STRENGTH OF BRIQUETTES AND PELLETS FROM ENERGY CROPS

Adam Swietochowski, Aleksander Lisowski, Magdalena Dabrowska-Salwin
Warsaw University of Life Sciences, Poland
adam_swietochowski@sggw.pl, aleksander_lisowski@sggw.pl, magdalena_dabrowska@sggw.pl

Abstract. The plant materials are characterized by a variety of chemical compounds containing both organic and inorganic of simple and complex chains. The variety of materials and their variability during the compaction process is causing difficulties in defining the intermolecular forces which have arisen as a result of sufficient approximation of the particles. Where as the internal forces have a direct effect on the strength properties of the agglomerates. The study used biomass from willow, Miscanthus, and Virginia mallow. Laboratory tests were conducted according to the developed program, in the range that allows to estimate the effect of the factors on the mechanical properties of the produced pellets and briquettes. Plant species (3 species), the way of deformation of formed fuel (shear, compression, bending) and form of solid fuel (briquettes, pellets) and their interactions double and triple in most cases proved to be statistically significant differences of the strength values. From the analysis of the mean values of strength parameters of Duncan's test it shows that plants did not survive reproducibility of their rankings between these parameters and methods and deformation took a different order for medium strength parameters. The average values of penetration resistance, elasticity modulus, maximum stress and the specific energy of deformation were however clearly lower for briquettes than pellets.

Keywords: biomass, mechanical strength, pressure agglomeration.

Introduction

As compared to other commonly used energy sources, biomass is a quite laborious fuel. First of all, this results from its physical and chemical properties. This material is heterogeneous and has a very low energy value related to the volume unit. Therefore, the technologies of production of the formed fuel from available in Poland resources are necessary. Instead of wood and waste materials from agricultural production, an important raw material to production of the green fuel could be perennial plantations of energy crops. The raw material from them could be converted into the form of pellets or briquettes in the pressure agglomeration process [1-2].

The plant materials have some ability to create a solid form with specific strength parameters under pressure. This ability is described as a material susceptibility on the compaction [3-5]. The agglomeration of shredded biomass under high pressures causes elasticity and plastic deformations [6-9], resulting in formation of the external shape of the particles and it allows to their common connection through mutual interlocking and wedging. The internal forces have a direct influence on the strength properties of the agglomerates. In the available literature there is a lack of results from strength comparative tests of the pellets and briquettes made of the same biological materials. For that reason, the aim of the study is to explain the influence of the chosen types of materials from energy crops and a type of formed solid fuel on the Young's elasticity modulus and stress strength during compression, shear and bending the pellets and briquettes.

Materials and methods

For the tests materials from three energy plant species (willow, Miscanthus and Virginia mallow)were used. It was manually cut and then stationary shredded by the forage harvester. The part of the material, after drying, was shredded again using the hammer mill shredder. The pellets and briquettes used for further tests were produced at the research stands in the technical scale. The briquettes were produced at a hydraulic press APT of Alchemik firm, equipped with a die with diameter of 50 mm, whereas the pellets were produced using a granulator type PD-1 of Testmer SA firm in Michałowice, with a ring die with the hole diameter of 6 mm. For trials for bending, compression and shear of the pellets and briquettes, the universal testing machine TIRA test was used. Its measurement range of the force was to 10 kN and the accuracy was 1 %, and for the displacement it was 1000 ± 0.02 mm. The measurement of compression of the pellets and briquettes placed on the metal plate took place using a rectangular stamp of dimensions 25 × 50 mm. The pellets and briquettes were compressed, cut and bended with the speed of 10 mm·min^{-1}. The strength tests were conducted in 10 repetitions on the randomly chosen samples of pellets and briquettes. The measurements of agglomerate dimensions (diameter and height) were made in the two mutually perpendicular surfaces with an electronic scale with an accuracy of 0.01 mm. To shear, the die of the testing machine was equipped with a flat knife having a thickness of 5 mm and the blade angle of 30º. During bending, the agglomerates were placed on two supports spaced at a distance of 20 mm for the pellets and 60 mm for the briquettes. The samples were bent by a metal pin mounted in the die and placed in the middle of the supports.

For the tested agglomerates the elasticity modulus and maximum stress at shear, compression and bending were determined. The elasticity modulus at shear, compression and bending was calculated as secant modulus, mean quotient of stress and relative deformation for the point, where the first inflection of the curve force-displacement was shown [10-11]. The elasticity modules were calculated from the formulas:

$$E_t = \frac{F_t d}{S \Delta l_t}, \; E_c = \frac{F_c d}{S \Delta l_c}, \; E_g = \frac{F_g l_b^3}{48 I y_c}, \tag{1}$$

where E_t, E_c, E_g – elasticity modulus at shear, compression, bending, Pa,
F_t, F_c, F_g – shear, compression, bending force, N,
d – diameter of a pellet and briquette before a load in the place of force application, N,
S – cross-section to the load, m^2,
Δl_t, Δl_c– cross deformation of the agglomerate under load, m,
l_b – spacing of the supports, m,
y_c – deflection of the sample, m,
I – polar moment of inertia, m^4.

The value of the polar moment of inertia for pellets and briquettes was determined for circular section from the formula:

$$I = \frac{\pi d^4}{64}, \tag{2}$$

where d – diameter of the pellet or briquette, calculated as arithmetic mean from the measurements made in two mutually perpendicular surfaces of the cross-section, m.

The maximum stress was calculated for the maximum loading force and the cross-section surface of the cutting, compressing or bending the sample or for a real surface, to which the compression force works, from the following equations:

$$\tau_{t\max} = \frac{F_{t\max}}{S_t}, \; \sigma_{c\max} = \frac{F_{c\max}}{S_c}, \sigma_{\mathrm{g}\max} = \frac{F_{\mathrm{g}\max} l_{\mathrm{b}} y}{4I}, \tag{3}$$

where $\tau_{t\max}$, $\sigma_{c\max}$, $\sigma_{g\max}$ – maximum stress at shear, compression and bending, MPa,
$F_{t\max}$, $F_{c\max}$, $F_{g\max}$ – maximum force for shear, compression and bending, N,
S_t – cross-section of a shear sample, mm^2,
S_c – surface where the loading force works, mm^2,
l_b – distance of sample support points, mm,
y – distance between the external surface of the pellet or briquette and the neutral axis of the sample, mm,
I – moment of inertiaof the cross-section, mm^4.

The statistical analysis of the results was conducted using the computer program Statistica v.10.

Results and discussion

The results of the analysis of variance allow to the conclusion that the main factors including the plant species (three species), the way of formed fuel deformation (shear, compression, bending) and the form of a solid fuel (briquettes, pellets) and their double and triple interactions, in most cases were statistically significantly differentiating the values of strength parameters, such as elasticity modulus and maximum stress (Tables 1 and 2). From the main factors only the form of fuel was statistically insignificant on the differentiation of the values of maximum stress of deformation ($F_{v1=1,\, v2=105} = 1.45$,

p = 0.2318, Table 2), and from the interaction – between the way of deformation and the material type on the elasticity modulus during deformation of the solid fuel ($F_{v1=4,\ v2=105}$ = 2.4, p = 0.0542, Table 1).

Table 1

The results of the analysis of variance of the factors affecting the Young's modulus of briquettes and pellets

Source	Sum of squares	Degree of freedom	Mean square	Test *F*	*p*-value
Specie: A	1969.8	2	984.9	5.07	0.0079
Load type: B	11856.3	2	5928.1	30.50	<0.0001
Form: C	32500.7	1	32500.7	167.20	<0.0001
Interaction: A × B	1869.8	4	467.4	2.40	0.0542
Interaction: A × C	1476.6	2	738.3	3.80	0.0255
Interaction: B × C	13865.5	2	6932.7	35.67	<0.0001
Interaction: A × B × C	1979.4	4	494.9	2.54	0.0437
Error	20407.4	105	194.4	-	-

Table 2

The results of the analysis of variance of the factors affecting the maximum stresses of briquettes and pellets

Source	Sum of squares	Degree of freedom	Mean square	Test *F*	*p*-value
Specie: A	14.17	2	7.09	10.00	0.0001
Load type: B	115.5	2	57.77	81.56	<0.0001
Form: C	1.02	1	1.02	1.45	0.2318
Interaction: A × B	55.92	4	13.99	19.74	<0.0001
Interaction: A × C	12.09	2	6.05	8.54	0.0004
Interaction: B × C	163.2	2	81.60	115.20	<0.0001
Interaction: A × B × C	15.46	4	3.87	5.46	0.0005
Error	74.37	105	0.708	-	-

The elasticity Young's modulus at shear, compression and bending the briquettes was comparatively low and was in the range (0.69-7.17 MPa, Fig. 1). The elasticity modulus at bending the briquettes has changed from 0.69 MPa (willow) to 2.26 MPa (Virginia mallow), at shear from 1.18 MPa (Miscanthus) to 2.97 MPa (Virginia mallow) and at compression from 4.26 MPa (Miscanthus) to 7.17 MPa (willow). The elasticity modulus related to the pellets was significantly more differentiated. The highest values of that parameter were obtained during bending, from 43.59 MPa (Miscanthus) to 82.87 MPa (willow). The elasticity modulus during compression was more aligned and was from 15.40 MPa (Miscanthus) to 34.75 MPa (willow), and the smallest differences were at shear, because the values of that modulus were from 15.31 MPa (willow) to 20.52 MPa (Miscanthus).

The maximum stresses during the tested methods of briquett and pellet deformations are more differentiated and unequivocal both in reference to plant species and to the method of deformation. For all plant species the ranking of the maximum stresses was the following: shear stress1.15 MPa, bending normal stress 2.75 MPa and compression normal stress 2.99 MPa. The ranking of the plant species in relation to the stresses was the following: Miscanthus 2.00 MPa, Virginia mallow 2.13 MPa and willow 2.70 MPa. During shear, the maximum stresses for pellets were more than twice higher. For pellets and briquettes made of plant materials, the maximum stresses at shear were aligned. The smallest maximum stresses at bending had briquettes and pellets from willow, and the highest from Virginia mallow – 2.36 MPa. The maximum stresses at pellet bending were almost 2.5 times higher than for briquettes.

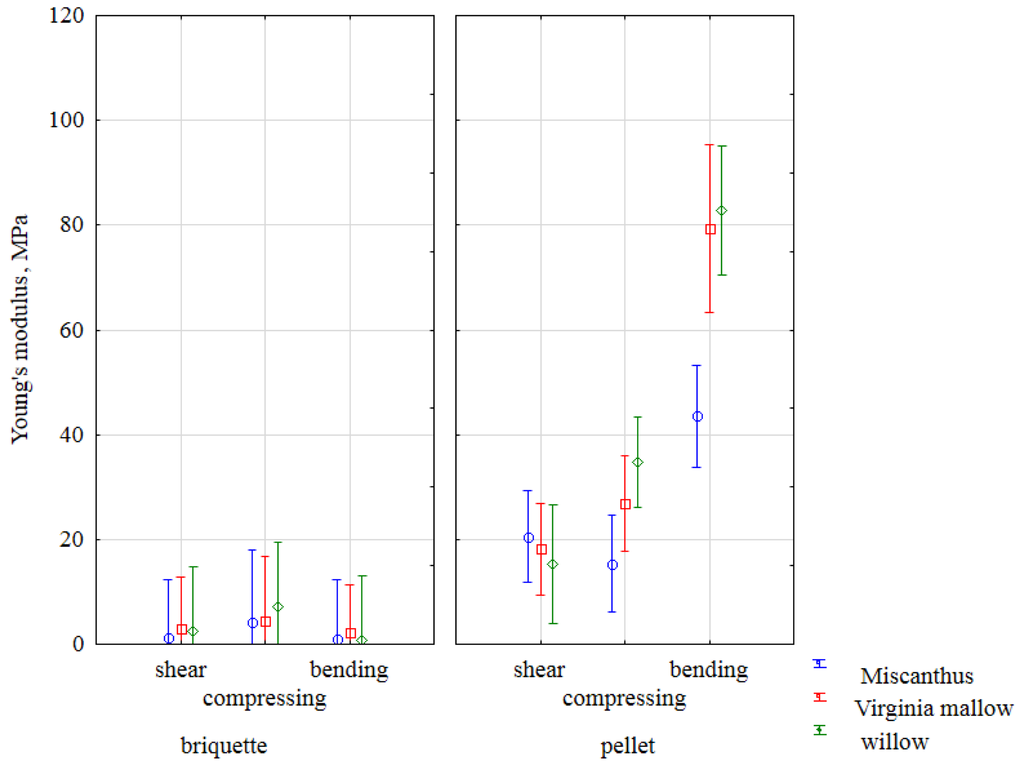

Fig. 1. **Interactions between fuel forms, plant species and the load type on the Young's modulus of briquettes and pellets**

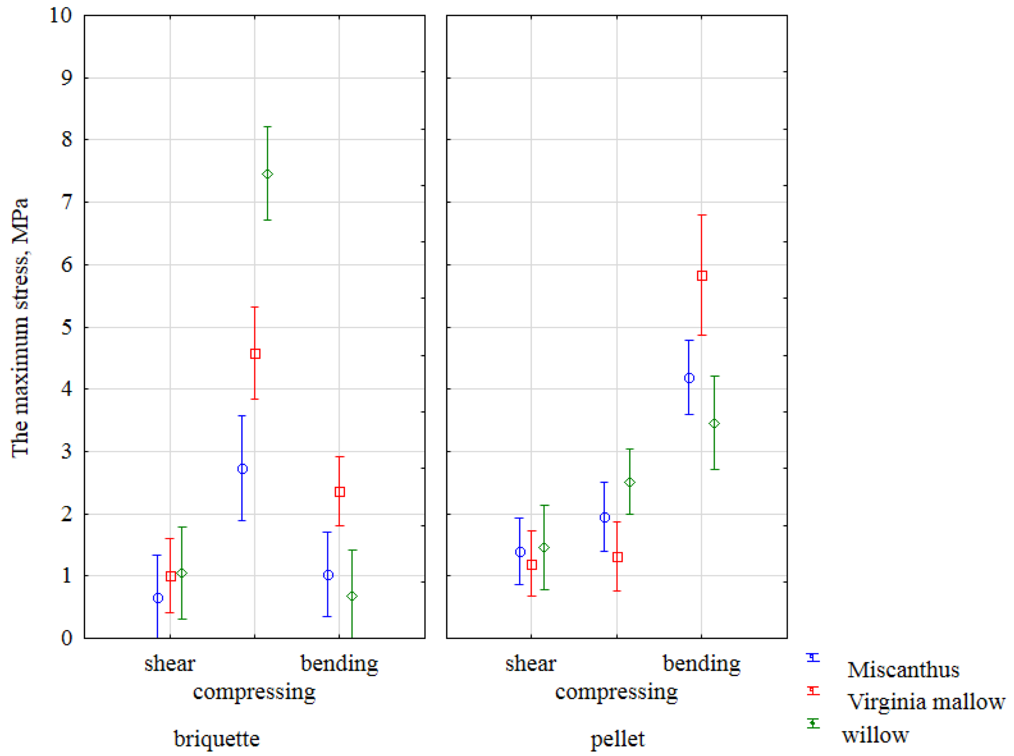

Fig. 2. **Interactionsbetween fuel forms, plant species and the load type on the maximum stress of briquettes and pellets**

The maximum normal stresses at briquettes shear had created three homogenous groups. The smallest maximum stresses at shear had agglomerates made of material from Miscanthus – 2.73 MPa.To the second group belonged the material from Virginia mallow – 4.58 MPa, and to the third one from willow 7.46 MPa. The maximum stresses at compression for pellets were more differentiated, from 1.32 MPa for Virginia mallow to 2.51 MPa for willow. For coal briquettes, Richards [12] recommended an acceptance level for compressive strength as 375 kPa.

Conclusions

1. The plant species (3 species), the method of formed fuel deformation (shear, compression, bending) and the form of solid fuel (briquettes, pellets) and their double and triple interactions in the most cases were statistically significantly differentiating the strength parameter values.
2. From the analysis of the mean values of the strength parameters results that for the agglomerates from energy plants, there was no recurrence of their ranking from the method of deformation. They took a different order for mean strength parameters.
3. The mean values of the elasticity modulus and the maximum stresses of deformation were in the most cases smaller for briquettes than for pellets.

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