CUTTING ENERGY ASSESSMENT OF HEMP STRAW

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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 fiber and stems for cement reinforcement, it should be cut in the definite length of particles. The shapes of the cutting knives and counter knives were designed. The experimentally obtained values for the mentioned hemp varieties of cutting properties and energy consumption using different cutting methods would be used for hemp cutter mechanism design. As a result of studies new blade as Archimedes spiral form with a number of different sectors was designed and patented. During pilot studies cutting energy change depending on the cutting speed were determined. It was found great decreasing of the cutting energy of hemp stems cutting using new blade. Compared with the smooth blade, one cut energy of hemp stems decreases from 1.7 to 2.4 times depending on stalk diameter.

Keywords: hemp, cutter, cutting energy.

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 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 in 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's reinforcement. Fibre particle length used for foam gypsum reinforcement varies between 5 and 20mm. To use hemp stems of foam gypsum reinforcement, it should be cut in a definite length of particles. There are several methods used for biomass fibres and stalks 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 patented method with a rotating knife and soft material support which was patented [4]. Fiber or stalks are 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]. Cutting energy for one cut was used as the main evaluation parameter. 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. In previous studies it was found that hemp fiber cutting, advantageous to use a disc-shaped cutter with a smooth blade of Archimedes spiral form [6]. Performing hemp straw cutting, it was observed a significant increase in energy consumption, due to the large friction forces on the blade side surfaces. These conclusions were also confirmed by a prior study of the theoretical research of cutting process [7]. The study aims to find out the effectiveness of the developed cutting blade of hemp straw cutting process.

Materials and methods

The cutting blade designed as Archimedes spiral form with a number of different sectors and helix parameters k. Sector 1 created with saw-tooth teeth and ensures efficient cutting of stems woody parts. A smooth part of the blade (sector 2) cut away remaining part of the fiber with sliding cutting to the elastic shearbars. Sector 0 is designed for loading stems in the mechanism (Fig. 1). This cutting blade was developed and patented in LUA Institute of Mechanics [4]. Experiments were performed to determine the energy consumed during hemp straw cutting with the new blade (Fig. 2). Cutting energy was determined using the developed prototype of the cutting equipment. To determine cutting energy 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. 3). The obtained data were stored on a computer as a torque changes depending on the blade rotation angle (Fig. 4).

Cutting energy is characterized by the area under the curve in Figure 3. The energy consumption of each operating cycle was determined using graphical integration method using a computer program Excel. The given method has been described in the previous publications [8]. To obtain the amount of energy that was consumed in the direct material cutting, of the total energy was subtracted the idle energy and shearbars friction energy losses. Idling energy losses were determined by running the machine at idle. It was determined the idle friction torque of at least 20 cutting cycles and calculated the average value of one cycle which correspond to one blade shaft revolution.

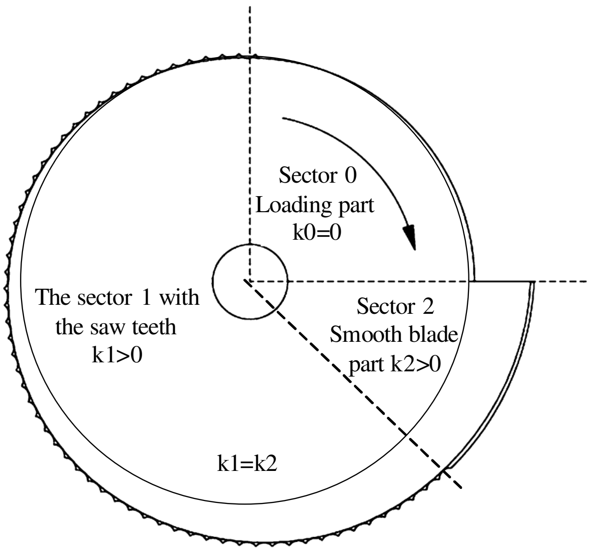

Fig. 1. **Design of the cutting blade**

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.

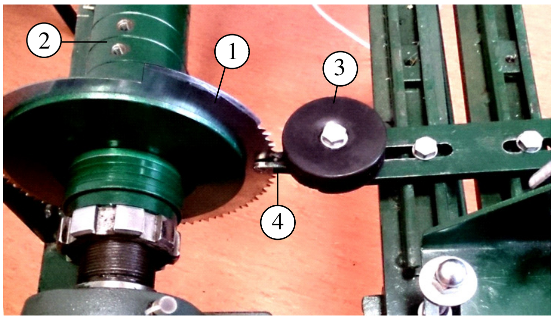

Fig. 2. **Equipment for stalk cutting:**
1 – blade, 2 – shaft, 3 – shearbar, 4 - support

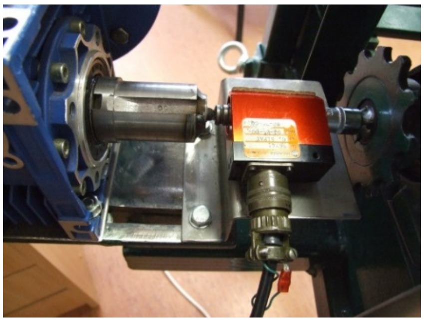

Fig. 3. **Torque sensor mounted on the equipment**

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 the each idle cycle (see Fig. 4). The loss of energy caused by shearbars was calculated using graphical integration method of at least 20 the idle cycles and the mean value was found.

To determine the cutting energy, hemp stalks samples were prepared. In order to compare the cutting energy values obtained in previous experiments, the samples of the same hemp variety were used. The hemp variety *Bialobrzeskie* stems with moisture content from 6 to 8 % were used for experiments. Hemp stalks were selected and grouped into size groups with diameters from 3 to

6.5 mm. It was selected stalks whose diameter variation along the length of not more than ± 0.25 mm. Cutting energy was determined for five different hemp stalks taking 6 to 8 cuts for each stalk.

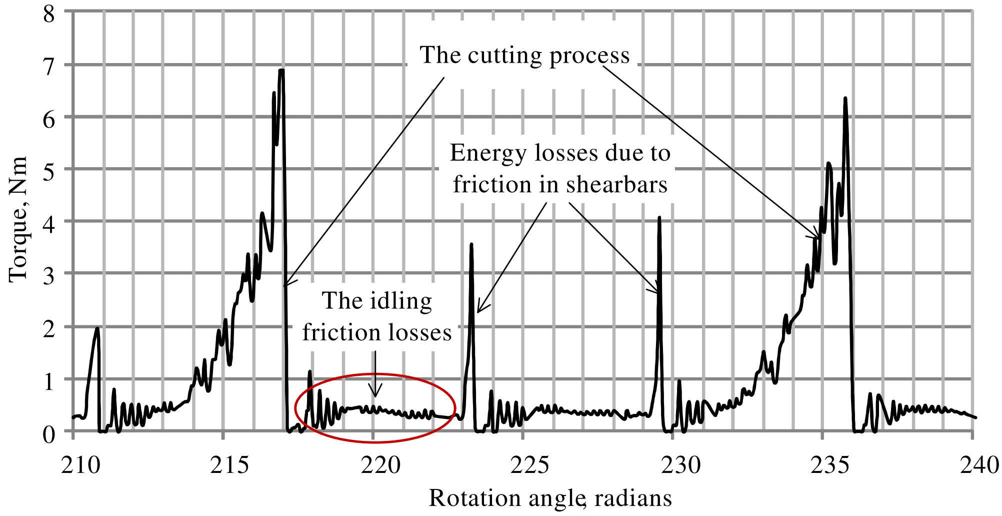

Fig. 4. **Torque variation in the cutting process**

For measurement data registration was used *MOUNTZ* torque gauge *Torque mate PTT*. 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 torque the smart sensor RTSX50i-A was used with a range of 565 cNm. Sensor's non-linearity is ± 0.2 %. Interchangeability error – does not exceed ± 0.3 %. Gauge bridge resistance is 350 Ω.

Results and discussion

The main task of the study was to compare the hemp straw cutting energy by cutting with a smooth blade and a toothed blade cutting. The blade shaft torque changes are shown in Fig. 4.

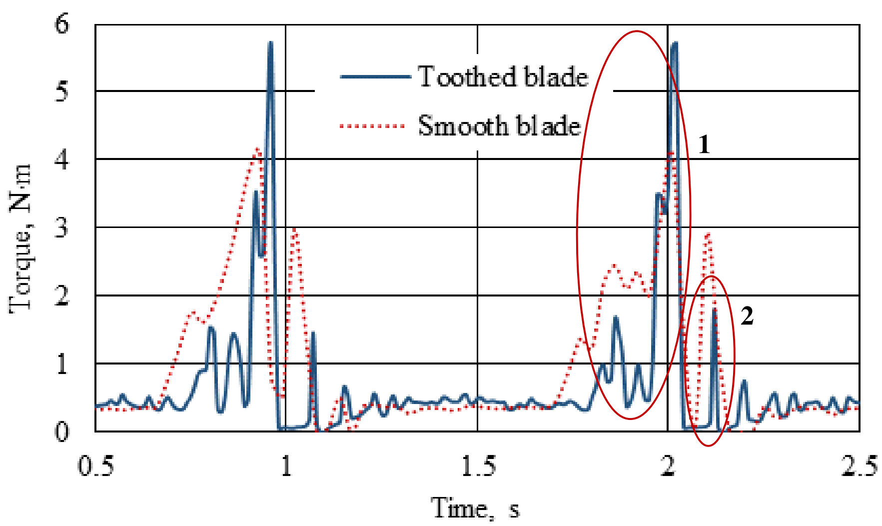

Fig. 5. **Torque change for hemp straw cutting process**

Analyzing the cutting process can be seen that it is divided into two parts: the cutting of a stems woody part (1, Fig.5) and the remaining fiber scission (2, Fig. 5). Comparing the torque change, in both cases, we see that with the smooth blade torque is growing rapidly and was maintained throughout the cutting time. This shows a frictional force significant influence on the cutting process [7]. Blade with saw teeth torque change is pulsing, so that there is a material division into chips and fiber breaking [9]. After the cutting of the woody part of stalk, smooth part of the blade with sliding cutting qualitatively cut the remaining hemp fiber (2, Fig. 5).

In order to assess the effectiveness of hemp straw cutting with designed cutters, the one cut energy was compared for both blades. Results of experiments showed that the stem cutting with a serrated blade consumes considerably less energy than cutting with a smooth blade (Fig. 6). Energy consumption of the straw with a diameter of 5 mm decreases on average 2.4 times, but for stalks with a diameter of 6 mm – 1.7 times. This means that for cutting of the fiber coating straw biomass is recommended to use cutting blades with saw teeth sector.

The cutting energy change depending on the rate of rotation of the knife was experimentally determined. The graph (Fig. 7.) shows that the increasing of knife rotation speed, cutting energy increases for the whole straw diameters.

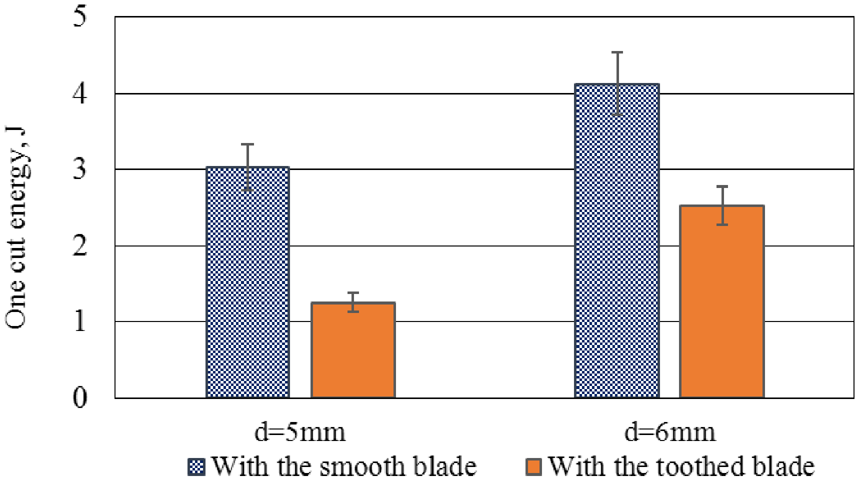

Fig. 6. **The energy consumed for different diameter stalk cutting**

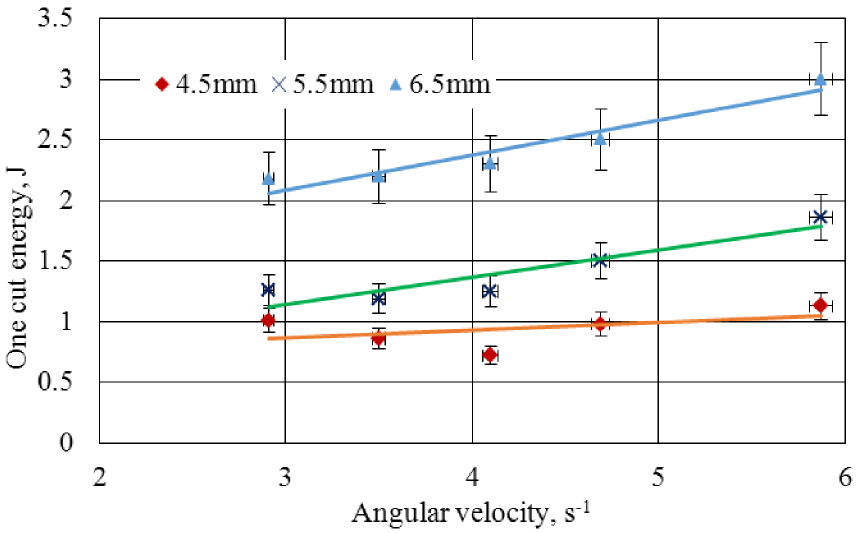

Fig. 7. **One cut energy depending on the angular velocity of blade**

For small stem diameters cutting energy increase is not significant and does not exceed the measurement errors. For larger diameters stalks knife rotation speed impact on the cutting energy increases significantly. Increasing of knife rotation speed of 2 times, cutting energy increases an average of 1.36 times for stalks with diameter 6.5 mm (Fig. 7).

Cutting energy change depending on the cross section of the stem for all blade rotation speeds displayed in Figure 8. One cut energy change depending on the stem cross section increases for all blade rotation speeds. The energy increase is proportional to the stalk-cut area as evidenced by the resulting linear regression equation with the coefficient of determination R^2 = 0.84. The resulting relationship is an empirical equation that describes the cutting energy changes of the hemp stalks with diameters from 4.5 to 6.5 mm. The obtained results allows to evaluate the cutting energy of hemp stalks with a these diameters to design the cutting equipment.

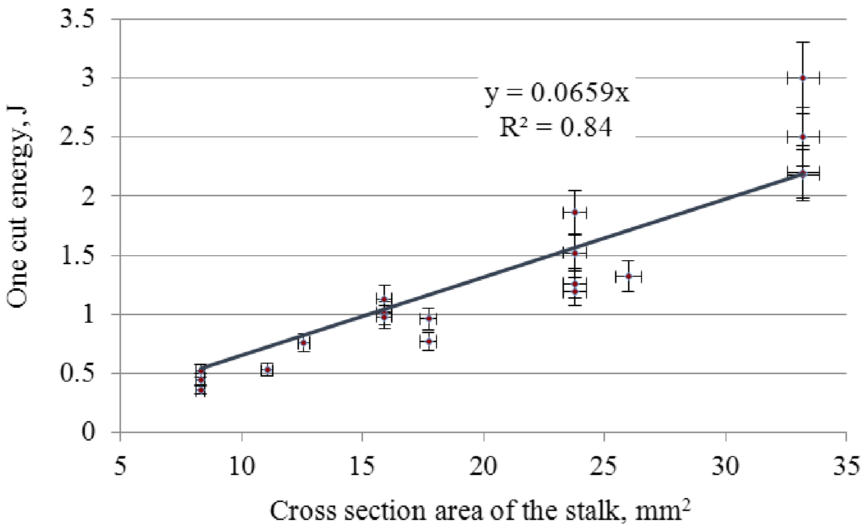

Fig. 8. **One cut energy depending on the stalk cross section**

Conclusion

1. The designed blade with a saw-tooth and smooth sectors reduces hemp straw cutting energy from 1.7 to 2.4 times, depending on the stem diameter.
2. Cutter with a smooth blade is recommended for hemp and flax fibre cutting, but saw-tooth blade for stalk material cutting, which is covered with fibre coating, for example – hemp stalks.
3. With the increase of stem cross section of 4 times, one cut energy increases an average of 4.2 times for stalks diameter range from 4.5 to 6.5 mm.
4. Increasing of knife rotation speed of 2 times, cutting energy increases an average of 1.36 times for stalks diameter 6.5 mm.

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