Analysis of the Yielding Behavior of Electrorheological Suspensions by Controlled Shear Stress Experiments

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Abstract:
The yielding behavior of two model electrorheological suspensions of uncoated silica particles and silica coated with polyaniline base in silicone oil using controlled shear rate and controlled shear stress experiments has been analyzed. The results demonstrate that unlike the uncertain dynamic yield stress values estimated from the results obtained in the former mode by extrapolation of the unsteady shear stresses to zero shear rate, the controlled shear stress measurement permits to detect sensitively the region starting from the initial rupture of particle chain structure in the electric field at rest corresponding to a static yield stress τ_y and ending in total breakage of suspension structure at a breaking stress τ_b.. The latter quantity can be detected with a good accuracy and proved to be a reliable criterion of the stiffness of ER structure.

Zusammenfassung:
Das Fliessverhalten von zwei elektrorheologischen Modellsuspensionen aus unbeschichteten und mit Polyanilin-Base beschichteten Silikapartikeln in Silikonöl wurde in schergeschwindigkeitskontrollierten und scherspannungskontrollierten Experimenten analysiert. Die Ergebnisse zeigen, dass im Gegensatz zu den unsicheren Werten der dynamischen Fliesspannung, die von Resultaten abgeschätzt wurde, die durch Extrapolation der nichtstationären Scherspannung auf eine Schergeschwindigkeit von Null erhalten wurde, die kontrollierte Scherspannungsmessung erlaubt, den Bereich, der mit dem anfänglichen Bruch der Teilchenkettenstruktur im elektrischen Feld bei Ruhe beginnt (entsprechend einer statischen Fliesspannung τ_y) und mit dem vollständigen Aufbrechen der Suspensionsstruktur bei der Bruchspannung τ_b endet, zu detektieren. Die letztere Grösse kann mit hoher Genauigkeit bestimmt werden und bewährte sich als zuverlässiges Kriterium der Steifigkeit der elektrorheologischen Struktur.

Résumé:
Le comportement seuil de deux suspensions électro-rhéologiques modèles de particules de silice non recouvertes et de silice recouverte avec une base de polyaniline dans de l'huile de silicone, a été analysé à l'aide d'expériences en contrôle de vitesse de cisaillement et en contrôle de contrainte. Les résultats démontrent que, contrairement aux valeurs incertaines de contrainte dynamique seuil estimées à partir des résultats obtenus par le premier mode par extrapolation des contraintes de cisaillement non permanentes à vitesse de cisaillement zéro, la mesure en contrôle de contrainte de cisaillement permet de détecter sensiblement la région qui part de la rupture initiale de la structure à l'équilibre de chaîne de particules dans le champ électrique qui correspond à la contrainte seuil statique τ_y, et qui finit par la rupture totale de la structure de la suspension à la contrainte de rupture τ_b. Cette dernière quantité peut être détectée avec une bonne précision, et s'avère être un critère de rigidité fiable des structures ER.

Key words: electrorheology, yield stress, suspensions, polyaniline, silica

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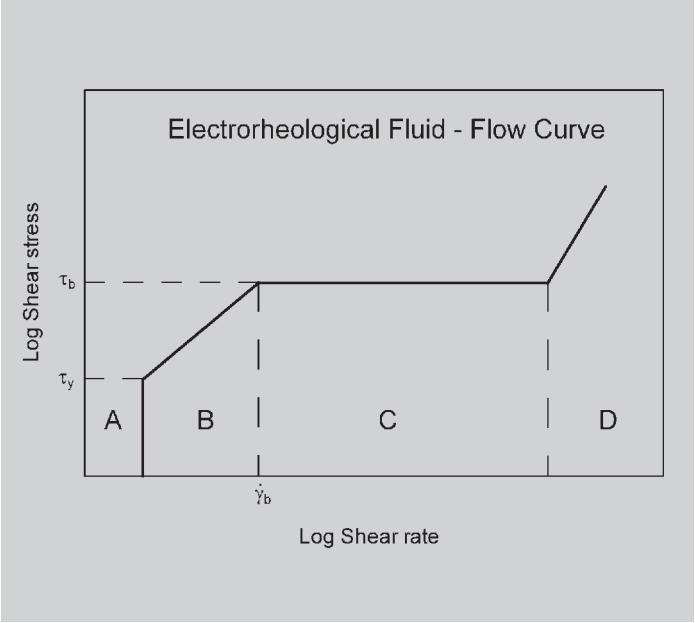

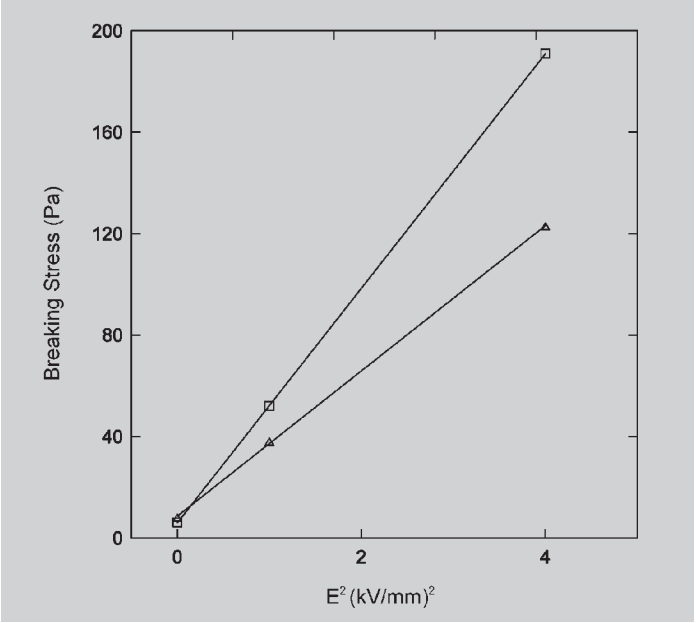

in this mode just before a steep increase in shear rate (flow curve discontinuity) proved to be very good. The linear plots of τ_b vs. E^2 for both suspensions of uncoated and coated sample (Fig. 5) confirms breaking stress as a criterion behaving in fully agreement with polarization theory [29].

4 CONCLUSION

The results demonstrate that in contrast to CSR experiments often used in ER studies, CSS mode provides more reliable way of evaluation of yielding properties of ER suspensions. Thus, the best and most accurate criterion of the original stiffness of suspension particle arrangement in the electric field proved to be the breaking stress at which the quasi-stiff structure is just completely destroyed by shear forces and the flow starts.

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REFERENCES

[1] Winslow WM: Induced fibration of suspensions, J. Appl. Phys. 20 (1949) 1137-1143.
[2] Block HJ, Kelly P: Electro-rheology, J. Phys. D: Appl. Phys. 21 (1988) 1661-1667.
[3] Jordan TC, Shaw MT: Electrorheology, IEEE Trans. Electric Insul. 24 (1989) 849-878.
[4] Parthasarathy M, Klingenberg DJ: Electrorheology: mechanisms and models, Mat. Sci. Eng. R 17 (1996) 57-103.
[5] Hao T: Electrorheological fluids, Adv. Mater. 13 (2001) 1847-1857.
[6] Hao T: Electrorheological suspensions, Adv. Colloid Interface Sci. 97 (2002) 1-35.
[7] Bonnecaze RT, Bray JF: Yield stress in electrorheological fluids, J. Rheol. 36 (1992) 73-115.
[8] Choi HJ, Kim JW, To K: Electrorheological characteristics of semiconducting poly(aniline-co-o-ethoxyaniline) suspension, Polymer 40 (1999) 2163-2166.
[9] Lu J, Zhao X: Electrorheological properties of a polyaniline-montmorillonite clay nanocomposite suspension, J. Mater. Chem. 12 (2002) 2603-2605.
[10] Lim YT, Park JH, Park OO: Improved electrorheological effect in polyaniline nanocomposite suspensions, J. Coll. Interface Sci. 245 (2002)198-203.
[11] Choi HJ, Cho MS, To K: Electrorheological and dielectric characteristics of semiconductive polyaniline-silicone oil suspensions, Physica A 254 (1998) 272-279.
[12] Choi HJ, Lee JH, Cho MS, Jhon MS: Electrorheological characterization of semiconducting polyaniline suspension, Polym. Eng. Sci. 39 (1999) 493-499.
[13] Choi HJ, Kim JW, Yonn SH, Fujiura R, Komatsu M, Jhon MS: Synthesis and electrorheological characterization of carbonaceous particle suspensions, J. Mat. Sci. Lett. 18 (1999) 1445-1447.
[14] Cho MS, Choi HJ, Chin IJ, Ahn WS: Electrorheological characterization of zeolite suspensions, Microporous Mesoporous Mater. 32 (1999) 233-239.
[15] Cho MS, Kim JW, Choi HJ, Weber RM, Jhon MS: Electrorheological characteristics of polyaniline and its copolymer suspensions with ionic and nonionic substituents, Colloid Polym. Sci. 278 (2000) 61-54.
[16] Cho MS, Cho YH, Choi HJ, Jhon MS: Synthesis and electrorheological characteristics of

Figure 4: Schematic representation of the flow curve of an electrorheological suspension measured in CSS mode.

Figure 5: Breaking shear stress as a function of E^2 for suspensions of uncoated (△) and PANI-coated silica particles (□).

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polyaniline-coated poly(methyl methacrylate) microsphere: Size effect, Langmuir 19 (2003) 5875-5881.
[17] Cho CH, Choi HJ, Kim JW, Jhon MS: Synthesis and electrorheology of aniline/pyrrole copolymer, J. Mater. Sci. 39 (2004) 1883-1885.
[18] Kim SG, Kim JE, Choi HJ, Suh MS, Shin MJ, Jhon MS: Synthesis and electrorheological characterization of emulsion-polymerized dodecylbenzenesulfonic acid doped polyaniline-based suspensions, Coll. Polym. Sci. 278 (2000) 894-898.
[19] Méndez-Sánchez AF, López-González MR, Rolón-Garrido VH, Pérez-González J, de Vargas L: Instabilities of micellar systems under homogeneous and non-homogeneous flow conditions, Rheol. Acta 42 (2003) 56-63.
[20] Choi HJ, Cho MS, Jhon MS: Electrorheological properties of poly(acene quinine) radical suspensions, Polym. Adv. Techol. 8 (1997) 697-700.
[21] Kim JW, Kim SG, Choi HJ, Jhon MS: Synthesis and electrorheological properties of polyaniline-Na^+-montmorillonite suspensions, Macromol. Rapid Commun. 20 (1999) 450-452.
[22] Kim JW, Noh MH, Choi HJ, Lee DC, Jhon MS: Synthesis and electrorheological characteristics of SAN-clay composite suspensions, Polymer 41 (2000) 1229-1231.
[23] Jang WH, Kim JW, Choi HJ, Jhon MS: Synthesis and electrorheology of camphosulfonic acid doped polyaniline suspensions, Coll. Polym. Sci. 279 (2001) 823-827.
[24] Sohn J, Sung JH, Choi HJ, Jhon MS: The effect of particle concentration of poly(p-phenylene on electrorheological response, J. Appl. Polym. Sci. 84 (2002) 2397-2403.
[25] Alanis E, Romero G, Martinez C, Alvarez L, Mechetti C: Characteristic times of microstructure formation in electrorheological fluids determined by viscosity and speckle activity measurements, Appl. Rheol. 15 (2005) 38-45.
[26] Souza Mendes PR, Dutra ESS: Viscosity function for yield-stress liquids, Appl. Rheol. 14 (2004) 296-302.
[27] Stejskal J, Gilbert RG: Polyaniline. Preparation of a conducting polymer (IUPAC technical report) , Pure Appl. Chem. 74 (2002) 857-867.
[28] Stejskal J, Trchová M, Fedorova S, Sapurina I, Zemek J: Surface polymerization of aniline on silica gel, Langmuir 19 (2003) 3013-3018.
[29] Marshal LJ,. Zukoski IV W, Goodwin J: Effects of electric fields on the rheology of non-aqueous concentrated syspensions, J. Chem. Soc., Faraday Trans. I 85 (1989) 2785-2795.

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