Tuning damage in porous architectured materials inspired by osteonal bone

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The intricate relationship between the structure, the mechanical properties and the toughening mechanisms in biological materials needs to be understood in order to develop resilient bio-inspired synthetic materials with enhanced mechanical properties.

There are many examples of biological materials around the world (*e.g.*, bone, nacre, glass sponge, teeth), that possess different mechanisms to mitigate crack propagation. Our focus is on how a porosity pattern can influence the interaction between a weak spot and a propagating crack. In our context, we draw inspiration from the osteonal bone, which employs multiple mechanisms, potentially including porosity, to protect its weak spot (*i.e.*, the Haversian canal containing its vascularisation).

The thesis therefore combines finite element simulations and additive manufacturing to study crack propagation and damage evolution. The simulations focus on notch sensitivity, hole attraction and the overall mechanical performance of the materials. The results reveal a complex interplay between material parameters that govern the damage initiation and evolution. In addition, incorporating a linear porosity pattern allows, depending on the features of the pattern such as pore spacing, to program the cracking behaviour by guiding cracks along predetermined paths. Although one week interface allows to deviate the crack, it does not improve the overall toughness of the system, suggesting that more weak interfaces may be combined, as seen in numerous biological materials.

To translate the computational models into physical prototypes, an additive manufacturing technique is employed, specifically PolyJet 3D printing. This method enables precise control over the microstructure and porosity of the materials, facilitating the creation of samples that closely align with the modelled designs. This experimental part thus involves designing, manufacturing and testing these samples to observe the damage evolution and fracture patterns. The results appear to corroborate the computational results.

Overall, this interdisciplinary approach, combining bio-inspiration with numerical simulations and an additive manufacturing technique, holds promise for the development of novel damage-tolerant materials for biomedical and engineering applications, motivating further research in this field.

Keywords: Biomimicry, Bio-inspired materials, Finite element simulation, 3D printing, Mechanical testing, Crack propagation, Mechanical properties, Damage-tolerant materials.

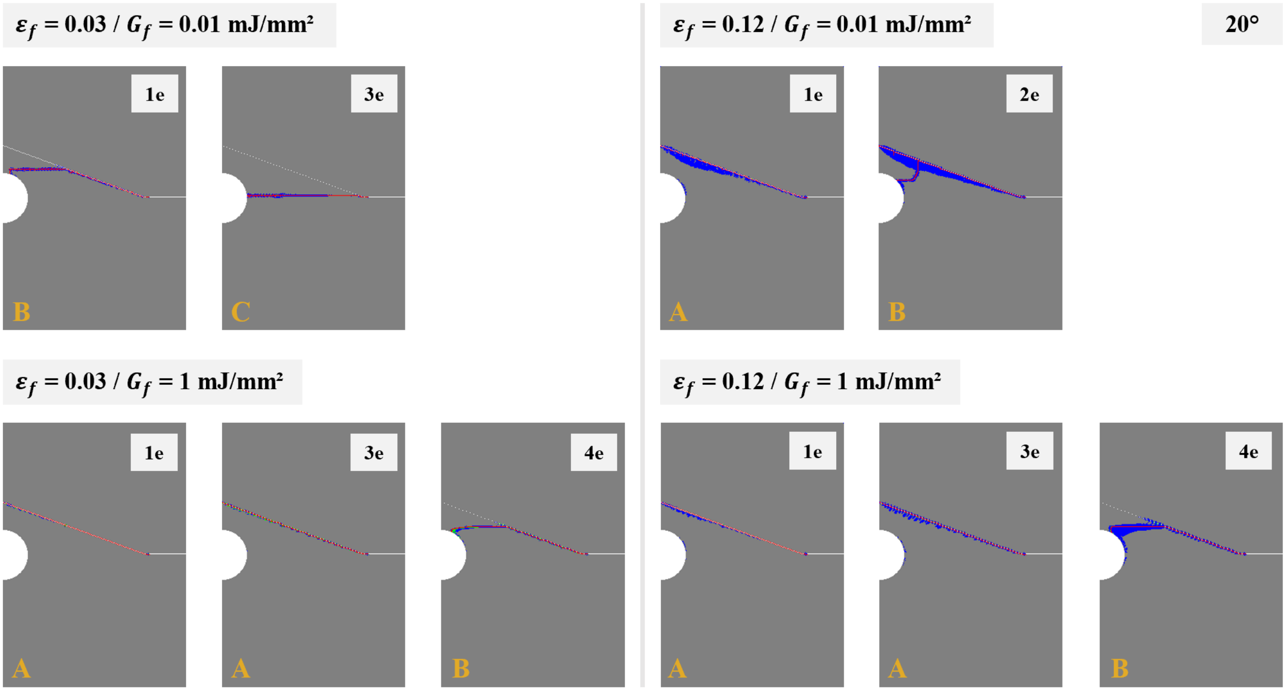

Figure 1: Fracture patterns of the hole model investigated for two values of fracture strain (ε_f), two values of damage evolution energy (G_f), a weak interface inclined at 20° and an initial crack length corresponding to 20% of the model width and a notch positioned at 0.15 mm. The number of elements shown in the models indicates the spacing between the pores for each case. Grey areas correspond to intact elements (DUCTCRT = 0), blue areas to damage initiation (0 < DUCTCRT < 1), green areas to damage evolution (SDEG > 0) and red areas to the crack path (SDEG = 1).

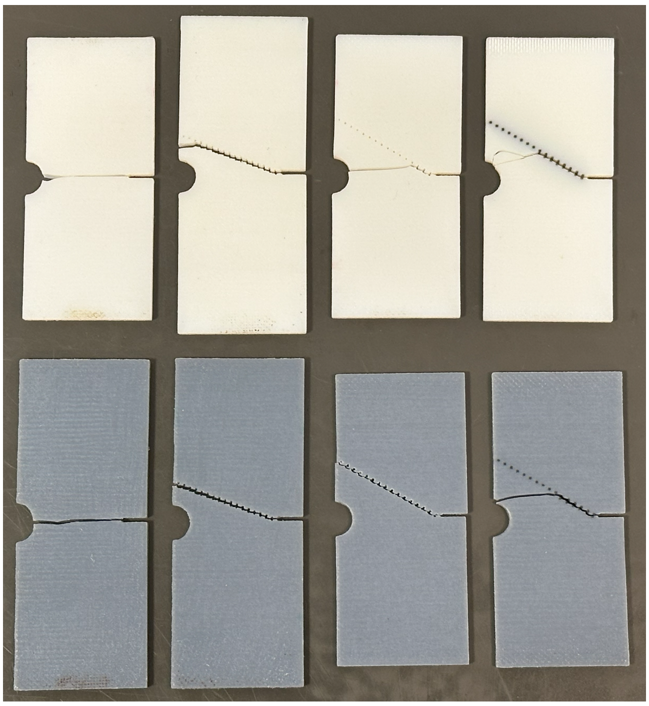

Figure 2: Fracture patterns after the tensile tests. Up: samples in VW. Down: samples in G60. Left: no pores. Middle: line of empty pores inclined at 20° and then 30°. Right: line of pores filled with TB+ inclined at 30°. Note that the larger samples are part of the second batch, in which the size of the grips has been increased.