The Preparation of multifunctional shear thickening fluid and the application in shock absorber

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Abstract. A multifunctional shear thickening fluid (MSTF) that exhibits both shear thickening (ST) effect and magnetorheological (MR) performance was prepared. The MR effect of MSTF was compared with magnetorheological fluid (MRF) when the CIP mass fraction varies from 10% to 70%. The results show that the MR effect of MSTF is higher than that of MRF obviously. Besides, the compression force and rebound force of the damper containing MSTF and MRF were tested and compared when the current was set as 0, 0.5, 1.0, 1.5, 2.0, 2.5 and 3A. When the CIP mass fraction is less than 30%, the forces of these two kinds of materials are almost the same at any current value. And as the CIP mass fraction is more than 30%, the rebound force of MSTF is obviously higher than that of MRF.

1. Introduction
Shear thickening fluid (STF) is a kind of smart material as its viscosity increases with the external shear rate[1]. In the absence of an external force, STF is not different from other kinds of liquids. However, the STF exhibits the transition from a liquid state to a gel state, or even a solid state when the external shear rate reaches a critical value [2]. When the force is removed, this kind of material will return to its original state. Due to the reversibility and the nonlinearity of its mechanical properties, STF shows a wide application in the fields of damper [3], body armor[4], civil engineering and automobile industry.

Magnetorheological fluid (MRF) is also a category of intelligent material that composes of magnetic particles and the liquid medium. The viscosity of MRF can be tuned quickly and reversibly by applying an external magnetic field. In the presence of a magnetic field, the magnetic particles form a chain-like microstructure along the magnetic field direction, resulting in the change of the mechanical properties of this kind of material. In recent years, MRF has gradually attracted a great deal of interest in the fields, such as intelligent sensors, dampers and industry.

In more recent years, the absorber used in the vehicle was divided into hydraulic damper (containing hydraulic oil) and magnetorheological damper (containing MRF). However, most of the studies related to the intelligent materials have focused on the rheological and mechanical properties of the materials including additional functional materials, such as carbon nanotube [5], graphene [6]. Besides, there was little literature in the application of absorber in the vehicle. The viscosity of MRF can be only changed by the magnetic field or the current value. However, the viscosity of multifunctional shear thickening fluid (MSTF) obtained by adding magnetic particles into STF can be not only adjusted by the magnetic
field, but also changed by the external shear rate. Furthermore, the STF, as a carrier, can also increase the ability of energy consumption.

In this paper, a MSTF was synthesized by dispersing CIP into the STF. The rheological properties were tested and compared. Interestingly, the MR effect of MSTF is remarkably higher than that of MRF. Furthermore, the indicator diagram of the damper containing MRF and MSTF were tested when the CIP mass fraction varies from 10% to 70%, and in this experiment, the current value is set as 0, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 A. Finally, the compression force and rebound force of the damper containing MSTF and MRF were compared and analysed.

2. Multifunctional shear thickening fluid preparation

2.1. Material composition

The experimental materials include polydimethylsiloxane (PDMS, Sinopharm Chemical Reagent Co., Ltd., Shanghai, China), carbonyl iron powder (CIP, Jiangsu Tianyi Ultra-fine Metal Powder Co., Ltd., Xuyi, China), dispersing agent absolute ethyl alcohol (analytical reagent, Tianjin BASF Chemical Co., Ltd., Tianjin, China), polyethylene glycol (PEG, analytical reagent, Wuxi Yatai United Chemical Co., Ltd., Wuxi, China) and SiO2 (Shandong Yousu Chemical Technology Co., Ltd., Shandong, China). The performance indexes of the CIP are shown in Table 1.

| Fe content | C content | O content | N content | Average particle size | Apparent density | Tap density |
|------------|-----------|-----------|-----------|-----------------------|------------------|------------|
| 98.030%    | 0.730%    | 0.276%    | 0.964%    | 3.500 μm              | 2.800 g·cm⁻³     | 4.200 g·cm⁻³ |

2.2. Preparation process

The preparation process of MRF and MSTF are demonstrated in Figure 1. The carrier liquid for MRF is the PDMS and absolute ethyl alcohol, and STF is composed of SiO2 particles and PEG. Furthermore, after adding the CIP, these two kinds of materials will become sensitive to the external magnetic field or electrical field.

Figure 1 The materials used in the test, and the preparation process of MRF and MSTF.
It is worth noting that in the preparation procedure, the CIP added in the material is adjustable. Before the magnetic saturation, the higher the mass fraction of CIP is, the more sensitive to a magnetic field the material is, and the more obvious the magnetorheological effect will be.

3. Mechanical properties

To compare the shear thickening effect and magnetorheological performance of each sample, the \( \text{RSTE} \) (relative shear thickening effect), \( \text{ASTE} \) (absolute shear thickening effect), \( \text{RMRE} \) (relative magnetorheological effect) and \( \text{AMRE} \) (absolute magnetorheological effect) were defined to evaluate their performance, as shown in equations (1), (2), (3) and (4):

\[
\text{RSTE} = \frac{G_{\text{max}} - G'_{\text{min}}}{G_{\text{min}}} \times 100\%
\]

\[
\text{ASTE} = G_{\text{max}}' - G'_{\text{min}}
\]

\[
\text{RMRE} = \frac{G_{\text{max}} - G_{\text{min}}}{G_{\text{min}}} \times 100\%
\]

\[
\text{AMRE} = G_{\text{max}} - G_{\text{min}}
\]

where \( G_{\text{max}} \) is the maximum shear storage modulus excited by the loading frequency and \( G'_{\text{min}} \) is the initial shear storage modulus.

Several groups of MRF and MSTF with 10% to 70% mass fraction of CIP were prepared and tested and the results are shown in Figure 2 and Figure 3. In this experiment, the 500 mm/s viscosity of PDMS and PEG400 were used in the preparation procedure, respectively.

The rheological properties of materials prepared in this test were tested by an MCR series rheometer (Anton Paar Co., Austria). The magnetorheological effect of both the MRF and MSTF change slightly when the CIP mass fraction is less than 30%, as illustrated in Figure 2(a) and 2(b). When the CIP mass fraction is more than 40%, the magnetorheological performance increases significantly and apparently, and is closely related to the CIP content added in the preparation process. However, the CIP has no relation with the shear thickening effect of MSTF, as shown in Figure 2(c). For the distinct molecular weight of PEG, as the same mass fraction of CIP, the MSTF with a small molecular weight of PEG is easily to obtain a high magnetorheological performance (Figure 2(d)).
Figure 2 The (a) magnetorheological performance and (b) shear thickening effect of MSTF with 10% to 70% CIP mass fraction, (c) magnetorheological effect of MSTF with different molecular weight of PEG when the CIP mass fraction is 40% and (d) the magnetorheological effect of MRF with 10% to 70% CIP mass fraction.

Figure 3 The materials used in the test, and the preparation process of MRF and MSTF.

4. Application in shock absorber
To compare the compression force and rebound force of the damper containing MRF and MSTF, the same CIP mass fraction of materials were prepared. The tests at different rates were carried out after an equal amount of MRF or MSTF was poured into the shock absorber. Samples with each CIP mass fraction were tested at current of 0, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 A, and the corresponding indicator diagrams were obtained. In this experiment, the velocity of 0.0790 m/s, 0.1570 m/s, 0.3140 m/s and 0.5200 m/s were considered, and part of the indicator diagrams were as shown in Figure 4.
The indicator diagram of (a) MRF, (b) MSTF at the current of 0.5 A, and (c) MRF, (d) MSTF at the current of 3.0 A.

The x-axis in the indicator diagram represents the working stroke (mm), the y-axis shows the compression force and rebound force (N), and the area surrounded by the curve means the energy consumption ability of the damper in this test. Obviously, compared the samples tested at 0.5 A current (Figure 4(a) and 4(b)), the compression force and rebound force increase significantly at the current of 3.0 A (Figure 4(c) and 4(d)). However, due to the density difference between magnetic particles and the liquid carrier, the indicator diagrams show the asymmetry. For example, when the current is set as 0.5 A, the symmetry of the diagram is not bad (Figure 4(b)). With the increasing current value, the symmetry of it is getting worse (Figure 4(c) and 4(d)). The test results and the change rules of all the samples prepared were as shown in Figure 5.

With the increasing CIP mass fraction from 10% to 70%, the increase rate of both the compression force and rebound force gradually decrease, as demonstrated in Figure 5. The increase rate is relatively stable for the compression force, and the increase rate of the rebound force shows a wide range of fluctuation. Besides, there is no obvious difference between the increase rate of force value of MRF and MSTF.

When the CIP mass fraction is less than 30%, the force values of these two kinds of materials fluctuate a little. As the CIP mass fraction is more than 30%, it is clear that, the rebound force of MRF reaches a minimum value, and the rebound force of MSTF reaches a maximum value. That is to say, it is feasible to replace MRF with MSTF in magnetorheological damper, and in some cases, the force values of the damper containing MSTF are higher than that of MRF.
5. Conclusions
A kind of MSTF that exhibits both shear thickening effect and magnetorheological performance was prepared, the RMRE and AMRE were tested and compared with the MRF for the mass fraction of CIP varying from 10% to 70%. The results show that when the CIP content is the same, the RMRE and AMRE of MSTF are higher than that of MRF. Besides, in the preparation process of MSTF, PEG with a smaller molecular weight is easier to obtain a better magnetorheological effect.

In the application field of shock absorber, when the CIP mass fraction is more than 30%, the rebound force of MSTF is higher than that of MRF, obviously. And the increase rate of the compression force and rebound force are almost the same, whereas the increase rate will decrease with the increasing CIP mass fraction significantly.

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References
[1] Brown, E., Forman, N. A., Orellana, C. S., Zhang, H. J., Maynor, B. W., Betts, D. E. et al. (2010) Generality of shear thickening in dense suspensions. Nat. Mater. 9, 220-224.
[2] Liu, M., Jiang, W. Q., Wang, S., Xuan, S. H., Bai, L. F., Sang, M., et al. (2018) Shear thickening fluid with tunable structural colors. Smart Mater. Struct. 27:095012.
[3] Zhang, X. Y., Li, X. H., and Gong, X. L. (2008) The rheology of shear thickening fluid (STF) and the dynamic performance of an STF-filled damper. Smart Mater. Struct. 17:035027.
[4] Gürgen, S., and Kushan, M. C. (2017) The ballistic performance of aramid based fabrics impregnated with multi-phase shear thickening fluid. Polym. Test. 64, 296-306.
[5] Liu, M., Zhang, S. S., Liu, S., Cao, S. S., Wang, S., Bai, L. F., et al. (2019) CNT/STF/Kevlar-based wearable electronic textile with excellent antiimpact and sensing performance. Compos. Part A-Appl. S. 126:105612.
[6] Boland, C. S., Khan, U., Ryan, G., Barwich, S., Charifou, R., Harvey, A., et al. (2016) Sensitive electromechanical sensors using viscoelastic graphene-polymer nanocomposites. Science. 354, 1257-1260.