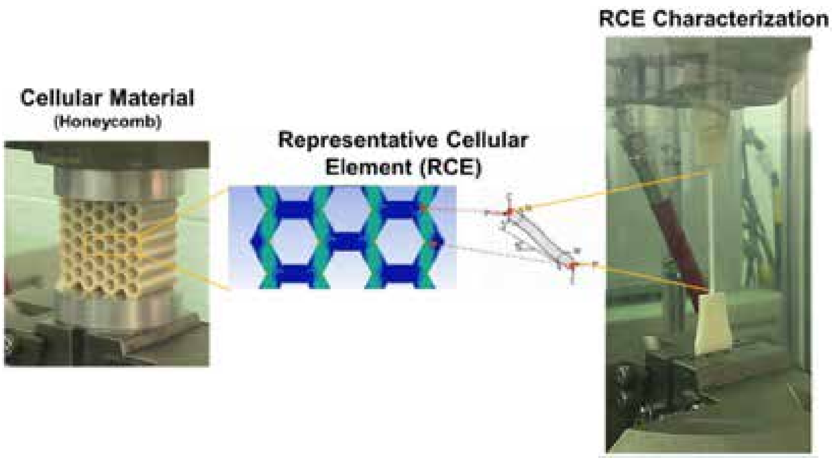
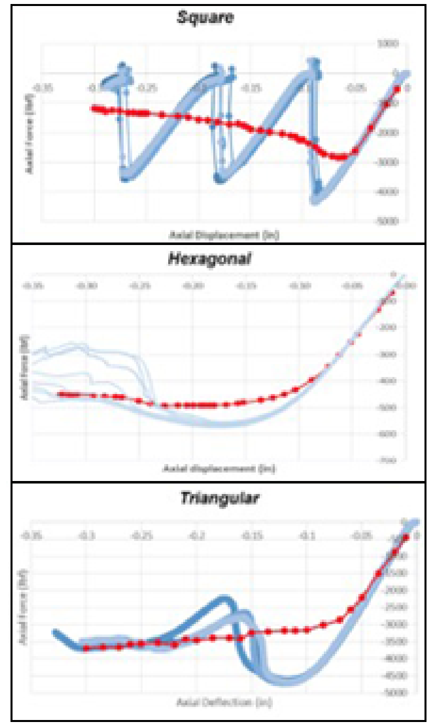
SUCCESS STORY

Develop and Validate a Shape Independent Model to Predict 3D Printed Cellular Material Stiffness and Failure Response

Shape Independent Models Predict Behavior of 3D Printed Cellular Materials with 90% Accuracy





A cellular material such as a honeycomb can be treated as an assemblage of beams and junctions which when characterized enables the development of predictive models, as shown here for three different shapes: square, hexagonal, and triangular (red is model prediction, blue lines are experimental curves).

PROBLEM

Despite the ability to design and manufacture cellular materials and structures with additive manufacturing, companies are reluctant to implement these in critical-to-function applications due to the large uncertainties in performance. The challenge in predicting cellular material behavior stems partly from the uncertainty attributable to the process itself, and partly due to the difficulties fundamentally intrinsic to cellular materials, such as shape and size dependence, junction effects, and nonuniform stress and damage states. The use of bulk material properties disregards behavior that includes these effects, and the use of homogenization techniques is limited due to their inherent, empirical dependence on shape.

OBJECTIVE

While previous work homogenized behavior on the cellular level, this project sought to go a level deeper and extract data at a material level. The objective of this project was to develop analytical equations that could be used not merely to study the effective performance of cellular structures, as is commonly done in literature, but also to extract a point-wise material property that is cell-shape independent. The primary workforce and education goal of this project was to develop a pilot online, living textbook in additive manufacturing, for and by the members of America Makes.

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to:

AM GENOME

ASTM PROCESS CATEGORY:
Material Extrusion, Powder Bed Fusion

EQUIPMENT:
Fortus 400mc & 450 mc, Concept Laser M2, Arcam Q20, MarkForged Mark Two

MATERIAL:
ABS, Ti6-Al-4V, IN 718, Onyx & Continuous Carbon Fiber

TECHNICAL APPROACH

The technical approach was to define point-wise material properties, not unit cell level properties, to exploit true lattice design freedom in end part manufacturing and implementation for structurally critical parts. The team leveraged two different techniques to extract valid material behavior that was representative of lattice behavior (as opposed to the bulk). The first method used closed-form analytical equations for extracting material properties by measuring effective properties. The second method defined a representative cellular element (RCE) that follows from the use of the representative volume element (RVE) in heterogeneous materials. The RCE was characterized and material properties were obtained and integrated into a finite element model to assess accuracy of the prediction. New considerations such as junction effects and strain rate sensitivity had to be added to the model to improve its accuracy. The scope of the project was limited to 2D honeycombs but addressed regular, irregular and graded shapes. Phoenix Analysis & Design Technologies (PADT) and Arizona State University (ASU) shared work related to design, manufacturing, characterization, and testing of the specimens. PADT led all simulation activities in FEA. Engineers from NIST, Honeywell Aerospace and Lockheed Martin attended meetings and provided technical guidance during the project. The workforce/education component generated a living textbook to create an online platform, the pilot demonstration of two chapters, and evaluated feedback.

ACCOMPLISHMENTS

A modeling methodology to predict the elastic-plastic response of FDM honeycombs was developed and validated. Effects of junctions (such as corner radii), manufacturing tolerances, and strain rate dependence were studied and included in the modeling approach.

The methodology was rigorously applied to FDM honeycombs of different shapes including hexagon, square, triangle, Voronoi, and graded and shown to have predictability to under 10% error for the elastic plastic regime. The modeling approach was extended to three more processes to identify applicability, limitations and opportunities for future work. These were the electron beam melting, laser powder bed fusion, and Markforged composite printing processes.

An online living textbook was piloted with two chapters completed on cellular materials and a workshop on cellular materials was delivered.

PROJECT END DATE

August 2018

DELIVERABLES

- A validated constitutive and failure model that can be implemented for additively manufactured cellular design, optimization and simulation [Report]
- Mechanical behavior datasets for FDM ABS, EBM Ti6Al4V, Laser-PBF IN 718 and Markforged Onyx-CCF composite honeycombs of different shapes [Excel Datasets]
- A how-to guide or plug-in for using the models in ANSYS, extendible to other software [Report]
- (WEO) A living textbook piloted for two chapters on cellular materials [Online website]
- (WEO) A workshop on "Additive Manufacturing of Cellular Materials: Design, Manufacturing, Characterization and Modeling"

FUNDING

$281K total project budget

($138K public funding/$143K private funding)

PROJECT PARTICIPANTS

Project Principal:

Phoenix Analysis & Design Technologies (PADT)

Other Project Participants:

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U.S. Department of Energy

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