Rheological Behaviour of Fibre Suspensions in Non-Newtonian Fluids

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Abstract:

The influence of short fibre addition on the rheological behaviour of different non-Newtonian fluids is investigated experimentally. Two types of suspending fluids are considered: power-law shear thinning fluids and yield-stress shear-thinning fluids. The power-law suspending fluids consist of aqueous xanthan solutions at different concentrations. The yield stress fluids are mortar tile adhesives characterised by different rheological parameters. The flow curves of the suspensions at different fibre contents are determined at controlled stresses. Three rheological parameters are inferred from the flow curves: the yield stress, the consistency and the fluidity index. The influence of the fibres on the rheological behaviour of purely shear-thinning fluids is found to be quite similar to what can be expected for Newtonian suspending fluids. On the other hand, addition of fibres to yield stress granular fluids leads to a qualitatively different change of their rheological properties compared to the case of Newtonian suspending fluids. In particular, it is found that the fibres can lead to the decrease of the apparent viscosity and the yield stress for low fibre concentrations in the case of granular suspending fluids. Our experimental findings indicate that the models for fibre suspensions in Newtonian solvents cannot be used straightforwardly in the case of fibre suspensions in granular materials such as building materials, ceramic materials, etc.

Zusammenfassung:

Der Einfluss der Zugabe von Kurzglasfasern auf die rheologischen Eigenschaften verschiedener nicht-Newtonscher Fluide wurde in dieser Arbeit experimentell untersucht. Zwei Typen von Flüssigkeiten wurden betrachtet: nach einem Potenzgesetz scherverdünnende Fluide und Fluide mit einer Fließgrenze. Die nach einem Potenzgesetz scherverdünnenden Fluide bestehen aus wässrigen Xanthan-Lösungen mit unterschiedlichen Konzentrationen. Die Fluide mit einer Fliessspannung sind Mörtelplattenadhäsive, die durch verschiedene rheologische Parameter charakterisiert werden. Die Fließkurven der Suspensionen bei verschiedenen Fasergehalten wurden durch Experimente mit einer kontrollierten Spannung bestimmt. Drei rheologische Parameter wurden von den Fließkurven abgeleitet: die Fließspannung, die Konsistenz und der Fluiditätsindex. Der Einfluß der Fasern auf das rein scherverdünnende Fluid war sehr ähnlich zu dem Verhalten, was von einem rein Newtonschen Fluid erwartet wird. Dagegen wurde durch die Zugabe von Fasern zu granularen Fluiden mit einer Fließspannung ein qualitativ unterschiedliches rheologisches Verhalten gefunden. Es wurde gezeigt, dass Fasern zu einer Verringerung der scheinbaren Viskosität und der Fließspannung bei niedrigen Konzentrationen im Falle von granularen Fluiden führen können. Unsere experimentellen Ergebnisse deuten an, dass die Modelle für Fasersuspensionen in Newtonschen Lösungen nicht direkt auf Fasersuspensionen in granularen Materialien wie Baumaterialien oder keramische Materialien angewandt werden können.

Résumé:

L'influence de l'utilisation des fibres courtes sur le comportement rhéologique de différents fluides non-Newtoniens a été étudiée expérimentalement. Deux types de fluides suspendant ont été considérés. Le premier est une solution aqueuse de Xanthane, caractérisée par un comportement rhéologique en loi de puissance. Le deuxième est une suspension granulaire présentant un seuil d'écoulement, il s'agit d'un mortier adhésif utilisé comme colle à carrelages. Pour chaque fluide suspendant différents dosages en fibres ont été considérés. Les courbes d'écoulement ont été obtenues selon la procédure à contrainte imposée. Trois paramètres rhéologiques sont alors déterminés : seuil d'écoulement, consistance et indice de fluidité. Nous avons constaté que dans le cas du fluide suspendant à base de Xanthane (sans seuil) l'influence des fibres sur le comportement rhéologique est qualitativement similaire à celle observée habituellement dans le cas des suspensions de fibres dans un fluide Newtonien. En revanche, l'addition de fibres dans une suspension granulaire à seuil entraine une différence qua-

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that Adhesive B is more shear-thinning than Adhesive A. We can note that the flow curve in the case of a fibre concentration of 1% is not regular. This is probably due to the presence of large fibre flocs, which are then broken at high shear-rates.

The evolution of the yield stress versus fibre concentration is represented in Figure 17. The yield stress first decreases when adding fibres. It is to be noted that this decrease is not an artefact since the experiments were repeated at least three times for each fibre concentration. The possible origin of this behaviour is the fibre induced fine aggregate breakage during mixing. Since the mixing procedure was fixed, the presence of the fibres may lead to more efficient dispersion of the fine particles (in particular cement), decreasing the yield stress of the suspending fluid. At sufficiently low fibre concentration the yield stress of the fibre suspension may then decrease. Increasing further the fibre concentration will lead to the increase of the global yield stress since the effect of the fibres contacts comes then into play.

The evolution of the consistency versus fibre content is very similar to that of the yield stress (Figure 18 a). One can put forward the same arguments than previously to interpret the behaviour of the consistency, in particular concerning the presence of a minimum. The behaviour of the fluidity index (Figure 18 b) versus fibre concentration is somehow complementary to that of the two previous rheological parameters: It starts growing, passes through a maximum and then decreases. At high fibre concentrations (1 %) the material is very close to an ideal plastic (n = 0). The decrease (fluidity index increases) of the shear thinning property of the fibre suspension may be related to the fact that the suspending fluid is less flocculated due to the probable fibre enhancement of the mixing efficiency. Adding a small amount of fibres may then lead to the increase of the fluidity index. At higher fibre concentrations the fibres will contribute to shear thinning, as in the case of Newtonian suspending fluids, leading to a global increase of the shear thinning feature of the fibre suspension.

4 CONCLUSIONS

We considered the influence of the non-Newtonian feature of the suspending matrix on the rheological behaviour of fibre suspensions. Two types of suspending matrixes were considered. Pure shear thinning fluids (xanthan solutions) and granular yield stress fluids (mortar tile adhesives). The influence of short fibres addition on the steady-state apparent viscosity and consistency of shear-thinning fluids is found to be qualitatively similar to that one expects for Newtonian suspending fluids. The fibres increased the shear-thinning aspect of the suspensions. This was attributed to both the shear-thinning arising from the fibres (due to contacts and eventually entanglements) and an eventual increase of the shear thinning property of the suspending fluid. In the light of our experimental results, the rheological behaviour of fibre suspensions in purely shear-thinning fluids can be modelled without fundamentally changing the approaches generally adopted for Newtonian suspending fluids.

Fibre suspensions in granular yield stress materials displayed on the other hand a qualitatively different rheological behaviour compared to fibre suspensions in Newtonian suspending fluids. It was found that the yield stress was affected at smaller fibre contents than expected. Moreover, the yield stress first decreased when the concentration of the fibre was increased. This was attributed to probable enhancement of the mixing efficiency, during the preparation of the suspension, due the presence of the fibres. The apparent viscosity was also found to decrease when increasing fibre content for some shear-rates and concentration intervals. This was attributed to possible fibre-induced cement aggregates breakage under flow. In order to model the rheological behaviour of fibre suspensions in a granular material such as cement or ceramic based materials, it seems necessary to explicitly take into account the granular (discrete) nature of the suspending fluid.

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