【Grant-in-Aid for Specially Promoted Research】

Science and Engineering

Title of Project：Challenge from mechanical self-organization to elucidate the physical properties of non-equilibrium soft matter / amorphous material

TANAKA Hajime
(The University of Tokyo, Graduate School of Frontier Sciences, Visiting Researcher)

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Keyword：Soft matter, amorphous materials, mechanical self-assembly

【Purpose and Background of the Research】

Materials without a periodic structure, including soft matter and amorphous materials, have unique mechanical (elasticity, yield and fracture behavior, and moldability) and thermal properties (specific heat and thermal conductivity) that are very different from those of crystalline materials, and have been shaping human history through their application in various fields. The structure of irregular systems has been studied based on the position of the center of gravity of the constituent particles, but the structural characteristics of these systems remain elusive. Therefore, a fundamental understanding of their structure-property relationships still lags far behind that of crystals. We are convinced that the momentum conservation law is closely related to determining the system state in the non-equilibrium state, even in the seemingly motionless solid state. By combining thermodynamic and kinetic approaches with the entirely new kinetic perspective of “self-organization of the mechanical network percolated throughout the system,” we aim at elucidating the structural features of materials in the non-equilibrium solid state, such as glasses and gels, as well as the physical mechanisms that determine their specific mechanical and thermal properties.

【Research Methods】

(1) Mechanical self-assembly of soft matter: We aim to elucidate the universal physical principles behind the mechanical self-assembly of soft matter by directly comparing simulations incorporating hydrodynamic effects with single-particle resolution imaging of phase separation and gelation in colloidal dispersions using 3D confocal microscopy.

(2) Mechanical topology, flow, and fracture: We will approach nonlinear rheology of colloidal systems (shear-thinning and thickening) from a new perspective, focusing on the relationship between flow and the topology of the network of force chains formed by colloidal and granular particles dispersed in a fluid.

(3) Understanding the properties of amorphous materials based on interaction network topology: Crystals are in thermodynamic and mechanical equilibrium, and the periodicity of their structures maintains their solidity. On the other hand, glass is in a non-equilibrium state and has no structural periodicity. Therefore, the principle of self-assembly, leading to the solidity of the structure of amorphous materials, is still unknown. We aim to elucidate the peculiar physical properties of amorphous materials based on the idea that solidification is a consequence of the mechanical self-organization of their structures. Specifically, we will elucidate the properties of the spatial mechanical network in amorphous solids by experiments and simulations, and challenge long-standing problems such as the mechanism of elasticity, fracture mechanisms, and the anomalies of heat conduction and specific heat at low temperatures, which are unique to amorphous materials.

【Expected Research Achievements and Scientific Significance】

Materials with a nonperiodic disordered structure are characterized by their unique mechanical properties, including deformation and fracture characteristics. We believe that the topology of the force transfer path is a critical structural factor governing their physical properties. In this research project, we aim to elucidate the structure-property relationships of aperiodic materials, focusing on the cooperation of thermodynamic and kinetic factors in their structuralization, which has not been considered before. We expect that this would deepen our physical understanding of the long-standing unsolved problems associated with aperiodically structured materials and create a new trend in developing highly functional materials with irregular structures.

【Publications Relevant to the Project】

- T Yanagishima, J Russo, H Tanaka, Common mechanism of thermodynamic and mechanical origin for ageing and crystallization of glasses, *Nature Communications* **8**, 15954 (2017).
- H Tsurusawa, M Leocmach, J Russo, H Tanaka, Direct link between mechanical stability in gels and percolation of isostatic particles, *Science Advances* **5**, eaav6090 (2019).

【Term of Project】 FY2020-2024

【Budget Allocation】 373,900 Thousand Yen

【Homepage Address and Other Contact Information】

http://tanakalab.iis.u-tokyo.ac.jp
tanaka@iis.u-tokyo.ac.jp