International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 1 Issue 9, November- 2012

Auxetic Fibers

Dr.Chinta S.K.* & Veena K.V & Vijay Rajendra Karoshi
D.K.T.E's Textile & Egg. Institute, Ichalkaranji

ABSTRACT

Auxetic textiles are extraordinary materials whose fiber diameter widens on stretching it whereas normal textiles flatten. This property is due to the Negative poisson's ratio. They are attaining lot of importance in the field of technical textile fields. Their application is versatile from medical sutures, dental floss and healthcare to defense blast migration, portable safety helmets. So by accepting a negative poisson's ratio as a positive property one can really expand the application of such fascinating materials.

Keywords: Auxetic, negative poisson's ratio, widening, flattens, stretching.

INTRODUCTION

The material like Rubber when stretched usually results in reduction in the diameter. But what if the material pops out and increases in its diameter when stretched. Such a phenomenon relates to material having AUXETIC PROPERTY.

The word "auxetic" was derived from Greek naming 'auxetos' meaning "that which grows". Henceforth Auxetic structures exhibit an extraordinary behavior of becoming fatter when stretched and thinner when compressed [2] and are increasingly attaining some prominence in many applications of technical textiles [6]. The use of auxetic fibers in an engineered textile structure can be facilitated by the development of cost effective, productive processes in which large quantities of textile materials exhibit the very unusual, interesting and useful property of becoming wider when stretched and thinner when compressed. Such a process will revolutionize the technical textiles and protective clothing industry [1].

First Auxetic Textiles was produced by using synthetic Auxetic material, which were made as open-cell polymeric foam fifteen years ago. Then rest was just a history in the following form:

1. Fibre
2. Yarn
3. Fabric(woven/knitted/etc)
4. polymer gels
5. carbon fiber composite laminates
6. metallic foams, honeycombs and micro porous

The above phenomena can be justified by the principal of Negative Poisson's ratio, which is an inverse of Poisson's ratio given by:

Poisson’s Ratio:

If a load is applied to the free end of a suspended wire, the wire gets elongated. At the same time there is decrease in diameter. This observation shows that longitudinal extension is accompanied with lateral contraction.

Negative Poisson’s ratio

The converse is also true; longitudinal contraction is accompanied with lateral extension. The ratio of Lateral strain to the longitudinal strain is called poisson’s ratio (σ)

$$\text{Lateral strain} = \frac{\text{change in diameter}}{\text{Original diameter}}$$

$$\text{Longitudinal strain} = \frac{\text{change in length}}{\text{Original length}}$$

$$\text{Poisson's ration} = \frac{\text{lateral strain}}{\text{Longitudinal strain}}$$

$$\nu_{yx} = -\frac{\text{transverse strain}}{\text{Axial strain}} = -\frac{\varepsilon x}{\varepsilon y}$$

Where,

V_{yx} is the resulting Poisson's ratio,

Transverse strain is (negative for axial tension, positive for axial compression)

Axial strain is (positive for axial tension, negative for axial compression) [3].

This ratio is normally positive since stretching in the y-direction (+ve strain), will normally be accompanied by a shrinkage in the transverse x-direction (-ve strain). However, in auxetic materials, this ratio is negative since stretching in the y-direction (+ve strain) will normally be accompanied by an expansion the transverse x-direction (+ve strain). The negative Poisson’s ratio imparts on a material’s several characteristics such as increased shear stiffness, increased plane fracture toughness and increased indentation resistance. The increased indentation resistance results from the fact that in auxetic, the bulk of the material flows to the zone of impact making them denser, contrary to conventional materials whereby the material flows away from the zone of impact.

Manufacturing Auxetic Materials

Any synthetic textile fibre can be imparted with Auxetic property unless it has the Particles size of at least 300micro mts. The particles used can be of small, rough, irregular shape. While spinning process maximum melting temperature of the fiber and its DSC-derived percentage of crystalline should be as close as possible to those of the powder from which it has been derived. There by accurate temperature control such auxetic fibers can be produced. Hence the powder particles must be sintered together as a result of some surface melting, without melting completely and so reducing their crystalline. The basic particles used in the process should be small, rough surfaced and particularly irregularly shaped. Particles used in the process should be up to 300 [micro] m in diameter ([+ or -] 10%), as mentioned earlier.

Fibers which can be used to are polyester [210 – 230 deg celcious is the accurate temperature] and polypropylene [160 deg celcious]. Polypropylene is a suitable polymer, in this case the temperature should be about [159 deg celcious] C. However, other polymers may be used in the process including nylon or other polyolefin’s or polyamides, particularly ultra-high molecular weight polyethylene (UHMWPE).

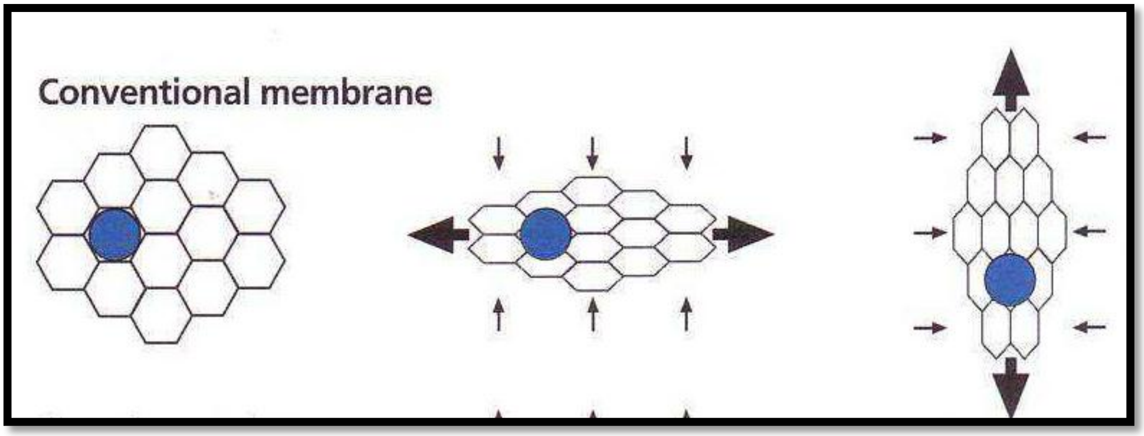
Polymer is heated and extruded to form filaments that have cohesion and desired Auxetic property. Wherein the Auxetic property can be imparted by extrusion without separate compaction or sintering has enabled them to form an Auxetic microstructure of fibrils and nodes. In this spinning process there is no post-extrusion drawing, the mechanical treatment being confined entirely, or substantially, to extrusion.

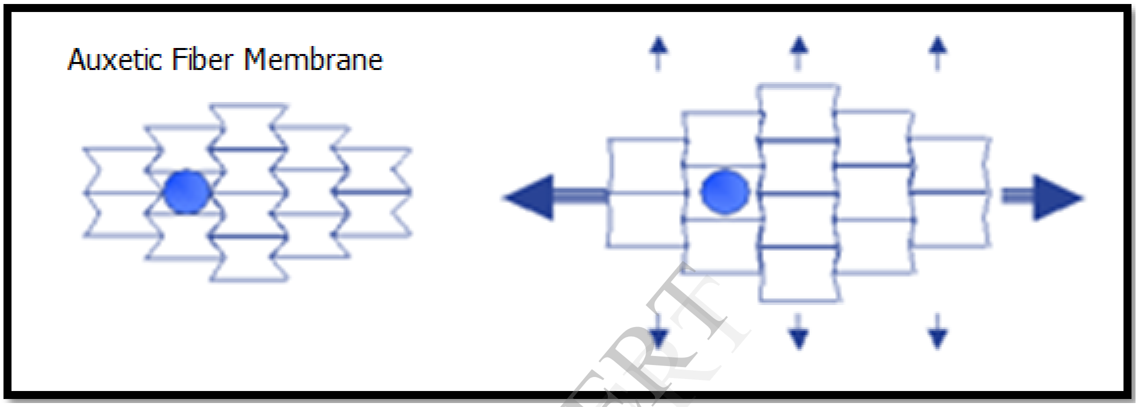
The melt extrusion system used to make fibers using Archimedean feed screw at its extrusion zone , where the temperature is maintained just above its glass transition temperature and just below its melting point, sufficiently enough for the cohesion of the fibers forming filament rather than complete coalescence into liquid due to melting. The temperature range is usually defined by reference to a typical differential scanning calorimetric (DSC) diffusion endothermic, and would fall on the low temperature side of that endothermic.

Spinning Process

In melt spinning process the Screw extrusion, rather than ram extrusion, creates the filaments, with the screw running at about 10 rpm [3]. To minimize traction forces, the filaments are taken over rollers at a speed of about 5 m a minute. The working process is similar to the usual melting process where hopper filled with the Polymer source is fed into the Archimedean screw extraction where the temperature is set to increment in 20 degrees after regular intervals to the maximum, leading to the barrel comprised of Feed, Compression and Metering zones respectively. The barrel has an adapter section that reduces the diameter and leads to a die comprising a spinneret. Then gradually the filament oozes out of the spinneret is cooled with a pinch roller and an air knife. Subsequently the guide rollers, guide rail and take up roller fall into place. Please note that there is no post drawing of the filaments produced.

Usually the normal filaments produced from melt spinning process have the cell membranes shaped in the Honeycomb form. But as there is no tensioned drawing in this melt spinning the membranes does not stretch out completely, thereby forming a BOW-TIE shape given by.





Auxetic materials have a negative Poisson ratio, they expand transversely to the direction in which they are stretched and contract transversely to the direction in which they are compressed.

Indentation Behaviors

Auxetic materials do not dent as easily as non-Auxetic materials and so have more resistance to indentations. When a non-Auxetic material is subjected to impact loading, the force compresses the material, and the material is compensated by spreading in direction perpendicular to and away from the direction of the impact as shown in the figure 1(a) .However, when an object hits an Auxetic material and compresses it in one direction, the Auxetic material also contracts laterally — material ‘flows’ into (compresses towards) the
Vicinity of the impact, as shown in the Figure 1 (b). This creates an area of denser material,

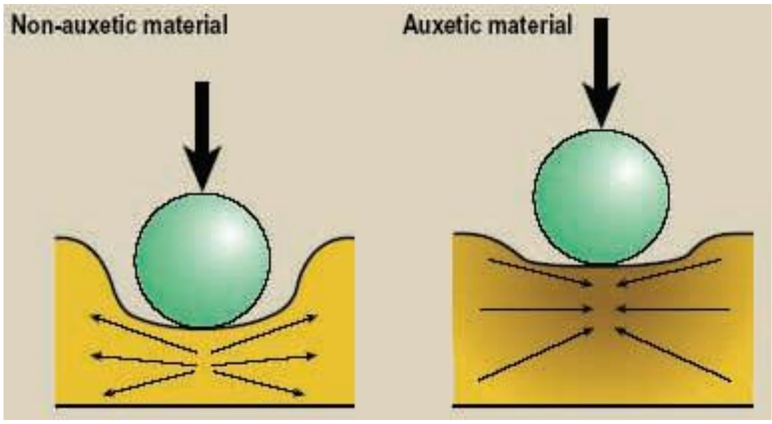


Figure 1 Schematic of deformation behaviors when both non-Auxetic and Auxetic materials are Subject to impact compressive loading (after Alderson, 1999; Evans & Alderson, 2000).

Which is more resistant to indentation? The investigation showed that re-entrant foams have higher yield strength (by) and less stiffness (E) than conventional foams with the same original relative density. It has also been further proven that re-entrant foams indeed density under indentation due to increase in shear stiffness (Smith, et al, 1999).

Based on the classic elasticity theory (Timoshenko & Goodier, 1970), the indentation resistance or hardness of an isotropic material is inversely proportional to $(1-V^2)$, that is:

$$H \propto \{E/\,(1-V^2)\}^{y}$$

Where $\gamma = 1$ stands for uniform pressure distribution and $\gamma = 2/3$ is Hertzian indentation. For a given value of E, the indentation resistance increases with negative Poisson's rati (ν). If the ν value approaches -1, the hardness becomes infinite. Hardness has been investigated for many of the synthetic Auxetic materials produced to date and enhancements have been found across the board in materials as diverse as polymeric and metallic foams (Chan & Evens, 1998; Lakes & Elms, 1993), carbon fiber composite laminates (Coenen, et al, 2001b) and micro porous polymers (Alderson, et al, 2000). For example, the hardness of the Auxetic micro porous ultra high molecular weight polyethylene (UHMWPE) was improved by up to a factor of 2 over conventional UHMWPE (Alderson, et al, 1994 & 2000). In addition, at lower loading (e.g., 10 ~ 100N), the indentation test showed that it was more difficult to indent and the hardness was increased by up to a factor of 8 if the Poisson's ratio was changed from approximately 0 to -0.8 (Alderson, 1994; Yang, et al, 2004).

Deformation Behaviour

Very recent investigations into low velocity impact of Auxetic carbon fiber laminates have also shown enhancements in energy absorption of up to a third for the first failure point (Coenen, et al, 2001a). Cold work in a re-entrant foam material has some effects due to the triaxial compression during manufacturing.

However, the annealing has an obvious effect on Young's modulus. Figure 2 shows the strain-stress relationships for conventional and re-entrant foam materials. The annealing normally reduces Young's modulus at a given volumetric compression ratio. In other words, the material becomes less stiff. So that re-entrant copper foam is less stiff than the conventional foam from which it was derived. For the conventional copper foams the properties in tension and compression are similar. However, the re-entrant foams show dissimilar behaviors in tension and compression. In addition, in both tension and

Compression, the conventional and re-entrant foams exhibit a rather long plateau above the proportional limit. This behavior is attributed to the plastic hinge formation of cell ribs (Choi & Lakes, 1992). From Figure 12, it can also be seen that the conventional foam has some strain-hardening tendency, but the re-entrant foam does not. Therefore, this material can be reasonably assumed as an elastic-perfectly plastic material in modelling.

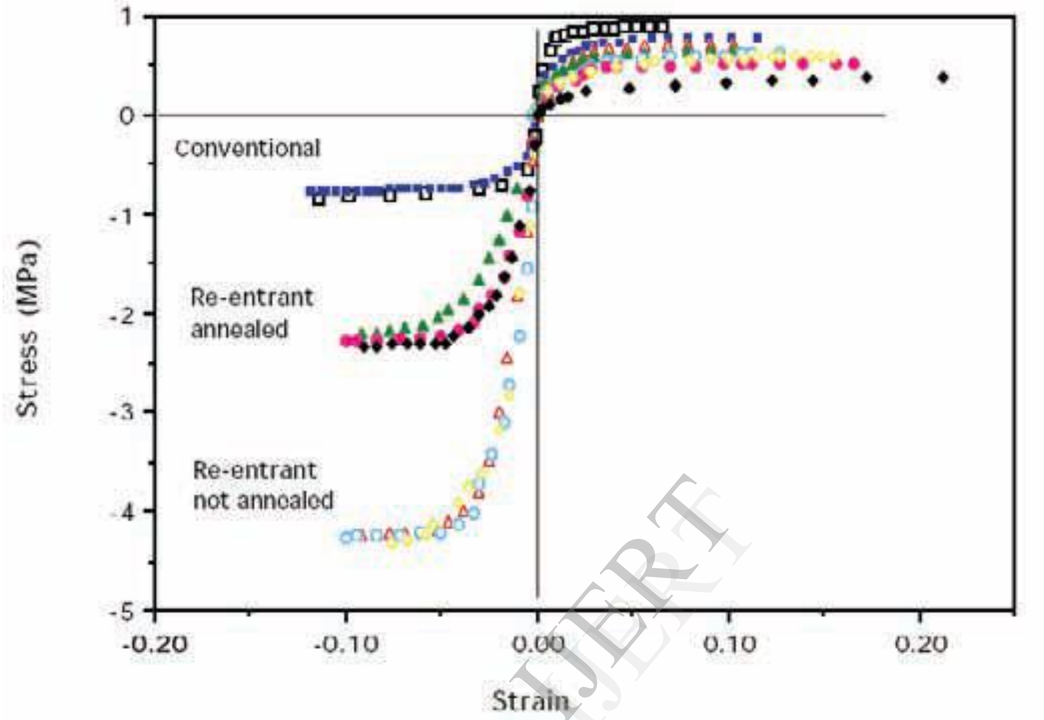


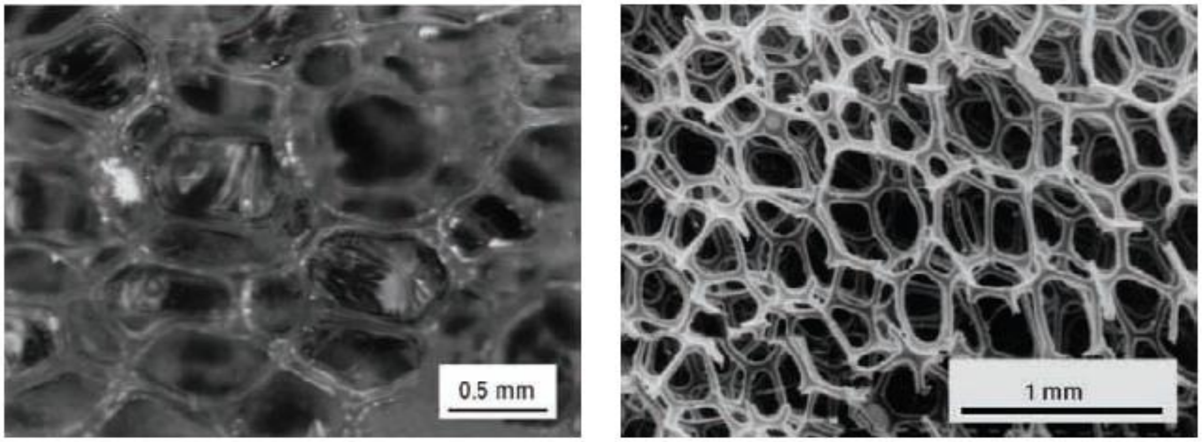
Figure 2 Stress- strain relationships for conventional and re-entrant foams. Initial relative density: 0.08. □ Solid symbols: annealed. Open symbols: not annealed. □ Squares: conventional foam, volumetric compression 1. Δ Triangles: re-entrant foam, volumetric compression 2.0. O Circles: re-entrant foam, volumetric compression 2.5. ◊ Diamonds: re-entrant foam, volumetric compression 3.0 (after Choi & lakes, 1992).

Microstructural Morphology:

The microstructure of the foam is complicated. Figure 4 shows the microstructures of the open cell and closed-cell conventional polyester urethane foams (Chan & Evans, 1997). In the closed-cell foam, most of the cell faces are closed off by thin membranes. The porous open-cell foams allow free movement of air through-out the material when flexed. Auxetic foams have a more complex, re-entrant geometry (Figure 5 (a)). Therefore, they are much more likely to deform by hinging and flexure rather than stretching in both tension (Figure 5 (b)) and compression (Figure 5 (c)). Under tension, the cells are seen to expand transversely under a longitudinal tensile force (Chan & Evans, 1997). The reason is that auxetic foam is consisted of nodules interconnected by fibrils (Caddock & Evans, 1989). Also, conventional foams are made up of convex polyhedral cells, but auxetic foams have much more convoluted cell structures (Choi & Lakes, 1995; Chan & Evans, 1997), as shown in Figure 3. [10]

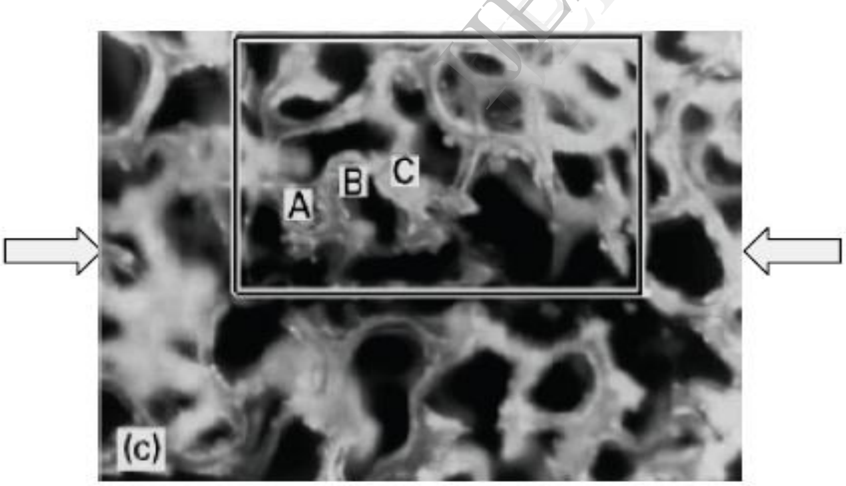
Crack Resistance

Compared with non-auxetic materials, auxetic materials also have other special and desirable mechanical properties. For example, if the material has a crack, when it is being pulled apart, it expands and closes up the crack. In other words, this type of material should possess more crack resistance to fracture. Also, it has high material resistance to shear strain. Shear resistance is particularly important in structural components such as sheets or beams in building, cars and aircraft.



(a) (b)

(Figure 4 Microstructures of the conventional polyester urethane foams: (a) Closed-cell (optical micrograph) and (b) Open-cell (SEM) (after Chan & Lakes, 1997).



(c)

Figure 5 Micrographs of the auxetic polyester polyurethane foams showing the elastic deformations under different type of loads. (a) Unloaded; (b) Under tension and (c) Under compression (after Chan & Evans, 1997).

APPLICATION OF AUXETIC TEXTILES

AS SOIL REINFORCEMENT:

Soil reinforcement is a newly emerging & demanding concept majorly carry out in civil engineering which providing wide-ranging benefits in structures such as retaining walls, bridge abutments, embankments, foundations, highways, and railways, coastal and military structures. Some research has been directed towards the study of the behavior of soil reinforced with conventional textile [11].

Reinforcement fibers can be used in composite structures to reduce weight or increase safety. The primary failure mechanism of most composite materials is through reinforcement "pull-out". This is a tensile failure caused by the reinforcing fibers getting narrower and breaking free of the resin that is meant to hold them together (de-bonding). They then slip through the remaining matrix until they break free – the energy required to do this defines the amount of energy that the structure can absorb during failure. Due to the fact that auxetic materials expand, however, if a small proportion (<5%) of the conventional fibers were replaced with fine auxetic yarns, the energy required to cause de-bonding and slippage would be much greater. This would increase the load required to cause structural failure, and also increase the structure's ability to absorb loads imposed by extreme events, such as impacts or explosions. In other words, a composite structure could be lighter for the same strength, or stronger for the same weight. A similar failure condition often occurs in reinforced concrete structures where the reinforcing rod pulls away from the surrounding material. An auxetic rod-cladding made, for instance, from carbon fiber could reduce such failures. Civil engineering companies will benefit from a new generation of materials like an auxetic textile that can be used in stabilization of soils in general and problematic soils such as expansive or collapsing soils in particular. [11]

FOR BLAST MITIGATION:

When a bomb explodes in an urban area it produces devastating effects, including structural and nonstructural damage to buildings, injuries and deaths. Numerous injuries in explosions result directly and indirectly from window glass failure. When an explosion occurs, there is an extremely rapid release of energy. This is takes the form of heat, sound and light, but also as a shock wave. It is the initial shock wave that is responsible for the majority of damage to buildings, including shattering of windows. If this was not destructive enough, the vacuum that follows the blast front then creates a high intensity wind which can transport debris across large distances. [12]

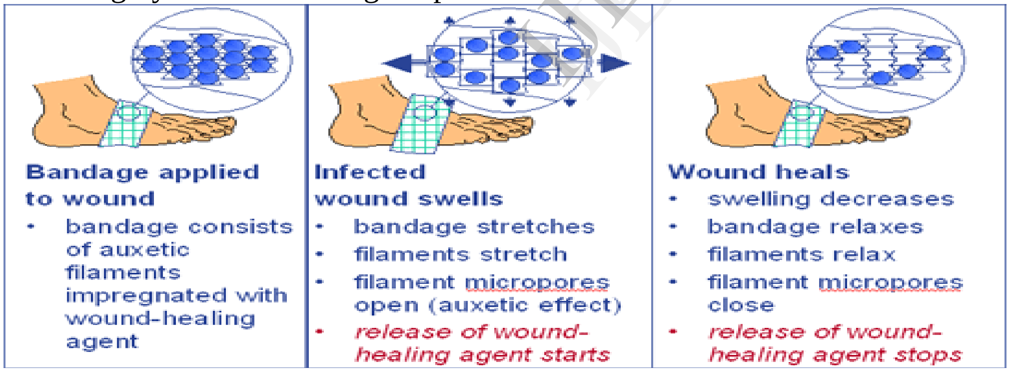
Thousands of windows were shattered by the Bishopsgate bomb, planted in London by the IRA in 1993.

The effects of blast damage can be clearly seen on these windows at a UK explosives research facility.

Current blast curtain design favors the use of translucent aramid nets that are longer and wider than the window. The excess curtain length is placed into a box at the base of the window. When the window shatters, the curtains billow out and capture a significant portion of the glass fragments stay together. However in practice, the net fabric is often torn by the force of the blast. This is because the net filaments have to be made thin to keep the curtain from blocking light out. What is needed is a smart textile that allows light through but is also capable of containing the huge forces involved in an explosion and providing a barrier to flying debris.

IN MEDICINE:

Auxetic materials have also found their place in the operations where a dilator for opening the cavity of an artery or similar vessels made with an auxetic component has been patented for use in heart surgery and related surgical procedures.



In this application, the coronary artery is opened up by the lateral expansion of a flexible auxetic PTFE hollow rod or sheath under tension. Smart bandage made from an auxetic material which can release the encapsulated medicine in a controlled manner. [12]

IN FILTRATION:

Auxetic materials and structures can also be used to replace conventional components in various products used in specialized applications to produce higher quality products. For example, auxetics can be used to make ‘smart filters’ where the pore size of the filter can be changed by varying the applied load thus controlling the size of particles that can be allowed to pass through the filter. This also permits easy cleaning of clogged filters Shown here is a smart filter where one can control the pore size. [12]

Here, a macro model of the auxetic filtration mesh principle can be seen in the unstrained (above) and strained (below) states. By varying the amount of strain applied, as well as the fiber winding angle and the relative dimensions and properties of the two main components, it is possible to control the size of the pores created.

Color-change Cargo Straps & Fabrics

Cargo straps need to be tightened correctly – if they are too loose, the load may come free – with potentially dangerous and / or expensive results. If the strap is too tight, the load may be damaged, or the strap itself may snap. To avoid these problems, Auxetic are developing a webbing which changes color as it is tightened – at the optimal tension it is one color – beyond this it changes to another. A color-change fabric is also being developed where an auxetic net is given a suitably-colored backing material. When it is stretched, the holes open up exposing the backing color. [12]

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*Address for correspondence:
Prof. (Dr.) S.k.Chinta
D.K.T.E. Society's, Textile and Engineering Institute,
Ichalkaranji, Maharashtra, India.