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Properties of magneto-rheological fluids based on amorphous micro-particles

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Abstract: To improve the magneto-rheological (MR) properties of magneto-rheological fluids, self-made amorphous alloy particles, the composition of which was $Fe_{76}Cr_2Mo_2Sn_2P_{10}B_2C_2Si_4$, were used as the disperse phase to replace traditional carbonyl iron (CI) particles to prepare amorphous based magneto-rheological fluid (AMRF). Soft magnetic properties and densities of the amorphous particles and the CI particles were tested and compared. The results indicate the amorphous particles present a lower density but larger magnetization intensity and larger permeability at lower field levels. Properties of the AMRF with 20% particles in volume fraction were tested and compared with the CI based MR fluid (CMRF). The AMRF presents a saturation yield stress of 41 kPa at ~227 kA/m and a sedimentation ratio of 80%. The results indicate the magneto-rheological fluid based on amorphous micro-particles has better MR properties and sedimentation stability than that based on CI particles at lower field levels (0−200 kA/m).
Key words: magneto-rheological fluids; amorphous particles; carbonyl iron; soft magnetic properties; microstructure

1 Introduction

Magneto-rheological fluids (MRFs) are suspensions of magnetic micro-particles in a carrier fluid, usually mineral or silicon oil [1−3]. When placed in magnetic field, their apparent viscosities greatly increase. As a result, they change from linear viscous fluids (Newtonian fluid) with free flow to semi-solid materials (Bingham fluid) with controllable yield stress, and the process is reversible. Their ability of changing shear stress in an applied magnetic field gives rise to their many possible applications. Typically, they can be used in semi-active controllable fluid dampers for vehicles and for buildings protection against vibrations [4−6].

Carbonyl iron (CI) particles are widely used as the magnetic phase for MR fluids due to their high magnetic permeability and soft magnetic properties. The MR fluids fabricated with CI particles show great MR effect, whose yield stress even reaches ~100 kPa at 250 kA/m [7−9]. However, one serious drawback of the MR fluids with CI particles is that they subject to thickening after prolonged use and need replacing, because the density of the CI particles is too high [10,11]. Adding surfactant or coating polymer only solves the problem to some extent [12−14]. Another shortcoming of the fluids is their relatively large magnetic hysteresis, which is harmful for their longevity. Besides, in some applications, the maximum yield stress needed is only ~40 kPa, but the magnetic field required to reach the yield stress for the CI based MR fluids is large.

Applying magnetic particles with lower density, less magnetic hysteresis, and higher magnetic permeability may solve those problems [15−17]. Many amorphous magnetic materials show more excellent soft magnetic properties and lower density with respect to the carbonyl iron. In this work, a new MR fluid was fabricated by amorphous micro-particles, as $Fe_{76}Cr_2Mo_2Sn_2P_{10}B_2C_2Si_4$. Their magneto-rheological properties, sedimentation stability, and microstructure were investigated and compared with the CI based MR fluid with the same particle content.

2 Experimental

$Fe_{76}Cr_2Mo_2Sn_2P_{10}B_2C_2Si_4$ particles were used to fabricate the amorphous magneto-rheological fluid (AMRF). The original amorphous material was prepared

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by an in-rotating-water quenching technique. Then micro-particles were prepared by ball milling. Carbonyl iron micro-particles purchased from Jiangyou Hebao Nanomaterial Co., Ltd., were used to produce the carbonyl iron based magneto-rheological fluid (CMRF). Magnetic properties of the CI particles and the amorphous particles were tested at room temperature with vibrating sample magnetometer (VSM, JDM−13).

Silicon oil was used as the carrier liquid. Its density was 0.97 g/cm^3, and its kinematic viscosity was 0.5 Pa·s. Titanate coupling agent was chosen as the surfactant to increase the stability of the fluid.

The particles were dispersed in a sodium hydroxide solution for a few minutes to etch off a layer of surface, and then washed several times using distilled water. Titanate coupling agent in 2% of the mass of the particles was dissolved in an acetone solution. The washed dry particles were then dispersed in the solution. To ensure that all the particles were coated with the surfactant uniformly, an ultrasonic wave was applied until all the acetone was volatilized. Finally, the treated magnetic micro-particles were obtained. Then the treated particles were mixed with the silicon oil. The particles volume fractions were 20% for the two kinds of MR fluids based on the CI particles and the amorphous particles. Intense agitation was applied to the mixture for more than 60 min to obtain MR fluids with uniformly dispersed micro-particles.

The viscosity—shear rate curves at zero magnetic field, shear stress—shear rate curves at constant magnetic field, and yield stress—magnetic field strength curves at constant shear rate were measured using a rheometer Physica MCR301 fitted with a magneto-rheological module which can apply different magnetic fields by changing direct current. As shown in Fig. 1, the diameter and the gap of the parallel-plate system were 20 mm and 1 mm, respectively. All the measurements were performed at room temperature.

A self-made system including two permanent-magnets, a stereomicroscope, a computer and a chase filling with MR fluids, as shown in Fig. 2, was used to observe the microstructure of the MR fluids in magnetic field.

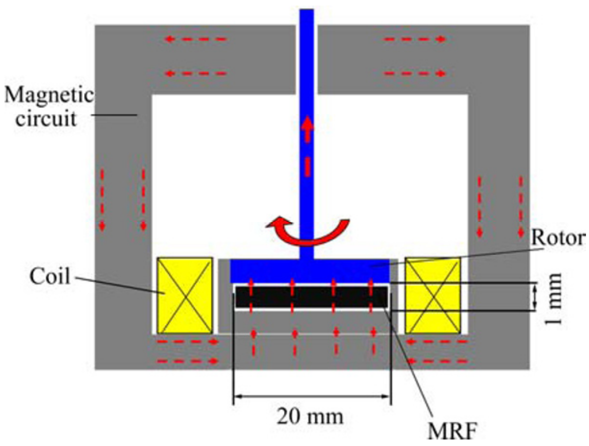

Fig. 1 Test system of MR properties

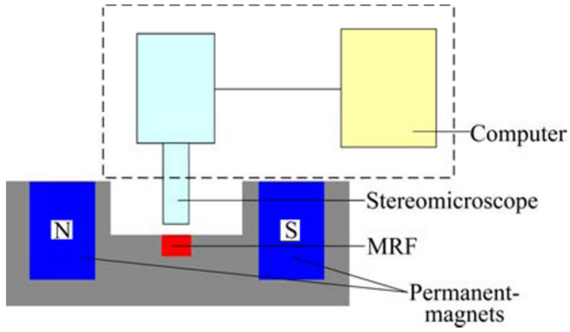

Fig. 2 Self-made microstructure observation system

The sedimentation experiments were carried out at room temperature using graduated flask. The sedimentation ratio, defined by the height percentage of the particle-rich phase relative to the total suspension height, was used to evaluate the sedimentation stability of the MR fluids.

3 Results and discussion

3.1 Properties of amorphous particles

As shown in Fig. 3, the amorphous particles are spherical and moderately polydisperse. The average size of the amorphous particles was ~5 μm. Figure 4 shows the X-ray diffraction pattern of the amorphous particles. The broad band between 30° and 60° confirms the amorphous structure.

The magnetic hysteresis cycles of the CI particles and the amorphous particles are shown in Fig. 5. It reveals that both particles have a similar behavior, but they differs in saturation and remnant magnetization, saturation magnetic field, and coercive field. As shown in Table 1, compared with the CI particles, the amorphous particles present lower density, lower saturation and remnant magnetization, lower saturation magnetic field and lower coercive field. The squareness ratio given by the ratio of M_r/M_s is essentially a measure of the soft magnetic properties for magnetic materials. The squareness ratios of the CI particles and the amorphous particles were 0.014 and 0.007, respectively, which indicates that the magnetic hysteresis of the amorphous particles is less than that of the CI particles.

The comparison of the initial M—H curves and the initial μ_r—H curves between the CI particles and the amorphous particles is shown in Fig. 6. At low field levels, the amorphous particles present larger magnetization intensity and larger permeability than CI particles.

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