# Deformation and failure mechanisms of architectured materials under impact

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**Abstract**

High-velocity impacts commonly referred to as ballistic threats, have evolved with advancing technology. Consequently, protective materials and systems have also steadily progressed. Over recent decades, additive manufacturing has seen remarkable advancements across various materials and has emerged as a promising technology for constructing customized, multi-scale materials designed for impact protection.
Architectured materials, created through the periodic repetition of a lattice cell, have been promising candidates for impact protection. Several studies have proposed scenarios and models to understand the effects of intrinsic geometric and material parameters on the energy absorption and deformation behaviour of these architectured materials under ballistic impact. Let us recall the discussion on scale effects between the material scale of the protection system and that of the projectile, their dependency on the type of loading (1), as well as the influence of geometric parameters and fabrication-induced errors on global behaviour (2). Furthermore, precise studies on geometric parameters include, for example, the effects of dimensions such as strut thickness, relative density, and cell size (3); the shape of the elementary cell (4); and equivalent stochastic structures with varying connectivity and orientations (5). Other studies have explored the impact of structural arrangement, number of repetitions, progressive density, and the presence or absence of elements between layers, among other factors (6, 7). Understanding these effects benefits from a combination of experimental and numerical methods, such as compression characterization tests on Hopkinson bars (8), along with adapted modelling approaches (9). Despite numerous efforts, interactions between global, or local, dynamic loading and architectured materials remain poorly understood, and no precise or universally applicable solutions to these challenges have yet been found.

Thus, this study focuses on understanding the deformation and failure mechanisms in various geometries of architectured materials across a range of global and local dynamic loadings.

Specifically, the dynamic behaviour of Gyroid lattice structures is investigated through experimental techniques and finite element simulations. The Gyroid lattice structures studied, featuring 5x5x5 unit cell geometries and relative densities of approximately 20%, are manufactured from Inconel-718 using the Selective Laser Melting (SLM) process at the millimetre

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scale.

High strain-rate experiments are performed using a split-Hopkinson pressure bar (SHPB) system. The testing campaign combines compression and shear to determine mechanical properties and examine strain rate dependency across range up 0.001 /s to 1000 /s. This approach provides insights into deformation and failure mechanisms under high strain-rate loading through stereo correlation and strain gauges. Concurrently, a series of localized impact characterization tests is being carried out to evaluate and compare the effectiveness of different architectural structure geometries. In these tests, projectiles are launched at varying speeds, with high-speed cameras used to capture dynamic penetration depth in ballistic gelatin. This campaign aims to investigate the effect of very high strain-rate deformation (over 1000 /s) on the overall structural response.

Explicit finite element analysis using the Johnson-Cook constitutive model demonstrates good agreement with the mechanical failure trends and deformation modes observed in the experiments. The model enables a sensitivity analysis of parameters such as relative density and the number of unit cells, and supports prediction for future experimental campaigns.

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