Investigation of lattice TPMS structures between low and high-speed rate compression

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Abstract

The aerospace industry has been interested in metal architected structures for many decades. Starting with metal foam (aperiodic pattern) in the 60's and honeycomb (2D pattern, extruded), metal additive manufacturing (AM) pushes the limit further with 3D periodic structures, often called lattices.
Characterized by their lightweight yet strong composition, periodic lattices are made up three different parameters: pattern nature, density and cells size. According to Yin et al (1), lattice patterns are divided into two families (2D pattern and 3D pattern) with 4 categories include in the 3D one (truss-based, plate-based, shell-based and hierarchical). These lattices are mainly studied for their mechanical properties and energy absorption.

In the literature, mainly since a decade, different types of lattices are tested in quasi-static compression for different materials (polymers, metals and mostly 316L). Al-Ketan et al (2) shows (on metal lattices) that shell-based lattices have a higher plateau stress than any other 3D categories (in quasi-static compression). The TPMS (Triple Periodic Minimal Surface) subcategory of 3D shell-based appears to be a better candidate for energy absorption due to a further densification point.

The literature also point out the role of the density and the cell size on the energy absorption capacity (see for example Mishra et al (3) and Yin et al (4)).

The vast majority of the experimental results previously discussed have been obtained for quasi-static loading rates. Only few studies deal with the response of such structures at high loading rates.

Therefore, this study will focus on dynamic loading rates effects on TPMS lattices. Three TPMS are studied: Primitive, Gyroid and Diamond. The samples are printed using Additive Manufacturing (LPBF technology) and Inconel 718 powder.

Each sample has a cell size of 5mm, with a repetition of 3x3x6 cells and a 25% density for a good printed thickness.

In this communication, quasi-static and dynamic effects for TPMS structures loading will

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be experimentally compared. The strain localization process is analysed with stereo-graphic imaging and local stereo digital correlation in order to detect dynamic inertia as Singh et al (5) pointed out from numerical results.

Our first experiment was with three different TPMS on quasi-static's loading rate. A comparison of stress plateau heights shows that the Gyroid and the Diamond dominate. Calculating the energy absorption from the experimental curves shows that the Gyroid at 93 J.m-3 outperforms the Diamond at 92 J.m-3.

The corresponding non-linear Finite Element numerical model is under progress in order to compare their prevision with the experimental results.

(1) Hanfeng Yin, Review on lattice structures for energy absorption properties, 2023

(2) Oraib Al-Ketan, Topology-mechanical property relationship of 3D printed strut, skeletal, and sheet based periodic metallic cellular materials, 2018

(3) Ashish Kumar Mishra, Effect of cell size and wall thickness on the compression performance of triply periodic minimal surface based AlSi10Mg lattice structures, 2023

(4) Hanfeng Yin, Crushing behavior and optimization of sheet-based 3D periodic cellular structures, 2020

(5) Agyapal Singh, Highly strain-rate sensitive and ductile composite materials combining soft with stiff TPMS polymer-based interpenetrating phases, 2024