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DETERMINATION OF LOADS AFFECTING A SLEEVE COMPACTING BRIQUETTE PRESSES

Key words

Compacting sleeve, characteristics of loads, fatigue life, briquette press.

Abstract

Compacting sleeves that are components of briquette presses undergo time variable loadings that are characteristic of the briquette press operation. These sleeves have a specific fatigue life; and, after having worked for a certain period of time, they fail to operate. In order to continue the operation process, they need to be replaced with new ones. Manufacturers of briquette presses define the life of compacting sleeves to be approximately 2 thousand hours. However, it often happens that the life of such a sleeve is significantly shorter than the expected one. This work presents calculation models for a sleeve with length 380 mm and diameter 50 mm (diameter of briquette) under a pressure with maximum value 16 MPa. The presented models allow one to determine stresses for unloading and loading with the use of a numerical method. These stresses can be used for the estimation of the fatigue life of operating sleeves or for the dimensioning of newly designed sleeves.

Introduction

The share of energy coming from renewable energy sources (RES) has been systematically growing from year to year [1]. In 2103, biomass played a very important role in the utilization of renewable energy [1]. Actually, it was dominant, and biomass utilization accounted for 46% of renewable energy sources in the European Union, but it was 80% in Poland.

In Poland, forest biomass has dominated for a long time on the market. However, according to the provision of the Minister of Economy (15 August 2008), since 2015, manufacturers have been obliged to eliminate the share of wastes and by-products of forest origin from the combusted biomass. Therefore, agricultural biomass is receiving more and more attention, because it is becoming a more competitive material used for burning than conventional fuels due to its low price [2, 3]. Agricultural biomass is characterized by a very low density, which causes problems during transport and storing. Thus, it needs to be compacted. This process is performed in presses, briquette presses, granulators, and devices which combine characteristics of the above listed machines [4, 5].

During the process of biomass compacting in the above-mentioned machines, there occur time variable loads. In consequence, these loads lead to quick destruction of their inappropriately designed working components. As far as briquette presses are concerned, the most affected component is the sleeve (further referred as compacting) including the chamber that compacts and transports the briquette. In order to provide the sleeve with adequate material and geometric properties, it is necessary to be familiar with the loads the sleeve has to withstand. It is very difficult to define these loads, because they depend on many variables including moisture, the contamination of the feedstock mass, and the density of the obtained briquette, etc. There are numerous publications [e.g., 6, 7] which include characteristics of available briquettes such as calorific value, bulk density, ash content, etc. However, it is not easy to find calculation models for compacting sleeves or briquette properties such as Young modulus, or Poisson ratio.

This work presents calculation models for a sleeve with 380 mm length and a working diameter equal to 50 mm (diameter of briquette) operating in a hydraulic briquette press for briquetting straw under the pressure of piston equal to 16 MPa. The presented models make it possible to calculate stresses for loading and unloading with the use of a numerical method.

1. Scheme of a hydraulic briquette press

A standard hydraulic briquette press consists of worm conveyor (1) (Fig. 1) transporting biomass to initially compacting chamber (6), two hydraulic cylinders (3 and 4), with an initial compacting punch (2), a pressing punch (5), and compacting sleeve (9). In the sleeve, there is the last hydraulic braking cylinder (8), which is used to control the degree of the sleeve closing (9).

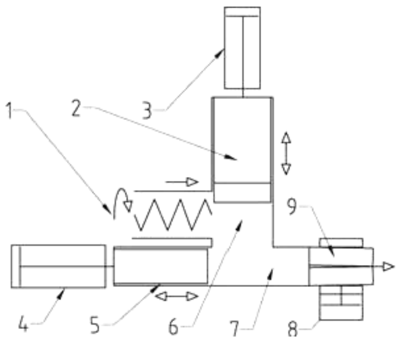

Fig. 1. Scheme of a hydraulic briquette press

During its operation, the analysed compacting sleeve is exposed to time variable loads. These loads change from minimum values to maximal ones at the rate equal to 11 times per minute. The minimum value of loading is connected with the cycle of unloading (see Figure 1, Punch 5 in the left position and 2 in the upper position); however, the maximum load value is within the cycle of loading (Punch 5 in the right position, Punch 2 in the lower position and for a closed braking Cylinder 8).

2. Defining loads affecting the sleeve

Work [4] is a very broad publication, which presents, among others, experimental tests of a sleeve during briquetting of spruce sawdust under loading of a press piston equal to 72 MPa. However, these are tests of an open sleeve with an internal diameter of 50 mm and a length of 305 mm. Due to similarity connected with the compacting sleeve and the briquette material, the calculation models have been developed based on work [4]. Since, in this case, the tests were conducted for an open sleeve, the load that was added came from the braking piston. Loads in the sleeve were classified in the following way (Fig. 2):

- Q_{r1} – radial force (lateral) [N] for unloading producing load per unit surface (lateral pressures) $\mathbf{q_{r1}}$ [MPa],
- Q_{r2} – radial force (lateral) [N] for the working cycle producing load per unit surface (lateral pressures) $\mathbf{q_{r2}}$ [MPa],
- T – friction force [N] for a working cycle producing tangent load per unit surface **t** [MPa],
- P_{tp} – compacting force [N] coming from the press piston and producing load per unit surface of briquette $\mathbf{p_{th}}$ [MPa],
- P_{th} – force that makes the sleeve bend [N] producing displacement of the sleeve in the area of application of the piston rod $\mathbf{U_{th}}$ [mm].

The load caused by the braking piston in Figure 2 is provided in brackets, since the characters of loads presented in diagrams (t-z and $q_{r1(2)}$-z) do not include this load.

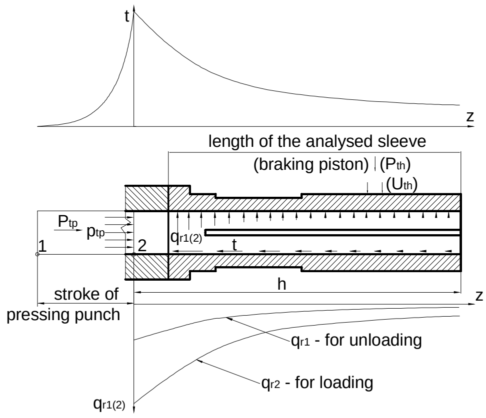

Fig. 2. Scheme of loads within the sleeve

Source: Author's research based on pos. [4].

Radial loads Q_r are connected with the pressure of the briquette pressed onto the internal walls of the sleeve. The loads per unit surface q_{r1} and q_{r2} that come from force Qr depend mainly on the loading generated by a pressing punch and the coefficient of friction between the briquette and the internal surface of the sleeve. According to pos. [4], the distribution of these loads per unit surface is the highest in the contact point of the briquette with the press piston in the operating mode (Point 2 in Fig. 2). Next, the load gradually decreases in the direction of the area where the briquette quits the sleeve. The author of [4] has conducted numerous tests and described the distribution of loads occurring in the sleeve, based on the tests results, with the use of an equation in the form of a polynomial of the third degree. An exemplary equation for q_{r2} with $R^2 = 0.9837$ is presented below:

$$q_{r2} = -57.369\left(\frac{z}{h}\right)^3 + 129.509\left(\frac{z}{h}\right)^2 - 95.511\left(\frac{z}{h}\right) + 28.401 \quad [4] \qquad (1)$$

where: h – length of sleeve according to Fig. 2,
z – distance "z" according to Fig. 2.

Tests results included in work [4] were used to produce equations q_{r1} [MPa] (2) and q_{r2} [MPa] (3) describing the character of pressures proportionally to the pressure of piston and the sleeve length. In order to be able to apply the equations for a numerical analysis, they were made dependent merely on distance "z" [mm], whereas Point 2 was accepted to be $z = 0$ (Fig. 2). Diagrams depicting the character of radial pressures are shown in Figure 3.

$$q_{r1} = 6.656967E\text{-}10 \cdot z^3 + 1.12744874E\text{-}5 \cdot z^2 - 7.9305064E\text{-}3 \cdot z + 1.66605114 \quad (2)$$
$$q_{r2} = - 2.3233465E\text{-}07 \cdot z^3 + 1.9930594E\text{-}4 \cdot z^2 - 5.5854386E\text{-}2 \cdot z + 6.311333 \quad (3)$$

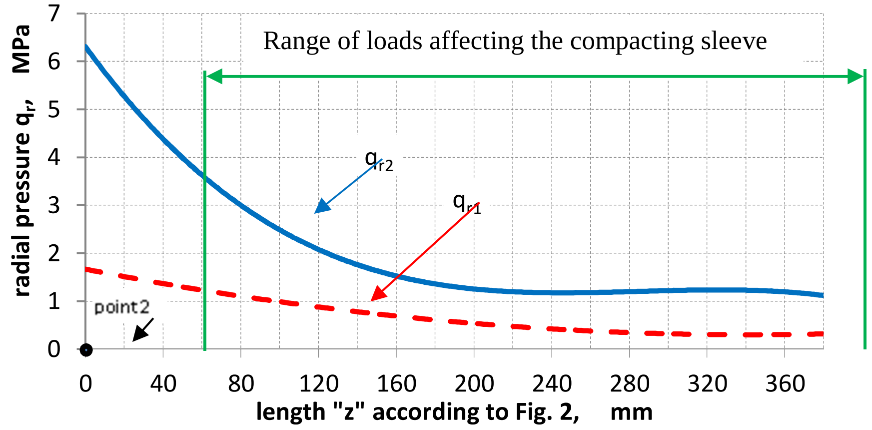

Fig. 3. Diagrams describing the distribution of radial pressures (lateral pressures) q_r in the function of the sleeve length

The tensile load of the sleeve is connected with friction forces *T* that occur between the briquette and the internal wall of the sleeve. In order to shift the briquette along the sleeve in the direction of the outlet opening, friction force *T* must be overcome by the press cylinder, which produces force P_{tp}. Force P_{tp} needs to be higher than the friction force *T*. According to the friction conditions of Coulomb (4), based on q_{r2}, it is possible to determine an equation of tangent stresses *t* to the sleeve surface that can be overcome by introduction of tensile stresses.

$$t = \mu \cdot q_{r2} \quad [4], \quad (4)$$

where: *t* – tangent stresses between the briquette and internal walls of the sleeve, [MPa],
μ – coefficient of friction between the briquette and the internal walls of the sleeve.

For this purpose, it is necessary to determine the coefficient of friction between the briquette and the internal surface of the sleeve walls μ. According to the author of [4], the lowest value of friction coefficient occurs at the beginning of the sleeve, where there are the highest values of compacting forces and lateral forces. In order to determine tangent stresses *t*, the friction coefficient was accepted to be μ = 0.35. It enabled the determination of tangent loads for the sleeve surface *t* [MPa]. The characters of these loads are presented in Figure 4. The results from the diagram are described by a polynomial regression function

(5). The $\mu = 0.35$ is a relatively low value presented in the paper [4]. The value of this coefficient depends on many variables (moisture, type of biomass, impurities, etc.). In order to avoid an underestimation of the sleeve loads, it is better to adopt a greater friction coefficient even up to $\mu = 0.6$.

$$t = -8.1317126E\text{-}08 \cdot z^3 + 6.9757079E\text{-}05 \cdot z^2 - 1.95490351 \cdot z + 2.2089666 \qquad (5)$$

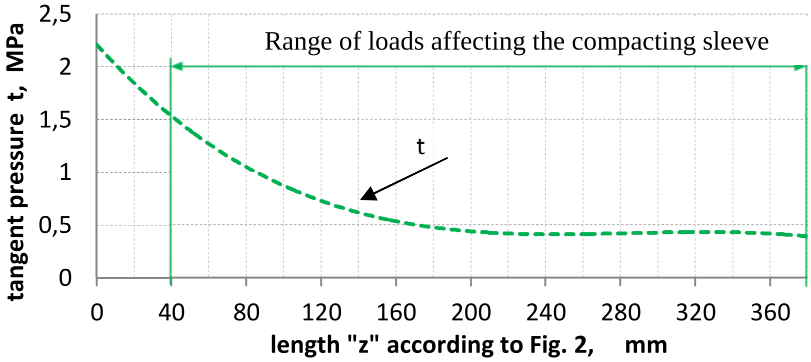

Fig. 4. Diagram of tangent pressure *t* in the function of the sleeve length

Force P_{th} that makes the sleeve bend derives from a braking hydraulic cylinder. In order to apply this load, it is necessary to be familiar with Young briquette modulus. It needs to be emphasized that the type of material used for briquettes is an anisotropic material that is characterized by different Young's modulus along the axis and along the radius. For instance, for rape straw, Young's modulus along the briquette axis is 25.9 MPa, and, along the radius, it is 14.3 MPa [8]. The same author provides Young's modulus along the briquette axis equal to 6.4 MPa (for density 680.9 kg/m^3).

Young's modulus for briquettes is accepted for numerical calculations and is of key importance for these calculations. The smallest values of Young's modulus are accepted for calculations of the higher values of stresses causing the sleeve to bend. This is because, for a lower Young's modulus, the displacements of the sleeve end along the breaking cylinder axis will be larger; therefore, it will cause higher stresses in the sleeve. Therefore, in order to avoid an error connected with selection of Young's modulus, the loading caused by the force of a braking piston was replaced by displacement.

The displacement was defined experimentally based on its measurements during the straw briquetting. The value of the gap between the upper and the lower part of the sleeve for unloading (Fig. 5a) was 5.4 mm. It was assumed that both parts of the sleeve shifted by the same value (the gap was 6 mm before mounting). This is only an assumption, since, in reality, the upper part of the sleeve is more loaded. This is connected, among others, with the mass mounted to the sleeve (hydraulic cylinder, body, screws, etc.) According to this assumption, the end of the upper part was lowered by $u_{k1} = 0.3$ mm, whereas the end of the lower part was raised by the same value $u_{k1'} = 0.3$ mm, producing a gap while unloading that is equal to 5.4 mm. However, during a work cycle, the upper and the lower ends almost come into contact with each other (Fig. 5b). The ends are prevented from coming into full contact either by fragments of straw that get between the contacting surfaces of the sleeve or by the stiffness of the briquette. The effect is that, during a working cycle, the gap between the sleeve ends was app. 1 mm. Moreover, assuming that both fragments of the sleeve are loaded identically, the total shift of the upper part (after summing displacement with unloading $u_{k1} = 0.3$ mm) is by $u_{K2} = 2.5$ mm.

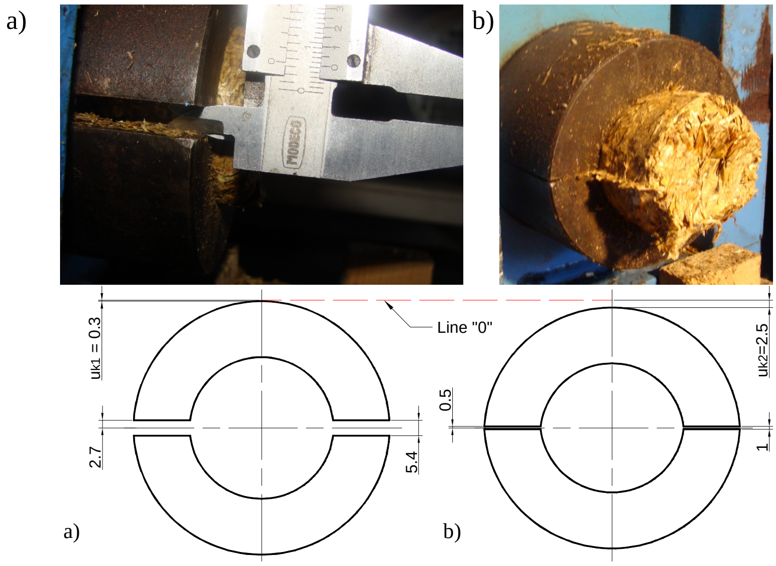

Fig. 5. The value of the gap between the lower and the upper part of the sleeve for an unloading cycle (a) and working cycle (b) during straw briquetting

Conclusion

The determination of loads affecting a compacting sleeve of a briquette press is a difficult issue, not often referred to in scientific literature in the field of strength and fatigue of materials. Many different factors contribute to the sleeve loading. They are connected with different parameters of the biomass (type, disintegration degree, moisture, etc.) intended for briquetting. The above presented calculation models are to assist in the process of the selection of the material and geometric characteristics of a compacting sleeve.

The numerical values of strain/stress determined with the use of these models should be treated as indicative results. A sleeve designed using these models should be verified by experimental tests according to the particular kind of briquette press and biomass.

References

1. http://stat.gov.pl/files/gfx/portalinformacyjny/pl/defaultaktualnosci/5485/1/3 /1 /energia2015.pdf.
2. Adamczyk F., Frąckowiak P., Mielec K., Kośmicki Z.: Trwałość brykietów ze słomy przeznaczonej na opał, uzyskanych metodą zwijania. Journal of Research and Applications in Agricultural Engineering, 51(1), 2005, 33–36.
3. Denisiuk W.: Produkcja roślinna jako źródło surowców energetycznych. Inżynieria Rolnicza, 5 (80), 2005, 123–131.
4. Hejft R.: Ciśnieniowa aglomeracja materiałów roślinnych, Radom 2002.
5. Borkowski G.: Wykorzystanie brykietowania do zagospodarowania odpadów, Lublin 2011.
6. Stolarski M.J, Szczukowski S., Tworkowski J., Krzyżaniak M., Gulczyński P., Mleczek M.: Comparison of quality and production cost of briquettes made from agricultural and forest origin biomass, Renewable Energy 57 (2013) 20–26.
7. Demirbas A.: Physical properties of briquettes from waste paper and wheat straw mixtures, Energy Conversion & Management 40 (1999) 437–445.
8. Ramírez-Gómez Á., Gallegoa E., Fuentes J.M., González-Montellanob C., Ayuga F.: Values for particle-scale properties of biomass briquettes made from agroforestry residues. Particuology 12 (2014) 100–106.

Zdefiniowanie obciążeń działających na tuleję zagęszczającą brykieciarki

Słowa kluczowe

Tuleja zagęszczająca, charakterystyka obciążeń, trwałość zmęczeniowa, brykieciarka.

Streszczenie

Tuleje zagęszczające pracujące w zespole roboczym brykieciarek poddawane są zmiennym w czasie obciążeniom wynikającym z charakteru pracy brykieciarki. Tuleje te posiadają określoną trwałość zmęczeniową i po przepracowaniu pewnej ilości godzin zostają zniszczone i w celu dalszej eksploatacji brykieciarki należy je wymieniać na nowe. Producenci brykieciarek najczęściej określają trwałość tuli zagęszczających na około 2 tys. godzin. Bardzo często okazuje się jednak, że trwałość takiej tulei jest zdecydowanie niższa od zakładanej. W niniejszej pracy przedstawiono modele obliczeniowe

dla tulei o długości 380 mm i średnicy roboczej 50 mm (średnica brykietu). Przedstawione modele umożliwiają określenie metodą numeryczną naprężeń przy odciążeniu oraz obciążeniu. Naprężenia te następnie mogą być wykorzystane do szacowania trwałości zmęczeniowej pracujących tulei lub do wymiarowania nowo projektowanych tulei.