Experimental Study on Shear stress of Magnetorheological Fluids

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Abstract. Test the Magnetorheological Fluids (MRFs) that prepared with carbonyl iron powder as soft magnetic particles and dimethyl silicon oil as carrier fluid by Rheometer Physica MCR 301. The experimental results demonstrate that the shear stress of MRFs increases slowly with the increase of shear rate. With good magneto-rheological effects, the dependence of shear stress on the external current tends to be linear. Volume ratio has a significant impact on the shear stress of MRFs.

Introduction

MRFs is a new type of intelligent material with a millisecond response speed and good controllability. It has become a hot research topic in many countries. Transmission and brake products that use MRFs as a medium are widely applied to machinery, construction and other industries. As a new kind of smart material, magneto-rheological fluids and their related application will have a tremendous impact on the development of industry [1] [2] [3].

Preparation

Components of MRFs. MRFs are composed of micron sized soft magnetic particles, carrier liquid and a little additives, the components are important factors to their shear yield stress. In general, soft magnetic particles are materials like iron, cobalt and alloy that with high permeability. Carrier liquid is the solvent of MRFs, the magnetic particles are uniformly dispersed in it. Carrier liquid should not only be of good oxidation and temperature stability [4], but also has characteristics like high density, non-pollution, low price, suitable viscosity, and nonflammable. The most common carrier liquids are silicon oil, synthetic oil and water. Additive is a molecular layer attached to the surface of the soft magnetic particles, which can effectively prevent the settlement of MRFs, and with suspension stability of the soft magnetic particles is ensured and the rheological property of the MRFs is increased, the properties of MRFs are greatly improved. The components selection should be taken comprehensive consideration on factors such as performance, price, and difficulty degree of preparation, in this paper, carbonyl iron powder and dimethylsilicone oil were selected as the soft magnetic particle and carrier liquid [5].

Preparation process. In the paper, utilising the traditional preparation method to prepare the MRFs [6]. The first step is to mix the carbonyl iron powder with SiO_2 and grinding them by ball mill for 2 hours. The second step is adding dimethylsilicone oil into the mixture that made in the first step and blending it with an electric mixer for 1h. Because the silicone oil contains oxygen that is invisible to the naked eye and the blending process will also mix with oxygen, the last step is vacuuming the MRFs. After the vacuumization is done, putting the MRFs into a bottle and seal it up for later use. The stability test on the prepared MRFs samples is performed with the Natural Precipitation Method [7], after being laid for 30days, there are no lumps in MRFs and the sedimentation rate is about 15%, which mean the experimental sample is qualified.

MR effect of MFRs. MRFs can flow freely without magnetic field, but after the magnetic field is applied, as showed in figure 1, under 3D high speed microscope, soft magnetic particles are magnetized and rapidly aggregate into chains along the direction of magnetic field. When forces

that perpendicular to the direction of the magnetic field are loaded on the particle chains, it will be cut off. The force that cut off the chain is defined as shear yield stress of MRFs. The shear yield stress is an important property of MRFs, preparing MRFs with high shear stress has become a hot research topic for domestic and foreign scholars in recent years. The MRFs instantly change into a solid state form, after revoking the magnetic field, MRFs returned to their original appearance, this process is called the MR effect of MFRs [8] [9].
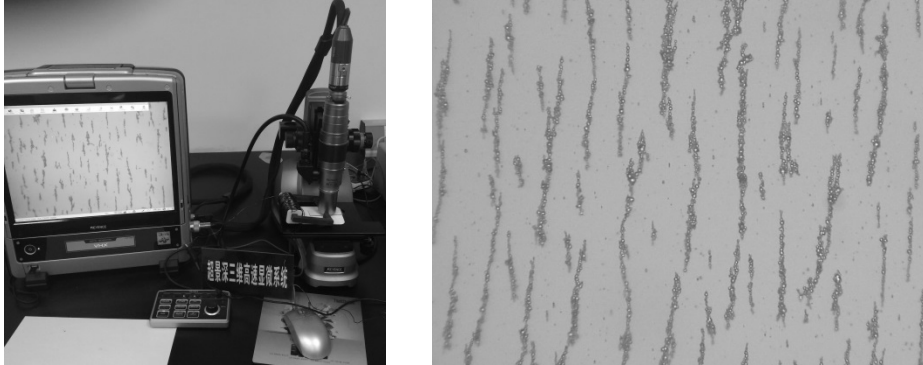
(a) 3D high speed microscope system (b) The chain of magnetorheological fluids
Fig.1 The chain structure of magnetorheological fluids

With the change of their apparent viscosity, the shear stress of MRFs enlarged by up to few orders of magnitude and the shear stress can be controlled by changing the external magnetic field strength [10]. After removing the magnetic field, the particles are still attracted to each other under the action of remanence and flow freely in the carrier fluid. But the attraction among particles will vanish and particles are uniformly dispersed in the dimethylsilicone oil eventually [11]. The chaining and dispersing process is controllable and reversible.

Experimental and Discussion

Using Rheometer Physica MCR 301 to study the dependence of shear stress on shear rate, magnetic field strength and volume ratio.

(1) Using the above method to prepar sample 1(viscosity 10cst, volume ratio 40%) and pour a certain amount of it into Rheometer Physica MCR 301, adjusting excitation current to 2A and maintaining this value throught the whole experiment. In the process of 0-10s, rising the shear rate from $0s^{-1}$ to $1000s^{-1}$ in a linear manner, after keeping it for 10s, adjusting the shear rate down to $0s^{-1}$ again in 10s. Testing the shear stress of the whole process.

The test result can be seen in figure 2, when shear rate is 0, the value of shear yield stress is 4.5KPa, so if the MRFs flows, the shear stress must be larger than 4.5KPa. When the shear rate increases from 0s-1 to 3s-1, the shear stress of MRFs comes to 44.5 KPa rapidly. As continue to raise the shear rate from 0s-1 to 1000s-1 in 10s, the shear stress of MRFs becomes larger and larger, but the growth rate becomes smaller. When the shear rate increase from 3 s-1 up to 1000s-1, the shear stress only rise 9.7%. In the process of 10s-20s, even though the shear rate remained stable, the shear stress of MRFs fluctuated a little and the maximal variation is about 1.6%. As the shear rate reduces to 3s-1, the shear stress decreased slowly to 44.4Kpa. But when the shear rate becomes 0s-1 again, the shear stress turn to 39.85Mpa, not around 4.5Mpa, because the shear process changes the viscosity of MRF which can't turn back to be its original.

(2) Pour a certain amount of sample 1 that showed in (1) into the Rheometer Physica MCR 301, adjust the shear rate to $700s^{-1}$ and maintaining this value throughtout the whole experiment. Given that the magnitude of the external current determines the magnetic field, the dependence of shear stress on the magnetic field can be figured out by the relationship between the excitation current and the shear stress. As shown in figure 3, adjust current to 0A during the first 10 seconds and increase it linearly to 2A in the next 10 seconds, keep this value for 10s then reduce it to 0A again in the next 10 seconds, at last, keep the current to be 0A for 10 seconds. Record shear stress for the entire experiment.

As shown in Fig.4, when current is 0A, the shear stress stabilized at 0.34Kpa, when current

increases linearly from 0A to 2A, the shear stress increases to 38.1Kpa in the same trend. This process means the dependence of shear stress on current tends to be linear. Because with the increase of current, the magnet field strength becomes stronger. The shear stress of MRFs is increasing since ferromagnetic particles of MRFs in the presence of magnet field are gradually magnetized and attract each other to form a chain.

（3）Using method that mentioned in section 1.2 to prepare 3 samples whose volume ratio are 20%, 30%, 40%, their viscosity are all 10cst. Test their relationship between shear stress and external current by Rheometer Physica MCR 301. Figure 4 shows the dependence of shear stress on volume ratio in the presence of different external current. As we can see from the 3 curves, volume ratio has a significant effect on the shear stress of MRFs, with the increase of volume ratio, the shear stress increases greatly. The volume ratio of the MRFs is inversely proportional to the distance between particles, so, the more particles, the smaller particle spacing. As the particle spacing becomes smaller, the shear stress of MRFs becomes smaller.
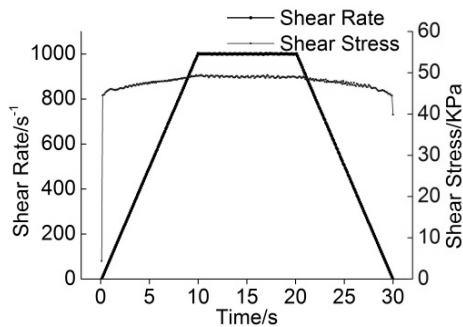

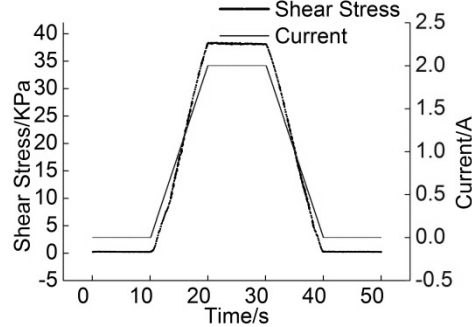Fig.2 The curve of shear rate and shear stress   Fig.3 The curve of current-shear stress
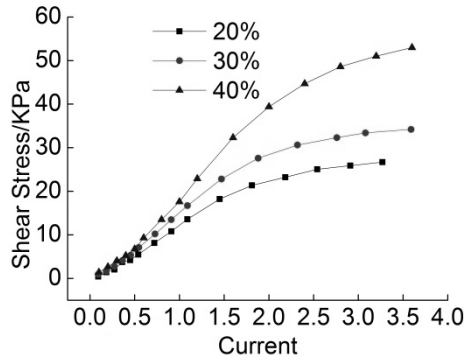

Fig.4 The curve of volume ratio -shear stress

Conclusions

After applying the magnetic field, the particles rapidly aggregate into chains along the direction of magnetic field, which can make shear stress up to 40kPa. The shear stress increases significantly with the increase of shear rate, volume ratio and magnetic field strength, so the shear stress of MRFs can be controlled by adjusting the shear rate, volume ratio and magnetic field strength. As the dependence of shear stress on the external current tends to be linear when magnetization of particles are not saturated, the most effective way to increase shear stress is to adjust the external current.

Acknowledgement

References

[1] Olabi A G, Grunwald A. Design and Application of Magnetorheolocical fluid[J]. Matericals and Design, 2007 10(28) 2658-2664.

[2] Kim I G, Kim J E, Liu Y D. Polyamide Coated Soft Magnetic Microspheres and Their Magnetorheology[J]. IEEE Transactions on Magnetics, 2012 48(11):3446.

[3] Kulkarni P A, Ciocanel C, Vieira S L, et al. Study of the behavior of MR fluids in squeeze torsional and valve modes[J]. J. Intell. Mater. Syst. Struct. 2003 14(2) 99-104.

[4] Jicheng Yi. Magnetorheological Fluids: Preparation, Property and Modeling. Ph D. Chongqing: Chongqing University, 2011.

[5] D J Klingenberg, C H Olk, M A Golden, Effects of Nonmagnetic Interparticle Forces on Magnetorheological Fluids [J]. J. Phys.: Condens. Matter. 2009 (149) 2283-2288.

[6] Jun Yao, Jinqiu Zhang, Zhizhao Peng, et al. Influence of Fe Content and Particle Size of Carbonyl Iron Powder on Shear Yield Stress of Magnetorheological Fluids[J]. Chinese Journal of Materials Research. 2014 28(12) 24-28.

[7] Jirong Wu, Xiaoqi Li, Xuehui Li, et al. Preparation of the Matneto-rheological Fluid and Experimental Study on Its Surface Tension Coefficient, J. Micronanoelectronic Technology. 2014 51 (3) 145-150.

[8] M. Sedlacik, R. Moucka, Z. Kozakova, et al. Correlation of Structural and Magnetic Properties of Fe3O4 Nanoparticles with Their Calorimetric and Magnetorheological Performance[J]. J. Magn. Magn. Mater. 2013 326(1) 7-13.

[9] Hans Martin Laun, Claus Gabriel, Christoffer Kieburg. Wall Material and Roughness Effects on Transmittable Shear Stresses of Magnetorheological Fluids in Plate-Plate Magnetorheometry [J]. Rheol. Acta. 2011 50 (2)141-157.

[10] Zuzhi Tian. Research on Magnetorheological Fluids and Transmission Technology. Ph D. Thesis. Beijing: China University of Mining and Technology, 2012.

[11] C.W. Zhao. Research of Mechanics Behavior of MRFs Based on Microstructure. Ph D. Chongqing: Chongqing University, 2014.