Influence of ball-milling time on the properties of silicone oil-based magnetorheological fluid

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In order to study the properties of oil-based magnetorheological fluid (MRF), ball-milling method is used to prepare oil-based MRF. Experiment materials and test methods are elaborated, and five kinds of MRF samples with different ball-milling time are prepared. Moreover, scanning electron microscope (SEM) images are taken to analyze the size and surface morphology of magnetic-particles. Finally, test experiments are carried out and the effect of ball-milling time on sedimentation stability, zero field viscosity and shear yield stress is discussed. Experimental results show that ball-milling time between 10 hours and 12 hours is the best for the requirement of mechanical transmission system.

(Received October 16, 2013; accepted March 13, 2014)

Keywords: Oil-based magnetorheological fluid, Ball-milling time, Sedimentation stability, Zero field viscosity, Shear yield stress

1. Introduction

As a kind of intelligent material, magnetorheological fluid (MRF) is composed of magnetic-particles magnetized easily and additive agents dispersed in a carrier fluid [1-3]. MRF has good rheological properties with excellent performance of reversibility, continuity, speediness and precise control [4-5], in other words, MRF shows nice fluidity like Newtonian fluids without an applied magnetic field, but in an applied magnetic field, it has mechanical properties similar to a solid [6-7]. Due to these characteristics, the study on MRF has been drawn much attention by overseas and domestic scholars, and MRF has quite broad applied foreground in the fields of civil engineering [8-9], vehicle engineering [10-11], mechanical engineering [12-13], equipment manufacturing industry [14-16] and other fields [17-18].

As a new mechanical transmission technology, magnetorheological transmission (MRT) was developed in 90s 20[th]. Due to the characteristics of short response time, less wear of transmission components, simple control and low energy consumption, MRT machines have a good application outlook in mechanical transmission systems. The performance of MRF is the main factor that affects its application in mechanical transmission systems, and there are many factors affecting the performance in process of MRF preparation, such as the volume fractions of magnetic-particles, the size of magnetic-particles, the density of magnetic-particles, the viscosity of carrier fluid, the kinds and amounts of additive agents, etc. So far, many scholars have carried out extensive research on magnetic-particles [19-20], carrier fluids [21-22] and additive agents [23-24], but few researchers have focused on the influence of ball-milling time on the properties of silicone oil-based magnetorheological fluid. Based on the past work on the preparation process and transmission properties of MRF, this paper tries to study this problem.

The rest of this paper is organized as follows: experiments and test methods are elaborated in section 2. Experiments are carried out and experimental results are discussed in section 3. Our conclusions and future work are summarized in section 4.

2. Experimental

2.1 Materials

Soft magnetic carbonyl iron particles (average particle size: 3.5um, density: 7.8g/cm^3, China) and dimethyl silicone oil (dynamic viscosity: 1000cSt in 25℃, density: 0.97 kg/m^3, Shin-Etsu, Japan) are used as magnetic-particles and carrier fluid for MRF, respectively. We choose sodium dodecyl benzene sulfonate as surface active agent, diatomite powders as inorganic thixotropic agent and graphite as antiwear agent. The details are carried out as following process: firstly, absolute ethyl alcohol is poured into the mixture of soft magnetic carbonyl iron particles, dodecyl benzene sulfonate (4wt. %) and diatomite powders (1wt. %), then add 2ml oleic acid slowly and keep stirring (200 rpm) at room temperature by a mechanical stirrer for 12 hours. Secondly, disperse the reactants by an ultrasonic generator. Thirdly, wash the reactants with absolute ethyl alcohol and pour the supernatant, then dry them at 75℃ in vacuum oven for 8 hours. Fourthly, grind and sieve them carefully, then the modified particles can be gotten. Fifthly, the density of modified particles is tested by the method of double specific gravity bottles [25] and then mixes dimethyl silicone oil, modified particles and additive agents with the volume fractions of magnetic-particles 20% and stir (800 rpm) for 6 hours. Finally, put the mixtures in a planetary ball mill and mill them for hours.

2.2 Test methods

The performance tests include sedimentation stability, zero field viscosity and shear yield stress. The sedimentation stability is tested by visual examination method and the zero field viscosity of MRF is measured by a SNB-1 rotary viscosity meter at 25℃, shear yield stress is tested by our self-designed experimental apparatus as shown in Fig. 1. The magnetic field of working gap is controlled by a direct-current power and measured by a tesla instrument, and the transmitted torque of MRF is measured by a static torque sensor. The relation between shear yield stress (τ) and transmitted torque of MRF (T) can be expressed as follows:

$$T = \frac{2}{3}\pi\tau(R_2^3 - R_1^3)$$

Where R_1 is the inner diameter of actuator disk and R_2 is the maximal diameter of actuator disk.

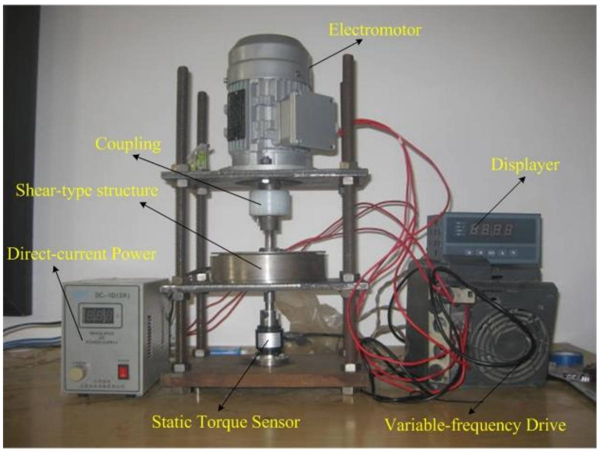

Fig. 1. Shear mode MRF test device.

3. Results and discussion

In this paper, ball-milling method (planetary ball mill, ball-to-powder weight ratio 2:1, rotate speed 160 rpm) is used for preparing MRF and ball-milling process (ball-milling time) is mainly studied on the properties of MRF. Five samples with different ball-milling time are prepared (the volume fractions of magnetic-particles is 20%) and the sample index is shown in Table 1.

Table 1. Five kinds of MRF sample index and the corresponding ball-milling time.

Index	MRF-1	MRF-2	MRF-3	MRF-4	MRF-5
Time	6h	8h	10h	12h	14h

3.1 Particles scanned by SEM

Scanning electron microscope (SEM) images (Fig. 2) are taken to analyze the size and surface morphology of magnetic particles. It can be seen that soft magnetic carbonyl iron particles are irregular and sphere-like. The average size of these particles is observed to be 3.5um. In Fig. 2b, obviously, both small and large particles could be coated with active agent very well. Fig. 2c shows the SEM images of coating layers clearly. The sphere-like particles are turned to be flaky particles after 14 hours ball-milling time (Fig. 2d).

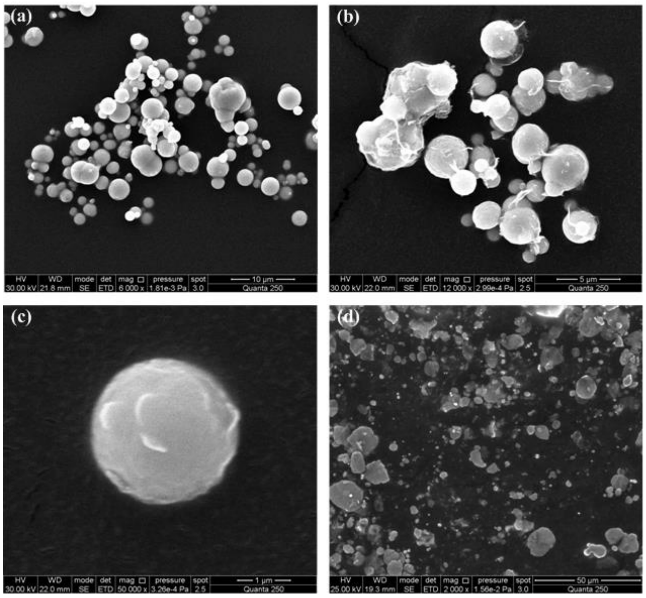

Fig. 2. SEM images of soft magnetic carbonyl iron particles (a), SEM images of modified particles (b) and (c) after 6 hours ball-milling time, SEM images of modified particles (d) after 14 hours ball-milling time.

3.2 Sedimentation stability

The sedimentation stability is tested by visual observation method and can be expressed by sedimentation ratio V calculated as follows:

$$V = \frac{h}{H} \times 100\%$$

Where h is the length of the clear fluid and H is the total length.

The sedimentation ratio of the samples is shown in Fig. 3. It is clearly observed that the sedimentation ratio of MRF-1 and MRF-2 is the highest among them, and MRF-5 is nearly equal to MRF-2. In addition, the sedimentation ratio curve of MRF-3 and MRF-4 is almost the same. It also shows that sedimentation stability is better with extending of milling time except MRF-5. The modified particles indicate slow sedimentation velocity during the initial 50 hours and then tend to get stable.

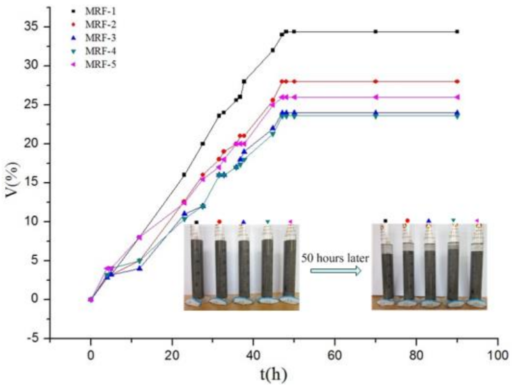

Fig. 3. Sedimental curve of the prepared MRF.

3.3 Zero field viscosity

Zero field viscosity of the samples under different ball-milling time is measured by a rotary viscosimeter and the results are shown in Fig. 4. Obviously, with the increasing of ball-milling time, zero field viscosity of MRF increases. In addition, the increasing tendency of zero field viscosity is relatively stable between MRF-1 and MRF-4. However, zero field viscosity of MRF-4 and MRF-5 from 3555mPas increase quickly to 4832mPas.

3.4 Shear yield stress

The relation between shear yield stress of MRF and magnetic field intensity can be illustrated as Fig. 5. It is clearly observed that shear yield stress of MRF increases with the increasing of magnetic field intensity. At the same time, the curve of MRF-1, MRF-2, MRF-3 and MRF-4 is very similar except MRF-5. In addition, the curve of MRF-3 and MRF-4 is nearly the same.

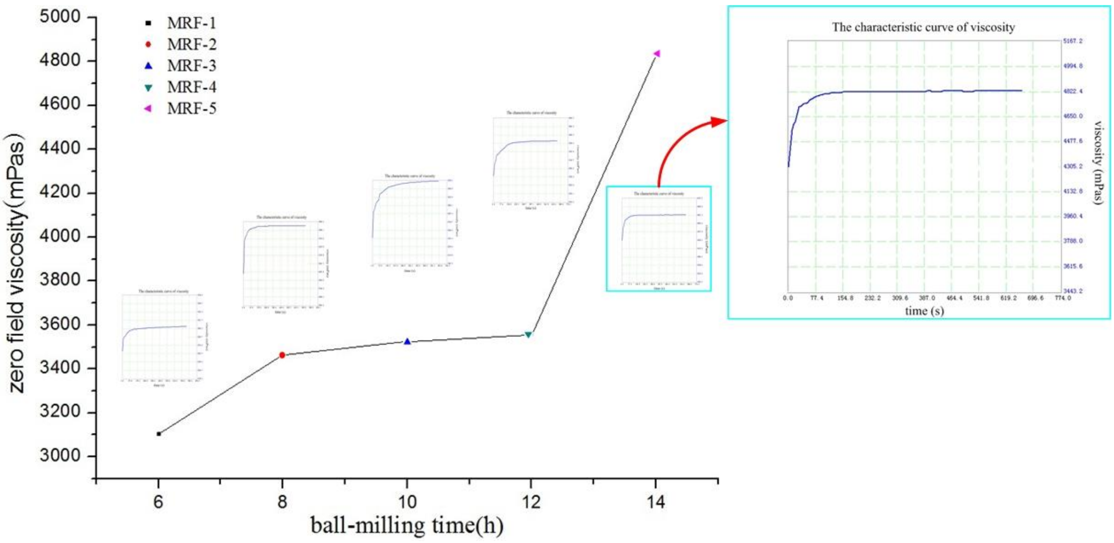

Fig. 4. Zero field viscosity under different ball-milling time.

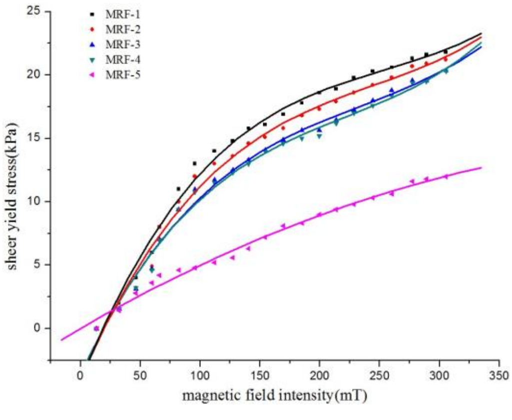

Fig. 5. Shear yield stress of the prepared MRF.

3.5 Discussion

By testing the properties of our prepared magnetorheological fluid, we can obtain that ball-milling time has a significant influence on the performance of MRF. The sedimentation ratio of five samples is 34.4%, 28%, 24%, 23.6% and 26%, respectively. The zero field viscosity of five samples is 3102mPas, 3464mPas, 3525mPas, 3555mPas and 4832mPas. The shear yield stress of five samples is 21.8kPa, 21.2kPa, 20.358kPa, 20.3kPa and 12kPa. Due to the shear yield stress of MRF-5 is too small and zero field viscosity is too large, it is unsuitable to mechanical transmission system. In addition, the sedimentation ratio of MRF-1 is relatively large. A conclusion is drawn that ball-milling time between 10 hours and 12 hours is the best for the requirement of mechanical transmission system.

4. Conclusions and future work

In order to prepare oil-based magnetorheological fluid with excellent performance, ball-milling method was studied. The experiment materials and test methods were elaborated, and a device was designed to test the shear yield stress of MRF. Five samples with different ball-milling time were prepared and test experiments were carried out. The experimental results indicated that ball-milling time between 10 hours and 12 hours was the best for the requirement of mechanical transmission system.

Ongoing and future work will also focus on other factors which would affect the performance of MRF. Furthermore, the application effect of prepared MRF is also an important research for the authors.

Acknowledgements

The support of National Natural Science Foundation of China (No. 51005231), Fundamental Research Funds for the Central Universities (No. 2014QNA38), Open Foundation of the State Key Laboratory of Fluid Power Transmission and Control (No. GZKF-201316) and Jiangsu Province National Engineering Research Center Cultivation Base for Coal Intelligent Mining Equipment in carrying out this research are gratefully acknowledged.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this article.

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