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PROCEEDINGS

Enhancement of Compression Behavior and Customizable Energy Absorption Capacities of a Bio-Inspired Graded Metamaterial

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ABSTRACT

Conventional energy-absorbing mechanical metamaterials primarily dissipate energy through irreversible plastic deformation, buckling, or fragmentation. Their applications are limited by structural fractures caused by 45° shear stresses and their suitability only for single-use impact protection, lacking the capability for repeated energy absorption. Inspired by the cancellous bone of the human skull, a Tangent Arc Curve Structure (TACS) was proposed in this study, followed by the modeling and fabrication of four types of 3D-TACSs: tensile, tensile-rotational, orthogonal, and diagonal. The shear resistance and repeatable energy absorption capabilities of TACS were systematically investigated through theoretical analysis, compression experiments, and numerical simulations. Relevant researches indicate that the strut-based BCC lattice structure exhibits the most severe and pronounced shear fractures, with 45° internal stresses identified as the direct cause of such failures [1–3]. Comparative analysis of the compression behaviors between BCC lattice structure and diagonal 3D-TACS reveals that TACS reduces unit cell constraints, enables vertical internal force transmission, effectively suppresses shear band formation, and thereby enhances mechanical properties and energy absorption capabilities. To expand the application scope of TACS, repeated compression experiments on 3D-TACS demonstrated their excellent and stable compressive resilience, showing promising performance in repeated energy absorption. The tensile 3D-TACS demonstrates superior resilience and exhibits stable performance in repeated energy absorption. The tensile-rotational 3D-TACS shows the most favorable characteristics for repeated energy absorption. The orthogonal 3D-TACS demonstrates optimal initial energy absorption performance, making it particularly suitable for protective scenarios involving a single high-intensity impact accompanied by multiple low-intensity impacts. Furthermore, numerical simulations were conducted to investigate the influence of graded coefficients and impact velocities on the mechanical performance of 3D-TACS. The results indicate that graded coefficients enable 3D-TACS to exhibit enhanced mechanical properties and energy absorption capabilities with increasing strain, making it adaptable to progressively intensified impact scenarios. Under moderate impact conditions, 3D-TACS maintains robust structural integrity and deformation stability, suggesting its potential for achieving repeatable energy absorption capabilities. This study provides novel insights for enhancing the mechanical performance and repeatable energy absorption capabilities of energy-absorbing metamaterials.

KEYWORDS

Mechanical metamaterial; bio-inspired design; graded design; shear band; repeated energy absorption; finite element simulation

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