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Processing of Polymer-based Nanocomposites

Introduction

Springer

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Preface

Over the last few years, “nanomaterial” and “nanotechnology” have become well-known terms, not only among scientists, engineers, fashion designers, and architects, but also the general public. Owing to their extraordinary and unexpected behavior, nanomaterials have gained tremendous attention in fields such as automotive, electronics, aerospace, health care, and biomedical and have significant potential for many modern advanced technological applications. In this direction, a great deal of research and development effort has emerged around the hybrid organic–inorganic systems, and, in particular, attention has been given to those in which nanofillers (or nanoparticles, NPs) are dispersed in a polymer matrix. This class of materials is called polymer nanocomposites (PNCs) and shows unique value-added properties that are completely absent in neat matrices and conventional composites.

NPs can be made from a wide range of materials, the most common being layered silicates, carbon nanotubes, graphene or graphite oxide, and metal oxides. Over the last two decades, various types of NPs have been used for the preparation of PNCs with almost all types of polymers and polymer blends. However, layered silicates, carbon nanotubes, and graphene-containing PNCs have attracted in current advanced materials research, because these NPs can remarkably enhance the inherent properties of neat polymers after PNCs formation.

Control of the dispersion of NPs in polymer matrices and the interactions between NPs and macromolecular chains are necessary to explore PNCs full potential for a wide range of applications. This can be achieved by proper surface functionalization and modification of the NPs, which enhance their interaction with matrix. Functionalization of NPs consequently influences the colloidal stability, dispersion, and controlled assembly of NPs.

The performance of a PNC is dictated by three main factors: (i) the inherent properties of the components; (ii) interfacial interactions; and (iii) structure of the PNCs. The structure of a PNC depends on the dispersion and distribution of the NPs in the polymer matrix. However, improving the dispersion by mechanical means or via chemical bonding can influence the properties of the obtained PNCs.

Therefore, elucidating the dispersion and distribution characteristics and the associated mechanisms is important and can allow prediction of the final properties.

Over the past few years, great deals of advancements have been made in PNCs research and development, and the dispersion of the NPs in the polymer matrix remains a key challenge to their widespread application. Undoubtedly, to maximize the interfacial area in the PNCs, the dispersion should be on the scale of the individual NPs, otherwise aggregation results in a lower specific surface area, and microcomposites are ultimately formed. A large portion of this book is dedicated to reviewing methods for manipulating the interface, as well as the kinetic aspects of the dispersion of nanoparticles in polymer matrices, for example, controlling extrusion parameters during melt-processing.

Another pressing matter is the control of the structural morphology of the PNCs to achieve time-independent equilibrium. Often, further processing, for example, extrusion and then injection molding, results in a different dynamic equilibrium, which makes it difficult to tune the emergent properties. A similar complex challenge involves scaling-up preparation of the PNCs to industrially viable quantities, especially for solvent-based systems. To secure economic and other societal impacts, sufficient volumes of NPs and PNCs need to be manufactured in order to be transformed into market-ready products. Most research and development laboratories around the world focus on processes with tightly controlled laboratory environments which are not necessarily appropriate for safe, reliable, effective, and affordable large-scale production. Funding to address these challenges is still required. In addition, as with other new technologies, societal aspects need to be considered in parallel with the development of the technology. Consumer perceptions regarding the risks of certain nanoparticles, whether proven or not, need to be addressed to ensure a smoother uptake of the technology.

In summary, the field of PNCs has shown disparate results, successes as well as challenges. Much work remains to be done in fundamental research to achieve better control of the desired properties, for example, processing PNCs to achieve the desired level of dispersion of the NPs. This book focusses the effect of process variables on the structural evolution of polymer composites and the production of either micro- or nanocomposites, as well as the effect of the dispersion state on the final properties at a fundamental level.

Processing these PNCs usually requires special attention as the resultant structures on the micro- and nanolevel are directly influenced by the polymer/NP chemistry and processing strategy, among others. The structure then affects the properties of the resultant composite materials. This book is structured into two volumes. The first volume introduces readers to nanomaterials and PNCs processing. After defining NPs and PNCs and discussing environmental aspects, Chap. 2 focuses on the synthesis and functionalization of nanomaterials with applications in PNC technology. A brief overview on nanoclay and nanoclay-containing PNC formation is provided in Chap. 3. Chapter 4 provides an overview of the PNCs structural elucidation techniques, such as X-ray diffraction and scattering, microscopy and spectroscopy, nuclear magnetic resonance, Fourier transform infrared spectroscopy and microscopy, and rheology. The last chapter provides an overview on how melt-processing strategy impacts structure and mechanical properties of polymer nanocomposites by taking layered silicate-containing polypropylene nanocomposite as a model system.

The second volume focuses heavily on the processing technologies and strategies and extensively addresses the processing–structure–property–performance relationships in a wide range of polymer nanocomposites, such as commodity polymers (Chap. 1), engineering polymers (Chap. 2), elastomers (Chap. 3), thermosets (Chap. 4), biopolymers (Chap. 5), polymer blends (Chap. 6), and electrospun polymer (Chap. 7). The important role played by NPs in polymer blends structures in particular is illustrated.

This two-volume book is useful to undergraduate and postgraduate students (polymer engineering, materials science and engineering, chemical and process engineering), as well as research and development personnel, engineers, and material scientists.

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