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MAGNETIC AND MAGNETIC FLUX EXCLUSION PROPERTIES OF SUPERCONDUCTIVE / FINE FERRIMAGNETIC POWDER COMPOSITES

KEYWORDS

fine particles, high T_C - superconductors, Meissner effect

ABSTRACT

The influence of internal magnetic field on the superconductive properties of composites consisted of a mixture of a superconducting powder such as $YBa_2Cu_3O_{7-x}$ (particle size 5 - 15nm) and fine ferrimagnetic particles Fe_3O_4 (10nm in diameter) was studied as function of concentration of magnetic particles and their magnetic state. The experimental data were discussed in framework of the theory where the distribution of internal magnetic field was taken into account.

INTRODUCTION

In papers [1, 2] we have studied the composites consisting of high T_C - superconducting material with magnetic fluids (fine magnetic particles dispersed in liquid carrier). The structuralization effects of high T_C - superconductive particles were observed using the Skjeltorp's idea [3] of magnetic holes. In paper [4] using the effective medium theory the influence of magnetic, surrounding and structure of high T_C - superconductive particles on the critical magnetic fields of a superconductor has been studied. The magnetic flux exclusion properties of superconductive material are strongly affected by the presence of magnetic field larger than the lower initial field H_{C1} . As an applied field rises above H_{C1} , magnetic flux penetrates into the body of the sample, reducing the amount of excluded flux. Many of the new high T_C - superconducting materials have low H_{C1} values and thus are particularly sensitive to magnetic fields. Flippen [5] studied the magnetic flux exclusion properties of composites of ferromagnetic and high T_C - superconductive powder. It was shown that the magnetic state of a magnetic material affects the flux exclusion properties of a superconductive material.

Our aim was to study the flux exclusion properties of composite material made up of high T_C - superconductive $YBa_2Cu_3O_{7-x}$ - oxide and magnetic particles (Fe_3O_4) traditionally used in magnetic fluid technology.

EXPERIMENTAL DETAILS

The samples of high T_C - superconductive powder of $YBa_2Cu_3O_{7-x}$ - oxide was prepared by standard sol - gel technique using the autocatalytic pyrolytic decomposition of yttrium, barium and copper nitrates sol [6]. The interproduct was annealed at 920°C in air for 16 hours and sintered at 920°C in oxygen for 16 hours in a platinum boat and cooled at $20^\circ\text{C}/\text{min}$. Morphology observation of this product by using scanning electron microscopy showed that grains of $0.4\mu\text{m}$ in size are aggregated in aggregates of $5 - 15\mu\text{m}$ in size. The magnetite particles were prepared by standard technique from ferrous and ferric salts. The electron microscopy examination showed the magnetite particles with the mean diameter $D_V = 10 \text{ nm}$ and the standard deviation $\sigma = 0.33$. Composites of the above mentioned powders were made by thoroughly mixing appropriate masses of the two in a nonreactive fluid such as ethanol, then evaporating fluid and pressing finally. Measurements of magnetic and magnetic flux exclusion vs. temperature were carried out on standard VSM magnetometer. The results were obtained by

1. zero field cooling (ZFC) the sample to 4.2K , after which the desired field was applied. This ZFC-curve corresponds to the shielding effect,
2. field cooling (FC) the sample in the applied field, thereby measuring the flux exclusion corresponding to a, true Meissner effect. The magnetic field $\mu_0H = 2\text{mT}$ was used in measurements.

RESULTS AND DISCUSSION

Figure 1 shows ZFC and FC curves for pure magnetite and $YBa_2Cu_3O_{7-x}$ oxide used in the experiments. Figure 2 represents ZFC and FC curves for two mass concentrations of magnetite. The very nice "pigeon-like" behaviour is observed for concentration $c = 0.19\%$. In Figure 3 a is plotted difference of Meissner (shielding) effect and linear combination of pure magnetite and superconducting signal as a function of mass concentration of magnetite at temperature $T = 25\text{K}$. The curves have minimum at concentration about $c \approx 60\%$. Very interesting behavior is observed in low concentration range. This is shown on Figure 3b. Figure 4 shows an example how the magnetized magnetite (magnetized at $\mu_0H = 0.4\text{T}$) effectively shifts the flux exclusion properties.

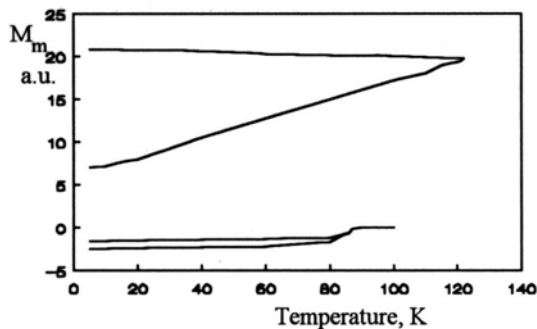


Fig. 1. ZFC and FC curves for magnetite powder (squares) and for $YBa_2Cu_3O_{7-x}$ powder (circles).

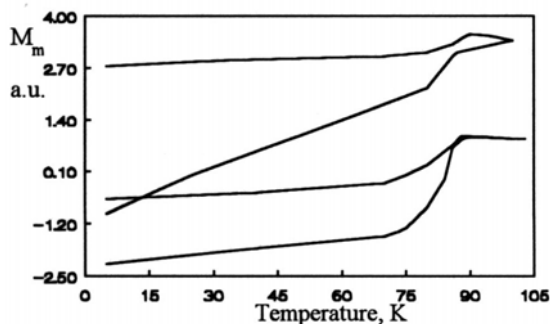


Fig. 2. ZFC and FC curves for two mass concentrations of magnetite: 5.18% - circles and 20.19% - squares respectively.

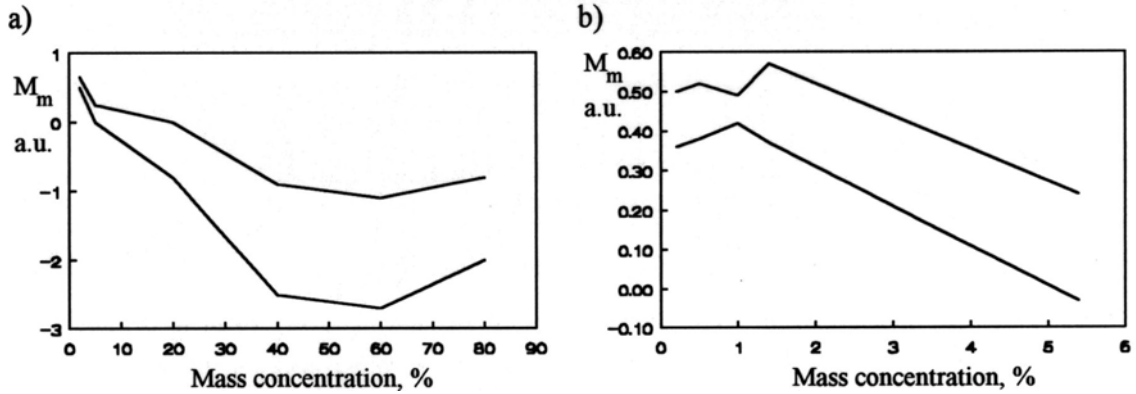


Fig. 3. a) The difference of Meissner (triangles), Shielding effect (squares) and linear transition of pure magnetite and superconductor signal as a function of mass concentration of magnetite particles, b). The same as in Fig. 3a but in low concentration range.

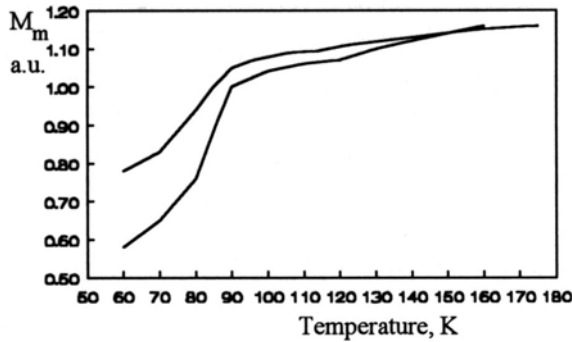


Fig. 4. The influence of magnetic state of magnetite on Meissner effect (triangles unmagnetized magnetite, squares magnetized magnetite in field, $\mu_0 H = 0.04 T$). Mass concentration of magnetite particles is 0.211%.

Our initial attempt to explain the measured dependencies of measured properties of composite materials was based on effective medium theory principles. The effective permeability μ_{ef} of two component composite system has been calculated using known permeabilities of superconductive μ_s and magnetic μ_f parts by means of often used Bruggeman's formula

$$\frac{\mu_{ef} - \mu_s}{\mu_f - \mu_s} \left(\frac{\mu_f}{\mu_{ef}} \right)^{1/3} = 1 - \varphi, \quad (1)$$

where: φ is a volume fraction of magnetic particles in composite. But even preliminary comparison of measurements leads to significant differences. Therefore, the purpose of further work was to abandon effective medium theory in such systems and to investigate the observed anomalies at low concentration region of magnetic particles, where their influence on Meissner effect presence seems to be very important.

Let us assume that system of magnetic particles in composite can be considered as a system of randomly positioned magnetic dipoles with density n , with Gaussian distribution of magnetic field [7]:

$$P(\vec{H}) = \frac{1}{2\delta\sqrt{\pi}} \exp\left[-\frac{H^2}{4\delta^2}\right] \quad (2)$$

with Gaussian spread:

$$\delta = \sqrt{\frac{4\pi\varphi^2 n}{9a^3}}, \quad p = \frac{4}{3}\pi a^3 M_s, \quad n = \frac{\varphi}{\left(\frac{4}{3}\pi a^3\right)}, \quad (3)$$

dependent on the magnetic particles diameter a , their magnetic moment p and saturation magnetization M_s . Then the probability P_{cl} the local field intensity $|H|$ at certain randomly chosen position in composite is larger than the lower transition field of superconductor fraction H_{cl} is:

$$P_{cl} = 4\pi \int_{H_{cl}}^{\infty} P(\vec{H}) H^2 dH = 1 - \frac{2}{\sqrt{\pi}} \Gamma\left[3/2, 0, \frac{H_{cl}^2}{4\delta^2}\right]. \quad (4)$$

In the frame of mean field approximation we can assume that introduced P_{cl} is close to volume fraction of normal and mixed-state regions in second order superconductor. To demonstrate this assumption for typical composite parameters quantitatively we choose the probability level 0.99, and therefore start analyzing inequality:

$$P_{cl} > 0.99, \quad (5)$$

which is equivalent to:

$$H_{cl} < 0.47923 \cong 1.159 M_s \sqrt{\varphi}. \quad (6)$$

Taking $\mu_0 M_s = 0.4\text{T}$ and $\mu_0 H_{cl} = 0.04\text{T}$ and using (6) we show, that even a very small magnetic particles admixture with $\varphi > 0.0074$ enough for significant Meissner effect disturbance (5). This probably correspond qualitatively to observed magnetic anomalies in low concentration region and recovers the source of difficulties in our initial applications of effective medium theory.

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