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RESEARCH ARTICLE

STUDY AND ANALYSIS OF SHEAR PROPERTIES OF MAGNETO RHEOLOGICAL FLUIDS

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ABSTRACT

Under the magnetic field, the shear stress and apparent viscosity of Magneto Rheological Fluid (MRF) increase significantly. The shear stress ranges from 1.08 kPa to 12 kPa, and the apparent viscosity ranges from 2.5 Pa•s to 28.7 kPa•s. When the magnetic field is constant, the shear stress increases and tends to stabilize with the increase of shear rate, and there exists shear thinning phenomenon. The shear yield stress calculated by Bingham and Casson models is 1043Pa ~ 8825Pa. With the increase of magnetic field, the shear stress of MRF increases remarkably, ranging from 200 Pa to 11 kPa.

INTRODUCTION

Magneto Rheological Fluid (MRF) is a suspension consisting of ferromagnetic particles, non-magnetic carriers and additives. In the absence of magnetic field, ferromagnetic particles are randomly dispersed in the non-magnetic carrier fluid. Under the magnetic field, these ferromagnetic particles attract each other and form a chain structure along the direction of the magnetic field, which produces the effect of resisting shear stress, and their appearance is solid-like. The shear resistance of MRF varies with the change of magnetic field. When the magnetic field is removed, the MRF immediately restores to the free flow state. The response time of magneto rheological effect is very short, usually in millisecond order, and the transformation between solid and liquid is reversible. As an intelligent material, magneto rheological fluid has the advantages of rapid change, continuity, high efficiency, safety and reliability. Compared with other products, the new products developed by MR effect have obvious advantages and market competitiveness in performance, manufacture, use and price. They have been applied in aviation, aerospace, machinery, automobile, precision processing, control and other fields. With the deepening of research, magneto rheological fluids will be used in more fields, showing broad application prospects.

Preparation and Experiment of Magneto Rheological Fluid

Preparation of Materials: In the preparation of magneto rheological fluids, carbonyl iron powder is the most widely used magnetic particle, because it is an industrial product with large output and low price. It has high permeability and low magnetic coactivity. Its magnetic saturation is about 2.1T, and it has excellent soft magnetic properties. Magneto rheological fluid carriers should have the following characteristics: high boiling point, low solidification point, good chemical stability, non-toxic, odorless, low price and so on. At present, non-magnetic carriers mainly include silicone oil, mineral oil, synthetic oil, water and ethylene glycol. Dimethyl silicone oil is used as carrier in this experiment. Magneto rheological fluids with 10% carbonyl iron powder volume fraction were prepared. Carbonyl iron powder, base solution and stearic acid were weighed according to the calculated ratio. The average particle size of carbonyl iron powder is 3.3 um. The base solution is dimethyl silicone oil with a viscosity of 25 cst. The surfactant is stearic acid. The mass fraction of stearic acid is 2% of carbonyl iron powder. Carbonyl iron powder and stearic acid were mixed into stainless steel container and stirred at high speed for several hours. The treated mixture was dried in a vacuum drying chamber to purify the surface of magnetic particles. Then the pretreated and dried suspended phase powder was mixed with dimethyl silicone oil in stainless steel grinding tank. Magneto rheological fluids are obtained by high speed grinding and dispersion.

Experimental test: The test instrument used in this experiment is Antongpa Physica MCR 301 flat plate rheometer. In the experiment, the magneto rheological fluids were put between the upper and lower plates of the rheometer and sheared at a shear rate of 50s-1 for 150s without magnetic field to ensure good dispersion of the magneto rheological fluids. Then the shear stress of MRF was measured under different conditions. Setting currents are 1A, 2A, 3A and 4A respectively. According to the instrument manual data, the magnetic induction intensity of the magnetic field is 0.23T, 0.44T, 0.65T and 0.86T respectively. Set the shear rate to change in the range of 0 ~ 1000s^{-1}, the temperature is 25 ℃, and the shear time is 10 s. The shear stress and apparent viscosity of MRF were measured every 0.1s. The shear rate is 300 s^{-1}, the magnetic field varies in the range of 0 ~ 0.5T, the

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shear time is 10 s, and the shear stress of MRF is measured every 0.1s.

RESULTS AND ANALYSIS

Type analysis of tension system: The relationship between shear stress and shear rate of magneto rheological fluids is shown in Fig.1 when applied magnetic field. It can be seen that with the increase of shear rate, the shear stress first decreases slightly, then increases gradually and tends to be stable under the action of constant magnetic field. The larger the magnetic field, the more obvious the initial decrease of shear stress is. At the same shear rate, the shear stress increases significantly with the increase of magnetic field, ranging from 1.08 kPa to 12 kPa. The relationship between apparent viscosity and shear rate of magneto rheological fluids is shown in Fig.2. It shows that the apparent viscosity decreases significantly with the increase of shear rate under constant magnetic field. At the same shear rate, the apparent viscosity increases with the increase of magnetic field, ranging from 2.5 Pa. s to 28.7 kPa·s.

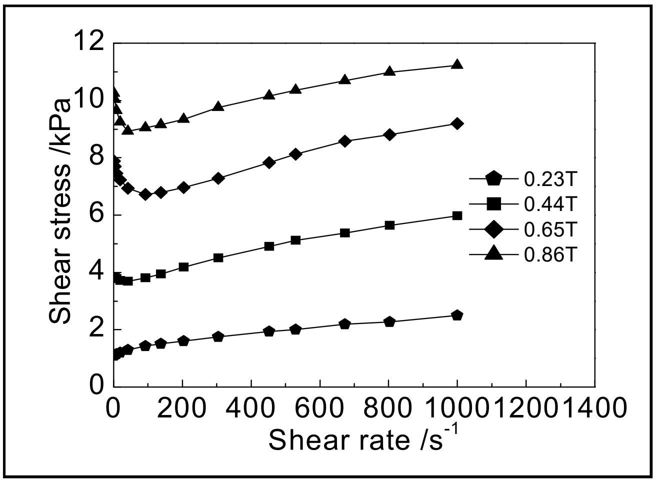

Fig. 1. Dependence of shear stress on shear rate

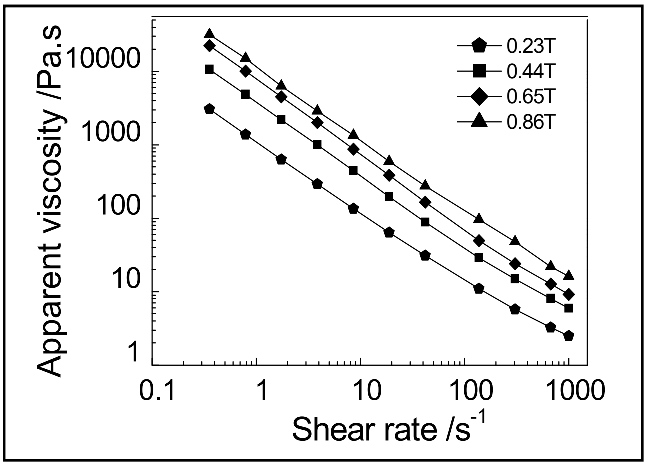

Fig. 2. Dependence of apparent viscosity on shear rate

Model fitting: Bingham model is used to fit the rheological behavior of MRF, as shown in Figure 3. The fitting results are shown in Table 1. It can be seen from Fig. 3 and Table 1 that there is a good linear relationship between the shear stress and the shear rate of MRF. The magnetic field increases from 0.23T to 0.86T. The shear stress calculated by Bingham model increased from 1369Pa to 8825Pa, that is, the magnetic field increased by 274%, and the shear yield stress increased by 545%.

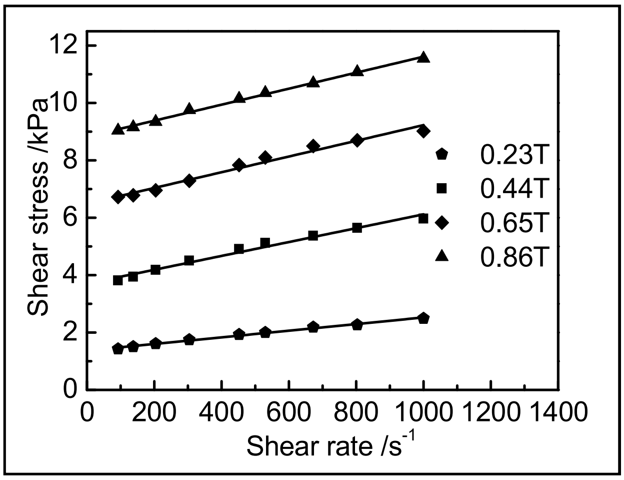

Fig. 3. The shear stress of MRF fitting by using Bingham model

Tab. Fitting calculation results on shear stress by using Bingham model

B/T	Fitting equation	R^2	τ_y/Pa	η/Pa.s
0.23	y=1.15x+1369	0.991	1369	1.15
0.44	y=2.41x+3703	0.980	3703	2.41
0.65	y=2.73x+6491	0.976	6491	2.73
0.86	y=2.79x+8825	0.995	8825	2.790

The rheological behavior of magneto rheological fluids is simulated by Casson model, as shown in Fig.4. The fitting results are shown in Tab.2. It can be seen from Fig.4 and Tab.2 that there is a good linear relationship between the shear stress and the shear rate of MRF. The magnetic field increases from 0.23T to 0.86T. The shear yield stress calculated by Casson model increased 7624 Pa, 274% and 631% from 1043 Pa. It can be concluded that the results of MRF shear stress fitting by two models have good linear correlation, and the value of shear yield stress fitting by Bingham model is slightly higher.

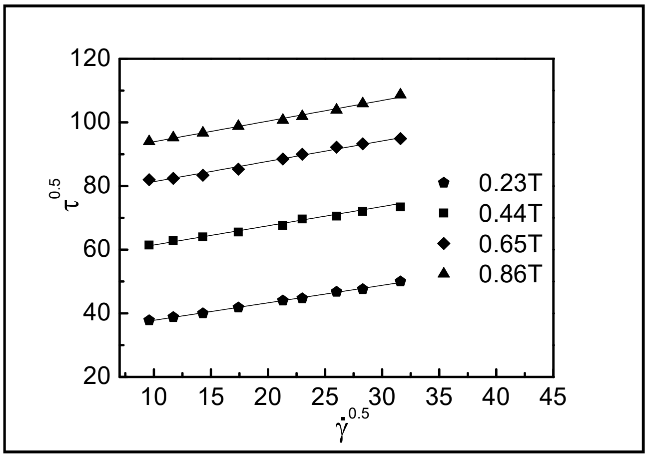

Fig. 4. The shear stress of MRF fitting by using Casson model

Tab 2. Fitting calculation results on shear stress of MRF by using Casson model

B/T	Fitting equation	R^2	τ_y/Pa	η/Pa.s
0.23	y=0.55x+32.3	0.997	1043	0.30
0.44	y=0.60x+55.5	0.992	3080	036
0.65	y=0.64x+75	0.985	5625	0.41
0.86	y=0.65x+87.4	0.992	7627	0.42

Under the action of magnetic field, the ferromagnetic particles in magneto rheological fluids are arranged in a chain structure. When the magneto rheological fluids begin to shear, the grain chains between the plates are suddenly destroyed and cannot be restored in time.

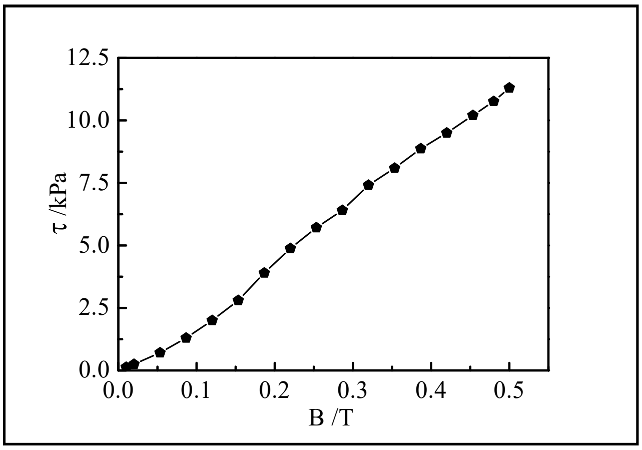

Fig. 5. Dependence of shear stress on magnetic field

The macroscopic manifestation is that the shear stress decreases. With the increase of shear rate, new particle chains are formed under the action of magnetic field, shear stress increases gradually, and apparent viscosity decreases. When the shear rate increases to a certain extent, the fracture and formation of grain chains will reach equilibrium. The larger the magnetic field is, the stronger the interaction force between particle chains in MRF is, and the larger the shear stress is. It can be concluded that with the increase of shear rate, the shear stress increases and tends to stabilize, and there exists a shear thinning phenomenon in the shear stress. The relationship between shear stress and magnetic field of MRF is shown in Fig.5. It can be seen that the shear stress increases significantly with the increase of magnetic field, ranging from 200 Pa to 11 kPa. When the magnetic field is small, the ferromagnetic particles in magneto rheological fluids are far from saturation. Under the action of magnetic field, particles interact to form a chain-column structure. The macroscopic behavior is that the shear stress increases rapidly, showing a rapid growth. With the increase of magnetic field, the ferromagnetic particles in MRF are locally magnetized and saturated, and the shear stress increases steadily. The macroscopic behavior is that the shear stress increases approximately linearly. It can be predicted that if the magnetic field continues to increase and the particles approach full magnetization saturation, the change of shear stress is very small. When the particles are fully magnetized saturation, the shear stress reaches a stable value. It can be concluded that the shear stress of MRF increases significantly with the increase of the applied magnetic field.

Conclusions

In this paper, silicone oil-based magneto rheological fluids with 10% carbonyl iron powder volume fraction were prepared by experimental method. Physica MCR 301 rheometer was used to test its rheological properties. Bingham model and Casson model are used to fit the rheological properties of MRF. Experiments show that Bingham model and Casson model can well describe the rheological behavior of MRF. Under the action of magnetic field, with the increase of shear rate, the shear stress increases and tends to be stable, the apparent viscosity decreases significantly, and the phenomenon of shear dilution exists. With the increase of magnetic field, the shear stress of MRF increases significantly.

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