International Journal of Modern Physics B
Vol. 21, Nos. 28 & 29 (2007) 4940–4944

World Scientific
www.worldscientific.com

THE MODIFIED ELECTRODES FOR THE APPLICATION OF POLAR MOLECULE DOMINATED ELECTRORHEOLOGICAL (PM-ER) FLUIDS

XUEZHAO WANG, RONG SHEN and GANG SUN

Beijing National Laboratory for Condensed Matter Physics,Institute of Physics, Chinese Academy of Sciences, Beijing, China

WEIJIA WEN

Department of Physics, The Hong Kong University of Science and Technology,Hong Kong, China

KUNQUAN LU

Beijing National Laboratory for Condensed Matter Physics,Institute of Physics, Chinese Academy of Sciences, Beijing, China
lukq@aphy.iphy.ac.cn

Received 31 August 2007

For polar molecule dominated electrorheological (PM-ER) fluids [1], the surfaces of ordinary metallic electrodes cannot satisfy the condition of polar molecules' aligning and interaction. Slide must occur at the interface between PM-ER fluids and electrodes so that the measured shear stress is much lower than the true value. Several modified electrodes are developed and tested for increasing the adhesion of PM-ER fluids to the electrodes and weakening the slide in shearing. The modified electrodes can not only improve the measured shear stress to approach the intrinsic one, but also greatly reduce the current density of PM-ER fluids. Using the modified electrodes is certainly necessary for measuring and applying the PM-ER fluids.

1. Introduction

Electrorheological (ER) fluids are complex suspensions consisting of nanometer or micron sized solid particles mixed with insulating oil, whose shear stress and yield stress can be continuously tunable with an applied external electric field. While the electric field strength is high enough, suspensions can be changed into a solid-like state. The reversible transformation of soft to hard state can occur in about millisecond. Those characters of ER fluids open up the broad prospects for their application in industry and technology. However, the shear stress of the conventional dielectric ER fluids, which are based on the interaction of polarized particles [2-6], is quite low (usually less than 10kPa).[2] The low shear stress of available ER fluids has blocked their application widely.

A new type of ER fluids [7, 8] with high yield stress has been developed in recent years, which are defined as polar molecule dominated electrorheological (PM-ER) fluids. [1] The yield stress of PM-ER fluids can reach hundreds of kPa which is orders higher than that of the conventional ER fluids, that owes to the polar molecules adsorbed on the particles. A model based on the interaction of polar molecule-charge in between the particles is proposed to explain the PM-ER effect.[1] The polar molecules in the gap turn to the field direction due to the high local field and interact with the polarized charges of the neighboring particles. The attractive force of the polar molecule-charge can be orders higher than that of pure polarized particles in conventional ER fluids.

The essential difference between the PM-ER and conventional ER fluids both in principle and characters results in the difference on measuring method.

For conventional ER fluids, the interaction between the electrodes and ER fluids is about the same as inside the ER fluid because of the image effect of the particles at the boundary of metallic electrodes. Therefore the ordinary metallic electrodes can be used for the measurement and application of the conventional ER fluids in principle, although some related experiments about effect of electrode surfaces on this type of ER fluids were studied. [10, 11] For PM-ER fluids, however, because the condition at the surfaces of metallic electrodes is not the same as in the gaps between the particles, where the interaction is weak obviously, the slide of the fluids on the electrodes will occur when the interaction of polar molecule-charge is strong enough in particles' chains. Then the measured yield stress must be much lower than the exact value of PM-ER fluids. This problem will also restrain the application of PM-ER fluids. Although by roughing the surfaces of metallic electrodes the slide can be weaken, the break down is easy to occur on the surfaces at high electric field.

In this paper, several modified electrodes substituting for the ordinary metallic ones will be presented. The modified electrodes can basically avoid the slide by increasing the adhesion of material to electrodes. With the application of the modified electrodes not only the measured shear stress is close to the intrinsic value, but also the current density is reduced essentially for PM-ER fluids. The principle and those modified electrodes can be used in all kinds of devices of PM-ER fluids for their application.

2. Experimental

The calcium titanate (CTO) nanopartical PM-ER Fluid was used in the experiment. Spheral nano-CTO particles of 50 nm in diameter were synthesized by means of co-precipitation method without adding any special additives to the particles.[8] Infrared spectrum demonstrated that there were C=O, O-H polar groups contained in Ca-Ti-O nano-particles. The contents of C=O, O-H polar groups in the particles were regulated in the washing procedure during the material manufacture. The CTO particles were suspended in silicone oil with the volume fraction $\phi \approx 35\%$.

The yield stresses of CTO PM-ER fluid under different electric field were measured with a parallel-plate rotating rheometer at shear rate of $0.2s^{-1}$, which were determined approximately by choosing the maximums on the curves of stress vs. strain. For comparing the surface effect of the electrodes in the yield stress measurement five different kinds of electrodes were used. (A) Smooth metallic electrodes, of which the surfaces were polished carefully. (B) Rough metallic electrodes, of which the surfaces were ground with a sand paper. (C) The surfaces of the metallic electrodes were covered with a layer of double sticking tape 70 μm thick. (D) The surfaces of the metallic electrodes were coated with alumina. By using plasma spraying technique 1 μm sized alumina particles were sprayed on the surfaces of electrodes to form a rough insulating layer 20 μm thick. (E) The surfaces of the metallic electrodes were plated with diamond grains, of which the grain size was 100 μm and the layer thickness was 20 μm.

3. Results and Discussion

Because the surfaces of metallic electrodes can not well satisfy the condition of polar molecules' aligning and interaction in the PM-ER fluids, the slide at the interface between fluids and electrodes must occur inevitably and be a hindrance in the application and measurement for PM-ER fluids. By using the above 5 pairs of electrodes respectively to measure a CTO PM-ER fluid, we found that the surface effect of electrodes on the measurement of the yield stress is obvious as shown in the Fig. 1. In order to obtain the exact yield stress of PM-ER fluids an apparatus has been developed, which can measure the intrinsic rheological property and avoid the influence of the electrodes. [9] The measured data with this method are also shown in Fig. 1 for a comparison. Under the same electric field strength 5000V/mm, the measured yield stress with smooth metallic electrodes (data A) is less than 30kPa, which is only 1/6 of real value of yield stress (data F). By using rough metallic electrodes the measured yield stress is 60 kPa (data B) which is double of that measured with smooth metallic electrodes. With other surface modified electrodes the measured yield stresses can be much improved. Especially, by using the electrodes coated with diamond and alumina grains the measured yield stresses is about 120 kPa (data D and E), which are about 4 times of that measured with smooth metallic electrodes and can reach 2/3 of the real one at 5000V/mm. At the rough surfaces consisted

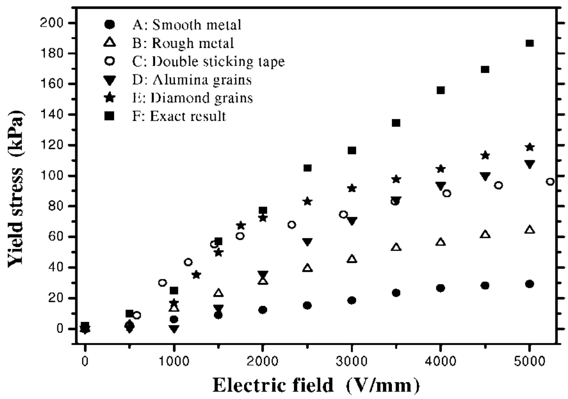

Fig. 1. The variation of yield stress vs. electric field measured with different electrodes.

of diamond and alumina grains the nano-CTO particles can fill into the clearances between the grains. The salients of the grains resist the fluid flowing to create a shear stress, which is much higher than that caused by a flat surface and can be estimated to be about 2/3 of the real shear stress. It can be seen that the values of the measured yield stress in data A-E of Fig. 1 deviate from the exact one (data F) more seriously at high electric field. This phenomenon may come from the mechanic property of the ER fluid at different electric field. The ER fluid is sticky at low electric field and is solid at high electric field. The slide of the solid ER fluid on the electrodes can easier occur. In the dynamic shear stress measurement by using the modified electrodes coated with diamond grains, the dynamic shear stress at shear rate of 250 s^{-1} can reach about 70 kPa as the electric field is 3 kV/mm. A detailed description will appear elsewhere. [1] However the dynamic shear stress is unable to be measured successfully when the electrodes are made of smooth metal due to the slide of the ER fluid on the electrodes.

Besides avoiding slide, the modified electrodes can also reduce the electric current through the sample greatly as shown in Fig. 2. The current density of our prepared ER fluid is very low, less than 1μA/cm^2. The current density with rough metallic electrodes is the largest one. It is easy to cause breaking down by using rough metallic electrodes, although applying a file-like metallic electrode can also greatly increase measured yield stress. The current densities are reduced greatly, even less than 0.2μA/cm^2, in using the modified electrodes with coating alumina or diamond grains because of their insulating property.

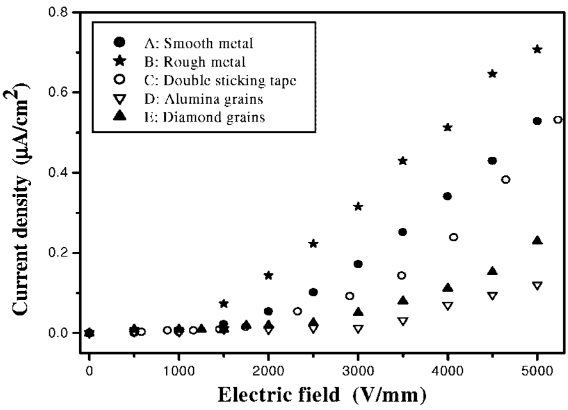

Fig. 2. The variation of current density vs. electric field measured with different electrodes.

According to the above results, electrodes play an important role in the measurement of PM-ER fluids and their application as well. Actually the ordinary metallic electrodes are unsuited to be used in the measurement and application of PM-ER fluids. In principle, if there are the particles with polar molecules contained on the electrodes, the boundary condition at the surface of electrodes can be satisfied for the PM-ER effect. Therefore the most convenient way is to glue those particles on the electrodes. Using the double sticking tapes is an example. However those electrodes can only be used for few times because of their less firmness. Although double sticking tape is not strong enough to be used in applied devices for a long time, it's convenient to be used for testing the material. Diamond and alumina are both durable, insulated and stable in the range of working temperature -50~200 ℃ , which are suitable for modifying the electrodes in the measurement and application of PM-ER fluids.

4. Conclusion

PM-ER fluids based on the interaction of polar molecule-charge in between the particles are newly developed.[1] The slide of the fluids inevitably exists at the surfaces of metallic electrodes because the interfaces cannot satisfy the boundary condition of polar molecules' aligning and interaction. Comparing the influence of different electrodes on the ER effect and electric current density of PM-ER fluids, we find that the electrodes are one of the critical factors in their measurement. The modified electrodes coated with diamond and alumina grains not only avoid the slide effectively to improve the measured stress, but also reduce the current density greatly, which are favorable for measuring and applying the PM-ER fluids.

Acknowledgment

The authors would thank Prof. S.Z.Yang and B.R.Zhao for technical help in the modification of electrodes. This work was supported by the National Natural Science

Foundation of China (Grant No.10674156), the National Basic Research Program of China (No 2004CB619005), the Knowledge Innovation Project and Outstanding Overseas Chinese Scholars Fund of Chinese Academy of Sciences and NSFC.

References

1. K. Q. Lu, R. Shen, X. Z. Wang, G. Sun, W. J. Wen and J. X. Liu, *in this proceedings.*
2. H. R. Ma, W. J. Wen, W. Y. Tam and P. Shen, *Phys. Rev. Lett.* **77**, 2499 (1996).
3. T. C. Halsey, Electrorheological fluids, *Science* **258**, 761 (1992).
4. R. Tao and J. M. Sun, *Phys. Rev. Lett.* **67**, 398 (1991).
5. Y. Chen, A.F. Sprecher, H. Conrad, Electrostatic particle-particle interactions in electrorheological fluids, *J. Appl. Phys.* **70**, 6796 (1991).
6. L. C. Davis, *J. Appl. Phys.* **81**, 1985 (1997).
7. R. Shen, X. Z. Wang, W. J. Wen, K. Q. Lu, *International J. Modern Phys.* ***B*** **19**, 1104 (2005) .
8. X. Z. Wang, R. Shen, W. J. Wen, K. Q. Lu, *International J. Modern Phys.* ***B*** **19**, 1110 (2005).
9. R. Shen et al, *in this proceedings.*
10. C. Y. Lee, K. L. Jwo, *Material & Design* **22**, 277 (2001).
11. R. Hanaoka, M. Murakumo, H. Anzai, K. Sakurai, *Transactions on Dielectrics and Electrical Insulation* **9**, 10 (2002).