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Mechanical Metamaterials: Geometry, Composition, and Mechanical Properties

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2018 Research and Creative for Undergraduate Students (RCEU) Proposal

Mechanical Metamaterials: Geometry, Composition, and Mechanical Properties

Mentoring Faculty Information

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Project Summary

With the fast- advancing additive manufacturing technology, metamaterials having highly detailed architecture are fabricated with a high production rate and low costs. Of particular interest, spatially-periodic lattices will be studied in this task as a light-weight core to support the sandwich structured envelope. Open-cell lattice/skeleton design and manufacturability: Cell topology has significant impacts on the mechanical properties, manufacturability, and cost of a meso-lattice structure. Fig. 1 (a) presents two representative configurations having different stress transferring mechanisms: the "tension dominant" lattice transform the external loads into tensile force on the meso-struts, yielding high stiffness and strength; whereas for a "bending dominant" lattice, the struts endure deformation and deflection by the flexing the struts, lending a more compliant but energy absorbing behavior.

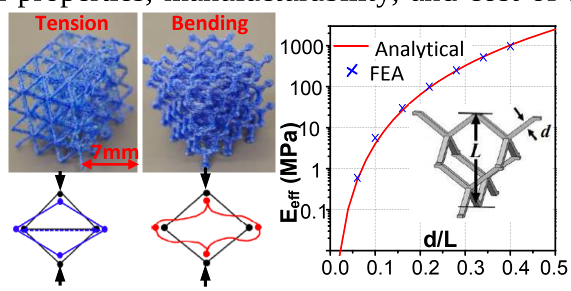

Fig.1 (a) Deformation mechanism and (b) influence of build parameter on meso-lattice properties

This research aims to study the interrelationship between the geometrical features of 3-D printed mechanical metamaterials and their mechanical and physical properties (density, acoustic). A combination of numerical simulation and experimental tests will be carried out for this research. Student will learn how to use 3-D CAD software, fast-prototyping with 3-D printing, mechanical experiments, and (possibly) finite element analysis.

Research Plan

In this research, topological study will be performed on the lattice structures with various configurations and build parameters including unit cell length (L) and strut thickness (d) (Fig. 1 (b)) to elucidate the relationship between the built parameters and the mechanical properties such as effective stiffness. For a diamond lattice used in our prototype construction, it is expected that the stiffness follows a 4th-order relation to the L/d ratio while the effective density follows a quadratic relationship. Similarly, the effective strength can be analyzed by setting failure criteria to the meso-strut elements. Validation tests of the lattice model will be performed using a MTS Insight material test system.

Once the desired lattice configurations are chosen based on the effective stiffness, strength, and density, mechanical properties of the materials will be analyzed using FEA models (ABAQUS) with varying internal pressures. Then the simulation results will be validated through a series of component-level tests carried out on a MTS servo-hydraulic test machine, including the center-point flexure (ASTM D3043), picture-frame shear, and dynamic vibration.

Student Duties

Prepare material samples; learn to perform mechanical experiments for 3-D printed metamaterials. Learn to set up experiments and instrumenting samples with sensors. Learn to process and analyze experimental data.

Tentative 10-week Schedule

(1) Weeks 1-2, familiarize with the lab environments, safety training, learn to prepare materials (i.e., concrete mortars, cement paste etc.);
(2) Weeks 3-4, design experimental test matrix and fabricate the material samples needed for mechanical testing;
(3) Weeks 5-6 Prototype multifunctional assemblies using the metamaterials developed;
(4) Weeks 7-8, learn and perform mechanical experiments in the laboratories and analyze the experimental data;
(5) Weeks 9-10, re-iterate the design and perform experiments.

Expected Student Background and Requirements

Students should have good background in general physics, materials; knowledge of mechanics of materials and civil engineering materials is advantageous; typically students with a major in Civil Engineering, or Mechanical and Aerospace Engineering. Pre-exposure to mechanical fabrication, 3-D CAD modeling is a plus.

It is expected that the students will work full-time (32-40 hrs/week) for 10-12 weeks during summer 2017. Students who consider pursuing the RCEU program may not register more than 6 credit hours of class during smr 2017 (i.e., two classes over the summer, or one class each mini-semester). Office space located in Technology Hall (OKT) and computers will be made available to the enrolled students. The students will have access to the newly established structural hazard mitigation and intelligent materials laboratory located in the high-bay area of Tech Hall.

Results and Deliverables

Students will learn state-of-art characterization techniques for building materials. Students are expected to be exposed to a combination of experimental and analytical techniques, including mechanical testing, 3-D CAD, and finite element analysis (FEA) software.

Mentor Supervision and Interaction

The faculty mentor will oversee the project throughout the performance period, including supervising the student and design the testing protocols associated with this project to ensure all project objectives are achieved. The mentor will examine all student's work and provide the assistance and resources needed. The student will report (in written or oral format) to the mentor periodically on a weekly base, and the mentor will ensure the student is progressing as planned. It is expected that a brief research report will be generated towards the end of the project.