THE YIELD STRESS - A NEW POINT OF VIEW

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INTRODUCTION

Barnes and Walters postulated 1985 [1] "that all liquids show Newtonian behaviour at low enough shear rate". This was the begin of an intensive discussion [2-7] about the existence of an yield stress. Barnes confirmed [8-10] his statement that all systems will show a Newtonian region at low enough shear rate. This will mean that all systems show structural-viscous flow behavior? Some suspensions with plastic flow behavior show in the fact at low shear rates a Newtonian region. The main question is if a system with Newtonian region has a structural-viscous flow behavior or plastic flow behavior. The existing definition for the systems with plastic flow behavior is obviously not precise enough to answer this question. We will try to answer this question and correspondingly to extend the definition for the systems with plastic flow behavior.

LETTER

The rheological measurements were carried out with a Weissenberg Rheogoniometer, WRG, Model R18, Sangamo Ltd., in air-coditioned room at 25 ± 0.2°C. We used a cone-plate arrangement with 6 degree cone angle and 5 cm diameter. The points of the viscosity curves represent the steady state values from stressing experiments (with a shear rate $\dot{\gamma}$ = const.). Just after the steady state value is reached the shear deformation is stopped and the stress relaxation begins. In the stress relaxation, after cessation of the shear deformation, the strip bar makes an effort to come to the starting point. If the starting point is reached, no residual shear stress τ_R will be observed. But an existing remaining structure opposes against the elastic (returned) springing of the strip bar to the starting point - it remains a residual shear stress. The relative residual shear stress τ_R/τ_S is the ratio of residual shear stress to steady state shear stress τ_S.

We suppose there are as well systems with structural-viscous flow behavior as systems with plastic flow behavior. The systems with structural-viscous flow behavior, like silicone oils, polymer melts and suspensions with a weak structure, show at low shear rates a Newtonian region with a zero-shear viscosity. As for instance, the silicone oil M100000 has a zero-shear viscosity of 100 Pas. The shear thinning region begins at 16 s^{-1} [11]. This silicone oil (see Fig.1) like all other systems with structural-viscous flow behavior [12] does not show any residual shear stress after cessation of the shear deformation, independent of the shear rate of the previously stressing experiment. The characteristic of the systems with structural-viscous flow behavior is the existence of a Newtonian region with a zero-shear viscosity and the absence of a residual shear stress in the stress relaxation. This is the answer of the first part of the question (see last paragraph of the introduction).

The model suspensions with 3.75, 5 and 7.5% Cab-o-sil TS 720 in Araldite GY 260)[13] have plastic flow behavior with yield stresses of 20 , 60 and 130 Pa respectively (see Fig.2). The sus-

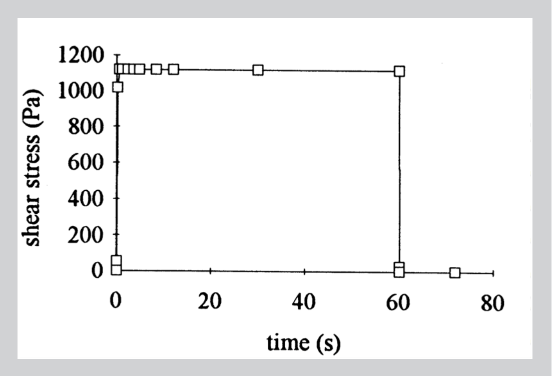

Figure 1 (right above): Stressing experiment with 11.25 s^{-1} (0 - 60 s) and stress relaxation (60 - 80 s) of the silicone oil M100000 (WRG, cone-plate, 25° ± 0.2°C).

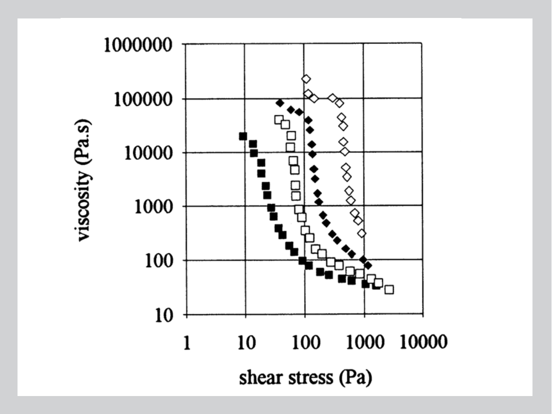

Figure 2 (right below): Viscosity curves of Araldite GY 260 with 3.75% (■), 5% (□), 7.5% (◆), 10% (◇) Cab-o-sil TS 720 (WRG, cone-plate, 25° ± 0.2°C).

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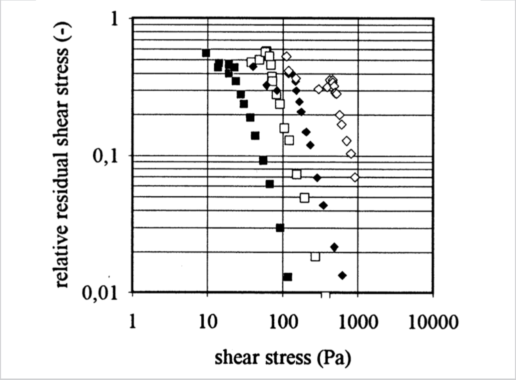

Figure 3 (left above): Relative residual shear stress curves of Araldite GY 260 with 3.75% (■), 5% (□), 7.5% (◆), 10% (◇) Cab-o-sil TS 720 (WRG, cone-plate, 25° ± 0.2°C).

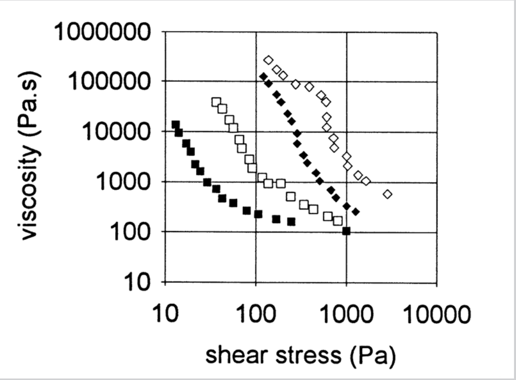

Figure 4 (right above): Viscosity curves of Araldite GY 260 with 15% (■), 17.5% (□), 20% (◆), 25% (◇) Bentone 27 (WRG, cone-plate, 25° ± 0.2°C).

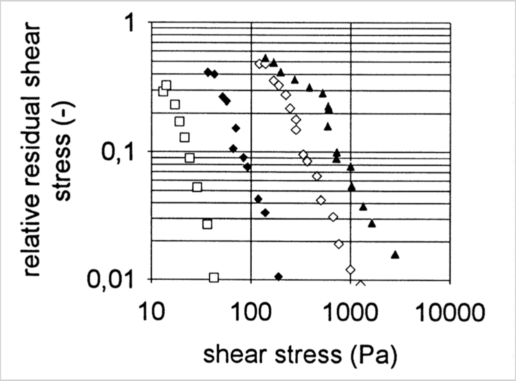

Figure 5 (left below): Relative residual shear stress curves of suspensions with Araldite GY 260 and 15% (■), 17.5% (□), 20% (◆), 25% (◇) Bentone 27 (WRG, cone-plate, 25° ± 0.2°C).

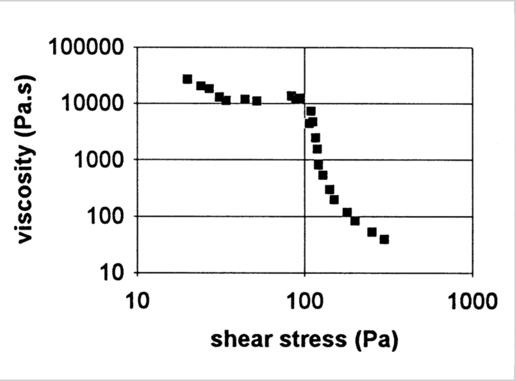

Figure 6 (right above): Viscosity curve of the suspension Araldite XW 461 (WRG, cone-plate, 25° ± 0.2°C).

pension with 10% Cab-o-sil TS 720 has a much more better structure and following two yield stress sections or yield stresses with 120 Pa and 450 Pa, respecticvely. The section between the two yield stress regions (between 120 Pa and 450 Pa) of the system with 10% Cab-o-sil TS 720 is a Newtonian region with a viscosity of 105 Pas. Is this suspension really a system with plastic flow behavior or a system with structural-viscous flow behavior?

The dependence of the relative residual shear stress on shear stress (see Fig. 3) will give the answer of this question. The suspensions with 3.75, 5 and 7.5% Cab-o-sil have a relative residual shear stress up to 0.5. The functions of the relative residual shear stress are similar - they are moved with increasing Cab-o-sil concentration parallel to higher shear stresses. The system with 10% Cab-o-sil has a well a high relative residual shear stress, although the viscosity curve has a Newtonian region. We can now postulate that if a system with a Newtonian region has also a high relative residual shear stress in this region, this system shows plastic flow behavior. This is the answer of the second part of the question (see the last paragraph of the introduction). The Newtonian region is the transition section between two yield stress regions and has a pseudo-Newtonian character (see Fig.3). The system with 10% Cab-o-sil exhibits between 140 Pa and 450 Pa a plateau (like that of the transition section of the viscosity curve) with a relative residual stress of 0.32. After this plateau or with the second yield stress, the relative residual shear stress begins to decline with a slope of $n = -2$. The decrease of the relative residual shear stress of the systems with 3.75, 5 and 7.5% occures also with a slope of $n = -2$. It is a similar well ordered destruction of the thixotropic agent structure with increasing deformation (shear stress).

The viscosity curve is obviously not enough to determine the flow behavior type of a system. One have consequently to carry out stressing experiments and stress relaxation to be sure if a system has structural-viscous flow behavior or plastic flow behavior. The transition section between two yield stress regions can have either pseudo-Newtonian character (see Fig.2 and 3) or shear-thinning (25% Bentone 27 in Araldite GY 260 - see Fig.4 and 5) or shear thickening (the suspension Araldite XW 461 - see Fig.6) character.

Windhab and Gleissle [14] reported that the slip effect causes the smaller value of the first yield stress and consequently accepted only the second yield stress as the really yield stress. A slip effect will lead not only to a smaller value of the first yield, but as well to a smaller relative residual shear stress compared to values of the second yield stress region. Our suspensions with two yield stresses (10% Cab-o-sil TS 720 in Araldite 260 and 20% / 25% Bentone 27 in Araldite 260) have a smaller values for the first yield stress, but a higher relative residual shear stress compared to that of the second yield stress region. This seems to be the evidence that there is not a slip effect in the first yield stress region, i.e. the first yield stress is also a true yield stress. Further measurements are necessary to confirm this statement.

We can now extend the definition for systems with plastic flow behavior:

- the systems with plastic flow behavior have consequently one or more yield stress regions or yield stresses,
- the transition sections between two yield stress sections can have pseudo-Newtonian, shear-thinning or shear thickening character,
- the relative residual shear stress has relatively high values,
- the relative residual shear stress decreases with shear stress after the last yield stress region as a straight line with a slope with n = -2.

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