Krzysztof WAŁĘSA, Dominik WILCZYŃSKI, Krzysztof TALAŚKA, Jan GÓRECKI, Dominik WOJTKOWIAK
Poznan University of Technology, Chair of Basics of Machine Design
ul. Piotrowo 3, 60-965 Poznań, Poland
email: krzysztof.walesa@put.poznan.pl

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PRELIMINARY RESEARCH OF THE BIOMASS CUTTING PROCESS FOR ITS MATHEMATICAL MODEL FORMULATING

Summary

Renewable energy sources are an important component of energy economy. One of its most popular types is plant-based biomass. Among its various types, grass plant straw in form of dried stems and leaves calls for particular attention. Its main source is the cultivation of grains for fodder and consumption. The use of biomass as an energy source requires mechanical processing which entails fragmentation of the material followed by compaction to form briquette which may be used as fuel in boilers. The fragmentation process is mostly breaking and cutting. The Chair of Machine Design Basics of the Poznań University of Technology has taken up work to analyze the energy consumption of the biomass fragmentation process with utilization of a drum-type cutting system. This article presents the preliminary study of cutting triticale straw, allowing to identify any possible problems arising during that process. The forces required for shearing grain stems will be established and utilized to design a mathematical model for the cutting process of similar materials. The obtained material characteristics for the course of the cutting process will be employed in the formulation of the physical model. The end result of such work shall be the analysis of process energy consumption for the drum type cutting system.

Keywords*: renewable energy sources, biomass, straw, shearing, cutting, breaking up*

BADANIA WSTĘPNE PROCESU CIĘCIA BIOMASY NA POTRZEBY BUDOWY JEGO MODELU MATEMATYCZNEGO

Streszczenie

Odnawialne źródła energii są ważnym elementem gospodarki energetycznej. Jednym z bardziej popularnych ich rodzajów jest biomasa pochodzenia roślinnego. Wśród jej odmian na szczególna uwagę zasługuje słoma roślin trawiastych w postaci zasuszonych łodyg z liśćmi. Jej głównym źródłem jest uprawa zbóż paszowych i konsumpcyjnych. Zastosowanie biomasy jako źródła energii wymaga jej obróbki mechanicznej, która polega na rozdrabnianiu i następującym po tym zagęszczaniu do postaci brykietu, który może być spalany w kotłach grzewczych. Proces rozdrabniania słomy jest realizowany głównie przez jej łamanie i ścinanie. W Katedrze Podstaw Konstrukcji Maszyn Politechniki Poznańskiej, podjęto prace badawcze polegające na analizie energochłonności procesu rozdrabniania biomasy z wykorzystaniem zespołu tnącego typu bębnowego. W artykule przedstawiono wstępne badania cięcia słomy pszenżytniej, które pozwolą na rozpoznanie ewentualnych problemów występujących podczas tego procesu. Wyznaczone siły niezbędne do ścinania łodyg zbóż będą wykorzystane przy opracowywaniu modelu matematycznego procesu cięcia takiego materiału. Uzyskana charakterystyka zachowania się tego materiału podczas cięcia będzie wykorzystana przy formułowaniu jego modelu fizycznego. Końcowym rezultatem prac będzie analiza energochłonności procesu rozdrabniania biomasy przy zastosowaniu zespołu tnącego typu bębnowego.

Słowa kluczowe: *odnawialne źródła energii, biomasa, słoma, ścinanie, cięcie, rozdrabnianie*

1. Introduction

Biomass is employed in energy generation and is classified as a renewable source. Following Art. 2 of the Directive no. 2009/28/WE of April 23, 2009 by the European Parliament and Council, on promoting the utilization of renewable energy sources, biomass stands for a „biodegradable part of products and waste, or leftover biological materials obtained from farming (including plant and animal substances), forestry and related industries including fishing and aquaculture” [3]. The above directive suggests that Poland should systematically increases the share of biomass in energy generation. The percentage share of renewable energy sources increases every year from the set minimal threshold value. By 2020, this percentage share should constitute 15% of generated energy [3]. The generation of thermal and electrical energy using compacted biomass becomes more relevant for the power generation industry [17]. Therefore, an appropriate policy serves to pursue the goal to increase the share of biomass fuels in energy generation [12]. Factors limiting the use of biomass include problems with: harvesting, loading, transportation and storage. The density of loose straw of for example: wheat, rye and triticale, is approx. 40 $kg \cdot m^{-3}$, considering the humidity about 15-20%, and therefore the material needs to be compacted [19].

The manufacturing process of straw briquettes usually consists of two stages: breaking up and compaction (Fig. 1). Biomass has non-homogenous structure and composition with low own density and rather small energy content [13]. Several compaction methods are utilized, e.g. pelletization or briquetting, which serve to improve these characteristics [14]. The energy content of solid fuel manufactured from broken up fibrous biomass, classified as a natural polymer, depends on its characteristics, working parameters of the compaction process, in particular the compacting force and temperature [9, 10]. A major influence on the mechanical properties of the ready solid fuel in briquette form are the cutting (fragmentation) process parameters which prepare the biomass for compaction [2, 4, 11, 15]. In order to obtain the desired properties of the biofuel from piston based or screw based compaction [6, 8, 16] it is necessary to modify the physical and chemical parameters of the loose biomass in order to improve its susceptibility to agglomeration. This mostly entails: selecting the appropriate degree of fragmentation, ensuring the proper degree of moisture, removal of impurities and selection of the working parameters of the agglomerating machine [18]. The influence of changing moisture level on the degree of compaction and friction coefficient value occurring between the components of the briquette maker and the compacted material is provided in the paper [7].

Source: own study / Źródło: opracowanie własne

Fig. 1. The course of straw processing during briquette production
Rys. 1. Przebieg procesu przetwarzania słomy na brykiet

As mentioned earlier, effective compaction requires mechanical processing of the biomass, that is its fragmentation (Fig. 1). In the classical sense, the process is carried out by stationary machinery utilizing beater mechanism or blades (blades fixed on a revolving drum). What is relevant, all such processes call for mechanical shearing of the material. One needs to point out that clean shearing does not happen during fragmentation with the beater mechanism, usually it results in a complex state of tensioning with dominant bending phenomenon, causing the breaking of the stems. In the case of devices equipped with blades, the state of tension mostly leads to shearing. At the preliminary stage of our considerations, for the purpose establishing a mathematical model of the biomass cutting model in drum-type systems [1] (which is to undergo further study), one can simplify this model as simple shearing. A major issue with fragmentation of grass-based material is the significant energy consumption. Research work focuses on this particular problem, both from the standpoint of the fragmentation processes (utilizing the drum and knife-based fragmentation mechanism) as well as compaction (the study focuses on piston and screw-based compaction methods). It is therefore relevant to analyze the influence of the biomass cutting process parameters on the forces employed in the technology process, and furthermore its energy consumption.

The scope of study includes simple shearing of straw stems, carried out with different cutting parameters in laboratory conditions. Such studies were carried out by other researchers and the results of these examinations were presented, among others, in paper [5]. The aim of the current study is the preliminary examination of the biomass behavior during shearing, analyzing the progression of shearing force as a function of the displacement of the cutting tool. Maximum shear force values were established for biomass material. This information will be employed in planning the subsequent stages of examination. The final result of this study will be the establishment of a mathematical model for the cutting process of this type of material and, consequently its reduction to the cutting process of an anisotropic material. The study in question also constituted an intermediate stage of establishing a physical model of biomass material. It is furthermore planned to model the shearing process in MES.

2. Study methodology

The testing station (Fig. 2, a and b) subjected the biomass in form of wheat and rye grain straw to shearing. The straw was collected by hand during the harvest season in order to avoid its processing by faming equipment. The material was gathered slightly above ground level, directly near the root. The collection took place in the final stage of the plant lifetime 99 according to BBCH scale, which stands for full maturity and end of second rest period. The collected sheaf with grains was kept under room conditions in the laboratory, loose, for approx. 10 months (Fig. 1 – first image from the top).

Tests of simple shearing of individual straws were carried out on the durometer with covered shearing station (Fig. 2, a and b), with different parameter values: shearing speed (speed of the cutting edge), the gap width between the blade and the counter-blade as well as the relative humidity of the examined material. The shearing was performed at approx. 5 cm stem length, from the side separated above ground level, below the first leaf node. The stem cross-section is the highest at this location, allowing to establish the maximum shear force value (compared to other stem cross sections located above – which are characterized by smaller cross-section values), this served to minimize the influence of measurement inaccuracy of the durometer. One needs to point out that grain stems are a material of natural origin and therefore it is difficult to ensure the same dimensions and mechanical properties for individual plant specimens. In order to obtain comparable test results, samples were selected from stems with similar external diameter in the planned location of shearing (external diameter was in range of 5 mm to 5,5 mm) as well as with similar side thickness.

The shearing of individual stems of biomass was performed on the durometer MTS Insight 50 kN with installed specialized simple shearing station (Fig. 2, a and b).

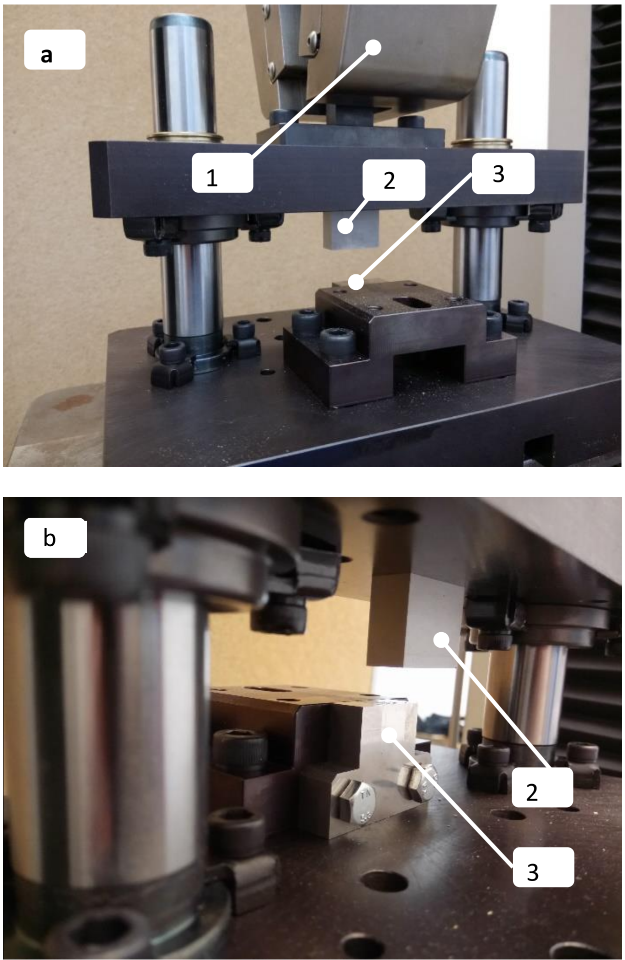

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Fig. 2. Testing station for measurement of straw cutting force installed on the durometer MTS Insight 50 kN; a – front view, b – rear view: 1 – durometer grip, 2 – shearing blade, 3 – counter-blade
Rys. 2. Stanowisko badawcze do pomiaru siły przecinania źdźbeł słomy zabudowane na maszynie wytrzymałościowej MTS Insight 50 kN; a – widok od przodu, b – widok z tyłu: 1 – uchwyt maszyny wytrzymałościowej, 2 – ostrze ścinające, 3 – przeciwostrze

The shearing of straw was carried out with different technological parameters of the process, including:

- wedge angle and blade alignment angle - 90°,
- 3 gap widths: 0,05 mm; 0,1 mm; 0,2 mm,
- 5 different motion speeds of the movable blade, in order to achieve different process dynamic states: 0,5 $\mathrm{mm \cdot s^{-1}}$ (quasi-static shearing); 1 $\mathrm{mm \cdot s^{-1}}$; 2 $\mathrm{mm \cdot s^{-1}}$ (intermediary state); as well as 4 $\mathrm{mm \cdot s^{-1}}$ and 8 $\mathrm{mm \cdot s^{-1}}$ (dynamic sharing).

The shearing test was divided into 2 stages. In the first one, shear testing was carried out on dry straw with initial humidity (WP). In this case, stems were not subject to any conditioning. The samples were obtained directly from the sheaf kept under room conditions.

In the second stage, the stems were moisturized in order to increase their relative humidity (NW). The samples were conditioned in a prepared container (Fig. 3). On the stand inside the container, the appropriate amount of stems, without leaves, were placed loose. To ensure elevated humidity conditions, approx. 2 liters of boiling water was poured into the container. The stand ensured no direct contact with the conditioned straw. The stalks were conditioned for approx. 120 hours with the container being tightly sealed.

Source: own study / Źródło: opracowanie własne

Fig. 3. Container for conditioning straw stems in order to achieve elevated moisture
Rys. 3. Pojemnik do kondycjonowania łodyg słomy w celu uzyskania podwyższonej wilgotności

Sample humidity was monitored on an ongoing basis. The measurements were takes using thermo-gravimetric dryer (Fig. 4).

Source: own study / Źródło: opracowanie własne

Fig. 4. Thermo-gravimetric dryer during testing straw humidity
Rys. 4. Suszarka termo-grawimetryczna podczas badania wilgotności słomy

Its principle of operation entails taking exact weight measurement of the sample, which is heated and dried. The weight measurement of dried sample with known weight of evaporated water allows to calculate relative humidity.

Five humidity measurements were taken for non-conditioned and moisturized straw, directly before the shearing test (Table 1).

As can be observed from the measurements, the average humidity of unconditioned samples is 14,8%, whereas for conditioned samples, it is equal to 44,5%.

Humidity measurements for samples undergoing the conditioning process were also taken. The relation between relative humidity and time is shown on Fig. 5.

Table 1. Relative humidity measurement results for dry triticale straws (WP) and moisturized triticale straws (NW) with average values

Tab. 1. Wyniki pomiarów wilgotności względnej próbek słomy pszenżytniej suchej (WP) oraz nawilżanej (NW) i wartości średnie

No.	Relative humidity (WP) – dry sample [%]	Relative humidity (NW) – moisturized sample [%]
1.	14,4	46,7
2.	18,1	52,4
3.	11,1	40,4
4.	11,9	34,0
5.	18,4	48,7
Av.	**14,8**	**44,5**

Source: own study / Źródło: opracowanie własne

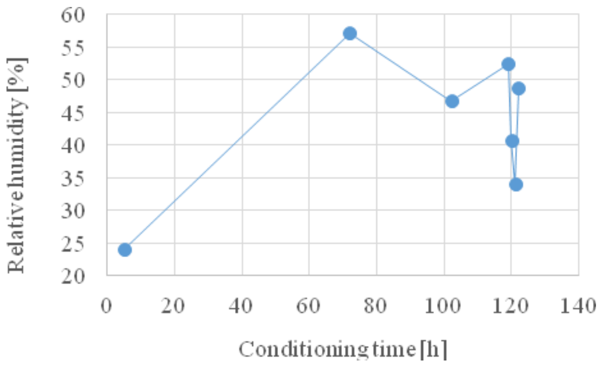

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Fig. 5. The relation between sample relative humidity and seasoning time

Rys. 5. Zależność wilgotności względnej próbek od czasu sezonowania

As seen on the diagram above, the biomass behaved in a predictable manner. One needs to point out that the humidity, despite a relatively long time of conditioning, did not exceed 60%. The value fluctuations at the end of the seasoning process were caused by the non-uniformity biomass material which caused differences in moisture absorption by the stems. The natural diversity of the sample may cause the presented measurement deviations.

3. Study results

For every combination of the parameters: cutting speed, gap width and sample humidity, at least five repetitions of the shearing test were performed. Representative results, each including three example progressions of cutting force, to be used in further analysis, were presented below. The results were segregated by discarding extreme cutting force values as well as progressions which were diametrically different from others.

The selected cutting force to displacement progressions for 0,1 mm gap width, two shearing speeds 1 mm·s^{-1} and 8 mm·s^{-1} with relative sample humidity 14,8%, were presented on Fig. 6 and Fig. 7.

The cutting force progression (Fig. 6 and 7) of biomass stems for both cutting speeds is similar. One needs to point out the slightly lower force values for dynamic cutting (8 mm·s^{-1}). Both progressions are characterized by a slight increase of force value at a displacement of the measuring head of approx. 1 mm – this corresponds to the point in which blade starting to affect the stem – the elastic compression. In both situations we observe a slight, momentary decrease in the cutting force, with the displacement of the measuring head by approx. 3,2 mm, which is where the stem ring breaks.

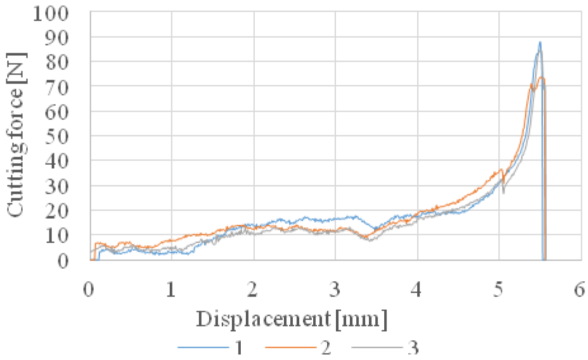

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Fig. 6. Selected progressions of triticale straw stem cutting forces for blade speed 1 mm·s^{-1}, gap width 0,1 mm and relative humidity 14,8%

Rys. 6. Wybrane przebiegi sił cięcia łodyg słomy pszenżytniej (dla prędkości ostrza 1 mm·s^{-1}, szczeliny o szerokości 0,1 mm oraz wilgotności względnej 14,8%

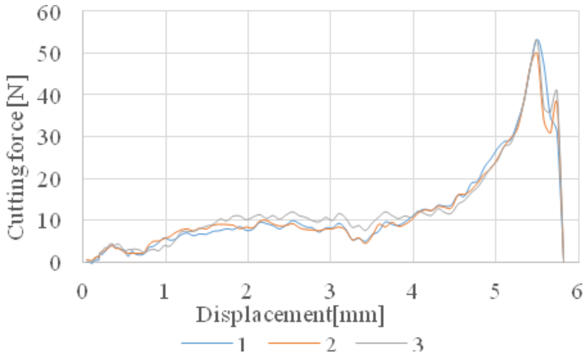

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Fig. 7. Selected progressions of triticale straw stem cutting forces for blade speed 8 mm·s^{-1}, gap width 0,1 mm and relative humidity 14,8%

Rys. 7. Wybrane przebiegi sił cięcia łodyg słomy pszenżytniej dla prędkości ostrza 8 mm·s^{-1}, szczeliny o szerokości 0,1 mm oraz wilgotności względnej 14,8%

Selected progressions of cutting force depending on displacement, for 0,1 mm gap width, cutting speed 1 mm·s^{-1} and 8 mm·s^{-1} as well as relative humidity of the sample 44,5% are shown on Fig. 8 and Fig. 9.

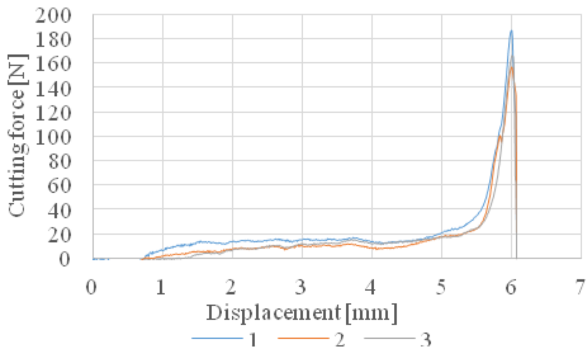

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Fig. 8. Selected progressions of triticale straw stem cutting forces for blade speed 1 mm·s^{-1}, gap width 0,1 mm and relative humidity 44,5%

Rys. 8. Wybrane przebiegi sił cięcia łodyg słomy pszenżytniej dla prędkości ostrza 1 mm·s^{-1}, szczeliny o szerokości 0,1 mm oraz wilgotności względnej 44,5%

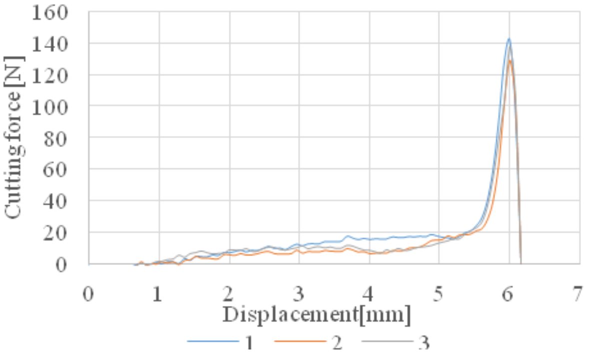

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Fig. 9. Selected progressions of triticale straw stem cutting forces for blade speed 8 mm·s^{-1}, gap width 0,1 mm and relative humidity 44,5%
Rys. 9. Wybrane przebiegi sił cięcia łodyg słomy pszenżytniej dla prędkości ostrza 8 mm·s^{-1}, szczeliny o szerokości 0,1 mm oraz wilgotności względnej 44,5%

As per the characteristics shown at Fig. 8 and Fig. 9, the progression of cutting force of biomass stems for both cutting speeds with moisturized samples is comparable. Similarly to the dry samples, shearing at higher speed is achieved with lower maximum force. Contrary to the results achieved with moisturized samples, no deviation was observed at increasing force value (e.g. momentary drop in force value), which entailed explicit, dry breaking of stems resulting from compression. The increase in force value in the first stage of stem compression is much smoother. This can be explained by the fact that moist straw is more susceptible to the load affected by the blade. Therefore, the share of elastic interactions during stem compression is lower and dry breaking does not occur.

The comparison of selected progressions of stem cutting force at quasi-static cutting (speed 0,5 mm·s^{-1}), for gap width 0,05 mm and both humidity values is presented on Fig. 10. A similar comparison was performed for dynamic sample cutting, and its result is demonstrated on Fig. 11.

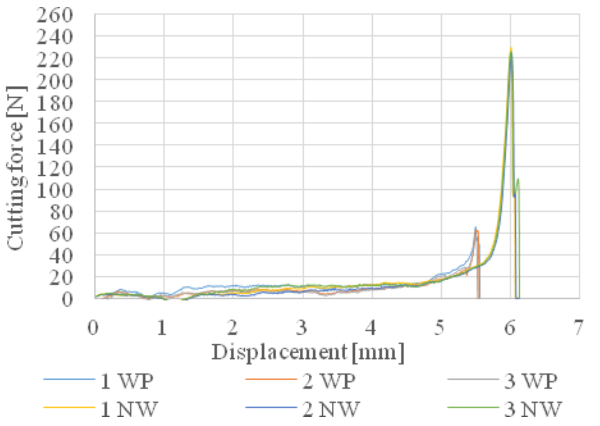

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Fig. 10. Comparison of cutting force progressions for gap width 0,05 mm, at quasi-static cutting for cutting speed 0,5 mm·s^{-1} and both sample humidity values
Rys. 10. Porównanie przebiegu sił cięcia dla szczeliny o szerokości 0,05 mm, przy quasi-statycznym ścinaniu dla prędkości ścinania 0,5 mm·s^{-1} oraz obu wilgotności próbek

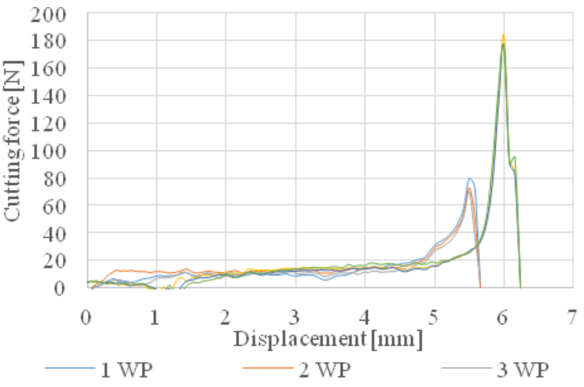

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Fig. 11. Comparison of cutting force progressions for gap width 0,05 mm, at dynamic shearing with speed 8 mm·s^{-1} and both sample humidity values
Rys. 11. Porównanie przebiegu sił cięcia dla szczeliny o szerokości 0,05 mm, przy dynamicznym ścinaniu dla prędkości ścinania 8 mm·s^{-1} oraz obu wilgotności próbek

The characteristics presented on Fig. 10 indicate that the force required to cut the moisturized samples (NW) have significantly higher values (nearly 4 times higher), than the cutting force for samples with initial humidity (WP). One can also observe that the characteristic progression of force with momentary decrease of value (resulting from the dry breaking of the sample), which is only present in the dry samples.

In of dynamic shearing, a major difference in maximum value of force necessary to cut the sample was observed for moisturized biomass (NW), and dry biomass, (WP). In contrast to quasi-static shearing, this increase in force value together with the increase in relative humidity is slightly lower (approximately 2 times). Similarly to the previous comparison (Fig. 10), one can notice a characteristic shape of force progression for the dry sample which does not happen with moisturized samples.

Another possible example when interpreting the test results is the relation between the maximum sample cutting force depending on the gap width between the blade and counter-blade, both for dry biomass (Fig. 12), and moisturized biomass sample (Fig. 13).

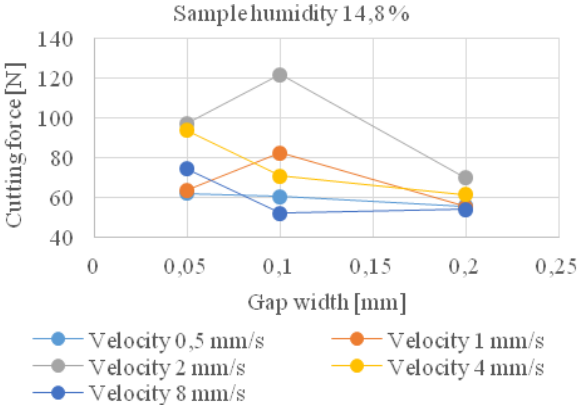

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Fig. 12. Relationship between the maximum cutting force required to separate the sample and the gap width between the blade and counter-blade, at sample humidity 14,8%
Rys. 12. Zależność średniej maksymalnej siły potrzebnej do przecięcia próbki od szerokości szczeliny pomiędzy ostrzem a przeciw-ostrzem, dla wilgotności 14,8%

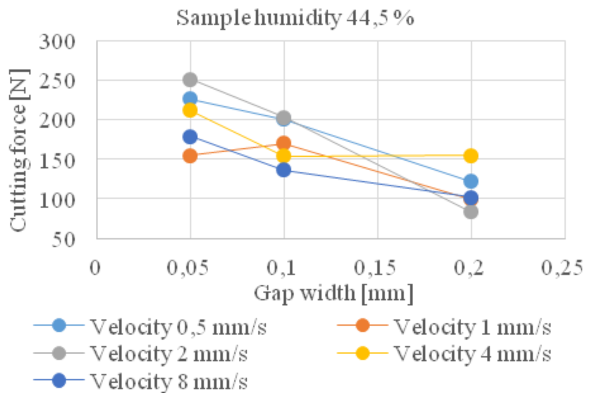

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Fig. 13. Relationship between the average maximum force required to cut the sample and the gap width between the blade and counter-blade, at sample humidity 44,5%
Rys. 13. Zależność średniej maksymalnej siły potrzebnej do przecięcia próbki od szerokości szczeliny pomiędzy ostrzem a przeciwostrzem, dla wilgotności 44,5%

As per the characteristics at Fig. 12 for unconditioned biomass, the influence of gap width is ambiguous. For quasi-static cutting (0,5 mm·s^{-1}) the increase in gap width causes a slight decrease in the maximum cutting force. For dynamic shearing (speed 4 mm·s^{-1} and 8 mm·s^{-1}) there is also a decrease in cutting force, but it is much more sudden. Whereas for intermediate states (speed 1 mm·s^{-1} and 2 mm·s^{-1}) the force increases at first, and then decreases at the largest gap width. The test results indicate that the issue calls for a further analysis. In the case of moisturized straw, a significant increase in cutting force value was observed together with the increase in gap width.

The maximum average cutting force dependence on cutting speed for a given low humidity was compared in a similar fashion (Fig. 14) as well as for moisturized straw (Fig. 15).

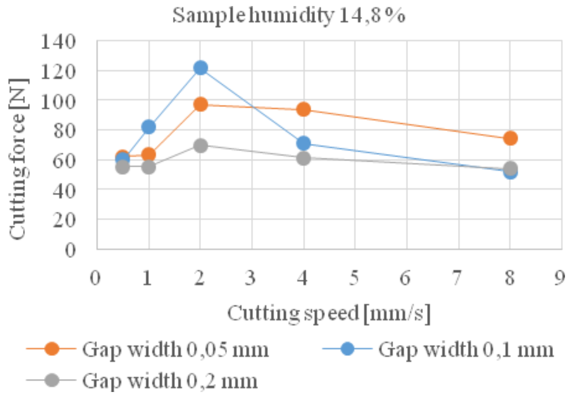

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Fig. 14. Dependence of maximum average force required to cut through the sample and cutting speed, for humidity 14,8%
Rys. 14. Zależność średniej maksymalnej siły potrzebnej do przecięcia próbki od prędkości, dla wilgotności 14,8%

On the basis of Fig. 14 it was established that for the sample with initial humidity (WP) together with the increase in shear speed from 0,5 mm·s^{-1} (quasi-static shearing) up to 2 mm·s^{-1} (intermediate stage between dynamic and quasi-static interaction) there occurs an increase in the force value.

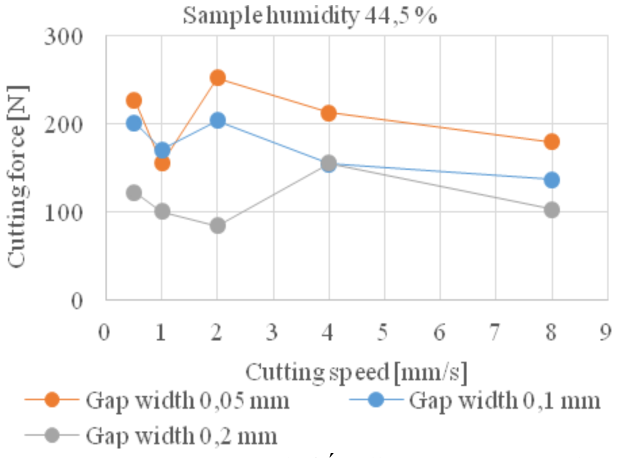

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Fig. 15. Dependence of maximum average force required to cut through the sample and cutting speed, for humidity 44,5%
Rys. 15. Zależność średniej maksymalnej siły potrzebnej do przecięcia próbki od prędkości, dla wilgotności 44,5%

Subsequently, with the increase of speed, the force value is significantly reduced. The lowest values of cutting force were registered for quasi-static shearing and are similar for all gap widths. For moisturized samples (Fig. 15) the shearing force value drops at the beginning (achieving the minimum at 1 mm·s^{-1}) and subsequently raises (achieving maximum values at 2 mm·s^{-1} and 4 mm·s^{-1}), and subsequently reduces its value with dynamic shearing (8 mm·s^{-1}).

The dependencies obtained from Fig. 14 and Fig. 15 are repeatable for all values of cutting gap width. Therefore, in both cases analyzing these graphs allows to draw the relevant conclusions regarding the selection of shearing speed in order to obtain the required, possibly lowest, energy expenditure.

4. Discussion on results

Analyzing the obtained results, as well as examining the sample behavior during shearing test, the following observations can be made:
– there is a general tendency for the shearing force value to increase in the sample together with the increase in humidity,
– in the majority of cases, the maximum value of cutting force was observed for cutting speed of 2 mm·s^{-1} (Fig. 14 and Fig. 15) and gap width 0,05 mm (Fig. 12 and Fig. 13),
– comparing the quasi-static shearing (Fig. 10) with the dynamic shearing (Fig. 11), one notices that the increase in stem cutting dynamic causes a decrease of sensitivity of the technological process parameters (among others, the cutting force) in relation to biomass humidity; as for the higher cutting speeds, the observed difference between the maximum values of cutting force is lower (Fig. 14),
– for dry samples and lowest cutting speeds, the values of force required to separate the stems are similar, regardless of the gap width between the blade and counter-blade, these values are also relatively low (Fig. 14),
– for cutting moisturized biomass, a clear minimum cutting force value that is required to separate the material depending on shearing force (Fig. 15) is observed, in the area of cutting with intermediate speed (between quasi-static and dynamic interaction),

– for both levels of straw humidity and all blade speed values, a noticeable decreasing trend is observed for the cutting force together with the increase in gap width, especially for moisturized biomass sample (Fig. 13). This should not be considered as a determinant, as for the dry straw, at certain shearing speeds, the force increases at the beginning and subsequently decreases (Fig. 12). This phenomenon is difficult to account for without further study and repetition of the shearing test,
– for larger gap values, in numerous cases, the process was not carried out properly. The state of clean shear was not obtained, instead resulting in a complex state of stress. During testing, the bending of the stem was observed, as well as its pressing between the blade and counter-blade. Subsequently, the stem was torn apart and separated. One cannot consider the above scenario to constitute a simple shear and therefore such results were not taken into account,
– no separation of material was observed for larger gap widths (in particular, 0,2 mm) together with higher biomass moisture (Fig. 16).

Source: own study / Źródło: opracowanie własne

Fig. 16. An example of moisturized sample which was not separated during a test at gap width 0,2 mm and cutting speed 2 mm·s^{-1}

Rys. 16. Przykładowa próbka nawilżona, która nie została ścięta podczas próby przy szczelinie 0,2 mm i prędkości 2 mm·s^{-1}

Similarly to the previous case. clean cutting was replaced with a complex state of stress with dominant bending. In such cases, the sample was broken, but not separated,
- the problem with incomplete separation of the stem or its bending between the blade and counter-blade at higher gap width value (in particular, 0,1 mm and 0,2 mm) was more prominent at lower cutting speeds (0,5 mm·s^{-1} and 1 mm·s^{-1}), whereas at higher testing dynamics, the samples were more often separated properly,
– the general tendency to decrease the shearing force value together with the decrease cutting speed, as well as the increase in gap width between the cutting elements may be caused by the change in physical phenomena occurring during that process together with the increase in speed. With quasi-static shearing, the separation of material occurs exclusively my means of cutting action by the blade and counter-blade. In the case of dynamic shearing, a major influence of stem cracking and breaking off is observed. From the examination of cutting test results, it is determined that the this phenomenon facilitates the separation of both parts of the sample during cutting.

5. Conclusions and further study directions

The performed tests and their results were analyzed from the standpoint of the energy consumption of the fragmentation process. This allowed to draw the following conclusions:
– in order to ensure proper quality of stem cutting, the gap between the blade and counter-blade must be no greater than 0,1 mm for dry samples (14,8% moisture), and 0,05 mm for moisturized samples (moisture 46,6%); for wider gaps, the phenomenon of incomplete separation of the stem was observed. The increase of humidity unfavorably affects the quality of stem cutting,
– in order to maintain the lowest possible value of cutting force, straw humidity should be in the range of 10÷15%, which is achievable without additional drying, whereas for humidity of 14,8%, the lowest cutting force was observed for gap width 0,1 mm and blade speed of 8 mm·s^{-1}. The general trend observable in the test results in the increase in force required to cut the biomass together with the increase in sample humidity.

The nature of the examination was preliminary, allowing to identify the behavior of biomass samples under shear stress. The conclusions indicate that further testing is required in order to verify the current results. Bearing in mind the above fact, together with the general objective of the study, which is the analysis of energy consumption of the biomass fragmentation process, further study efforts were planned, including the following:
– performing similar tests on a larger sample volume with different relative humidity. This will allow to establish an unambiguous trend for the progression as well as the maximum value of cutting force in relation to sample humidity. The planned further testing entails sample humidity values of approx. 30% (intermediate point between the tests performed in this paper) as well as humidity values below 10% (the samples will require additional drying),
– modifying the testing station in order to establish the change in cutting force depending on blade alignment and face angle of the blade. This examination will allow to determine the influence of cutting implement geometry on the quality and energy consumption of the separation process,
– carrying out an examination of cutting force values with simultaneous separation of larger number of stems. The expected result is to achieve larger force values with greater variability, depending on, e.g. stems breaking as a result of stress. Such testing will require a more careful selection of samples for specific cross-section values,
– establishing a mathematical model of the cutting process allowing to analyze its energy consumption,
– formulating the model for the straw stem biomass,
– numerical simulation of the cutting process for the purpose of analyzing its energy consumption,
– examining the process on a drum machine for biomass fragmentation and establishing its mathematical model for the purpose of analyzing the energy consumption of the process.

The undertaken research topics is current due to the increasing share of biomass – in particular grain straw – as a source of renewable energy. One needs to point out that the cutting process for materials of this type is not sufficiently examined from the standpoint of the physical phenomena involved, and is not fully described mathematically.

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