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The Influence of Continuous Shear, Shear History and Relaxation on the Rheological Behavior of SiO_2/Glycerine Suspensions

Yi Chen*, Xianggang Li, Guangsheng Zeng, Wenyong Liu

Key Laboratory of Advanced Materials and Technology for Packaging of Hunan, Hunan University of Technology, Zhuzhou 412008, P. R. China

* Corresponding author: yiyue514@aliyun.com

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Abstract:

Suspensions of SiO_2 microspheres in glycerine exhibit drastic shear-thickening behavior under steady shear and dynamic oscillatory shear test. The rheological behavior of suspensions agrees with the modified Cox-Merz rules as the dynamic oscillatory rheological behavior at low frequency could be reasonably interpreted in terms of the steady shear behavior. As new insight, the effect of shear history and the relaxation on the rheological behavior was investigated in detail. The result showed that under continuous shear, the viscosity decreases after a "pulse": The degree of decrease is directly proportional to the shear rate. Similar phenomenon is also found under the continuous stress and dynamic oscillatory shear rate sweep. The shear history shows a non-negligent effect on the rheological behavior, the suspensions with higher viscosity show a lower viscosity under the same shear rate. Moreover, the relaxation time of suspensions shows the direct dependency on the initial viscosity, while the volume fraction of suspensions also affect the relaxation time. For more enlapsed times, also longer relaxation times are needed for the suspensions with lower volume fraction and higher initial viscosity.

Key words:

SiO_2, glycerine, shear-thickening, shear history, steady shear, dynamic oscillation

1 INTRODUCTION

Shear thickening behavior as a significant continuous or discontinuous steep increase in viscosity is a common phenomenon existing in concentrated colloidal suspensions when they are subjected to applying stress [1–3]. Shear thickening behavior was studied for its damages to processing equipments and dramatic changes in suspension microstructure such as cement systems and concrete systems [4–6]. After all, such rheological behavior was found and investigated in various suspensions systems. It has a great potential for use in producing ski boot cushioning, shock absorber fillings and body armors due to their specific ability to absorb a large amount of energy once suffering from a high velocity projectile [7, 8].

The reasons for shear-thickening was explored deeply and a series of models have been developed. Hoffman used a combination of rheology with in situ light diffraction to elucidate microstructural changes that occur during shear-thickening [9]. He concluded that the incipience of shear-thickening at a critical shear rate corresponds to a transition from an easy flowing state where the particles are ordered into layers to a disordered state where this ordering is absent. This mechanism is generally called an order-disorder transition. Bender and Wagner noted that although order-disorder transitions may accompany the shear thickening transition, the underlying order-disorder transition is neither necessary nor sufficient to trigger shear thickening [13]. They have shown that reversible shear thickening results from the formation of hydroclusters, or transient stress bearing particle aggregates that form as a consequence of short range hydrodynamic lubrication forces overcoming the interparticle repulsive forces during flow. Percolation of these hydroclusters with increasing shear results in the formation of larger aggregates that can jam the flow, leading to discontinuous shear thickening behavior. The formation of jamming clusters bound together by hydrodynamic lubrication forces, often denoted by the term "hydroclusters" [10, 11]. Rheo-optical experiments [12, 13], stress-jump measurements [14, 15], neutron scattering, and Brownian simulation [16–19] were all used to prove the validity of such models.

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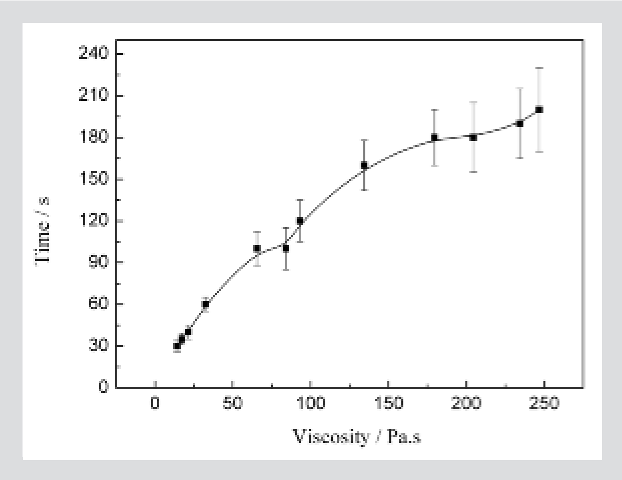

Figure 10: The relaxation time as a function of start viscosity. The volume fraction of suspensions is 51 %.

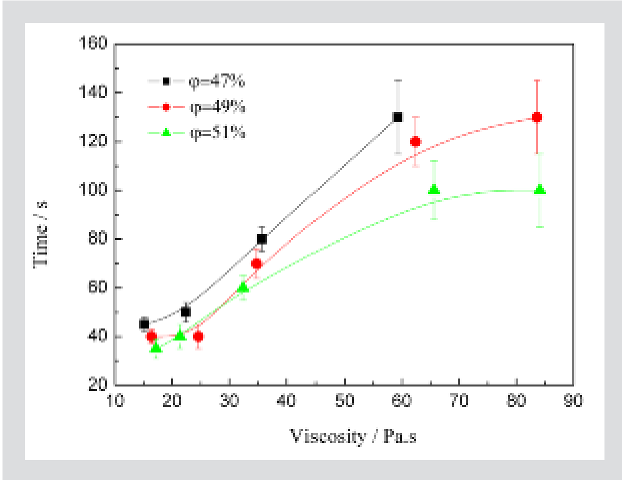

Figure 11: The relaxation time as a function of start viscosity. The volume fraction of suspensions is the 47, 49, and 51 %.

which is different from the previous researches focusing on the sequential and steady shear sweep. The followed results were gotten.

Firstly, keeping shearing the suspensions at fixed rate for a certain time, the viscosity of suspensions shows a rudely increase as a "pulse", after that, the obvious discrepancy of viscosity change appears in different rate interval. When the shear rate is low, the viscosity remains unchanged, indicating the formation of balance. Relatively, the viscosity decreases gradually to some specific degree under the high shear rate, which is dependent on the rate of shear. This phenomenon was also observed in continuous stress and oscillatory shear with the absent of "pulse". It could be concluded that the same, unchanged stimulus strength under both steady and dynamic oscillatory shear is hard to keep the suspensions at the same viscosity, especially under the high rate of shear, the particles in suspensions should happen rearrange and reach a new balance with the extension of time. Secondly, the shear history affects the rheological behavior of suspensions under the followed shear significantly. When the previous shear rate is low, the viscosity in the followed shear is higher than that with the higher previous shear rate. The lower previous shear is similar as a "pre-shear" process, the particles aggregate in a slight degree, which is conducive to the next greater aggregation. Inversely, the previous high shear rate is similar as a "overshooting" process, the decrease of shear rate (stress) should lead to the rearrangement of particles in suspensions. Thirdly, the relaxation process of suspensions from aggregation status needs certain time, which is dependent on the initial viscosity and the volume fraction of suspensions. The relaxation time should be prolonged gradually with the increase of initial viscosity significantly and reach a "platform" when the initial viscosity reaches a special value. With the same initial viscosity, the suspensions with higher volume fraction need longer time for relaxation due to the longer distance from the aggregation status to the balance status.

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