Title	粒子サイズ制御を基盤とした超高分子量ポリエチレンの材料設計
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Abstract

Ultra-high-molecular-weight polyethylene (UHMWPE) exhibits outstanding toughness, impact strength, wear resistance, and self-lubricating properties due to its ultra-high molecular weight above 10^6. However, such an ultra-high molecular weight also results in high melt viscosity and poor melt flowability, limiting its processability in conventional techniques such as injection molding and extrusion molding. As a result, UHMWPE is commonly processed directly from reactor powder using compression molding or ram extrusion. In these methods, particle size has a significant effect on the mechanical properties. Commercial UHMWPE typically consists of macroparticles with average diameters of 80–300 μm, and larger particles tend to result in incomplete particle fusion and interparticle voids during molding, which can deteriorate mechanical properties. Polymer composites with functional fillers can improve properties such as mechanical performance and conductivity. Since melt mixing is not viable for UHMWPE nanocomposites due to the high melt viscosity of the polymer, powder-state mixing is the only practical approach for preparing UHMWPE/filler mixtures. This method relies on simple physical mixing of the polymer particles and fillers, which often results in poor filler dispersion and incomplete coalescence of the polymer particles. These structural deficiencies have hindered the development of multifunctional UHMWPE-based composites. To address the aforementioned limitations, this thesis employs particle size control by introducing microfine UHMWPE synthesized using a nano-sized Ziegler-Natta catalyst. The microfine particles fill interparticle voids and promote particle fusion. The proposed approach establishes a strategy to control filler distribution, which in turn enhances the mechanical properties as well as electrical and thermal conductivities of UHMWPE nanocomposites.

In Chapter 2, UHMWPE composites with graphene nanoplatelets (GNP) were prepared using microfine particles with 1−2 μm and the macroparticles. It was revealed that UHMWPE particle size governed the filler distribution and consequently the mechanical–electrical performance. The macroparticles induced segregated filler networks, achieving conductivity at low filler loadings but with poor mechanical properties, whereas the microfine particles enabled uniform filler dispersion and retained high strength even at higher loadings. A mixed matrix system with the microfine particles and the macroparticles achieved a favorable balance between mechanical performance and electrical conductivity, highlighting the role of UHMWPE particle size as a simple yet powerful design parameter.

In Chapter 3, the influence of sintering and drawing conditions was examined to further improve the mechanical properties of UHMWPE/GNP composites. Increasing sintering temperature effectively enhanced toughness without compromising conductivity, and high-temperature uniaxial drawing achieved an extension ratio of 38.2, demonstrating the superior interfacial fusion of the microfine particles and its potential for high-performance tapes and fibers.

In Chapter 4, the functionality of the microfine particles as a reinforcing and nucleating agent in polypropylene (PP) blends was investigated. The microfine particles enhanced PP crystallinity and stiffness through heterogeneous nucleation, establishing its versatility beyond UHMWPE-based systems.

In conclusion, this thesis establishes a materials-design strategy for UHMWPE and its composites based on particle size control, enabling control over filler distribution. This approach allows the fabrication of composites with well-balanced electrical, thermal, and mechanical properties. The findings provide fundamental insights into structure–property relationships in UHMWPE-based materials and propose a new design strategy for multifunctional polyolefin systems through particle size control.

Keywords: Ziegler-Natta catalyst, Ultra-high-molecular-weight polyethylene, Polymer nanocomposite, Particle size control, Conductivity