FRACTURE AND FATIGUE STUDIES ON META-SANDWICH AUXETIC CORE

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Abstract
Inspired by the Parker solar probe's heat shield, a carbon-carbon semi-auxetic laminate sandwiching a lightweight carbon auxetic core has been designed in this work. The fracture and fatigue crack propagation in 2D and 3D auxetic core at ambient and extreme temperatures has been predicted and compared with conventional honeycomb cores and foams. Comparative studies have been performed between the results obtained by in-house codes of phase-field fracture (PFF) in *FEniCS* and the extended finite element method (XFEM) in *ABAQUS*™.

1. Introduction

Advanced materials like foams and composites used in spacecraft experience high thermal stresses due to the constituent's mismatch in thermal expansion coefficients, leading to significant internal damage. It can be prevented by appropriate design and characterization of the internal structure with architected materials or metamaterials. During the service life, these materials must withstand the thermal shock which occurs due to the exposure of these materials to extremely high-temperature environments. Therefore, investigating the fracture behavior under thermal shock behavior is one of the essential considerations of the designers. Carbon foams have an interconnected three-dimensional cellular network, which endows them with many attractive performances for enhanced functionalities, including extremely low density, high surface area, electrical insulation, thermal shock resistance, non-ablating (filled with aerogel), ablating, and catalyst support. If we replace carbon foams with auxetics, additional control on the density of the material, sizes of cells and windows, and physical properties is achievable. Auxetic topologies in literature studies have illustrated a higher out-of-plane conductivity, strong in-plane thermal anisotropy, and the lowest peak temperatures during heat transfer. This paper focuses on predicting fracture and fatigue crack propagation of 2D and 3D cellular auxetic-core of different configurations implemented for the heat-resistant effective meta-sandwich system.

2. Results

PFF and XFEM analyses were performed to predict the fracture and fatigue behavior of the cellular auxetic structure. Fatigue fracture analysis can also be carried out by numerically integrating Paris law and using the ASTM formulation for the stress requirements. The advantages of PFF over XFEM include no need for ad-hoc criteria, crack initiation, propagation, merging and branching quantitative prediction, and the capability to solve complex fracture problems. To improve results accuracy and cut down on computational expenses, the direct cyclic low-cycle fatigue technique is linked with the XFEM and PFF. The well-known Paris law is used to achieve the fatigue reaction. Few observations from this study include

1. Auxetic 3D metamaterial shows the most negative Poisson's ratio values in all three directions, with the lowest thermal conductivity compared to other configurations. The thermal conductivity of the core gets reduced with an increase in auxeticity or more negative Poisson's ratio.
2. The input energy release rate value of the base material in PFF is one of the most sensitive parameters governing the effective fracture properties of the auxetic cellular structure. Also, a very fine mesh size is required for predicting the fracture behaviour of auxetic metamaterial without adaptive meshing.
3. The force-displacement behaviour, as shown in Fig. 1, shows better performance of AUX-2, for the same effective density and same material

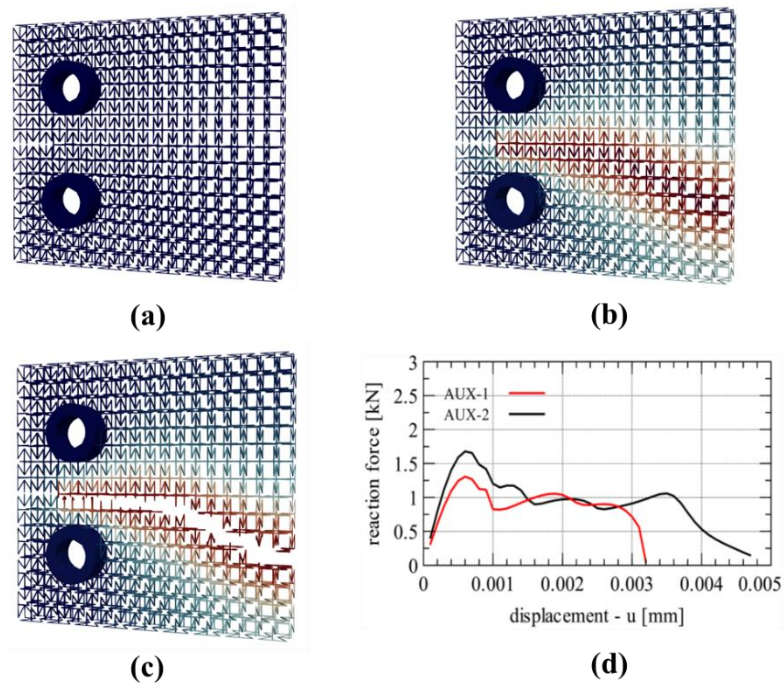

Fig.1 – Fracture study on 3D auxetic metamaterial CT specimen (a) Original designed geometry (b) Initiation of fracture (c) Fractured specimen using in-house codes via FEniCS (d) Force-displacement behavior of proposed auxetic configuration (AUX-1) and comparison with literature (AUX-2)

In the examined auxetic specimens, the geometry and distribution of cells significantly affect the direction of the fatigue failure route. The studied specimens underwent quasi-static and low-cycle fatigue testing to determine the auxetic specimens' fatigue behaviour. Re-entrant auxetic system AUX 2 showed a little higher fatigue resistance than re-entrant auxetic structure AUX 1 when the regression lines for the two structures were compared.

3. Conclusions

Conventional graphite foam has a higher thermal conductivity than metallic foam like aluminum. However, the thermal resistance can be improved because of the tunability and large specific surface area of open pores and inter-connected voids in the auxetic structure made of graphite. The cell wall length dominates the failure modes of the auxetic system, including cell angle, crack size, and density under a specific external temperature jump. The results of the study show that the crack topology largely depends on the cell's topology relative to the original notch orientation. Such systems for which the crack path is pre-defined can have more capacity to function as a structural component. Furthermore, the results also show a significant influence of the cell topology on fatigue lifetimes and failure pathways under cyclic loading conditions. These outcomes will advance the adoption of auxetic metamaterials in space applications such as heat shields and insulations, heat exchangers, filters, demisters, storage batteries, scaffolds, and thermal management.

Acknowledgments

The financial support of the ISRO Bengaluru via Grant No. SRC-1560-CED (STC-04) ISRO-IIT Roorkee Space Technology Cell, IIT Roorkee, is gratefully acknowledged.