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

Design engineering for outstanding materials with controlled soft-stiff heterogeneity (outstanding materials project area)

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Purpose and Background of the Research

●Outline of the Research

Our daily lives are supported by a wide range of materials, from soft and stretchable materials, such as rubber, gel, and plastic, to hard and difficult-to-stretch materials, such as glass and metal. However, such materials face problems in various situations, such as breaking when a strong force is applied or bending because the material is too soft. The traditional theory of materials development was to achieve homogeneity to minimize defects. However, this results in the tradeoff where a hard material becomes brittle, and making it tougher results in it becoming soft. Research in this project area involves the design of heterogeneous structures that are both “soft” and “stiff,” and that can be universally applied to a wide variety of materials. The design principle of this “soft-stiff” heterogeneous structure will be used as a basis to develop a group of materials that exceeds tradeoffs (outstanding materials). Furthermore, a new material design science will be developed to achieve ideal structural materials that are strong and flexible and that would be common to all solid materials, such as metals, polymers, and ceramics.

●Background and purpose

Our highly developed modern civilization is supported by a wide variety of materials. Not a day goes by where we do not see light and moldable plastics, flexible and shock-absorbing elastomers (soft polymeric materials, such as gel and rubber), strong and processable metals, and transparent, hard, and deterioration-resistant glass. The fundamental goal of developing these materials is making them durable, flexible, and strong. The common and conventional method for creating such ideal materials has been to use a material design strategy that synthesizes homogeneous materials by eliminating unevenness in the material as much as possible, regardless of material type. However, all materials have a tradeoff between strength and deformation when homogeneous, with the common issue of one property deteriorating when another is improved, as shown in Fig. 1. Simply changing the composition is not a surefire way to eliminate these mechanical tradeoffs.

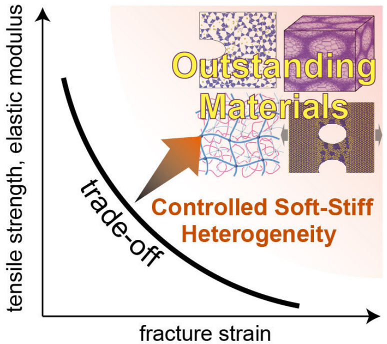

Figure 1. Diagram of outstanding materials design

The researchers of this project area tackled this fate of material properties by casting aside the commonly held homogeneous material strategy for each material, and instead aiming for materials that transcend this tradeoff by intentionally creating a microscopic heterogeneous structure within the material. The researchers will develop an academic field that investigates the kind of heterogeneous structure that needs to be designed to achieve this, and establish a universal field of study that allows this to be applied to any material.

● Aim of project area

In this project area, an intentionally controlled heterogeneous structure is created within the material to achieve strong and flexible materials that transcend the tradeoffs that exist in homogeneous materials.

Researchers with expertise in ceramics, metals, plastics, and elastomers are developing outstanding materials based on their unique heterogeneous material design policies and clarifying how heterogeneous structures influence mechanical properties. They will then integrate the results of each individual material from the perspective of universal mechanics and develop a universal design theory for heterogeneous materials that does not depend on the material. Furthermore, each researcher feeds back the design guidelines to their own material design to create even better materials. Such a cycle (Fig. 2) will integrate the knowledge of each material and achieve the development of even better outstanding materials as well as establish a universal soft-stiff heterogeneous mechanical design.

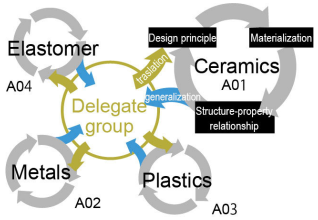

Figure 2. Diagram of research cycle in this project area

Expected Research Achievements

●Project area goals

The goal of this project area is to create a new academic field that breaks through the limits of material properties through heterogeneity that can be applied to various materials. A specific focus will be on ceramics, metals, plastics, and elastomers, which are important artificial materials, and the heterogeneous structures of soft-stiff materials that operate on different sizes and principles will be utilized to develop outstanding materials (Fig. 3). The heterogeneity of these soft and stiff materials is also characterized by the fact that the deformation regions where functions are expressed are different (Fig. 4).

- Elastic region: Heterogeneous glass that disperses force at the crack tip and makes crack propagation difficult (A01)
- Near yield point: Strong and stretchable heterogeneous metal (A02)
- Plastic deformation region: Heterogeneous plastic whose atomic arrangement changes at the crack tip and makes crack propagation difficult (A03)
- Network rupture region: Heterogeneous elastomer whose molecular network changes owing to force and makes cracking difficult (A04)

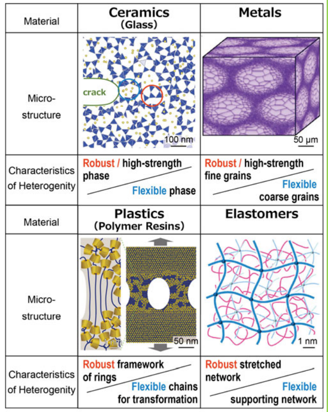

Figure 3. Diagram of the soft-stiff heterogeneous structure, which is the focus of this study

The manner in which heterogeneous structures govern deformation and fracture will be clarified, and the unique and common aspects of the results observed in each planned study will also be clarified. Each planned study will focus on the following three points to understand commonalities across materials.

- Analysis and evaluation of materials that deform and fracture in different ways based on an integrated philosophy
- Systematic changing of material parameters and elucidation of correlation between material parameters and mechanical functions
- Simulation of relationship between microscopic material structure and mechanical function

These aspects will be used as a basis to pioneer new academic research that will realize new material designs that transcend mechanical tradeoffs through material heterogeneity in which stiff and soft structures support each other.

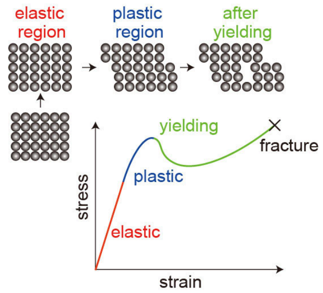

Figure 4. Team composition based on dynamic model

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