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Stretch most materials and you will expect to see their cross section shrink. But Alderson and Evans[1] have synthesized a microporous polymer that swells as it is stretched, and Milton[2] has designed a laminated composite that does the same.

These advances in the newly developing science of materials with a negative Poisson's ratio (the Poisson's ratio is the ratio of lateral contraction to longitudinal extension in in the direction of stretching force) promise improved control of properties and open the door to a new class of applications. Virtually all common materials become narrower in cross section when they are stretched. The reason why, in the continuum view, is that most materials resist a change in volume more than they resist a change in shape. Specifically, Poisson's ratio is $\nu = (3K - 2G)/(6K + 2G)$ with K as the bulk modulus and G as the shear modulus. In a structural view, imagine a material made of atoms interacting by central forces (think of spring elements) between nearest and next nearest neighbors. Stretching of the material will stretch the diagonal springs, causing a lateral contraction. It is possible to have materials which become fatter when stretched, that is, which have a negative Poisson's ratio, since the theory of isotropic elasticity[3] allows Poisson's ratios in the range from -1 to 1/2. Physically the reason is that for the material to be stable, the stiffnesses must be positive; the bulk and shear stiffnesses are interrelated by formulae which incorporate Poisson's ratio. Familiar materials have positive Poisson's ratios, typically about 1/3 both for stiff materials such as steel and aluminum and for compliant spongy materials, to just under 1/2 for rubber. Since negative Poisson's ratio materials easily undergo volume changes but resist shape changes, they may be viewed as the opposite of rubbery materials.

Several types of negative Poisson's ratio solids are known. Honeycombs with inverted hexagonal cells exhibit negative Poisson's ratios in two dimensions[4,5] and may be viewed as structures. Some highly anisotropic materials including a few natural single crystals, some synthetic off axis composite laminates, and microporous oriented polytetrafluoroethylene[6] have been reported to have a negative Poisson's ratio in some directions. Foams, based on polymers or metals, with a 're-entrant' cell structure (which bulges inward) exhibit negative Poisson's ratios in three dimensions[7] and can be made isotropic. They represent the first intentional synthetic example and the first which can be made isotropic. Causal mechanisms as well as other materials and structures are reviewed in Ref. 8. Both the honeycombs and foams require substantial porosity to achieve negative Poisson's ratios. They are therefore substantially less stiff than the solids from which they are made. It has been proposed that stiffer materials could be made by creating re-entrant structure on the molecular level[9].

The recent work of Alderson and Evans[1] deals with formation of microporous ultra high molecular weight polyethylene (UHMPE) with a negative Poisson's ratio, denoted 'auxetic' materials by the authors. The processing required to achieve this property consisted of compaction of powdered polymer, sintering, and extrusion. The material following processing was found to contain a network of microscopic size particles connected by fibrils (Fig. 1). As a result of the extrusion process, the polyethylene was mechanically anisotropic, with Poisson's ratios as small as -1.24 for compression in the radial direction, and zero for compression in the axial direction. The degree of anisotropy was less than in the expanded polytetrafluoroethylene examined earlier[6].

A family of laminate structures designed by Milton[2] allows isotropic elastic properties with Poisson's ratio approaching -1, which is the lower limit for isotropic solids. Milton calls negative Poisson's ratio solids 'dilational'. The laminates have a chevron structure, with multiple length scales in two dimensions (Fig. 2); a three dimensional version was also given. The laminates are structurally anisotropic, but can be made mechanically isotropic by proper choice of geometry and of constituent properties. The smallest Poisson's ratios of the laminates approach the rigorous lower bounds of Cherkaev and Gibiansky[10]. To achieve a negative Poisson's ratio in the laminate[2], the two constituents must differ in stiffness by more than a factor of about 25; to approach a Poisson's ratio of -1, the ratio in constituent stiffness must become large. These developments suggest the possibility of achieving high density and a corresponding high stiffness in materials with negative Poisson's ratios. Such materials could be of interest in structural applications.

Work on these strange materials is not meant just for our entertainment; negative Poisson's ratio materials may be useful for a variety of reasons. First, the Poisson's ratio itself can confer useful properties. For example, one may envisage a press fit fastener which contracts laterally when inserted into a socket, facilitating insertion, then expands laterally to resist any attempt to remove it. In a wrestling mat, it is desirable to minimize impact force for impacts by both a small object (an elbow) or a larger one (a back). The smallest possible Poisson's ratio is desirable in such an application since the distribution of stress in the mat depends on Poisson's ratio. Poisson's ratio also influences the concentration of stress around holes and cracks; in some geometries a negative Poisson's ratio can be helpful. Second, other physical properties arise indirectly as a consequence of the unusual microstructure of negative Poisson's ratio materials; these properties may be useful. For example, the negative Poisson's ratio foams exhibit more resilience, toughness, and compliance than foams of conventional structure, as well as higher absorption of sound due to the convoluted cell ribs. In some potential applications such as knee pads, sound absorbing material, tear resistant sponges, or cores for sandwich panels, a material of low density and low stiffness is appropriate. However for structural applications a stiff material is required, and high stiffness is difficult to achieve in a foam.

These recent advances have provided scope for creativity in the design of new material microstructures with unusual material properties. Since negative Poisson's ratio materials are now available in the form of polymers and laminates as well as foams, there is the possibility that such solids will find use in structural applications.

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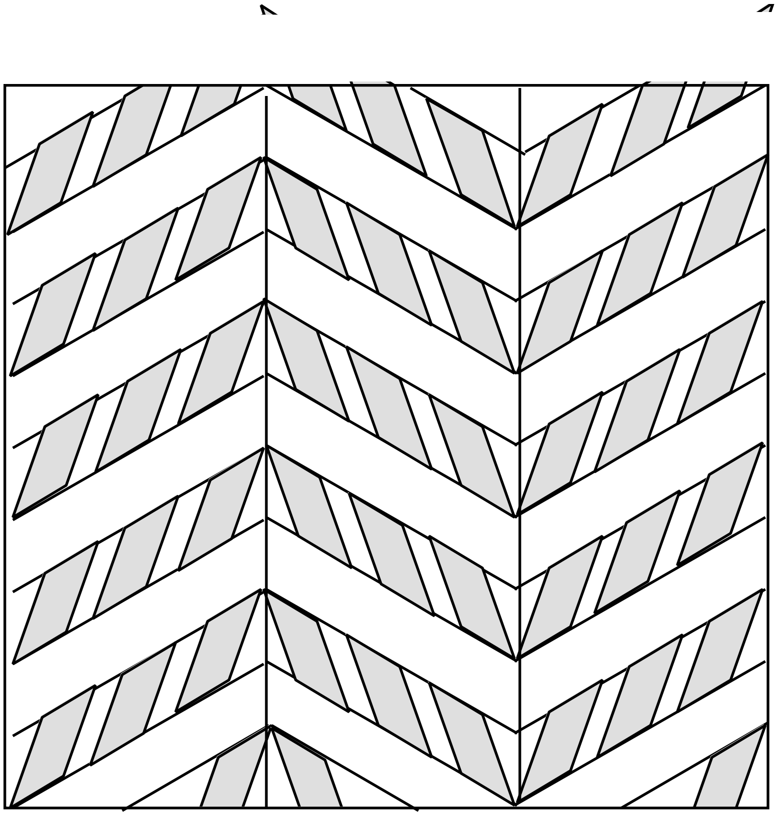
Figures

See the original for this.

1 Micrograph of negative Poisson's ratio polyethylene made by Alderson and Evans.



2 Negative Poisson's ratio laminate of Milton. The compliant phase is shaded.