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Widespread use of multi-functional materials in various industries (automotive, aerospace etc.) motivates the research in hybrid/composite materials having combination of conflicting properties (e.g. light-weight, high stiffness, damping and toughness). However, increasing toughness of a stiff material is one of the biggest challenges in the material research community. From Ashby's [1] toughness-modulus data for various materials, it appears to increase the toughness and stiffness of a material, type of metal or metallic alloys needs to be used that eventually increases the weight of the material. On the other hand, most of the stiff polymers are usually brittle. The concept of architectured materials offers opportunities to generate combination of such conflicting properties by tailoring the architecture and combining ideal constitutive (base) materials [2]. In the present research work, the objective is to extend knowledge regarding how hierarchical interlocking mechanisms can be explored to improve toughness while maintaining stiffness in an architectured material made of stiff, brittle polymers. The basic hypothesis of the design is that the interlocking mechanism will act as a load bearing entity in which stress transfer occurs through pure geometric contact between two material blocks despite having discontinuity between them. In addition, the discontinuous surfaces between two materials will serve as weak interfaces. Those weak interfaces would force the material blocks to fail in a controlled manner under external loading. Such predefined failure in the interfaces helps the toughness of the architectured materials to increase significantly. A thin layer of soft, viscous polymer in the interface reduces friction as well as acts as an adhesive between contacting surfaces. By assembling blocks of brittle stiff polymers with another soft polymer in the intefaces, an architectured material can be designed that includes interlocking mechanisms at various order of hierarchy. Therefore, it is expected to achieve a multifunctional lightweight material with simultaneously high toughness and stiffness. In the present study, finite element simulations are performed to predict stiffness and fracture toughness of the interlocking polymer blocks, considering polymethylmethacrylate (PMMA) as the brittle, stiff material. PMMA is extremely brittle in tension. PMMA is assumed to behave as an elastic-perfectly plastic material where reaching the yield strain can be practically considered as failure. To model the interfacial delamination in the weak interfaces, a cohesive zone based interface model has been used. A traction-separation law based on the fracture energy of the interface has been considered to phenomenologically describe the interface degradation. The interfaces are assumed to be weaker than the stiff materials. Once damage initiates, the cohesive zones start to open and slide promoting local failure of the interfaces; while the interlocking acts as load bearing mechanism and helps the material to carry the load. From uniaxial tensile simulations of the architectured material, it is seen that the stiffness goes down compared to the bulk PMMA due to the sliding and opening across the interfaces. However, the final strain at which PMMA starts to yield becomes considerably larger with the presence of interlocking. The bulk PMMA sample is extremely brittle as yielding in PMMA starts really quickly; whereas in the interlocked geometry yielding gets delayed as applied energy is spent on promoting interface failure. Therefore, it is shown that allowing relative sliding across the interfaces and opening them would result in better toughness. It is also seen, introducing hierarchy within the interlocks eventually improves ductility without reducing the stifffness. This understanding will set guidelines to optimize the architectured material with hierarchical interlocking for an ideal combination of stiffness and toughness.

References [1] Ashby, M. F., et al. "The mechanical properties of natural materials. I. Material property charts." *Proc. R. Soc. Lond. A*. Vol. 450. No. 1938. The Royal Society, 1995
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