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MECHANICAL PROPERTIES OF HEMP (*CANNABIS SATIVA*) BIOMASS

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Abstract. *In Latvia approximately of 14.6% of unfarmed agricultural land can be used for herbaceous energy crop growing. Herbaceous energy crops would be as the main basis for solid biofuel production in agricultural ecosystem in future. Herbaceous energy crops as hemp (Cannabis sativa) are grown in recent years and can be used for solid biofuel production. Experimentally stated hemp stalk material ultimate tensile strength the medium value is 85 ± 9 N mm^{-2}. The main conditioning operation before preparation of herbaceous biomass compositions for solid biofuel production is shredding. Therefore hemp stalks were used for cutting experiments. Cutting using different types of knives mechanisms had been investigated. Specific shear cutting energy for hemp samples were within 0.02 – 0.04 J mm^{-2}. Hemp stalk material density was determined using AutoCAD software for cross-section area calculation. Density values are 325 ± 18 kg m^{-3} for hemp stalks. Specific cutting energy per mass unit was calculated on basis of experimentally estimated values of cutting energy and density.*

Keywords: *energy crops, hemp, mechanical properties.*

Introduction

Latvia has target [1] in 2020 for renewable energy resources to be 40% in gross final consumption of energy. In 2005 EU biomass accounted for 66 % [2] of renewable primary energy production. Biomass has relatively low costs, less dependence on short-term weather changes and it is possible alternative source of income for farmers. Herbaceous energy crops would be as the main basis for biofuel production in agricultural ecosystem in future. There is not problem in Latvia that if bioenergy crops are encouraged, then less land will be available for growing food. In 2005 year investigation was stated that 14.6% of agricultural land [2] of Latvia was unfarmed. Therefore herbaceous energy crop growing on these lands can provide sustainable farming practice. Sources of renewable energy are also by-products of hemp (Cannabis sativa) straw of the process of fiber extraction and the whole plants of hemp cultivated for biomass. Hemp and waste hemp residues after processing can be used for production of solid biofuel pellets and briquettes.

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 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 were investigated in order to find methods for cutting (shredding) with minimal energy consumption. The main hypothesis for cutter design is that 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 cutting properties of hemp stalk materials and energy efficiency of cutting knives mechanisms.

Materials and methods

Herbaceous biomass as hemp is prospective stalk materials for solid biofuel production in Latvia. For production of solid biofuel mainly herbaceous plant stalks are used. Hemp

(Cannabis sativa) in Latvia is cultivated only in recent years and it 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 significant woody part – resource for solid biofuel production.

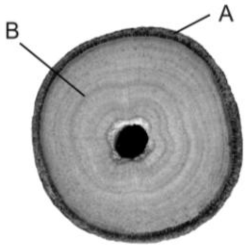

Fig.1. **Hemp stalk cross-section**
(A - fibrous layer, B - woody part)

As sample materials for investigation of cutting properties eight varieties of hemp were used in experiments. Average biomass yield in DM (in 2010) of hemp varieties are presented in Table 1.

Table 1.

Hemp biomass in DM yields

Hemp variety	Yield, t 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

Hemps, with moisture content ~10%, were used for density calculation and experiments for investigation of mechanical properties.

Mostly hemp stalk material cross-section shape is irregular; therefore cross-section area can't be calculated by using geometry equations. For irregular cross-section area calculation AutoCAD software functions “Spline”, “Region”and “Object properties” (Figure 2) had been used. The scanned hemp stalk sross-section images in real measurements for area calculation were used. Bouth border lines of cross section were marked with function “Spline”. With function “Region” the area included in border lines is marmed. For bouth regions in “Object properties” areas in mm^2 are shown. The difference between outside border region area and inside border region area is a real hemp stalk cross-secrion area. By using function “Substract” is possible to cut out inner region from outer region. In that way in “Object properties” is shown real hemp stalk cross-section area.

Cross-section area was calculated from data obtained from direct measurement with sliding caliper (accuracy ± 0,01 mm). Hemp stalk cross-section area was used in material density and mechanical properties calculations. In density calculations for each stalk test piece were determined cross-section areas for both stalk ends. By multiplication of average area and length the volume of each test piece was found. Volume values were used for density calculation.

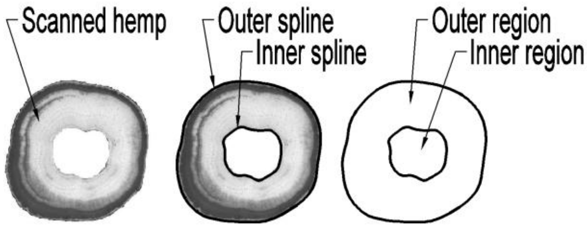

Fig.2. **Cross-section area calculation in AutoCAD software**

Ultimate shear strength and energy consumption for stalk cutting has 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 shear cutting parameter determination original cutting device has been designed. For all experiments the displacement speed of cutting knives did not exceeds 50 mm min^{-1}. Cutting device was equipped with five different cutting knives mechanisms (Figure 3).

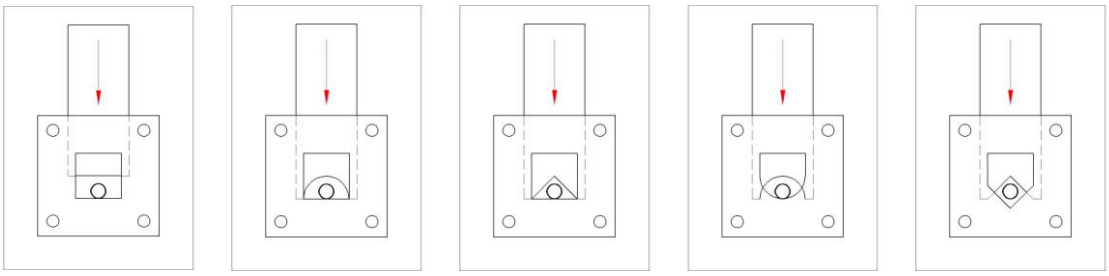

Fig.3. **Shear cutting knives mechanisms**

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 were used 15 samples of every plant stalk material variety.

Results of cutting experiments were processed by Microsoft Excel program.

The cutting (chopping) energy E for stalk material mass unit is calculated [3] 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}.

Ultimate tensile strength for hemp stalk has been investigated using the GUNT 20 materials testing machine with force resolution 1% and displacement resolution 10 µm and the maximal force for testing is 20 kN. For average ultimate tensile strength determination original clamping part has been designed (Fig. 4).

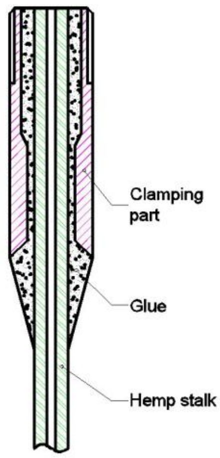

Fig.4. **Hemp stalk gripper mechanism**

Ultimate tensile strength was calculated:

$$\sigma = \frac{F_P}{A} \tag{4}$$

where: σ - ultimate tensile strength, N mm^{-2};
F_P - maximal tensile force, N;
A - stalk cross-section area, mm^{-2}.

Results and discussion

Hemp stalk material ultimate shear cutting strength and specific cutting energy is shown in Table 2. Average specific cutting energy for hemp stalks is within 0.02 – 0.04 J mm^{-2}.Hemp stalk material ultimate shear cutting strength and specific cutting energy is shown in Table 2. Average specific cutting energy for hemp stalks is within 0.02 – 0.04 J mm^{-2}.

Table 2.

Hemp and common reed stalk material mechanical properties

	Cutting mechanism									
	№ 1		№ 2		№ 3		№ 4		№ 5	
Sample	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

The cutting knives mechanisms № 1 and № 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}). Cutting knives mechanism with round shape (№ 2) is recommended because the rounding in cutting knives are increasing nip angle. Increased nip angle improve the biomass shredder technical parameters by reducing rotation speed deviation and wear of cutting and counter knives.

The cutting mechanism № 3 is recommended then it is necessary to reduce cutting force values, because minimal average ultimate shear strength is 14.5 ± 1.9 N mm^{-2}. For all cutting knives mechanisms cutting parameters depend on material deformation process during cutting. The ultimate shear strength values are decreasing if bevel angle for knives is increased. But increased bevel angle causes significant material deformation, therefore specific cutting energy is increasing.

Specific cutting energy of hemp stalks with mechanism № 2 is shown in Figure 4. It can be noted that specific cutting energy is increasing if hemp sample cross-section is increased.

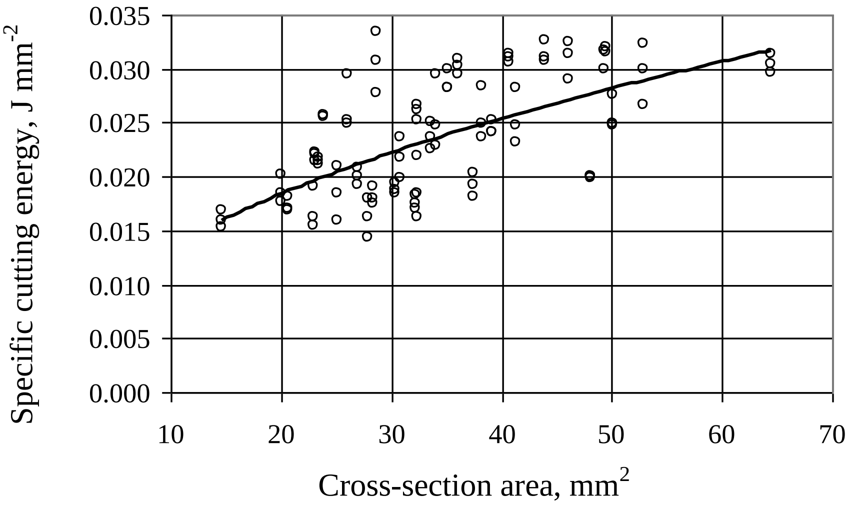

Fig.4. **Specific cutting energy of cutting mechanism № 2**

Ultimate tensile strength of different hemp varieties samples depending on cross-section area is shown in Figure 5. The average hemp stalk material ultimate tensile strength is calculated 85 ± 9 N mm^{-2}.

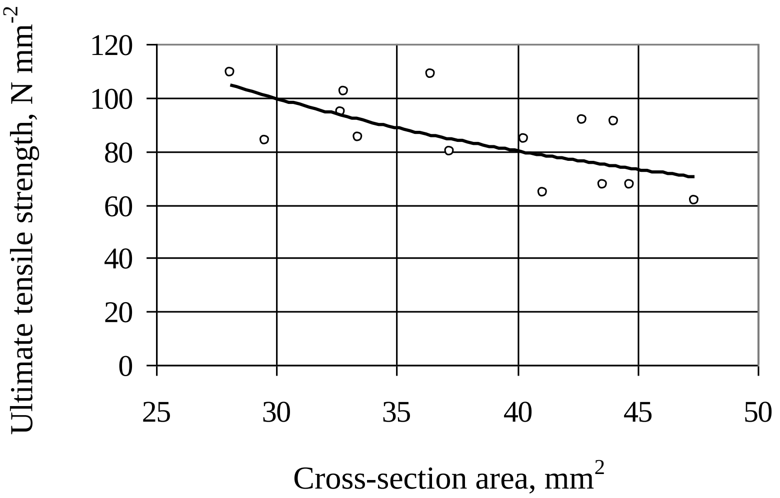

Fig.5. **Hemp stalks material ultimate tensile strength**

The trendline shows that hemp test piece area increasing causes decreasing of ultimate tensile strength. Figures 4 and Figure 5 shows that there is significant dependence between stalk mechanical properties and ratio of cross-section area and perimeter. For all hemp samples there are tendency of specific cutting energy growing and ultimate tensile strength decreasing, if cross-section area is increasing.
Investigated hemp stalk material density is shown in Table 3.

Table 3.

Hemp biomass density

Hemp variety	Density, kg m^{-3}
Bialobrzeskie	300
Felina 32	340
Epsilon 68	310
Benico	340
Uso - 31	320
Futura 75	340
Fedora 17	300
Santhica 27	360

The average calculated hemp stalk material density is 325 ± 18 kg m^{-3}. These values are used in cutting knives mechanism cutting energy per mass unit calculation (Figure 6). It can be noticed that for hemp varieties Fedora 17 and Bialobrzeskie have the least values of density (300 kg m^{-3}) and also the least value of specific cutting energy (0.021 and 0.023 J mm^{-2}) with cutting knives mechanism № 2. It can be concluded that the minimum values of specific cutting energy are for hemp samples with least values of density.
On basis of calculated stalk material density specific cutting energy per mass unit (Figure 6) is determined. Specific cutting energy per mass unit is growing considerably when shredding size is less than 30 mm for hemp stalk material.

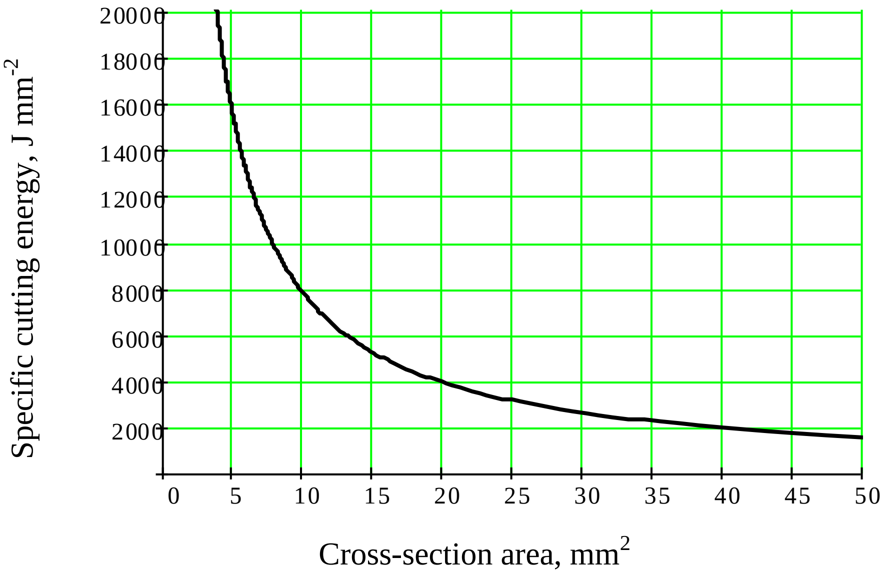

Fig.6. **Hemp stalk material cutting energy**

Conclusion

Average specific shear cutting energy is within 0.02 – 0.04 J mm^{-2} for hemp stalks.

The cutting knives mechanism № 2 is approved as the most energy efficient, where the average cutting energy consumption for hemp stalks is 0.026 ± 0.003 J mm^{-2}.

The cutting mechanism № 3 is recommended then it is necessary to reduce cutting force values, because minimal average ultimate shear strength is 14.5 ± 1.9 N mm^{-2} for hemp samples.

The average hemp stalk material ultimate tensile strength is 85 ± 9 N mm^{-2}.

For all hemp samples there are tendency of specific cutting energy growing and ultimate tensile strength decreasing, if cross-section area is increasing.

The average calculated hemp stalk material density is 325 ± 18 kg m^{-3}.

Hemp varieties Fedora 17 and Bialobrzeskie have the least values of density (300 kg m^{-3}) and also the least value of specific cutting energy (0.021 and 0.023 J mm^{-2}) with cutting knives mechanism № 2.

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References

1. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (Text with EEA relevance). http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32009L0028:EN:NOT, (Accessed on 30.03.2010).
2. Land politics statement for years 2008. – 2014. The Order of the Cabinet of Ministers of the Republic of Latvia Nr. 613 (in Latvian), http://www.mk.gov.lv, (Accessed on 30.03.2010).
3. Srivastava AK, Goering CE, Rohrbach RP. Engineering principles of agricultural machines. ASAE Textbook Number 6. Pamela De Vore-Hansen, Editor, Books&Journals. 1993. p. 601.

Anotācija. *Latvijā aptuveni 14.6% no lauksaimniecībā neizmantojamās platības var tikt izmantota enerģētisko stiebraugu audzēšanai. Enerģētisko stiebraugu audzēšana lauksaimniecībā nākotnē varētu būt kā galvenais cietā kurināmā ražošanai nepieciešamais izejvielu avots. Sējas kaņepju (Cannabis sativa) audzēšana Latvijā notiek tikai pēdējos gados un varētu tikt izmantota kā izejviela cietā kurināmā ražošanai. Eksperimentāli noteiktā kaņepju stiebru robežizturība stiepē ir 85 ± 9 N mm^{-2}. Kā galvenā apstrāde pirms cietā kurināmā ražošanas ir smalcināšana, tādēļ kaņepju stiebri tika izmantoti griešanas pētījumos. Griešanas pētījumos tika izpētīti pieci dažādi griešanas mehānismi. Īpatnējā griešanas enerģija kaņepju stiebraugiem bija robežās no 0.02 – 0.04 J mm^{-2}. Kaņepju stiebraugu materiāla blīvums tika noteikts, izmantojot datorprogrammā AutoCAD aprēķinātos stiebra šķērsgriezuma laukumus. Kaņepju stiebru materiāla blīvums ir 325 ± 18 kg m^{-3}. Stiebru materiāla griešanas enerģija uz masas vienību ir aprēķināta, izmantojot eksperimentāli iegūtās materiāla blīvuma un īpatnējās griešanas enerģijas vērtības.*