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# How to protect a weak spot inside a load-bearing architectured material: a lesson from bone

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Economic and environmental constraints are triggering the development of materials with enhanced mechanical efficiency and reduced over-dimensioning. These challenges can be met with so-called architectured materials, which have well controlled structural features sitting at intermediate length scales between overall component size and microstructure. However, architectured materials often contain potentially weak spots such as pores and interfaces, which can trigger damage. To minimize and predict failure in these materials, it can be instructive to consider how nature has coped with such problems. As an example, bone is a biological material that not only tries to minimize failure, but can also tolerate and repair damage. One essential feature enabling bone renewal is the presence of an intricate multiscale porosity to house blood vessels and cells. As a consequence, bone must avoid that stress concentrations around pores cause failure. Moreover, cracks forming due to daily loading must not reach the functional pores. In cortical bone, blood vessels are accommodated in the central canals of osteons, which are cylindrical features consisting of several concentric layers of bone lamellae and bordered by a thin protective sheet, called cement line. Osteons are important for bone toughness as incoming cracks can be deflected by the cement line or twisted by the lamellae. In our study, we combine computational modeling with 3D printing to explore the mechanical behavior of osteon-inspired materials. In analogy with the cement line in bone, the protective role of interlayers around a weak region is characterized using damage-based finite element analysis, which assumes that a critical equivalent plastic strain is needed to initiate damage and that damage evolution is controlled by a specific energy [1]. Increasing damage decreases stiffness and strength. We designed 2D notched models featuring a homogeneous matrix with a central hole, bordered by a thin interlayer. We systematically varied the position of the notch with respect to the hole as well as interlayer stiffness, yield stress and fracture energy. After finding the critical notch position that causes a crack to reach the hole, we introduced the interlayer around the hole and we investigated damage behavior. Our results indicate that even a minimal interlayer (having a thickness one order of magnitude smaller than the diameter of the hole) can have a large and non-trivial impact on damage mechanisms, influencing the interaction between the crack and the hole. Interlayers with yield stress smaller than matrix strength are able to trap damage, thus shielding the weak spot. Interlayers more compliant than the matrix can hamper the propagation of cracks after reaching the hole. We used 3D polyjet printing to prototype selected models with interlayers (cement line) printed using different material (stronger or weaker) than the matrix. Our prototypes showed a programmable failure behavior dependent on interlayer properties. This work demonstrates that bone's design strategy to hamper damage can be translated to higher length scales, even using completely different building blocks, into 3D-printed synthetic materials.

## REFERENCES

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