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Extreme Classical and Nonclassical Physical Properties in Heterogeneous Materials

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Extreme classical and nonclassical physical properties in heterogeneous materials

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Materials with unusual physical properties and extremely high, even singular values of physical properties, both classical and nonclassical, are developed. Conceptual, synthesis, and characterization aspects are presented.

Negative Poisson's ratio, which entails a transverse expansion on stretching, is considered counter-intuitive; indeed such materials were once thought not to exist or even to be impossible. Indeed, normal elastic materials resist both shape changes and volume changes. Rubbery materials, which easily change shape but not volume, become thinner in cross-section when stretched. For rubber, Poisson's ratio is close to 0.5; for most other common materials it is between 0.25 and 0.35. We have developed a class of spongy materials with a negative Poisson's ratio [1] as small as -0.8. Other groups have subsequently developed many composites, cellular solids, materials near phase transformations, and lattices with a negative Poisson's ratio.

Negative stiffness entails a reversal in the usual assumed direction between forces and resulting deformations. Negative structural stiffness is known to occur in buckled structural elements, including buckled tubes and buckled single cells of foam. Negative material compressibility is claimed to be impossible in some thermodynamic texts but is demonstrated in the laboratory. Negative compressibility is not in fact illegal, it is only unstable in a block with free surfaces. Materials with negative compressibility may be stabilized by constraining them externally or by embedding them in a composite. Materials with designed heterogeneity including inclusions of negative compressibility can exhibit extremely high values of viscoelastic damping [2] approaching a singularity, high Young's modulus (even greater than that of diamond) [3] or thermal expansion. Such behavior exceeds the usual theoretical bounds. The reason is that assumptions made in deriving the bounds can be relaxed in certain materials and microstructures.

Hierarchical materials have been designed to exhibit extremely high values of specific strength [4]. Thermal expansion can be made extremely large, zero, or large negative in designed lattices [5,6]. Piezoelectric sensitivity can be made extremely large in designed lattices. Conventional bounds are greatly exceeded because assumptions made to derive them are relaxed.

Nonclassical effects, understood via Cosserat elasticity, have been observed experimentally in a variety of materials with microstructure, including bone [7], foams [8,9], and designed lattices. Cosserat solids can be elastically chiral [10] and exhibit stretch-twist coupling. Polymer lattices as negative Poisson's ratio solids [11] and as chiral solids [12] are shown to be Cosserat elastic. Strong Cosserat effects are achieved in designed lattices; effects may become unbounded.

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