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Flow Properties of Bulk Material as a Product of the Beech Chips Grinding

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The article deals with the various methods of characterization and evaluation of the shape and dimensions of particles that are a product of grinding the beech chips in a knife mill. The speed of rotor with knives and two types of die were tested parameters.
The product that was obtained by grinding has non-isometric particles. The main problem how to evaluate the particle size distribution for such materials is the choice of the characteristic size and the method for determining the particle size distribution. At present it is possible to use the modern, optical dynamic methods, based on particle visualization. The results from the both milling methods are processed into the various graphical dependencies, taking into account the shape of the particles and the particle size distribution. However, the particle size distribution also has an effect on the flow properties of the bulk materials. A special rheometer for measuring the flow properties of powders is used.
The results of measurements are used for characterization the influence of the grinding process parameters on the flow properties of the product.

1. Introduction

Milling can be considered as one of the basic operations in various industries. It is primarily aimed at reducing the size of individual particles. Different principles are used. The dynamic effect of the impact of the grinding element on the particle is used for brittle materials. In this case, the impact creates normal and shear stresses in the particle (Bird et al., 2007). These, if they exceed the strength limit, will cause cracks in the particle and break it. Another mechanism is based on the preferential generation of shear stress. In this case, the geometric arrangement of the grinding elements is such that a shear plane is created in which shear stresses are generated. This mechanism is mainly used for grinding flexible materials.
Cellulose-based materials are e.g. wood chips, as input ligno-cellulose raw material for various technologies, e.g. in the paper or energy industry. They therefore represent a large group of substances, and their products, which have applications in a wide range of industries.
According to the content of water bound in them, their mechanical properties change. They are relatively elastic and malleable with a higher water content, e.g. wood from freshly cut trees, to relatively brittle, if dried. Very often, however, it is necessary to first modify these materials so that they can be further technologically processed. Milling is one of the basic and often used operations of their treatment. However, these two moisture limit intervals affect the milling process itself. Therefore, shear mills are mainly used for their milling. Shear mills enable the grinding of both wet and dry materials. The difference is mainly in the performance of the mill and the quality of the product. Wet materials are milled worse. This is due to their elastic properties. There is a greater dissipation of energy and the mill and material are heated more. The performance of the mill is also reduced due to the poorer flow properties of the ground particles. Wet particles tend to agglomerate and therefore agglomerates of individual particles and not the particles themselves must pass

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through the openings of the sieve. Dry materials, due to their fragile nature, have less energy dissipation. Their tendency to agglomeration also decreases (Peciar et al., 2019).

2. Measurements

The article deals with various methods of characterization and evaluation of the shape and dimensions of particles that arise as a product of milling the beech chips. Milling was performed in a knife mill. A grinding device operating on the knife grinding system is based on the mechanism of shearing of the material by cutting. Thus, the shear stresses τ are predominant, Figure 1. This principle is suitable for elastic materials (plastics, wet wood, etc.) but also for fragile raw materials (minerals, dry wood, etc.) as well as for mixed wastes such as municipal solid waste (Fekete et al., 2007).

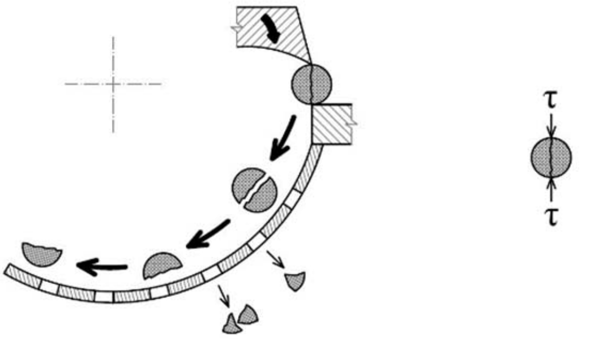

Figure 1: Basic principle of knife mill operation and particle shear stress

The product formed by milling has non-isometric particles. The main problem in evaluating the particle size distribution for such materials is the choice of the characteristic size and the method for determining the particle size distribution. The basic method is sieve analysis on shaking devices with a set of sieves with different mesh sizes. The results are affected by the random position of the particle relative to the sieve at the moment when it is to fall through the hole. There may be a situation where the particle hits the surface of the sieve with its larger projection. Then it will not fail and will remain on the site. If it falls on its surface with a small projection, it will fall through the hole. This causes scatter in the results. At present, it is possible to use modern methods based on particle visualization, e.g. Microtrac PartAn3D. The device captures free-falling particles and scans their random rotation during their fall. This will give a series of images with two-dimensional imaging at different particle rotations. The 2D series of two-dimensional images allows obtaining a 3D image of a particle shape. This data is then used to calculate equivalent parameters to calculate particle size distribution (PartAn3D Dry Particle Image Analyzer Operation and Maintenance Manual, 2015, Microtrac). For evaluation of this particle size distribution, an equivalent parameter according to D_a was used, Figure 2.

Notation	Description	
D_a		the projection area of a real particle into an ideally circular with diameter D_a

Figure 2: The basic parameter calculations of the measured particles (PartAn^{3D} Dry Particle Image Analyzer Operation and Maintenance Manual, 2015, Microtrac)

However, the particle size distribution also has an effect on the flow properties of the bulk materials. Therefore, the main focus was on examining the flow properties of milled products. A FT4 Powder Rheometer was used for this, which is intended for measuring the flow properties of powders (Freeman Technology, 2020). The measurement is based on the stress theory of bulk materials and the resulting flow properties (Standard Shear Testing Techniques for Particulate Solids Using the Jenike Shear Cell, 1989). These are characterized mainly by the flow function *FF* and the internal friction angle *AIF*.

The material analyzed in this article was prepared by milling in a knife mill. Grinding was performed at rotor speeds n = 1500 min^{-1} and 3000 min^{-1}. In addition, the effect of two different hole geometries in the matrices was investigated. The first matrix was a screen sieve with squared openings and the second was a screen sieve with trapezoidal openings Figure 3.

a) b) c)

Figure.3 Knife mill. a) view at the mill, b) screen sieve with squared openings(4HR), c) screen sieve with trapezoidal openings (LICH).

The samples after milling were placed in vessels and successively processed by methodologies for determining the particle size distribution and flow properties Figure 4. A Microtrac PartAn3D particle shape analyzer was used for measuring the particle size distribution. The projection of a free-falling particle is used and the equivalent size of an ideally circular particle is calculated, in this case according to the projection area of a real particle Figure 2. The particle number is then recalculated according to their equivalent volume.
The flow properties of the raw material were measured in the FT4 Powder Rheometer designed for powder materials. The methodology is quite extensive and developed especially for this rheometer. It is based on the methodology of the standard shear testing techniques for particulate solids using the Jenike shear cell.
The results of the measurements were plotted, selecting certain combinations so that the influence of the milling parameters on the particle size distribution and flow properties of the product could be assessed.

a) b) c)

Figure 4: Particle shape after milling the raw material on a screen sieve with squared openings (4HR), with dimensions a) 6x6mm, b) 4x4 mm, c) 2 x 2mm.

The particle size distribution is one of the basic characteristics of bulk materials. In Figure 5 shows the particle size distribution of beech chips particles when they were processed at different rotor speeds and at different dimensions of the square hole matrix. As the matrix decreases, the width of the particle size distribution also changes. The largest is at 1500 rpm and the matrix 6 mm, the smallest at 3000 rpm.

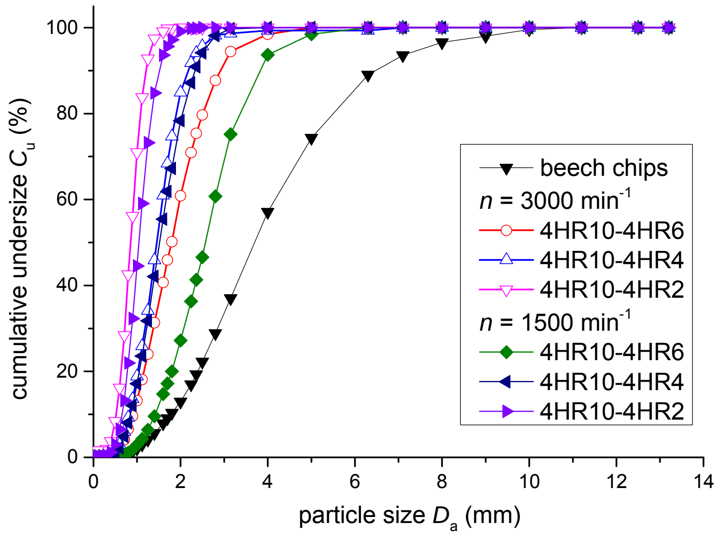

Figure 5: Particle size distribution for different screen sieves and rotor speeds. 4HR10 - hole 10x10mm, 4HR6 - hole 6x6mm, 4HR4 - hole 4x4mm, 4HR2 - hole 2x2mm

From Figure 5 it can be seen that the particle size depends on the size of the holes in the screen, but also on the speed of the rotor with the milling knives.

The effect of this parameter is shown in Figure 6. It is evident that the particle size distribution is almost linear in the interval D10 - D90. This suggests that the mechanism of grinding such materials in a knife mill tends to produce a relatively narrow particle size spectrum. However, it has no effect on the particle shape, as all Mean Sphericity values are in a very narrow range of scattering.

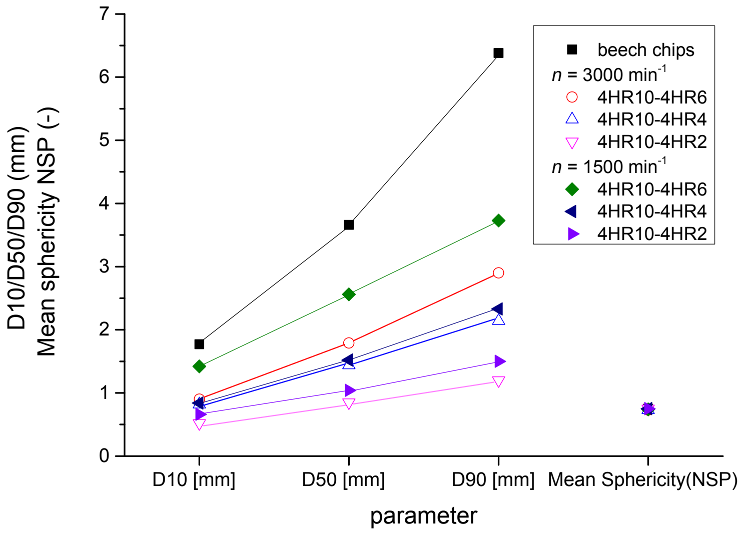

Figure 6: Influence of rotor speed and hole size in the screen sieve on the characteristic dimensions D10, D50, D90 and Mean Sphericity (NSP).

If the results of milling on a matrix with a trapezoidal shape are compared, the particle size distribution behaves similarly to the previous measurement. However, the particle size is significantly smaller, which is a result of the size of the holes in the matrix.

The speed of the rotor with milling knives has a significant effect on the reduction of particle dimensions also, Figure 7.

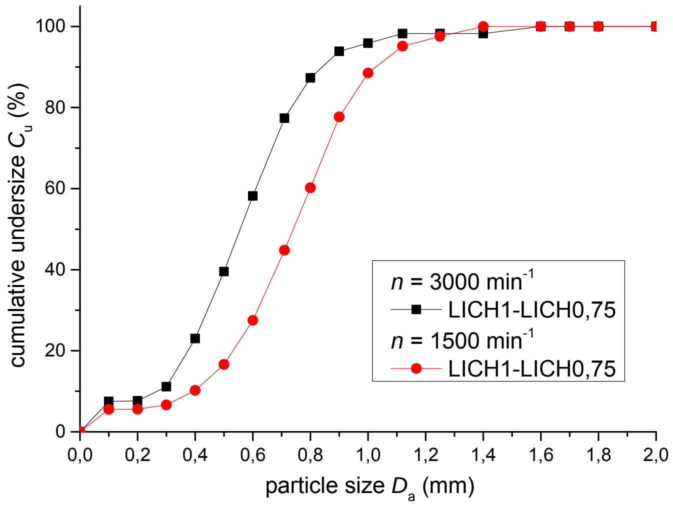

Figure 7: Particle size distribution for rotor speed at trapezoidal matrix

The flow properties of the product are shown in Figure 8. It is not possible to clearly conclude from the results the influence of the size and shape of the screen and the rotor speed on the flow properties and the angle of internal friction of the product. The values of these parameters, i.e. the flow function *FF* and the internal friction angle *AIF*, are in a relatively narrow interval and intersect each other. What is evident is the decrease in the flow function of the *FF* and the internal friction angle of the *AIF* with increasing consolidation pressure.

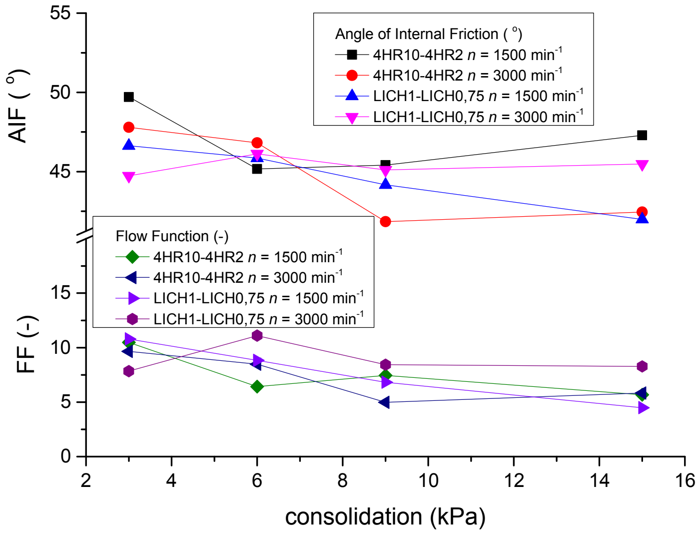

Figure 8: Flow properties of the product obtained at different parameters of the matrix and rotor speed

The values of the flow function *FF* are from the interval (4.48 - 11.1), they decrease with increasing consolidation pressure. These values are characteristic for the easy-flowing or free-flowing materials (Mehos, 2017). This means that the flow properties deteriorate slightly with increasing load. It can be assumed that when handling, e.g. filling of molds, there should be no problems with arching.

This phenomenon could be explained by the non-isometric shape of the particles. It is possible that with increasing consolidation pressure, the orientation of the particles occurs in such a way that the particles are directed parallel, with their larger area to the shear plane. However, this assumption needs to be verified.

3. Conclusions

The measurement results show that the speed of the rotor with milling knives has a significant effect on the reduction of particle dimensions. As the speed increases, its size decreases. In addition to the speed, the size of the matrix holes also affects the particle size distribution. However, different combinations of these parameters do not have a significant effect on the flow properties of the product. It is not possible to unambiguously draw conclusions from the measurements regarding their influence on the internal friction angle of the *AIF* and on the flow function of the *FF*. Only it can be stated that these quantities decrease with increasing consolidation pressure. This may be due to the elastic nature of the ligno-cellulosic materials and the non-isometric shape of the particles after grinding.

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References

Bird R. B., Stewart W.E., Lightfoot E.N., 2007, Transport Phenomena, John Wiley & Sons, Inc., ISBN 978-0-470-11539-8.

Fekete R., Peciar M., Gužela Š., 2007, Procesné strojníctvo I, STU Bratislava, ISBN 978-80-227-2766-2

Freeman Technology, 2020., https://www.freemantech.co.uk/powder-testing/ft4-powder-rheometer-powder-flow-tester

Mehos G., 2017, Powder flowability - FFC, FF, ff, and WTF!, https://www.linkedin.com/pulse/powder-flowability-ffc-ff-wtf-greg-mehos

PartAn3D Dry Particle Image Analyzer Operation and Maintenance Manual, 2015, Microtrac. https://www.microtrac.com/products/particle-size-shape-analysis/dynamic-image-analysis/partan-3d/

Peter P., Fekete R., Peciar M., Jirout T., 2019, Milling of Materials on the Base of Cellulose. 27th European Biomass Conference & Exhibition, Lisbon – Portugal.

Standard Shear Testing Techniques for Particulate Solids Using the Jenike Shear Cell, A Report of the EFCE Working Party on the Mechanics of Particulate Solids, The Institute of Chemical Engineers EFCE, 1989, ISBN 0 85295 232 5.