Doctoral Dissertation Evaluation Review

Degree requested Doctor of Soft Matter Science Applicant’s name Sukamto

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Title of Doctoral Dissertation

Study on Bone-Inspired Soft/Hard Composite with Unique Toughening Mechanism Trough Multiple Sacrificial Structure

(骨に着想を得た複数の犠牲構造による強靭化機構を備えたソフト/ハード複合材料に関する研究)

Results of Evaluation of the Doctoral Dissertation (Report)

Bones achieve exceptional mechanical properties through their multiscale structure, where different hierarchical levels work together to enhance toughness. At the macroscale, the combination of cortical and trabecular bone allows resistance to catastrophic fractures, while at the nanoscale, interactions between collagen and hydroxyapatite (HAp) nanocrystals introduce additional energy dissipation mechanisms, such as sacrificial bonds. Inspired by this natural system, the author has developed a bioinspired soft/hard composite material that mimics bone’s toughening mechanisms by integrating a porous biphasic calcium phosphate (BCP) ceramic skeleton with a poly(acrylic acid) (PAAc) hydrogel matrix.

The ceramic skeleton was fabricated using a sponge templating method, replicating the trabecular architecture of bone. The sintering process resulted in a biphasic structure, where HAp provides structural integrity, while β-tricalcium phosphate (β-TCP) facilitates calcium ion-mediated interactions. The hierarchical porous network enhances hydrogel infiltration, interfacial bonding, and efficient stress transfer, improving energy dissipation and mechanical performance. Mechanical testing revealed that the composite exhibits exceptional toughness and self-healing ability. Uniaxial tensile tests demonstrated that energy dissipation occurs through a combination of ceramic skeleton fracture, calcium-mediated ionic bonds, and dynamic re-adhesion between newly exposed ceramic surfaces and hydrogel. Cyclic tests further confirmed the composite’s high energy dissipation capacity, while faster self-healing behavior was observed in composites with lower crosslinker concentrations.

To optimize performance, two soft/hard composites were fabricated using ceramic skeletons with distinct architectures, S1 and S2. The PAAc-S2 composite, incorporating the S2 ceramic skeleton with smaller and more uniform pores, demonstrated greater toughness and energy absorption, attributed to enhanced stress distribution and stronger interfacial adhesion. These findings underscore the synergistic effect of hierarchical porosity, sacrificial bonds, and dynamic ionic interactions in improving the composite’s toughness.

This work provides a new biomimetic strategy for designing tough, self-healing composites, with potential applications in tissue engineering and regenerative medicine. The findings contribute valuable insights into bone-mimetic materials and soft-hard composite mechanics. Therefore, we acknowledge that the author is qualified to be granted the Doctorate of Soft Matter Science from Hokkaido University.