Rheological properties of suspensions with spherical particles in shear and elongational flows

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Abstract:
The rheological behaviour of model suspensions with spherical particles was experimentally investigated in shear an elongational flows. Particular attention was focussed on the main parameters affecting the flow behaviour of suspensions such as particle size distribution, particle size, particle surface, humidity, temperature and viscosity of the matrix fluids. All variables were investigated depending on the pre-shear conditions. In this regard the validity of the time-temperature-superposition and the Trouton-ratio was verified for suspensions with spherical particles.

1 INTRODUCTION

Highly filled suspensions are frequently encountered in several manufacturing and transport processes. Paints, printing inks, tar or food stuff are only some examples for industrial applications of suspensions. For an optimization of processing parameters it is essential to predict the rheological behaviour of suspensions depending on the predominating deformation (i.e. shear flow, elongational flow). Although it is well known that the steady shear flow behaviour of suspensions is strongly influenced by the properties of the filler (i.e. volume fraction Φ_t, particle shape and size distribution, specific surface area of the particles) and by the matrix properties [1-5] still many open questions remain. In this connection particular attention is focussed on the relevance of the maximum packing faction Φ_{max} which especially for concentrated bidisperse suspensions has been shown to be the dominating parameter in the high-shear-(stress)-state.

In comparison to the extensive information available on the viscosity function in steady shear flow there are only few studies which focus on the development of the viscoelastic material functions of colloidal and non colloidal concentrated suspensions [6-8]. Furthermore only little literature can be found on investigations of the validity of the time-temperature superposition principle for concentrated suspensions [7-10]. Although it is well known that the actual state of suspension architecture strongly influences its rheological behaviour it is worth mentioning that a systematic investigation of the rheological properties of suspensions depending on the pre-shear conditions cannot be found in literature.

The intention of the Ph.-D.-work was to experimentally contribute to open questions in the field of suspension rheology in shear and elongational flows. Since the flow behaviour of suspensions is very complex for experiments in shear flow model suspensions containing defined spherical particles in Newtonian fluids were examined. Using the Münstedt tensile rheometer (MTR) suspensions of spherical particles in non-Newtonian fluids were additionally investigated in elongational flows. In this review, however, three important findings in shear flow will be presented whereas all results shown were obtained by applying a systematic pre-shearing. First it will be demonstrated how the polydispersity of a particle size distribution influences the maximum packing fraction Φ_{max} and hence the rheological behaviour in the high shear-(stress)-state of a concentrated suspension. Furthermore it will be shown that the time-temperature superposition principle is valid for the model suspensions investigated if a systematic pre-shearing is applied prior to the determination of the dynamic moduli.
At last it will be demonstrated that depending on the actual particle structure the magnitude of the elasticity of suspensions can exceed the elasticity of polymer melts by decades.

2 MATERIALS

As the matrix fluids three Newtonian non-polar low molecular weight polyisobutylenes (PIB 1, PIB 2, PIB 3) with a density of g/cm² were chosen. Their weight average molecular weight M_w and

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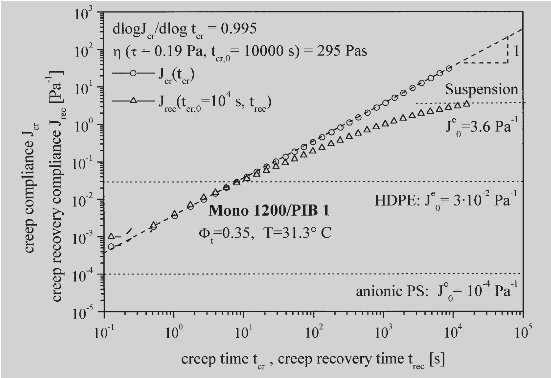

Figure 6: Creep compliance $J_{cr}(t_{cr})$ and creep recovery compliance $J_{rec}(t_{rec}, t_{cr,0})$ for a very low shear stress of τ = 0.19 Pa (system Mono 1200/PIB 1, Φ_t=0.35)

ian behaviour whereas at τ = 0.19 Pa a non-Newtonian behaviour was observed. The Newtonian matrix PIB 1 can be considered as purely viscous since its creep recoverable compliance J_{rec} was lower than the resolution of the magnetic torsional bearing rheometer. For both applied shear stresses (i.e. τ = 0.19 Pa and τ = 200 Pa) in good approximation a constant slope of the creep compliance $J_{cr}(t_{cr})$ is reached after a creep time of $t_{cr} = 10^4$ s. Interestingly no significant recoverable creep compliances J_{rec} can be obtained after applying a shear stress of τ = 200 Pa in the creep test for the suspension investigated. This strongly indicates that in this state the suspension behaves a purely viscous, as well.

After applying low shear stress of τ = 0.19 Pa in the creep test a significant recoverable creep compliance can be observed, however. For the findings obtained after applying a shear stress of τ = 0.19 Pa in the creep test the creep compliance $J_{cr}(t_{cr})$ and the recoverable creep compliance $J_{rec}(t_{rec})$ are plotted in Fig. 6 on a double logarithmic scale as a function of the creep time t_{cr} and the creep recovery time t_{rec}, respectively. The magnitude of the resulting creep recoverable compliance $J_{rec}(t_{rec})$ obtained for the suspension is compared with the upper and lower boundary of the steady state recoverable compliance J_e^o that can be found in literature for different polymer melts [29-33]. As can be seen from Fig. 6 a steady-state recoverable compliance of approximately $J_e^o \approx 3.6$ Pa^{-1} is obtained for our suspension which exceeds the largest steady-state recoverable compliances J_e^o of polymer melts by more than 2 decades. Considering the fact that the same suspension does not show significant creep recoverable compliances after applying a shear stress of τ = 200 Pa in the creep test and hence behaves as a viscous liquid the results from Fig. 6 are even more fascinating. This outstanding finding clearly demonstrates the strong influence of the present particle structure on the elastic properties of suspensions.

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