cdot t^{-1}$ ($\omega = 1.3$ s^{-1}).
4. The hemp straw shredding energy is much larger than the fibre shredding energy and reaches 14.26 $kWh \cdot t^{-1}$. A knife with silicone oil lubrication reduces the cutting energy on average 3 times. The hemp straw diameter substantially affects the cutting energy, increasing the straw diameter from 6 mm to 8 mm, the cutting energy increased 1.3 times, and it was in proportion with the increase of the diameter.
5. The flax straw and fibre cutting energy is significantly less than the hemp straw and fibre cutting energy, it was in the range of 1.44 $kWh \cdot t^{-1}$ to 2.11 $kWh \cdot t^{-1}$.

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