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Strain rate hardening in biological and biomimetic composites: a critical ingredient to mechanical performance?

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ABSTRACT

Natural materials such as nacre, bone, collagen, or spider silk boast unusual combinations of stiffness, strength, and toughness. Behind this performance is the staggered microstructure, which consists of stiff and elongated inclusions embedded in a softer and more deformable matrix. The micromechanics of deformation and failure associated with this microstructure are now well understood at the “unit cell” level, the smallest representative volume for this type of material. However, these mechanisms only translate to high performance if they propagate throughout large volumes, an important condition which is often overlooked. Here we present, for the first time, a model which captures the conditions for delocalization in staggered composites, and which determines whether the material is brittle or deformable at the macroscale. The macroscopic failure strain for the material is derived as function of the viscoplastic properties of the interfaces and the severity of the defect. As expected, larger strain can be achieved with smaller defects or with more strain hardening at the interface. The model also shows that strain rate hardening is a powerful source of delocalization for the material, a result we confirmed and validated with tensile experiments on glass-PDMS nacre-like staggered composites. An important implication is that natural materials, largely made of rate-dependent materials, may rely on strain rate hardening to tolerate initial defects and damage to maintain their structural integrity. Strain rate hardening should also be harnessed and optimized in bio-inspired composites to maximize their overall performance.