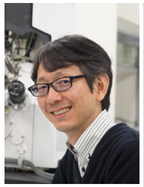
【Grant-in-Aid for Scientific Research (S)】

Material Mechanics of Quantum Supremacy Governing Complex Fracture Phenomena



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Project Information	Project Number : 24H00032 Project Period (FY) : 2024-2028 Keywords : Mechanical Engineering, Mechanics of Materials, Complex Fracture, Quantum Mechanics

Purpose and Background of the Research

● Outline of the Research

To create innovative devices that take advantage of the rich and diverse physical properties of materials, it is essential to have a fundamental understanding of material strength and to create and design strength based on that understanding. Detailed studies on the mechanics of fracture have been accumulated, and their academic achievements are approaching maturity. However, we humans still do not have sufficient means to intervene and manipulate the universal origin of material strength. Our research group has discovered that by intentionally injecting excess electrons and/or holes into materials using techniques such as electron beams, the materials can exhibit deformation and strength characteristics that they cannot originally possess (Figure 1). This effect dramatically amplifies in complex fracture phenomena sensitive to structural defects such as cracks, dislocations, and atomic vacancies (cracking, plastic deformation, creep, fatigue, etc.), surpassing the limits of conventional material strength (Figure 2). Such dramatic strength changes in complex fracture phenomena go beyond the effects of classical interpretation (quantum supremacy of material strength), and we believe that this will force a paradigm shift in material strength science.

Therefore, in this study, we conduct complex fracture strength experiments on specimens with controlled structural defects (mechanical field) and electron/hole distributions and strength analysis based on quantum mechanics, and elucidate the combined effect of the mechanical field generated by the structure and the quantum strengthening effect. We clarify the fundamental mechanisms of quantum supremacy that dramatically alter the complex fracture phenomena, and establish universal theories governing these phenomena.

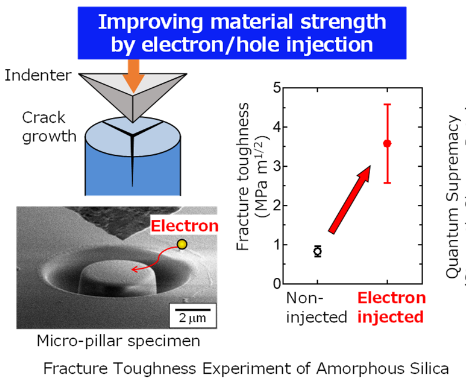

Figure 1. Effect of electrons/holes on material strength

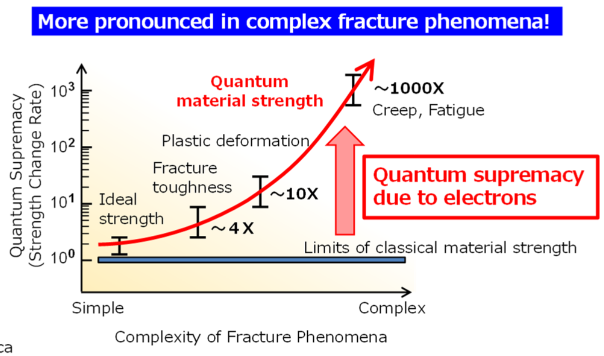

Figure 2. Quantum supremacy of material strength in complex fracture phenomena

● Methods

These complex fracture phenomena are all sensitive to microscopic structural defects, such as cracks and dislocations, and these defects play a crucial role in dramatic strength changes. The quantum supremacy of material strength appears as the combined effects of the mechanical fields generated by structural defects and the quantum effects of electrons. Therefore, we conduct complex fracture strength experiments that control structural defects and electron/hole distribution, observe and analyze changes in the microscopic defect structure induced by electron injection using electron microscopy at the atomic level. In addition, we perform quantum mechanics analysis on electron/hole-injected materials. Furthermore, based on a unique electronic stress theory that decomposes and extracts the stress that individual electrons are responsible for, we investigate the fundamental principles underlying the strength variations.

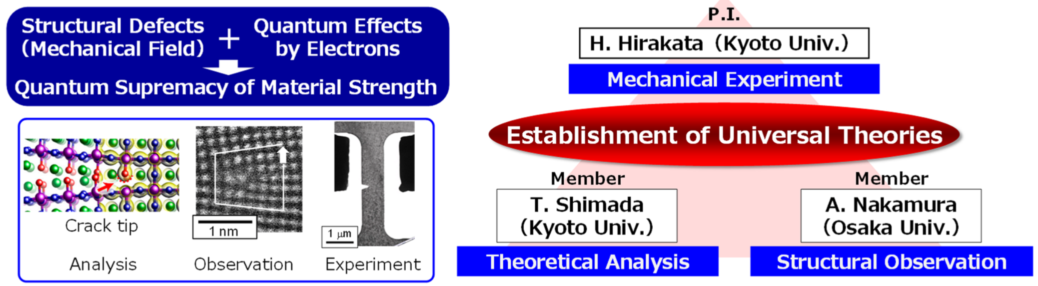

Figure 3. Research Methodology and Research Structure

Expected Research Achievements

● Features and Significance of This Research

- Elucidates the mechanisms and laws that alter various deformation and fracture phenomena by using the ultimately small particles, electrons and holes.
- Targets complex fracture phenomena (cracking, plastic deformation, creep/fatigue) that are problematic in actual structures.
- Establishes foundational techniques, including control and evaluation of excess electrons/holes, complex strength experiments under electron state control, observation of defect structures, electron analysis techniques, and the conceptualization of electronic stress theory.
- Brings about a paradigm shift from classical materials strength science, which designs strength based on materials and structures, to "Quantum Supremacy Material Mechanics“, where material strength is dramatically altered by electrons.
- The dynamic particles, excess electrons/holes, can be injected, retained, or removed within materials, offering controllable rewritability of material strength. In other words, this brings about a conceptual revolution in material strength design, from "creating" materials to "drawing" functions.

● Ripple Effects on Science and Technology, Industry, and Society

Unlike simple fracture strength, complex fracture phenomena such as fatigue and creep are difficult to predict and prevent. Even in today's advanced understanding of material strength, they remain critical issues in the industrial sector and central challenges in mechanical engineering. This study aims to create a safe societal foundation for the increasingly diversified future by exponentially improving complex fracture strength.

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