Rheological Behavior of Composite Structurally Reinforced Materials in a Magnetic Field

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For carrying out a monitored change in the strength and damping characteristics of thin-walled structures, use can be made of material layers that are placed inside them and that change their viscoelastic state under the action of external fields (electric or magnetic). This change occurs adaptively to the change in the dynamic state of the structure.

With this aim in view, we have developed magnetosensitive composite dispersion-reinforced materials (MCDRM), which are highly filled pastes on a dispersion base, i.e., on the Mobil synthetic oil. As a dispersed phase we used a complex filler consisting of microparticles, structured under the action of a magnetic field, and the nano- and microsizedparticles that form a thixotropic reinforced lattice. The ferromagnetic particles of carbonyl iron had a size of about 3 µm.

We carried out an investigation of the effect of the type of reinforcing finely dispersed (of size ~ 1 µm) particles of bentonite clay, aerosil, and chromium dioxide, on the degree of mechanical response (sensitivity) of the MCDRM to the external magnetic field.

The results of measurements have shown that the values of the rheological parameters of dispersely reinforced magnetorheological fluid without magnetic field effect depend the main on the general concentration of a complex filler and on the mass relationship between its disperesely reinforced and magnetosensitive components. The maximum values of the rheological parameters: yield stress τ_0 and storage modulus G' are typical of the MCDRM-1 paste containing aerosil. The use of mixtures of two types of reinforcing fillers, e.g., aerosil and chromium oxide, CrO_2 (MCDRM-2) as a dispersely reinforcing material leads to the reduction of the mechanical indices of the shear resistance of the paste: τ_0 fivefold and G' fifteenfold, respectively, as compared with the MCDRM-1 sample.

Under the action of an external magnetic field, the value of τ for all of the samples of pastes increases in the measured range of shear rates. Only in the MCDRM-3 samples containing bentonite clay, the shear stress depends on the shear rate in the entire range of change of the magnetic field induction, which allows one to smoothly control its viscoelastic properties.

This characteristic feature of the mechanical behavior of the considered pastes is connected with the effect exerted by the material of reinforcing lattice on the interaction of magnetic particles in a field that determines degree of the strength of the paste or its damping characteristics. Thus, a strong thixotropic matrix produced by the particles of bentonite clay (MCDRM-3) fails gradually with increase in a shear load, impeding the process of structuring of ferromagnetic particles. The lattice of aerosil particles breaks down at the lowest shear rates as compared to the bentonite one, which allows the ferromagnetic particles to easily interact in a magnetic field.

The storage modulus G' increases substantially with the external magnetic field intensity – first linearly and then nonlinearly up to the zone of weak nonlinearity and saturation. In the studied range of the magnetic field induction, G' increases by 1-2 orders of magnitude and in a magnetic field with induction 1000 mT the storage modulus of all of the MRF samples attains 2500 kPa.

The loss modulus G'' of the MCDRM-3 and MCDRM-4 attains maximum values at the magnetic field induction $B<100$ mT. A further increase in the induction reduces the values of the loss modulus pointing to the decrease in the viscous component.

The possibility of varying the properties of a material by changing the reinforcement structure allows one to additionally “adjust” the mechanical parameters of the elements of thin-walled engineering constructions on change in the viscoelastic properties of layers in the structures of composite beams, plates, and envelopes of the “sandwich” type lamellar structure.