Effect of silicone oil viscosity on the properties of magnetorheological fluids

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Aiming to study the effect of silicone oil viscosity on the properties of silicone oil-based magnetorheological fluids (MRF), experiment materials, preparation process and test methods are elaborated, and five kinds of MRF samples with different silicone oil viscosity are prepared. The microstructures of both carbonyl iron particles and coated carbonyl iron particles are observed by scanning electron microscope (SEM). Moreover, test experiments are carried out and the effect of silicone oil viscosity on sedimentation stability, zero field viscosity and shear yield stress is discussed. Experimental results show that the silicone oil viscosity has a significant influence on sedimentation stability and zero field viscosity of MRF, but little impact on shear yield stress of MRF. Furthermore, the MRF with silicone oil viscosity 350cst and 500cst is best for the requirement of engineering applications.

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1. Introduction

As a kind of controllable smart materials, magnetorheological fluids (MRF) have a good development prospect and application value in engineering application [1-3]. These kinds of fluids are colloidal systems typically consisting of magnetic-particles with a size of about 10nm in diameter and additive agents dispersed in a nonmagnetic carrier fluid [4-8]. The remarkable change of MRF in rheological behavior under the application of an external magnetic field is called MR effect, which can be reversibly transformed from a liquid state to a solid state in the milliseconds [9]. The main performance is that MRF shows original fluidity with a given viscosity and behaves like Newtonian fluids in the absence of the magnetic field, but in the presence of a magnetic field, the metal particles of these fluids form a chain performing a Bingham solid [10-11]. This transform is rapid-response, controllable and the change of viscosity is continuous. Owing to the unique rheological behavior, MRF is widely used in various engineering applications such as in dampers [12-13], brake apparatus [14], medical equipment [15-16] as well as aerospace materials [17], etc.

In the 1940s, J. Rabinow [18] discovered MRF phenomenon and invented MRF, but many researchers studied on electro-rheological fluid (ERF) discovered by W. Winslow [19-20] rather than MRF at that time. Until recently, MRF has regained interest from the scholars and the researchers because of the unique rheological properties of MRF, and then some controllable devices based on the technology of MRF are now beginning to appear and evolve quickly [21-22]. However, the development of MRF in engineering applications is hindered by the poor properties of MRF such as weak sedimentation stability and low shear yield stress, etc. The main factors which affect the properties of MRF are sedimentation stability, zero field viscosity and shear yield stress. In the past, many scholars have carried out extensive research on MRF, but few scholars study the effect of silicone oil with different viscosity on the properties of MRF, this paper tries to study this problem.

The rest of this paper is organized as follows: experiments are presented in section 2. Results and discussion based on the experiments are discussed in section 3. Our conclusions and future work are summarized in section 4.

2. Experimental

2.1 Materials

Magnetic particles used for preparing MRF are soft magnetic carbonyl iron particles (purchased from Shanghai Chemical Reagent Co.) with a density of 7.8g/cm^3 and diameter in the range of 1.5μm ~4μm. Dimethyl silicone oil (Shin-Etsu, Japan) is used as a continuous medium. In order to improve the properties of MRF, diatomite powders is used as inorganic thixotropic agent which can reduce agglomeration and graphite is used as antiwear agent which can reduce wear between magnetic particles [23]. Sodium dodecyl benzene sulfonate (SDBS) and oleic acid (purity 90%) supplied by Tianjin of China are used as surfactant for preventing polymerization [24-25]. Absolute ethyl alcohol is also used in the whole process of the preparation process.

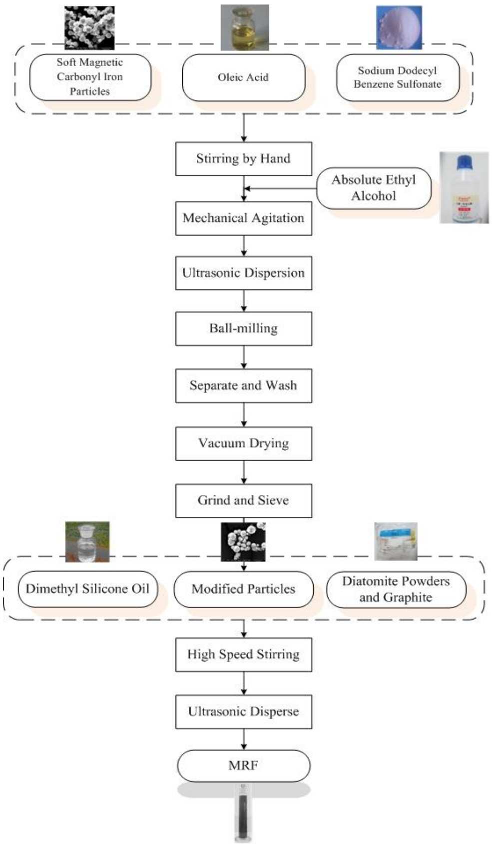

Fig. 1. The preparation process of MRF.

2.2 Preparation process of MRF

The preparation process of MRF can be realized by existing technology. The detail steps can be described as follows. Firstly, soft magnetic carbonyl iron particles, SDBS and oleic acid are mixed with certain proportion in a container, the mixture is stirred evenly by hand, and then absolute ethyl alcohol is poured slowly into the container. Secondly, the mixture is stirred continuously by a mechanical stirrer for about 8h and the stirring speed is fixed at 500rpm. This step aims to ensure that soft magnetic carbonyl iron particles are coated sufficiently by surfactant. Thirdly, the mixture is dispersed with ultrasonic dispersion instrument to remove part of the aggregated grains. Fourthly, after the dispersion process, the mixture is milled by a planetary ball mill for 10h. Fifthly, the particles are separated by a magnet from the mixture and washed with absolute ethyl alcohol for several times. After washing, the particles are dried in a vacuum at 75℃ for at least 8h, and then the dried particles are delicately grinded and continuously sieved. Finally, the modified particles, dimethyl silicone oil, diatomite powders and graphite are mixed with the volume fractions of magnetic-particles 20%, and the whole steps can be shown in Fig. 1.

2.3 Test methods for the properties of MRF

In this experiment, sedimentation stability, zero field viscosity and shear yield stress of MRF are tested, respectively. The visual examination method that MRF settled in a measuring cylinder is observed and recorded in a certain interval to obtain the length of turbid fluid is a common approach used for observing the sedimentation stability of MRF. The zero field viscosity is tested by a SNB-1 rotation viscometer made in Shanghai and the shear yield stress of MRF is measured with a device designed by ourselves as illustrated in Fig. 2 [26]. All experiments are carried out at room temperature.

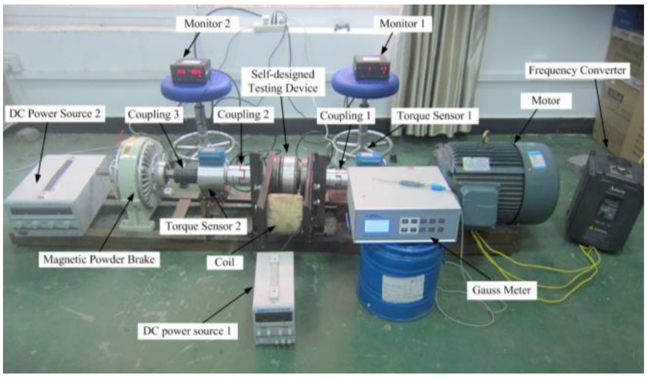

Fig. 2. Experimental device for the shear yield stress of MRF.

3. Results and discussion

A number of MRF samples with different silicone oil viscosity are involved in the experiments to investigate the effect of silicone oil with different viscosity on the properties of MRF in engineering application. With this aim, MRF samples with different silicone oil viscosity are prepared and the volume fractions of magnetic-particles are 20%. The details of silicone oil viscosity and the index of samples are given in Table 1.

Table 1. Five kinds of MRF sample index and the corresponding viscosity.

Index	MRF-1	MRF-2	MRF-3	MRF-4	MRF-5
Viscosity	50cst	100cst	350cst	500cst	1000cst

3.1 SEM images of particles

The microstructures of both carbonyl iron particles and carbonyl iron particles coated with surfactant are observed by scanning electron microscope (SEM), respectively. Fig. 3 (a) indicates that the size distribution of carbonyl iron particles is polydisperse (diameter ranging between 1.5μm and 4μm) and the morphology is nearly spherical. Fig. 3 (b) is the SEM image of coated carbonyl iron particles, showing that the surface of carbonyl iron particles are wrapped by the fibrils after adding additive agent and surfactant to the suspension, which means we have obtained surface modified carbonyl iron particles.

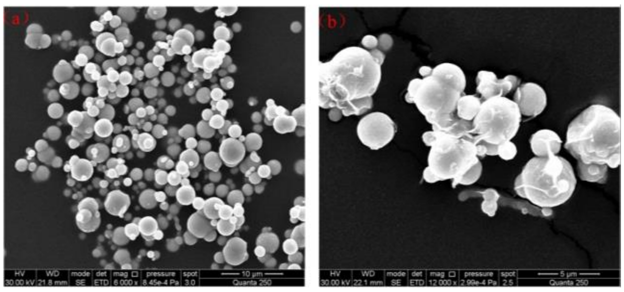

Fig. 3. SEM images of carbonyl iron particles (a) and coated carbonyl iron particles (b).

3.2 Sedimentation stability of prepared MRF

The sedimentation stability of the prepared MRF is roughly evaluated from sedimentation ratio *S* calculated as follows:

$$S = \frac{H-h}{H} \times 100\%$$

In this formula, *h* expresses the length of turbid fluid after sedimentation and *H* expressing the total length of MRF. The values of *h* and *H* are obtained through the observation.

The sedimentation ratio *S* for all of the samples is illustrated in Fig. 4. All the sedimentary curves show a similar trend, which the sedimentation ratio of five samples increases with time lasting and tends basically to steady after long settling times. In addition, it also shows that the change of sedimentation ratio for MRF-3, MRF-4 and MRF-5 with time is less than that for MRF-1 and MRF-2, so we may consider that MRF-3, MRF-4 and MRF-5 are stabler than the rest samples. Furthermore, the sedimentation ratio of MRF-3, MRF-4 and MRF-5 are all below 20% when they become stable. According to the research result from Lord Corporation which is expert in the application of MRF, sedimentation ratio of MRF less than 20% is very good [27], so we can say that MRF-3, MRF-4 and MRF-5 are stable in the long term.

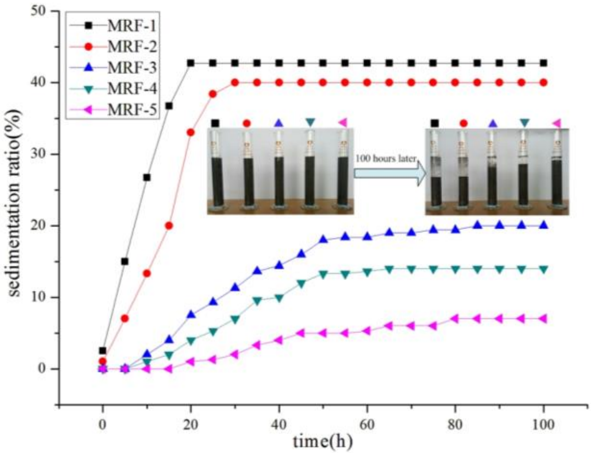

Fig. 4. Sedimentation ratio curves of MRF with different viscosity.

3.3 Zero field viscosity of prepared MRF

The values of zero field viscosity for five MRF samples are showed in Fig. 5. The experimental results indicate that the zero field viscosity of MRF-1 is the smallest one in all samples, and on the contrary, the zero field viscosity of MRF-5 is the biggest one. From the figure of zero field viscosity, we can conclude that the higher the viscosity of silicone oil, the larger the value of the zero field viscosity for MRF. Generally, MRF with high performance is requested for lower zero field viscosity, but taking into account the sedimentation stability of MRF, the samples of MRF-3 and MRF-4 whose zero field viscosity are between the maximum (6800mPas) and the minimum (398mPas) are relatively good selection.

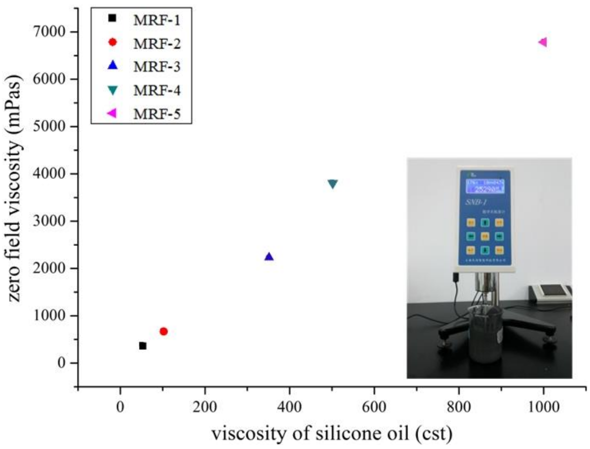

Fig. 5. Zero field viscosity of the prepared MRF.

3.4 Shear yield stress of prepared MRF

Shear yield stress of MRF is measured with a device designed by ourselves. In this experiment, electric current intensity is from 0A to 5A, motor speed is set at 300r/min by frequency converter and braking torque is set at 80N·m by magnetic powder brake in the whole experimental procedure. The dependency of shear yield stress on electric current for five MRF samples is illustrated in Fig. 6, which clearly shows that shear yield stress of MRF increases with the increasing of electric current intensity. Moreover, for a given electric current applied to the MRF, the associated shear yield stress increases with increasing the viscosity of dimethyl silicone oil, but according to the curves of five samples, we can find that the increase of associated shear yield stress is very slight. In other words, the silicone oil viscosity has little influence on the shear yield stress of MRF.

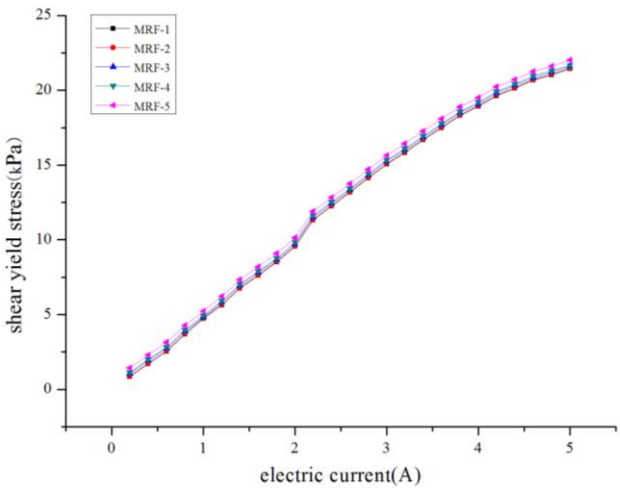

Fig. 6. Shear yield stress curves of the prepared MRF.

3.5 Discussion

According to the experiment results on the properties of our prepared MRF, we can find that the silicone oil viscosity has a significant influence on the zero field viscosity and the sedimentation stability of MRF, but has little influence on the shear yield stress of MRF. The sedimentation ratio tested with the visual examination method shows that MRF-3, MRF-4 and MRF-5 are stable in the long term and their sedimentation ratios are less than 20%. On the other hand, taking into account the sedimentation stability of MRF, the experimental results of the zero field viscosity indicate that MRF-3 and MRF-4 are a comparatively good choice. Finally, the shear yield stress of the samples is 21.43kPa, 21.462kPa, 21.61kPa, 21.68kPa and 22.01kPa, due to the gap of shear yield stress is very small, so we can find out that silicone oil viscosity has little effect on shear yield stress. By comprehensive analysis, a conclusion is drawn that MRF-3 and MRF-4 have good overall properties.

4. Conclusions and future work

The materials and preparation process of MRF were elaborated, and five samples of MRF with different silicone oil viscosity were prepared. The properties of prepared MRF were tested to investigate the impact degrees of the silicone oil viscosity on zero field viscosity, sedimentation stability and shear yield stress. Experiment results indicated that MRF-3 and MRF-4 in the five samples were best for the requirement of engineering applications.

Ongoing and future work would continue to focus on the preparation method of MRF applied in large power magnetorheological fluids transmission system. Furthermore, the improvement for the performance of MRF is also an important research for the authors.

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Conflict of Interests

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

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