Biomass cutting tests to determine the lowest value of the process force

D Wilczyński, K Wałęsa, M Berdychowski and M Kukla
Chair of Basics of Machine Design, Poznan University of Technology, Piotrowo Street 3, 60-965 Poznan, Poland
Email: dominik.wilczynski@put.poznan.pl

Abstract. The paper presents experimental investigations of straw cutting in the form of triticale. The cutting was performed using a specialized testing station adapted for mounting on a MTS Insight 50 kN testing machine. It is allows to change the cutting blade, which made it possible to study the effect of changing the rake angle of its blade and the inclination of the cutting edge on cutting force value. The influence of the linear speed of the knife and the size of the gap between the blade and the counter-blade was also investigated. The results obtained allowed to select the most favorable values of the above-mentioned parameters of the cutting process in terms of obtaining the lowest value of the cutting force, which consequently determines the process energy consumption. Obtained results are not only guidelines for machine design and cutting devices, but these can also be used as input data for multicriteria analysis, which can result in looking for other values of process parameters not taken into account in the presented studies, and key ones in the direction of the next ones.

1. Introduction

The compaction process of loose biomass allows to improve its fuel characteristics. Recently, together with the increased share of biofuels as an energy source, we observe a sudden development of machinery and devices necessary for this process. In order to design a device allowing to obtain biofuel with good fuel characteristics one needs to examine the characteristics of the briquette with attention given to the compaction process as well as the degree of fragmentation of the biomass [1–3]. Cutting the biomass is an important process as a stage in the manufacturing of biofuel in briquette form, from the standpoint of the process energy consumption as well as the influence of biomass fragment size which affects fuel quality [4–8].

Due to an increasing demand on clean energy, biofuels lately became a popular substitute for fossil fuels [9–11]. Globally, the major source of biofuels is agricultural waste material, for example straw. Its share in the manufacturing of biofuel is described as significant for Central Europe, right next to wood biomass [12–14]. Straw, through its compaction in auger or piston based technology, allows to obtain biofuel in briquette form. Agglomeration techniques are furthermore utilized in the compaction process of other materials, such as dry ice, as presented in papers [15–17].

The paper presents a study of straw cutting process for the purpose of subsequent determination of energy consumption of the process as well as for its modeling. The study utilizes a specialized testing station suitable for installation on a MTS Insight 50 kN testing machine. It is equipped with special blades allowing to examine the influence of their geometrical parameters on the value of cutting force. The geometrical parameters of the blade have a material influence on the force requirement for carrying
out the process, and as a consequence, on its energy consumption which is the subject of analysis of numerous studies [18–24]. The process is furthermore influenced by the geometrical parameters of machine components and assemblies, which was touched upon in papers [25–28].

2. Research

The study of the cutting process was performed on a specialized testing station presented in figure 1. It comprises of two main components, i.e. an immobile base 2 and a movable plate 1 which traverses vertically along guides equipped with bearings 3. The motion is facilitated through the connection to the strength testing machine grip 4. The lower part is equipped with a component acting as a counter-blade 5 for the blade 6 installed in the upper, movable plate 1. The counter-blade 4 can be moved linearly in the horizontal direction, enabling to set the gap between the blade 6, and counter-blade 5. The upper movable plate 1 allows to replace the knife 6. The examination used twelve knives with different blade geometry expressed in the blade angle $\alpha$ and rake angle $\beta$ (figure 2). The aim of the study was to determine the influence of variance in these angle parameters on the value of cutting force. These values were respectively $\alpha = 15^\circ$, $30^\circ$ and $45^\circ$ as well as $\beta = 5^\circ$, $15^\circ$ and $30^\circ$. Consequently, 12 blades were made and used in the examination with variable angle values of $\alpha$ and $\beta$ (figure 2) in the provided range. The examination entailed introducing a triticale straw stem between the blade 6 and counter-blade 5 (figures 1 and 2). As a result of the linear motion of the blade 6, a cut was performed. The parameters registered during the examination are cutting force as a function of displacement of the strength testing machine cross-beam. For every blade 6 type with specific value of angles $\alpha$ and $\beta$, 16 cutting attempts were made. Subsequently an average value was determined together with standard deviation.

The gap length value between the blade and counter-blade was assumed on the basis of a previous study discussed in the paper [29], which resulted in the lowest cutting force value. The value was 0.1 mm for dry straw. Dry straw is assumed to be straw collected from the field and stored for several months in a dry environment. Straw moisture content was determined with use of a scale-dryer. Its average value estimated on the basis of five measurement attempts was 10.5%. During all testing attempts, the travel speed of the blade was 8 mm s$^{-1}$.

Based on an earlier experiment [29], additional moisturizing of the straw during conditioning is aimless, as higher straw moisture content calls for employing a higher cutting force [29].

![Figure 1. Straw cutting process testing station: 1 – movable plate, 2 – base, 3 – guide, 4 – strength testing machine grip, 5 – counter-blade, 6 – blade.](image-url)
3. Results of research

Table 1 presents averaged force values for individual variable parameters of angles $\alpha$ and $\beta$. The force values in the table are provided in Newtons (N). $F_{avg}$ is the arithmetic mean of the force determined from sixteen tests and $\sigma$ is the standard deviation based on sixteen tests.

**Table 1.** Breakdown of cutting force values for each of the sixteen attempts together with the average value for specific values of angles $\alpha$ and $\beta$.

| No. | $\alpha=0^\circ$, $\beta=5^\circ$ | $\alpha=15^\circ$, $\beta=5^\circ$ | $\alpha=30^\circ$, $\beta=5^\circ$ | $\alpha=45^\circ$, $\beta=5^\circ$ | $\alpha=0^\circ$, $\beta=15^\circ$ | $\alpha=15^\circ$, $\beta=15^\circ$ | $\alpha=30^\circ$, $\beta=15^\circ$ | $\alpha=45^\circ$, $\beta=15^\circ$ | $\alpha=0^\circ$, $\beta=30^\circ$ | $\alpha=15^\circ$, $\beta=30^\circ$ | $\alpha=30^\circ$, $\beta=30^\circ$ | $\alpha=45^\circ$, $\beta=30^\circ$ |
|-----|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| 1.  | 42.55 48.14 40.11 34.94 26.54 34.41 20.70 22.59 16.93 24.12 23.43 17.81 |
| 2.  | 40.37 49.82 35.36 35.90 28.90 32.46 22.01 27.83 19.96 23.79 23.26 18.84 |
| 3.  | 27.57 55.47 34.49 28.74 23.28 32.58 19.06 21.74 18.89 24.12 21.15 17.01 |
| 4.  | 29.45 58.71 37.99 27.56 25.43 33.28 26.66 22.85 11.48 21.99 15.69 14.82 |
| 5.  | 36.01 42.54 48.14 29.54 27.96 26.25 24.17 21.66 14.16 20.08 15.86 14.84 |
| 6.  | 34.54 61.17 48.97 25.64 41.85 30.37 20.54 22.07 15.68 20.27 16.65 13.35 |
| 7.  | 22.93 57.16 40.66 34.08 42.51 36.47 31.77 28.83 15.21 26.36 14.45 14.61 |
| 8.  | 43.95 61.80 28.36 33.16 42.28 38.70 32.16 25.56 18.09 19.69 16.83 14.35 |
| 9.  | 49.18 60.24 26.72 30.28 32.55 29.47 25.33 25.36 16.50 23.91 15.66 13.43 |
| 10. | 43.30 60.94 36.93 36.06 30.93 31.65 27.81 27.99 15.47 24.11 23.12 14.36 |
| 11. | 43.89 43.57 33.96 26.33 30.16 24.84 25.65 20.34 15.25 22.27 21.56 13.49 |
| 12. | 34.79 41.38 44.38 33.96 32.11 35.10 28.26 23.91 15.78 28.29 13.98 16.48 |
| 13. | 36.28 39.29 32.90 41.39 33.12 37.56 30.65 26.02 16.12 23.92 16.68 19.38 |
| 14. | 29.78 40.40 39.06 24.71 31.73 29.91 33.94 27.17 18.12 25.09 13.36 18.58 |
| 15. | 34.89 48.69 33.20 28.09 28.09 21.53 29.31 25.15 26.12 16.56 24.03 17.25 16.43 |
| 16. | 23.04 38.89 28.34 23.06 21.97 32.30 32.66 24.63 15.32 22.75 14.97 13.88 |

$F_{avg}$ (N) | 35.78 50.51 36.85 30.84 30.80 32.17 26.66 24.67 16.22 23.42 17.74 15.73
$\sigma$ (N)  | 7.54 8.47 6.40 4.85 6.53 3.69 4.53 2.51 1.93 2.19 3.40 2.00

Figure 2. Straw cutting process testing station: 1 – movable plate, 2 – base, 3 – guide, 5 – counter-blade, 6 – blade, $\alpha$ – blade angle, $\beta$ – rake angle.

Figure 3 presents the characteristics of variable cutting force to separate the straw stem as a function of the variable blade angle $\alpha$ and rake angle $\beta$.

Figure 4 presents a characteristic of variable cutting force to separate the straw stem as a function of variable blade angle $\alpha$ and rake angle $\beta$, where the abscissa is the axis of variable rake angle $\beta$. 
Figure 3. The characteristic of variable cutting force to separate the straw stem as a function of variable value of angles $\alpha$ and $\beta$.

Figure 4. Characteristic of variable cutting force of the straw stem as a function of variable angles $\alpha$ and $\beta$.

4. Conclusions

Based on the above characteristic, it was determined that the cutting force decreases significantly together with the increase in the rake angle of the blade. This effect was expected as the increase in the blade rake angle changes the distribution of forces during cutting. In such a case, the share of vertical force, which is measured with the strength testing machine, decreases in favor of the horizontal force load on the testing station guides. An additional horizontal force load on the guides causes friction and an additional travel resistance. Due to the fact that the movable plate with the blade (figures 1 and 2) travels on guides with bearings, the traverse resistance caused by a multiplication of horizontal force and the frictional coefficient
(in this case, with negligible value) is very low. Consequently, the total force necessary to move the blade (cutting force) decreases together with the increase of the blade rake angle.

It was observed that the scatter of cutting force values is lowest at the lowest value of the rake angle \( \beta \). The examined straw is a natural material, therefore it is characterized by a variety of mechanical characteristics, despite preselecting the samples for examination (in order to achieve maximum similarity between samples). For the low value of the rake angle \( \beta \), the mechanical parameters of the cut material have a much higher influence on the force required in the process, as a consequence of the force distribution as described above. Therefore, the variance in individual samples caused an observed highest variance in results for low rake angle \( \beta \) value.

Further analysis determines that the cutting force depends in the lowest degree on the blade angle \( \alpha \). According to figure 3, we observe a tendency to increase the cutting force value until the value \( \alpha = 15^\circ \) is achieved. This result is probably caused by the change in the character of the phenomenon of destruction of the straws together with the increased sharpening angle. In every case, during cutting of the material, the straw is first pressed and crushed, and afterwards the edge cutting action causes separation of the material. For an unsharpened blade, \( (\alpha = 0^\circ) \) after crushing the straw, it is most likely broken through the action of the flat blade surface against the support of the counter-blade (the phenomenon of bending and breaking off). Subsequently, the flat edges of the blade and counter-blade separate the material due to reciprocating motion (clean cut). With the increase of the value of the blade angle \( \alpha \) above \( \alpha = 15^\circ \), after compressing the straw, the sharp edge results in a process similar to a knife cut, it penetrates the material causing its separation acting on a single support of the counter-blade, resulting from a wedge action of the blade.

Based on the obtained results, it is concluded that the blade angle \( \alpha = 15^\circ \) is the transitory value between the two types of destructive action described above. This phenomenon requires further study of the destructive mechanics which necessitates performing subsequent examinations.

4. References
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