BOOK OF ABSTRACTS

Failure mechanisms and strength of mesostructurally modified Ti-6Al-4V lattice metamaterials fabricated with laser powder bed fusion

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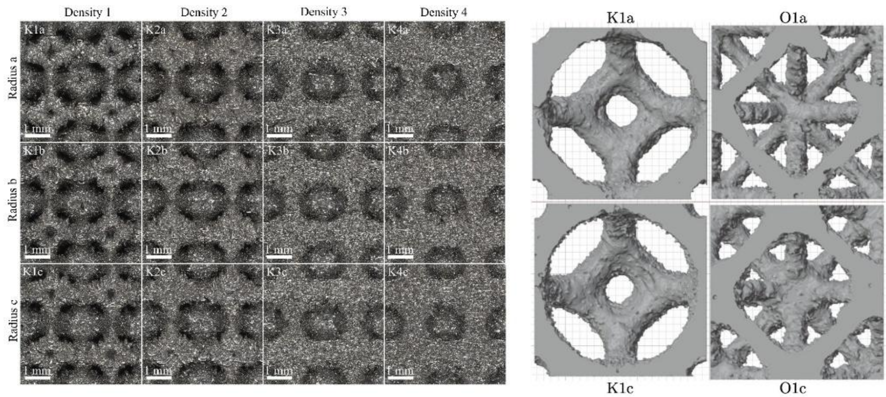
Additively manufactured lattices are metamaterials with consciously designed mesostructures. They exhibit targeted macroscopic properties, referred to as effective properties. These properties depend on three main factors: the base material, the metamaterial's internal mesostructure, and the manufacturing technology, including processing and post-processing parameters. Mesostructures may be periodic, functionally graded, or stochastic. Periodic mesostructures are characterised by the architecture of a unit cell, which fills the entire volume of the metamaterial through periodic repetition. Multiple approaches to unit cell design exist, with strut-based designs representing a standard option. Strut-based unit cells are defined by unit cell size, the spatial arrangement of struts and nodes, and strut thickness. The combination of these parameters results in a specific relative density and pore size. Certain applications, such as biomedical bone-replacement implants, impose strict requirements on relative density and pore size to ensure proper functionality [1]. This study investigates how modifications of strut-based unit cells influence the effective strength, stiffness, and failure mechanisms of metamaterials. The proposed modifications extend beyond conventional strut-based designs by introducing joint smoothing at strut nodes, thereby transitioning unit cells from purely strut-based configurations toward full three-dimensional solid geometries. These modifications promote more uniform stress and strain distributions within the mesostructure, leading to improved effective properties of the metamaterial.

Four primary categories of defects and stress concentrators can be identified in lattice structures: material-related imperfections, micro-notches arising from structural features, mesostructural imperfections caused by insufficient manufacturing precision, and geometric notches introduced by the intended mesostructure topology. Material imperfections originate from discontinuities within the base material and typically occur at interfaces between powder particles. Structural micro-notches and mesostructural imperfections arise from deviations in the component's external geometry that are inherent to the layer-by-layer manufacturing process. These deviations manifest as non-uniform wall thicknesses and increased surface roughness. Geometric notches, by contrast, are rooted in the design methodology. Unlike material and structural micro-defects, geometric notches can be deliberately controlled during the design phase, allowing mechanical performance to be designed through shape refinement. The present study focuses specifically on the role of geometric notches in governing the mechanical behaviour of metamaterials.

The study comprises both experimental and numerical components. Multiple variants of modified Kelvin and Octet Truss unit cells were prepared, with parameters including the nodal fillet radius systematically varied. The numerical simulations employed an experimentally obtained [2] plastic hardening curve for the Ti-6Al-4V alloy. The three-dimensional finite element models utilised a very fine mesh to capture local stress and strain gradients accurately. Physical samples were manufactured and examined using micro-computed tomography and optical microscopy. The specimens were subsequently subjected to tensile testing with simultaneous high-speed camera recording to characterise both mechanical properties (strength and stiffness) and failure mechanisms. The results demonstrated a strong dependence of failure mechanisms and effective mechanical properties on the geometry of the nodal junctions. Both nodal and inter-nodal failure mechanisms were identified. The Kelvin cell structure exhibited consistent improvement with increasing modification across the investigated range, with negligible changes in relative density. In contrast, for the Octet Truss configuration, moderate modifications enhanced mechanical performance. Excessive modification reduced effective strength and induced a transition from nodal to inter-nodal failure. It was shown that the observed failure mechanisms do not necessarily coincide with the traditional classification of stretch-dominated or bending-dominated lattice types.



Microscopic and tomographic of the manufactured samples

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