【Grant-in-Aid for Scientific Research (S)】

Metabolic Material System: Material Growth by Metabolic-like Destruction and Remodeling

Principal Investigator	Hokkaido University, Faculty of Advanced Life Science, Professor GONG Jian Ping	Researcher Number:20250417
Project Information	Project Number : 22H04968 Keywords : Metabolism, Reconstruction, Double Network, Mechanoradical	Project Period (FY) : 2022-2026

Purpose and Background of the Research

●Outline of the Research

Living tissue is a growable material whose structure is constantly remodeled through metabolism using nutrients taken from the environment. Through this metabolism, tissues renew its structures and functions to adapt to the environment. On the other hand, typical artificial materials such as metals and plastics seldom change their structure once synthesized. Since they do not undergo structural reconstruction, it is inherently difficult for them to develop their functions in response to their environment.

Therefore, our goal is to construct a material growth system that is similar to the metabolic reactions of living organisms. As shown in Figure 1, tissues firstly take nutrients such as amino acids from the outside. Next, the original structure is partially destructed. Finally, at the position where the partial destruction occurs, a new structure is formed using the taken nutrients. Structure, mechanical properties, and functions of tissues gradually change through these processes. Learning from the biological metabolism, we propose following three requirements for the growable artificial materials (stem materials): (1) an open system where molecules can be introduced from the outside, (2) partial destruction of the existing structure in response to stimuli, and (3) formation of a new structure at the position where the destruction occurs.

The purpose of this study is to realize various mechanical, morphological, and functional growth of stem materials through renewal of their internal structure. Such a material growing system by structural reconstruction is called a "metabolic material system".

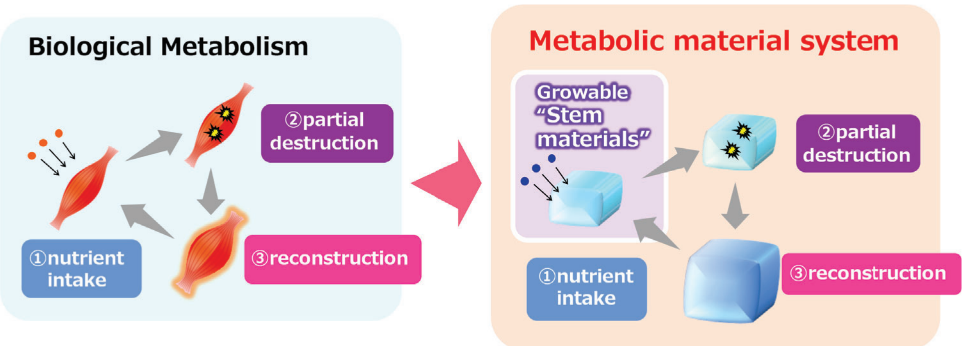

Figure 1. (left) Three elementary processes of biological metabolism, (right) schematic illustration of metabolic material system.

●Double-network gels

We propose double-network gels (DN gels) as a candidate stem material that satisfies the above requirements. DN gels consist of brittle and flexible networks, as shown in Figure 2. Gels are generally open systems that allow material exchange through solvents, satisfying requirement (1). When DN gels are deformed, the brittle network is preferentially ruptured, which is regarded as partial destruction (requirement (2)). The rupture of the brittle network generates mechanoradicals, which can induce polymerization inside the DN gel. This mechanoradical polymerization can be regarded as structure reconstruction (requirement (3)).

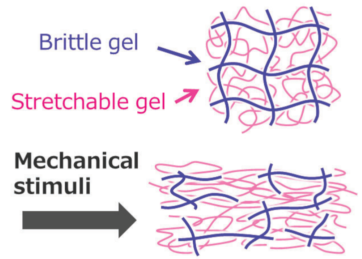

Figure 2. Structure and fracture process of a DN gel

Expected Research Achievements

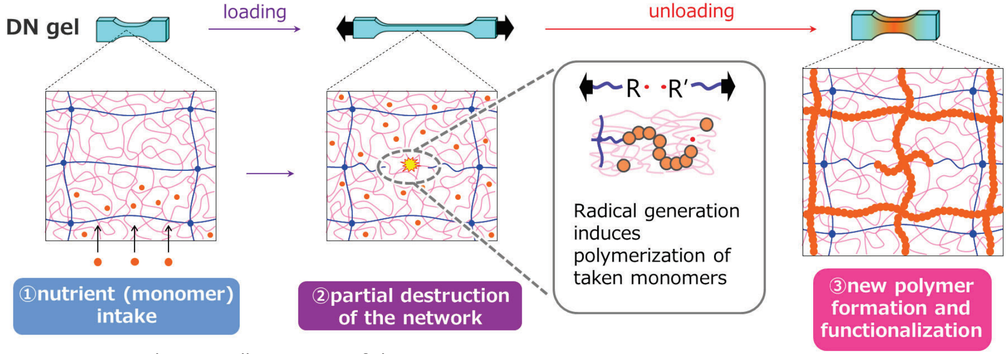

Figure 3. Schematic illustrations of the structure reconstruction process using a DN gel as a stem material

Figure 3 illustrates the growing process of a DN gel. First, the DN gel is immersed in a monomer solution (nutrient) to allow the molecules to diffuse inside. Next, mechanical stimuli is applied to the DN gel, which induces partial fracture of the brittle network. The rupture of the polymer chains generates radicals, which induce polymerization of monomers to form new polymers inside the DN gel. This structural reconstruction can be used to achieve various mechanical, morphological, and functional growth of DN gels (Figure 4). To date, muscle-like materials that grow in strength and weight with repeated mechanical loading, and methods that arbitrarily control the shape of DN gels with mechanical stimuli have been developed.

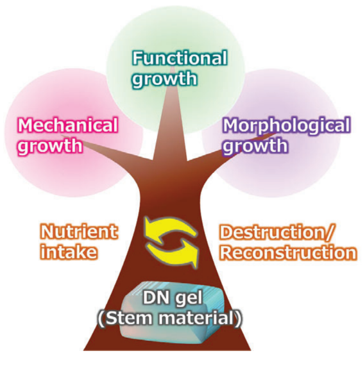

Figure 4. Diverse growths of DN gels realized by this work

Homepage Address, etc.	https://altair.sci.hokudai.ac.jp/g2/index_e.html