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Predictive Design of Disordered Lattices for Enhanced Damage Tolerance

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Abstract

O Introduction & Purpose Lattice materials are popular in a wide range of applications as they offer high mechanical properties at low densities. Lattices are usually designed with a periodic microstructure: this is ideal for stiffness and strength, but it promotes damage localisation and brittle failure. Recent studies have shown that introducing controlled geometrical disorder can improve damage tolerance, with minimal on stiffness and strength [1-3]. While these studies demonstrate the potential of disorder, quantitative design guidelines linking disorder variables to mechanical performance remain limited. The purpose of this work is to (i) quantify how two different forms of disorder influence the stiffness, strength, and work of fracture of a triangular lattice, and (ii) identify the optimal degree of disorder for damage-tolerant designs. O Methods We used finite element simulations to predict the tensile response of a notched triangular lattice made from an aluminium alloy. Our model was validated against experimental results [4] for the case of a periodic lattice. Disorder was introduced in two forms: randomly perturbating the position of each joint and strut thickness variations. Each form of disorder was governed by a uniform distribution with a prescribed maximum level. We considered each form of disorder individually and then, simultaneously. A large-scale numerical campaign with a total of 34,000 finite element simulations was conducted. From each simulation, the stiffness, maximum force, and fracture work were extracted. Statistical analyses of median and peak values were employed to characterise the effect of disorder on mechanical properties. O Results In

general, increasing disorder slightly reduces the stiffness and maximum force, but significantly enhances the work of fracture. Joint perturbations are found to be more effective than thickness variations in promoting distributed stress fields and tortuous crack paths. In contrast, thickness variations can maintain stiffness and strength over moderate disorder ranges, while providing limited toughness enhancement. When both forms of disorder are coupled, the work of fracture is nearly doubled in comparison with a periodic lattice, with minimal reduction in stiffness and strength. The mechanical responses exhibit statistical variability, but clear deterministic trends emerge when large sample sizes are considered. O Conclusions This study demonstrates that disorder can be treated as a controllable design parameter rather than a purely stochastic imperfection. Specific ranges of joint perturbations and thickness variations are identified to balance stiffness, strength, and work of fracture. The results provide quantitative guidelines for designing damage-tolerant lattice materials and highlight the importance of large-scale statistical sampling to uncover robust structure–property relationships. Overall, the findings advance the predictive design of disordered lattices and contribute to the development of tougher lightweight structural materials.

Keywords:

Lattice Materials Geometric Disorders Damage Tolerance Fracture Finite Element Method

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