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Correlation between Conductivity and Electrorheology of Polyacene Quinone Radical Polymer Dispersion

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Through the research of the conductivity and electrorheological (ER) properties of semiconducting polyacene quinone radical (PAQR) polymer dispersion in silicon oil, it is found that current-voltage curve and torque(shear stress)-voltage (electric field) curve both confirm to power law under scale assumption. The power index depends little on temperature and it increases as the shear rate decreases. It is no doubt that the correlation is very important to deepen the understanding of ER properties and the role of conductivity of this kind of materials.

KEYWORDS: PAQR, conductivity, electrorheology, polymer dispersion, conducting polymer, polyacene quinone radical

ポリアセンキノイドラジカルを分散した液体の導電率と電気粘性の相関

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1. Introduction

There are great concerns in electrorheology [1]-[4], especially in intrinsic(dry) ER fluids [4]-[7], because it involves interdisciplinary and has wide application prospect. Usually it appears to be linear dependent of shear stress on the square of electric field derived from the interaction force between the polarized particles. Instead, experiment results show a power law with a power index between 2-2.4 [3]

At present, many reporters only discuss the influence of the two phase mismatch and the dielectric spectrum on ER properties. Though they stressed the important effect of conductive particles and discussed the non-ohmic dependence of conductivity with power index of 2-2.5 based on double layer polarization theory, the correlation between current-voltage property and shear stress-voltage relationship of ER fluids seems to have been neglected.

In this paper, we will report the current-voltage and torque-voltage power function relationship of polyacene quinone radical (PAQR) dispersion in silicon oil, discuss the influence of temperature and shear rate on power index and consider the correlation of the changing trend.

2. Experimental

The preparation and dielectric properties of eka-conjugated PAQR polymer refer to reference 8. ER fluid is prepared from PAQR polymer powder dispersed in silicon oil with volume fraction of 20%. With two stainless steel distance-adjustable electrodes of 60㎜ diameter, the rheological and electrical measurements under DC high voltage can be carried out simultaneously by a self-designed rheological device. In our case, the electrode distance is 0.2㎜ and torque is calculated through force measurement.

3. Results and Discussion

Figure 1 shows the current-voltage characteristic at various sheer rates at electrode edge (e.g. the maximum value) under two temperatures. Figure 2 shows the same characteristic under various temperatures at two shear rates. They all exhibit power function forms. The power index A (value between3-4) depends little on temperature and decreases greatly as the shear rate increases.

At our present level of understanding of the ER phenomenon, the conductivity of such fluids under low and dielectric fields is of great significance. However, we don't quantitatively or even

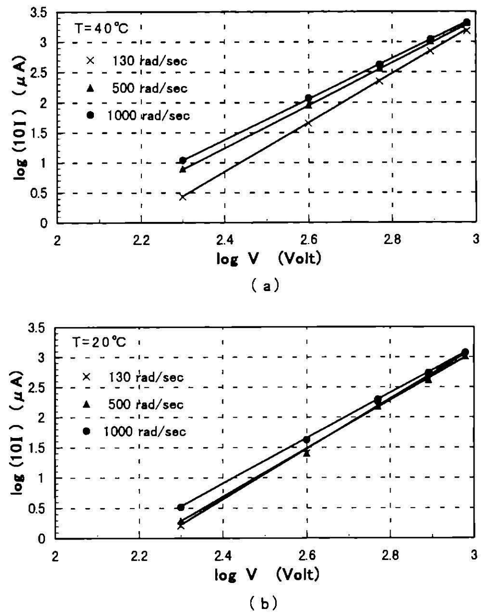

Figure 1: Dependence of current I on DC voltage V at various shear rates at 40℃(a) and 20℃(b).

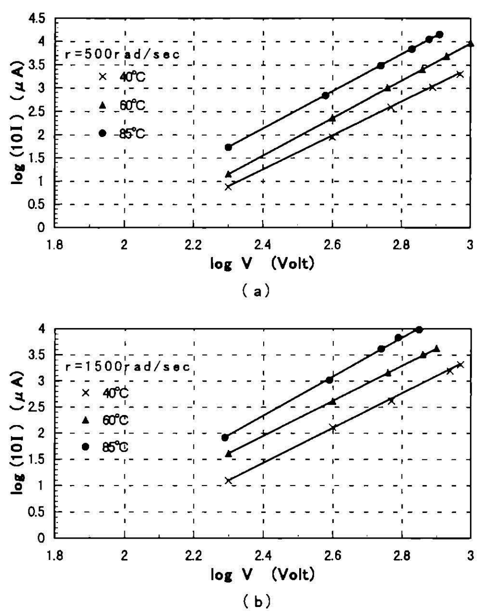

Figure 2: Dependence of current I and DC voltage V at various temperatures at under shear rates of 500rad/sec(a) and 1500rad/sec(b).

qualitatively understand the origin of the current involved. Our results perhaps are related to the following elements:(a) In case of 0.2 volume fraction of PAQR phases, particles can basically contact with each other, the electric field is locally enhanced, both leading to the easy tunneling of charge carriers through the solid-liquid interface. (b)Percolating or non-percolating clusters (longer chains linking two electrodes, or short ones) formed

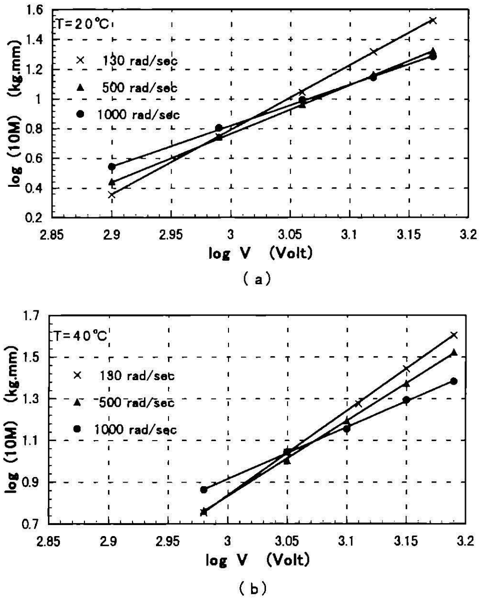

Figure 3: Dependence of torque M on DC voltage V under various shear rates at 20℃ (a) and 40℃(b).

by interface polarization can provide pathways for conductance. (c) Dielectric breakdown and local electric discharge may also contribute to such a big current. (d) The flow field can destroy the special cluster structure, then the value of A decreases. (e) The bound carriers in the double layer emit fastly, thus leading to the apparent increase of B (the interception of the curve). This seems similar to that of normal electric conductivity. B depends on carriers concentration and A depends on activation energy or molecule structure. Even if the electric field is 3 kV / cm , current density or power consumption still meet the application demand. In any case, it is needed to study deeply on such a big value of A.

Figure 3 shows the torque-voltage characteristic at various shear-rates at two temperatures. They are also power functions. Power index A' is nearly independent of temperature. Its value(2.5-4) approximately corresponds to that of the current-voltage curve and decreases apparently as shear rate increases. This is similar to the results of Klass and Martinek [2], though our result is much larger.

Except for the above reason for explaining the

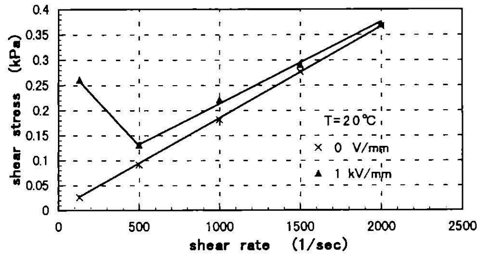

Figure 4: Dependence of shear stress on shear rates under no applied field and 1 kV/mm.

current-voltage characteristic, it is also probably due to the following reasons: the interface polarization which is greatly enhanced because of the remarkable mismatch of the conductivity and dielectric constant between the solid and liquid phases leads to the easy formation of percolating clusters linking the two electrode [9]. Most particles arrange in the direction of electric field and form clusters, some form side-chains and lead to a 3-D network structure similar to the conductivity of random resistance network [10]. This probably relates to the complex changes of dielectric properties of the fluids due to the stress and strain. Moreover, temperature has little influence on A', indicating the large interaction force between the particles, and thermal motion has little effect on structure damage.

The shear-stress rate curve of ER fluids are shown in Figure4. This confirms to the results anticipated by Block [4]. Compare to our static value which is 6 times that of the motion state, the results of the yield stress of Block is only 1 times higher. This indicates that our sample has a more close structure at stàtic state thereby shows remarkable shear-thinning phenomenon, and the minimum shear rate of the beginning of Newtonian flow moves to higher side.

4. Conclusion

Due to the easy motion of carriers in PAQR dispersed phase, interface polarization is reinforced and Debye shield-distance is decreased whereby the dispersed phase has a more close structure of percolating clusters at static state. This brings about the similar change trend in current-voltage and torque-voltage relationship (that is correlation). Here more emphasizes should be laid on the importance of conductivity to some extent to ensure the ER response. Only trial explanation has been given to the increase of power index and its change trend. To clarify detailed mechanism more quantitative research is necessary in the future.

References

[1] W.M.Winslow: J.Appl.Phys.20(1949) 1137

[2] D.L.Klass and T.W.Martinek: J.Appl.Phys.38(1967) I.67, II.75

[3] T.C.Jordan and M.T.Shaw: IEEE Trans. Electr. Insul. 24 (19879) 849

[4] H.Block and J.P.Kelly; J. Phys. D:Appl.Phys.21(1988)1661

[5] H.Block and J.P.Kelly; "Electrorheological Fluids". U. S. Pat. (1987) No.4, 687,589

[6] F.E.Filisko and W.E.Armstrong:"Electric Field Dependent Fluids". U.S. Pat.(1988) No.4, 744,914

[7] A.Inoue:Proc.2nd.Conf.E.R.Fluids, Raleigh NC, Aug. (1989) 7-9. Technomic pub.Co.

[8] S.F.San, Y.Fan et al; Solid State Comm. 91(1994) 507

[9] D.J.Klinenberg, F.Van Swol and C.F.Zukoski: J. Chem. Phys. 91 (1989) 7888

[10] R.Zallen; The Physics of Amorphous Solids (Wiley, New York, 1983)

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