INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS

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SHORT ABSTRACT

Synergistic effects of 3D printing and composites expand the opportunities for designing high-performance light weight structures like auxetic lattices, that exhibit negative Poisson's ratio. This thesis endeavors design, simulation, and experimental verification of 3D printed auxetic structures with an aim to attain improved energy absorption and young's modulus by suggesting intuitive designs such as introducing low rotational stiffness nodes, vertical struts, and tessellation (arrangement of basic building block in the design space) followed by characterization of compressive behaviour of cementitious composites embedded with 3D printed re-entrant structure.

The development of high-performance lightweight lattices with improved energy absorption and stiffness has attributes has attracted considerable attention in the research community. In this work, conventional auxetic structure (2D re-entrant honeycomb) was tested under quasi-static compressive loading. As the estimating energy absorption performance of auxetic structure during the design phase has been observed indispensable, finite element method (FEM) based simulation having appropriate boundary conditions has been developed to calculate the stress-strain response in corroboration with experimental measurement. It was found that rotational stiffness of the node influenced the energy absorption of the structure. Based on this finding, a novel auxetic unit cell with low rotational stiffness called, 'modified re-entrant auxetic structure' was designed, 3D printed and tested under compressive loading. With the help of statistical models (derived by response surface methodology) and parametric study, it has been shown that link length ratio has the highest influence on the energy absorption properties followed by joint angle effects. The crushing analysis indicates that the optimized structure outperforms (+36%) regular re-entrant honeycomb in terms of energy absorption performance, but compressive strength increment was marginal.

Two new auxetic lattices were designed by selectively introducing vertical ligaments to the modified re-entrant lattice and 3D printed via fused filament fabrication technique. The deformation patterns were investigated both via Finite Element (FE) simulations and experiments to understand the role of vertical ligaments under quasi-static compression. The measured mechanical characteristics of the two lattices were compared to conventional re-entrant honeycomb lattices of the same relative density. Despite higher Poisson's ratio, the specific energy absorption of two 3D printed auxetic lattices (Type A and Type B) were 165% and 147% higher than conventional re-entrant honeycomb respectively due to deformation of higher relative density cells at higher strains. Similarly, the elastic moduli of the Type A and B lattices exhibit an improvement of about 355% and 198% with respect to conventional re-entrant honeycomb due to reduced bending dominated behaviour. The theoretical formulae for effective Young's modulus of the proposed structures were also developed using an energy-based approach and validated by FE results.

Next, interlocking designs based on tessellation such as 'edge-to-edge' 'non-edge-to-edge' and 'overlapping' were explored using the Type A auxetic structure. The findings of this study suggest that the strength, Young's modulus, energy absorption capacity and Poisson's ratio of auxetic lattices can be tailored by applying different tessellation strategies. The FE results corroborated by experiments unveil the role of tessellation on the effective mechanical properties of tessellated lattices. The results indicate that the overlapping tessellation offers highest Young's modulus and yield strength among all tessellated structures, which makes it most suitable for load-bearing applications. On the other hand, overlapping tessellation offers highest specific energy absorption without any interface failure. To understand the significance of auxetic structures, 3D printed auxetics were used to design high performing cementitious composites to strengthen existing structures due to their negative Poisson's ratio and high Young's modulus. The auxetics were used as reinforcing meshes into cementitious mortar matrix and tested in compression to understand their failure patterns, load-displacement responses, ductility and energy absorption. Despite lower peak stress, the lattice reinforced composites have higher yield strain than plain concrete. It was confirmed that Young's modulus of cementitious composite increases with increase in Poisson's ratio and Young's modulus of auxetic lattice. Due to higher failure strain, auxetic reinforcement leads to larger plateau region and hence, higher energy absorption capacity.