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The Effect of Pellet Length on Mechanical Durability and Breakage Behaviour of Torrefied Biomass

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Abstract

The transportation, handling, and storage of biomass pellets are challenging due to pellet breakage and fines generation. The amount of fines generated during transportation and handling of biomass pellets is mostly measured in the laboratory using mechanical durability testers such as tumbling can method according to ISO 17831-1. This standard sets requirements on the amount of pellets, but not on the pellet length distribution (PLD) to be used for the mechanical durability measurements. This study aims to investigate the effect of PLD on the mechanical durability of biomass pellets. Two different types of torrefied biomass of Poplar and Mixed wood were used in this study. Samples were classified into three different groups of shorter than 15 mm, between 15 and 30 mm, and longer than 30 mm before durability test. In addition, a random PLD was considered as a reference case. The results show that the mechanical durability strongly depends on the PLD and increases from 83.6% to 96.4% for torrefied Poplar and from 92.7% to 98.5% for torrefied Mixed wood by increasing the PLD from shorter than 15 mm to longer than 30 mm. Therefore, it is highly recommended to consider the PLD of the pellet samples before durability tests.

Keywords: Biomass Pellets, Mechanical Durability, Breakage Behavior, Pellet Length Distribution

1. Introduction

The use of biomass pellets for energy production purposes is increasing rapidly while there is a lack of knowledge of transportation and handling issues [1]. Biomass, due to its fragile nature, is prone to break during transportation, handling, and storage which increases the risk of fines and dust generation. Generation of fine particles is detrimental in terms of material loss, increasing the risk of fire, equipment fouling, and environmental issues.

The potential of fines generation is linked to the material strength. The strength of biomass pellets depends on many factors from the raw material properties to the possible pre-treatment processes and pelletization process parameters. Different methods have been used in literature to characterise the pellets' strength. In general, these methods can be divided into two main groups, namely individual and bulk strength measurements. The individual pellet strength is mostly measured either by compression or by impact tests [2, 3], while, the bulk material strength is measured using different devices and techniques [3].

Biomass pellets are mostly shipped overseas from North American and Asian countries to Europe. However, it seems that the quality of the pellets at the end user does not always meet the quality on the certificate accompanying the shipment and determined at the moment of loading. While the breakage behaviour of biomass pellets are not yet linked to the operational steps, it is suspected that there might be an effect of pellet length on the durability.

Durability of pellets is evaluated by using various devices such as rotating drum, tumbling can, and the ligno tester [4]. The ISO 17831-1 (EN 15210-1) [5] standard prescribes a method for characterizing the mechanical durability of solid biofuels using a tumbling can. This standard sets requirements on the amount of pellets, but not on the PLD to be used for the mechanical durability measurements. The importance of knowing the pellet length distribution in a mechanical durability test is twofold; the effect of pellet length on mechanical durability during transportation, and the change in PLD which may intensify the fines generation in the next transportation and handling steps. For simplicity, in the rest of this paper, the mechanical durability is referred as durability.

The present paper aims to investigate the effect of PLD on the durability characteristics of biomass pellets in accordance with the standard ISO 17831-1 method. The pellet lengths before and after the durability tests are measured using a novel and quick in-house developed image processing tool.

2. Materials and Methods

Two different types of commercial torrefied biomass pellets (Poplar, and Mixed Wood) were used in this study. The moisture content and diameters of the pellets are shown in Table 1. The diameters are measured according to the standard CEN/TS 335 [6] and the determination of the moisture contents was based on the standard EN 14774-2 [7]. There is no information about the torrefaction and pelletization processes of the samples.

Table 1. Properties of the samples

Sample	Diameter (mm)	PLD as Received (mm)	Moisture Content (%)
Torrefied Poplar	8	5 to 65	7.9
Torrefied Mixed Wood	6	5 to 48	9.7

The durability was measured using a tumbling can device based on the standard durability test method for biofuel pellets (ISO-17831) [5]. The standard procedure is to place a sample portion of 500 gr of the sieved pellets (3.15 mm-round holes) in a steel chamber with the dimensions of 300×300×125 mm with a baffle (230×50 mm) attached diagonally to one of the walls of the can as shown in Figure 1. The chamber is mounted on a shaft and the shaft rotates for 10 min at 50 rpm (in total 500 rotations). After tumbling, the sample is sieved again with the aforementioned sieve. The weight of the remaining sample over the initial sample weight determines the durability of the samples. Each test is repeated twice and the reported durability value is the mean of the results.

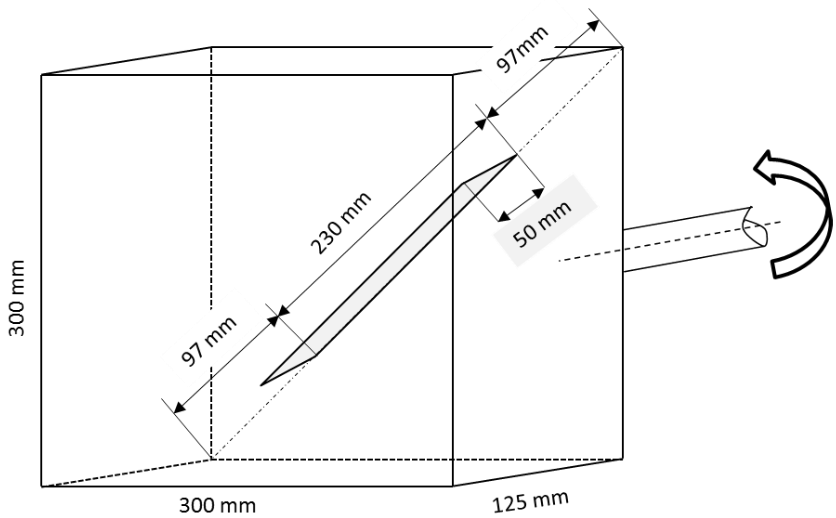


Figure 1. The main parts of the durability tester based on ISO 17831-1

In order to investigate the effect of PLD, all the samples were manually classified in three different categories of shorter than 15 mm (category 1), between 15 and 30 mm (category 2), and longer than 30 mm (category 3). In addition, for each sample, a random PLD was selected and used as a reference case.

The PLD is usually measured using the sieving methods such as CEN/TS 335 standard [8]. However, sieving is not an accurate method as the pellets longer than sieve holes may pass the sieves in their axial orientation. Therefore, there is a need for a more accurate method to measure the PLD. In the present work, the PLD is measured using a novel, quick, and easy method based on the image processing using MATLAB codes developed specifically for this research. The procedure is as follows: A camera is installed above a light panel. In order to calibrate the tool, first an object with a known length is placed on the panel and an image is taken. Then, one layer of sufficiently separated sample is placed on the light panel while the user controls the pellets to prevent touching each other. Then a 2D image is taken from the pellets and then the images are processed with MATLAB codes. The output includes the length of each pellet, and consequently, the number of pellets and the PLD. The pellet density is also included in the model to convert the PLD based on the pellet mass.

Figure 2 shows how the in-house image processing tool measures the length of a pellet. As the biomass pellets are mostly broken at both ends, the ends are not smooth. Thus, here the pellet length is defined as the maximum length of a pellet from one end to another one according to EN 16127 standard [6]. The MATLAB codes first draw a horizontal line from the axis of the pellet (dashed line in Figure 2). Then determines the extreme points of the pellets at each end (circular parts in Figure 2) and draws a perpendicular line to the horizontal line at every extreme point (solid lines). The maximum distance between each two solid lines determines the pellet length.

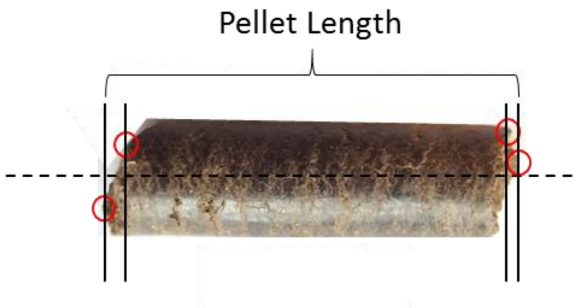


Figure 2. 2 D image of a typical biomass pellets under analysis with MATLAB

3. Results and Discussions

A sample image of the Mixed wood pellets from category 3 before and after the durability test is shown in Figure 3. As can be clearly seen, the pellets are placed on the light panel without touching or crossing each other.

The PLD for each test before the durability test for Mixed wood and Poplar is shown in Figure 4. It should be noted that this figure only shows the results of one of the two replications for each test while the differences between the replications are negligible.

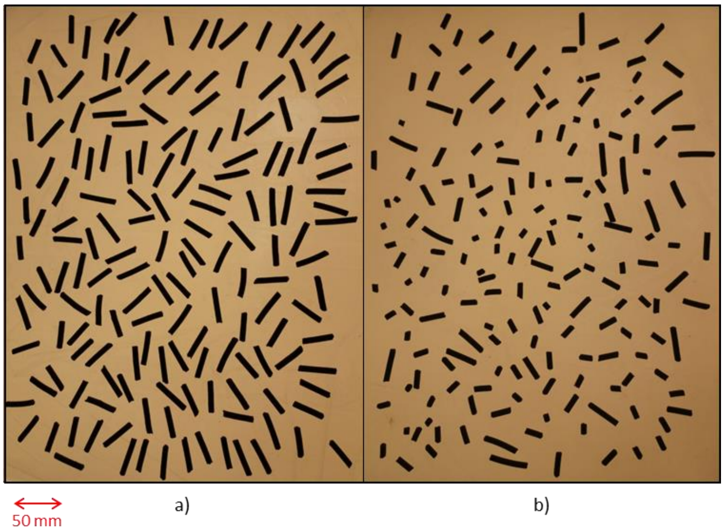


Figure 3. Mixed wood pellets category 3 a) before durability test and b) after durability test

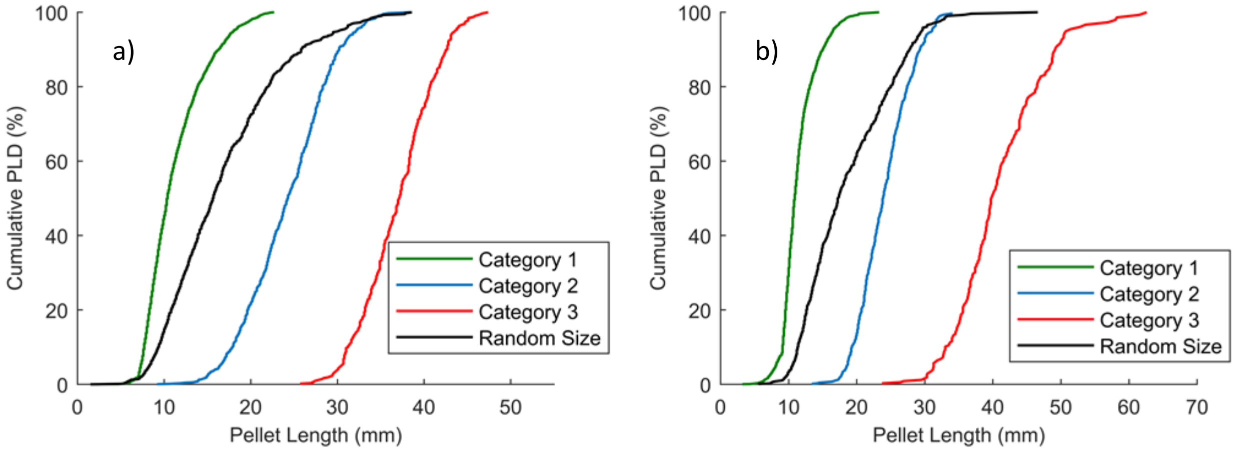


Figure 4. PLD before durability test a) Mixed wood and b) Poplar

Figure 5 shows the durability values of different pellet categories. It is clearly shown that by increasing the PLD, the durability increases. For Mixed wood, the durability value for random PLD is 94.64 %, while for category 1 the value is 92.73%, for category 2 is 97.39%, and for category 3, the durability value is 98.58%. For Poplar, these values are 88.54%, 83.60%, 96.38%, and 96.41%, respectively.

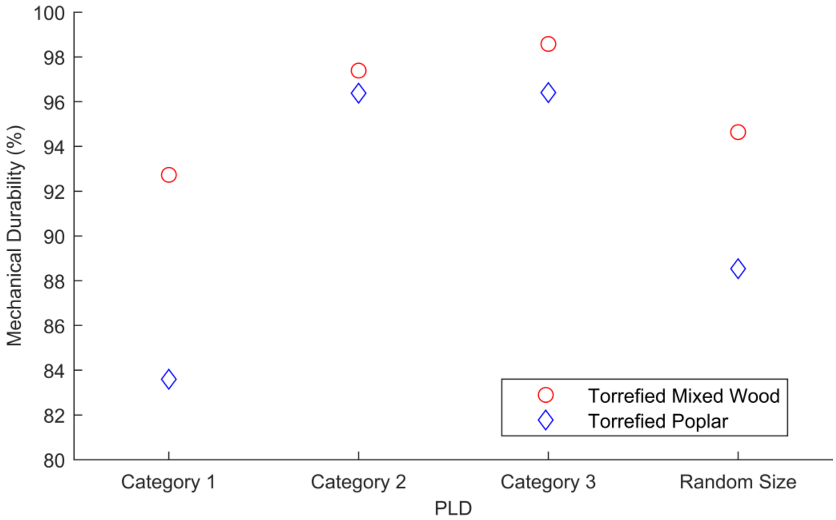
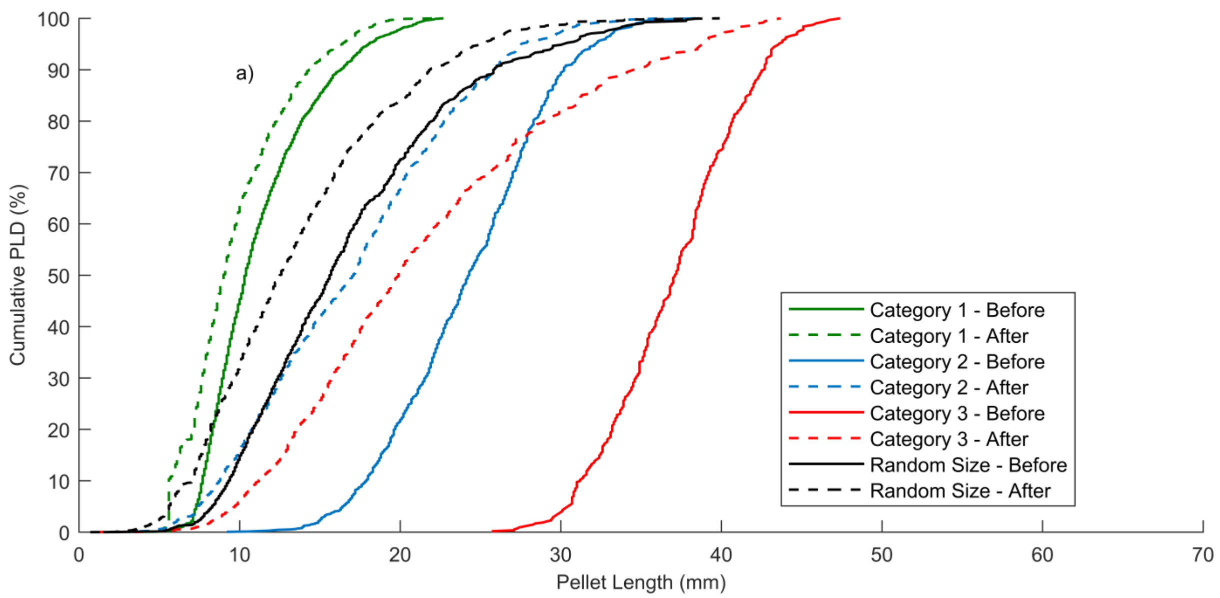


Figure 5. Durability of the different pellet categories

Changes in the PLDs of the samples after the durability test is shown in Figure 6. As expected, the PLD has been shifted to the left for all the samples meaning a shorter length for the pellets due to pellet breakage and fines generation. However, this change is much higher for the longest pellets (category 3). Knowing this fact at one hand and the higher durability value for longer pellets at the other hand, it is concluded that pellet breakage (dividing pellets to two or more parts) leads to fewer fines generations while the smaller pellets produce more fine particles during tumbling. The number of Mixed wood pellets in category 3 before durability was 404 and after durability test was 857 which shows a 112% increase in the number of pellets. The pellet numbers for category 2 of Mixed wood pellets before the durability test was 658 and after durability was 1094 which shows 66% increase in the number of pellets. For random size Mixed wood pellets, the pellet numbers increased around 39% from 1075 pellets to 1498 pellets after the durability test. The increase in the number of pellets for Poplar samples shows the same trend, 112 % for category 3, 66% for category 2, and 31% for random size pellets. For the pellets in category 1, there is a decrease in the number of pellets since pellets tend to break into smaller parts which are not cylindrical anymore, hence, not considered as pellets in this study.



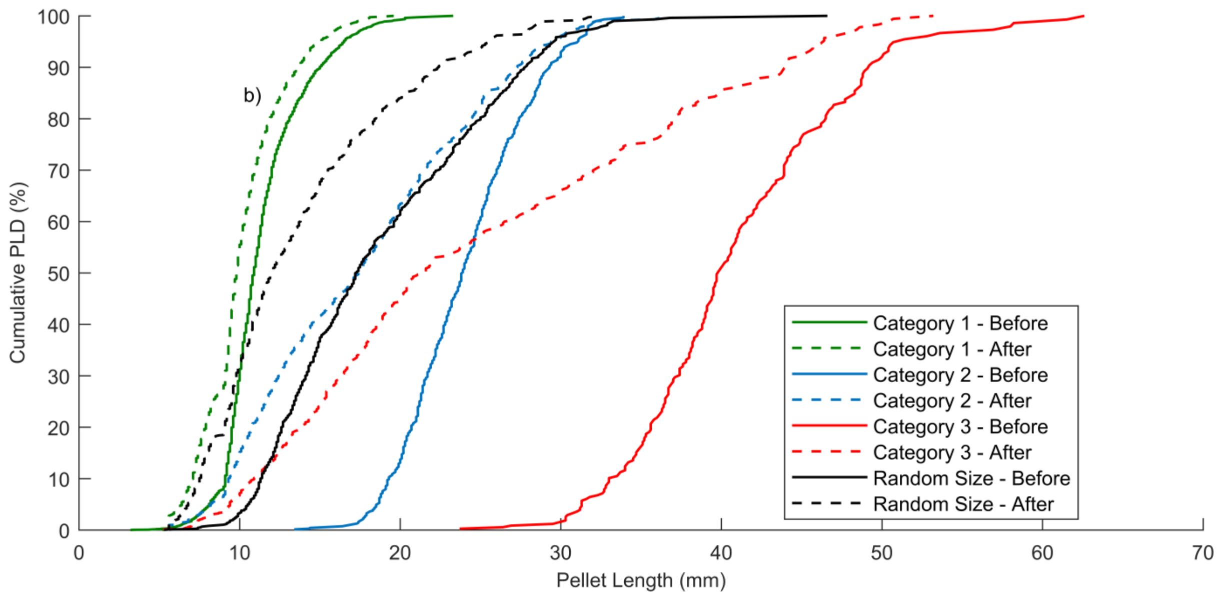


Figure 6. PLD before and after durability test a) Mixed wood and b) Poplar

The higher durability of longer pellets could be explained in two aspects. Firstly, the higher ratio between the pellet length and the apparatus dimensions and secondly, the number of collisions inside the apparatus. In the former issue, due to existence of a baffle in the middle of the device, the flow of the pellets is relatively chaotic, therefore, not all the pellets pass the same route during the test. However, it could be expected that the longer pellets may tolerate lower impacts as they pass shorter routes from one side to the other side of the device. At the other hand, the longer pellets show higher weights in compare to the shorter ones, resulting in higher impact at the collision time which makes the conclusions more complex. Using a bigger size apparatus may mitigate the effect of pellet to device ratio. The latter point returns to the number of pellets during the test which rises by increasing the number of pellets. Considering the Mixed wood samples, the number of pellets in category 2 was 658 while in category 1 was 2241 which shows around 3.4 times increase in the number of pellets. This means a remarkable increase in the number of collisions which can result in an increased fines generation. More research is required to investigate the effect of the device size and the number of pellets in the test on the durability.

Different biomass pellets are mostly classified based on their chemical and physical properties. One of the most important physical properties normally considered in classifications is durability. There exist many regional and global standards and recommendations for the minimum required durability values regarding the pellet lengths. For instance, the European standard committee (CEN/TS 14961:2005 [9]) classifies biomass pellets in three different groups based on their durability values namely DU97.5, DU96.5, and DU95. These classifications correspond to the durability values of higher than 97.5%, 96.5%, and 95%, respectively. Moreover, the maximum acceptable standard length depends on the pellet diameter. For pellets with a diameter lower than or equal to 6 mm the maximum accepted length is five times higher than the diameter, and for pellets having a diameter of 8 and lower the maximum accepted length is four times the diameter. Looking at the durability results of Mixed wood samples, the random size and category 1 never meet the minimum required durability values to be considered in the CEN/TS 14961:2005 classifications, while category 2 classifies in DU96.5 and category 3 classifies in DU97.5. Although categories 1 and 2 still meet the requirements for CEN/TS 14961:2005 standard length/diameter ratio, their durability values are not the same. This emphasizes the importance of knowing the PLD in the reported durability values.

Table 2 shows the mean values of the pellet lengths based on the total mass (L_{50}). Considering the values before and after the durability test, it is clearly seen that the L_{50} of category 3 after durability is close to the L_{50} of category 2 before the durability test. The same trend applies between category 2 and random size pellets and between random size pellets and category 1. This trend shows that after each durability test, the L_{50} decreases, thereby, after around three durability test the PLD drops from category 3 to category 1. As shown previously, category 3 shows higher durability values than category 1. Therefore, in practice, it might imply that increasing the transportation and handling steps during a pellet journey from the production location to the end user's location decreases the PLD and durability of the pellets which could lead to increased fines generation.

Table 2. Mean values (L_{50}) of the pellets before and after durability test

Sample	**PLD**	**L_{50} Before Durability (mm)**	**L_{50} After Durability (mm)**
Torrefied Mixed Wood	Category 1	10.4	9
	Category 2	24.3	17.1
	Category 3	37.1	19.9
	Random Size	15.7	12.5
Torrefied Poplar	Category 1	10.9	9.8
	Category 2	23.9	17.5
	Category 3	39.8	21.6
	Random Size	17.2	12.1

4. Conclusions

The primary goal of this research was to investigate the effect of pellet length on the durability values of biomass pellets by using the ISO 17831-1 standard test. The results show that PLD has a considerable effect on the durability value for two different kinds of torrefied biomass pellets, Mixed wood and Poplar, with different diameter values. The higher the PLD, the higher the durability. Therefore, it is highly recommended to report the PLD before the durability test. We believe that based on this research it is of high importance to consider the pellet length and to include it in the standard.

The results are useful for further research on the breakage behavior of densified biomass, pelletization process parameters, and design specifications of different equipment used in transportation, handling, and storage of densified biomass materials to reduce the amount of generated fines and dust.

Acknowledgements

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