EXPERIMENTS REGARDING MECHANICAL BEHAVIOUR OF ENERGETIC PLANT MISCANTHUS TO CRUSHING AND SHEAR STRESS

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Abstract. During the mechanical processing operations, from harvesting until the process of obtaining pellets or combustible briquettes, the energetic plants go through many processing stages. Thus, they are subjected to raw grinding and fine grinding with various equipment, which realize these operations: grinding equipment, hammer mills, crushers. During these operations the plants are subjected to complex mechanical stresses like: crushing, compression, shearing, cutting etc. These processes can not be decomposed in simple stresses, mostly the plants suffer combined stresses, but in order to determine their behaviour during these processes it is necessary to do some lab research in order to establish the plants behaviour for each type of request and also necessary to determine the mechanical characteristics of the plants. The paper presents the results of the experimental research, on a mechanical testing machine, Hounsfield type, regarding crushing and shear stress behaviour (until rupture) of Miscanthus energetic plant for later processing. Determinations were done on samples from the internodal region with the height of 20 mm, with diameters in the range of ϕ 4.0-9.0 mm. The results have been gathered and processed with Qmat programme, and a part of the graphs are presented in the paper, together with the mechanical characteristics and with the energy consumption for the two types of stresses presented. Energetic plant mechanical behaviour characterisation is necessary for specialists in their line of work, from equipment designers to exploitation specialists.

Keywords: miscanthus stalk, crushing stress, shearing behaviour, shearing energy consumption, yield point.

Introduction

Biomass represents a renewable energy source which consists mainly of plant matter grown to generate electricity or produce heat.

For economic and environmental considerations, as well as the fact that it provides higher yields of cellulose [1], non-wood material is now gradually substituting wood as an alternative source of paper, paperboard, and cellulose derivatives [2; 3]. The energy crops grown for solid and liquid fuel production are nowadays more preferable because delayed harvesting in the winter time allows to obtain biomass with humidity less than 15 % [4].

A very important step in processing raw biomass is size reduction. Irregular shape and size, low bulk density, high moisture content make biomass very difficult to handle, transport, store and use in its original form, thus the material is transformed in briquettes or pellets.

In the process of pellets and briquettes obtainment the vegetal material is subjected to grinding, drying, milling, briquetting operations. Milling the grinded biomass for obtaining a higher density material is done with hammer mills and also special disintegrators that transform the grinded particles into dust material. Inside the grinding apparatus, but also inside the milling machines, stalks and stalk fragments are subjected to complex mechanical stresses, combined by crushing, shearing, bending, torsion, simple cutting or slide cutting, etc, the result of which being a particle that goes back into the technological flow [5].

The resistance to cutting equipment and also the variation of the mechanical properties of the plant stalks have to be known in order to understand the behaviour of material subjected to different operations [6]. The physical properties of the material are very important in operations like cutting, compression, bending, grinding, etc. Shear, friction, tension compression and other stresses appear in the process of cutting and grinding. In order to improve the grinders design and reduce the energy consumed during the process of grinding it is necessary to identify the biomass shear response.

Using a mechanical testing machine, Womac et al. [7; 9] determinations have been made regarding shear resistance on corn, nut tree and virgatum stalk, using v shaped plates with angles of 30 and 45 degrees. The conclusion was that the shear energy at a 30 degree angle was smaller than the necessary energy for testing the probes with 45 degree angle plates. Also, for the nut tree probes the shear resistance was 10 times larger. The energy requirement for rice stalk shearing is different from probe to probe, according to the plant humidity. So, the energy consumed for shearing rice stalks was between 86.89-236.06 mJ for two types of Japanese rice, at the first three inter-nods. Regarding the equipment for biomass milling, the paper [8] shows that there is a strong connection between the particle size and the power necessary for milling them, disregarding the type of equipment used (hammer mill, knife mill, disk mill). Also, the most important parameters for the work process were the rotor angular speed of the mill, feed flow, the screen size and type of biomass [10].

Also, the performances and the necessary power for milling depend on the biomass humidity, milling being more pronounced at lower humidity levels, characterized by the size of the milled particles.

In paper [4], were investigated mechanical properties of resistance of reed strains in order to determine the cutting energy. It was found that tensile strength of reed stalks is about 200 $N \cdot mm^{-2}$ which leads to a larger chopping energy, the bulk density of the reed stalk at baling being 100-200 $kg \cdot m^{-3}$.

Materials and methods

In order to determine the behaviour of Miscanthus stalk to crushing and shear stress, samples from the internodes region of the plant strain of approximately 20 mm for crushing and also of 20 mm for shear stress were used. The diameters of the samples were in the range of ϕ 4.0-9.0 mm. Miscanthus stalks were harvested in March 2010, from the field of the National Institute of Agricultural Machinery Bucharest. Miscanthus crop was planted in 2008 and is currently in its third year. From the plants harvested from the Institute we used the one that had 234 mm in length, 22 g weight, 16 internodes counted from the bottom to the top of the plant.

The samples used during the tests were weighted with an electronic balance Kern RH 120-3 with a measuring precision of 10^{-3} g, the samples were also measured to determine their length and diameter, the apparatus used being a caliper with 10^{-2} mm precision.

The moisture content of the stalks determined was 9.8 % for the plant leaves and 8.9 % for the grinded stalks without leaves. The test consisted in subjecting the plant to 105 ºC of heat in a drying chamber (oven), Memmert Celsius 2007.

The apparatus used is the mechanical trial equipment Hounsfield H1KS type.

Fig. 1. **Hounsfield equipment:** 1 – crushing adapter; 2 – display; 3 – screen display; 4 – support of the equipment

The tests consisted in subjecting Miscanthus probes to repeated tests of crushing and shearing determining each time the break point, yield point, break displacement point, the limit of proportionality. For the crushing test a stainless steel adapter was connected to the load cell. The adaptor had a diameter of 34 mm and a thickness of 8 mm. The crushing device travel speed was 50 mm/min, while the shearing plate speed was of 100 $mm \cdot min^{-1}$ and was established so it would not significantly influence the results of experimental determinations, in concordance with the information presented by other authors in published scientific papers [6-8; 11]. In Fig. 2, b, the material sample deformation is presented for compression stress where $\sigma = P/A$ (P – compression force, A – transversal section area) in Pa, ε – strain (Δd – absolute strain, D – undamaged sample diameter).

In Table 1 the probe characteristics are presented, but also the results obtained at experimental determinations regarding the miscanthus plants behaviour at shearing on different inter-nods.

The tests done in order to determine the shear stress were made with a stainless steel plate, an adapter connected to the load cell. The base fixture of the universal test machine supported the base of the plate of the shear fixture. The plate dimensions were 100x70x3 mm and the angles used for the shear stress tests were 30, 50, 60, 75 degrees.

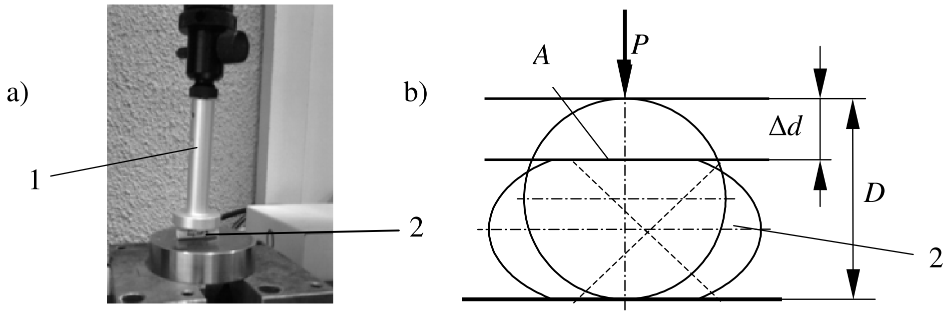

Fig. 2. **Crushing test:** a – picture of the equipment test;
b – transversal strain of miscanthus stalks; 1 – crushing adapter; 2 – plant sample

Table 1

Measured data and obtained results at experimental determinations regarding miscanthus behaviour at shearing (compression)

Inter-nodes	Length, mm	Average diameter, mm	Sample weight, g	Force, N	Extension, mm	Break point, N	Yield point, N
1	21.04	8.18	0.459	188.8	0.860	150.6	188.9
	21.82	8.07	0.432	220.3	1.020	178.8	220.3
	22.34	7.75	0.378	233.3	1.140	233.3	233.3
	21.47	7.95	0.342	138	1.468	111.6	120.9
2	20.33	8.06	0.362	194.4	0.925	156.2	194.4
	20.41	7.05	0.373	236.8	0.920	196.8	236.8
	21.38	7.11	0.316	173.4	1.626	139.2	117.6
	20.77	7.26	0.287	-	5.75	1030	1030
3	20.85	7.08	0.322	127.2	1.618	101.3	102.8
	22.14	7.14	0.275	118.8	1.418	96.6	81.9
	20.94	6.55	0.248	104.3	1.598	83.5	93
	21.24	7.22	0.277	111.1	1.340	88.9	73.8
4	20.79	7.56	0.285	100.4	1.181	82.1	85.1
	19.51	6.37	0.209	169.6	0.669	169.6	169
	20.74	6.11	0.213	60.7	0.907	60.7	60.7
	21.89	5.96	0.220	102.9	1.040	83.1	78.4
5	21.06	5.08	0.167	54.4	0.674	54.4	54.4
	20.14	6.03	0.182	102.8	0.978	101.6	83.1
	21.07	6.06	0.178	46.30	0.609	46.3	46.3
	20.56	6.18	0.186	63.3	0.924	63.3	63.3

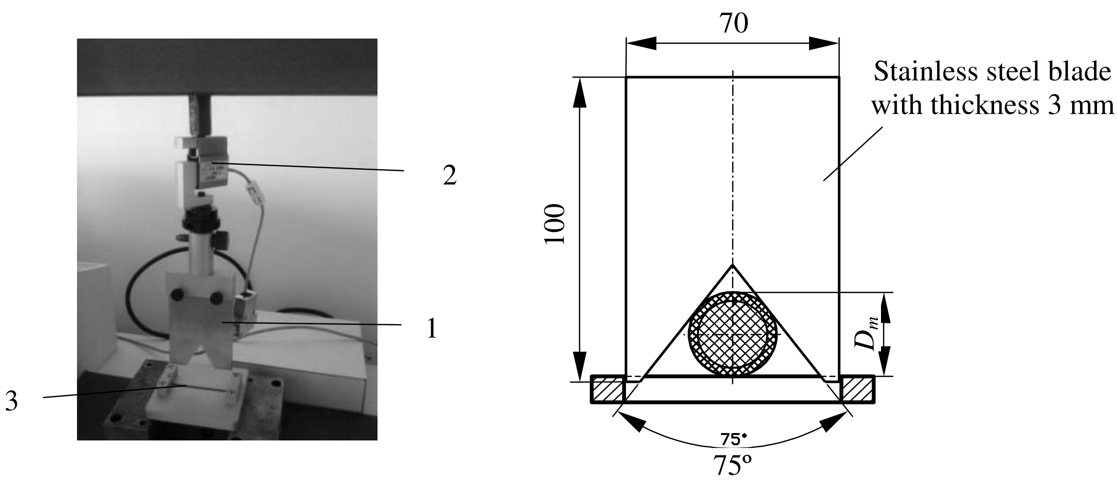

Fig. 3. **Shear test:** 1 – shear stainless steel blade; 2 – load cell; 3 – gap

From our determinations we concluded that the miscanthus stalk is elliptical in transversal section, presenting variations in diameter and on inter-nod height, the tables presenting their average diameter. Also according to the inter-nod, but also in other conditions, the width of the cellulose blanket is different from inter-nod to inter-nod, but even at the same inter-nod, the blanket giving mechanical resistance to plants, for shearing and crushing, while the core has higher elasticity.

In Table 2 the probe characteristics are presented, as well as the results obtained for experimental determinations regarding the behaviour of mischantus stalk at shear testing for different inter-nods, using shear plates with different angles (30, 50, 60, 75°)

Table 2

Data measured and results obtained at experimental determinations regarding miscanthus behaviour at shear tests, using shear plates with different angles

Inter-nodes	Length, mm	Average diameter, mm	Weight, g	Coating thickness, mm	Blade angle, °	Force, N	Extension, mm	W, J	Yield point, N
1	20.89	7.70	0.318	0.98	30	669	12.6	4.003	794
	22.59	7.67	0.342	0.86	50	869	12.7	2.530	803.3
	21.66	7.43	0.347	0.97	60	766	12.8	1.934	216
	21.47	7.95	0.342	0.92	75	633.8	12.7	2.095	152.3
2	20.38	7.15	0.311	0.67	30	215.3	9.6	3.624	711
	21.40	7.69	0.313	0.83	50	91.3	14.7	3.421	264
	20.36	7.97	0.362	0.99	60	108.3	13.7	2.315	222.3
	20.57	7.49	0.277	0.44	75	803	16.0	2.101	235.5
3	19.94	7.03	0.242	0.57	30	488.5	16.0	2.688	474.6
	21.14	7.29	0.271	0.92	50	559.5	15.0	2.70	223.5
	20.84	7.08	0.322	0.98	60	733.5	17.1	2.460	236.3
	21.27	6.86	0.272	0.50	75	132.3	16.8	1.972	239.3
4	20.88	6.96	0.210	0.70	30	711	30.6	2.429	504
	19.51	7.22	0.209	0.59	50	826	30.8	2.395	173
	20.79	7.50	0.285	0.78	60	94.6	18.0	2.451	262.5
	21.92	6.75	0.220	0.59	75	533.3	31.2	1.215	184
10	21.01	5.04	0.081	0.60	30	97.4	32.0	0.585	70.4
	21.34	5.02	0.083	0.43	50	122.4	30.7	0.392	110.3
	21.56	5.08	0.088	0.62	60	504	31.1	0.280	100.8
	21.64	5.08	0.086	0.46	75	732.8	14.4	0.405	101.1
11	20.72	4.29	0.058	0.15	30	462	14.7	0.308	63.9
	21.12	4.29	0.054	0.27	50	533.3	14.6	0.276	94.6
	21.53	4.47	0.060	0.20	60	669	14.6	0.249	89.5
	21.31	4.39	0.057	0.21	75	136.5	15.3	0.262	90.9

Results and discussion

On the basis of the obtained results at experimental determinations linked with the crushing and shearing mischantus stalks behaviour and the data presented in Tables 1 and 2 force-deformation variation graphs have been drawn, both for crushing and shearing. Some graphs obtained are presented in Figures 4-6. For some of the samples subjected to crushing tests the curves are presented in Figure 5. The tests generated by the mechanical testing machine Hounsfield showed the curves load-displacement (deformation) both for crushing and shearing. The shear stress curves presented in Figure 6 for some samples used to determine the behaviour of the miscanthus stalks.Because the material probes had un-uniform variations in diameter, mass and width of the lingo-cellulosic blanket, variations in rupture forces, both at crushing as well as shearing, disregarding the plate angle, as well as energy necessary at shearing or the corresponding force to the bio-flow point is between large limits. Still, we find that the shearing energy variation with the mischantus diameter has an exponential variation rising from 0.308 J for 4.29 mm diameter, to 2.315 J to diameter of 7.95 mm.

Also we find that for small widths of the cellulose blanket, disregarding the shearing plate angle, the deformations are more pronounced until the point of rupture, this is due to higher elasticity of the stalk core.

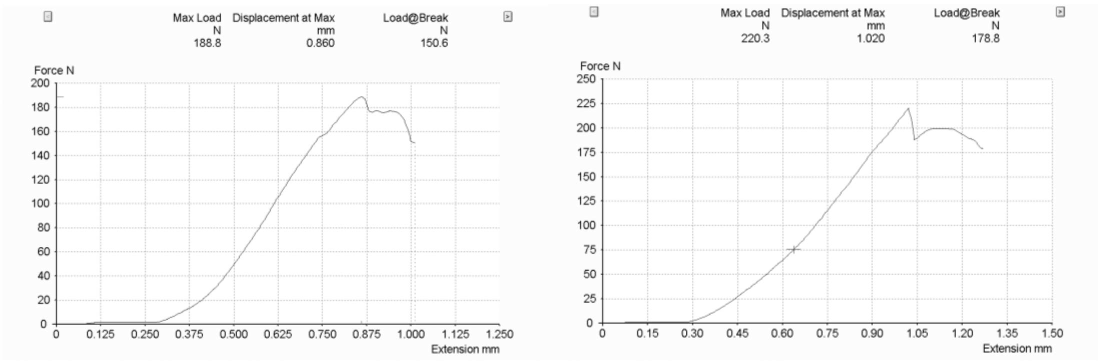

Fig. 4. **The force-deformation crushing curves for samples 1 and 2**

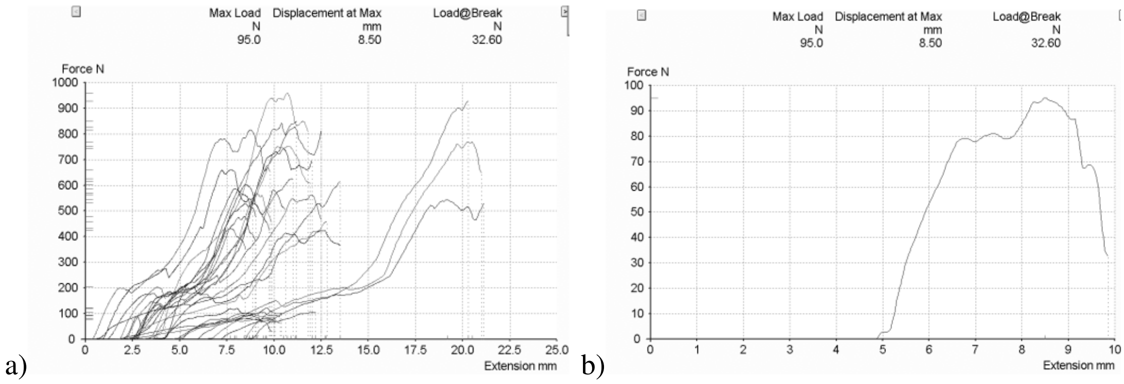

Fig. 5. **The curves resulted from shear stress, force-extension:**
a – shear curves for 20 material probes; b – deformation-force shearing curve for 7 sample

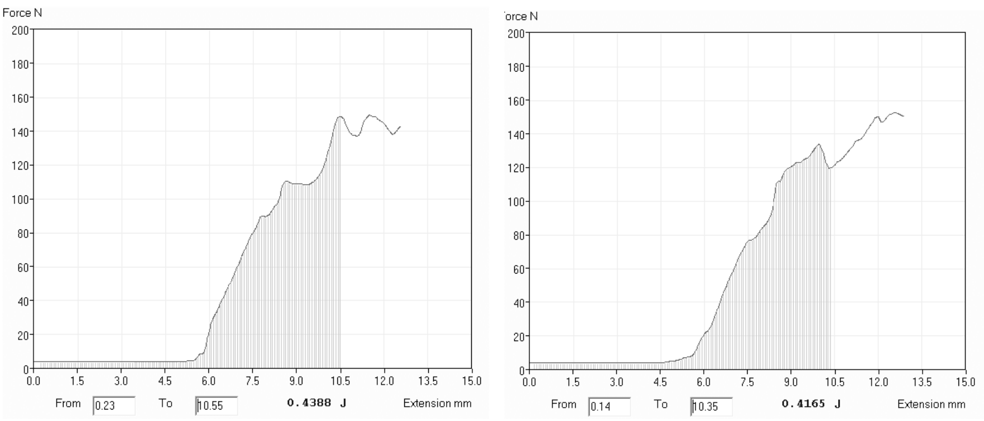

Fig. 6. **Energy consumption determination for samples subjected to shearing tests**

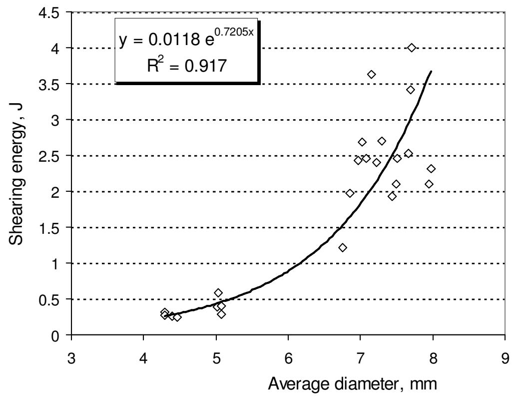

Fig. 7. **Shearing energy versus average diameter**
for analysed miscanthus stalk samples

Conclusions

Variations in large limits of mischantus stalk mechanical characteristics are due to heterogeneity of the biological characteristics and the inter-nods from which the probes have been gathered. We find that the dependence of the rupture force at shearing and at the blade angle is not conclusive. A more profound analysis of the experimental determination results is necessary, that the authors will do, in concordance with other scientifically manifestations, conclusions being made public so specialists in this field can benefit from corresponding data so that designing, manufacturing and exploitation of mischantus stalk mechanical preparation equipment is made on the basis of conclusive experimental data.

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