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THE METHODS FOR MEASURING SHEAR STRESS OF POLAR MOLECULE DOMINATED ER FLUIDS

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A series of ER fluids materials with high shear stress have been developed recently, which named as polar molecule dominated electrorheological (PM-ER) fluids. Difficulties have been met in shear stress measurement process due to the slide of PM-ER fluids on the surface of metallic electrodes. In this paper, two shearing configurations have been developed to remove the interface effect. The intrinsic shear stress of ER fluids can be obtained by using the devices.

1. Introduction

Electrorheological (ER) fluids are a class of materials whose rheological property is controllable by applying an electric field. The mechanical properties of ER fluids may vary within a wide range (almost from a liquid to a solid), so how to measure and character the varieties is a key problem in the experiment. Rheometers with parallel-plate sensor system and inner-outer cylinder sensor system are widely used in the measurement of the rheological properties (viscosity, yield stress, etc.) of ER fluids. For traditional ER fluids whose shear stress is less than 10kPa, the interface state between electrode and ER fluids is similar to that inside of ER fluids according to the image effect of the particles at the boundary of metallic electrodes. Though the chains in such ER fluids are slightly easier to be broken at either end, the resulted difference of the shear stress is quite small. [1] The parameters measured by using ordinary rheometers equipped with the metallic electrodes can reflect the rheological characteristics of ER fluids.

A newly developed class of ER fluids, which we name as polar molecule dominated electrorheological (PM-ER) fluids, [2] exhibits high yield stress. [3-7] The static yield stresses of PM-ER fluids can be as high as hundreds of kPa or even higher, which are several orders higher than that of traditional ER fluids. The dynamic shear stress of the PM-ER fluids is also enhanced tremendously compared with that of ordinary ones. The principle of PM-ER fluids is quite different from the traditional dielectric theory, which we will report elsewhere.[2] The basic principle of PM-ER fluids is that the polar molecules adsorbed on the particles play crucial role and the high yield stress comes from the interaction of polar molecule-charge in between the particles, where the local electric field is much higher than the external one and can cause the polar molecules aligning.

At the interfaces of PM-ER fluids and the electrodes the boundary condition is not same as the inside of the fluid. The image effect of the electrode at the boundary only offers a half real distance of that in between particles, where the polar molecules on the particles can hardly be aligned along the direction of the electric field as in the gap of two particles. This is the reason why the fluid will slide at the surfaces of metallic electrodes, as a result, the measured shear stress must be much lower than the real value.

Several methods are applied to improve the adhesion between PM-ER fluids and metallic electrodes, and excellent results have been gotten in our experiment. The detailed results will be reported in another paper.[8] Although the measured shear stresses of PM-ER fluids by using those modified electrodes can be several times higher than that measured with smooth metallic electrodes, the measured values still do not reflect the intrinsic shear stress of the fluids. It is necessary to find a way to measure the intrinsic rheological property for understanding the PM-ER fluids and for their applications.

In this paper, we will provide two methods for measuring the real yield stress of PM-ER fluids, with which the shortcomings of using the normal rheometer can be overcome in high shear stress measurement and the intrinsic shear stress of PM-ER fluids can be obtained. The solid character of the ER fluids at high electric field strength and the ordinary shear stress measurement applied for solid matter inspired us to use those methods.

2. Experimental

There are two designed shearing modes for measuring the shear stress of PM-ER fluids.

One configuration designed for high shear stress measurement is sketched in Fig.1, which can be defined as unilateral shearing mode. Two metallic electrodes are embedded into two grooves of insulating blocks respectively. The materials of insulating block could be chosen from nylon, teflon, organic glass, etc. ER fluids are filled in the gap between the electrodes. A high DC voltage is applied to the electrodes, then step motor pushes one insulating block forward, meanwhile a force sensor attached to the block can detect the force F acted on the block by ER fluids. The data of F are collected by a computer

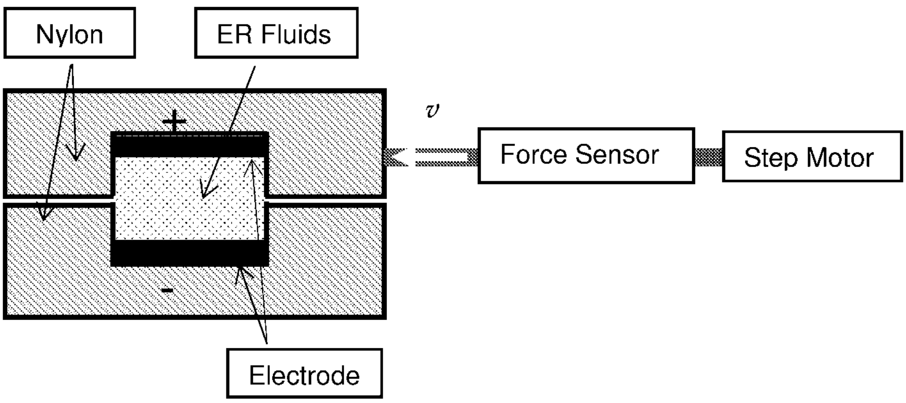

Fig. 1. Sketch of unilateral shear configuration. The upper electrode (+) moves, and the lower electrode (-) is fixed.

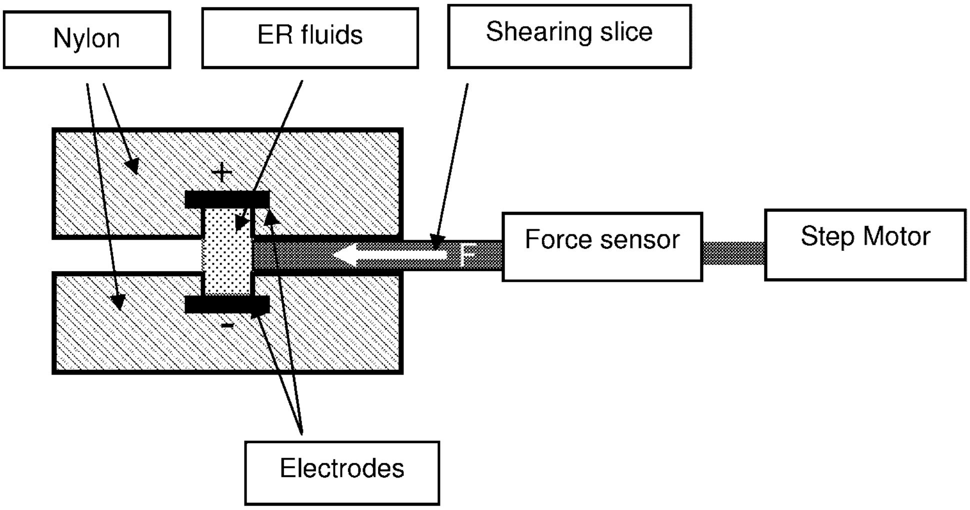

Fig. 2. Sketch of slice shearing configuration. Two insulating blocks with electrodes are fixed, the slice moves to shear the PM-ER fluid.

connected to the force sensor. The shear stress τ of ER fluids can be calculated with $\tau = F/S$, where S is the cross section area of the ER fluids. In our measurement, the gap distance of two electrodes was about 3.3mm and the cross section area $S= h\times l = 7\times2\text{mm}^2$, in which l is the length of the sample in moving direction and h is the thickness of the sample. The minimum moving velocity v of the upper block was 0.01mm/s.

Another configuration is named as slice shearing mode shown in Fig.2. Two metallic electrodes also are embedded in the grooves of insulating blocks just as in Fig.1. The gap between the electrodes is filled with PM-ER fluids, and the electrodes remain fixed. An insulating slice with 1mm thickness and 10mm height inserts the ER fluids under applied electric field. The movement of the insulating slice is pushed by a step motor; meanwhile the ER fluids act a force F to the slice. The calculation of shear stress of the ER fluids can be compared with double shear test in plastic metallic materials, that is $\tau = F/2S$, where S is the cross section area of the ER fluids. In our measurement, the velocity of the insulation slice was 0.01mm/s, the gap width between two electrodes was 4 mm and the cross section area of the slice $S= 1\times10\ \text{mm}^2$.

The dynamic shear stress of ER fluids could be measured conveniently by using the devices described above. The shear rate is controlled by step motor.

2. Results and Discussion

The rheological properties of nano-TiO_2/silicone oil ER fluid have been measured by using the experimental set-ups. The nano-TiO_2/silicone oil ER fluid is consisted of TiO_2 nano-particles, which contain polar molecules, with volume fraction about 35%. By measuring the yield stress with unilateral shearing mode under different electric fields respectively, the dependence of the yield stress on electric field can be obtained as shown in Fig.3. The values of the yield stress were taken from the curves of shear stress and displacement at different electric fields. As an example, the inset in Fig. 3 plots the relation of shear stress and shear displacement under 3 kV/mm, in which the yield stress corresponding to the maximum value is 150kPa at the displacement of 0.2mm. In Fig. 3 the dependence of the yield stress on electric field measured by using an ordinary rheometer consisted of parallel metallic electrodes is also shown for a comparison. It can be seen that the shear stress measured with unilateral shearing method is about five times of that measured with ordinary rheometer. The big reduction of the yield stress measured with ordinary rheometer indicates the slide of the PM-ER fluids arising on the metallic electrodes. Using the unilateral shearing method for the measuring the yield tress of PM-ER fluids gives the ability to avoid such slide efficiently and obtain the intrinsic value of yield stress. The characters of the slide on metallic electrodes and the linear dependence of the measured yield stress on the electric field demonstrate that the PM-ER fluid is different from the traditional ER fluid and has been explained with a new mechanism. [2]

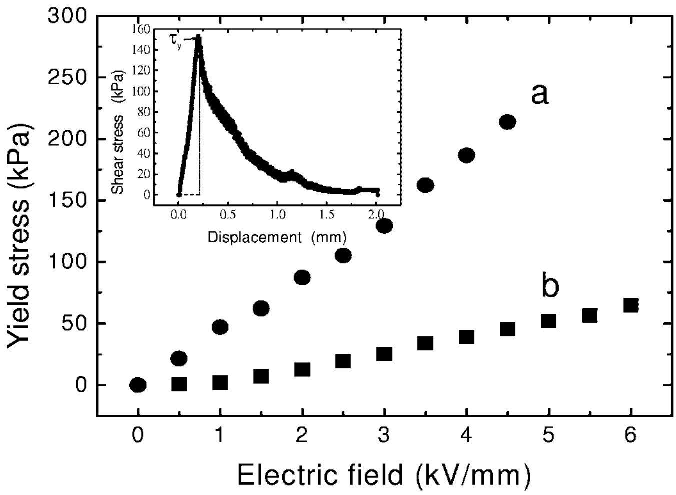

Fig. 3. (a) Yield stress of nano-TiO_2/silicone oil ER fluids vs. electric field measured with unilateral shearing mode. (b) Yield stress of nano-TiO_2/silicone oil ER fluids vs. electric field measured with ordinary parallel metallic electrodes rheometer. The insert is the relation of shear stress and displacement measured using unilateral shear test under 3 kV/mm. The shearing velocity v was 0.01mm/s.

The shear modules can be extracted from the data in inset of Fig.3. The shear modules $\kappa=\tau/\delta$, where τ is the shear stress and δ is the shear strain. The slope from start point to maximum of shear stress expresses the value of shear modules. Approximately, the shear strain δ is the ratio of the displacement and the half gap length between electrodes. It is calculated for the nano-TiO_2/silicone oil ER fluid that the shear modules κ=1.27 MPa at 3 kV/mm.

The same result can be obtained by using slice shearing mode. The variation of the yield stress measured with two methods is about 5%.

When the shearing velocity in the measurement increases the measured shear stress also increases as shown in Fig.4. The shear stress under higher shearing velocity is limited by data collection of our force sensor. However, in principle the dependence of shear stress on shear rate can be measured with those two shearing modes by using a high frequency data collection system.

The results obtained above clearly indicate that the shear stress of PM-ER fluid must be measured with new methods instead of using the ordinary rheometer as in the case of traditional ER fluids. Two devices with unilateral shearing mode and slice shearing mode can meet this requirement. They are able to measure the intrinsic shear stress of PM-ER fluids and avoid the slide of the ER fluids on the electrode. In addition, both configurations are simple and easily operated in experiment.

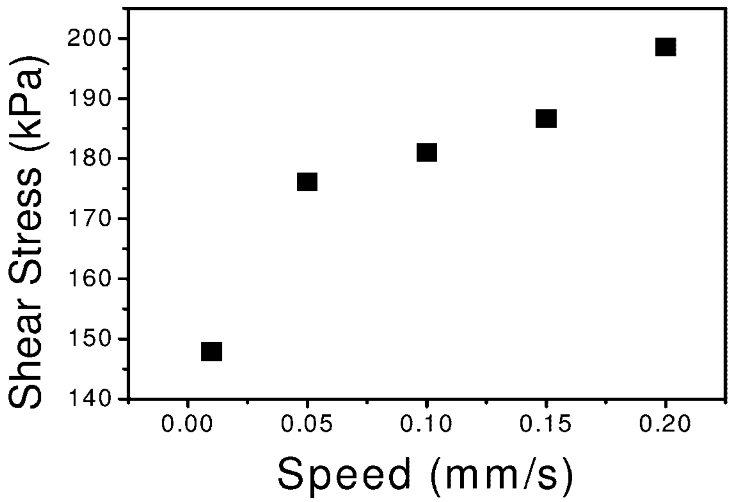

Fig. 4. The shear stress vs. shearing velocity of nano-CTO/silicone oil ER fluid measured by using unilateral shearing mode. CTO is calcium titanate synthesized in our laboratory.

For the applications of PM-ER fluids in practice the modified electrodes have been developed to reduce the influence of the slide on electrodes.[8] By using the modified electrodes the yield stress and the dynamic shear stress approaching the intrinsic ones of PM-ER fluids can be achieved.

3. Conclusion

Two kinds of devices, unilateral shearing mode and slice shearing mode, have been developed for measuring the rheological property of PM-ER fluids. The intrinsic characters of the fluids under electric field applied have been obtained and the interface effect of the electrodes can be removed efficiently.

Acknowledgements

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