

## Designing architected materials with tunable damage behavior inspired by osteonal bone

Timothy Volders (1), Laura Zorzetto (2), Hajar Razi (3), Richard Weinkamer (2), Davide Ruffoni (1)

(1) University of Liege, Liege, Belgium. (2) Max Planck Institute of Colloids and Interfaces, Potsdam, Germany. (3) ETH Zurich, Zurich, Switzerland, and WoodTec Group, Cellulose & Wood Materials Laboratory, Empa, Dübendorf, Switzerland.

Providing materials with well-controlled architectural features sitting at intermediate length scales between overall specimen size and microstructure is a powerful strategy to expand the design space and to improve material performance. Developing architected materials in engineering can profit from the observation of natural materials, especially when looking for damage tolerance and multifunctionality. An instructive example of a biological material which can tolerate and even repair damage is bone. 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 multimaterial printing to explore the damaging behavior of osteon-inspired systems. 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. Increasing damage decreases material 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 yield strain. 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 influence on the interaction between the crack and the hole. A critical material parameter for damaging behavior is the yield stress of the interlayer. A yield stress of at least 2.5 times smaller than matrix strength is required to trap damage inside the interlayer, whereas the yield stress needs to be increased by 3 times to enable damage deflection by the interlayer. In both cases the weak central spot is shielded. Ongoing work considers additional notch positions to investigate the role of the angle at which the damage meets the interlayer. In parallel, 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 shows that 3D-printed synthetic materials can benefit from strategies used by nature to increase damage tolerance.