MECHANICAL PROPERTIES OF BIOMASS PELLETS

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Abstract
The presented paper deals with the assessment of mechanical properties of pellets. Waste biomass in a form of wooden parts of vine prunings, spruce sawdust, and ground sunflower straw were utilized for the pellet production. Mechanical properties were observed by an experimental device Andilog Stentor 1000, using a quasi-static test – compressive loading test between two pistons in the pellets' axial direction. Based on the measured values, loading curves between compress force $F(\varepsilon)$ and compressive strain $\sigma(\varepsilon)$ were plotted, and moduli of elasticity were calculated for each of the materials. The maximum compressive force was 180.76 N for vine prunings pellets; 315.98 N for spruce sawdust pellets; 239.89 N for sunflower straw pellets. The modulus of elasticity showed mean values of 70.83 MPa for vine prunings pellets, 47.37 MPa for spruce sawdust pellets, and 7.48 MPa for sunflower straw pellets.

Key words: *biomass; force; pellet; stress; modulus of elasticity.*

INTRODUCTION
The change in climate conditions and the exhaustion of fossil fuels represent the basic arguments for changing the approach to heat production and biomass processing for energy purposes, whether it is the biomass from fast-growing trees or waste biomass. For its thermal properties, popularity of biomass is growing (*Božiková et al., 2021*); furthermore, the energy sector considers it an extremely important element in terms of reducing CO_2 emissions and it can be seen as an ecological fuel (*Mohanti et al., 2014*). Investigating the properties of fuels is the basis for their efficient utilization. In terms of solid biofuels, compacted biomass represents an alternative for reducing emissions and eliminating landfills (*Malaťák et al., 2020*). Biomass in a form of pellets and briquettes eliminates the disadvantages of so-called raw biomass, which has an irregular shape, low bulk density, high moisture content, which results in issues during handling and storage (*Puig-Arnavat et al., 2014; Zhou et al, 2016*). The pellet quality is influenced by the basic properties of input biomass – particle size, moisture content and chemical composition – and operating conditions under which they are produced, such as die temperature, application pressure, pressing time and mold geometry (*Lestander et al. 2012*). Leftovers from forestry and agricultural production sectors are considered an input biomass for the purposes of solid biofuel formation process (*Križan et. al., 2015; Liu et al., 2016; Nizamuddin et al., 2016*). As a part of the policy for reducing emissions in energetics, significant efforts are made to produce high-quality pellets with utilization of different types of materials – the pellets can be produced from a single material or from a mixture of various types of biomass (*Liu et al., 2013*), by combining mineral raw materials with biomass (*Tsuchia et al., 2017*). Pelleting and briquetting are the most frequently utilized methods for solid biofuel production; mechanical properties represent the essential data on the quality of produced biofuel regardless of whether it is a pellet or a briquette (*Stasiak et al., 2017*). The goal of this paper was to determine the mechanical properties of pellets produced from waste biomass, which can serve as a substitute for fossil fuels.

MATERIALS AND METHODS
The pellet samples were produced from waste biomass including vine prunings, spruce wood and sunflower straw. All materials were obtained locally. All materials were compressed to a pellet form using a MGL 200 pellet press (Kovo Novak, Czech Republic) without adding a binder. Pressing die hole size was 8mm. For the purposes of stabilization, the pellets produced were left on the mat for 48 hours at a constant environmental temperature and humidity. The length and weight of pellets did not change after this time. In order to subject the pellets produced to the experimental loading test to determine their

mechanical properties, the pellet contact surfaces were adjusted for the purposes of test requirements. Ten pellets made of each material were subjected to loading test.
The mechanical properties of biomass pellets were assessed using a static loading test on an Andilog Stentor 1000 experimental device. A pellet was placed on the piston of the experimental device and compressed by the second piston at a speed of 10 mm.min^{-1} in the axial direction until the pellet strength limit was reached, destroying the pellet tested. The upper piston of experimental device automatically returned to its initial position after breaking the pellet.
The test output is a compression diagram expressing the dependence of $F(\varepsilon)$, where F represents the loading force and ε represents the pellet strain following the equation (1):

$$\varepsilon = \frac{\Delta L_0}{L_0} \qquad (1)$$

where ε stands for strain (-), L_0 stands for original pellet length (mm), ΔL_0 movement of the upper experimental device piston.
The maximum loading force F_m and maximum strain ε_m were determined based on the compression diagram.
Subsequently, the dependence was established, in which σ represents the compressive stress calculated according to the equation (2):

$$\sigma = \frac{F}{S} \qquad (2)$$

where σ stands for compressive stress (MPa), F stands for force (N), S stands for cross-sectional area of the pellet (mm^2).
The pellet cross-sectional area was calculated based on the following equation (3):

$$S = \frac{\pi d^2}{4} \qquad (3)$$

where S stands for cross-sectional area of the pellet (mm^2), d stands for pellet diameter (mm).
The maximum compressive stress σ_m was determined based on the compression diagram $\sigma(\varepsilon)$. The modulus of elasticity was determined based on the startup part of the compression diagram. The linear regression method was used to calculate the modulus of elasticity, which is expressed by equation (4):

$$\sigma = E\varepsilon + b \qquad (4)$$

where σ stands for compressive stress (MPa), E stands for modulus of elasticity (MPa), ε stands for strain (-), b stands for σ-intercept (MPa).

RESULTS AND DISCUSSION

Tab. 1 shows the statistical evaluation of observed parameters of pellets made of all investigated types of biomass.
Considering the results of observed pellets from all materials, it was found that the mechanical properties of pellets produced utilizing an industrial press are quite variable, which is mainly due to the fact that the material is not pressed in a closed mold with a fixed bottom, but continuously pushed through the machine die.
The highest loading force, and consequently pressure, was showed by pellets made of spruce sawdust. *Gorzelány et al. (2020)* achieved an average value of F_m = 222.85 N when testing spruce pellets, which is a value lower than the value observed in the experiment presented. On the contrary, the authors also achieved an average value of σ_m = 7.88 MPa that is higher than the value found in the experiment presented, which is most likely due to the different diameters of tested pellets. The strength of pellets made of spruce sawdust was also investigated by *Huang et al. (2017)* who monitored the compressive strength of spruce pellets. The authors achieved significantly higher values of strength and modulus of elasticity, which was caused by application of higher pressure and temperature values during compaction process.
Lower mean force and pressure values were recorded for sunflower straw pellets. The median values of F_m did not differ significantly for spruce and sunflower pellets.
The lowest values of F_m and σ_m were showed by vine prunings pellets. *Gallego et al. (2020)* also dealt with the topic of determining the modulus of elasticity, observing the mean modulus of elasticity value of spruce pellets of 73.33 MPa, which might have been affected by the increasing moisture content in the samples. Very similar value was observed for the vine prunings pellets.

Tab. 1 Descriptive statistics of pellet compression tests

	F_m N	E MPa	ε_m -	σ_m MPa
Vine prunings pellets				
Mean	180.76	70.83	0.12	3.17
Standard Error	34.84	8.63	0.06	0.61
Median	174.31	63.24	0.05	3.07
Standard Deviation	104.53	25.88	0.19	1.84
Minimum	86.86	37.23	0.02	1.53
Maximum	437.49	123.80	0.63	7.71
Spruce sawdust pellets				
Mean	315.98	47.37	0.18	5.58
Standard Error	48.21	10.06	0.02	1.51
Median	275.98	46.43	0.17	8.86
Standard Deviation	144.64	30.17	0.07	4.52
Minimum	117.78	17.00	0.07	2.09
Maximum	548.72	111.60	0.34	9.67
Sunflower pellets				
Mean	239.89	7.48	0.35	4.06
Standard Error	37.27	1.61	0.04	0.66
Median	208.65	6.09	0.33	3.43
Standard Deviation	111.79	4.83	0.11	1.98
Minimum	100.84	3.43	0.23	1.59
Maximum	436.85	19.54	0.56	7.70

Values of modulus of elasticity similar to the values presented were obtained by *Matkowski et al. (2020)* when investigating pellets produced from wheat straw with addition of calcium carbonate. The mean value of the modulus of elasticity of the mixture pellets examined was E = 7.42 MPa, which is approximately the same value as in pellets made of pure sunflower biomass observed in this research.
The mean maximum strain values ε_m were approximately the same for vine and spruce pellets. A higher value was recorded for sunflower pellets, which is due to the fact that the ground straw is culm plant material.

CONCLUSIONS

The work presented was aimed at determining the mechanical properties of pellets made of three types of wood and plant biomass. Based on the results obtained utilizing compression tests, it can be concluded that the mechanical properties of pellets produced by employing industrial technology are quite variable, yet it is possible that the plant waste biomass can be used for the production of pellets in the same way as wood biomass. Improving the mechanical properties of pellets produced from plant biomass will be the subject of future research.

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