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Deformation and Failure Mechanisms of Optimized Architected Materials under High-Strain-Rate Loading

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Extended Abstract

Abstract

Over the past decades, additive manufacturing has made significant progress across a wide range of materials, establishing itself as a promising approach for the fabrication of complex and multiscale architectures, positioning architected materials as promising candidates for energy absorption. Architected materials, based on the periodic repetition of a unit cell, can be tuned over many parameters to tailor mechanical properties. Numerous studies have investigated the influence of these intrinsic geometrical or material parameters on energy absorption and deformation mechanisms. Focus has been placed on the effect of geometric parameters and manufacturing defects on overall behavior. More detailed studies have examined the role of geometric characteristics, including strut thickness, relative density, and unit cell size, unit cell topology, and stochastic architectures with variable connectivity and orientation. Other investigations have addressed the influence of structural configuration, number of repeated cells, graded density, and interfacial features between layers. These investigations, combining experimental and numerical approaches, have significantly advanced the understanding of architected materials. This study examines deformation and failure mechanisms under quasi-static and high strain-rate loading, particularly regarding how the geometry influences damage localisation, strain-rate sensitivity and energy absorption which are less understood The deformation and failure mechanisms of Gyroid structures made of Inconel-718 has been characterised through combined quasi-static and high-strain-rate compression tests supported by DIC and numerical simulations. Five distinct mechanical regimes associated with elasticity, shear-band formation, and densification has been identified. At higher strain-rates, the structures exhibited an increase of stiffness in compression and an earlier onset of failure compared to the quasi-static response. Overall, the analysis revealed that local geometrical features act as preferential sites for shear-band initiation and propagation. This presentation aims to analyze optimized architected materials to reduce deformation and failure mechanisms by introducing a combination of density gradients, interlayer elements and multi-material structures and stochastic structures. First, introducing density gradients exhibits better properties, particularly by softening the post-impact response. Placing the lowest density on the opposite face reduces the transmitted peak force and improves energy dissipation. Then, interlayers promotes a more homogeneous redistribution of loads, limits localized failure mechanisms, and thereby increases the overall structural resistance. Combined with multi-material approaches, this strategy enables the design of lighter structures by incorporating low-density layers that reduce structural mass while preserving good mechanical performance. Furthermore inserting topological disorder via spinodoidal fields enables the generation of structures with tailored properties. These allow the creation of spatially variable materials with evolution of stiffness, porosity, or anisotropy gradually in space. Combining Gyroid with spinodoidal perturbations opens the way to disrupt shear-band propagation while keeping the advantages of a stochastic architecture.

Keywords:

architected materials additive manufacturing high-strain rate digital image correlation numerical simulations