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Advances in Polymer Science

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Advances in Polymer Science

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High Solid Dispersions

Volume Editor: Michel Cloitre

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G. Fytas · J.P. Gong · L. Isa · Y. Osada · W.C.K. Poon
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Advances in Polymer Sciences

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Aims and Scope

The series *Advances in Polymer Science* presents critical reviews of the present and future trends in polymer and biopolymer science including chemistry, physical chemistry, physics and material science. It is addressed to all scientists at universities and in industry who wish to keep abreast of advances in the topics covered.

Review articles for the topical volumes are invited by the volume editors. As a rule, single contributions are also specially commissioned. The editors and publishers will, however, always be pleased to receive suggestions and supplementary information. Papers are accepted for *Advances in Polymer Science* in English.

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Preface

High solid dispersions refer to a broad class of materials comprising colloidal or non-colloidal particles dispersed at very high volume fraction in a liquid phase. They are ubiquitous in daily life, in industry, in biology and in geophysics, encompassing a great variety of systems at the frontier between polymers, colloidal glasses and granular materials. Among these are personal care products, paints, drilling muds, biological tissues and various types of synthetic or natural slurries. In spite of their huge diversity in composition, high solid dispersions have an amorphous jammed structure in common, which is at the origin of remarkable properties. At high volume fraction, the individual motion of particles is dramatically reduced unless a sufficient force is applied to overcome steric constraints. A striking consequence is that high solid dispersions behave like solids at rest but yield and flow under large stresses. The existence and the nature of this solid–liquid transition, which can take a variety of forms, have perplexed engineers and scientist for a long time. Over the years, high solid dispersions have stimulated a lot of work both from an applied and fundamental perspective. On the applied side, controlling the flowability of high solid dispersions is central to the formulation of a large range of commercial products and to the processing of high performance materials such as coatings, ceramics and serigraphic inks. On the fundamental side, understanding the complex behaviour of high solid dispersions is an outstanding challenge for statistical and condensed-matter physics as well as for materials science, biology and geophysics. During the last decade, it has become clear that macroscopic descriptions of high solid dispersions have reached their limits, and that a microscopic approach linking the structure and the dynamics at different scales is highly desirable. The contributions collected in this volume review some results obtained recently in this direction.

The volume begins with a chapter by Vlassopoulos and Fytas who survey how macromolecular and colloidal chemistry can be used to design high solid colloidal dispersions exhibiting a rich variety of phase states and material properties. The authors describe two strategies. The first strategy uses well-defined colloidal particles with tunable interaction potentials much softer than the very short-range repulsion existing between solid particles. Soft particles, which can be as diverse as grafted hard spheres, multiarm star polymers, microgels, block copolymer micelles, dendrimers and dendritically branched polymers, display an extraordinary variety

of architectures and topologies. The second strategy consists in engineering soft nanocomposites by blending different classes of colloidal particles or polymers. In both types of materials, interactions and transitions are manipulated by tuning the chemical (composition, architecture and topology) and physical (temperature, solvent, depletion, enthalpy–entropy balance) parameters. This in turn provides unique tools to tailor the dynamics and the rheology of soft particle dispersions.

As explained above, several aspects of the structure, local dynamics and macroscopic rheology of high solid dispersions exhibit strong analogies with the physics of glasses. In Chap. 2, Fuchs focuses on concentrated suspensions of colloidal, slightly polydisperse hard spheres interacting through excluded volume interactions, which constitute one of the simplest systems undergoing a glass transition. He discusses the universal scenario of the glass transition under shear and reviews recent extensions of Mode Coupling Theory that offers a microscopic theory of the linear and non-linear rheology of colloidal fluids and glasses under shear, starting from first principles.

In Chap. 3, Bonnecaze and Cloitre focus on high solid dispersions made of elastic and deformable particles packed together at volume fractions well above close-packing, they term soft glasses. Unlike hard sphere glasses, soft glasses interact through slowly varying repulsive forces of elastic origin that develop at the contacts between the particles. The solvent plays an important role in transmitting the elastic interactions through the glass. After reviewing some generic features of soft glasses, the authors show that many of their properties result from a subtle interplay between disorder and solvent-mediated elasto-hydrodynamic interactions, which thus constitute the two basic ingredients of a micromechanical description of soft glasses. The theory quantitatively accounts for near-equilibrium properties (statistical distribution, osmotic pressure, shear modulus), for the slip phenomena occurring when soft glasses are sheared near smooth surfaces, and for the non-linear rheology of soft glasses.

Generally, high solid dispersions do not flow homogeneously when they are sheared; instead the macroscopic deformation is localized in slip zones, shear-bands or fractures. In Chap. 4, Isa, Besseling, Schofield and Poon review modern advances in fast confocal microscopy imaging and data analysis techniques, which enable time-resolved tracking of individual particles in Brownian and non-Brownian suspensions and glasses. After describing the sample environments and the experimental technique needed to perform this kind of experiments, they present several applications of fast confocal imaging as a unique tool to probe the flow response of hard sphere suspensions and glasses, giving emphasis to the relation between particle scale dynamics and non-linear rheological phenomena such as yielding, shear localization, wall slip and shear-induced ordering.

Chapter 5, by Gong and Osada, is devoted to biological tissues which constitute one particular class of high solid dispersions, consisting of water and various macromolecular components. Bio-tissues have exceptional mechanical properties such as low friction, high toughness, specific adhesion and shock-absorbance capacity. The authors discuss recent progress on the study and development of model synthetic soft and wet hydrogels as substitutes to natural bio-tissues. A strong emphasis is

given to the rich and complex surface friction and lubrication properties of these materials, which are found to share common features with the slip properties of soft glasses reviewed in Chap. 3.

It was our intention to provide the Soft Matter community with a comprehensive review of some recent approaches on the rheology of polymer–colloid dispersions. We hope that the reader will feel that the different topics discussed in this volume, which each address a particular facet of high solid dispersions, complement each other and help to draw a bridge between microscopic phenomena and macroscopic rheology.

France

Michel Cloitre

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