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Auxetic Materials

Chidire Anurag[1], Ch Kesava Anvesh[2], Sharanya Katam[3]
Vardhaman College of Engineering, Mechanical Engineering

Abstract— Auxetic materials are known for their peculiar behavior unlike conventional materials the thickness of these materials increase under the action of axial pull. In this paper we are going to study the properties of Auxetic materials, their occurrence in nature, methods of synthesis, applications. Our ideas of other possibilities to make use of these materials. The current status of research into auxetic (negative Poisson's ratio) materials is reviewed, with particular focus on those aspects of relevance to aerospace engineering. Developments in the modeling, design, manufacturing, testing, and potential applications of auxetic cellular solids, polymers, composites, and sensor/actuator devices are presented. Auxetic cellular solids in the forms of honeycombs and foams are reviewed in terms of their potential in a diverse range of applications, including as core materials in curved sandwich panel Composite components, random applications, directional pass band filters, adaptive and deployable structures, MEMS devices, filters and sieves, seat cushion material, energy absorption components, viscoelastic, damping materials and fastening devices. In this paper we are going to put forward our proposals of using auxetic materials in helmet, seat of a bike, car bumpers.

Index Terms— Auxetic Materials, Auxetic foam , Formation of Dome shape, Negative Poisson's Ratio, Novel behavior.

I. INTRODUCTION

The development of a section of a community is decided by the materials they are using. In our daily life we select different materials for various specific jobs. Hence selection materials are plays a crucial role in the job or project that we are handling. Materials can be divided into two classes- Structural and functional. Today our lives are made more luxurious because of usage of functional materials like Smart materials. Examples of smart materials are Semi-conducting polymers, piezo-electric materials, Auxetics. The term auxetics derived from the word Auxetikos-that tends to increase. It was coined by Professor Ken Evans. Poisson's ratio is one of the basic properties which make these materials different from other materials.

A. Poisson's Ratio

For an elastic body which is under tension this Poisson's ratio is defined as the ratio of Lateral strain in the body to that of longitudinal strain.

For conventional materials this ratio is a positive value whereas auxetic materials exhibit negative Poisson's ratio.

When an elastic material is stretched axially its thickness decreases, when an auxetic material is stretched its thickness increases which is one of the striking properties of these materials.

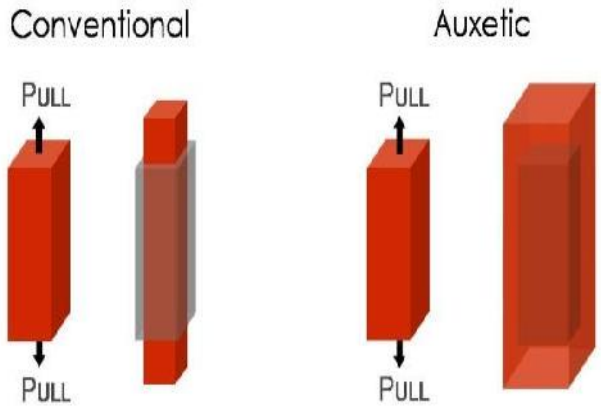


Fig. 1. Diagrammatic representation of axial pull on materials

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Fig. 2. An auxetic material increases in thickness under tension.

II. HISTORY &NATURAL OCCURRENCE

A negative Poission's ratio was first found in single crystals of Iron-Pyrites,during late 1920's. Large-scale auxetics were first realized in the year 1982 in the form of Silicone rubber, aluminium honeycombs. But these structures are elastically anisotropic .



Fig. 3. Iron-pyrites

Auxetic behavior was thought to exist in some super conducting oxides. This thought was due to the discovery of auxetic behavior in **$YBa_2Cu_3O_7$**-Yittrium Barium Copper Oxide. Some naturally occurring single crystal elements like arsenic, cadmium exhibit this behavior. In the year 1988 experiments conducted by Ray Baughman with his colleagues revealed that 69% of the metals having cubic structure exhibit this auxetic behavior when stretched along some specific direction. Some rare gas solids also auxetic. Some biological materials like cat skin, salamander skin, Cancellous bones from human shins honey-comb structure exhibits this effect.

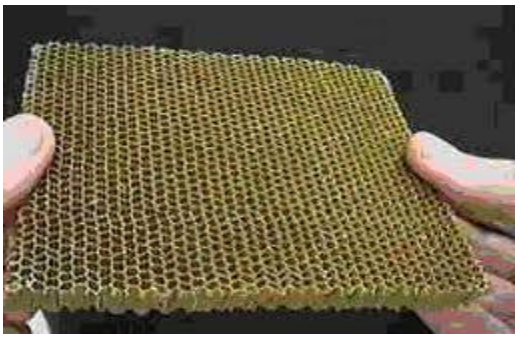


Fig. 4. Honey-combexhibiting auxetic nature.

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A. Structure

Most of the auxetic materials have Hexagonal hinge like structure. This resembles bow-tie. These auxetix hexagons become squarer when stretched perpendicularly. Due to this phenomenon their thickness increases under tension acting axially.

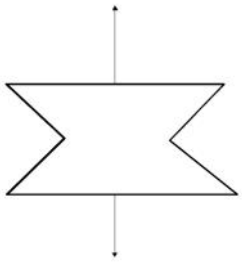


Fig.5. Hexagonal-hinge



Fig. 6. Bow-tie network of auxetic materials

B. Properties

Earlier we came across negative Poisson's ratio due to which the thickness of the body increases when it pulled along the axis. The other properties are

1) *Indentation Hardness:* When a non-conventional material is hit by an object, the material at the site of action flows away from that point by making the material less denser. In case of auxetic materials, when it is hit by any type impact load the material tends to flow towards the site of load acting and makes the material more denser. This phenomenon in auxetic material makes to find application in manufacturing of army jackets, which resists penetration of foreign bodies like bullets.

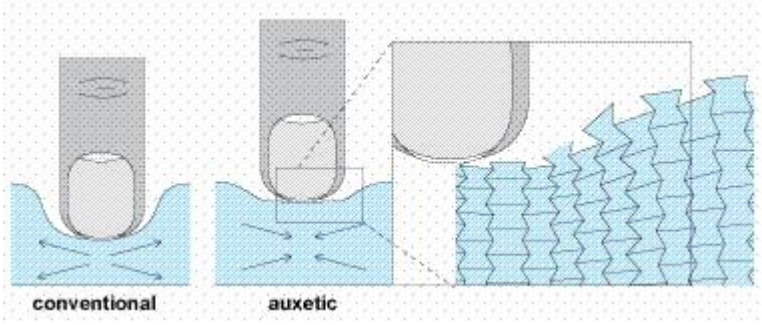


Fig. 7. Indentation hardness of convention VS auxetic.

2) *Synclastic Behavior:* When conventional materials are subjected to bending force they form Saddle shape, but when auxetic materials are subjected to bending force they form Dome shape rather than saddle shape. Hence these can be used in mattresses.

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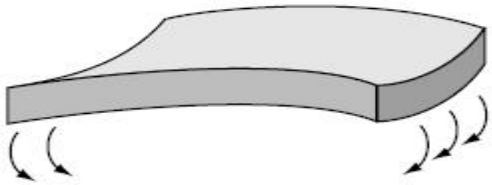


Fig. 8. Formation of saddle shape by a conventional material under bending force.

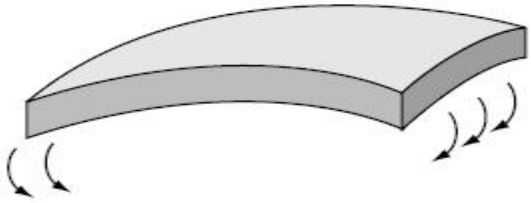


Fig. 9. Dome shape attained by auxetic material when subjected to bending force.

3) *NTE & Expansion Under Pressure:* Baughman proposed twisted-chain auxetics. These auxetics have wide range of interesting properties. When these structures are heated the material gets contracted hence they have NTE-Negative Thermal Expansion. These materials expand under pressure.

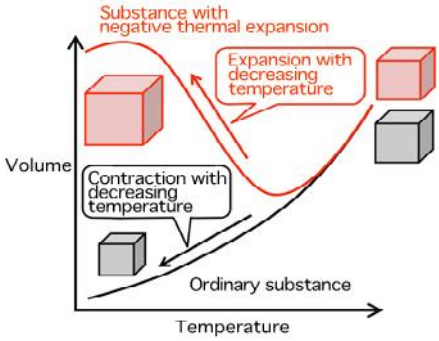


Fig. 10. Graph showing expansion of material under cooling.

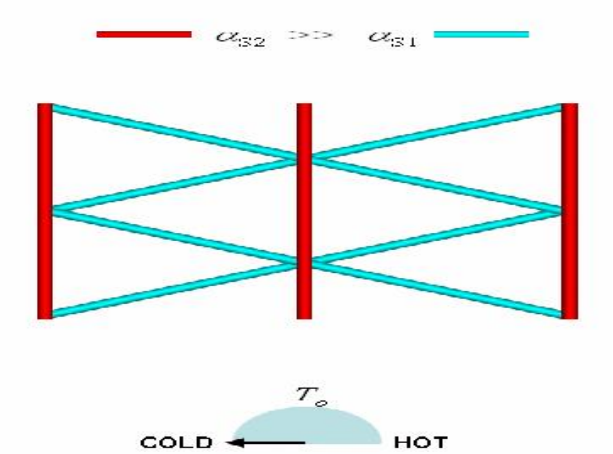


Fig.11 . Rotating triangles exhibit NTE & negative compressibility.

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4) *Stiffness:* Scientists at Leed's University have configured that Carbon-fiber-reinforced-epoxy composite laminates exhibit auxetic behavior. Generally laminates are damaged even by low indentation load. But these composites which have auxetic nature have good stiffness, improved fracture toughness, indentation resistance.

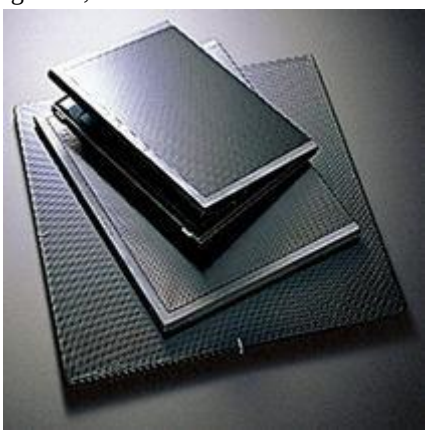


Fig. 12.Carbon reinforced epoxy laminated panels.

5) *Resilience:* Experiments on auxetic foams (Synthetic Auxetic materials) proved that they have ability to absorb more energy when compared to conventional foams.
6) *Acoustic Absorbption:* Scientists at Liverpool University processed an auxetic called Ultra High Molecular Weight Poly-Ethylene-UHMWPE, which has improved indentation resistance and capacity of attenuation of ultra sonic signals. Hence these can be used as acoustic absorbers.
7) *Auxetic Foams-Synthesis:* Auxetic foams are synthetic auxetics. These were first manufactured by Roderic Lakes.

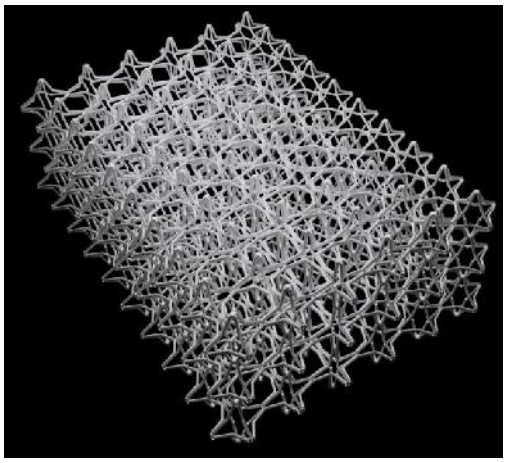


Fig. 13.Auxetic foam

III. APPLICATIONS

This strange class of materials has wide range applications; these are in the areas where conventional materials cannot be used. Auxetic materials find applications in various areas like Medical, Defense, Construction etc.

A. Medical Field

1) *Dental Floss:* Auxetic dental floss offers many benefits over normal dental floss. This dental floss expands to fit into the wide gaps in between teeth. It also has ability to deliver the fluorides and flavors directly into the gum line. Its usage assists in removal of debris, which makes flossing process more efficient.
2) *In-situ drug delivery:* Some drugs cannot be injected directly into blood, in such cases this in-situ drug delivery process is used. In this process the auxetic yarn is dipped in chemotherapeutic, the pores present in the yarn absorbs the drug. This yarn is

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transferred into human body; the yarn stretched as soon as the yarn reaches target tissue, pores gets opened up and delivers the drug at the target site.

3) *Artery Dilator:* When the blood vessels like arteries gets closed or choked, the surgeon performs angioplasty operation. In this the surgeon has to widen the artery by introducing a balloon and blows it. In this context the usage of auxetic artery dilator for angioplasty and other surgical procedures has been patented. This dilator consists of a **PTFE**-Ploy Tetra Fluro Ethylene Sheath on one side and a handle for application of tension on the other side. When the surgeon applies tension this soft PTFE sheath bulges without causing any rupture on the walls of blood vessels.

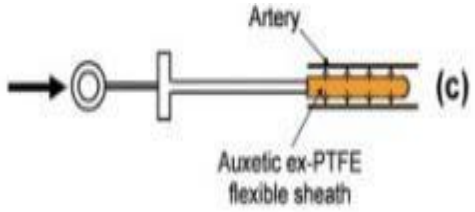


Fig. 14. Auxetic Artery Dilator

4) *Knee-caps:* Many people suffers from joint pains, when knee-caps made up of auxetic network are worn, they provides soothing effect when knee is moved.



Fig. 15. Knee-cap made up of auxetic network

5) *Smart Wound Dressings:* The bandage made up of auxetic material is impregnated with anti-inflammatory drug is dressed around wound. When the wound swells the pores gets opens and the drug gets released, this cures wound.

6) *Artificial Intervetebral Disc:* This allow same amount of motion as that of natural disc. It is soft material and does not cause any disturbance with adjacent nerves.

B. Defense

1) *Blast proof curtains:* Normal laminated panels made up of composites cannot bear impact load. Hence these blast proof curtains which are made up of auxetic materials, where series of layers of auxetic materials are laminated. As soon as the foreign element like bomb particle with great velocity hits this curtain, the curtain gets thicker and decelerates the particle. This protects buildings.



Fig. 16. Blast proof Curtains.

2) *Army Jackets:* The Defense Clothing and Textile Industry in Colchester have been conducting experiments to make use of

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auxetic textiles for military purposes. If these experiments are successful then soldiers can wear thin, light weight, bullet-proof armours.



Fig. 17. Military Armour

C. Construction

German University developed a fibre to reinforce the walls of older buildings. The fibre named *Sisma Calce* absorbs the vibrations produced during earth -quakes and provides grace period for evacuation.



Fig. 18. Sisma Calce Sheets

IV. OUR PROPOSALS- OTHER POSSIBLE APPLICATIONS

A. Inner Lining of Helmets

Helmets saves life of the rider by reducing the severity of the impact on riders head caused during accident. The material used for inner lining in the helmet is not that soft and it also hurts the rider. So if we provide auxetic foam in the inner lining of the helmet then the magnitude of force that is transferred to head is minimized. Not only that at the time of the collision when head gets pressed to the inner lining this auxetic foam forms dome shaped structure which meticulously guards the head without causing any hurt.

B. Seats in motor bikes

Today we see many of the working age group people are suffering from Lumbago or lumbalgia or lower back. There are many physiological reasons for its cause like obesity, imperfect posture. But there is another reason on which we have to work. The imbalance our lower spine can also cause the lower back to be overused and strain. Let us see how this imbalance may be caused. We all are aware of the condition of the roads in our country. Bike riders in the city has to travel at least 20 kms everyday on such uneven roads. Shock absorbers in the bikes helps to avoid strong reaction forces from the road, but it could not help the imbalance of spine and discs of human body. Sensitive parts like intervertebral discs faces reaction pressure from seat. So if the auxetic foam is filled under the seat then wherever the pressure is high due to the body weight the particles inside the foam travels to that area and acts as a cushion by safeguarding the spine.

C. Car Bumpers

Generally these bumpers are made up of materials like Carbon Fiber Reinforced Plastics which can absorb shocks to some extent. But the auxetic laminates have much better fracture toughness than composites. The resilience of auxetic foam is high, from which

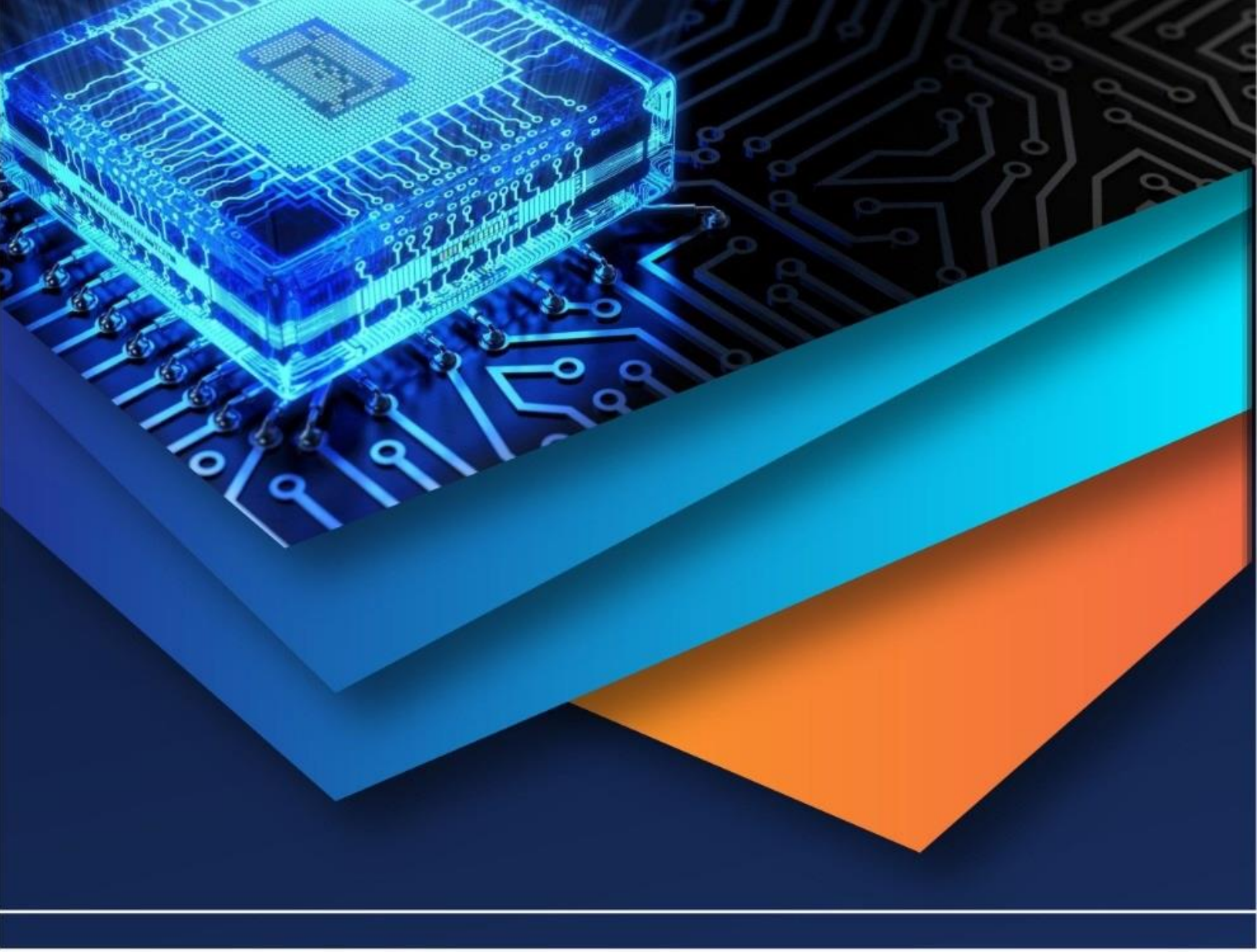
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we can say that it has capacity to absorb major amount of shocks which arise during collision. And the striking behavior of formation of dome shape also minimizes damage caused for other body which is collided.

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