# Study of the Effects of Random Inclusions in Composite Construction with Isotropic Negative Poisson's Ratio

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## Abstract

Materials with negative Poisson's ratio (NPR) effects have been reviewed and conclude that the studies have mainly focused on 2D periodic structures which only have NPR effects in certain in-plane directions. In this paper, composite structures with isotropic NPR effects using NPR random inclusions is developed by Ansys software. A finite element analysis is done for deformation mechanisms of a 2D representative cell which is embedded with a re-entrant triangle. Based on the analysis results, the re-entrant triangles are selected as random inclusions into a matrix to form 2D composite structures. Composite structures are built with different numbers of inclusions through a parametric model, and their NPR effects and mechanical behaviors are analyzed using the finite element method.

## Introduction

In 1944, the concept of a negative Poisson's ratio (NPR) materials was first described. An intentional development of the materials with NPR was first published by Lakes in Science. Since then, many efforts have been done to study the NPR effects and to fabricate materials with this nonconventional behavior [1]. NPR materials have increased shear modulus, indentation resistance, fracture toughness and energy absorption ability. NPR materials have ample potential applications to improve engineering materials for textile, automotive, military, bio medical and aerospace engineering etc.

## Poisson's Ratio

Poisson's ratio ν is the ratio of transverse contraction strain to longitudinal extension strain in the direction of stretching force. Tensile deformation is considered positive and compressive deformation is considered negative. The definition of Poisson's ratio contains a minus sign so that normal materials have a positive ratio. Poisson's ratio is usually represented as a lower case Greek nu, ν.

$$\nu = -\varepsilon_{transverse}/\varepsilon_{longitudinal}$$

Strain ε is defined in elementary form as the change in length divided by the original length.

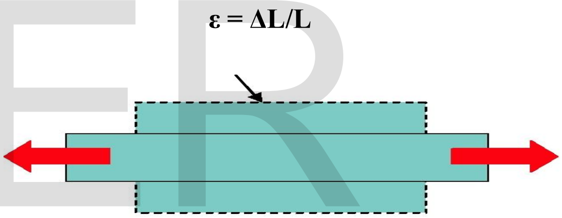


**Fig.1 A material deformation with positive Poisson's ratio [2]**

## Poisson's Ratio: Why Usually Positive

Virtually all common materials become narrower in cross section when they are stretched. There as on why, in the continuum view, is that most materials resist a change in volume as determined by the bulk modulus K more than they resist a change in shape, as determined by the shear modulus G. In the structural view, the reason for the usual positive Poisson's ratio is that inter-atomic bonds realign with deformation.

## Poisson's Ratio: Relation to Elastic Modulus in Isotropic Solids

Poisson's ratio in isotropic material is related to elastic modulus K (also called B), the bulk modulus; G as the shear modulus; and E, Young's modulus, by the following (for isotropic solids, those for which properties are independent of direction). The elastic modulus is measures of stiffness. They are ratios of stress to strain. Stress is force per unit area, with the direction of both the force and the area specified.

$$\nu = (3K-2G) / (6K+ 2G)$$

$$E = 2G (1 + \nu)$$

$$E = 3K (1 -2 \nu)$$

The theory of isotropic elasticity allows Poisson's ratios in the range from- 1 to ½ for an object with free surfaces with no constraint. Physically the reason is that for the material to best able, the stiffness's must be positive; the bulk and shear stiffness's are inter related by formulae which in corporate Poisson's ratio. Objects constrained at the surface can have a Poisson's ratio outside the above range and best able.

### Poisson's Ratio in Bending

Bend a bar or plate. Poisson's ratio governs the curvature in a direction perpendicular to the direction of bending. This anticlastic curvature is easily seen in the bending of a rubber eraser. Shown here is bending, by a moment applied to opposite edges, of a honey comb with hexagonal cells. If the honey comb cells are regular hexagons, the Poisson's ratio can approach +1. Since the honey comb is an isotropic, the Poisson's ratio need not lie within the above range.

### Negative Poisson Ratio

Modern technology requires new materials of special properties. One of the reasons for interest in material so fun usual mechanical properties comes from the fact that they can be used as matrices to form composites with other materials of other required properties, e.g. electric, magnetic, etc. A new field of endeavor is to study materials exhibiting negative Poisson‘s ratio (NPR). These types of materials get fatter when they are stretched, or become smaller when compressed, in contrast to conventional materials (like rubber, glass, metals, etc.). Large-scale cellular structures with NPR property were first realized in 1982 in the form of two-dimensional silicone rubber or aluminum honey combs deforming by flexure of the ribs. In 1987, Lakes first developed the NPR polyurethane foam with re-entrant structure. This polymeric foam had a Poisson‘s ratio of-0.7. These new types of materials were named auxetic by Evans. Auxetic comes from the Greek word auxetos, meaning—that which may be increased.

Studies and experiments have demonstrated that auxetic materials (i.e., materials with NPR) can improve mechanical properties, including shear resistance, indentation resistance and fracture toughness, compared to conventional materials from which they are made. These auxetic materials also off every good sound and vibration absorption and could have many potential applications to aerospace and defence areas. This report briefly reviews the latest advances in research work in auxetic materials, structural mechanisms, properties and applications, particularly in aerospace and defence. Indeed, these new types of materials have a lot of potential applications to Defence such as personal protective equipments (e.g., protective clothing, body armour, bullet-proof vest, etc).

People have known about auxetic materials for over 100years, but have not given them much attention. This type of material can be found in some rock and minerals, even animal such as the skin covering a cow‘s teats. To date, a wide variety of auxetic materials has been fabricated, including polymeric and metallic foams, micro porous polymers, carbon fibre laminate sand honeycomb structures. A typical example is a well-known synthetic polymer-poly tetra fluorothylene (PTFE), which has been in use for many years.

Materials with a negative Poisson‘s ratio (NPR), the so called auxetic, ‘are those that when stretched in a particular direction expand in an orthogonal direction. NPR behavior is a counter intuitive material property that has been observed only in a handful of materials that often have intricate structures and characteristic lengths much larger than an atomic bond length.

## Mechanism and Structure

As stated above, a material with NPR expands (gets fatter) when stretched, as opposed to most materials, which tend to get thinner. A typical mechanism is shown in Figure 2. When a force pulls the structure in one direction (e.g., here vertically), the structure opens up or expands in the perpendicular direction (here, horizontally), i.e., the structure gets fatter. Based on this simple mechanism, a network-like structure can be built up, as shown in Figure 3, where a 2D structure of such a material consists of a regular array of rectangular nodules connected by fibrils (Burke, 1997). Deformation of the structure is by hinging ‘of the fibrils. For the open ‘geometry, the cells elongate along the direction of stretch and contract transversely in response to stretching the network, giving a positive v (refer to Figure 3(a)). However, the structure is modified to adoptare-entrant 4 geometry, Figure 3(b), and the network now undergoes elongation both along and transverse to the direction of applied load. In other words, this is an auxetic structure.

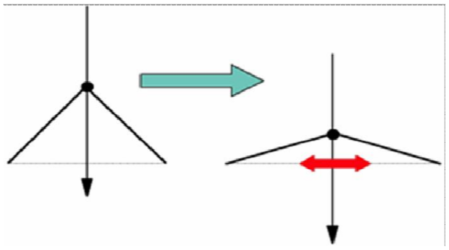


**Fig. 2 Schematic of basic deformation mechanism in auxetic material [2]**

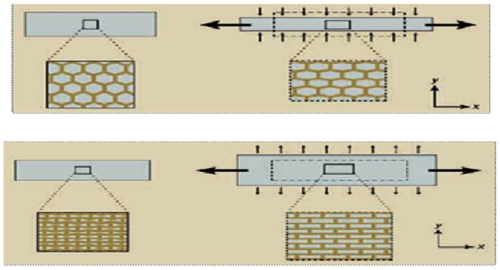


**Fig.3 Comparison of deformation behaviors [2]**

Figure 4 shows the deformation mechanism of the auxetic honey combs along with conventional honey comb structure. For a conventional hexagonal geometry (Figure 4(a)), under the stretch in the y direction the cells elongate along the y-axis and close up in the x direction, leading to a positive Poisson‘s ratio. However, for an auxetic structure, the cells undergo elongation both parallel and perpendicular to the direction of the applied load.

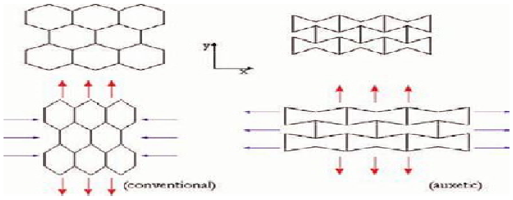


**Fig. 4 Two-dimensional deformation mechanisms, which are subjected to loading in they-direction: (a) Conventional honey comb structure [3] (b) Auxetic honey comb structure (after Evans & Alderson, 2000 a; Evans & Alderson, 2000 b). [3]**

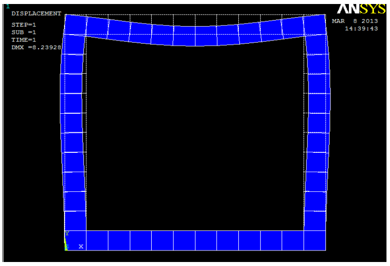
For auxetic micro-porous polymer, the characteristics of the microstructure can be interpreted by a simple 2D model, as shown in Figure 6. This basically consists of an interconnected network of nodule sand fibrils. If a tensile load is applied, the fibrils cause lateral nodule translation, leading to a strain-dependent negative Poisson‘s ratio.

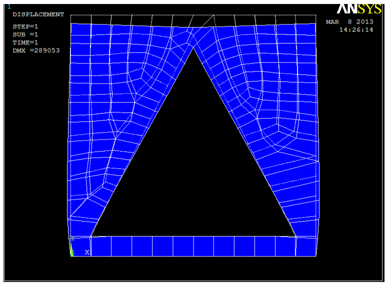
## Properties of Materials

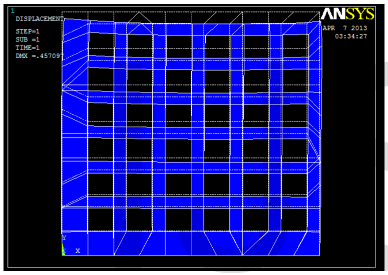
Materials with NPRs have the following special properties:

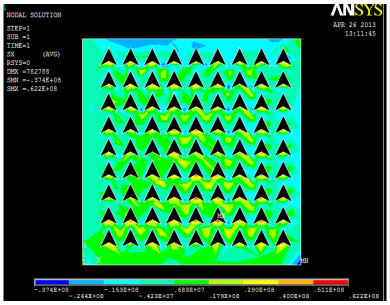
- High in-plane indentation resistance
- Good fracture toughness
- High transverse shear modulus
- High dynamic properties.

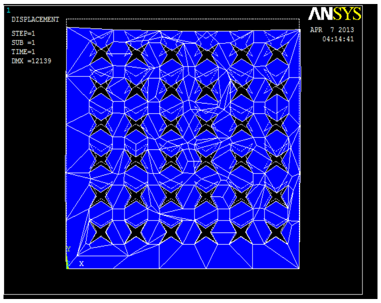
## Solution Methodology (Using Ansys)

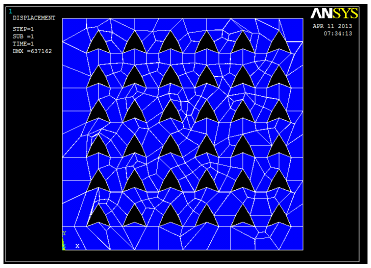




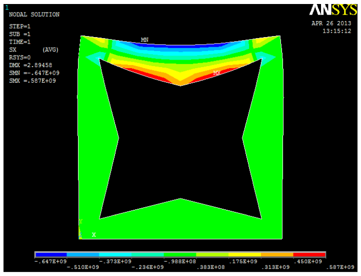


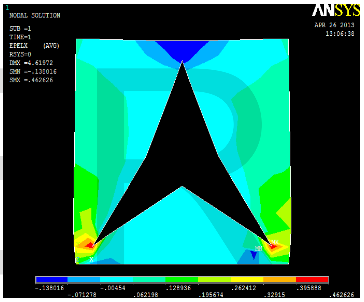


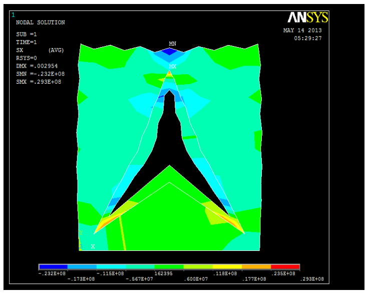




## Results







## General Applications

The Poisson's ratio in fluencies deformation kinematics in many ways which may be useful and it influences the distribution of stresses. For example, stress concentration factors are reduced in some situations and increased in others, when Poisson's ratio is negative. Materials with NPR can enhance the performance of piezoelectric transducers. Auxetic materials are also likely to find uses in applications such as fasteners, car bumpers, sound proofing and shin pads. Some applications are given below-

- Sensors
- Biomedicine
- Auxetic Fibre Reinforced Composites
- Potential Applications in Aerospace and Defense
- Smart or “Intelligent” Textiles
- Bullet-Proof Helmets and Vests
- Fasteners and Rivets
- Energy Absorption Material for the Protection of Air borne Cargo Drops

**Limitations**

As stated above, auxetic materials potentially have many applications, because of their wonderful properties compared to conventional (i.e. non-auxetic) materials. However, they also have their own limitations like other materials. The special micro structural features for auxetic materials need space to allow the—hinges to flex, or the —nodules to spread out. The materials often need substantial porosity. Therefore, materials with negative Poisson‘s ratio are substantially less stiff than the solids from which they are made and this causes limitations on the structural applications of the materials with negative Poisson‘s ratio. For example, they are normally not stiff enough or not dense enough for load-bearing applications.

**Conclusions and Recommendations**

Materials with NPR show unique properties, compared to ordinary materials such as enhancement of shear modulus, indentation resistance or plane strain fracture toughness, although they have less stiffness. Therefore, they have many potential applications to Defense such as personal protective equipment (e.g., protective clothing, body armour, bullet-proof vest, etc) and others (e.g., smart sensors, sonar, panels etc). Also, these materials could potentially be used to build completely new structures with special functions. However, more research work needs to be done for further understanding of these materials and applications to real components. For future work, experimental tests need to be carried out to further understand the behaviors of these types of materials. Also, for future work it is necessary to collaborate with researchers from textile, chemical & biological areas to explore the potential applications for protecting military personnel from injury, or chemical & biological attacks from enemy or terrorists.

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