Influence of the grinding method on the flow properties of barley

Thomas Hoffmann*, Christian Fürll

(Leibniz Institute for Agricultural Engineering Potsdam-Bornim, Max-Eyth-Allee 100, 14469 Potsdam, Germany)

Abstract: Hammer mills or roller mills are used to grind grain for feed for animal husbandry. The grinding process in hammer mills is based on impact stress on the grain kernels. Roller mills, however, apply pressure and shear stress. The different working principles in hammer mills and roller mills lead to different physical properties of the ground material. The aim of the project was to quantify the physical properties of barley which was ground by a hammer mill or a roller mill. Therefore, the particle size distributions of the ground material were determined by sieving. The particle form was characterized by a form factor. Shear experiments according to Jenike were carried out to determine the flowability. The bulk density was obtained from the quotient of the filling weight and the filling volume of a test vessel. The angle of repose was observed on bulk material, which was flowed from a hopper onto a round plate. In the result, the material from the hammer mill shows an increasing flowability with increasing particle sizes and a direct correlation between bulk density and the particle size class. The values of the angle of repose become smaller with increasing particle size. The material from the roller mill shows the same tendencies but to a less extent.

Keywords: flow properties, particle size, hammer mill, roller mill

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1 Introduction

Grain is increasingly being processed worldwide to produce feed for animal husbandry. The changes taking place in eating habits contribute to this situation. In order to lower the energy consumption involved, less use is being made of impact stress with the help of hammer mills to reduce grain particle sizes. This is because far less energy is required when pressure and shear stresses are applied in roller mills (Fürll et al., 1996; Hoffmann et al., 2011). However, what is interesting here is whether the different kinds of stress lead to changes in the physical properties of the ground product that than need to be taken into account when dimensioning plant and equipment. As barley represents a significant component in dry compound feed formulations, studies were first conducted with this cereal.

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***Corresponding author: Thomas Hoffmann,** Leibniz Institute for Agricultural Engineering Potsdam-Bornim, Max-Eyth-Allee 100, 14469 Potsdam, Germany. Email: thoffmann@atb-potsdam.de

Since about the mid-1950s, in dry compound feed production grain size has largely been ground with the help of hammer mills. Methods using pressure and shear stress were hardly used anymore. The advantages of hammer mills by comparison with roller mills lie in the lower investment requirement and the higher mass flow rates, but they have the disadvantage of far higher specific energy requirements and the relatively large share of particles in the range <500 μm (Löwe and Feil, 2011). As energy is now becoming increasingly more expensive, thus driving up the cost burden of the end product, roller mills and comparable machines are being used more frequently in practice again (Fürll et al., 1996; Hoffmann et al., 2011). There are virtually no objections to this from the standpoint of animal nutrition, as it is above all the particle size and size distribution parameters that are crucial for the performance parameters and the effects on animal health (Wolf, 2012).

It is known that these two size reduction methods do not lead to the same particle size distribution and particle form of the ground product (Löwe and Feil, 2011). Consequently changes in the physical properties result

(Fürll, 2006; Fürll, 2007; Fürll and Hoffmann, 2012; Fürll and Hoffmann, 2013).

In order to quantify the physical properties of the ground barley for the grinding methods impact stress (hammer mill) and pressure/shear stress (roller mill), examinations are being conducted to determine the following relationships:

- flow properties depending on the particle size and grinding method
- angle of repose as a function of the particle size and grinding method
- bulk density as a function of the particle size and grinding method.

2 Materials and methods

2.1 Experimental material

The experimental material is barley, which accounts for a large share in the formulations of dry compound feed. The size reduction was performed in each case with a laboratory roller mill "QC-109 Pionier" of the company "Labor" MIM Budapest (Hungaria) and a laboratory hammer mill "RECORD A" of the company Jemlich (Germany). The dry matter content was a uniform DM = 85.5%. In order to be able to determine the influence of the particle size, after grinding samples with the following size fractions were produced with the help of a flat screening machine:

315 μm > x > 250 μm

250 μm > x > 200 μm

200 μm > x > 160 μm

160 μm > x > 100 μm

All the samples lie in the fine-grain size range. This was intentional because even slight shares of cohesive fines affect the flow behaviour of the entire material system (Fürll, 2007; Fürll and Hoffmann, 2012; Fürll and Hoffmann, 2013). Above all, the physical properties of the fine material are of interest.

2.2 Experimental methods

2.2.1 Determining the flow properties

The flow properties are determined with the help of shear strength measurements for which the Jenike shear cell is ideally suited in the particle size range x < 1.0 mm (Figure 1):

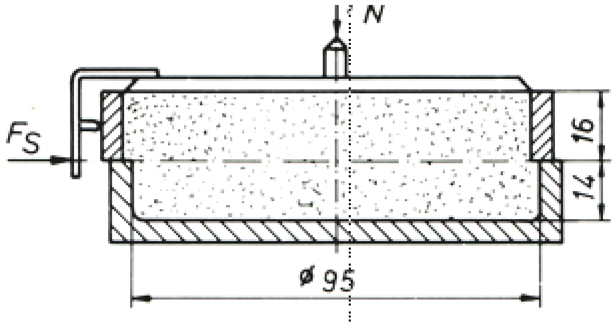

Figure 1 Jenike shear cell

In the performance of the experiment, the normal stress σ^*_N for a certain material sample of constant density at which the shear stress remains constant throughout the shearing and the material flows at a constant sample volume is sought. The point with the associated shear stress (σ^*_N, τ_e) represents the end point of a yield locus. In all further experiments, pre-shearing is first carried out at the normal stress σ^*_N until the upper ring of the Jenike shear cell moves from the original eccentric position into the centric position. Then the normal stress is reduced to $\sigma_{Ni} < \sigma^*_N$ and the sample is sheared off. If this is repeated several times with shear stresses reduced step by step, a complete flow locus results. Further yield loci of a family of yield loci are obtained for other constant product densities. The maximum main stress of the Mohr circle that is tangential to the end point of a flow locus is the consolidation stress σ_1. The maximum main stress of the Mohr circle that is tangential to the yield locus and of which the second main stress has the value zero is the unconfined yield strength σ_c. The ratio of these two sizes is the flowability ff_c to Jenike:

$$ff_c = \frac{\sigma_1}{\sigma_c} \quad (1)$$

2.2.2 Determining the bulk density

To determine the bulk density, a test vessel with an inner diameter of d_i = 55 mm is filled. With this diameter, the fault existing as a result of the edge influence that occurs at insufficient values of the inner diameter can be neglected. The value for the bulk density is obtained from the quotients of filling weight and filling volume.

2.2.3 Determining the angle of repose

From among the many methods described in literature, a method in which the bulk material flows continuously from a hopper onto a circular plate arranged beneath it was selected. A material cone forms on the plate and its angle of repose is measured (Figure 2):

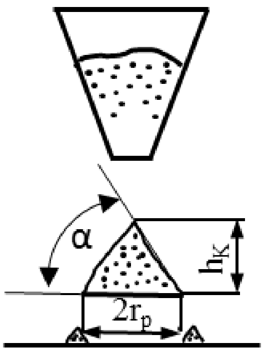

Figure 2 Determining the angle of repose

α angle of repose

h_K hight of material cone

r_p radius of the base area of the material cone

$$tan\ \alpha = \frac{h_k}{r_p}$$

2.2.4 Particle form

The literature contains a whole series of suggestions for characterising the particle form (Saad et al., 2011). For the following examinations, the ratio of particle length a to particle width b was selected as form factor FF (elongation). As 60 particles were measured for each sample, the central value $FF_{50;0}$, the modal value FF_h and the standard deviation $\sigma_{\zeta FF}$ could be taken from this as distribution parameters of a logarithmic normal distribution.

Furthermore, the particle form was characterised by determining the fractal dimension D. It is determined by approximating the actual circumference of a particle by the length L of a polygon course with the side length η:

$$L = K \cdot \eta^{1-D} \quad (2)$$

The two constants K and D characterise the irregularity of the particle contour. D lies between 1 and 2 and is larger the more irregular and rougher the contour is (Tomas, 2015).

3 Results and discussion

3.1 Flowability

With the exception of the smallest particle size fraction, the flowability according to Jenike calculated with Equation (1) from the results of the shear experiments shows clear dependence on the particle size and the grinding method (Table 1) (Figure 3):

Table 1 Experimental results

Particle size Fraction µm	Average particle size µm	Fractal dimension	Elongation-	Flowability	Bulk density kg/m ³	Angle of repose °
Grinding with a roller mill						
100<x<160	130	n.m.	n.m.	7.41	286	47
160<x<200	180	n.m.	n.m.	7.59	324	45
200<x<250	225	1.2785	1.387	12.11	350	46
250<x<315	285	1.2436	1.370	8.20	331	44
Grinding with a hammer mill						
100<x<160	130			4.27	300	52
160<x<200	180			12.24	394	40
200<x<250	225	1.2364	1.584	12.93	422	40
250<x<315	285	1.2160	1.413	18.23	472	37

n.m. not measured

While the values of the flowability for both grinding methods are relatively close together for the particle fraction 100 < x < 160 µm, with increasing particle size flowability improves distinctly for the samples ground in a hammer mill.

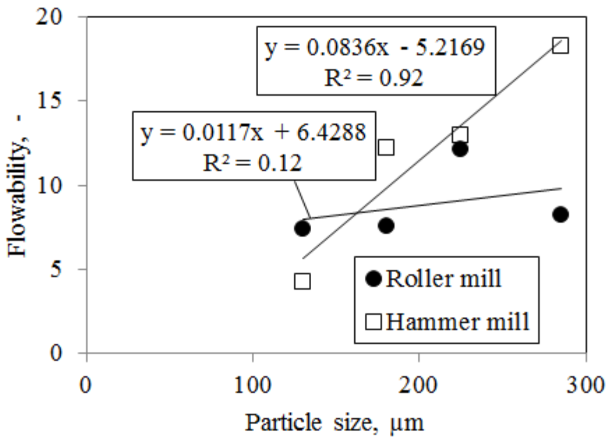

Figure 3 Dependence of the flowability to Jenike of the ground barley on particle size and grinding method

The lower values for the larger particle size fractions in the samples ground with a roller mill with are very probably attributable to the higher values of the fractal dimension, although the elongation values for the samples after grinding in a hammer mill are larger (Table 1). This means that the flowability is shaped above all by the roughness of the particle surface.

3.2 Bulk density

The courses of the bulk density values as a function of the particle size correspond to those for the flow properties. For the smallest fraction 100 < x < 160 µm, the bulk densities for the samples of both grinding methods are the same. This in turn is due to the certainly higher value of adhesive force/mass force. With further increasing particle size, the rise in bulk density values for samples ground in a hammer mill is larger than for samples ground in a roller mill (Figure 4). This too can be attributed to the rougher particle surface, expressed by the fractal dimension. The elongation evidently exerts less influence in this sector.

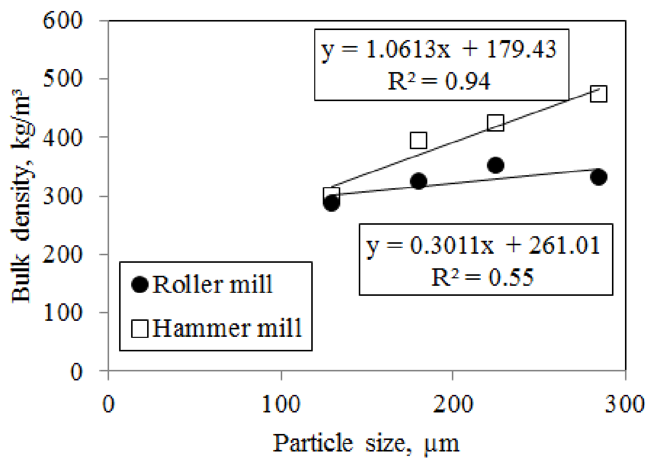

Figure 4 Dependence of the bulk density of the ground barley on the particle size and the grinding method

3.3 Angle of repose

The courses of the angles of repose as a function of the particle size also correspond to those of the flow properties and the bulk density. In the case of the smallest particle size fraction 100 < x < 160 µm, the values of the angles of repose are similarly high for both grinding methods. With increasing particle size, the angle of repose for the samples after grinding with a hammer mill is reduced more than for the samples after grinding with a roller mill. This too can be explained in line with the fractal dimension by the greater surface roughness of the particles after grinding with the roller mill (Table 1) (Figure 5):

4 Conclusions

The studies of the influence of the size reduction method on the physical properties of ground barley were conducted using four particle size fractions in the range 100 < x < 315 µm. The elongation and the fractal dimension were determined to characterise the particle form. For the fraction 100 < x < 160 µm, the influence of the small particle size prevails in the physical properties examined. In this range it is to be assumed that the ratio of adhesive forces to weight forces is higher than in the case of the larger particle fractions.

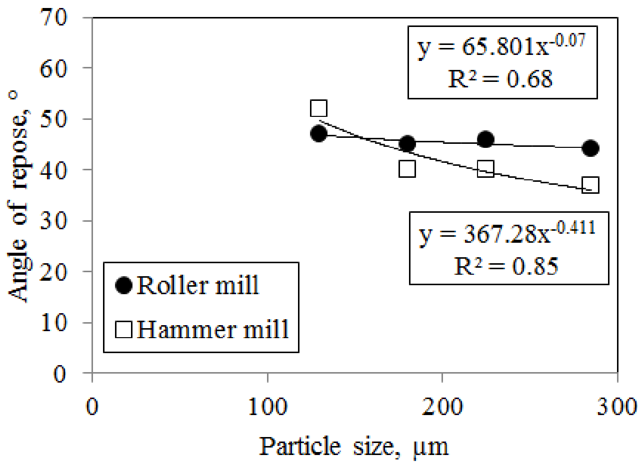

Figure 5 Dependence of the angle of repose of the ground barley on the particle size and the grinding method

This makes the values for the flowability according to Jenike, the bulk density and the angle of repose almost identical for the samples produced with both grinding methods. In the three larger particle fractions the values of the flowability and the bulk density increase with larger particle sizes. Here the increase is greater for the samples ground with a hammer mill than for the particles ground with the roller mill. The values of the angles of repose become smaller with increasing particle size, with the decline being larger for samples ground with a hammer mill. It can be assumed that this behaviour is caused by the larger surface roughness of the particles after grinding with a roller mill.

As the use of hammer mills for grinding is now declining for reasons of energy saving, it should be noted when planning technical installations that the material ground with roller mills displays lower flow properties.

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