CUTTING PROPERTIES OF HEMP FIBRE

Aivars Kakitis, Uldis Berzins, Roberts Berzins, Raitis Brencis
Latvia University of Agriculture
aivars.kakitis@llu.lv

Abstract. In recent years, there is a growing interest for the use of natural materials in composite applications, where cellulose materials are reinforced in foam 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. Hemp fibres are natural fibres and their properties vary according to the plant growing regional climatic conditions, fertilizers, plant density, harvesting time and pre-treatment technological processes. To use hemp fibre for gypsum reinforcement, it should be cut in a definite length of particles. The cutting energy of six different hemp varieties was experimentally investigated. 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 the fibre cutter mechanism design. The experimentally obtained specific cutting energy of the six hemp varieties lies between 97.5 $J \cdot m \cdot kg^{-1}$ (*Ferimon*) and 70.83 $J \cdot m \cdot kg^{-1}$ (*Tygra*).

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, auto 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. Hemp fibres are natural fibres and their properties vary according to the plant growing regional climatic conditions, fertilizers, plant density, harvesting time and pre-treatment technological processes. To use hemp fibre of foam gypsum reinforcement, it should be cut in a definite length of particles. The cutting properties of six different hemp varieties were experimentally investigated. 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 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

The study was carried out in the Institute of Mechanics, Faculty of Engineering. Six hemp varieties were tested, produced in 2011. To obtain fibre, air dried hemp plants were manually processed using laboratory-scale equipment. Firstly, hemp plants were passed through a breaker to crash the stems. Then fibres were separated from the cores with a scotching machine consisting of a wooden blade and board. Finally, the fibre filaments with small core particles were obtained. The fibre filaments were twisted into spins with diameter approximately 10 mm and then used as the samples for cutting tests. The length and weight of an every sample was measured.

To determine the cutting energy changes depending on the sample one meter mass industrially manufactured hemp rope with a diameter of 10mm was used. The rope is made by twisting together three equal parts. In order to obtain three different cross-sectional samples, one of the twine was removed. The result was obtained in three tightly spun samples with 1 meter mass 47.25 $g \cdot m^{-1}$, 31.5 $g \cdot m^{-1}$ and 15.75 $g \cdot m^{-1}$. To determine the cutting energy changes depending on the stiffness of the twisted fibers, each sample was unraveled to form a free tow of fibers.

There are several methods used in cutting fibres: knife and bedplate, squeeze reels with knife slash through, rubber covered squeeze rolls with protruding knives etc. [3]. It has been proved that the lowest energy consumption of stalk shredding provides for shear cutting [4]. Primary experiments with hemp fibers using shear cutting method showed the observed fiber penetration between the knife and bedplate. It impairs the quality of fiber shredding.

The result of the research was developed and the fiber cutting method with a rotating knife and soft material support was patented, Fig. 1 [5]. Fiber 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 [6].

To determine the factors that affect the cutting energy, a theoretical model for cutting was worked out. According to Fig. 2 and Fig. 3 the force equilibrium can be found:

$$\overline{F} = \overline{R}_1 + \overline{R}_2 + \overline{N}, \tag{1}$$

where F – blade compression force;
R_1 and R_2 – reactions applied to blade from material;
N – cutting force acting to the knife-edge.

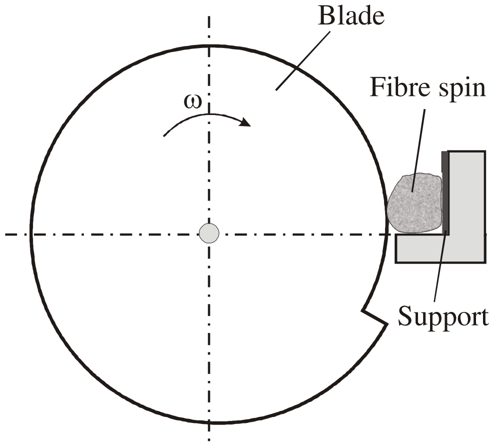

Fig. 1. **Fibre cutter with rotating knife**

Suppose the blade is symmetrical, than $R_1 = R_2$. Reactions can be calculated according to equation (2):

$$R_1 = \sigma_b \cdot b \cdot l = \sigma_b \cdot \frac{h}{\cos\alpha} \cdot l, \tag{2}$$

where σ_b – rupture stress of the material.

Cutting force acting to the knife-edge can be calculated according to equation (3):

$$N = \sigma_b \cdot 2r \cdot l, \tag{3}$$

where r – knife-edge radius;
l – thickness of the material to be cut.

Theoretical calculations assume the material in a rectangular cross-sectional area, Fig 2. According to the force vector a diagram in Fig. 3 follows:

$$F = R_1 \sin\alpha + R_2 \sin\alpha + N. \tag{4}$$

Then

$$F = 2\sigma_b \cdot \frac{h}{\cos\alpha} \cdot l \cdot \sin\alpha + \sigma_b \cdot 2r \cdot l = 2\sigma_b \cdot l\left(h \cdot tg\alpha + r\right). \tag{5}$$

The cutting force N and the reaction forces R_1 and R_2 cause the friction force F_f and blade side friction forces F_{fs}, Fig. 2. Friction forces can be calculated according to equations (6) and (7):

$$F_f = N \cdot f = \sigma_b \cdot 2r \cdot l \cdot f \,, \tag{6}$$

$$F_{fs} = R_1 \cdot f = \sigma_b \cdot \frac{h}{\cos\alpha} \cdot l \cdot f \,. \tag{7}$$

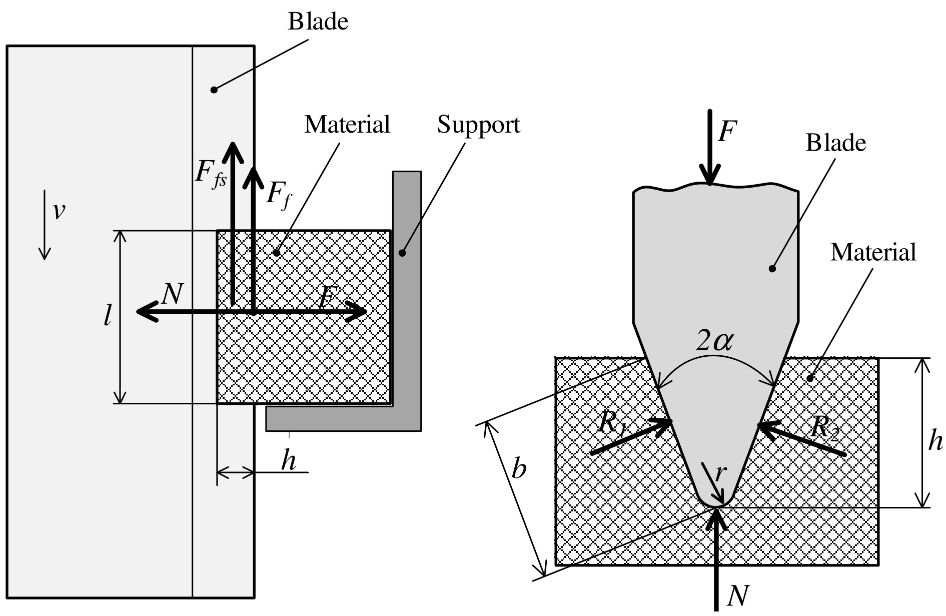

Fig. 2. **Interaction model between fibre and cutter**

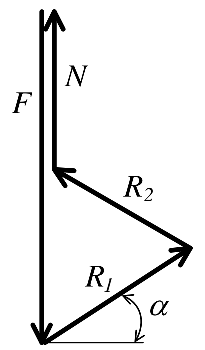

Fig. 3. **Force vector diagram**

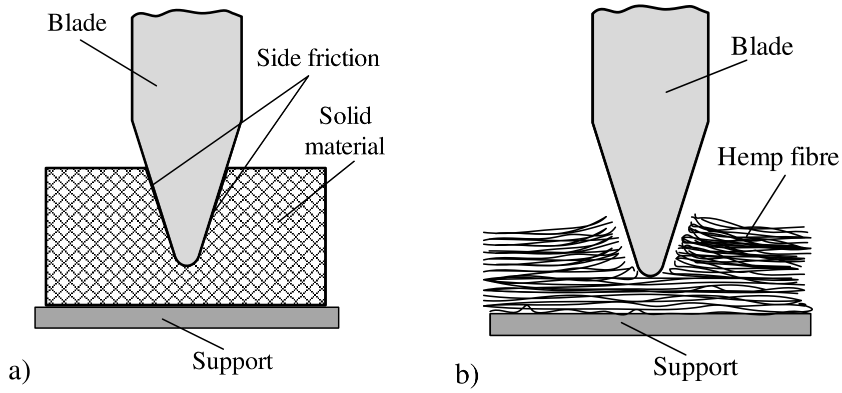

Fig. 4. **Cutting process**
a – solid material cutting, b – fibre cutting

The total cutting energy can be defined as the friction force work:

$$E = E_{cut} + E_f = \sum_{i=1}^{n} F_{if} \cdot s = \sigma_b \cdot 2r \cdot l \cdot f + 2\sigma_b \cdot \frac{h}{\cos\alpha} \cdot l \cdot f \,, \tag{8}$$

where E_{cut} – material cutting energy;
E_f – friction force energy;
F_{if} – all friction forces;
s – distance of the blade movement;
f – coefficient of friction.

From the equation (8) it can be concluded that the cutting energy depends on:

- knife-edge radius r,
- blade side friction force F_{fs}.

The cutting energy strongly depends on the knife-edge radius, if the $r \to 0$, then $E_{cut} \to 0$. The friction force energy depends on the knife-edge angle and material properties. Cutting hard materials it is closely pressed against the knife blade and a large friction force is formed, Fig. 4a. Cutting fibrous material, it becomes convex, and the friction force does not arise, Fig. 4b.

Energy consumption for hemp fibre cutting has been investigated using experimental equipment with a rotating knife Fig. 5. The torque and angle of rotation were measured. The torque was measured using a calibrated tenzoresistor bridge circuit. The angle of rotation was measured using a rotating potentiometer (Fig. 5). The measurement data were recorded with a virtual data logger *Picoscope* and calculated with *Excel* software. The total cutting energy for one cut E_1 was represented by the area underneath the entire torque – rotating angle curve, Fig. 6. The calculation of the energy E_1 is done according to equation (9):

$$E_1 = \left[\left(\frac{M_2 + M_1}{2}\right)\Delta\varphi + \left(\frac{M_3 + M_2}{2}\right)\Delta\varphi + \ldots + \left(\frac{M_n + M_{n-1}}{2}\right)\Delta\varphi\right], \tag{9}$$

where E_1 – is energy for one cut, J;
M_1 – first data point, Nm;
M_2 – second data point, Nm;
M_n – nth data point, Nm;
$\Delta\varphi$ – angle interval between the data points.

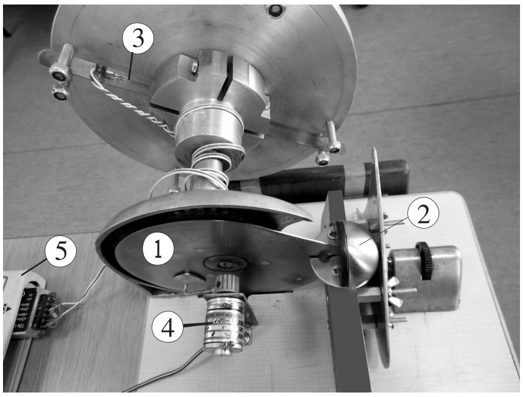

Fig. 5. **Experimental equipment with rotating knife:** 1 – knife; 2 – support; 3 – bridge circuit; 4 – rotating angle sensor; 5 – data logger

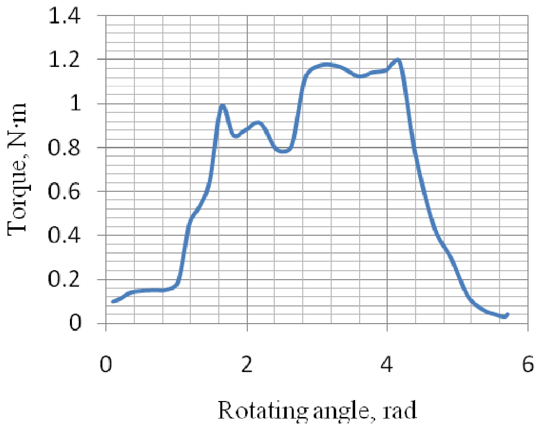

Fig. 6. **Torque depending on the rotating angle**

Results and discussion

Cutting experiments were realized with six hemp varieties *Bialobrzeskie*, *Futura 75NT*, *Tygra*, *Wojko*, *Fedora 17* and *Ferimon*. The specific cutting energy e was calculated by equation (10):

$$e = \frac{E_1}{m_1}, \tag{10}$$

where m_1 – one meter mass, kg·m^{-1}.

The total energy depends on one cut energy and particle length Δl.

$$E = e \cdot \frac{m}{\Delta l}, \tag{11}$$

where e – specific cutting energy, J·m·kg^{-1};
m – total mass of hemp fibres, kg;
Δl – particle length, m.

To determine the cutting energy changes depending on the sample one meter mass industrially manufactured hemp rope was used. Three different specific one meter mass ropes were used for cutting energy testing. It is stated, that the one cut energy depends on the specific one meter mass and changes linearly depending on the specific mass, Fig. 7. Calculated by the equation (10) the specific cutting energy of the hemp rope shows that the specific energy does not depend on the specific mass, Fig. 8.

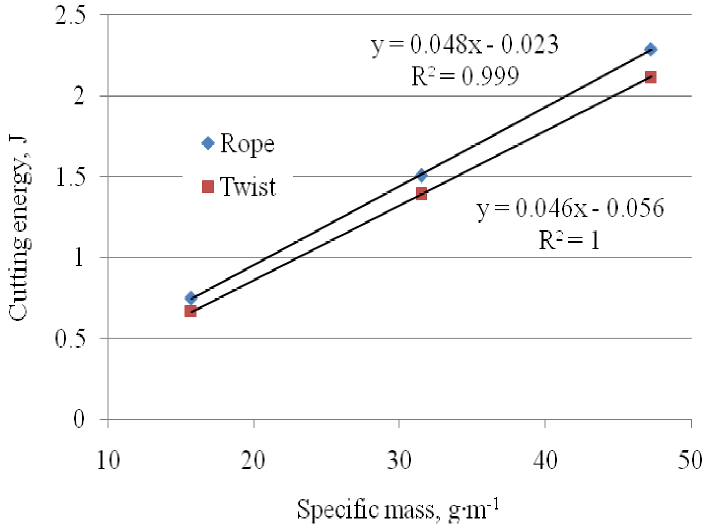

Fig. 7. **Cutting energy depending on the specific mass of the rope**

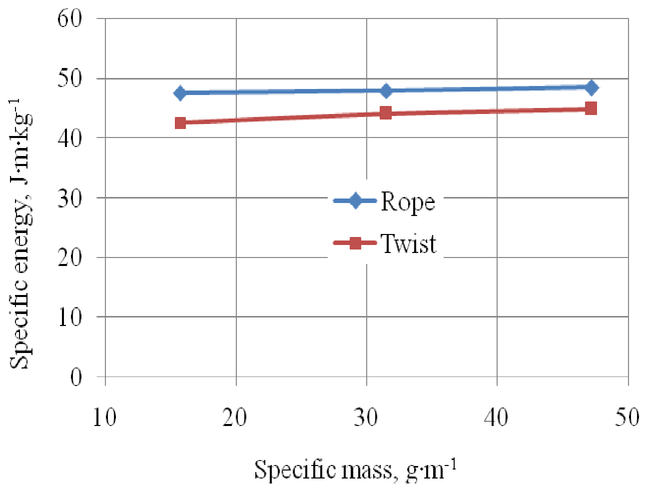

Fig. 8. **Specific cutting energy of industrially produced hemp rope depending on the twisting stiffness**

Fig. 9. **Strongly twisted hemp rope cutting**

Fig. 10. **Soft twisted hemp fiber cutting**

Industrially produced hemp rope is strongly twisted. The specific cutting energy is greater than the same fiber soft twisted, Fig. 8. The difference does not exceed 8.5%. Higher specific energy of strongly twisted rope points to higher frictional forces on the blade surface. Figure 9 indicates that there is no gap between the rope and a knife, which contributes to the occurrence of frictional force. Soft twisted hemp fiber becomes convex near the blade surface and friction forces do not appear (Fig. 10).

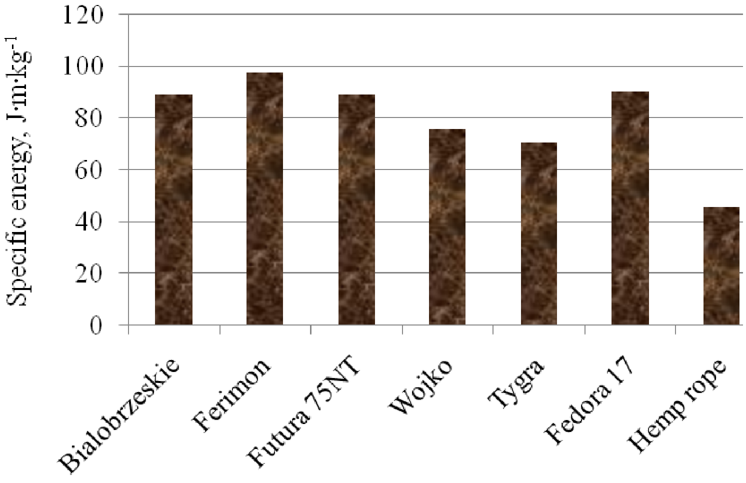

Fig. 11. **Specific cutting energy of different hemp varieties**

Soft twisted spins of the six hemp varieties were tested to determine the specific cutting energy. The average specific energy of all hemp varieties lies between 97.5 $J \cdot m \cdot kg^{-1}$ (*Ferimon*) and 70.83 $J \cdot m \cdot kg^{-1}$ (*Tygra*), Fig. 11. Industrially manufactured hemp rope specific cutting energy is less than twice the cutting power of natural hemp fiber.

Conclusions

1. Cutting energy using a rotating knife depends on the knife edge sharpness and material properties which cause the knife blade side friction forces.
2. Cutting energy of the industrially produced hemp rope depends on the one meter mass of the rope and changes linearly depending on the one meter mass.
3. Specific cutting energy depends on the rope twisting hardness. Strongly twisted rope has 8.5 % greater specific cutting energy compared together with soft twisted fibres.
4. Specific cutting energy of natural hemp fibres of the six hemp varieties lies between 70.83 $J \cdot m \cdot kg^{-1}$ (*Tygra*) and 97.5 $J \cdot m \cdot kg^{-1}$ (*Ferimon).*

Acknowledgments

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