CUTTING PROPERTIES OF DIFFERENT HEMP VARIETIES IN DEPENDENCE ON THE CUTTER MECHANISM

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Abstract. The cutting properties of eight different hemp varieties in dependence on five types of cutter mechanisms were experimentally investigated. The shapes of the cutting knives and counter knives wear designed straight and curved lines with the aim to determine the optimal form. Specific cutting energy was used as the main evaluation parameter. Ultimate shear strength was determined for eight hemp stem material varieties. The experimentally stated shear strength of hemp varieties is within 11.8-19.4 $N \cdot mm^{-2}$. The experimentally stated value of specific cutting energy for all five types of the cutter mechanisms is within 0.020-0.047 $J \cdot mm^{-2}$. Two cutting knives mechanisms (No. 1 and No. 2) are approved as the most energy efficient, where the average cutting energy consumption for hemp varieties is minimal (0.026±0.003 $J \cdot mm^{-2}$). Eighteen different cutting knives were used for bevel and blade angle affect on hemp cutting properties. For all types of cutting knives the maximal cutting force is decreasing for approximately 40% if the blade angle is increased from 0º to 20º. The experimentally obtained values for the mentioned hemp varieties of cutting properties and energy consumption using different cutter mechanisms would be used for biomass shredder cutter mechanism design.

Keywords: cutting energy, shear strength, hemp.

Introduction

In 2005 EU biomass accounted for 66 % of renewable primary energy production. Herbaceous energy crops would be as the main basis for solid biofuel production in agricultural ecosystem in future. There is not a problem in Latvia that if bioenergy crops are encouraged, then less land will be available for growing food. In 2005 investigation it was stated that 14.6 % of agricultural land [1] of Latvia was unfarmed. Therefore, herbaceous energy crop growing on these lands can provide sustainable farming practice. Hemp (Cannabis Sativa) is a potentially profitable crop, fitting into sustainable farming systems. It is mainly used for fiber production but its core can be used as an energy source. For solid fuel production in shape of briquettes or pellets all hemp stem material or its core part can be used. Investigation of cutting properties of this stalk material is necessary for mechanization mechanism designing.

The main conditioning operation before compacting of herbaceous biomass in shape of pellets and briquettes is shredding. It is size reduction of biomass stalks and residues by cutting operation. In Latvia hemp growing as biomass for solid fuel production is a new activity. For this reason mechanical properties of different varieties of hemp have to be investigated in order to develop shredding equipment design methodology. Mainly shear strength of hemp samples was investigated in order to find methods for cutting (shredding) with minimal energy consumption. The main hypothesis for cutter design is that the cutting method has to be used with minimum of energy consumption by reducing frictional forces to a minimum. Different cutting knives mechanisms have to be investigated for energy consumption evaluation. The objective of this study is to determine the cutting properties of hemp stalk materials and energy efficiency of the cutting knives mechanisms.

Materials and methods

Hemp (Cannabis sativa) in Latvia is cultivated only in recent years and its mechanical properties are not broadly investigated. Cross-sections of hemp stalks show the complicated structure (Figure 1) of this material. It can be noticed that hemp stalks have a significant woody part (Figure 1. B) – resource for solid biofuel production.

As sample materials for investigation of the cutting properties eight varieties of hemp were used in the experiments. Average biomass yields in DM (in 2010) of hemp varieties are presented in Table 1. emps, with moisture content ~10 %, were used for density calculation and experiments for investigation of mechanical properties.

Mostly the hemp stalk material cross-section shape is irregular; therefore, the cross-section area cannot be calculated by using geometry equations. For irregular cross-section area calculation AutoCAD software functions “Spline”, “Region” and “Object properties” were used. The scanned hemp stalk cross-section images in real measurements for area calculation were used. Both border lines of the cross section were marked with the function “Spline”. With the function “Region” the area included in border lines is marked. For both regions in “Object properties” areas in mm^2 are shown. The difference between the outside border region area and inside border region area is a real hemp stalk cross-section area. The cross-section area was calculated from the data obtained from direct measurement with sliding caliper (accuracy ±0.01 mm).

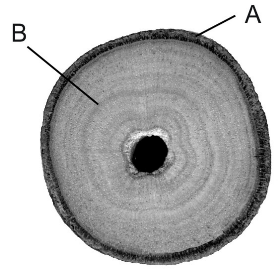


Fig. 1. **Hemp stalk cross-section:** A – Fiber, B – woody part

The hemp stalk cross-section area was used in material density and mechanical properties calculations. In density calculations for each stalk test piece the cross-section areas for both stalk ends were determined. By multiplication of the average area and length the volume of each test piece was found. The volume values were used for density calculation.

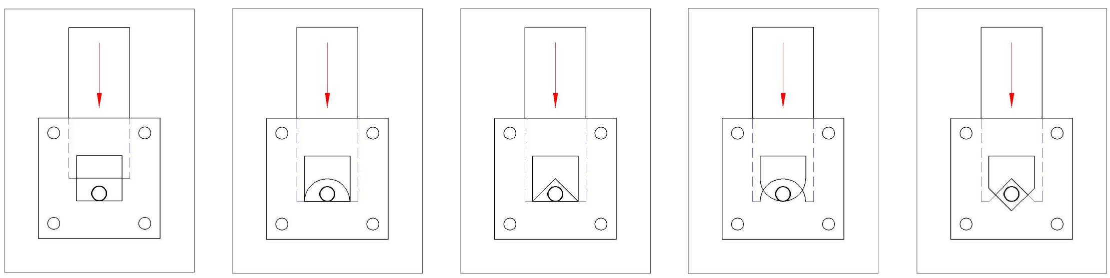
Table 1

Hemp biomass in DM yields

Hemp variety	Yield, $t \cdot ha^{-1}$
Bialobrzeskie	14.0
Felina 32	13.2
Epsilon 68	15.8
Benico	12.7
Uso 31	14.4
Futura 75	16.9
Fedora 17	15.9
Santhica 27	16.4

Ultimate shear strength and energy consumption for stalk cutting have been investigated using the Zwick materials testing machine TC-FR2.5TN.D09 with force resolution 0.4 % and displacement resolution 0.1 µm and the maximal force for testing 2.5 kN. For all experiments the displacement speed of the cutting knives did not exceed 50 $mm \cdot min^{-1}$. For cutting parameter determination original cutting devices have been designed.

The first experiment series of the cutting devices were equipped with five different cutting mechanisms (Figure 2).



No. 1 No.2 No. 3 No. 4 No. 5

Fig. 2. **Shear cutting knives mechanisms**

In shear cutting knives mechanism investigation 15 hemp samples were used for each hemp variety. Hemp stalks were fixed on one side. In cutting experiments the strongest and weakest hemp variety were determined. These two varieties were used in the second experiment by knives with different blade and bevel angles.

For the second experiment series the cutting mechanism No.1 was equipped with eighteen different cutting knives (Figure 3.).

The nip angle of hemp stalk material was determined in previous investigations. The value of hemp and steel materials nip angle is 25º±0.2º what is equal to the blade angle for the cutting knife No.6, No. 12 and No. 18.

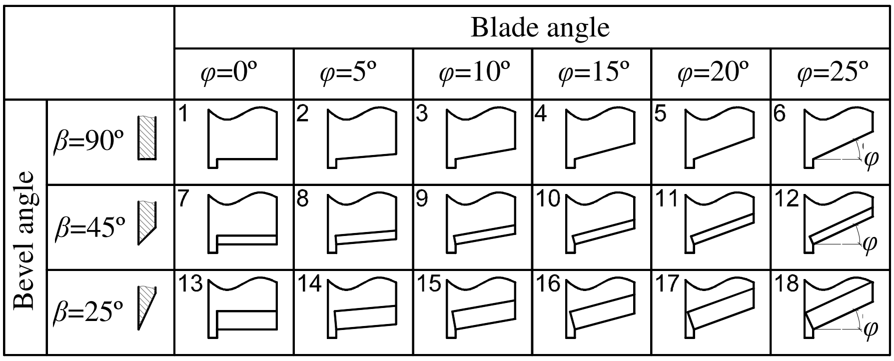


Fig. 3. **Cutting knives with different blade and bevel angles**

Ultimate shear strength was calculated:

$$\tau_C = \frac{F_C}{A} \tag{1}$$

where τ_C – ultimate shear strength, N·mm^{-2};

F_C – maximal cutting force, N;

A – cutting area, mm^{-2}.

Specific cutting energy was determined:

$$E_{SC} = \frac{E_C}{A} \tag{2}$$

where E_{SC} – specific cutting energy, J·mm^{-2};

E_C – cutting energy, J;

A – cutting area, mm^{-2}.

Displacement and stress data were collected and processed by using Zwick software program TestXpert V9.01. The energy consumption was obtained by integrating force – displacement diagram. Specific cutting energy consumption was investigated for all varieties of hemp. For investigation of each knives mechanism 15 samples of every plant stalk material variety were used.

The results of the cutting experiments were processed by Microsoft Excel program. The cutting (chopping) energy E for stalk material mass unit is calculated [2] using equation:

$$E = \frac{E_{SC}}{L_C \cdot \rho} \tag{3}$$

where E – cutting energy per mass unit, J·kg^{-1};

L_C – length of stalk cut, mm;

ρ – stalk material density, kg·mm^{-3}.

Results and discussion

The hemp stalk material ultimate shear cutting strength and specific cutting energy are shown in Table 2. The average specific cutting energy for hemp stalks is within 0.026-0.038 J·mm^{-2}. The ultimate shear strength was determined for eight hemp stem material varieties. The experimentally stated shear strength of hemp varieties is within 11.8-19.4 N·mm^{-2}. The experimentally stated value of specific cutting energy for all five types of the cutter mechanisms is within 0.020-0.047 J·mm^{-2}. The cutting knives mechanisms No. 1 and No. 2 are approved as the most energy efficient, where the average cutting energy consumption for hemp stalks is minimal (0.026±0.003 J·mm^{-2}).

Table 2

Hemp and common reed stalk material mechanical properties

Sample	Cutting mechanism									
	№ 1		№ 2		№ 3		№ 4		№ 5	
	τ_{max}, N·mm^{-2}	*E*, J·mm^{-2}	τ_{max}, N·mm^{-2}	*E*, J·mm^{-2}	τ_{max}, N·mm^{-2}	*E*, J·mm^{-2}	τ_{max}, N·mm^{-2}	*E*, J·mm^{-2}	τ_{max}, N·mm^{-2}	*E*, J·mm^{-2}
Bialobrzeskie	14.9	0.021	15.3	0.023	11.8	0.030	14.1	0.024	15.5	0.037
Felina 32	15.8	0.025	17.0	0.026	14.4	0.035	15.6	0.031	13.5	0.037
Epsilon 68	13.8	0.020	15.9	0.022	13.8	0.028	14.6	0.023	14.4	0.029
Benico	18.9	0.031	19.4	0.029	18.8	0.045	18.9	0.032	19.0	0.043
Uso 31	16.6	0.030	17.1	0.032	13.4	0.039	17.8	0.039	13.3	0.047
Futura 75	17.5	0.030	18.4	0.030	15.9	0.041	17.3	0.034	16.1	0.042
Fedora 17	13.5	0.022	14.3	0.021	12.3	0.029	12.6	0.022	13.1	0.028
Santhica 27	17.0	0.030	17.7	0.029	15.4	0.037	16.4	0.029	16.4	0.038
Average for hemp	16.0	0.026	16.9	0.026	14.5	0.036	15.9	0.029	15.2	0.038

Cutting knives mechanisms with a round shape (No. 2) are recommended because the rounding in cutting knives is increasing the nip angle. Increased nip angle improves the biomass shredder technical parameters by reducing rotation speed deviation and wear of cutting and counter knives. The cutting mechanism No. 3 is recommended when it is necessary to reduce the cutting force values, because the minimal average ultimate shear strength is 14.5±1.9 N·mm^{-2}.

The hemp variety Uso 31 is approved as the strongest, but the variety Fedora 17 as the weakest material in shear cutting. These hemp varieties were used in the cutting experiments with knives with different geometry (according to Figure 3). The specific cutting energy dependence on knife geometry for hemp varieties Uso 31 and Fedora 17 is shown in Table 3.

Table 3

Specific cutting energy dependence on knife geometry, J mm^{-2}

Material	Bevel *angle* β, °	Blade angle					
		0°	5°	10°	15°	20°	25°
Uso 31	90°	0.039	0.039	0.039	0.040	0.041	-
	45°	0.025	0.025	0.024	0.025	0.026	0.023
	25°	0.027	0.023	0.024	0.024	0.023	0.025
Fedora 17	90°	0.023	0.023	0.025	0.028	0.034	-
	45°	0.013	0.015	0.014	0.016	0.016	0.014
	25°	0.016	0.017	0.019	0.018	0.015	0.014
Average for hemp	90°	0.031	0.031	0.032	0.034	0.037	-
	45°	0.019	0.020	0.019	0.021	0.021	0.019
	25°	0.022	0.020	0.021	0.021	0.019	0.019

In the experiments it was noticed that in several cutting experiments the hemp stalk has horizontal displacement. For that reason all data from the cutting experiments with the knife No. 6 were deleted.

During the experiments it was stated that cutting energy depends on the material deformation process and friction forces. Significant material deformation was noticed for the cutting knives with bevel angle 90º. The estimated values prove that blade angle increasing causes significant specific cutting energy increasing. The specific cutting energy is not affected from the blade angle for knives with bevel angle 25º and 45º.

The ultimate cutting strength dependence on knife geometry for hemp varieties Uso 31 and Fedora 17 is shown in Table 4. There is no considerable difference in cutting strength values between the knives with bevel angle 25º and 45º. Ultimate cutting strength values for the knives with bevel angle 90º are significantly higher as for the knives with bevel angle 45º and 25º. For all types of cutting knives the maximal cutting force is decreasing for approximately 40 % if the blade angle is increased from 0º to 20º.

Table 4

Ultimate cutting strength dependence on knife geometry, N mm^{-2}

Material	Bevel angle β, º	Blade angle					
		0º	5º	10º	15º	20º	25º
Uso 31	90º	19.9	16.2	13.3	12.0	11.7	-
	45º	7.8	6.9	6.2	6.0	5.0	4.3
	25º	6.4	5.8	5.4	4.4	4.2	4.5
Fedora 17	90º	14.5	12.1	9.7	10.1	6.7	-
	45º	7.1	6.3	5.3	4.8	4.3	3.4
	25º	7.0	7.1	5.5	4.3	4.3	3.6
Average for hemp	90º	17.2	14.1	11.5	11.0	9.2	-
	45º	7.5	6.6	5.8	5.4	4.7	3.9
	25º	6.7	6.4	5.4	4.4	4.3	4.1

The investigated hemp stalk material density is shown in Table 5. The average calculated hemp stalk material density is 325 ± 18 kg·m^{-3}. On basis of the calculated stalk material density specific cutting energy per mass unit for cutting mechanism No. 2 is determined for all hemp varieties (Figure 4).

Table 5

Hemp biomass density

№	Hemp variety	Density, kg·m^{-3}
1	Bialobrzeskie	300
2	Felina 32	340
3	Epsilon 68	310
4	Benico	340
5	Uso 31	320
6	Futura 75	340
7	Fedora 17	300
8	Santhica 27	360

It can be noticed that for the hemp variety Fedora 17 is the lowest, but for variety Uso 31 is the highest cutting energy consumption. For all other hemp varieties the cutting energy values are between these two values. It can be concluded that the hemp variety with the lowest proportion of specific cutting energy and material density has the minimum values of cutting energy.

The specific cutting energy per mass unit is growing considerably when the shredding size is less than 30 mm for hemp stalk material.

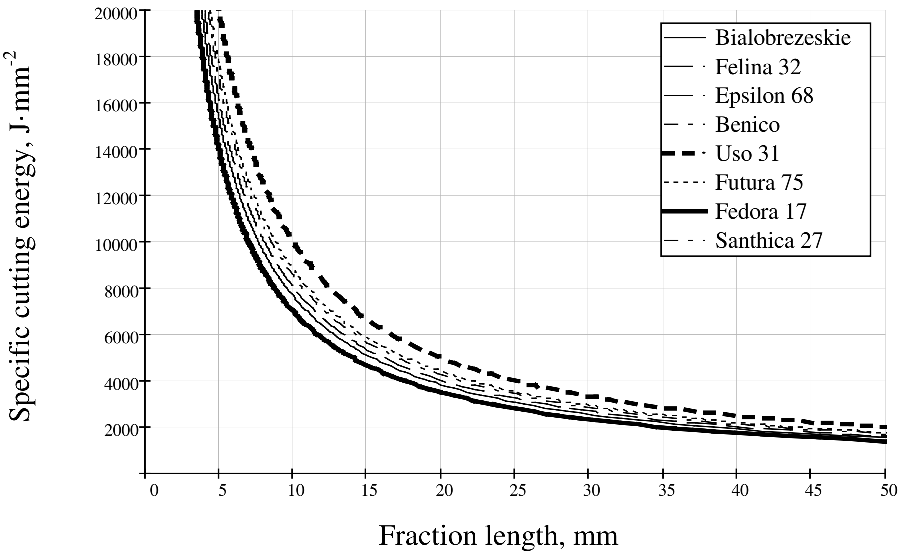


Fig.4. **Hemp stalk material cutting energy**

Conclusions

1. The cutting knives mechanisms No. 1 and No. 2 are approved as the most energy efficient, where the average cutting energy consumption for hemp varieties is minimal (0.026±0.003 J·mm^{-2}).
2. Energy consumption for shear cutting of the hemp variety Uso 31 (0.032 J·mm^{-2}) is maximal, but minimal for the variety Fedora 17 (0.021 J·mm^{-2}) when the cutting mechanism No. 2 is used.
3. The cutting mechanism No. 3 is recommended when it is necessary to reduce the cutting force values, because the minimal average ultimate shear strength (14.5±1.9 N·mm^{-2}) is determined with it.
4. The knives with the bevel angle 25º and 45º and blade angle 25º have the least cutting energy consumption (0.014 J·mm^{-2}) with the hemp variety Fedora 17.
5. For all types of cutting knives the maximal cutting force is decreasing for approximately 40 % if the blade angle is increased from 0º to 20º.
6. The average calculated hemp stalk material density is 325±18 kg·m^{-3}.
7. The specific cutting energy per mass unit (>3000 J·kg^{-1}) is growing considerably when the shredding size is less than 30 mm for hemp stalk material.

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