Research area in Strategic Objective *"Precision control of bonding and decomposition for resource recycling"*

Secure bonding and gentle degradation for sustainable material design

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Overview

This research area focuses on the effective use of resources and the construction of sustainable material production systems, and its goal is to establish research and develop original fundamental technologies for the creation of sustainable materials, which stably demonstrate excellent functions and performance in use, with the characteristics of secure bonding and gentle degradation. Gentle degradation refers to the rapid degradation of materials into intermediate or sub-components, or else degradation at atomic or molecular levels under mild conditions in order to cycle them into reusable materials after use.

Specifically, we will conduct research and development of precise control technologies for bonding and degradation of polymeric, organic, biological, inorganic, and metallic materials, and their composites, with the goal of designing and developing high-performance sustainable materials. We will also investigate the materials with bonds that can control not only physical properties and structure but also degradability, and the catalysts that can selectively cleave chemical bonds, and material design to introduce the degradable segments into the materials. Our goals include developing technologies for controlling bond formation and cleavage of organic and inorganic compounds by external stimuli, creating technologies for controlling adhesion and desorption of different material interfaces, and developing technologies for controlling higher-order structures to establish degradation and recycling methods for composite materials, such as phase-separated and hierarchical structures.

We also deal with the development of measurement and analysis techniques required in this field, such as visualization of nano-, meso-, and highly ordered structures in composite materials using such techniques as Ultra Small Angle X-ray Scattering, 3D Tomography, and Transmission Electron Microscopy. We develop predictions of bonding and degradation using theoretical chemistry and computer simulation. In addition, we focus on the integration of materials science and biology and promote research on the use of biocatalytic enzymes besides conventional catalysts to achieve bonding and degradation under mild conditions such as in water systems, at ambient temperature, and at ambient pressure. Through these efforts, we will contribute to the realization of a sustainable society by establishing the methods to flexibly control secure bonding and gentle degradation for recycling.

Research Supervisor's Policy on Call for Application, Selection, and Management of the Research Area

1. Background

Plastics are the most important industrial products of the 20th century and have enriched the lives of human beings. They have light, strong, and long-lasting properties, and are used for not only daily necessities, but also in the fields of medicine, electronics, automobiles, aerospace, construction and so on. However, in recent years, the disposal of plastics after use has become a major social issue in Japan due to the impact of marine plastics on the biological environment caused by disposing them, and due to import restrictions in China and other countries that have been importing waste plastics as recycled materials. In addition, it is expected that the disposal of advanced materials will cause social issues in the future, which includes lithium-ion batteries, whose production is expanding due to the widespread use of electric vehicles, rare metals and semiconductors used in electronic devices, and carbon fiber composite materials, whose use for aircraft and automobiles is increasing due to their light weight and high stability. The materials, including composites, are strongly required to have high strength, high heat resistance, and long-term stability to prevent degradation during use. Their molecular structure is strong and rigid, and they are tightly bonded to the surrounding matrix.

In Japan, where resources are scarce, there is a strong need to recycle products by disassembling them into raw materials or intermediate components at the end of their product life. However, major issues include the difficulty of separating the reinforced materials added to meet the required performance and the difficulty of disassembly due to the complexity and multilayered nature of the products. Therefore, it is desirable to design and develop sustainable materials that can be returned to raw materials or intermediate components after the end of product life. The degradation of strong and rigid materials requires a great deal of energy, and products may unfortunately not be reusable after they have been degraded under severe conditions such as at high temperatures, high pressure, or in strong acids or alkalis. In the study of materials to date, there has been a strong focus on stability and functionality, and research on degradation and separation has remained undeveloped. To create sustainable materials, there is an urgent requirement to understand degradation and separation from the nano- to macro-level, and to advance the science of degradation. The goal of this research area, "secure bonding and gentle degradation," is essentially a trade-off theme, and is considered one of the most difficult problems in the materials field. However, looking at it from a different perspective, it is an extremely important and challenging theme that we must seriously face by concentrating our knowledge. We are looking for groundbreaking and innovative research themes that are conceived originally by young researchers.

2. Principle of invitation project and selection

(1) Application policies

(a) This area covers all materials that make up industrial products, including polymeric, organic, biological, inorganic, and metallic materials and their composites. However, proposals that focus on drugs, plants, animals, or microorganisms themselves are excluded.

(b) We are seeking proposals for research on the rapid degradation of various materials to intermediate or sub-components, or else degradation at atomic or molecular levels, research to advance structural/interface measurement and visualization techniques, simulation of bonding/degradation, computation to support the research, and research to advance lifetime prediction methods.

Specifically, we are seeking proposals to investigate materials with bonds that can control not only physical properties and structure but also degradability, and the catalysts that can selectively cleave chemical bonds, and material design to introduce the degradable segments into the materials. Our goals include developing technologies for controlling bond formation and cleavage of organic and inorganic compounds by external stimuli, creating technologies for controlling adhesion and desorption of different material interfaces, and developing technologies for controlling higher-order structures to establish degradation and recycling methods for composite materials, such as phase-separated and hierarchical structures.

(c) Proposals for the coexistence of degradation and stable bonding (structure) are also welcome.

(d) With the goal of fusing materials science and biology, research proposals using enzymes, which are biocatalysts, are also welcome.

(e) Proposals on the subject of detail material characterization are also welcome.

(2) Selection Policy

(a) Proposals should be challenging and attractive based on the proposer's original ideas.

(b) The proposal should contribute to the creation of sustainable materials.

(c) Some of the proposals were made solely for the purpose of material synthesis. Proposals should include evaluation of the physical properties of the materials synthesized by the applicant and their incorporation into components.

(d) Excellent and challenging research proposals without being bound by the research fields adopted last year will be accepted.

(e) This year, with the aim of forming diverse collaborative research, the selection process in a way that is not biased toward universities, national institutes, regions, or gender will be conducted.

3. Research periods and research funds

The research period of PRESTO is 3.5 years, and the upper limit of research expenses is 40 million yen.

4. Principle of research-area management

This area will promote basic research that contributes to the creation of sustainable materials with a focus on degradation, based on the original and attractive ideas of individuals, while emphasizing the exchange of opinions among the research director, research area advisor, and researchers. In addition to actively encouraging publication of the results obtained, we will promote collaboration and academic exchange with CREST "Precise Materials Science for Degradation and Stability," which is being implemented under the same strategic goal, by holding workshops and symposia.