DILATANT BEHAVIOR OF SYSTEMS WITH THE THIXOTROPIC AGENT AEROSIL 380 IN THE EPOXY RESIN ARALDITE GY260

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ABSTRACT
Model suspension with Aerosil 380 in epoxy resin Araldite GY260 and Aerosil 380 in silicone oil M20000 are compared. The systems with 7.5%, 10% and 12.5% Aerosil 380 in Araldite GY260 show shear thickening flow behavior. A shear induced hydrodynamic force effects at the onset of shear thickening a disorder of the well ordered movement of the Areosil particles in layers. The Areosil particles build-up a pseudo-mixture that lead to a sudden development of a three dimensional structure, *i.e.* to viscosity incerease. One can assume that the shear thickening can be explained with an order-to-disorder transition. The viscosity increase of the shear thickening region is limited – It can reach topmost the plastic viscosity curve that has to be expected from the beginning. The dilatant system begins in the third straight line section to coincide the viscosity curve of the expected plastic system for the subsequent thixotropic agent concentration.

ZUSAMMENFASSUNG
Modellsuspensionen mit Aerosil 380 im Epoxidharz Araldit GY 260 und Aerosil 380 im Silikonöl M20000 werden verglichen. Die Systeme mit 7.5%, 10% und 12.5% Aerosil 380 im Araldit GY 260 weisen dilatante Eigenschaften auf. Eine scherinduzierte hydrodynamische Kraft verursacht beim Beginn der Dilatanz eine Störung der gut geordneten Schichtenbewegung der Aerosil-Partikel. Die Aerosil-Partikel erfahren eine Art Pseudo-Durschmischung, die zu einer schlagartigen Bildung der zu erwartenden dreidimensionalen Struktur, bzw. zum Viskositätsanstieg führt. Man kann annehmen, dass bei den untersuchten Systemen die Dilatanz durch eine ”order-to-disorder transition“ erklärt werden kann. Der Viskositätssprung ist nicht unbegrenzt – er kann höchstens die ”normale“ plastische Viskositätskurve erreichen, die von Anfang an zu erwarten wäre. Nachdem die potential möglich dreidimensionale Struktur erreicht wird, verläuft der dritte Bereich der Viskositätskurve des dilatanten Systems deckungsgleich mit der Viskositätskurve des zu erwartenden plastischen Systems für die entsprechende Thixotropiermittelkonzentration.

RÉSUMÉ
Des suspensions modèles de Aerosil 380 dans une résine epoxy Araldite GY260 et de Aerosil 380 dans une huile de silicone M20000 sont comparées. Les systèmes avec 7.5%, 10% et 12.5% d’Aerosil 380 dans l’Araldite Gy260 présentent un comportement rhéo-épaississant. Une force hydrodynamique induite par le cisaillement a pour effet, au commencement du comportement rhéo-épaississant, de désordonner le mouvement en couche bien ordonné des particules d’Aerosil. Celles-ci s’arrangent en un pseudo-mélange qui conduit au développement soudain d’une structure tri-dimensionnelle, et par suite à une augmentation de la viscosité. On peut expliquer ce “rhéo-épaississement” avec une transition order-désordre. Cette augmentation, dans la région de comportement rhéo-épaississant, est limitée. Au mieux, la viscosité peut rejoindre la courbe de viscosité plastique à laquelle on s’attend depuis le début. Le systeme dilatant commence dans la troisième section à coincider avec la courbe de viscosité du système plastique correspondant pour une telle concentration en agent thixotropique.

KEY-WORDS:
Dilatancy, order to disorder transition, limited viscosity increase

1 INTRODUCTION

Reynolds describes for the first time the so-called volumetric dilatancy. According to him, the liquid phase in a concentrated suspension fills out uniformly the space between the solid particles [1]. At low shear rates, friction within the system is slight because the liquid phase behaves as lubricant. At high shear rates, the uniform distribution of the solid particles is destroyed. The distance between the particles increases and the liquid phase can no longer fill out the space inbetween. Consequently, the volume of the suspension increases - volumetric dilatancy.

According to Reiner dilatancy is much more complex than the explanation as deformation of volume expansion [2]. Bauer and Collins maintain that the appearance of dilatancy does not have to be necessarily preceded by an increase in volume [3]. On the other hand, according to

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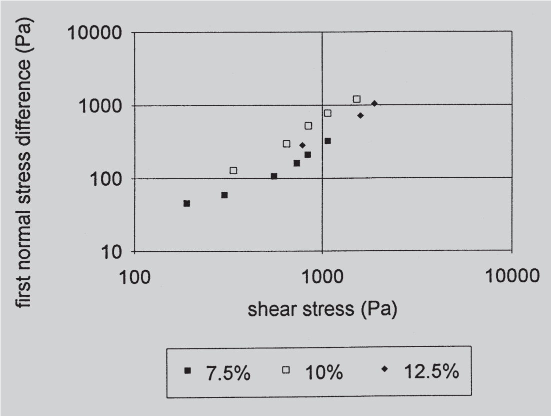

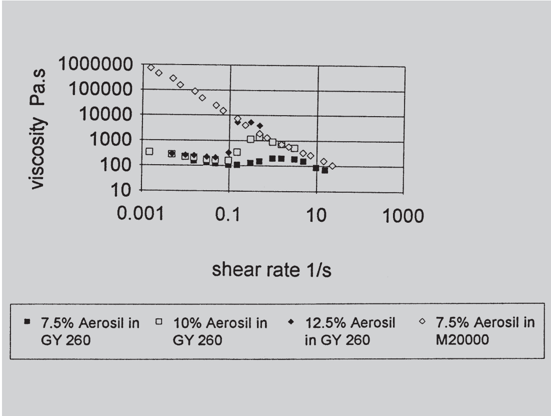

Figure 8 (left): Normal stress curves of Araldite GY 260 with different concentrations of Aerosil 380 (WRG, cone-plate 6°, 25°C).

Figure 9: Viscosity curves of Aerosil 380 in Araldite GY 260 and Aerosil 380 in M20000.

development of a three dimensional structure. At a very special shear stress (12, 13 and 15 Pa for the suspension with 7.5%, 10% and 12.5% Aerosil 380 in Araldite GY 260) a shear induced hydrodynamical force effects a disorder of the well ordered movement of the particles in the layers. The Aerosil particles come to a kind of pseudo mixture, that leads to a suddenly development of the expected three dimensional structure, *i.e.* to viscosity increase. We can also assume that the shear thickening of the measured systems can be explained with an order to disorder transition.

This shear induced viscosity increase will happen stronger with rising Aerosil 380 concentration (see Fig.1). The viscosity increase of the shear thickening region (see viscosity curve of 10% Aerosil 380 in Araldite GY 260) is limited – it can reach topmost the plastic viscosity curve that has to be expected from the beginning (compare for example with the viscosity curve of 7.5% Aerosil 380 in M20000). Once reached the potential possibly three dimensional structure, the dilatant system begins in the third region to coincide the viscosity curve of the expected plastic system for the subsequent thixotropic agent concentration.

The dilatant viscosity increase of the suspension with 7.5% (4.31 Vol%) Aerosil 380 in Araldite GY 260 can not reach the viscosty curve of the directly comparable plastic system with 7.5% (3.57 Vol%) Aerosil 380 in M20000 (see Fig.9). The comparison of both suspensions is limited because they have different liquid phases.

The third straight line section of the suspension with 12.5% Aerosil 380 in Araldite GY 260 has higher values compared to the plastic system with 7.5% Aerosil 380 in M20000. The susension with 12.5% Aerosil 380 in Araldite GY 260 is due to the high thixotropic agent concentration able to develop a shear induced structure, that corresponds to a plastic system with more than 7.5% Aerosil 380 in M20000.

4 SUMMARY

The dilatant systems with Aerosil 380 in Araldite GY 260 have in the first straight line region an unexpected low viscosity. Aerosil 380 acts in this region as a filler. The Aerosil particles are obviously in well ordered layers in the flow direction that makes difficult the development of a three dimensional structure. At a very special shear stress (between 12 and 15 Pa for the suspension with 7.5%, 10% and 12.5% Aerosil 380 in Araldite GY 260) a shear induced hydrodynamical force effects a disorder of the well ordered movement of the Aerosil particles in the layers. The Aerosil particles come to a kind of pseudo-mixture, that leads to a suddenly development of the expected three dimensional structure, *i.e.* to viscosity increase. We can also assume, that the shear thickening of the measured suspensions can be explained with an order to disorder transition.

The viscosity increase of the shear thickening region is limited: it can reach topmost the plastic viscosity curve that has to be expected from the beginning. Once reached the potential possibly three dimensional structure, the dilatant system begins in the third straight line section to coincide the viscosity curve of the expected plastic system for the subsequent thixotropic agent concentration.

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REFERENCES

[1] Reynolds, O.: Philos. Mag. 8 (1885) 20.
[2] Reiner, M.: Amer. J. Math. 67 (1945) 350.
[3] Bauer, W.H., E.A. Collins, in F.R. Eirich (Ed.), Rheology, Vol. 4 (Academic Press, New York, 1967).
[4] Metzner, A.B., M.Whitlock: Flow behavior of concentrated (dilatant) suspensions, Trans.Soc.Rheol. 11 (1958) 239-254.
[5] Efremov, I.F.: Russian Chem. Rev. 51 (1982) 160.
[6] Barnes, H.A.: Shear-thickening in suspensions of nonaggregating solid particles dispersed in Newtonian liquids, J. Rheol. 33 (1989) 329-366.
[7] Hoffman, R.L.: Discontinuous and dilatant viscosity behavior in concentrated suspensions. I. Observations of a flow instability, Trans. Soc. Rheol. 16 (1972) 155-173.
[8] Hoffman, R.L.: Discontinuous and dilatant viscosity behavior in concentrated suspensions. II. Theory and experimental tests, J. Colloid. Interface Sci. 46 (1974) 491-506.
[9] Hoffman, R.L.: Interrelationship of particles structure and flow in concentrated suspensions, Mater. Res. Bull.16 (1991) 32-37.
[10] Boersma, W.H. et al.: Time-dependent behavior and wall slip in concentrated shear thickening dispersions, J. Rheol. 35 (1991) 1093-1120.
[11] Hadjistamov, D.: Time-related flow behavior of shear thickening systems, in Proceedings of the Third European Rheology Conference, edited by D.R.Oliver, (Elsevier Applied Science, London and New York, 1990)
[12] Hadjistamov, D.: Rheological characterization of systems with shear thinning and systems with shear thickening flow behavior, in Proceedings of the IXth International Congress on Rheology, edited by B.Mena et al., (Universidad Nacional Autonoma De Mexico, 1984)
[13] Brady, J.F. and G.Bossis: The rheology of concentrated suspensions of spheres in simple shear flow by numerical simulation, J. Fluid Mech. 155 (1985) 105-129.
[14] Brady, J.F. and G.Bossis: Stokesian dynamics, Annu.Rev.Fluid Mech. 20 (1988) 11-157.
[15] Kruyt, H.R.: Colloid Science (Elsevier, New York, 1952).
[16] Bossis, G. and J.F.Brady: The rheology of Brownian suspensions, J. Chem. Phys. 91 (1989) 1866-1974.
[17] Phung, T. and J.F. Brady: Microstructured fluids: Structure, diffusion and rheology of colloidal dispersions, in Slow Dynamics in Condensed Matter, edited by K.Kawasaki et al. (AIP, Woodbury, 1992).
[18] Bender, J.W. and N. J. Wagner: Optical measurement of the contributions of colloidal forces to the rheology of concentrated suspensions, J. Colloid Interface Sci. 172 (1995) 171-184.
[19] Bender, J.W. and N. J. Wagner: Reversible shear thickening in monodisperse and bidisperse colloidal dispersions, J. Rheol. 40 (1996) 899-916.
[20] D'Haene, P.D., J.Mewis and G. G. Fuller: Scattering dichroism measurements of flow-induced structure of a shear thickening suspensions, J. Colloid Interface Sci. 156 (1993) 350-358.
[21] Chow, M.K. and C. F. Zukoski: Gap size and shear history dependencies in shear thickening of a suspension ordered at rest, J. Rheol. 39 (1995) 15-32.
[22] Boersma, W. H., J. Laven and H.N.Stein: Computer simulations of shear thickening of concentrated dispersions, J. Rheol. 39 (1995) 841-860.
[23] Laun, H.H., R. Bung, S. Hess, W. Loose, O. Hess, K. Hahn, E. Hadicke, R. Hingmann, F. Schmidt and P. Lindner: Rheological and small angle neutron scattering investigation of shear-induced particle structures of concentrated polymer dispersions submitted to plane Poiseuille and Couette flow, J. Rheol. 36 (1992) 743-787.
[24] Chow, M.K. and C.F. Zukoski: Nonequilibrium behavior of dense suspensions of uniform particles: Volume fraction and size dependence of rheology and microstructure, J. Rheol. 39 (1995) 33-59.
[25] Fagan, M.E. and C.F. Zukoski: The rheology of charge stabilized silica suspensions, J. Rheol. 41 (1997) 373-397.
[26] Hoffman, R.L.: Explanation for the cause of shear thickening in concentrated colloidal suspensions, J. Rheol. 42 (1998) 111-123.
[27] Frith, W.J., P.D'Haene, R. Buscall and J. Mewis: Shear thickening in model suspensions of sterically stabilized particles, J. Rheology 40, 531-548 (1996)
[28] Hadjistamov, D.: Viscoelastic behavior of filled and unfilled silicone oils, in Proceedings of the XIth International Congress on Rheology, (Elsevier, Amsterdam, 1992)
[29] Meissner, J.: J. Appl. Polym. Sci. 16 (1972) 2877.
[30] Hadjistamov, D.: Anlauf- und Relaxationsverhalten von dispersen Systemen, die Thixotropiemittel enthalten, Rheol. Acta 19 (1980) 345-355
[31] Hadjistamov, D.: Relationship between the normal stress difference and the shear stress Rheology, March, 29-33 (1995)

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