Experimental Analysis of Magnetorheological Fluid

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Abstract

An silicone-based magnetorheological fluid(MR fluid) was prepared with 20% volume fraction of carbonyl iron powder. Anton Paar Physica MCR 301 rheometer flat was used to test rheological properties of MR fluid. It is found that the MR fluid has good shear yield stress. Under no magnetic field, MR fluid is shear thinning of Bingham fluid, its yield stress is about 0.2Pa. In the prescence of magnetic field, the shear stress and viscosity of the MR fluid are increased remarkably. When the external current increases from 0 to 0.1A, the shear stress increases from about 1.3Pa to about 70Pa, and the viscosity increases from about 0.024Pa.s to about 1.5Pa.s. MR fluid is shear thinning of Bingham fluid and conforms to Bingham model in magnetic field.

Keywords

magnetorheological fluid; shear property; magnetic field; viscosity .

1. Introduction

In intelligent materials, magnetorheological fluid(MR fluid) has been widely valued for their particular magnetic rheological effects[1]. MR fluid is a kind of suspension which is composed of micron sized magnetic particles and non magnetic liquid (mineral oil, silicon oil, etc.)[2-3]. Rheological properties of MR fluid change in the prescence of magnetic field. It reveals non-Newton rheological behavior without magnetic field. Its microscopic structure and macroscopic mechanical behavior will change significantly and has a certain shear yield stress in the external magnetic field[4]. MR fluid has the advantages of controllable, rapid and reversible, which is widely used in the fields of vehicle, building structure, medical equipment, sports equipment, polishing and sealing of precision materials [5-6].

The Bingham model is usually used to describe the rheological behaviors of MR fluid[7]. Alghamdi[8]proposed a structural viscosity model of MR fluid. Kim [9] studied the dependence of the shear stress of MR fluid on magnetic field. Sternberg[10] analyzed the application of MR fluid on the damper. In this experiment, the rheological behaviors of MR fluid under magnetic field are analysised. The viscosity and shear stress of MR fluid in the perscence of magnetic field are studied,which have referential value to the technical application of MR fluid.

2. Constitutive Model of MR Fluid

The rheological properties of MR fluid are analyzed by Bingham model[7], as the shear stress reaches to a certain value, the Bingham fluid begins to flow, there is a linear relationship between shear stress and shear rate like the Newton fluid. The basic Bingham model can be expressed as

$$\begin{cases} \tau = \tau_y(B) + \eta\dot{\gamma} & \tau \geq \tau_y(B) \\ \dot{\gamma} = 0 & \tau < \tau_y(B) \end{cases}, \quad (1)$$

where B is magnetic induction density of magnetic field and $\tau y(B)$ is yield stress induced by magnetic field, η is viscosity of MR fluids and $\dot{\gamma}$ is shear rate.

3. Preparation of MR Fluid

Silicone-based MR fluid was prepared with 20% volume fraction of carbonyl iron powder. Carbonyl iron powder and dimethyl silicon oil were weighted based on calculation. Carbonyl iron powder came from Jiangsu Tianyi Super Fine Metal Powder Co. Ltd. The average size of carbonyl iron powder is 3.5μm. The viscosity of dimethyl silicon oil (Ji'nan Duoweiqiao Chemical Co. Ltd) is 25cst. Surface active agents, antioxidant and anti-wear additive were also produced by Ji'nan Duoweiqiao Chemical Co. Ltd.

Processes A and B were used to prepare the MR fluid samples. The steps in process A were: (1) Carbonyl iron powder and surface active agents were mixed into the stainless steel container with high speed stirring for several hours; (2) In order to purify the surface of carbonyl iron powder, put the treated mixture in a vacuum oven to dry. The steps in process B were:(1) Put the pretreated-dry carbonyl iron powder and dimethyl silicon oil into the stainless steel mill; (2)Add antioxidant and anti-wear additive to the mixture, during high speed grinding and dispersion, MR fluid samples were obtained, as shown in fingure 1.

Fig. 1 MR fluid samples

4. Experiments

4.1 Experimental Process

Rheometer Anton Paar Physica MCR 301 was used to test the rheological performances of MR fluid. MR fluid was dripped in rheometer and then shear stress and viscosity of MR fluid were measured under different conditions.

Without magnetic field, shear rate was changed in the range of $0\sim100s^{-1}$, shear stress and viscosity of MR fluid were measured, and the dependence of shear stress and viscosity of MR fluid on shear rate was studied.

Under magnetic field, external current was arranged 0.1A, shear rate was changed in the range of $0\sim1000s^{-1}$, shear stress and viscosity of MR fluid were measured, and the dependence of shear stress and viscosity of MR fluid on shear rate were studied.

Shear rate set to $100s^{-1}$, external current was changed in the range of 0~0.5A, shear stress and viscosity of MR fluid was measured, and the dependence of shear stress and viscosity of MR fluid on external current was studied at the same shear rate.

4.2 Experimental Results

Under no magnetic field, the dependence of shear stress and viscosity on shear rate is shown in Figure 2. Shear rate increases and the range is 0.2~2Pa with the increase of shear rate. The viscosity decreases and its range is 22~65mPa.s with the increase of shear rate.

There is an interaction force between ferromagnetic particles in MR fluid, with the increase of shear rate, the magnetic force between particles will reduce which decrease the viscosity of MR fluid. This shows that the MR fluid is a non-Newtonian fluid with shear thinning under no magnetic field.

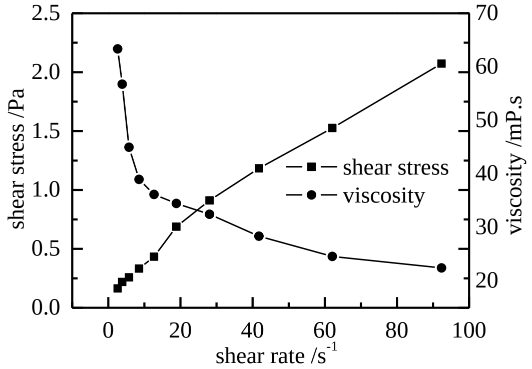

Fig.2 The dependence of shear stress and viscosity on shear rate without magnetic field

Under the magnetic field, the dependence of shear stress and viscosity of MR fluid on shear rate is shown in Figure 3. With the increase of shear rate in the range of 0~1000s^{-1}, shear stress increases remarkably at the same external current which is 0.1A, shear stress is in the range of 55~110Pa.With the increase of shear rate in the range of 0~1000s^{-1}, viscosity decreases at the same external current which is 0.1A, and it is in the range of 0.1~2.2Pa.s. This shows that MR fluid is shear thinning of Bingham fluid in the prescence of magnetic field.

Under the external magnetic field, magnetic particles are magnetized, formed chain structures. At this time, MR fluid flows very slow with a great viscosity. With the shear stress increases, the MR fluid flows in a constant viscosity. The viscosity decreases in the range of 0.1~2.2Pa.s with the increase of shear rate. With the increase of the shear rate, the dependence of shear stress on shear rate is not entirely linear. It shows that the MR fluid is Bingham fluid and conforms to Bingham model.

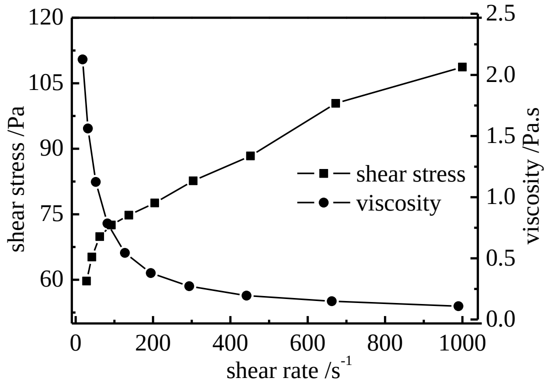

Fig. 3 The dependence of shear stress and viscosity on shear rate within magnetic field

With the prescence of magnetic field, the dependence of shear stress and viscosity on external current is shown in Figure 4. Shear stress increases significantly in the range of 36Pa~5kPa with the increase of external current in the range of 0~0.5A at the same shear rate. Viscosity increases remarkably in the range of 0.12~16Pa.s with the increase of external current in the range of 0~0.5A at the same shear rate. The experimental results show that magnetic particles in MR fluid are far from reaching magnetization saturation, magnetic particles interact with each other to form chain structures, leading to the exponential growth of shear stress with the increase of magnetic field.

With the increase of the magnetic field, MR fluid ferromagnetic particles tend to magnetization saturation, the magnetic force that maintains the microstructure of MR fluid will no longer be increased. It can be predicted that shear stress will tend to a stable value with the magnetic field is large enough.

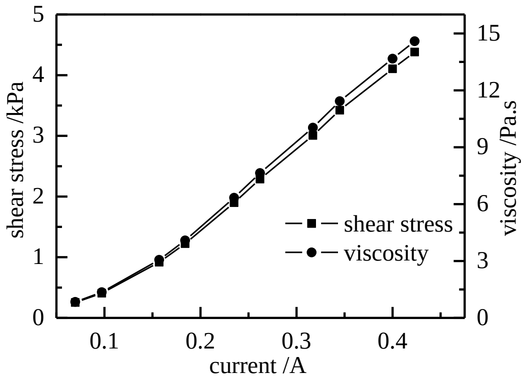

Fig. 4 The dependence of shear stress and viscosity on external current

5. Conclusions

According to the experiments and theory analysis of MR fluid, the conclusions are shown as follows.

(1) under no magnetic field, the MR fluid is non Newtonian fluid with shear thinning. Shear rate increases and the range is 0.2~2Pa with the increase of shear rate. The viscosity decreases and its range is 22~65mPa.s with the increase of shear rate.

(2) The viscosity decreases in the range of 0.1~2.2Pa.s with the increase of shear rate. With the increase of the shear rate, the dependence of shear stress on shear rate is not entirely linear. It shows that the MR fluid is Bingham fluid and conforms to Bingham model.

(3) Shear stress increases significantly in the range of 36Pa~5kPa with the increase of external current in the range of 0~0.5A at the same shear rate. Viscosity increases remarkably in the range of 0.12~16Pa.s with the increase of external current in the range of 0~0.5A at the same shear rate. Shear stress increases significantly with the increase of external current. It can be predicted that shear stress will tend to a stable value with the magnetic field is large enough.

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