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Achievement of extreme and reversed values of physical properties

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ABSTRACT
Materials with unusual physical properties and extremely high, even singular values of physical properties 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. These materials become fatter in cross section when stretched, and thinner when compressed. Negative Poisson's ratio also occurs in phase transitions in ferroelastic solids.

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 approaching a singularity, high Young's modulus (even greater than that of diamond) 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.

Materials inspired by (not imitating) hierarchical materials of biological origin, can be designed to exhibit extremely high values of specific strength, energy dissipation, thermal expansion (exceeding the usual bounds), or toughness. Toughness relates to size scales in the material; experiments disclose Cosserat elasticity, which has a characteristic length scale, applies to a variety of cellular solids.

KEYWORDS: *negative Poisson's ratio, negative stiffness, heterogeneity, hierarchical materials*