Stimulated fluidity of Nd-Fe-B powder in magneto fluidized bed

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Abstract. Experimental studies results of electromagnetic effect influence on stimulated fluidity of Nd-Fe-B powder are presented in the paper. Fine Nd-Fe-B powder doesn’t have natural fluidity. To make it flow through hopper nozzle, the powder was affected by constant and alternating gradient magnetic fields. Constant magnetic field induction lines were horizontal, and alternating field lines were vertical with gradient towards efflux direction. We studied influence of magnetic fields on powder fluidity speed to find optimal magnetic fields parameters that form steady efflux of Nd-Fe-B powder with an average particle size 4.6 µm through nozzles with diameters 1 and 2 mm.

1. Introduction

Powders from Nd-Fe-B alloys are widely used in many areas of modern equipment [1, 2]. The production of quality magnets from powders require precise press-mould filling that is complicated by the tendency of ferromagnetic powders to particle aggregation [3-5]. Interaction between particles leads to the formation of large aggregates [6-8] and arc-effects preventing uniform efflux through nozzle. Fine Nd-Fe-B powders don’t possess natural fluidity, press-mould filling through a nozzle of several millimetres diameter isn’t possible by only means of gravitation. Various methods of stimulated fluidity formation are applied to intensify the process of powder transportation [9-11]. Fluidity can be increased by forming fluidized bed from powder by applying vibration or gas fluidization [12, 13]. However, in case of magnetic powders these approaches are not effective because of strong magnetic interaction between particles. Fluidization by magnetic fields application is effective in case of ferromagnetic powders [14-16]. The effect of crossed constant and alternating gradient magnetic fields to the powder flow is considered in the paper. Alternating gradient magnetic field effects on powder particles with force: $F = p_m \frac{dB}{dy} \cos \alpha$ ($\alpha$ - angle between magnetic moment of particle or aggregate $p_m$ and magnetic induction $B$, $\frac{dB}{dy}$, - induction gradient). Force direction varies with frequency of alternating magnetic field. Constant magnetic field holds hovering powder in selected volume. Effect of these two fields forms magneto fluidized bed - dynamically steady hovering state of magnetic particles and aggregates. The goal of the paper is to study influence of magnetic fields values on flow of Nd-Fe-B powder with average particle size 4.6 µm through 1 mm and 2 mm nozzles.
2. Experiment
Schematic illustration of the device used to study stimulated fluidity is presented on Fig. 1. Constant magnetic field is formed horizontally by the poles 1, alternating field is formed vertically by poles 2. Alternating magnetic field gradient is caused by the pointed pole below the filling chamber 3. Hopper 4 contains Nd-Fe-B powder that goes into magneto fluidized state by the effect of constant and alternating gradient fields and flows through nozzle 5 of the hopper 4 to the filling chamber 3. Hopper 4 contains mesh 6 with 0.5 mm size of holes to prevent nozzle jamming by large powder particles and aggregates. Rounded form of hopper bottom was chosen to minimize powder clumping by repeating movement up and down due to alternating field effect. Also, such form helps to avoid arc formation around the nozzle.

Figure 1. Schematic illustration of stimulated fluidity formation device

Powder under study was rapidly quenched [17] neodymium-iron-boron powder with 4.6 µm average particle size. Particle size distribution histogram and lognormal curve are presented on Fig. 2.

After activation of both electromagnets powder in the hopper formed magneto fluidized bed and flowed through the nozzle attracted to high gradient area. The powder flowed for a fixed time, then electromagnets were turned off and the mass of poured out powder was measured by electronic balance.

Magnetic field seeks to align magnetic particles along the direction of resulting induction vector. Also, particles are affected by local magnetic fields of surrounding particles. In the alternating gradient magnetic field, the direction of force effecting on powder particles, changes on the opposite with frequency of 50 Hz. At certain parameters of electromagnetic effect, the powder becomes fluidized forming dynamically steady weighted state of particulate medium. Varying parameters of electromagnetic effect one can change the intensity of structural elements mobility in the magneto fluidized bed [18, 19]. Both processes of aggregate destruction and formation of secondary aggregates take place in the fluidized bed influencing on the speed of mass efflux from nozzle [20].
3. Results and discussion
Experiments were conducted for constant magnetic field induction from 5 to 15 mT and for alternating magnetic field gradient from 400 to 900 mT/m. This range of electromagnetic parameters provides stable magnetofluidized bed formation. While alternating magnetic field is the main cause to make powder flow through the nozzle, constant magnetic field controls speed and stability of this process. Too low constant field induction leads to lack of holding of powder in desired area giving unstable fluidity with high speed value scattering, too high holds powder not allowing it to flow through the nozzle.

Figure 2. Histogram and lognormal approximation curve of Nd-Fe-B powder particle size distribution

Figure 3. Dependency of Nd-Fe-B powder flow speed $dm/dt$ from induction of constant magnetic field $B_c$ and alternating field gradient $dB/dy$ through 1mm nozzle
Figure 4. Dependency of Nd-Fe-B powder flow speed $dm/dt$ from induction of constant magnetic field $B_c$ and alternating field gradient $dB/dy$ through 2 mm nozzle

We have collected experimental data points to a matrix in Origin 9.0 [21] for further plotting of smoothed 3d surface. Dependencies of flow speed $dm/dt$ in milligrams per second from induction of constant magnetic field $B_c$ in millitesla and alternating field gradient $dB/dy$ in millitesla per meter are presented on Fig. 3 (for 1 mm diameter nozzle) and on Fig. 4 (for 2 mm diameter nozzle).

Maximums on the surfaces correspond to electromagnetic field parameters providing both high and stable powder flow speed. Optimal range of electromagnetic fields parameters (high and stable flow speed values) for 1 mm nozzle lies between $B_c$ from 8.5 mT to 12.5 mT and $dB/dy$ from 700 mT/m to 850 mT/m giving flow speed values from 20 mg/s to 24 mg/s. Optimal range of electromagnetic fields parameters for 2 mm nozzle lies between $B_c$ from 7 mT to 9 mT and $dB/dy$ from 600 mT/m to 800 mT/m giving flow speed values from 180 mg/s to 220 mg/s. Both high values of constant and alternating field inductions lead to high but unstable flow speed providing low accuracy of press-mould filling. Flow speed doesn’t depend on nozzle size in a linear manner. Nozzle section area changed in 4 times from diameter 1 mm to 2 mm, but flow speed changed in 10 times. 3mm diameter nozzle gave unstable results of flow speed.

4. Conclusions
Experimental studies of application of magneto fluidization to the press-mould filling process showed that this method allows to stimulate fluidity of neodymium-iron-boron fine powder. While the powder doesn’t have natural fluidity, simultaneous effect of crossed constant and alternating gradient magnetic fields translated it to hovering pseudo fluidized state with low friction between particles and made it flow through thin nozzle. Turning the fields off ceased the flowing immediately.

Ranges of electromagnetic field parameters providing stable fluidity were found out for the Nd-Fe-B powder with 4.6 µm average particle size.

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