OPTIMIZATION PROPOSAL FOR FERRITE MAGNET PRODUCTION

Jiří ZEGZULKA [1,2], Lucie JEZERSKÁ [1], Jakub HLOSTA [1], Alice VALDEROVÁ [2], Jan NEČAS [1]

[1] *VSB - Technical University of Ostrava, ENET Centre, Bulk Solids Centre, Ostrava, Czech Republic, EU,* *jiri.zegzulka@vsb.cz*

[2] *VSB - Technical University of Ostrava, Faculty of Mining and Geology, Ostrava, Czech Republic, EU*

Abstract

This paper deals with optimization of ferrite magnet production. The study is divided into two parts. The first part introduces general information about magnets and their division. The process of the magnet is described in detail. In the second, experimental part of the input raw material, ferrite metal powder, the basic mechanical and physical parameters were determined, including the angle of internal friction, the particle size distribution, the particle shape and the flow function, serving for a more detailed description of the behaviour of the material throughout the technological line. On the basis of evaluation of measured data, specific steps were proposed to optimize ferrite magnet production and general optimization of weak points of storage and feeding processes. The support of Discrete Element Method was used for the final hopper design.

Keywords: Magnet, ferrite powder, angle of internal friction, hopper

1. INTRODUCTION

Magnet is an object that creates a magnetic field around it. The magnetic field allows the magnet to have its specific ability to attract magnetic materials. The magnet may take the form of an electromagnet or a permanent magnet. Electromagnets need electricity to create a magnetic field. Permanent magnets do not need external influences to create the magnetic field, they are able to create a magnetic field around them permanently. We distinguish rare earth magnets, AlNiCo magnets and ferrite magnets. Rare Earth magnets are made from the group of elements that are referred to in the periodic table as alkaline earth metals. AlNiCo magnets are materials made of mixtures of aluminium, nickel, cobalt, iron, copper and titanium [1,4]. Ferrite magnets, also known as ceramic magnets, are among the most widely used and affordable magnet materials. Their worldwide consumption is still growing and now reaches around 300,000 tonnes per year [2]. These materials are made of iron oxide and barium or strontium carbonate. The most common are $BaFe_{12}O_{19}$ and $SrFe_{12}O_{19}$. Raw materials for their production are well-available and cost-effective [1]. The ferrite magnet's superior properties are brittleness, hardness and corrosion resistance. Due to their very high brittleness they require grinding using a diamond wheel [3]. They are highly efficient and are not easy to demagnetize (demagnetization is a process that reduces the overall magnetic polarization in the magnet, also called demagnetization). They are also very resistant to chemicals such as thinners, weak alkalis and acids. Resistance to strong organic and inorganic acids is influenced by temperature, concentration and duration of action. They are the least powerful permanent magnets [1]. Ferrite magnets have a wide range of applications. Applications are found in the automotive industry as part of magnetic couplings and brakes, are applied as holding magnets in industry, office or household, are useful in toy manufacture, position sensors manufacturing, switches etc [2]. Each type of permanent magnet its specific production process. The common production technology for all types of magnet is powder metallurgy, the method by which a mixture of metal powders is mixed, then compressed into a mould and subsequently sintered at high temperatures. The resulting product is very hard and cannot be repaired or repaired in the required form. The ferrite magnet is produced by weighing Fe_2O_3 and $SrCO_3$, subsequently mixing these two feedstocks with minimal spraying in the mixer. The dry mixture is delivered to granulator where the granules of 6 mm diameter are formed and calcined subsequently. Calcination is a high-temperature process in which one solid material is eliminated as a gaseous substance and the other forms a solid. The calcinate is then crushed on a continuous rod vibratory mill. Subsequently, the moulding is done in the desired form in dry form or in the form of an aqueous suspension. In dry form, isotropic magnets or magnets with the same magnetic properties in all directions are moulded. Anisotropic magnets, i.e. magnets with different properties in different directions, are compressed in the aqueous slurry. The final shape, size and toughness of the magnets are obtained by firing (sintering) at 1200 °C. They are then magnetized and packaged and dispatched after the final check.

2. EXPERIMENTS AND METHODS

This study deals with the optimization of ferrite magnet production. The basic mechanical-physical parameters, the particle size distribution, the particle shape and the flow ability (angle of repose) have been determined for input raw material, ferrite metal powder. On the basis of measured data evaluation, specific steps were proposed to optimize the production of ferrite magnets and general optimization of weak points of storage and feeding processes by DEM modelling.

2.1. Materials

The material examined in this work is the strontium hexaferite $SrFe_{12}O_{19}$, the so-called Ferrimagnet, the basic component of permanent magnets. The composition of the material was verified by X-ray diffraction analysis. Strontium hexaferrite is a hard magnetic material due to their high coercivities (6.64 kOe) which originates from its high magnetocrystalline anisotropy and it is strongly dependent on the size and the shape of the particles. Moreover, the Curie temperature of $SrFe_{12}O_{19}$ is around 470 °C and the saturation magnetization between 74.3 and 92.6 emu/g. For the preparation of hexaferrite, the solid state reaction method is commonly employed that involves firing of a stoichiometric mixture of strontium carbonate and iron oxide at high temperature (~1,200 °C) but the obtaining fine, high chemical homogeneity and monodispersed particles may not be easy. [5] Raw input material is shown in **Figure 1**.

Figure 1 Raw input material

2.2. Particle size distribution

Particle size distribution of ferrimagnet material was determined by sieve analysis. The analysis was performed by Fritsch Analysette 3 Spartan Vibratory Sieve Shaker. The duration of sieving was 20 minutes with amplitude of 1.5 mm. The sieves from 63 µm up to 3,350 µm were chosen for testing procedure. At first, all of specimen was weighted. The sieves were arranged in order as the smaller openings sieve to the last and larger openings sieve to the top. After sieving process all of the sieves were weighted separately to each size class mass determination. The results of particle size distribution can be seen in **Figure 2**.

2.3. Angle of repose

Angle of repose (AoR) is one of the basic properties of particulate materials that affect transport and storage in all areas of industry, e.g. food, construction, agriculture, energy or pharmaceutical industry. In contrast to liquids or solids, the granular material creates an angle of repose that depends on many of the material's properties. Parameters such as angle of internal friction, particle size and shape, size distribution, surface, moisture, electrostatic or cohesive forces may influence the value of the natural angle of repose. Angle of repose is also used as the basic calibration parameter for virtual materials in the DEM method.

Patented device (Zenegero) for an angle of repose measurement was used [6]. Ferrimagnet material is poured into the cell (plate), while gradually creating the pile and surplus material falls into the receptacle. After the pile creation, the drive makes the cell rotating. The cell rotates around its vertical axis and the camera successively records a pile of all eight sides. The results were processed by the eScope software.

2.4. DEM modelling

A Discrete Element Method (DEM) is a more and more respected method for the numerical modelling of granular systems. Using the DEM, particulate material is simulated as a set of individual particles interacting with each other or with any other solid object within a storage, transport or process system. [7] The trajectory and velocity of each particle is calculated in discrete time steps, which provide a wealth of information such as collision frequency and duration of contact with adjacent particles. DEM simulations in this study were done using commercial EDEM Academic software. [8] Commercial codes like EDEM include a powerful graphical user interface that is linked to 3D CAD drawing formats. Due to computational constraints, the current DEM software has certain limits. There are also limitations on determining the input parameters necessary for simulation. All these limitations lead to uncertainty about the accuracy of DEM modelling, and often DEM simulations are qualitative rather than quantitative. [9] One of the key issues is still the representation of real particle shapes with particle size and number of particles.

3. RESULTS AND DISCUSSION

The particle size distribution of raw input material, measured by the methodology in Chapter 2.2, is illustrated in **Figure 2**.

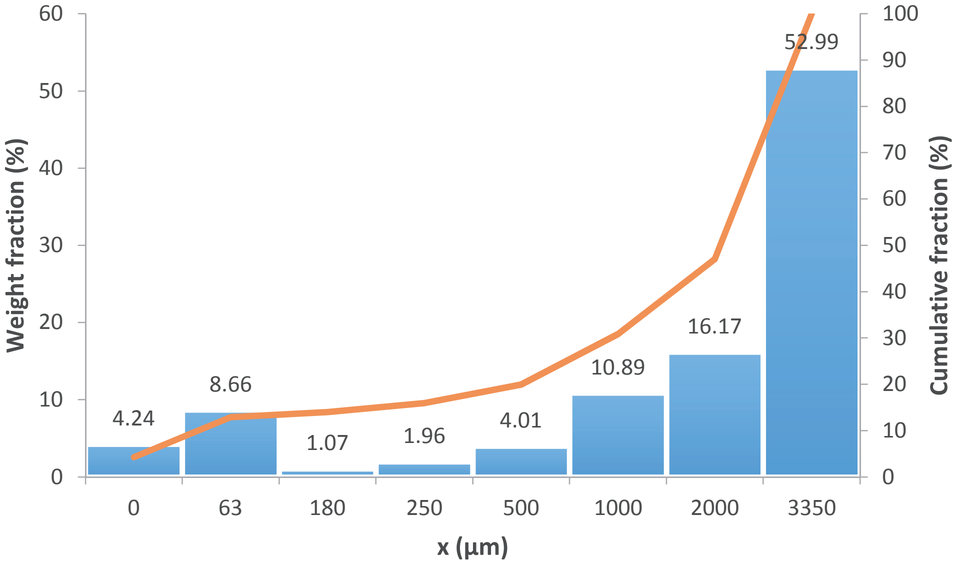


Figure 2 Particle size distribution

The granulometry analysis of the raw input material showed that the largest amount of particles was in the range from 1 mm and above. The measured results are consistent with the production requirements and therefore it can be stated that the production processes used are properly designed. The sieve analysis will be also used for the virtual material of DEM model definition.

The angle of repose measured by the methodology given in Chapter 2.3 is shown in **Table 1**.

Table 1 Angle of repose of input raw material determined by Zenegero method

Measurement No.	Angle of repose (°)		
1	38.9	38.4	38.6
2	36.2	39.8	36.8
3	38.8	37.9	38.9
4	36.8	38.3	37.8
5	39.6	38.8	37.5
6	36.7	37.3	36.2
7	37.9	35.4	39.8
8	38.8	38.1	39.2
Average value (°)	38.0±1.2	38.0±1.2	38.1±1.2

Average value of angle of repose is 38.1° for the input material, the optimum angle of repose is 30°. The measurement results show that this part of the production process needs further optimization. It is necessary to work with this fact in production.

The measured angle of repose of raw input material is shown in **Figure 3**.

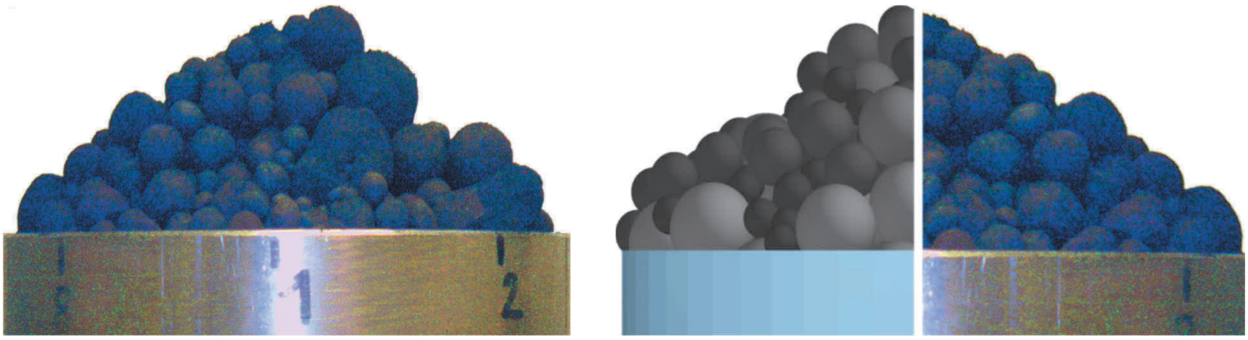
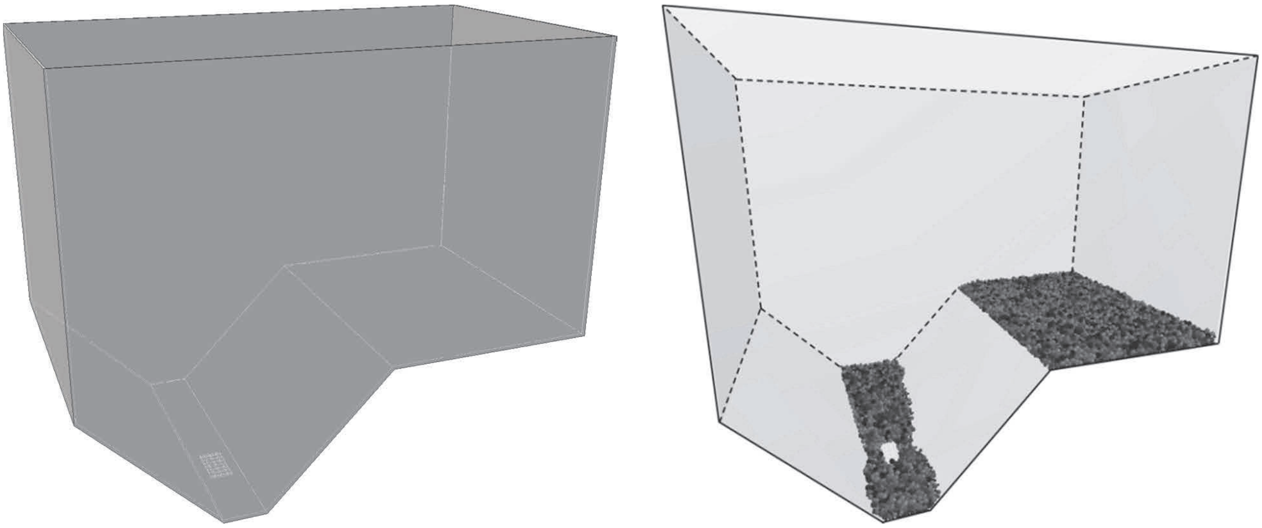

a)
b)

Figure 3 Raw input material measured by Zenegero method (a), AoR of virtual and real material comparison

The **Figure 3a** shows the real shape of angle of repose of raw input material. It can be traced that the left part of the measured material is symmetrical. In the right part, there are irregularities that can make the production of the ferrite magnet disadvantageous.

The raw input material is now transported in the production by a hopper, which can be seen in **Figure 4a**. This hopper has proven to be inappropriate because it stucks the material and creates dead zones, which disturbs the flow of the production process. In the **Figure 4b** is a final state of simulation of the discharging process, where the rest of the stuck material can be seen "death zones".

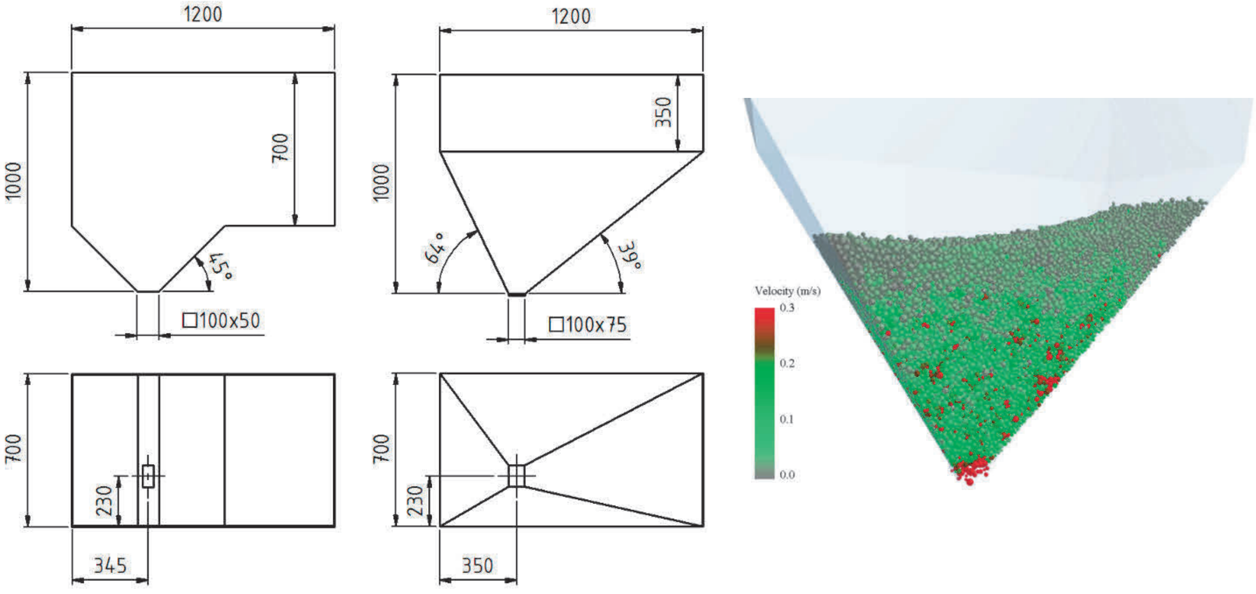


a) b)

Figure 4 Original (unsuitable) hopper design (a), the particles stucked in the “death zones” (b)

Using a DEM simulation a new shape of the hopper was designed (**Figure 5b**). The higher values of hopper angle will ensure mass flow of particulate material. Flow visualization is displayed in the **Figure 5c**. Particle size distribution and angle of repose were used to validate the method. Due to the optimization of the hopper geometrical shape, will be the hopper completely discharged and material does not stuck on the walls of the hopper.

To visualize the flow of ferrite in the hopper was created virtual material in a form of the spherical particles according to the measurement of the real material. This material was set up according to the angle of repose, which is important for storage processes. The result of simulating of angle of repose of a virtual and real substance suggests that this method will be useful in practice.



a) b) c)

Figure 5 Original (a) and optimized (b) design of the hopper, visualization of hopper discharging process (c)

4. CONCLUSION

The objective of this study was to optimize the production of ferrite magnets. A weak point was marked in inappropriate hopper design for raw input material storing. The analysis and evaluation of the processes and all the measurements made have shown that the hopper is unsuitable. Using a particle size distribution (in the range of 1 mm above), the angle of repose (38.1 ° for the input material) and DEM modelling, a hopper was designed. Due to the optimization of the hopper geometrical shape, the hopper is discharged and the material does not stuck on the walls of the hopper in simulation. DEM simulation seems to be appropriate for optimizing the shape of the hopper.

ACKNOWLEDGEMENTS

This paper was conducted within the framework of the project LO1404: Sustainable development of ENET Centre and by student grand competition SP2018/47: Calibrating and experimental devices for research and validation of simulation models.

REFERENCES

[1] [online] Permanentní magnety (Update: jan. 2016); [viewed 2017-07-21], Available from: http://www.feromagnet.cz/images/soubory/Permanentni_magnety.pdf

[2] [online] Alnico Magnets; [viewed 2018-02-08], Available from: http://www.arnoldmagnetics.com/en-us/Products/Alnico-Magnets

[3] [online] Types of Permanent Magnets (Update: 2018); [viewed 2017-08-16], Available from: https://www.magcraft.com/types-of-permanent-magnets

[4] RUIXUE, Sun, JUN, Zheng, BOTIAN, Zheng, NAN, Qian, JIPENG, Li, ZIGANG Deng. Referencing: New magnetic rails with double-layer Halbach structure by employing NdFeB and ferrite magnets for HTS maglev [online]. 2018. vol. 445, pp. 44-48 [viewed 2018-01-01]. Available from: https://doi.org/10.1016/j.jmmm.2017.08.082.

[5] [online] LH magnet; [viewed 2017-09-28], Available from: http://www.lhmagnet.cz/

[6] GELNAR, Daniel, ZEGZULKA, Jiří, SOOS, Lubomír, JUCHELKOVA, Dagmar, NECAS, Jan. Validation device and method of measuring static and dynamic angle of discharge, 2016, Czech Republic, 306123 *Patent*. Assigned 29.06.2016. Registered 10.08.2016.

[7] WEERASEJARA, Nirmal, POWELL, Malcolm, LIU, L.X, Referencing: Estimating energy in grinding using DEM modelling [online]. 2016. vol. 85, pp. 23-33 [viewed 2017-02-16]. Available from: https://doi.org/10.1016/j.mineng.2015.10.013.

[8] HAILI, Zhou, ZHANQI, Hu, JIGANG, CHen, XUAN, Lv, NAN, Xie, Referencing: Calibration of DEM models for irregular particles based on experimental design method and bulk experiments [online]. 2018. vol. 332, pp. 210-223 [viewed 2017-03-17]. Available from: https://doi.org/10.1016/j.powtec.2018.03.064.

[9] HAIYANG, Zhao, XIZHONG, An, YONGLI, Wu, QUAN, Qian, Referencing: DEM modelling on stress profile and behaviour in granular matter [online]. 2018. vol. 323, pp. 149-154 [viewed 2017-01-17]. Available from: https://doi.org/10.1016/j.powtec.2017.10.006.