学　位　論　文　内　容　の　要　旨

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学　位　論　文　題　名

BIOINSPIRED COMPOSITE GYROID AND BIOMIMETIC VORONOI LATTICES FOR BIOMECHANICAL APPLICATIONS

(生体力学的応用のための生体に着想を得た複合ジャイロイドと生体模倣ボロノイ格子に関する研究)

This study investigates the design, fabrication, and optimization of bioinspired lattice structures to address challenges in automotive safety and dental implant performance. The research is organized into three interrelated studies that leverage advanced additive manufacturing and finite element analysis to mimic natural bone properties and enhance mechanical functionality. In the first study, composite triply periodic minimal surface (TPMS) gyroid lattices are developed and fabricated as shock absorbers for automotive applications. By combining two different TPMS gyroid architectures, the study demonstrates that these structures can significantly improve energy absorption and mechanical resilience under impact conditions. Finite element analysis and experimental tests validate the influence of lattice varied relative density on energy dissipation, demonstrating the potential of these designs to enhance crashworthiness. The second study focuses on dental implant design, where fully and hybrid configurations integrate both solid and gyroid TPMS lattice architectures to optimize stress distribution and reduce stress shielding. By varying lattice cell sizes and incorporating features such as anti-rotational connectors and square thread for initial stability, the fully and hybrid implants achieve improved stability and enhanced osseointegration. Dynamic loading simulations confirm that these implants maintain a balanced stiffness-to-compliance ratio, minimizing microstrains at the bone-implant interface and paving the way for personalized implant solutions. In the third study, a novel approach is presented to advance three-dimensional finite element analysis of dental implants by incorporating biomimetic Voronoi lattice trabecular bone models. These models accurately replicate the complex porosity of trabecular bone by varying pore sizes, which leads to a more realistic depiction of stress and strain distributions during functional loading. This biomimetic strategy deepens our understanding of implant-bone interactions and supports the development of implants that better accommodate the anisotropic nature of natural bone. Generally, the findings demonstrate the ground-breaking potential of tailored lattice structures across different biomechanical engineering applications. By integrating bioinspired design principles, additive manufacturing techniques, and robust computational analysis, this study offers promising approaches for enhancing both vehicle safety and dental implant systems, ultimately contributing to improved performance and clinical outcomes.

Chapter 1 establishes the background by investigating the impact of bioinspired lattice structures on a variety of applications, including automobile crashworthiness and dental implant stability. It describes the study’s scope, methodology, and the potential influence these structures might have on biomechanical engineering.

Chapter 2 investigates the significance of bioinspired lattice structures, especially composite TPMS-Gyroid lattices made using fused filament fabrication (FFF), in improving energy absorption in automotive and medicinal settings. It discusses the design, manufacturing procedures, mechanical testing, and finite element analysis used to optimize these structures for use in automotive safety equipment.
Chapter 3 introduces a hybrid biomechanical approach to dental implant design that combines solid and gyroid TPMS lattice architectures. It describes the use of sophisticated CAD modeling and finite element techniques to modify stress distribution and increase implant stability. The chapter compares fully and hybrid latticed implants, highlighting their significance in lowering stress concentrations, increasing implant lifespan, and enhancing outcomes in clinical trials.
Chapter 4 explores the use of biomimetic Voronoi lattice models in finite element analysis (FEA) to replicate human mandibular trabecular bone porosity and mechanical properties in dental implants. The study reveals that a 2.0 mm pore size enhances implant life and performance, emphasizing the importance of biomimetic designs in dental implant design.
Chapter 5 of the thesis summarizes major results and outlines future research topics. It summarizes the study's contributions to biomechanical engineering, notably improving lattice structures for automotive and dentistry applications, and makes recommendations for furthering the field of study.