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THE EFFECT OF FRICTION WITH THE COLLECTING SURFACE ON THE BUILD–UP MASS IN THE AXIAL HGMS CONFIGURATION

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Abstract The influence of the roughness of a plane collecting surface on the amount of the magnetically intercepted deposit in axial high–gradient magnetic separation configuration was studied. It has been experimentally established that capture surfaces with different levels of roughness, i.e. with different friction coefficients, lead to different build–up capacities. Theoretical description is based on the fact that the condition that the friction force exceeds hydrodynamic drag force, i.e. $F_f \geq F_d$ is satisfied in a region of the capture surface whose width depends on the friction coefficient.

INTRODUCTION

During a capture experiment performed in the axial high–gradient magnetic separation (HGMS) configuration we have noticed that the build–up mass was different on two cylindrical ferromagnetic wires made of the same magnetic material and having the same diameter, one with smooth surface and the other with rough surface. Though the working conditions were the same, the wire with the rough surface captured more paramagnetic particles.

A possible explanation rests in the fact that the roughness creates local supplementary gradients resulting in the formation of a more intense magnetic force. The problem is whether, besides this effect of the roughness of the wire, the build–up capacity is not affected also by the friction between the the first layer of the captured particles and the wire.

In order to eliminate the first possible effect we have designed a capture device intended to emphasise only the the latter aspect of the problem namely, if and under what working conditions the roughness of the collecting surface influences the size of the particle build–up.

In studies dedicated to the capture on a single wire the friction problem has only been discussed in connection with the last layer of the deposit (the layer in contact with flowing liquid) where the equilibrium conditions between the concurrent forces have been established, particularly in in transverse and longitudinal HGMS configurations [1, 2]. It is worth noticing that in these cases the roughness is representing by particles in the penultimate layer of the build–up.

In this work we have studied experimentally the way in which friction between the build–up and the plane collection surface parallel to the ferromagnetic wire influences the accumulation capacity, in the case of the axial configuration of HGMS.

At the same time we have tried to present a theoretical basis of the fact that the increase in the coefficient of friction between the capture surface and the first layer of particles leads to the increasing amount of the captured particles.

EXPERIMENTAL

A cross–section of the set–up used in our tests is shown in Figure 1. Ferromagnetic wire of diameter $2a$ and saturation magnetisation M_s (1) is axially encapsulated in the semi–cylindrical non–magnetic body (2). A tape–shaped sheet (4) with particles of corundum (Al_2O_3) is glued on support (3), This support is introduced inside a groove machined in the non–magnetic body parallel with the ferromagnetic wire. Rough surface of the sheet thus represents a planar collecting–capturing surface. The assembly placed in a glass tube (5) was introduced vertically into the gap of an electromagnet.

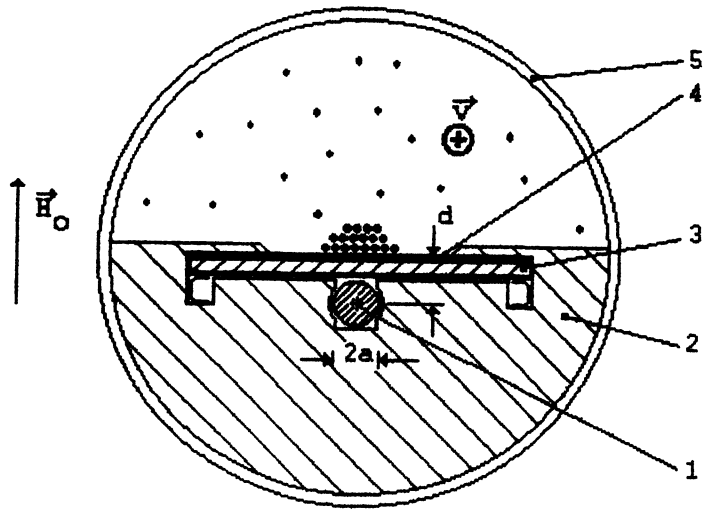

Fig. 1 Cross–section through the experimental set–up ($2a$ = 2.5 mm, $M_S = 1.44 \times 10^6$ A/m, ferromagnetic wire length = 250 mm)

A suspension containing paramagnetic particles flows through the empty half of the glass tube parallel to the collecting surface and perpendicularly to the magnetic force lines (axial HGMS configuration).

As a result of its design, the device allows to maintain the constant distance between the axis of the ferromagnetic wire and the collecting surface (d = const.) when changing the sheet with the corundum particles.

In order to emphasise the effect of roughness only, and to eliminate the effect of other variables, the following conditions had to be met:

i. To keep constant the position of the device within the gap and the value of the background magnetic field intensity (H_0 = const.).

ii. To keep the collecting surfaces parallel to the surface of the pole–pieces of the electromagnet.

iii. The magnetisable material to be captured, with close size distribution and constant magnetic susceptibility must be used (v_p, χ_p = const.)

These conditions had to be imposed to allow us to assume a constant magnetic force so that the friction force depends on the friction coefficient only. In order to reduce the effect of the experimental error the collected mass was determined as the mean value of five readings obtained in five identical capture operations.

A large series of experiments were carried out under different experimental conditions and the material to be captured consisted of the rutile particles (TiO_2).

RESULTS AND DISCUSSION

Figure 2 depicts the captured mass m_c versus the roughness e of the collecting surface for the rutile particles of mean size $2b$. The dependence of the mass of the deposit on the roughness of the collecting surface can be seen. This dependence becomes more pronounced with increasing particle size.

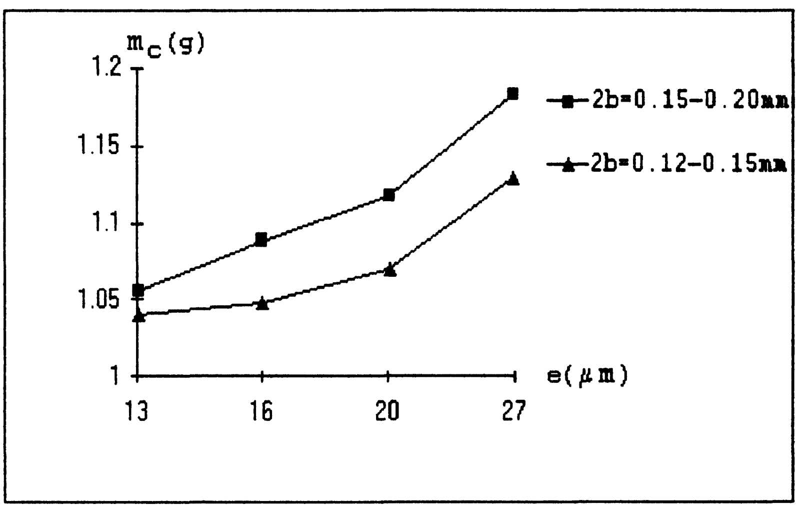

Fig. 2 Mass of the build–up vs roughness of the collecting surface, for H_0=0.1168×10^6 A/m and v_{mean} = 21.21 cm/s.

In Figure 3 the dependence of the build–up mass on the mean velocity of the carrier fluid is shown, for two collecting surfaces with different degree of roughness, for the rutile particles of mean size $2b$ = 0.12 to 0.15 mm.

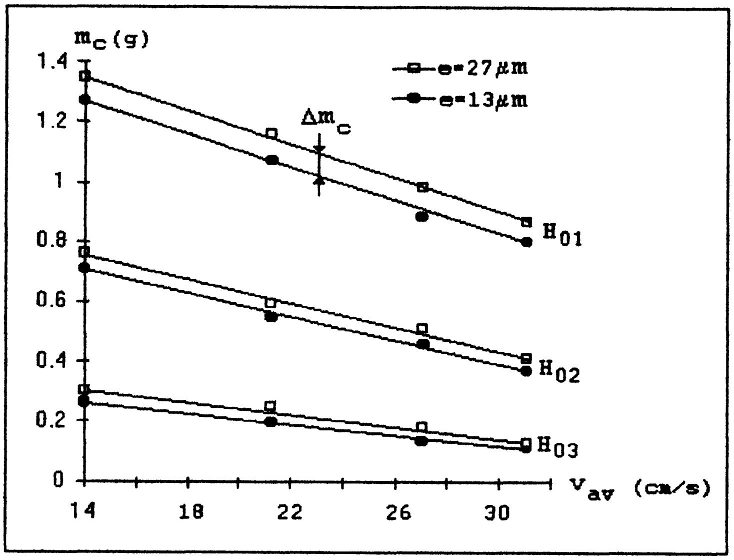

Fig. 3 The build–up mass vs the mean fluid velocity for two different collecting surfaces. H_{01}=0.1168×10^6 A/m, H_{02}=0.0848×10^6 A/m, H_{03}=0.0568×10^6 A/m.

It can be seen that under identical capture conditions the mass collected on the rough surface is larger. It can also be noticed that for the same background magnetic field, the curves for two different degrees of roughness are practically different. It means that the fluid velocity does not influence the absolute mass difference (Δm_c = const.).

THEORETICAL ANALYSIS

The condition that a particle remains on the collecting surface is that $F_f \geq F_d$ where F_f is the friction force and F_d is the hydrodynamic drag. In the classical mechanics, $F_f = \mu F_n$ where μ is the coefficient of friction considered to be dependent of the surface roughness, and F_n is the normal pressure force equal, in our case, to the normal component of the magnetic force.

A component of the magnetic force normal to the plane, written in rectangular coordinates, as can be seen in Figure 4, is given by:

$$F_y = K \frac{3x_p^2 - y_p^2}{(x_p^2 + y_p^2)^3} y_p \qquad \text{for } H_0 > M_s/2$$

or

$$F_y = K' \frac{3x_p^2 - y_p^2}{(x_p^2 + y_p^2)^3} y_p \qquad \text{for } H_0 \leq M_s/2$$

where

$$K = \mu_0 V_p \chi_p M_s H_0 a^2 \qquad \text{and} \qquad K' = 2\mu_0 V_p \chi_p H_0^2 a^2$$

and x_p and y_p are the coordinates of the particle centre. The short–range term of the magnetic force (proportional to r^{-5}) has been neglected [3, 4].

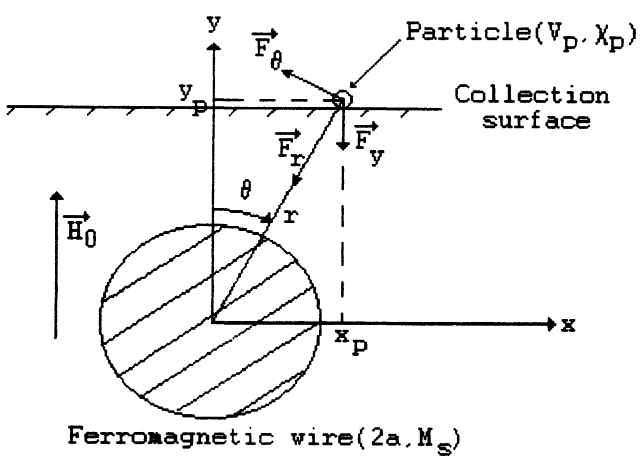

Fig. 4 Component of the magnetic force normal to the collection surface

Solving the equation $F_y = 0$ the solutions $y_p = 0$ and $x_p/y_p = \pm\sqrt{3}/3$, the last two solutions being appropriate; they correspond to critical angles $\theta_{crl} = \pi/6$ and $\theta_{crl} = -\pi/6$.

The dependence of the F_y component on the x coordinate, for a particle located in two successive layers $y_1 = d + b$ and $y_2 = d + 3b$ is shown in Figure 5.

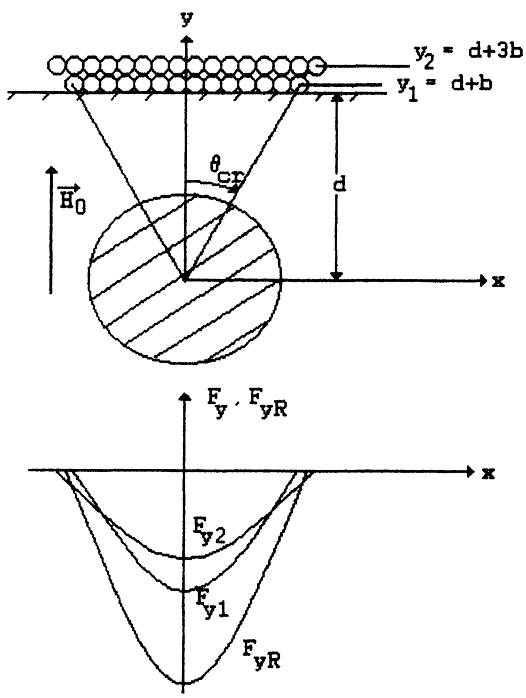

Fig. 5 F_y and F_{yr} versus x coordinate

Pressure exerted in this case on the collecting surface is represented by the function $F_{yr}(x) = F_{y1}(x) + F_{y2}(x)$. Since the force of friction F_f with the collecting surface is the product of the resulting force F_{yr} and the friction coefficient (a constant), it can be concluded that $F_f = F(x)$ curve is similar to the $F_{yr} = f(x)$ curve.

Figure 6 depicts the curve of the friction force $F_f = \mu F_{yr}(x)$ for two cases which differ from one another by the roughness of the collecting surface, as well as the drag force F_d considered to be constant under the given conditions.

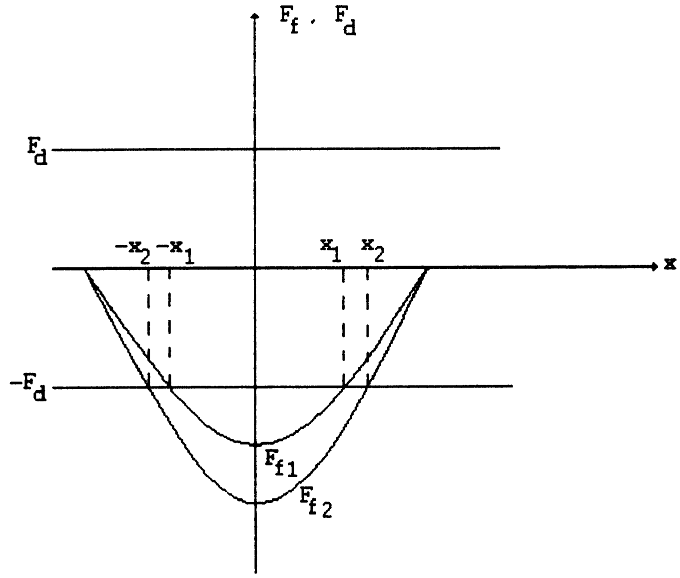

Fig. 6 The curve of the friction force for two different collection surfaces ($\mu_2 > \mu_1$).

It can be seen that the range when the condition $F_f \geq F_d$ is satisfied is different for two cases considered above; the range $[-x_1, x_1]$ corresponding to the surface with μ_1 is less extended than that corresponding to the surface with μ_2, $[-x_2, x_2]$, respectively. Therefore, the particle deposit obtained under identical conditions will be wider when the roughness of the collecting surface is larger. In other words, the mass of the deposit retained on a rougher surface should be, as a rule, larger.

CONCLUSIONS

This work dealt with an effect resulting from the roughness of the collecting surface, on the capture, in the axial HGMS configuration. Experimental results show that under all working conditions employed in our tests, the mass of the deposit obtained in the axial HGMS configuration increases with increasing roughness of the collecting surface.

It transpires from the theoretical analysis that the above mentioned effect represents the result of friction only at the edge of the particle deposit, which could be wider or narrower, depending on the friction coefficient. It can be stated that the roughness of the collecting surface increases the collection capacity as a result of the friction with this surface.

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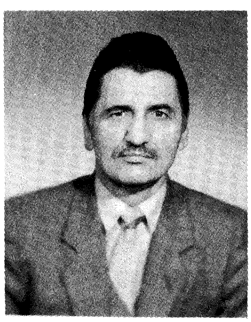

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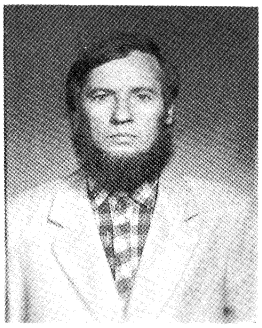

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