INFLUENCE OF THE ELECTRIC FIELD ON THE ELECTRORHEOLOGICAL BEHAVIOUR OF CRYSTALLINE CELLULOSE SUSPENSIONS IN SILICONE OILS

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ABSTRACT

This work deals with electrorheological (ER) behaviour of moist crystalline cellulose dispersed in silicone oils of different viscosities (0.1, 0.35 and 1.0 Pa.s) in DC and 50 Hz AC electric fields. The experiments were performed on a parallel-plate viscometer with various width of the gap. In the AC field the intensity of the ER effect was lower and the rheological behaviour of suspensions was in accordance with the Bingham law. In the DC field, on the other hand, the flow curves were rather complex. Higher viscosity of the continuous phase limited reorganization of the ER structure in the flow field; hence, the ER effect intensity was lower. The plot of relative viscosity, η/η_c, *vs.* the Mason number, *Mn*, provided a common line, which supports an idea of a pronounced influence of the ratio of viscous and polarization forces as the main factor controlling electrorheological properties of the system.

KURZFASSUNG

Diese Arbeit befasst sich mit dem elektrorheologischem Verhalten von kristalliner Cellulose, dispergiert in Silikonölen unterschiedlicher Viskositäten (0.1, 0.35 und 1.0 Pa.s) in einem Gleichstromfeld und 50Hz Wechselstromfeld. Die rheologischen Messungen wurden mit einem Platte-Platte Rheometer unterschiedlicher Plattenabstände durchgeführt. Im Wechslestromfeld wurde ein schwacher elektrorheologischer Effekt gefunden und ein Binghamsches Fliessverhalten. Im Gleichstromfeld wurden dem entgegen ein komplexes Fliessverhalten beobachtet. Die höhere Viskosität der kontinuierlichen Phasen behinderte die Ausbildung von elektrorheologischen Strukturen im Strömungsfeld und als Folge wurde ein schwächerer elektrorheologischer Effekt gemessen. Durch die Auftragung der relativen Viskosität η/η_c als Funktion der Manson Nummer Mn kann gezeigt werden, daß das Verhältnis von viskosen zu polarisierenden Kräften einen entscheidenen Einfluss auf die elektrorheologischen Eigenschaften des Systems hat.

RÉSUMÉ

Ce travail porte sur le comportement électrorhéologique (ER) de suspensions de cellulose cristalline dispersées dans des huiles silicone de différentes viscosités (0.1, 0.35 et 1 Pa.s) soumises à des champs électriques continus et alternatifs (50 Hz). Les expériences ont été réalisées à l'aide d'un viscosimètre à géométrie plan-plan avec différentes valeurs d'entrefer. Lorsqu'un champ alternatif est appliqué, l'intensité de l'effet ER est plus faible et le comportement rhéologique des suspensions suit une loi de type Bingham. Par contre, lorsqu'un champ électrique constant est appliqué, les courbes d'écoulement sont plus complexes. Une phase continue plus visqueuse limite la réorganisation de la structure ER dans le champ d'écoulement; par conséquent, l'effet ER est moindre. Si on trace la viscosité relative, η/η_c, en fonction du nombre de Mason, Mn, on obtient une droite unique qui laisse suggérer que le rapport entre les forces de polarisation et les forces visqueuses est le principal facteur qui contrôle les propriétés électrorhéologiques de ces systèmes.

KEY WORDS:

electrorheology, AC and DC electric field, polymer suspensions, crystalline cellulose, silicone oils of different viscosity

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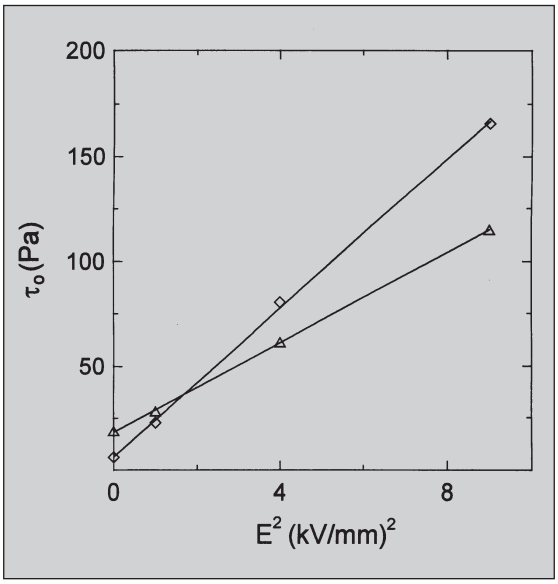

Figure 5 (left): Dependence of the yield stress, τ_o, of the suspensions in SO 100 (◇) and SO 1000 (△) on the squared field strength E^2 at the shear rate 2.1 s^{-1}.

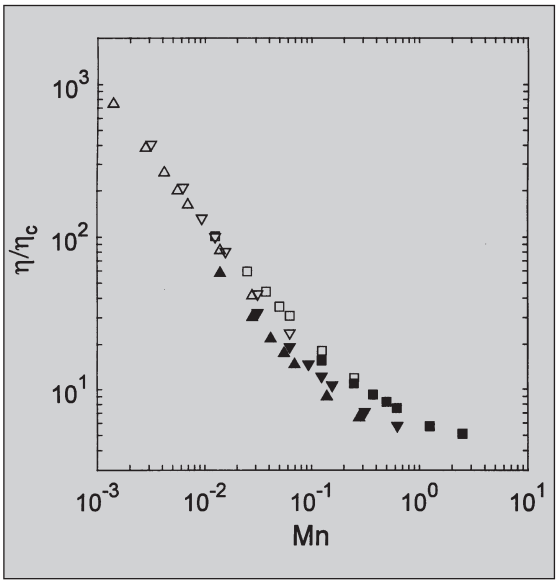

Figure 6 (right): Dependence of the relative viscosity, η/η_C, on the Mason number, Mn, for the suspensions in silicone oils SO 100 (open points) and SO 1000 (solid points) (Field strength (kV/mm): 1 (□, ■), 2 (▽, ▼), 3 (△, ▲)).

where τ is the shear stress, τ_o is the yield stress, η_{pl} is the plastic viscosity and γ is the shear rate. On the other hand, if the DC electric field was applied, after a short linear increase, the shear stress became independent of the shear rate, which suggests a rather more complex pseudoplastic flow.

The yield stress values obtained by extrapolation of flow curves in Fig. 2 to the zero shear rate showed a steep increase with the electric field strength similar to viscosity at low shear rates. In both cases, the yield stress-electric field strength dependence obey the power law

$$\tau_o = aE^n \qquad (3)$$

For the DC field the parameter *a* was about ten times higher than for AC field (Fig.3). The exponent *n* for the AC field has the theoretical value 2 [16,17], whereas for the DC field it was only a little higher than unity.

This finding suggests that the ER effect induced by the AC electric field at low frequency depends on the specific character of the suspension and may considerably differ from the effect of the DC field. In the DC field, when the maximum polarization of suspension particles sets in, a more stable ER structure of suspension particles arises. In the AC field, if the polarization of the particles is able to follow the field oscillation, the ER effect is comparable with the DC electric field of the same strength. Obviously, this is the case in a suspension of silica particles reported in the literature [17]. Our results, however, showed a considerable decrease in the ER intensity when the 50 Hz AC field was applied, which indicates an inability of the cellulose particles to reach maximum polarization. Nevertheless, the flow curves under these conditions proved to be much simpler than for the DC field, and the viscosity or yield stress – electric field strength dependences corresponded to theoretical relations.

4.3 EFFECT OF PHASE VISCOSITY

The viscosity of silicone oils influences the electrorheological response of the suspensions for two reasons: (i) A higher viscosity of silicone oil increases zero-field viscosity of the suspension; (ii) It prevents reorganization of the ER structure of the particles broken by the flow field. Fig. 4 shows the plot of shear stress vs. shear rate of suspensions in silicone oils of different viscosities in the AC field (0.1 and 1.0 Pas). The Bingham character of the dependences does not change with the viscosity of the continuous phase. The value of the yield stress, τ_o, varies with the electric field strength while the plastic viscosity, η_{pl}, for the suspension medium remains virtually unchanged. Dependences of the yield stress on the electric field strength for suspensions in the oils with lowest and highest viscosity are shown in Fig. 5. In both cases the yield stress depends on E^2 linearly. At lower *E* values, the higher viscosity of the continuous phase results in a higher yield stress, but with increasing electric field strength, the yield stress of the suspension in a less viscous oil (SO 100) becomes larger. Slopes of the curves also vary with viscosity of the continuous phase and change from 10.7 (in SO 1000) to 17.8 (in SO 100).

According to the bulk polarization theory [16], the relative viscosity of electrorheological suspensions, η/η_c, (ratio of apparent viscosity of a suspension and viscosity of the continuous phase), depends only on the volume fraction of the particles and the dimensionless Mason num-

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ber, *Mn*, which characterizes the ratio of viscous to polarization forces in the system.

$$Mn = \frac{\eta_c \dot{\gamma}}{2\varepsilon_o \varepsilon_c (\beta E)^2} \qquad (4)$$

where ε_o is the permittivity of the free space, ε_c is the permittivity of the continuous phase, $\dot{\gamma}$ is the shear rate, and E is the applied electric field strength. The particle dipole coefficient, $\beta = (\varepsilon_p - \varepsilon_c)/(\varepsilon_p + 2\varepsilon_c)$, is a measure of particle polarizability relative to that of the continuous phase in the electric field.

Fig. 6 shows the relative viscosity, η/η_c, of suspensions in silicone oils SO 100 and SO 1000, as a function of the Mason number. In line with the theory, the values obtained at different field strengths and shear rates are reduced to a single descending line, which takes a horizontal course at a constant viscosity η_∞ at the critical value of *Mn*.

5 CONCLUSIONS

The results obtained in the research may be summarized as follows:

The maximum intensity of the ER effect can be achieved in suspensions with low-viscosity continuous phase when the DC electric field is applied. Due to strong electrostatic interactions of particles polarized in one direction of electric field and quick reorganization of the ER structure, a more stable rigid particle arrangement is formed. On application of the flow field to this material, a high yield stress appears and a steep pseudoplastic decrease in viscosity with shear rate occurs.

In the AC field, where polarization of particles changes with frequency, weaker particle interactions set in and consequently a ”softer“ ER structure arises. In comparison with the DC field the suspension flows as a Bingham body. The yield stress is lower and the dependence of viscosity on the shear rate is less pronounced.

Under certain circumstances depending on the specific character of the particles, the particle polarization is able to follow the field oscillation when the field frequency is low. Then the ER effect may reach similar intensities for both AC and DC fields.

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