Diagnostic method for the selection of regimes of electromagnetic effect on the particulate ferromagnetic material

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Abstract. The recycling of obsolete permanent magnets, the processing and reusing of the obtained powder for a new magnets production has both economic and environmental benefits. The processing of recycled magnetic slur to the particle size distribution required for the magnets production has a problem specific for fine magnetic powders – particle aggregation limiting the milling efficiency. One way of solving this problem is milling the magnetic material with the formation of the magneto fluidized bed. In the present work we study the behavior of the recycled from old electromotor stators strontium hexaferrite powders with average particle sizes 56.8 µm and 7.5 µm in the magneto fluidized bed formed by mutually perpendicular constant and alternating gradient magnetic fields. The desired state of the fluidized bed for milling is the one with the maximal particle motion intensity that prevents particle aggregation. The intensification of particle motion could be done by the increase of the alternating magnetic field gradient, but this also increases energy consumption of the process. In the present paper we propose using the inductive method for estimating rheological state of the strontium hexaferrite powder in the magneto fluidized bed. Such estimation allows finding the optimal parameters of electromagnetic fields forming the fluidized bed for the efficient powder milling process.

1 Introduction

Fine powders of the magneto hard materials are widely used in the powder metallurgy for the permanent magnets production [1-4]. The most popular production method is the pressing of powder with further sintering and magnetizing. The permanent magnets properties such as remanence, degrade during the exploitation. Harsh exploitation conditions, overheating, deformations, external magnetic fields accelerate the magnet properties deterioration and the failure of the permanent magnet [5, 6]. One of the advantages of the powder metallurgy is the possibility to save resources by recycling the broken or degraded permanent magnets and reuse the obtained powder for a new product [7-9]. The recycled powders are obtained by crushing the magnet waste in a coarse crusher and subsequent fine milling in various devices.
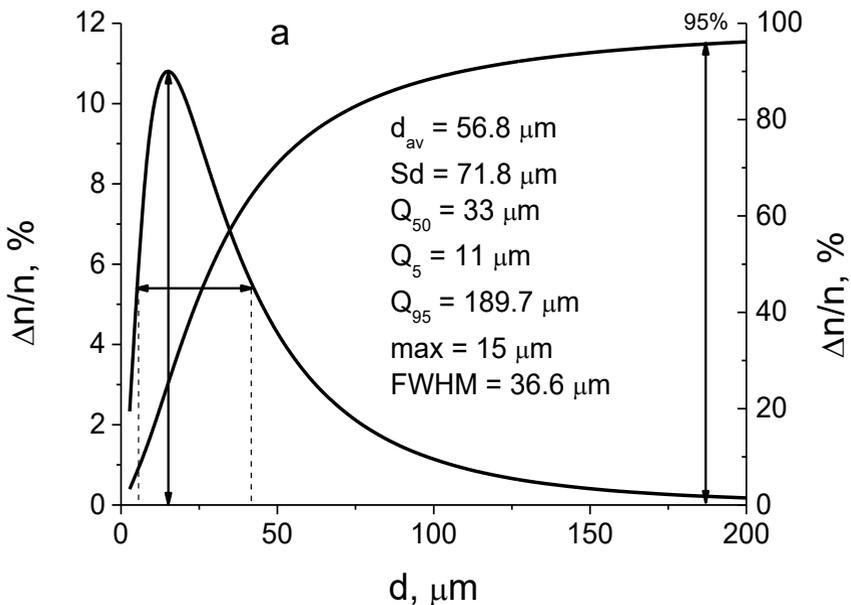
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The common problem of the magnetic materials fine milling is the particle aggregation caused by the interparticular magnetic interactions [10, 11] that leads to decrease in milling efficiency. One of the methods partially solving this problem is the milling in the impact mill with the creation of the pseudo fluidized bed [12-14]. The combination of constant and alternating fields [15-17] proved to be an effective method of pseudo fluidization. On the one hand the additional magnetic fields forming the fluidized bed consume extra energy, one the other – the pseudo fluidization effect allows to decrease the total energy needed for obtaining the fine powder with required particle sizes. The task of optimizing energy consumption of the milling process is an actual problem of the powder metallurgy [18-21].

The goal of the current study was studying the regularities of the influence of the electromagnetic effect parameters on the particles and aggregates motion intensity and the power consumption analysis.

2 Experiment

The materials for the study were the particulate strontium hexaferrite ($SrFe_{12}O_{19}$) samples obtained after crushing the old stators of electric motors with various particle size compositions. The particle size distributions were studied with the optical microscope (for more coarse powders) and the scanning electron microscope Ziess Supra 25. Fig. 1a and 1b show the differential and cumulative curves of the $SrFe_{12}O_{19}$ particle size distributions.
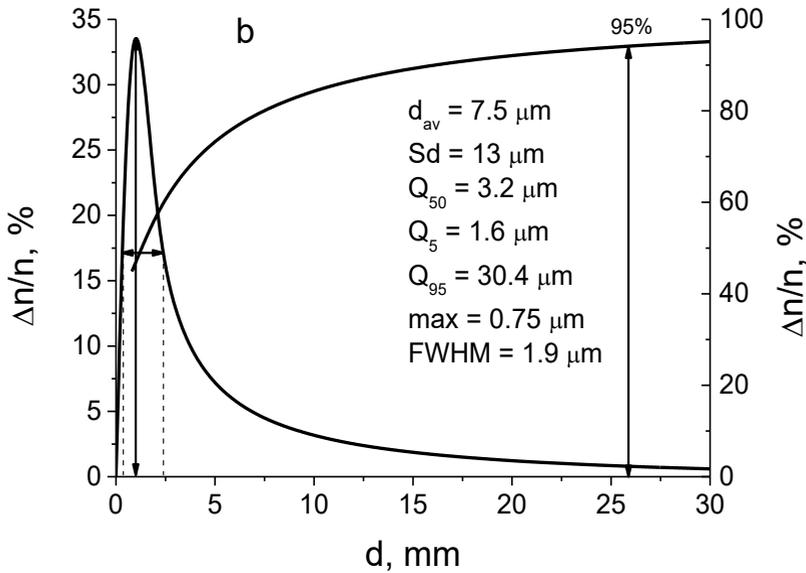

d_{av} = 56.8 μm

Sd = 71.8 μm

Q_{50} = 33 μm

Q_5 = 11 μm

Q_{95} = 189.7 μm

max = 15 μm

FWHM = 36.6 μm

Fig. 1. The differential and cumulative curves of the particle size distribution of the particulate SrFe$_{12}$O$_{19}$ with the average particle size 56.8 μm (a) and 7.5 μm (b)

For studying the magnetic particles motion intensity in the magneto fluidized bed, we used the induction method. The experimental chamber with the powder under study was put inside the inductive coil and placed between the poles of the electromagnets. To create the magneto fluidized bed, we used constant field electromagnet with horizontal induction lines and alternating gradient field electromagnet with vertical induction lines and stronger gradient area in the upper part of the powder containing chamber. The particles of strontium hexaferrite possess magnetic moments and reciprocate in the magneto fluidized bed, thus the volume of the particulate system increases comparing to bulk filling. Both the moving magnetic particles and external alternating magnetic field induce the current in the inductive coil which is registered by a voltmeter. For distinguishing the signal induced by the moving particles from the background from magnetic fields, we measured separately the signal with an empty chamber (ε_0) and the signal with the powder filled chamber (ε). The difference between these values ($\Delta\varepsilon=\varepsilon-\varepsilon_0$) was caused only by the moving particles and is affected by the rheological properties of the particulate system. We measured the dependencies of a relative signal ($\Delta\varepsilon/\varepsilon$) induced in the coil by the particulate system in the magneto fluidized bed from the constant field induction B$_c$ at various alternating field gradient values (Fig. 2, 3).
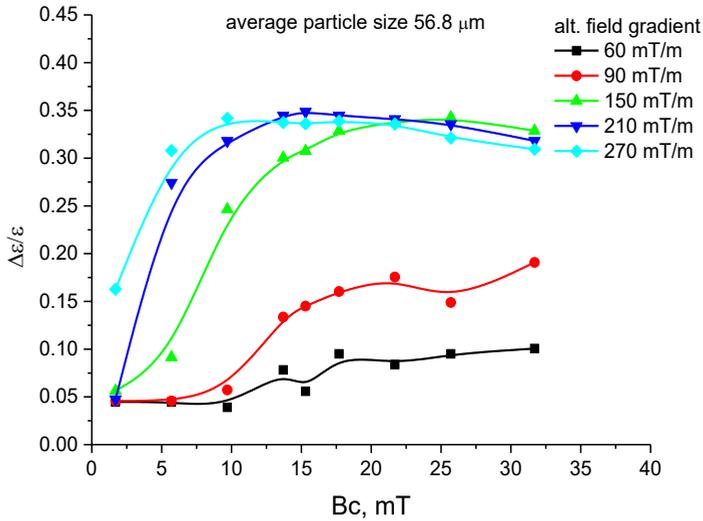
Fig. 2. The dependency of the relative signal Δε/ε, induced by the strontium ferrite powder with an average particle size 56.8 µm from the constant magnetic field induction

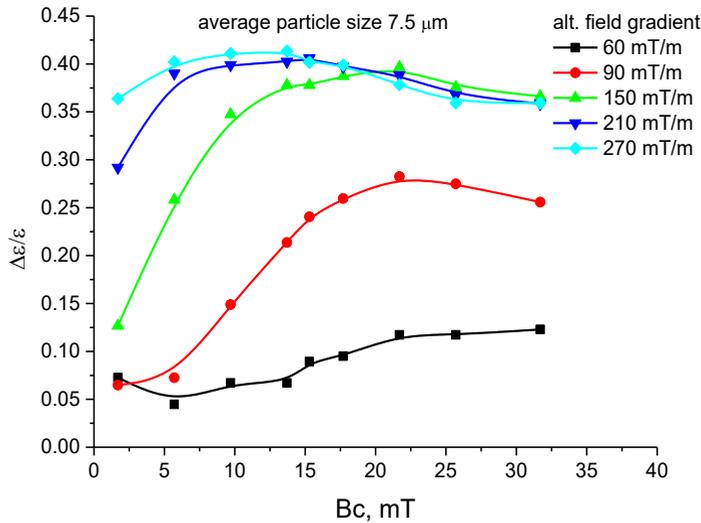**Fig. 3.** The dependency of the relative signal Δε/ε, induced by the strontium ferrite powder with an average particle size 7.5 µm from the constant magnetic field induction

3 Results and discussions

Fig. 2 and 3 show that the relative signal at the alternating field gradient values 60 mT/m and 90 mT/m are significantly lesser than at the higher gradient values. Fig. 2 shows that at the values of the constant magnetic field induction up to 10 mT, the relative signal increases with the increase of the alternating field induction gradient from 150 mT/m to 270 mT/m. This

can be explained by the growing quantity of the powder involved in the magneto fluidized bed, the aggregate destruction and the formation of secondary aggregates with aligned particle magnetic moments. At the increase of Bc from 20 mT, the relative signal decreases at the gradient values of 210 mT/m and 270 mT/m.

Such dependencies of Δε/ε from Bc are witnessed for a particulate system with an average particle size 7.5 μm. However, at the 90 mT/m alternating field induction gradient, the maximal values of Δε/ε for strontium ferrite powders with average particle sizes 7.5 μm and 56.8 μm are 0.28 and 0.15 correspondingly. So, the processes of particle aggregates destruction and their reconstruction into the aligned aggregates are more intense in the finer powder.
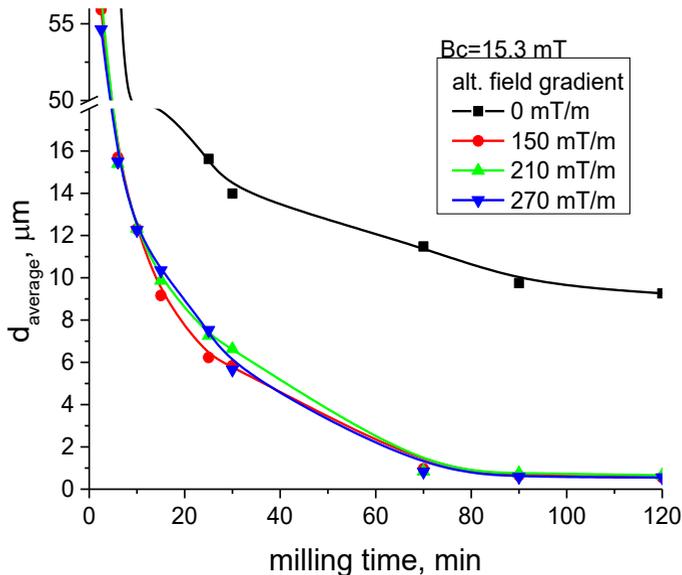

Fig. 4. The dependencies of the strontium ferrite powder average particle size from the milling time in an impact mill in the magneto fluidized bed

The obtained experimental results show that the regime of the maximal aggregate destruction and particle motion intensification is at constant field induction Bc=15.3 mT and the alternating field gradient values from 150 mT/m to 270 mT/m. However, the energy consumption at 150 mT/m gradient is smaller than the one at higher values of the gradient. This makes 150 mT/m the most energy efficient alternating field induction gradient for the formation of the magneto fluidized bed. The dependencies of an average particle size of the powder obtained by milling in the impact mill in the magneto fluidized bed are presented on Fig. 4. They behave similar to the relative signal dependencies at Bc=15.3 mT, both has the asymptotic character with the increase of the alternating field gradient.

4 Conclusion

The proposed method of analyzing the relative signal Δε/ε dependencies can be used to estimate the rheological state of the particulate system. The dependencies of the relative signal from the magnetic field parameters correlate with the analogical dependencies of the average particle size of powder obtained by milling in the impact mill with the magneto

fluidized bed. This allows selecting electromagnetic fields parameters optimal for the required technological process can be used in powder metallurgy.

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