Application of High Performance Auxetic Materials in Textiles

By:

T. Karthik

&

P. Ganesan

Application of High Performance Auxetic Materials in Textiles

By: T. Karthik & P. Ganesan

Assistant Professor, Department of Textile Technology, PSG College of Technology, Coimbatore

Abstract

Auxetic materials are not natural. No known biological examples exist. The first auxetics were foams with specifically engineered microstructures. Depending on the size of the air gaps in the microstructure, the auxetic effect in these materials can be more or less extreme. Most auxetic foams expand by a factor of about 30% or so before shredding due to the stretching force. With more advanced auxetics, structured on the molecular level, more impressive expansion may be possible. Auxetic materials are interesting both because of their novel behavior and because of enhancements in other material properties that are related to Poisson's ratio. This paper was deals about the auxetic material and their applications in textile fields.

Keywords: Auxetic; Fibre; Optical Sensor; Poisson Ratio; Textiles.

---

1. Introduction:

Materials can be divided into two basic categories: structural or functional. Development of structural materials is focused on improving their mechanical or physical properties, often with a saving in weight or cost. By contrast, functional materials are designed to detect and/or respond to events or stimuli that occur during their life time. These materials often display novel and counterintuitive behavior. Examples include electrically (semi) conducting polymers, materials that contract when heated, and those that expand when subjected to hydrostatic pressure. Another example is a remarkable class of materials known as auxetic materials. When stretched lengthways, these materials get fatter rather than thinner (see Figure 1).

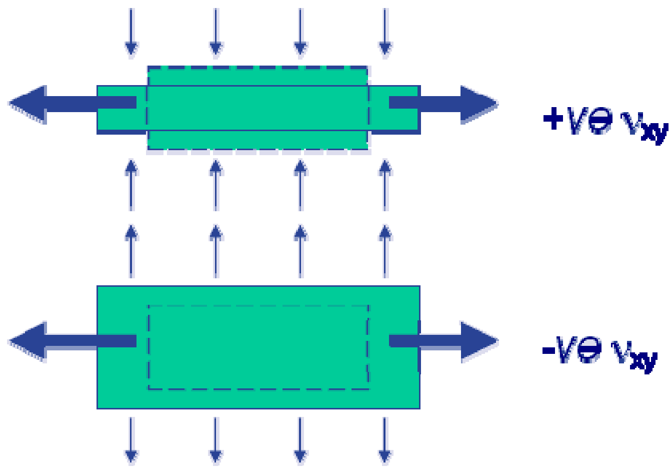


Fig 1 behavior of auxetic and normal material

2. What are Auxetic Materials?

Auxetics are materials with a negative Poisson ratio - when you stretch them, they get fatter instead of thinner. Poisson's ratio is defined as the ratio of the lateral contractile strain to the longitudinal tensile strain for a material undergoing uni-axial tension in the longitudinal direction. In other words, it determines how the thickness of the material changes when it is stretched lengthways. When an elastic band is stretched the material becomes thinner, giving it a positive Poisson's ratio. Indeed, most solids have a Poisson's ratio of around 0.2–0.4. For example, hardness can be increased in an auxetic material (see Figure 2).

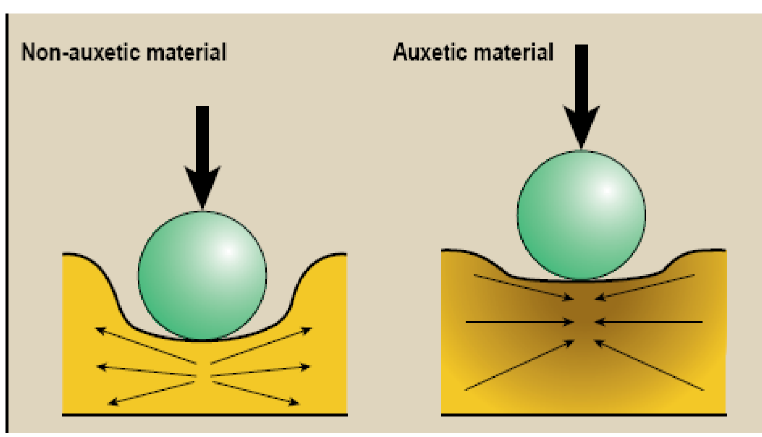


Fig. 2 Comparison of hardness of material having auxetic and non-auxetic material

When an object hits an auxetic material and compresses it in one direction, the auxetic material also contracts laterally — material 'flows' into the vicinity of the impact. This creates an area of denser material, which is resistant to indentation. Importantly, elasticity — and hence auxetic behavior — does not depend on scale. Deformation can take place at the macro-, micro- or even molecular level (see Figure3). This means that we can not only consider auxetic materials, but also auxetic structures.

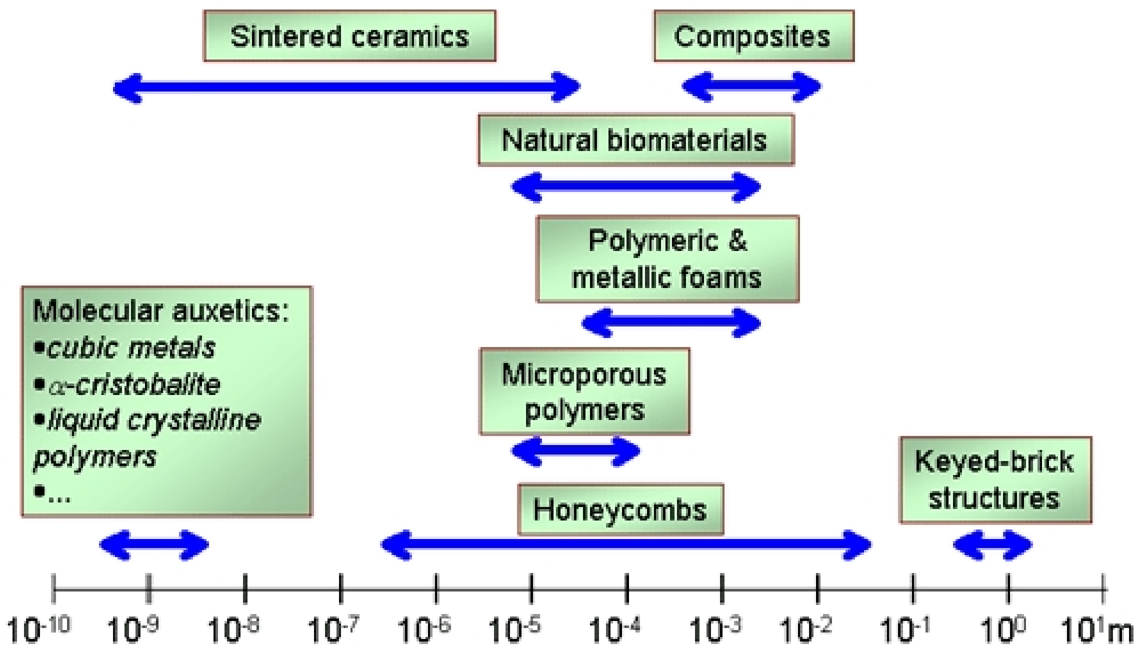


Fig. 3 Structural sizes of different auxetic materials

3. Applications of Auxetic Materials

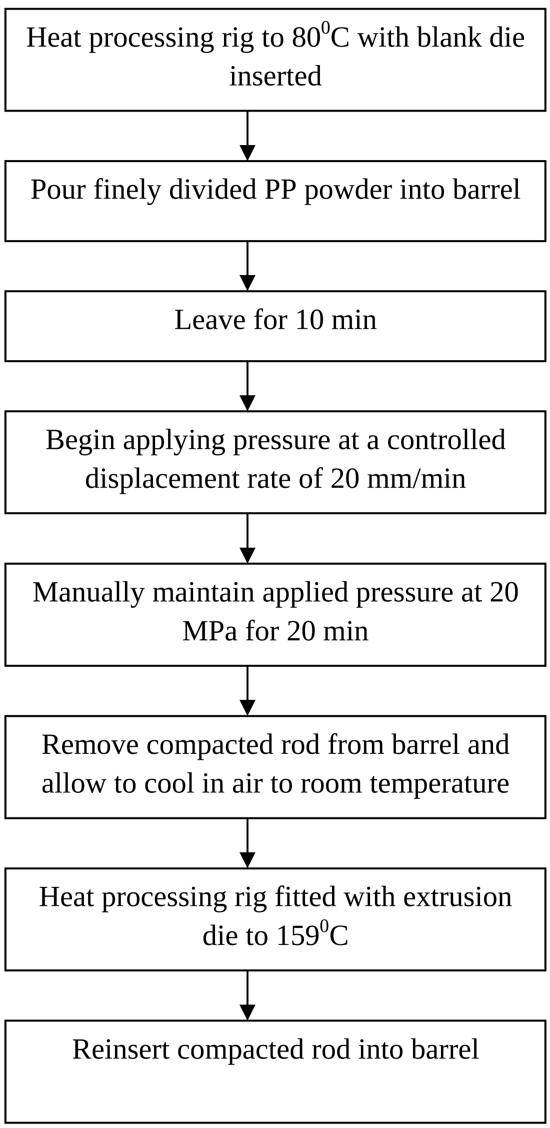
Currently the uses of auxetics are limited, and in those applications they are probably not knowingly used for the auxetic effect itself. Examples include pyrolytic graphite for thermal protection in aerospace applications, large single crystals of Ni_3Al in vanes for aircraft gas turbine engines, and an expanded form of PTFE used to make Gore-Tex.

3.1 Auxetic Fibres

An auxetic material, which has a negative Poisson ratio so that it has the property of expanding or contracting transversely to a direction in which it is extended or compressed, is made in filamentary or fibrous form. A suitable process involves cohering and extruding heated polymer powder so that the cohesion and extrusion is effected with spinning to produce auxetic filaments. Typically the powder is heated to a temperature sufficient to allow some degree of surface melting yet not high enough to enable bulk melting.

3.1.1 Manufacturing of Auxetic Fibre:

A conventional polymer processing technique (melt spinning) is the basis of this technique, with novel modifications. The process flow of manufacturing typical polypropylene auxetic fibre is illustrated in figure 4.



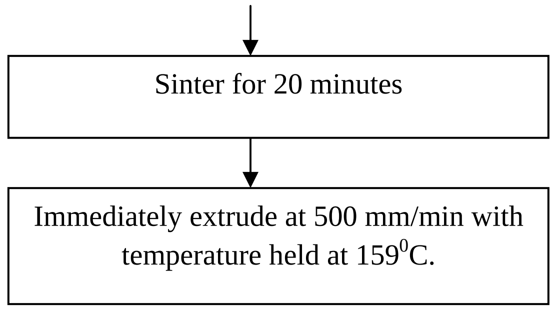


Fig. 4: Manufacturing flow chart for Polypropylene Auxetic fibre

3.1.2 Applications:

Auxetic fibres can be used as fibre reinforcements in composite materials e.g. polyolefin auxetic fibres in a polyolefin matrix. The auxetic fibres improve resistance to fibre pull out and fibre fracture toughness, and give enhanced energy absorption properties. Sonic, ultrasonic and impact energy can be absorbed enabling superior composites to be made for sound insulation of walls of buildings, body parts for submarines or other vehicles, etc, bumpers for cars, etc.

Auxetic fibres can be used alone or in combination with other materials for personal protective clothing or equipment as a consequence of the superior energy absorption and impact resistance properties. Crash helmets and body armor (e.g. bullet proof vests) are examples of applications. It may be desirable to make the protective material in the form of an auxetic macrostructure made from auxetic fibres (i.e. a hierarchical auxetic material). These properties should also lead to enhanced sports protective clothing, e.g. shin pads, knee pads, batting gloves etc.

Auxetic materials have pore size/shape and permeability variations leading to superior filtration/separation performance in several ways when compared to non-auxetic materials. Application of an applied tensile load on a non-auxetic porous material causes the pores to elongate in the direction of the applied load, which would tend to increase the filter porosity. Benefits for auxetic filter materials, therefore, include release of entrapped particulates (e.g. drug-release materials) and self-regulating filters to compensate for pressure build-up due to filter fouling.

Advanced auxetic fibres will include multi-filament yarns in which an auxetic filament is wrapped with one or more other yarns, perhaps high stiffness/strength, dye able or conductive filaments, so that the benefits of the auxetic material are combined with other beneficial properties for smart technical textiles applications. This will lead to the possibility of hierarchical composites displaying auxetic behavior at more than one length scale.

Typical performance characteristics expected of auxetic fibres and structures are detailed in the table of applications, (Table 1), together with a list of the applications in which these characteristics could offer significant benefits.

Application	Fibre pull-out resistance	Fibre Fracture Tough	Energy Absorption	Indent. Resistance	Impact Resistance
Composite Materials Auxetic fibre reinforcement in composites	X	X	X	X	X
Personal Protection Clothing Crash helmets, body armour, sports clothing			X	X	X
Filtration Woven structures using auxetic structures					
Mechanical Lungs Micro porous hollow auxetic structures					
Ropes, Cords & Fishnets High strength, Lower weight		X			
Upholstery Fabrics Enhanced abrasion properties & entrapment of fire retardant components			X	X	
Biomedical Controlled release of drugs					
Medical Bandages Prevents swelling of wound by application of wound healing agent					
Fibrous Seals			X	X	X

Table 1 (Part A) Application-performance characteristic matrix for auxetic fibres and auxetic fibre based structures.

Application	Release Entrapped Particles	Wear Resistance	Micro porous Breathable Structure	Constant Pressure Structure
Composite Materials Auxetic fibre reinforcement in composites				
Personal Protection Clothing Crash helmets, body armor, sports clothing			X	X
Filtration Woven structures using auxetic structures	X		X	X
Mechanical Lungs Micro porous hollow auxetic structures	X		X	
Ropes, Cords & Fishnets High strength, Lower weight		X		
Upholstery Fabrics Enhanced abrasion properties & entrapment	X	X		

of fire retardant components				
Biomedical Controlled release of drugs	X		X	
Medical Bandages Prevents swelling of wound by application of wound healing agent	X		X	X
Fibrous Seals		X		X

Table 1 (Part B) Application-performance characteristic matrix for auxetic fibres and auxetic fibre based structures.

3.2 Auxetic Material in Communications:

3.2.1 The Auxetic Optical Sensor

The helical-auxetic principle has been exploited to produce a novel low-cost optical sensor that looks much like stretchy fishing line. This is constructed from a clear elastomeric core around which there is a high-strength helical winding. It produces a linear and noise-free signal that is around 600% more sensitive than the output from conventional sensors made from the same materials. It is a bend, stretch, load and torque sensing device that is suitable for use in many diverse markets, including smart textiles, where it could be incorporated into clothing or instrumented gloves. As such, it would be ideal for wearable computation, computer gaming, virtual reality and remote control, as well as for use in defence and law enforcement, medical devices and sports clothing.

The sensor's increased sensitivity is due to the high modulus wrapping component, which induces marked structural deformations in the optical elastomer when it is loaded. This serves as a simple strain amplification system which can be used to measure bending, stretching, torque or load. The device is primarily aimed at the smart apparel market – its light weight, high flexibility and low physical profile make it ideally suited to such applications as data gloves and instrumented clothing(Fig 5). The sensors can be implemented in the form of dedicated devices that are similar to knee or wrist braces, or as more conventional clothing.

Fig. 5: Auxetic Optical Sensor mounted on a Velcro strip

3.3 Auxetic Material in Defence:

3.3.1 Blast Materials

Recent terrorist threats have renewed concerns about the protection offered to our buildings both domestically and internationally. One issue that has received a lot of attention in recent years is the hazard posed by flying window glass. Typically more than 80% of deaths and serious injuries are caused by flying debris. Blast curtains could help to mitigate the number of casualties caused by this during a terrorist strike. This would not only reduce the level of human suffering, but would ease the load on medical resources at a particularly critical time.

Such a blast-protection device could be made from an auxetic net, and used in the form of a window curtain. The underlying concept here is very simple – since blast fronts carry enormous amounts of energy, there is little point in trying to physically block them with rigid barriers. In order to make them effectual, they would have to be so large that one might as well wall up the window. Instead, the idea is to let the actual pressure front pass through the curtain, but prevent any flying debris from following it. The problem, however, is that when curtains made from conventional net-like fabrics are subjected to a blast, the material becomes stretched, and the holes either close up or tear apart. Once the fabric has torn, any hope of successfully trapping shrapnel is lost. Under the same circumstances, however, the holes in an auxetic net would open up, allowing the blast to pass through, leaving the curtain itself intact. In this instance, the helical windings would be made of a high-strength fibre, such as steel, titanium, carbon fibre or an aramid.

The auxetic blast curtain could be made either as a single sheet fabric, or as a laminated textile. In the latter case, the blast would have to successively pass through from one layer to the next, with each one reducing the energy it carries. Auxetic fabrics could also find application in blast-resistant blankets and panels.

3.4 Auxetic Material in Healthcare:

3.4.1 Biomedical Industry

Key areas of application are seen in the biomedical field. Prosthetic materials, surgical implants, suture/muscle/ligament anchors and a dilator to open up blood vessels during heart surgery are all possible. Another area relates to the use of auxetic materials in piezoelectric sensors and actuators. Auxetic metals could be used as electrodes sandwiching a piezoelectric polymer, or piezoelectric ceramic rods could be embedded within an auxetic polymer matrix. These are expected to increase piezoelectric device sensitivity by at least a factor of two, and possibly by ten or a hundred times.

3.4.2 Dental floss

Auxetic dental floss offers several key benefits, including the ability to expand to fit the widely differing gaps between human teeth and the ability to deliver chemotherapeutics, fluorides or flavours directly to the gum line. The porous nature of auxetic floss would also assist in debris removal, making the flossing process more efficient. The market is currently held back because the procedure of flossing is dull, and the benefits to the user are not immediately apparent. This has lead to the situation where a large proportion of users only floss on an occasional basis.

3.4.3 Medical Sutures

Recently the first prototypes of a ‘smart-suture’ were made. Basically, it is a part-braided, part-wound system that has a core which can be soaked in an agent, such as a chemotherapeutic. When you stretch the yarn, the outer cover expands - as it does so, it opens up a large number of pores - simultaneously, it squeezes the core, forcing the agent out. This would appear to be very useful for in-situ drug delivery. For instance, if it was soaked in vitamin E, it would help reduce the formation of scar-tissue, or if antibiotics were used, it may be appropriate for use in third-world countries, or on battlefields.

(a) (b) (c)

Fig.6. Use of Auxetic material in a drug delivery system

Dental flosses and medical sutures can be made that are able to deliver agents such as chemotherapeutics or flavours by using the system shown here (Fig. 6). **a)** A semi-braided, semi-wrapped auxetic yarn containing an absorptive core. **b)** The same material treated with walnut oil. **c)** When this is placed under a tensile load, a series of pores open up and the oil is squeezed out.

3.5 Auxetic Material in Manufacturing & Textiles:

3.5.1 Filtration

Auxetic foam and honeycomb filters offer enhanced potential for cleaning fouled filters, for tuning the filter effective pore size and shape, and for compensating for the effects of pressure build-up due to fouling. These benefits rely on the pores opening up both along and transverse to the direction of a tensile load applied to an auxetic filter. The pores of a non-auxetic filter open up in the stretching direction but close up in the lateral direction, leading to poorer filter performance, (Figure 7). However, stretching an auxetic filter improves performance by opening pores in both directions.

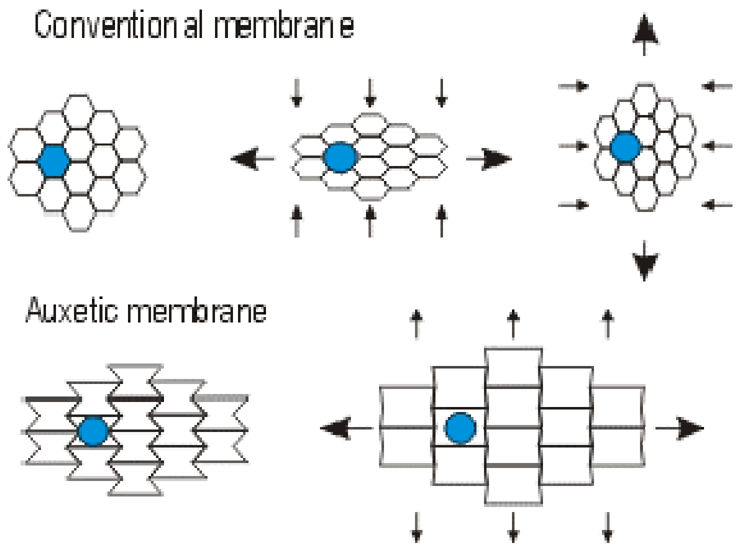


Fig. 7 Action of Auxetic Filter Membrane & Non-Auxetic Filter Membrane

When a conventional net-like material is stretched, the holes close up, whereas in an auxetic version the holes open up. This can be exploited to create a range of objects where controlling the hole size may be important. This could be particularly significant in the industrial filtration market. Most conventional filters get blocked by debris and need regular maintenance. A 'smart filter', however, could be made from auxetic materials – in this situation a specific pore size could be set and maintained, simply by controlled stretching.

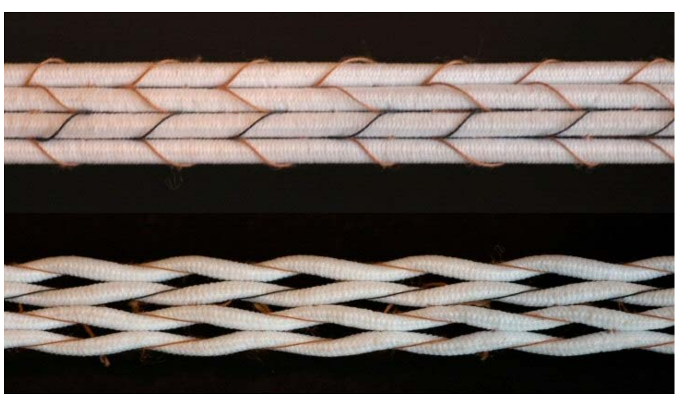


Fig 8 Auxetic Filtration Mesh Principle

A macro model of the auxetic filtration mesh principle can be seen in the unstrained (above) and strained (below) states in Figure 8. By varying the amount of strain applied, as well as the fibre winding angle and the relative dimensions and properties of the two main components, it is possible to control the size of the pores created.

3.5.2 Self-locking Stitching Threads

One of the main purposes of a securing thread such as a shoe lace, a medical suture, or a stitching thread, is to prevent unwanted textile movements. In all of these situations there are two issues where the auxetic effect could be beneficial. Firstly, there is the problem of thread slippage, and secondly, there is the propensity for the securing knot to come undone. Having your shoelaces come untied may not be a major drama, however, if a stitching thread works loose from a parachute cord, or an eye suture comes undone, it is going to be very bad news indeed. In all these examples, the fact that the thread gets thinner as it is pulled makes it easier for the failure to occur. If, however, the threads were auxetic, they would expand as tension was applied, and effectively lock themselves in place, preventing both knot and stitch slippage.

3.6 Auxetic Material in Automotive, Aerospace & Construction:

3.6.1 Seat Belts & Safety Harnesses

As an example, consider how a passenger seat belt behaves in a vehicle collision. In an accident, the passenger is usually thrown forwards – the forces involved can be enormous. In attempting to restrain this movement, the seat belt gets stretched and, much like an elastic band being pulled becomes narrower. This is exactly the opposite of the behavior that you want at such a critical time, for, in getting narrower; it concentrates all the forces into a much smaller area. An auxetic seat belt, however, would get wider – this would spread the loads over a much larger area, potentially reducing any injuries experienced.

3.6.2 Composite & Concrete Reinforcements

Auxetic fibre reinforcements should also enhance the failure properties of composites. Fibre pull-out is a major failure mechanism in composites. A unidirectional composite loaded in tension will undergo lateral contraction of both the matrix and fibre materials, leading to failure at the fibre/matrix interface. Auxetic fibres, on the other hand, allow the possibility of maintaining the interface by careful matching of the Poisson's ratios of the matrix and fibre (Figure 9).

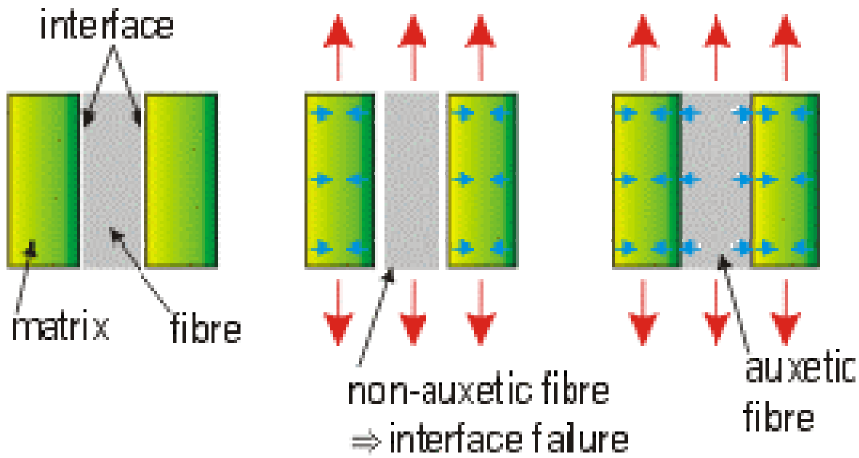


Fig. 9 Avoidance of Interface Failure Mechanism in Composites using Auxetic materials

Reinforcement fibres 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 fibres 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 fibres 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.

3.6.3 Smart Sensor Yarns – Composite Structures

Smart sensor yarns can be used in a variety of masonry and composite structures as *in-situ* monitoring devices. One of the problems with conventional structures is that when they experience loads or shocks that may have weakened or damaged them, there is rarely any satisfactory method of assessing their integrity. One way around this is to incorporate embedded sensors during the construction phase. This can present its own problems, however. If conventional optical fibre sensors are used, they are usually not sensitive enough to measure movements in relatively brittle materials. They are also limited in many other ways – the novel sensors being developed at Auxetix provide much higher signal resolution whilst also providing a range of other benefits.

3.6.4 Colour-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, Auxetix are developing webbing which changes colour as it is tightened – at the optimal tension it is one colour – beyond this it changes to another. A colour-change fabric is also being developed where an auxetic net is given a suitably coloured backing material. When it is stretched, the holes open up exposing the backing colour.

4. The Future

So what does the future hold for auxetics? Despite the very significant developments to date we have only scratched the surface of this exciting and multi-disciplinary field. The successful synthesis and development of molecular and multi-functional auxetics represent key opportunities for the future. In addition to leading to materials with extreme properties such as high modulus and strength, these advanced materials will have potential in sensor, drug-release and separations applications. By accepting a negative Poisson's ratio as a positive property we are truly expanding the applications of these fascinating materials.

5. References

1. Evans, K.E., Nkansah, M.A., Hutchinson, I.J. & Rogers, S.C., *Nature*, 1991, **353**, 124
2. Almgren, R.F., *J. Elasticity*, 1985, **15**, 427-30
3. Wei yang, zhong-ming li, wei shi, bang-hu xie, ming-bo yang, review on auxetic materials, journal of materials science **39** (2004) 3269 – 3279.
4. R. Lakes, “Foam structures with a negative Poisson’s ratio,” *Science*, vol. 235, pp. 1038–1040, 1987.
5. K.L. Alderson and V.R. Simkins, “Auxetic materials,” U.S. Patent 6878320, Dec. 21, 2004.
6. G. Burriesci and G. Bergamasco, “Annuloplasty prosthesis with an auxetic structure,” European Patent EP 05425926.2. Dec. 28, 2005.

7. Andy Alderson, Kim Alderson, Expanding materials and applications: exploiting auxetic textiles, *TechTextiles Int.* 777, Sep.2005, 29-34.
8. Ravirala N., Alderson K., Davies P., Simkins V., Alderson A., Negative Poisson's ratio polyester fibers, *Text. Res. Jour.* 2006, 76(7), 540-546.
9. Philip J. McMullan, Satish Kumar, Anselm C. Griffin, Textile Fibres Engineered from Molecular Auxetic Polimers, *Project M04-Gt21*, National Textile Center, Annual Report 2006, p1-10.
10. Smith C.,Grima J., Evans K., A novel mechanism for generating auxetic behavior in reticulated foam: Missing rib foam model, *Acta Materiala*, 2000, 48, 4349-4356.
11. Ugbolue, S.C., Warner, S. B., Kim, Y.K., Fan, Q.,and Yang, Chen Lu, *The Formation and Performance of Auxetic Textiles*, National Textile Center Annual Report, Nov. 2006.