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USING A HIERARCHY OF POROSITY TO IMPROVE THE FRACTURE TOUGHNESS OF METAMATERIALS

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Abstract

Mechanical metamaterials have been quickly growing in popularity based on their lightweight, multifunctional properties. One of the factors limiting their widespread adoption in weight baring applications, however, is their poor fracture toughness compared to bulk materials. Arrestor planes have been added to gyroid surface metamaterials and solid beams to manipulate the path of a propagating crack and improve the fracture toughness. The arrestor planes used a hierarchy of porosity interacting with the features inherent in the gyroid topology to direct propagating cracks into natural features that served to arrest the crack. This methodology was tested in both brittle polymer and stainless steel with toughening ranging from 22% to 300% depending on material.

1. Introduction

Metamaterials are known for their low density structures, however for most topologies metamaterial fracture toughness exponentially decreases with decreasing density. A crack propagates in traditional strut-based metamaterials as the tensile strength of the ligament directly ahead of the crack front is reached, advancing the crack one unit cell at a time. This differs from a crack in a monolithic material where the crack is continuously interacting with the surface. This study considered crack propagation in a gyroid surface metamaterial, where due to the sheet-based nature of the topology, the crack is continuously in contact with the metamaterial surface as it propagates rather than jumping from strut to strut in a lattice-based metamaterial. The effect of the crack continuously interacting with the material forces the crack to interact with modifications made to the surface of the metamaterial. To improve the fracture toughness of the gyroid surface metamaterial, planes of porosity have been added that redirect propagating cracks and improve the metamaterial fracture toughness.

2. Results

Three arrestor planes of porosity have been added to the gyroid surface metamaterial perpendicular to the direction of a propagating crack. Arrestor planes were also added to solid beams to test how the arrestor planes interacted with the gyroid surface topology. Specimens were additively manufactured out of glassy polymers and 316L stainless steel to compare the interaction between topology and base material.

When a gyroid surface metamaterial without the added planes of porosity was loaded the crack propagated in a macroscopically sharp and straight manner with minimal interactions between the crack tip and the pore like features inherent within the gyroid surface metamaterial. When the gyroid surface metamaterial with planes of pores was loaded the crack propagated similarly until it reached the first planes of porosity. At which point the crack diverted 90 degrees along the plane of porosity, stopping its dangerous Mode I direction propagation and putting the crack tip in a mixed Modes I, II, and III loading. Upon further loading the crack continued to grow along the plane of porosity until the crack reached large pore-like features inherent in the gyroid surface metamaterial which served to completely arrest the propagating crack. Figure 1 shows the crack tip in a gyroid surface metamaterial diverting in either direction along an added plane of porosity 90 degrees from its original direction of crack growth.

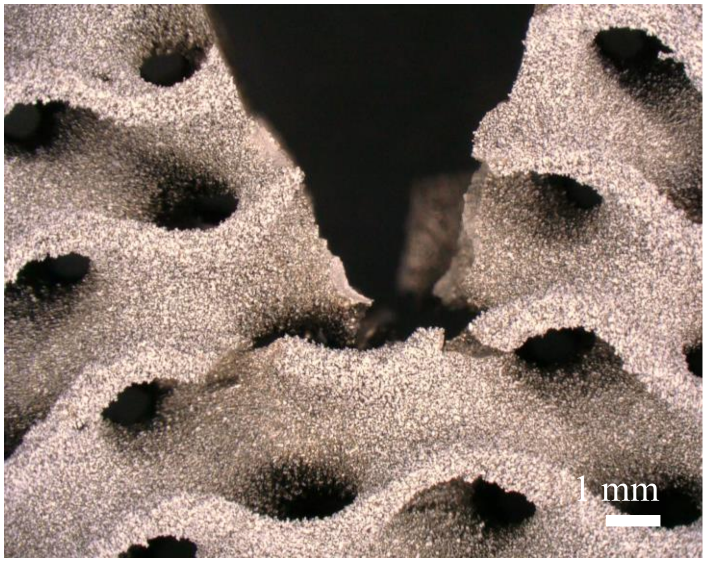

Figure 1: Crack branching at arrestor plane and then terminating at pore like features inherent in the gyroid metamaterial

The mechanisms and amount of toughening due to the added planes of porosity were dependent on specimen topology and base material and ranged from 22% to 300% increase in material fracture toughness.

3. Conclusion

Added planes of porosity in a gyroid surface metamaterial creates a toughening porosity hierarchy between the added porosity and the pore-like features inherent in the topology to first divert and then arrest propagating cracks that does not happen with just the gyroid surface or adding porosity to a solid beam. Mechanisms of toughening are dependent on both topology and base material and change the amount of toughening present.

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