Experimental and numerical analysis of quasi-static deformation mechanisms of additively manufactured lattice structures

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Motivation
One major drawback of superalloys is their high density of the baseline material (e.g., Ni (7.8 g/cm³) and Titanium (4.5 g/cm³)) compared to conventional lightweight elements such as Al (2.70 g/cm³). Lattice Structures (LS) (Figure 1c) deliberately allow removal of mass from a structure (using additive manufacturing (AM) technique). Accordingly, they are one of the most efficient solutions to use the superb features of superalloys. Another advantages of LS over bulk samples is that by just focusing on architectural aspects (Figure 2), rather than microstructural aspects, mechanical and physical properties of materials can be tailored at elemental length scale (Figure 2).

Objective
The objectives of this study are: (1) understanding the deformation mechanisms that control the post-yielding behavior of additively manufactured LS, (2) using those information to optimize the structure for the desire application.

Impact

Methodology
Using newly modified experimentally driven yield surface (i.e. volumetric hardening model), finite element simulation-based were able to replicate the stress-strain behavior of AMLS under quasi-static loading condition. Furthermore, dominant deformation mechanisms of LSs under quasi-static compression was studied by analyzing the number of element in tension (NET) and the number of element in compression (NEC) as a ratio of the total number of elements which are calculated and plotted for each increment in the Figures 7.

Key Findings
Based on the numerical analysis, the new optimized topology, which is combination of OT and RD is created. The new topology is stronger that RD and can absorb more energy compared to the OT topology.

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Figure 1. Superior strength and ductility of super alloys (a) under dynamic loading and (b) elevated temperature (c) considerable weight reduction using LS, which also (d) enables significant energy absorption property.

Figure 2. Different mechanical behavior of various topologies

Figure 3. The Wellington bomber’s lightweight gridshell lattice structure uncovered

Figure 4. Potential application for LS materials in rocket’s body and boosters. (Image courtesy: Jung-Chew Tse, ETH)

Figure 5. Stress-strain behavior (black), NET (blue), NEC (red), NET+NEC (green) for; a) Octet and b) Rhombic.

Figure 6. Stress-strain behavior of the new designed topology (Rh octet), Octet Truss, and Rhombic.

Credit: fourth door.