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STUDY OF THE PROPERTIES OF MAGNETORHEOLOGICAL SUSPENSIONS BASED ON AMORPHOUS MAGNETIC POWDERS

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Magnetorheological characteristics of a ferrosuspension based on $Fe_{86}P_{14}$ *amorphous powder are studied. In the magnetic field a 50-fold increase in the effective viscosity and yield stress of the suspension is attained, which characterizes the latter as an effective magnetorheological composition and allows prediction of wide use of the powders of amorphous magnetic materials for creating ferrosuspensions for various functional purposes.*

In recent years magnetorheological technologies have been ever more widely introduced into state-of-the art engineering objects [1, 2]. The principle of functioning of magnetorheological systems is based on contactless control, by the magnetic field, over the internal structure and, as a consequence, the rheological (viscosity, plasticity, and elasticity) and thermophysical properties of magnetorheological suspensions (a magnetorheological effect). The latter are usually free-disperse microheterogeneous systems consisting of a dispersion system (organic, mineral, and synthetic oils, water-containing mixtures, etc.) and magnetic particles of a size of 0.1–20 μm.

The aggregation and sedimentation stability of suspensions and their initial rheological parameters are provided by introducing stabilizing additives and surfactants to the dispersion medium and by pretreatment of the surface of the disperse magnetic particles. As particles of the disperse magnetic phase in magnetorheological suspensions (MRS) use is made of powders of ferrites, magnetodielectrics, and ferric and chromic oxides, according to the range of application [3]. While possessing necessary electromagnetic parameters, these powders successfully function in MRS designed for electrohydraulic and robotic systems, magnetorheological braking and damping devices, electromagnetic clutches, filling of the magnet gap of electrodynamic transformers in order to increase their rated power, etc.

However, the use of MRS in objects of chemical industry and in the technologies of magnetorheological polishing of glass, ceramic, semiconductor, and nonferrous-metal articles [4] is frequently restricted by insufficient durability, hardness, corrosion resistance, and temporal and thermal stability of the above-mentioned magnetic materials.

Owing to structural features, alongside the high magnetic softness such that the level of electromagnetic loss at high induction values is lower than for all known magnetic materials, amorphous magnetic materials exhibit exceptionally high mechanical hardness (of 800 kg/mm^2) and strength. In some cases they have a thermal expansion coefficient close to zero, display a unique temporal and thermal stability of the magnetic properties, and are highly corrosion resistant [5].

A characteristic particle size for the currently produced powders of amorphous magnetic materials is 1–50 μm, which is quite acceptable for creating fine magnetorheological suspensions. By introducing various additives to the initial melt when producing amorphous magnetic powders it is possible to widely vary both mechanical and magnetic properties of the particles, specifically, to control the coercive force, the residual induction, the Curie

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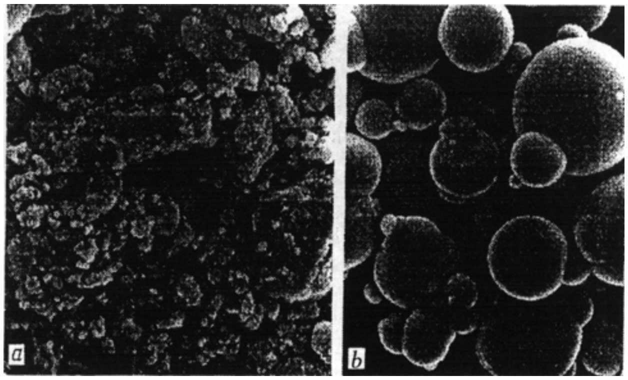


Fig. 1. Photographs of particles of the MRS-1 (a) and MRS-2 (b) disperse phase.

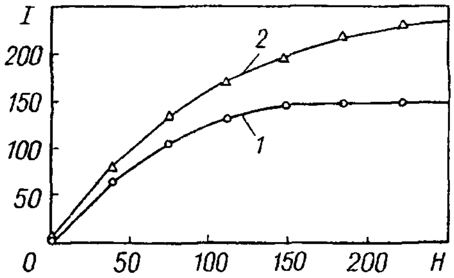


Fig. 2. Curves of magnetization of the studied MRS: 1) MRS-1, 2) MRS-2. I, H, kA/m.

temperature up to room temperature, and the saturation induction. The latter in many amorphous materials amounts to magnitudes comparable with parameters of the best ferromagnetics. Depending on the method of manufacture, particles of the powders of amorphous magnetic materials can be of diversified geometric shapes, namely, spherical, ellipsoidal, laminated, etc. [5].

All these factors indicate that the powders of amorphous alloys are a very promising material for creating new magnetorheological compositions for various functional purposes.

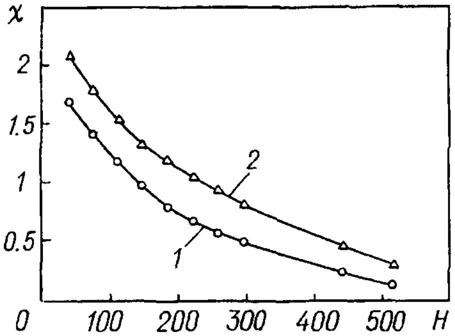
We studied rheological and magnetic properties of MRS based on an amorphous magnetic powder of the $Fe_{86}P_{14}$ type (the particle density was 7.6 g/cm^3 and the saturation induction 1.5 T). Its preparation technology was as follows. At the first stage, a 100 μm belt was made using a method of electrolytic precipitation and thereafter it was ground in a ball mill in the presence of a fabricating fluid (kerosene) for 18 h. The produced powder was washed sequentially in gasoline and acetone, and dried at a temperature of 40°C. As a result, a polydisperse powder with an irregular shape of particles of a size of 0.5–10 μm and a mean particle size of 4–5 μm was formed.

Figure 1 presents photographs, made on an electronic microscope, of $Fe_{86}P_{14}$ alloy particles (a) and R-10 carbonyl iron particles, traditionally employed in MRS (b).

MRS, whose disperse phase consisted of amorphous particles (MRS-1) with a dispersion medium based on transformer oil, was prepared via blending the components in a mortar mill for 6 h. Simultaneously, a standard MRS (MRS-2) with the disperse phase in the form of spherical particles of the magnetodielectric powder (carbonyl iron of the R-10 type with a mean particle size of 3.5 μm) was prepared by an identical technology. It should be noted that the indicated type of ferromagnetic powder is used most frequently in MRS in order to attain a maximal magnetorheological effect (a maximal increase in viscous stresses in the magnetic field) [2]. The volume concentration of particles of the disperse magnetic phase in both MRS was 28%.

Rheological characteristics of the above-mentioned compositions in the magnetic field were studied using a magnetorheometer with a measuring cell of the disc–disc type [2].

Figure 2 presents curves of static magnetization for MRS-1 and MRS-2.



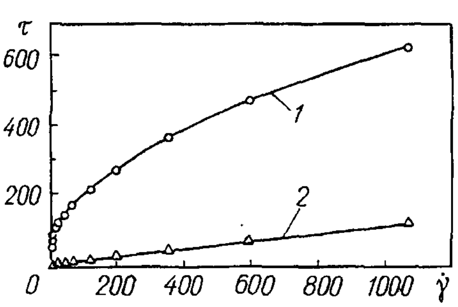


Fig. 3. Magnetic susceptibility of the studied MRS vs intensity of the magnetic field: 1) MRS-1, 2) MRS-2.

Fig. 4. Rheological curves of the flow ($H = 0$): 1) MRS-1, 2) MRS-2. τ, Pa; $\dot{\gamma}$, $\sec^{-1}$.

In large magnetic fields the magnetorheological suspension based on amorphous magnetic powder (MRS-1) has a magnetic susceptibility χ 1.5 times lower than that of the suspension based on R-10 carbonyl iron powder (MRS-2). In magnetic fields of low intensity (< 100 kA/m) the susceptibility ratio of suspensions is close to unity.

Magnetic particles in the dispersion medium of MRS have spatial degrees of freedom. Particles of $Fe_{86}P_{14}$ powder suspended in the dispersion medium, most of them being of elongated shape, even in small magnetic fields acquire a magnetic moment as a result of polarization (magnetization) and are oriented so that their long axis (coinciding with the axis of light magnetization of a particle) is directed along the lines of magnetic force. In this case, their demagnetizing factor is smaller than that of spherical particles of the carbonyl iron powder and they are magnetized more readily.

In fields close to saturation the effect of the demagnetizing factor weakens and the susceptibility of MRS-2 is noticeably higher than that of MRS-1. It should be noted that both suspensions display the properties of a magnetically soft material characterized by the coincidence of direct and inverse branches of the magnetization curve for both MRS.

Figure 4 presents rheological curves for the flow of MRS-1 and MRS-2 not exposed to the magnetic field.

The consequence of a somewhat elongated, irregular shape of amorphous particles and of a large portion of very small (smaller than 1 μm) particles in the initial amorphous powder (see Fig. 1a) is higher effective viscosities of MRS-1 and a yield stress reaching 40 N/m^2. A small initial yield stress in some MRS can in some cases be regarded as a positive factor facilitating the preservation of the sedimentation stability of MRS-1 even without special measures for stabilizing the suspension.

The plasticity and the effective viscosity of MRS-1 in the magnetic field increase. Its yield stress τ_{0H} can be controlled by the magnetic field up to a value of $2 \cdot 10^4$ N/m^2 and larger, and the range of the effective viscosity η_{ef} comprises a few orders of magnitude.

Rheological characteristics of MRS-1 in the magnetic field, like those of most of the familiar magnetorheological compositions, can be fairly reliably described by the Shvedov–Bingham equation

$$\tau = \tau_{0H} + \eta\dot{\gamma},$$

where η is the MRS viscosity in the absence of the field.

An absolute increase in the shear stresses $\Delta\tau$ ($\Delta\tau = \tau_H - \tau_0$) of the considered MRS fits their magnetic characteristics well (Fig. 5). In low-intensity magnetic fields (50–100 kA/m), the difference in the attained magnetorheological effects is insignificant for MRS-1 and MRS-2 (in a field of up to 50 kA/m an increase in the viscous stresses for the first is even greater somewhat than for the second), because the magnetic properties of particles of the disperse magnetic phases in this intensity range of the magnetic field are identical.

With subsequent augmentation of the field, MRS-2 has higher magnetic susceptibility and the observed increase in the viscous stresses for it is higher somewhat (by 30–35%).

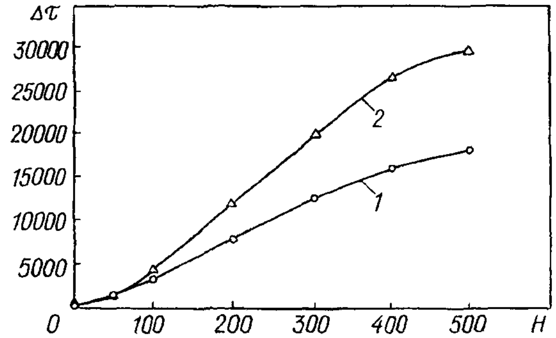


Fig. 5. Increase in shear stresses in magnetic fields of different intensities (the rate of shear is 67 $\sec^{-1}$): 1) MRS-1, 2) MRS-2. $\Delta\tau$, Pa.

Nonetheless, in the considered range of rates of shear ($\dot{\gamma} = 0-250 \sec^{-1}$) in MRS-1 a more than 50-fold increase in the effective viscosity and the yield stress is attained due to the effect of the magnetic field. This circumstance allows its characterization as a very promising magnetorheological composition and prediction of wide use of the powders of amorphous magnetic materials for creating highly efficient MRS for various functional purposes.

NOTATION

H, intensity of the magnetic field; I, magnetization; χ, magnetic susceptibility; τ, shear stress; τ_{0H}, yield stress; τ_H, shear stress of MRS in the magnetic field; τ_0, shear stress with no field; $\Delta\tau$, increase in the shear stress; $\dot{\gamma}$, rate of shear; η, viscosity of MRS with no field; η_{ef}, effective viscosity.

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