Fracture toughness and crack propagation of architected orthotropic triangular lattices

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Abstract

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Lightweight structural materials are crucial to the transport industry as they offer an efficient option to reduce their CO2 emissions. For example, reducing the mass of a Boeing 787 by 20% decreases its fuel consumption by 12% (1). This industrial demand for lightweight materials can be fulfilled by a range of solutions, which among them, lattice materials have become increasingly popular in engineering because their architecture can be tailored to achieve desired properties (2). Lattice materials are made from tessellation of an interconnected unit-cell of struts or cell-walls filling 2D (planar lattices) or 3D (spatial lattices) spaces (3). They are frequently manufactured with polymers, ceramics, or metals providing stiff, strong, tough, and lightweight materials. Albeit the theoretical upper bound for strength and stiffness are reached by conventional planar lattices, there is no limitation in improving toughening behavior (4, 5).

Enhancement in toughness and resistance against crack propagation in lattice mate- rials is crucial because it increases the reliability and lifespan of structures. Triangular lattice is a planar lattice presenting high fracture toughness among conventional lattices (6). However, there is a room to enhance the resistance of triangular lattice against crack propagation (R-curve) by controlling their toughening mechanisms. Since the micro- architecture of lattices can be altered, the concepts of changing the thickness of struts is employed to investigate the possibility of R-curve improvement in triangular lattice.

The crack propagation in lattices was predicted using Finite Element (FE) simulations rely on a boundary layer method introduced by (7, 8). For each tessellation, we used a square domain with a side length of 1600, where is the length of a cell wall. The domain contained an initial crack in the negative x1 direction. The ratio of the thickness of bars aligned in x2 direction to the inclined bars T = t2/t1 was altered so that maintain the constant relative density with that of triangular lattice with uniform thickness. The effect of T on propagation was examined for a brittle and ductile materials.

Results show that increasing amount of T up to 2 could significantly enhance rising of R-curve, especially for ductile materials. For the ratio of T > 2 the orthotropic effect changes the direction of propagation in comparison with that of isotropic triangular lattice. Also, brittle triangular lattice gets mutually tougher and stronger in x2 with increasing T. This study provides insight into tailoring the micro-architecture of conventional lattices to improve their damage-tolerance in industries.

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