Review

Auxetic Textiles

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Abstract

Common materials have Poisson's ratio values ranging from 0.0 to 0.5. Auxetic materials exhibit negative Poisson's ratio. They expand laterally when stretched longitudinally and contract laterally when compressed. In recent years the use of textile technology to fabricate auxetic materials has attracted more and more attention. It is reflected in the extent of available research work exploring the auxetic potential of various textile structures and subsequent increase in the number of research papers published. Generally there are two approaches to producing auxetic textiles. The first one includes the use of auxetic fibers to produce an auxetic textile structure, whereas the other utilizes conventional fibres to produce a textile structure with auxetic properties. This review deals with auxetic materials in general and in the specific context of auxetic polymers, auxetic fibers, and auxetic textile structures made from conventional fibers and knitted structures with auxetic potential.

Keywords: Auxetic, textiles, fibers, knitted fabric, Poisson's ratio

1. Introduction

Auxetic materials are different from most conventional materials in that they exhibit a negative Poisson's ratio (NPR). They expand laterally when stretched and contract laterally when compressed.[1] This counterintuitive behaviour gives auxetic materials various beneficial effects, such as enhanced shear stiffness, increased plane strain fracture toughness, increased indentation resistance, and improved energy absorption properties.[2,3] An improved indentation resistance makes them suitable for use in protective equipment; an enhanced ability to form doubly curved surfaces is particularly desired in materials used to construct dome-shaped structures/surfaces while enhanced acoustic properties make them suitable for sound-proofing applications.[4] As the Poisson's ratio is a physical parameter that is independent of the material scales, the auxetic behaviour can be achieved at any material level, from molecular to macroscopic.[5,6]

After Lakes's[7] successful production of auxetic foams, a variety of products with negative Poisson's ratio have been proposed, investigated and fabricated, including polymeric and metallic foams[7,8,9,10,11,12,13], honeycombs[14,15,16,17,18,19] and microporous polymers. At present, auxetic materials can be produced in different materials including polymers, metals, ceramics and composites.

Auxetic materials are now used in composite materials to promote fiber reinforcement in textiles for crash helmets and sports clothing, as sponges, as ropes, in filtration and as shock absorbing materials.[20] They have a lot of potential applications, from biomedical to automotive and defense industries. Also, these materials could potentially be used for completely new structures with special functions.[21]

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2. Auxetic Polymers

The first synthetic auxetic microporous polymer was an anisotropic form of expanded polytetrafluoroethylene (PTFE). Caddock and Evans[22] and Evans and Caddock[23] found that a large negative strain-dependent Poisson's ratio, with values as large as -12, was a consequence of the polymer's complex microstructure and not an intrinsic property of the PTFE itself. Nodules interconnected by fibrils of approximately 1 μm diameter react to applied force by hinging the fibrils and co-operatively producing an auxetic effect. Once the fibril hinging is complete, the additional stage of fibril stretching was proposed as an explanation of the experimental data on tensile loading at higher strains for auxetic PTFE.[24,25]

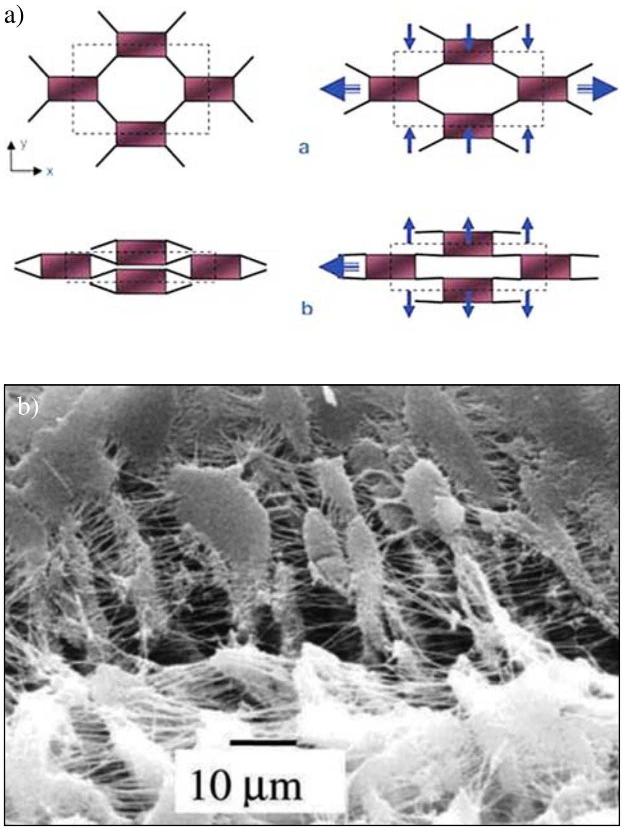

Figure 1. (a) Schematic illustration of auxetic effect – fibrils act as hinges to cause the nodules to translate (a – conventional structure, b – auxetic structure) and (b) microstructure of expanded polytetrafluoroethylene (PTFE).[26]

Different attempts were made to reproduce that microstructure and to achieve auxetic behavior in other polymers. Alderson and Evans[27] presented a similar microstructure of a microporous form of ultra high molecular weight polyethylene (UHMWPE) produced by a novel thermoforming processing route. These polymers demonstrate Poisson's ratios as low as –1.2, depending on the degree of anisotropy in the material.

A similar three-stage thermal processing route was used to engineer polypropylene[28] and nylon,[25] also consisting of nodules interconnected by fibrils. The polymers were processed by compacting finely divided powder with a rough surface, sintering, and extruding the powder through a conical die. Examination of powder morphology on the auxetic behavior revealed that particle shape, size, and surface roughness are critical variables for successful processing. The negative Poisson's ratio values for this polypropylene were up to –0.22 at 1.6% strain.[28]

Alderson et al.[29] reported the fabrication of a highly fibrillar auxetic form of UHMWPE, utilizing a powder processing route comprising only two stages: sintering and extrusion. The density, flexural modulus and flexural strength of the UHMWPE were substantially reduced due to the omission of the compaction stage that usually occurs prior to sintering and extrusion. However, attenuation absorption for this two-stage material excelled that seen for either the structural (i.e. with a modulus of at least 0.1 GPa and produced in a three stage process) auxetic material or the conventionally processed UHMWPE. Therefore it is likely to be an ideal material for use in energy absorption applications.

The extrudates were produced in the form of cylindrical rods. Despite the auxeticity there are limitations in the production of cylindrical auxetic materials (diameters varying between 8 and 15 mm) on a large scale, since the fabrication process is not continuous, therefore restricting it to the laboratory.[30,34]

3. Auxetic Fibers

Alderson et al.[31] were the first to successfully produce auxetic fibers. They developed a kind of auxetic polypropylene (PP) fiber by employing a novel thermal processing technique, based on modified conventional melt spinning technique. This enabled a continuous fabrication process of auxetic polypropylene (PP) fibers. They used a laboratory scale melt extruder in place of a benchtop extruder and a flat profile of 159 °C across all zones of the extruder.[26] Even though aligning the molecules, as a consequence of drawing, gives fibers their high modulus, drawing the auxetic fibers causes a loss of the auxetic property.[26] Ravirala et al.[30] reported that the main approach for the production of auxetic fibers lies in maintaining the minimum draw ratio.

Due to the relatively low modulus of auxetic fibers, Simkins et al.[32] considered the possibilities to increase it to avoid the problematic post processing of fibers on a conventional textile equipment. They annealed fibers at various times and temperatures. Annealing enhanced the mechanical properties of these fibers, it increased the modulus; the tensile strength was at least 1.5 times higher in comparison to the un-annealed fibers,[33] and the fibers were more uniformly auxetic.

The developed fabrication process of polypropylene fibers is flexible enough to be used for the production of other polymeric fibers with the ability to achieve auxetic behaviour. The same partial melt extrusion technique was used to produce auxetic fibers from polyester and nylon.[34]

Ravirala and co-workers[30] produced auxetic polyester fibers. They observed that the key processing parameter was extrusion temperature which played a critical role in attaining the auxetic effect. The auxeticity of the polyester fibers increased considerably in the fibers fabricated at a processing temperature of 225 °C, in comparison to fibers fabricated at 220 °C. It was found that the auxetic effect occurs over an extremely narrow temperature window.[35] This applies also to polypropylene and nylon fibers.

This thermal processing technique seems to result in lower modulus fibers which cannot be drawn to improve mechanical properties.[26] Heat treatment improved the properties (strength) just enough to allow textile production, while limiting its overall effect.

The reason for this kind of behaviour lies in the microstructure of the fibers. Kim L. Alderson[26] concludes that larger scale auxetic polymers such as cylindrical rods appear to have a different causal mechanism to auxetic fibers. Extensive microscopy of the fibers revealed no evidence of the expected nodule-fibril microstructure.[35] Figure 2 shows the microstructure of an interlocked particle model, which seems to have a granular structure that consists of powder particles "glued" together exclusively by surface melting[26] and a low porosity. Alderson et al.[35] explained the possible causal mechanism for auxetic behaviour in this system based on a closely packed rough particle assembly, where particles undergo surface melting, which results in the formation of a network of connected interlocking rough particles. Besides the barrel temperature, which has the main role in processing the appropriate connected microstructure of auxetic fibers, the differential ratio of surface-melted thickness to particle diameter is another important factor. The mechanical properties of these auxetic fibres are a consequence of a structure and deformation mechanisms at the microscale. Consequently the stiffness and strength are not comparable to corresponding conventional fibers, extruded from a fully molten polymer, where mechanical properties arise due to structure and deformations at a molecular level.[36]

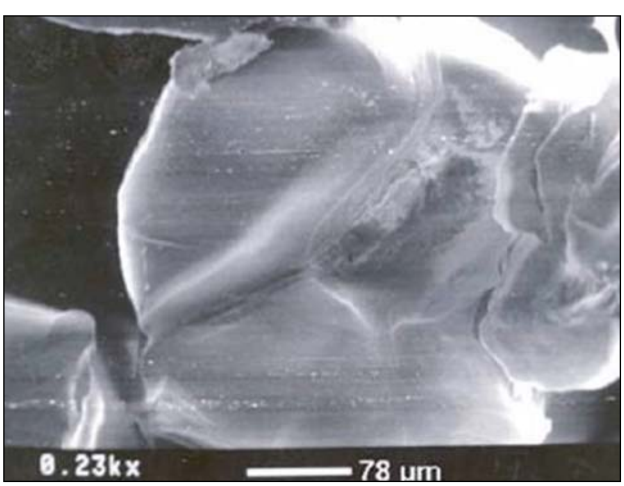

Figure 2. The microstructure of an interlocked particle model.[26]

Experts at the University of Bolton have used the auxetic fibers produced by a partial melt spinning process and integrated them into prototype fabrics, both knitted and woven. The results have not yet been published.[26]

To increase the modulus of auxetic fibers for use in textile structures without additional fiber treatments, fibers will have to be produced in a different manner. One theoretical proposal was made by Evans et al.[1], who presented molecular level auxetic polymer. Polyphenylacetylene single crystalline network based on the auxetic re-entrant honeycomb structure was already proposed and analysed by Abd El-Sayed et al.[37] and Gibson et al.[14]. Evans et al.[1] employed a general approach in designing molecular auxetics, namely the downscaling technique of known auxetic macro structures to the molecular level.[38] Although auxetic behaviour, which is assumed to arise from concurrent stretching, hinging and flexing of the 'arms' of this molecular network under tension, was predicted in one plane, the structure was too heavily cross-linked to be physically possible.

The flexyne/reflexyne networks model by Evans et al.[1] was further developed by Wei[39], who proposed a self-assembled copolymer having a double-arrow-like 'hard' block and a spring-like 'soft' segment. A hydrogen-bonded polymer network is more realizable with auxetic property predicted in the plane of the structure.

Molecular auxetics consisting of open, hinged networks from molecular building blocks have also been proposed by Gardner et al.[40], based on low-barrier rotational changes that would result in polymorphic molecular solids having significantly different volumes under strain.

Wojciechowski[41] proposed a two-dimensional nonchiral model of tri-atomic molecules. The cyclic trimers form a mechanically stable and elastically isotropic auxetic phase based on modeling considerations. Grima and Evans[42] suggested a series of self expanding polyphenylacetylene molecular networks consisting of connected rotating triangles as a potential molecular deformation mechanism for auxetic behaviour, also named cooperative rotation of the corner-sharing triangles. Grima et al.[43] predicted auxetic networked polymers based on calix[4]arene

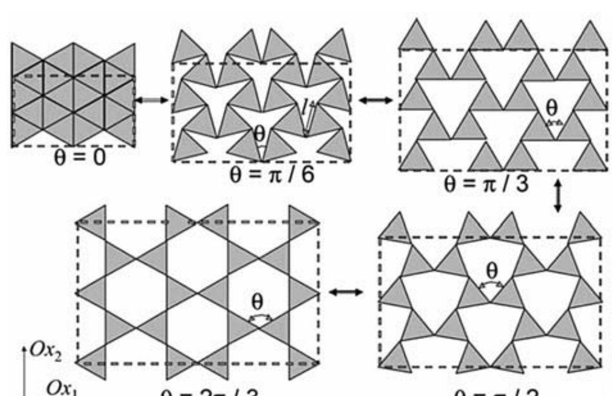

Figure 3. Rotating triangles principle[45]

molecular building blocks, which are not as easily realized. Baughman and Galvão[44] discussed twisted-chain structures in polymeric materials, where the auxetic property is the result of a mechanism called the change in twist of helical chains.

Another approach being one of the most simple and promising approaches in the endeavour to produce synthetic molecular-level auxetic polymer was predicted by He et al.[46,47], who described a system that was more easily reproducible, based on liquid crystalline polymers (LCPs).

The LCP is composed of chains of rigid rod molecules transversely or longitudinally connected to flexible spacer groups. The laterally attached rigid rods in the quiescent or un-stretched state orient parallel to the terminally attached rigid rods. However, when the system is stretched, the laterally attached rigid rods change their position. This site-connectivity driven rigid rod reorientation causes an increase in the inter-chain distance, which resembles the nodule-fibril mechanism. Thus far such materials with negative Poisson's ratio have not been created.[38]

4. Auxetic Textile Structures Made From Conventional Fibers

An entirely different way to overcome the disadvantages of producing auxetic materials, which includes a post-processing stage or processing by non-traditional methods, with each step providing additional costs, is to produce auxetic textiles with conventional yarns, as defined by Alderson[48].

Hook[49] presented an auxetic multifilament construction consisting of a high-stiffness filament helically wrapped around a thicker, low-stiffness filament, with neither of these two constituents required to be auxetic. Upon longitudinal stretching, the high stiffness filament straightens and causes the lower stiffness filament to helically wrap around it. Such multifilament construction exhibits auxetic behaviour and can be fabricated on existing textile machinery, such as warp spinning.

Sloan et al.[50] showed that the starting wrap angle of the helical auxetic yarn (HAY) has the greatest effect on auxetic behavior as regards both the magnitude and the strain range over which it appears. Other parameters which influence auxetic performance are the diameter ratio of wrap to core fibers and the fibers' inherent Poisson's ratio. They reported the characterization of the helical auxetic yarn with a focus on stiffer yarns, suitable for higher modulus applications such as composites and blast mitigation. Wright et al.[51] reported on the manufacture and characterization of different HAYs and fabrics with low stiffness or tensile modulus. The auxetic effect of HAY is present in real-world strain regimes. Therefore, these yarns and fabrics are suitable for healthcare, particularly bandages, compression hosiery and dynamic stiffness support garments, as well as fashion apparel. The HAY is especially well suited to woven fabrics, even though knitting is also feasible. The manufactured plain weave narrow fabric exhibited a thickening of the fabric and thus an out-of-plane negative Poisson's ratio. Shanahan et al.[52] also considered auxetic effect in the thickness of fabric. They reported on the theoretical auxetic behavior present in the fabric's effective thickness, as a consequence of the geometrical effect of woven structure and modulus of yarns.

Miller et al.[53] produced helical auxetic yarns and further used them in a simple weave pattern to fabricate an auxetic textile. Woven textile structure was then used to manufacture a low modulus auxetic composite. The first reported composite to exhibit auxetic behaviour using inherently auxetic yarns was produced using standard manufacturing techniques.

As presented with examples above, combining two or more multifilament constructions in an appropriate manner enables the production of auxetic structures.

Hook[49] patented the woven porous fabric in warp arrangement comprising an array of pairs of adjacent helical auxetic yarns with mirror placement of helices. The weft fibers, interconnecting warp yarns may be auxetic or non-auxetic. Helical auxetic yarns that provide a net increase in the effective diameter of the composite yarn under strain, thereby exhibiting pore-opening effect, when in-

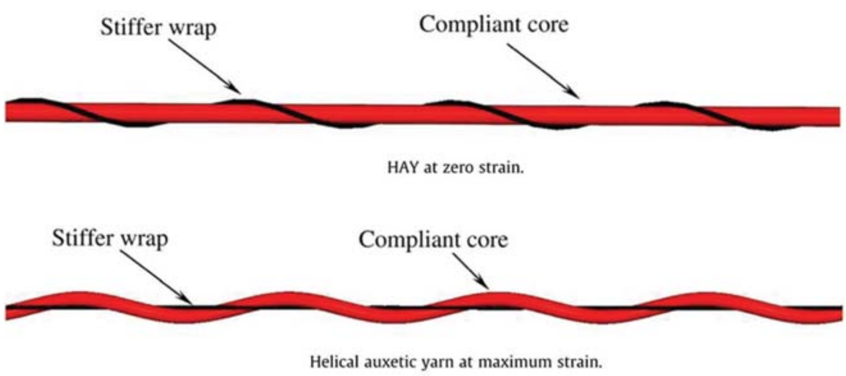

Figure 4. Helical auxetic yarn[50]

corporated into fabrics are suitable for different applications. One such case are fabrics that change colour and can be used for indicative or aesthetic purposes. These fabrics comprise a basic fabric of different colour than the overlaid porous material made from auxetic fibers. Such an arrangement enables colour change under an application of strain. This has potential in fashion and other fields where an accurate indication of the suitable tension is required.[49] Pore-opening is also applicable in filtration, where intentional scaling of tensile or compressive load application serves as a tool to vary the pore size in order to control the filtration process.[49,54] Hook[49] also presented a sample of these fibers made into a porous material that was then used to disperse blast energies from an explosion. The porous material, comprising a plurality of layers, enabled energy from the explosion to be efficiently dispersed through layers and voids between them to mitigate the blast effect. The third possible area of application includes release capabilities, such as garments containing anti-perspirant in the pores of the material, which is released upon stretching the garment and pore-opening.[48] Other possible substances stored in the porous material include antibacterial, antifungal, antiviral, antiyeast or antiamoebic agents, different additives for use in dental floss[49]; applications also include drug delivery and exudate removal, for instance.[51]

In comparison to the patent by Hook[49] who described a flat textile structure constructed from two-unit composite yarn, Hook et al.[55,56] presented composite materials and structures exhibiting negative Poisson's ratio, constructed from similarly comprised units made up of two components, with an additional core element in the minimum repeat unit. The core element should preferably be auxetic. The structure may also include matrix components, which are preferably in contact with all the other composite components and may amplify auxetic effect of the material. As the authors claim, the auxetic material is relatively easy to fabricate, is consistent in its structure and properties, has a significant (the system could have a Poisson's ratio of between 0 and –5) and controllable auxetic effect, and it can also be used to develop complex and useful forms. The structure is appropriate for impact and acoustic absorption applications.

Structures visually similar to the one presented by Hook[49], were reported to be auxetic as a result of other external factor besides the usual, namely a pseudo tensile force created by wetting. Lee et al.[57] described making auxetic fibers consisting of two components, of which one is moisture sensitive filament, i.e. it shrinks when it is in contact with moisture. Therefore an auxetic effect can be caused when the fiber is simultaneously exposed to external strain and moisture, or the auxetic effect can be caused by one of these two factors alone.

An array of auxetic fibers is comprised of a woven structure in the same way as presented by Hook[49], where a pair of adjacent fibers is of opposite handidness regarding the helices.

Ge and Hu[58] recently presented an innovative three-dimensional nonwoven fabric structure with negative Poisson's ratio for composite reinforcement. The structure was made by combining both non-woven and knitting technologies. Four fabric samples with different warp yarn diameters were first manufactured manually. Then their Poisson's ratio values, under compression along the direction of fabric thickness, were experimentally evaluated. A geometrical model was proposed for the theoretical calculation of Poisson's ratio values of these fabrics and was compared with experimental data. There was good agreement between the calculated and experimental data. The results showed that all 3D fabrics displayed auxetic effect under compression, resulting in a unique feature that allows the structure to concentrate itself under the compressive load to better resist the load. This special feature makes this innovative 3D fabric structure very attractive for many potential applications in the automobile industry, the aerospace industry, and in defence and sports equipment, where impact protection can be a highly desirable property.

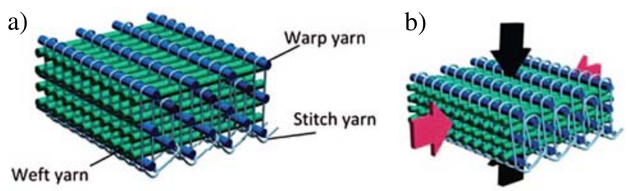

Figure 5. Three-dimensional (3D) NPR textile structure: (a) initial state; (b) under compression.[58]

5. Knitted Structures With Auxetic Potential

Besides multifilament constructions with negative Poisson's ratio, conventional fibers can also be made into fabric structures, which are in themselves auxetic (to produce such structures auxetic fibers or yarns can also be used).

All three reported methods that resulted in auxetic structures include a knitting process, which is the most versatile technique to produce textiles. It allows for a vast range of structures and production possibilities. Ugbolue et al.[59] have further explored the concept presented by Hook[56] and produced some warp knit auxetic structures in which filling yarn inlays are used to effect compound repeating units. The chain is used as a base structure. First they produced separate wales knitted from open loops, using a thicker lower stiffness filament and a high stiffness filament inlaid around the underlap loops. Construction expands laterally upon longitudinal stretching; the high-stiffness filament straightens and becomes fully aligned, causing the open loops formed by the lower stiffness filament to wrap around the straightened high-stiffness filament. Then they combined two or more wales so that the inlay filaments were effectively connected to the separate wales to form an inlay warp knit fabric, which exhibited auxetic properties. Ugbolue et al.[59] developed a warp knit auxetic structure with construction similar to the geometrical model developed by Smith et al.[60] who presented the theoretical broken-rib model. This also served as a basis for Gaspar et al.[61] who made a material from a regular plastic mesh with an exact microstructure. The results showed that warp knit auxetic structure with such an arrangement of ribs does produce a negative Poisson's ratio. In this case it is necessary to employ a high elastic yarn in the base structure. This yarn must be positioned between the stitch wale in the knitting direction to ensure that the fabric structure retains the necessary configuration after relaxation. The filling yarn must be laid between neighbouring wales to wrap the junctures of the ground loops and provide better stability in the fabric structure. All the produced samples exhibited negative Poisson's ratio.

Ugbolue et al.[62,63] designed and investigated auxetic hexagonal knit structures (Figure 6B). Employing a highly elastic yarn (polyester-covered Spandex), placed between the stitch wales in the knitting direction of base structure, enabled the fabric structure to retain the required configuration after relaxation. Inlay component affects the geometry of the auxetic samples which combined with the intrinsic unit size displacement results in negative Poisson's ratio of the warp knit fabrics. It is noted that the auxetic properties depend on the interaction of vertical and horizontal ribs in the knitted structure, which depends on chain course numbers.[64] Samples showed auxetic ability especially during deformation at low-strain levels (elongation up to 10 %). But two samples had negative Poisson's ratio at high strain levels of 50–70 %. The tensile and recovery tests performed on the samples showed that deformations up to 150 % strain levels were completely recoverable. The factors that influence Poisson's ratio were identified as yarn type, number of chain courses and strain level. Yarn type was found to be the most important factor.

Starbuck and co-workers[65] patented auxetic warp knit textile structures consisting of double arrowhead or triangular construction, which is known to lead to an auxetic effect.[17] Auxetic effect, measured at –45° and +45° to the warp direction, is a consequence of hinging of the ribs of re-entrant triangles to deform towards regular triangles, leading to opening of the arrowheads. In 2010, Anand et al.[66] filed a second more detailed patent on the same topic. Alderson et al.[33] and Anand et al.[67] further reported that the designed knitted fabrics, besides being auxetic in the first stage of stretching were also able to undergo subsequent stretching, whereas other reported auxetic fabrics are effectively only one stretch auxetic materials. Two components were introduced to fabricate the structure – the auxetic component, comprising shapes that provide an auxetic behaviour, and a stabilizing component, which restores the fabric after deformation. The characteristics of the produced fabrics were defined by the interaction of included components in the knit pattern and relative properties of the fibers of its two components, auxetic component being of a relatively higher modulus than the other. It is believed that the fabric's modulus will be governed by the modulus of the stabilizing component.

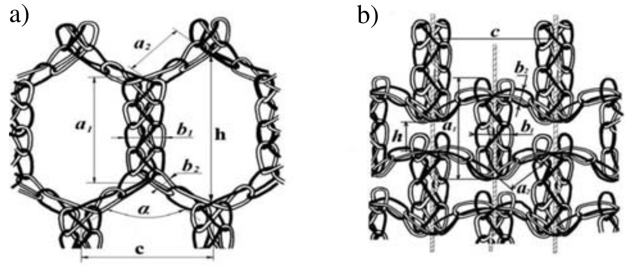

Figure 6. Warp knitted mesh structure: (a) non-auxetic structure and (b) auxetic structure[62]

Optical microscopy analysis indicated that a multiple deformation model is needed to completely comprehend the response mechanism of the fabric presented. Probably the models based on hinging, flexing and stretching of the fabric components are likely to act in a concurrent manner, with other possible mechanisms also occurring such as, fiber translation determined by friction, leading to slippage.[33]

As stated by Alderson et al.[33] the combination of design and progress in auxetic structures with the design and production of knitted structures has enabled auxetic warp knit fabrics to be produced from conventional fibers. However, auxetic fabrics fabricated from conventional fibers are known to be successfully produced also using flat knitting technology, which is, compared with other knitting technologies such as warp knitting and circular knitting, recognized for its high process flexibility and broad structure variety. Liu and co-workers[68] reported the production of weft knitted auxetic fabrics based on a structure of parallelogram planes of the same shape and size connected side to side to form a 3-dimensional zigzag. While warp knitted structures are made by reproducing the geometry of known auxetic structures with the knitting technology, foldable weft knitted auxetic structures present a new kind of auxetic geometry and deformation mechanism. We called it "opening of the foldable structure". The fabrics produced are solid with no network spaces to allow hinges to flex or nodules to spread out in order to achieve the auxetic effect. The knit pattern was based on a purl structure through a zigzag arrangement of face and reverse loops. The structural disequilibrium of the arrangement induced curling of the fabric during the relaxation process after knitting. Under applied external strain the 3-dimensional structure unfolded resulting in the whole structure increasing its dimensions in both course and wale directions. A negative Poisson's ratio as low as v = –0.5 was reported, which decreased with increased strain in the course direction, the only one measured, since the fabrics exhibited an auxetic effect only in this direction. The main structural parameter influencing the auxetic effect of the fabric is the opening angle at its initial state. The fabrics that are more closely folded can result in a smaller opening angle and consequently have higher NPR values. The scope of fabric folding due to structural disequilibrium has the principal influence on the auxetic effect of all kinds of foldable structures.

NPR weft knitted fabrics have potential applications in different fields, such as functional clothing, sportswear, medical care etc. Research shows that flat knitting technology can provide a simple, but highly effective way of fabricating auxetic fabrics from conventional yarns.

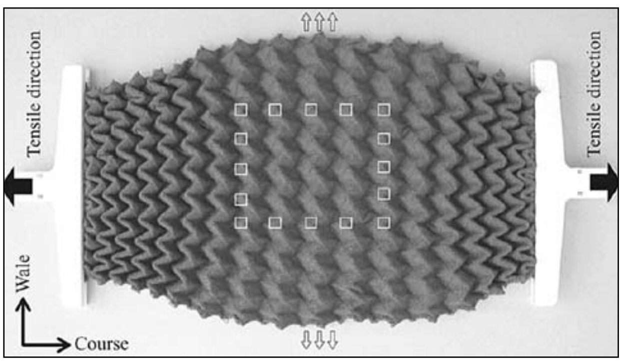

Figure 7. Foldable weft knitted auxetic structure[68]

Buhai et al.[69] also investigated the zigzag arrangements of face and reverse loops. The main focus of their research was the influence of raw material and stitch length on the auxetic effect. They used two types of conventional yarns with positive Poisson's ratio: acrylic and cotton, and three different tightness values, which enabled the production of tight, medium and loose fabrics. The results show that decreasing values of the stitch length in the production process also decreases the values of the initial angles of foldable structures and at the same time enables the production of tighter fabrics, which maintain their shape better and consequently exhibit higher auxetic effect. Stitch length values influence the auxetic effect of foldable structures. Regarding the comparison of the fabrics made of different yarns, the calculated results, the only ones reported, show higher auxetic effect of the fabrics made of acrylic yarn.

Hu et al.[70] reported on three kinds of geometrical structures performed in weft knitting technique that were used to produce new kinds of auxetic fabrics. The foldable structures presented by Liu et al.[68] were supplemented by two arrangements of face and reverse loops; one in rectangular form, which was stretched only in the course direction exhibiting an increase of the auxetic effect at the initial stage of loading followed by a decrease and the other in the form of horizontal and vertical stripes, which exhibited auxetic effect in two principal directions, yet this time decreasing with an increase of the axial strain. The latter applies also to both other structures presented by Hu et al.[70], rotating rectangle and re-entrant hexagon. A number of studies revealed that auxetic effect can be achieved by developing constructions based on rotating units such as squares[71,72], rectangles[43,73], triangles[45,74], rhombi[75,76] and parallelograms[76,77].

Developed rotating rectangle structure based on partial-knitting technique exhibited auxetic effect only when extended in the course direction. Theoretically rigid rectangles that can be easily changed into parallelograms under loading, elastic yarn used to connect the units, slippage effect occurring among the yarns, and passing the yarn from one unit to the next, all affect the value of Poisson's ratio.

Re-entrant hexagonal structures have also been found in several auxetic materials presented by Grima et al.[19], Liu and Hu[6], Evans and Alderson[2]. The real re-entrant hexagonal structure and pseudo re-entrant hexagonal geometrical configuration which is a close structure, exhibited auxetic effect only when extended in the wale direction. The nature of the knitted material limits the rotations around the connecting points due to loop connections and also provides components of the structure, which can easily be deformed under loading.

6. Conclusions

Extensive recent investigations of textile structures exhibiting auxetic potential and performance properties of the analysed auxetic materials indicate that there will be further development of auxetic polymers and auxetic fibers.

The auxetic potential of the textile structures made from conventional raw materials has become the interest of many researchers. As the knitting technology enables the design of various mesh planar structures and foldable 3D structures with auxetic potential, this research field has greatly expanded.

Based on the analysis of the research presented above, it can be concluded that weft knitted structures with auxetic potential exhibit extreme versatility and multifunctionality. Consequently, research at the Department of textiles of the University of Ljubljana has been focused on developing technical textiles including weft knitted structures, produced on a flat knitting machine that could be used for food packaging and sound absorbent coverings with curved surfaces, respectively. On the other hand, 3D foldable weft knitted structures with auxetic potential can also be an inspiration for fashionable knitwear with an unconventional visual effect. For this reason, all developed knitted structures with auxetic potential have also been analysed from the artistic-aesthetic point of view.

7. Acknowledgements

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Povzetek

Vrednosti Poissonovega števila konvencionalnih materialov se gibljejo med 0,0 in 0,5. Oksetični materiali imajo v nasprotju s konvencionalnimi negativno Poissonovo število. Pod vplivom vzdolžnega raztezanja se prečno povečujejo in obratno se pod vplivom vzdolžnega stiskanja zmanjšujejo tudi v prečni smeri. Na področju izdelave oksetičnih materialov je v zadnjih letih vse več pozornosti namenjene uporabi tekstilne tehnologije. Slednje se odraža v količini raziskovalnega dela, ki obravnava oksetični potencial različnih tekstilnih struktur in posledičnemu porastu števila objavljenih člankov na to temo. Na splošno so oksetične tekstilije lahko izdelane na dva načina. Prvi način vključuje uporabo oksetičnih vlaken za izdelavo oksetičnih tekstilnih struktur, medtem ko gre pri drugem načinu za uporabo konvencionalnih vlaken, iz katerih so izdelane tekstilne strukture z oksetičnim delovanjem. Pregledni znanstveni članek obravnava oksetične materiale na splošno in natančneje področje oksetičnih polimerov, oksetičnih vlaken in oksetičnih tekstilnih struktur, izdelanih iz konvencionalnih vlaken, ter pletenih struktur z oksetičnim potencialom.