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LETTER

Comment on "Synthesis and electrorheological effect of PAn–BaTiO$_3$ nanocomposite"

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Recently, Wei et al. [1] synthesized polyaniline–barium titanate (PAn–BaTiO$_3$) nanocomposites by inorganic–organic in-situ complex technique and reported that the PAn–BaTiO$_3$ nanocomposites based electrorheological (ER) fluid showed very high shear stress (2800 Pa) at 3.5 Kv/mm DC field compared with both the pristine PAn, and pure barium titanate. They attributed this superior ER performance to the interaction of PAn and BaTiO$_3$. In this comment, we reanalyzed their ER data of shear stress which corresponds to dynamic yield stress as a function of applied electric field strengths via both the polarization and conductivity models. It is found that our universal yield stress equation collapses their data onto a single curve.

Based on the polarization and the nonlinear conductivity models for ER fluids, good agreement exists between predicted and measured ER behavior for various ER systems. The correlation between yield stress (τ_y) and electric field strength (E) is presented in a power law form as follows [2–4],

$$\tau_y \propto E_0^m \tag{1}$$

The polarization model showing the dependency of the yield stress on the electric field strength with E^2, in general, relates the material parameters of ER fluids, such as dielectric response on both liquid and solid particles and the electric field strength, to the rheological properties [5]. Under this condition, the applied electric field includes electrostatic polarization interactions among the particles and also between the particles and the electrodes. This polarization model shows an excellent agreement with the data for small volume fraction and applied electric field. However, when the ER response is influenced by the conductivity mismatch and the interaction between particles and medium, the nonlinear conductivity effect plays dominant role in bulk conducting particle model and the power law index for yield-stress approaches to $m = 3/2$ at high E, implying that the electric response of the fluid becomes nonlinear, *e.g.*, electrical breakdown or particle discharge at the high electric field strength occurs, as the gap between the conducting particles in the fluid decreases. Here, the ER effect is caused by the fluid media induced conductivity enhancement among nearly touching particles. The conductivity mismatch rather than the dielectric constant mismatch between particles and liquid media was considered to be a main factor for the dc and low frequency ac excitation [6].

Recently, the critical electric field strength, E_c, was introduced via the universal scaling function to interpret not only the deviation of the yield stress from the polarization model performance [7] but also the conductivity model at the same time. The proposed yield stress equation for a broad electric field strength range is

$$\tau_y(E_o) = \alpha E_o^2 \left(\frac{\tanh \sqrt{E_o/E_c}}{\sqrt{E_o/E_c}} \right). \tag{2}$$

Here, the parameter α depends on the dielectric property of the fluid, the particle volume fraction, the critical electric field, E_c originated from nonlinear conductivity effect can be obtained by the crossover point of the slopes for all ranges of the electric field strengths [7]. Equation (2) has the following two asymptotic characteristics at both low and high electric field strengths:

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$$\tau_y = \alpha E_o 2 \quad \text{for} \quad E_o \ll E_c. \tag{3}$$

On the other hand,

$$\tau_y = \alpha \sqrt{E_c} E_o^{3/2} \quad \text{for} \quad E_o \gg E_c. \tag{4}$$

We then normalized Eq. (2) using E_c and $\tau_y(E_c) = 0.762\alpha E_c^2$ to collapse all the data onto a single curve.

$$\hat{\tau} = 1.313\hat{E}^{3/2}\tanh\sqrt{\hat{E}}. \tag{5}$$

Here, $\hat{E} \equiv E_o/E_c$ and $\hat{\tau} \equiv \tau_y(E_o)/\tau_y(E_c)$ Various ER fluids [8–12] were found to fit for this universal yield equation quite well. The E_c which gives the criteria for selecting low and high electric field strengths in the normalized scaling function is not a universal quantity and depends on the system properties.

We reanalyzed the original Fig. 3 given in Ref. [1] by replotting it in a log–log scale (The replotted Figure is not shown here), and then found the E_c of three different samples which resulted from the crossover of two slopes, corresponding to the polarization model (slope = 2) and conductivity model (slope = 1.5), respectively. The composite particles showed a strong polarization strength and more polarization charges in the surface of the particles when an external electric filed is applied, in which way improved the ER effect [1]. The E_c becomes smaller for system with a higher yield stress. The estimated $E_c s$ are 3.4 kV/mm for $BaTiO_3$ nanocomposite, 3.25 kV/mm for pristine PAn, and 3.10 kV/mm for pure $BaTiO_3$, separately.

Figure 1 represents the universal curve for $\hat{\tau}$ *vs.* $\hat{E}$ for PAn–$BaTiO_3$ nanocomposite, pristine PAn, and pure $BaTiO_3$ based ER fluids. We were satisfied to find that the data derivated from the Fig. 3 of Ref. [1] fitted our universal yield stress equation (Eq. (5)) onto to a single curve very well.

In conclusion, we successfully replotted and reanalyzed the universal scaling yield behavior for the original data of shear stress which corresponds to dynamic yield stress in this comment as a function of applied electric field strengths obtained from Ref. [1] by using our universal equation. It is found that our universal yield stress equation collapses their data onto a single curve.

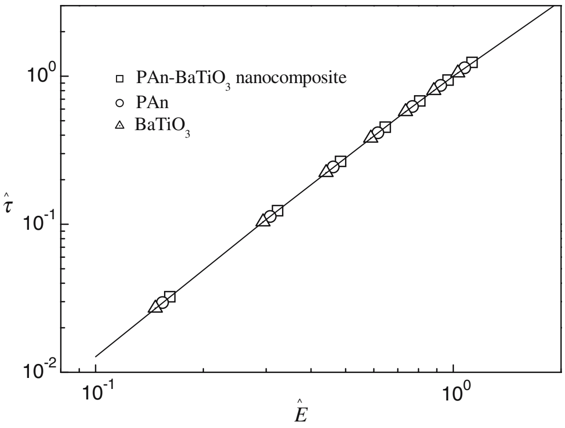

Fig. 1 The universal curve for $\hat{\tau}$ *vs.* $\hat{E}$ for PAn–$BaTiO_3$ nanocomposite, pristine PAn, and pure $BaTiO_3$ based on ER fluids

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