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THE RHEOLOGY OF HIGH ASPECT RATIO NANO-PARTICLE FILLED LIQUIDS

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ABSTRACT

The objective of this review is to elucidate the recent developments in the rheology of suspensions containing high aspect ratio (> 100) nano-scale fillers. In particular, this review focuses on industrially important nanoparticles, namely layered silicates or nanoclays, carbon nanotubes, and carbon nanofibers, suspended in low and high molecular weight liquids. This review begins with the critical aspects of nanoparticle structure. In addition, the surface chemistry is discussed in the context of particle-particle interactions leading to flocculation or aggregation, because optimum suspension properties occur in well-dispersed, non-aggregated systems. A comprehensive review of large aspect ratio nanoparticles in low and high molecular weight liquids is then presented, with discussions of the effects of particle size, surface treatment, meso-structural development on linear and non-linear viscoelastic properties (complex, steady shear, and extensional viscosity; shear thinning; stress overshoot; and primary normal stress difference where applicable). These sections elaborate on the following results of nanoparticle suspensions. First, nanocomposites require much lower concentrations for the same rheological effects as conventional micro-composites, because of the nanoparticle's larger available surface area and the development of a meso-structural polymer-nanoparticle network. Second, the linear viscoelastic properties generally increase with the addition of nanofiller, and the nanoparticles profoundly broaden the relaxation dynamics of the polymer melt. Third, the primary normal stress difference (N_1) becomes negative at high stresses and high nanoparticle loadings. Finally, nanoparticles increase the values of extensional viscosity as a function of Hencky strain to a greater extent than micron sized fillers. This review concludes with a discussion of recent theory concerning particle network development and the nature of particle-polymer interactions with an emphasis on what types of constitutive relations are needed to describe the rheology of fluids containing high aspect ratio nanoparticles.

KEYWORDS: Nanocomposite; rheology; viscoelasticity; normal stress; yield stress; extensional viscosity; layered silicates; carbon nanotubes; carbon nanofibers; colloidal suspensions.

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RHEOLOGY OF FRESH CEMENT AND CONCRETE

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ABSTRACT

Cement-based materials are of enormous technological importance and their satisfactory performance depends on being able to transport and mould them in the freshly mixed state. This article describes the rheology of fresh cement, mortar, concrete and related products in the context of practical situations, and deals with testing and measurement, together with the main features of their behaviour. It explores the links between rheology and technology, and identifies areas where these are weak and could benefit from further experimental and computational effort.

KEYWORDS: Cement; concrete; mortar; grout; composites; rheometry; viscoelasticity; thixotropy; modelling.

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INSTABILITIES IN EXTENSIONAL DEFORMATION POLYMER PROCESSING

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ABSTRACT

Instabilities in extensional deformation polymer processing have been reviewed focusing on the draw resonance, a Hopf bifurcation instability frequently occurring in hyperbolic systems. This draw resonance instability is usually one of the most industrially important productivity issues as well as the academically intriguing stability problem because its nonlinear dynamics is complicated and it always affects in a profound way the typical continuous polymer processing such as fiber spinning, film casting and film blowing where extensional deformation plays a dominant role in shaping and imparting desirable properties to the final polymer product. Experimental and theoretical results on draw resonance instability reported in the literature during the past four decades have been reviewed starting from the first discovery and naming as such in experimental observations, and the first theoretical modeling of each process, and then ending with pertinent recent research results. Also, the most important research topics and directions to be pursued in the future for each process are explained with highlights on several recent results that are showing crucial, relevant progress.

KEYWORDS: Coordinate transformation; draw resonance; extensional deformation; fiber spinning; film casting; film blowing; flow-induced crystallization; helical instability; nonlinear dynamics; orthogonal collocation; polymer processing; sensitivity; stability; transient solution.

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MOLECULAR DYNAMICS SIMULATION AND ITS APPLICATION TO NANO-RHEOLOGY

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ABSTRACT

Over the last 15 years molecular dynamics (MD) simulations have become one of the important tools to tackle many of the complex problems that are faced by rheologists and engineers. The advent of modern areas of science such as nano-technology and the need to understand physical phenomena including rheology and tribology at the molecular scale have helped the growth of research both experimentally and computationally at nano-scales. Molecular dynamics simulations among other molecular simulation methods have been used for computational research in those areas. Application of molecular dynamics to rheology has helped to understand the behaviour of polymers qualitatively; also important progress has been made in predicting quantitative rheological properties such as the viscosity of simpler liquids (such as alkanes). In particular the application of MD to the behaviour of confined fluids and lubricants at nano-scales has revealed some important properties and explained the underlying physics of observed phenomena that include enhanced viscosity and relaxation times and the role of normal stress differences in supporting large loads. MD has been a valuable tool in studying the relationship of the molecular structure and the rheological properties. In this review we will give an introduction about the method and will discuss some of the progress made to date. Our main focus will be on the application of MD in the nano-rheology of ultra-thin confined films.

KEYWORDS: Rheology; molecular dynamics simulation; nano-rheology; confined films; boundary conditions; slip; friction; tribology; polymers, liquid crystals, amorphous surface, crystalline surface.

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THE RHEOLOGY OF WORM-LIKE MICELLAR FLUIDS

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ABSTRACT

This article reviews what has been published on the rheology of worm-like micellar fluids (WLMFs). It is written primarily for those interested in continuum (non-Newtonian fluid) mechanics: it covers the bulk rheological behaviour of typical WLMFs and rheological equations of state (REoS) that reflect this bulk behaviour; it also covers molecular dynamics and Brownian dynamics models that aim to predict observed behaviour. It is concluded that experimental measurements have been restricted to a limited range of flow kinematics only, and so agreement with particular (suitably parametrised) theoretical models for REoS has not been conclusively validated. It also raises the question of whether WLMFs can be treated as "simple fluids" once shear banding and rheological chaos ensue, as have been observed.

KEYWORDS: Worm-like-micellar; simple-shear rheometry; extensional rheometry; rheological equations of state; molecular dynamics; Brownian dynamics; living polymers

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RHEOMETRY FOR BLOOD COAGULATION STUDIES

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ABSTRACT

This review considers some of the various rheometrical approaches that have been adopted to study blood coagulation, with special reference to the rheological assessment of clotting time and studies of the evolution of viscoelasticity during the course of fibrin polymerization and cross-linking. A common feature of many of these studies is that they attempt to detect a liquid-to-solid transition during coagulation and the significance of the Gel Point in blood coagulation studies is discussed. Coagulation studies based on various forms of shear viscosity measurements and complex shear modulus measurements are considered, the latter being based principally on instruments such as the various controlled stress and controlled strain rheometers. Also considered is the long established technique of thromboelastography, while several emerging techniques are described. The latter include damped oscillation rheometry, various forms of wave propagation measurements and other, less widely used techniques such as free oscillation rheometry, quartz crystal microbalance measurements and surface plasmon resonance.

KEYWORDS: Blood coagulation; Clot viscoelasticity; Incipient clot; Gel point; Clot formation time.