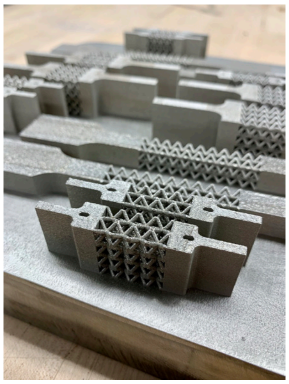
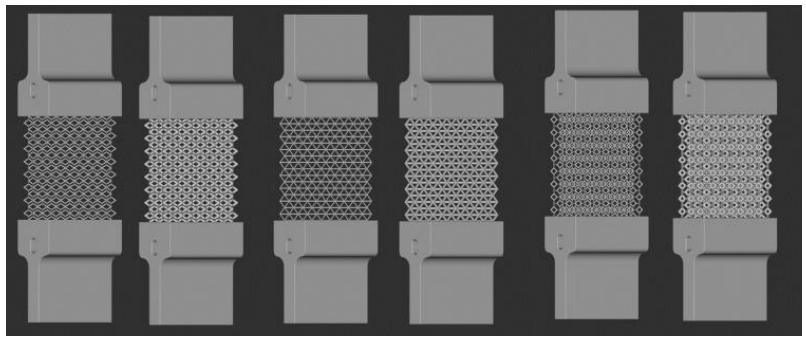
SUCCESS STORY 5001.001.002.001

Utilize 3D digital image correlation (DIC) to obtain real-time failure information and visualization of complex 3-dimensional features.

Provide repeatable mechanical property measurements for a range of different metal printed lattice designs.





Proposed tensile test geometry with multiple lattice designs created using nTopology software.

PROBLEM

Complex cellular and lattice structures are an exciting field of materials development offering revolutionary opportunities in medical devices, light weighting, and impact protection. Additive manufacturing (AM) is uniquely suited to produce lattice structures and there has been a synergistic development cycle between the lattice design community and AM. There is, however, an unmet need for a standard approach to mechanical testing and evaluation of these lattice structures to support their introduction into demanding applications for defense and commercial use.

OBJECTIVE

The objective of this effort was to develop a standard approach to mechanical testing and evaluation of lattice structures. The program aimed to deliver an ASTM work item style final report proposing a test geometry and supported with a technical data package including tensile results and digital image correlation (DIC) imaging from a design of experiment (DOE) matrix of lattices.

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to: MATERIAL

ASTM PROCESS CATEGORY: Powder Bed Fusion

EQUIPMENT: Concept Laser M2

MATERIAL: 3016L

TECHNICAL APPROACH

The Ohio State University's Center for Design and Manufacturing Excellence (CDME) led the effort. The technical approach included lattice demonstration geometry created using nTopology, printed in 316L with laser powder bed fusion on a Concept Laser M2, then evaluated using multiple approaches for tensile testing and measured using DIC. The core of the technical approach was defining and measuring the specific dimensions of the tensile bars as a function of lattice unit cell and strut size that produced a low scatter, uniform mechanical evaluation. This technical approach was envisioned to be translatable to other materials such as Ti64 and to be used to develop lattice coupons for compression and shear loading conditions as well.

The proposed tensile test geometry consisted of a lattice structure in the gauge section with printed solid material for gripping. The initial geometry was a nominal 1cm x 2cm x 2.5cm gauge section specifically sized so that only complete lattice unit cells were within the gauge section (no partial cells "clipped" at the grip sections) with grips sized to interface with the lattice gauge section. Lattice designs were produced using nTopology software. Samples were printed using a Concept Laser M2 in 316L stainless steel and then stress relieved before tensile testing with the as printed surface finish. Mechanical testing was performed using mechanical test frames and 3D DIC hardware and software.

ACCOMPLISHMENTS

This four-month rapid innovation project examined a variety of metal printed lattice designs and developed initial test artifacts to better understand tensile properties. Over the course of the effort, 65 different specimens were manufactured and tested, resulting in the evaluation of 14 different lattice designs. Of the 14 different lattice designs, 3 different gauge sections were evaluated, and 6 different lattice unit cell topologies were utilized. The lattice designs tested in this program include body centered cubic (BCC), fluorite, kelvin, octet, triply periodic minimal surface (TPMS) gyroid, and auxetic structures. The project team created a preliminary parametric rectangular lattice model which was a key deliverable for this project. The nTop workbook was provided in the technical data package. The use of 3D-DIC allowed the project team to observe the failure modes of different gauge sections, grip designs, and lattice unit cell structures. Based on initial test data, Ohio State University recommends continuing development of the rectangular lattice specimen for tension testing as well as exploring ways to reduce the size of the ASTM E8 specimen. Further development is needed to create a clear definition for the number of required unit cells as well as development of gradient lattice structures to shift lattice fractures from the boundary areas to the gauge section.

PROJECT END DATE

April 2021

DELIVERABLES

- Test artifact designed to characterize AM metal lattices
- Technical data package including all mechanical test data, build plans, and post-test inspection
- Draft standard for tensile testing of metal printed lattices
- Final report detailing material and process parameters used during the project and outlining all results from each task

FUNDING

$150,000 total project budget
($120,000 public funding/$30,000 private funding)

PROJECT PARTICIPANTS

Project Principal:
The Ohio State University Center For Design and Manufacturing Excellence (CDME)

Public Participant:
U.S Department of Defense