【Grant-in-Aid for Transformative Research Areas（B）】

Hierarchical dynamics of complex systems

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Project Information	Project Number : 26B206　Project Period (FY) : 2026-2028 Keywords : Hierarchical dynamics of complex systems, Crystalline polymer, Composite material, Polymer structure and physical properties, Interface

Purpose and Background of the Research

●Outline of the Research

Toward the realization of a carbon-neutral society, the use of lightweight, high-strength plastics as structural materials is increasing. Composite materials prepared by adding fillers to crystalline (semicrystalline) polymers are widely used to achieve desired mechanical properties. However, these materials are a "**complex system**" in which **mechanical properties** are difficult to understand from individual production conditions, and development has relied on empirical approaches. Establishing scientific principles to understand the necessary conditions for improving mechanical properties has been left behind.

Although the structures and mechanical properties of crystalline polymers with **hierarchical structures** have been individually clarified at each scale, understanding their cross-scale interactions remains a challenging problem.

This project aims to understand the **mechanical properties** of **crystalline polymer/filler composite materials** from the bottom up. By clarifying deformation and fracture processes and revealing the correlations among mechanical properties from nano to macro scales, "**Hierarchical dynamics of complex systems**" is established and applied in materials development and design. Through the collaboration of computational science, experimental mechanics, and materials design, this research project will bring about an academic transformation in materials science.

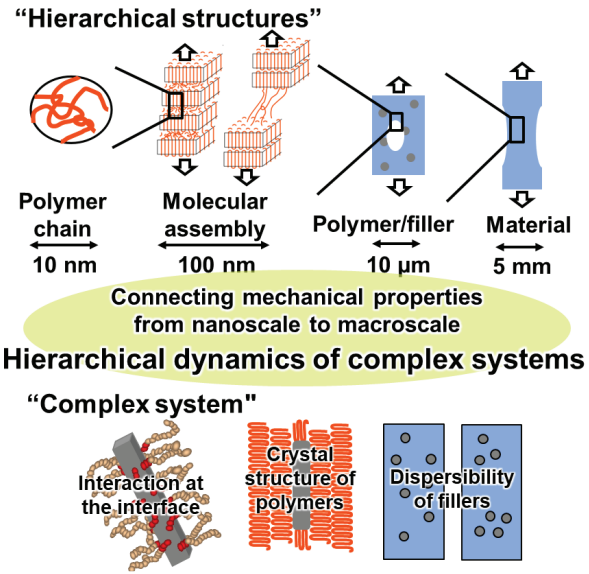

Figure 1. "Hierarchical Dynamics of Complex Systems"

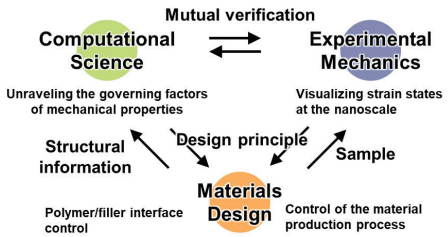

Figure 2. Collaboration in this research area

●Connections to Everyday Life

Mechanical properties of plastics: Phenomena such as the ease of cracking and deformation of plastics.
Lightweight, high-strength, and easily processable plastics: Lightweight automotive parts, etc.

Expected Research Achievements

By focusing on polymer chain orientation and its change processes in crystalline polymer/filler composite materials, the correlations between structures and mechanical properties from nano to macro scales are elucidated, establishing the scientific principles of hierarchical dynamics of complex systems. Through the collaboration of polymer science, interfacial science, statistical physics, and materials development research, the governing factors of mechanical properties are revealed across multi scales. This will lead to a departure from empirical development and the integration of research across separate disciplines, bringing about an academic transformation in materials science that leads the world.

● A01 Computational Science

Yuji Higuchi (PI, Kyushu Univ.), **Erika Uehara** (Co-I, Osaka Univ.), **Yutaka Oya** (Co-I, Tokyo Metropolitan Univ.)
We elucidate nanoscale deformation and fracture processes and clarify structure–mechanical property correlations from nano to micro scales.

● A02 Experimental Mechanics

Go Yamamoto (PI, Tohoku Univ.), **Tomohiro Miyata** (Co-I, Tohoku Univ.)
TEM-based techniques are established to visualize nanoscale strain states. A micro to macro analytical model is constructed to predict macro-scale mechanical properties.

● A03 Materials Design

Keita Sakakibara (PI, AIST), **Naoto Kamiuchi** (Co-I, AIST), **Yuta Hikima** (Co-I, AIST)
We elucidate the effects of interfaces and processing conditions on the structure of polymer/filler composite materials, and characterize the structural information.

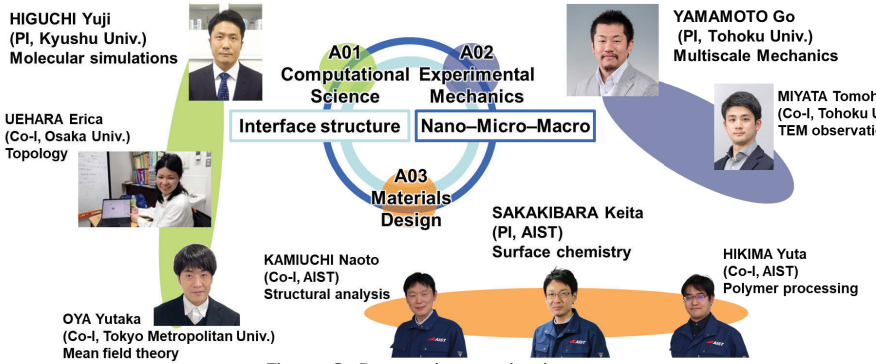

Figure 3. Research organization

● Expected Broader Impacts and Future Developments

The findings will broadly advance materials science, as nanoscale interfacial interactions influencing macroscopic properties through hierarchical structures are universal across polymers, ceramics, and metals. The proposed design guidelines will support durability improvements, cost reduction, and recycling applications. Redefining hierarchical dynamics of complex systems in a broader context will also illuminate parallels with cellular and artificial cell deformation.

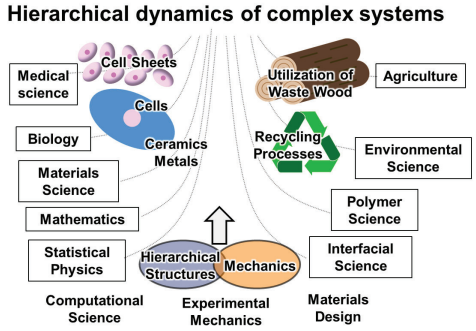

Figure 4. Creation of larger-scale and interdisciplinary scientific fields

Website(s)	https://ri2t.kyushu-u.ac.jp/~hierarchical-dynamics/