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Mechanical Properties of Hexagonal Lattice Structures Fabricated Using Continuous Liquid Interface Production Additive Manufacturing

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Architected materials, additive manufacturing, lattice, honeycomb

INTRODUCTION

Additive manufacturing (AM) offers design freedom that is very attractive for architectured lattice materials, due to the geometric complexity that can be achieved. Recent advancements in AM have enabled rapid production speeds, high spatial resolution, and strong materials [1]. This paper presents design, production, and mechanical property testing of hexagonal lattice structures manufactured using continuous liquid interface production (CLIP) based AM. We printed and tested over 50 parts, in four polymer materials and with four different truss sizes. The measured elastic moduli of the printed structures are close to the values expected from the material vendor's specifications, although there is some variation; this variation is different for different materials. The failure of the printed structures depends upon the material and the specific values of the truss length and thickness. To our knowledge, this is the first published report of mechanical testing on lattice materials produced using CLIP.

METHODS

Figure 1 shows four parts printed using CLIP; the lattice consists of regular hexagons. The largest part has overall dimensions 110 X 104 X 45 mm, and the smallest part has overall dimensions 35 X 35 X 22 mm. The four parts have truss thickness to length ratio (*t*/*l*) ranging from 0.05 to 0.20, corresponding to relative densities from 0.06 to 0.23. The parts were produced in four different materials: additive epoxy (EPX), rigid polyurethane (RPU), cyanate ester (CE), or flexible polyurethane (FPU) [2].

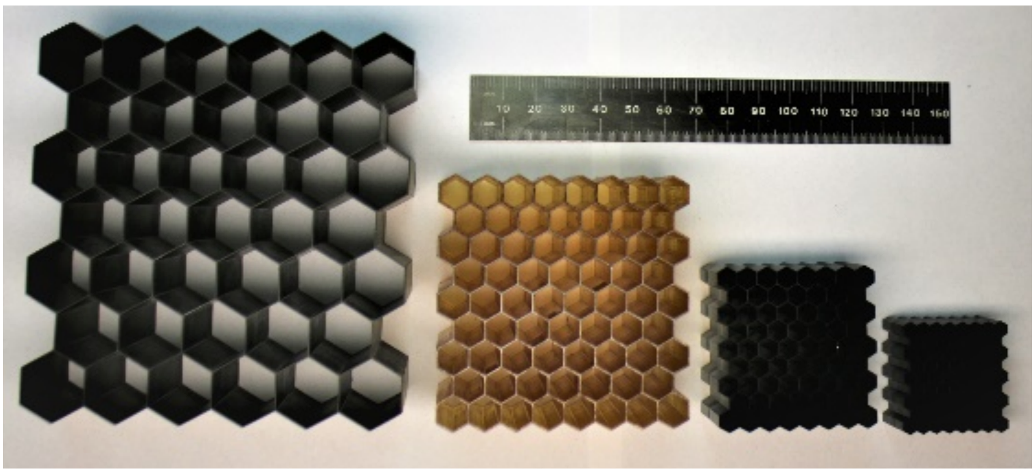


Figure 1: Hexagonal lattices printed using CLIP in four different materials (left to right) EPX, CE, RPU, and FPU at relative densities of 0.06, 0.12, 0.12, and 0.23 respectively. The ruler shows millimetres.

Our objective is to select combinations of lattice geometries and intrinsic properties to cover a wide range of attractive lattice material behaviors. We designed the lattice dimensions to obtain relative densities ranging from 0.06 to 0.23, and failure mechanisms ranging from brittle, to plastic and elastic buckling. Under the assumption that the truss members are slender (t/l << 1), expressions for the relative densities, elastic moduli, and failure strengths can be calculated for the hexagonal lattices [3]. As the slenderness of the truss decreases (t/l increases), the validity of these equations decay; for relative densities under 0.4 the modelling is accurate to within 10% of actual values [4].

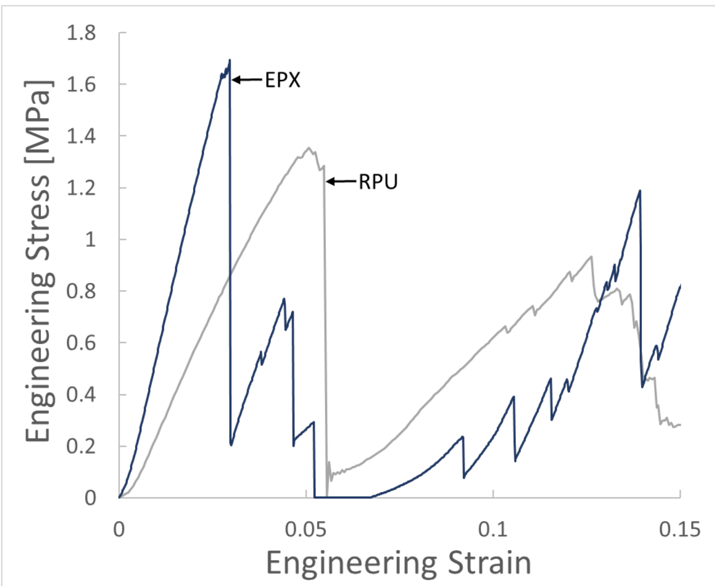
Solving for all mechanistic failure strengths, we predict the lattice strength as the minimum of the accessible failure strengths. For our four design points and four materials, the lattices have predicted moduli ranging from 0.55 – 970 MPa, and strengths ranging from 0.02 – 38 MPa. These numbers reflect properties for all three (in-plane and out-of-plane) compression directions.

RESULTS

All designs were tested in uniaxial compression in the in-plane (X2) and out-of-plane (X3) directions, with optical recordings capable of observing the failure mechanics. Some designs were also tested in the orthogonal in-plane (X1) direction.

Figure 2 shows example data of two parts tested in the X2 direction; one part was fabricated in RPU, and the other in EPX. The parts have identical geometry, with t/l = 0.20 and relative density of 0.23. The results illustrate how the distinct bulk material properties and failure strengths govern the performance and failure of these two parts. While both parts experience brittle fracture, the stress-strain curve for the RPU part indicates plastic yield before fracture.

We can compare the measured lattice performance with the performance expected from theory using the material property data from the vendor specification sheets [2,3]. For the EPX part, the measured elastic modulus is 64.0 MPa compared to the expected value of 58.0 MPa, and the measured failure strength is 1.7 MPa compared to the expected value of 2.1 MPa. For the RPU part, the measured elastic modulus is 31.3 MPa compared to the expected value of 35.1 MPa, and the measured failure strength is 1.3 MPa compared to the expected value of 1.1 MPa.



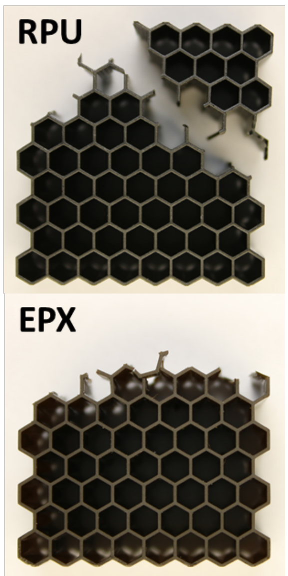


Figure 2: (Left) Example test data showing stress vs strain for two parts compressed in the X2 direction. The parts are printed from either EPX or RPU, with *t/l* = 0.20 and relative density of 0.23. (Right) Post compression samples in RPU and EPX.

References

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