International Journal of Modern Physics B
Vol. 19, Nos. 7, 8 & 9 (2005) 1110–1113

World Scientific
www.worldscientific.com

HIGH PERFORMANCE CALCIUM TITANATE NANOPARTICLE ER FLUIDS

XUEZHAO WANG[1] RONG SHEN[1] WEIJIA WEN[1,2] KUNQUAN LU[1]

1. *Institute of Physics, Chinese Academy of Sciences, Beijing, China*
2. *Department of Physics, The Hong Kong University of Science and Technology, Hong Kong, China*

E-mail: lukq@aphy.iphy.ac.cn

A type of calcium titanate (CTO) nanoparticles was synthesized by means of wet chemical method [1] without coating on the particles. The CTO/silicone oil ER fluid exhibits excellent electrorheological properties: high shear stress (~50-100 kPa) under dc electric field, a low current density (less than 2μA/cm2 at 5kV/mm), and long term stability against sedimentation. Although there are not special additives in the ER fluids, it is found from the chemical analysis that a trace of alkyl group, hydroxyl group, carbonyl group and some ions is remained in the particles which may dominate the ER response.

1 Introduction

Electrorheological fluids (ERF) consisting of nanometer or micron sized solid particles suspended in insulating oil can be transformed from liquid-like state to solid-like state under an applied external electric field. The reversible transformation from soft to hard state with the time of milliseconds opens up the broad applied prospects for ER fluids, so the investigation has attracted much attention [2-6]. In fact, few ER fluids can satisfy the requirement of different applications because of some deficiencies [7,8] in their properties, such as low shear stress, high current density, or settling, absorbed water.

In this paper, we present a new kind of CTO/silicone oil ER fluid with the attractive properties: high shear stress, low current density, anti-settling, no pollution and corrosion.

2 Experimental

Nanometer-sized CTO particles were synthesized by means of co-precipitation method without adding any special additives on/in the particles [1]. Calcium chloride, orthotitanate, absolute ethyl alcohol, de-ionized water were made into an initial solution, into which oxalic acid were added as a precipitator. With the adding of oxalic acid, white precipitate was formed. After 8 hours aging at room temperature, the precipitate was filtrated, washed and dried in atmosphere to remove the absorbed water. Energy Dispersive Spectroanalysis (EDS) and FT-IR spectroscopy helped to confirm the components of the particles to be nearly Ca_2TiO_3. Also there were traces of alkyl group, hydroxyl group, carbonyl group and some ions remained in the particles coming from reactants and solvents. The dry CTO particles were suspended in silicone oil with the volume fraction $\phi \approx 35\%$ and 10% respectively. The static rheological properties in some low shear rate were measured with a rheometer established by ourselves as described elsewhere [9]. The dynamic rheological properties were measured with HAAKE cv 20 type rheometer in the shear rate range of 0~300 s^{-1}. The samples were preserved for a long time to observe the particle sedimentation in the suspensions.

3 Results and Discussion

A lot of different CTO particles have been prepared by using different processes. Most of CTO/silicone oil ER fluids possess the similar ER behavior. Here, we will only show the typical results. Due to the limitation of our experimental device, all of the following data were collected at the room temperature. CTO/silicone oil suspension exhibits a high performance of ER effect . The static yield stress for a $\phi \approx 35\%$ sample reaches 75 kPa at a DC electric field of 5 kV/mm (shown in Fig.1), which exceeds the theoretical upper bound [9] and far surpass most reported ER fluids [5]. The yield stress displays near-linear dependence on the field strength. It is noticeable that for the linear dependence the slope $\Delta\tau_y/\Delta E \approx 15$ kPa/(kV/mm) and the linearity starts at a critical field $E_c \approx 0.5$ kV/mm. A very low current density of this ER fluid is another remarkable advantage as seen in Fig.2. Even under field strength of 5 kV/mm the current density is less than 2μA/cm^2. Moreover, we found that the static yield stress became higher and the current density became lower after a half year preservation. All those characters of our CTO ER fluids are most favorable for the application.

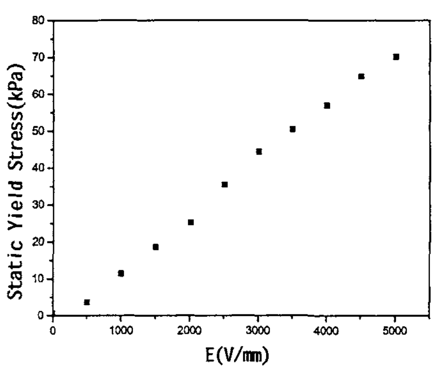

Fig.1 The variation of static yield stress vs. electric field

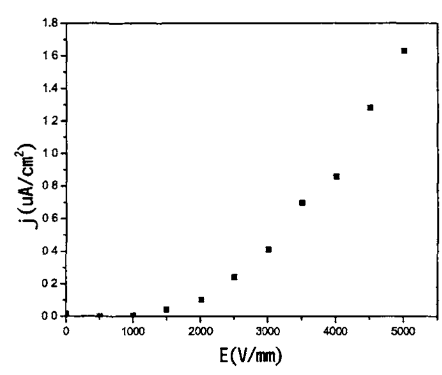

Fig.2 The variation of current density vs. electric field

We also measured the shear stress in shear rate range of 0~300 s^{-1} with HAAKE cv20 type rheometer. Since the maximum measurable shear stress by the HAAKE cv 20 type rheometer was limited to τ_{max}= 5.0 kPa, we diluted the sample to $\phi \approx 10\%$ for collecting sufficient data. It can be seen from Fig.3 that shear stress increases gradually with shear rate. The shear stress is larger than 2.7 kPa at 3.2kV/mm and is low at zero electric field. The current was too low to be detected in the measurements.

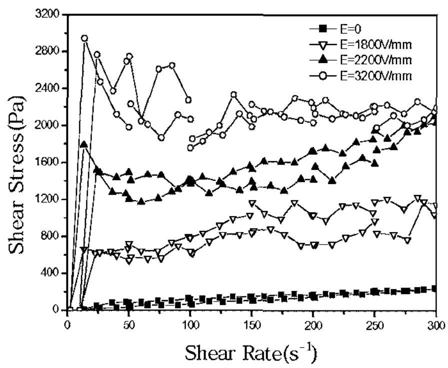

Fig. 3 Curves of shear stress vs. shear rate under different electric field. The twin curves at each electric field indicate both field increasing and decreasing.

In addition, the CTO/oil ER fluids are very stable and long-term against sedimentation. We cannot observe obvious sedimentation occurred in half a year.

According to the conventional dielectric theory the yield stress is limited to be about 10 kPa at 5kV/mm [9] and is quadric dependence on the electric field [10]. In the GER model [6] the high yield stress and its linear dependence were attributed to the polarization saturation layers in the contacting region between neighboring coated particles. However, in our case without any coating layers on CTO particles, the ER response is still very large and shows a linear dependence on field strength. This phenomenon must be caused by the trace dipole molecules remained in the particles. A brief discussion on the mechanism of this effect is presented in another paper [11]. A further theoretical work is needed to give a deeper understanding on the mechanism.

4 Conclusions

By means of simple and convenient wet chemical method we have developed a new type of high performance CTO based ER fluids. The excellent ER properties are attractive for the applications. The further studies on the characterisation of the ER fluids and the mechanism are needed.

5 Acknowledgement

This work is supported by The Outstanding Overseas Chinese Scholars Fund of Chinese Academy of Sciences. The authors would thank Prof. S. H. Zhang for help in the measurement of shear stress and Prof. G. Sun for fruitful discussion.

References

1. X. Z. Wang and R. Shen and K. Lu *Chinese Patent*
2. W. M. Winslow, Induced fibration of suspensions, *J. Appl. Phys.* **20** (1949) pp. 1137-1140
3. M. Whittle and W. A. Bullough, The structure of smart fluids: News & Views, *Nature*(London) **358** (1992) pp. 373-373
4. W. Wen and K. Lu, Experimental investigation of dipole-dipole interaction in a water-free glass particle/oil electrorheological fluid, *Appl. Phys. Letter.* **68** (1996) pp. 3659-3661
5. Y. Zhang, Y. Ma, K, Lu and W. Liu, The electrorheological behavior of complex strontium titanate suspensions, *Appl. Phys. Letter.* **73** (1998) pp. 1326-1328
6. W. J. Wen, X. X. Huang, S. H. Yang, K. Q. Lu and P. Shen, The giant electrorheological effect in suspensions of nanoparticles, *Nature. Mater.* **2** (2003) pp. 727-730
7. T. Y. Chen and P. F. Luckham, A study of the electrical current passing through water-activated electro-rheological fluids, *J. Phys. D.* **27** (1994) pp. 1556-1563
8. H. Block and J. P. Kelly, Electro-rheology, *J. Phys. D,* **21** (1988) pp. 1661-1677
9. H. R. Ma, W. J. Wen, W.Y. Tam and P. Sheng, Frequency dependent electrorheological properties: Origin and Bounds, *Phys. Rev. Lett,* **77** (1996) pp. 2499-2502
10. T. C. Halsey, Electrorheological fluids, *Science* **258** (1992) pp. 761-766
11. Kunquan Lu, Rong Shen, Xuezhao Wang, Gong Sun, Weijia Wen *in this proceedings.*