ADVANCEMENT IN KNITTED STRUCTURE FOR INDUSTRIAL APPLICATIONS- A REVIEW

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ABSTRACT

Knitted fabrics, due to their properties like shape fitting, softer handle, bulkier nature and high extensibility at low tension is being extensively used for dress materials, are now gaining strong ground in the area of technical textiles. Knitted preforms show lower mechanical properties and lack of formidable dimensional stability compared to that of woven structures. Warp and weft knits however, can be designed with enhanced properties by the use of laid-in yarns.

Due to high conformability and improved characteristics of modified structures, 3D spacer, 3D seamless shaped and multi axial knits ,offer comprehensive versatile design range for composite structural applications. Now a day's knitting technology has expanded its application in various areas such as geo textile, sports, agricultural sector, aerospace industry, protective textiles, medical & automotive textile etc. Recently, knitted preforms have been used in geo textile applications, wherein they have been designed and produced to suit various soil types and conditions. Compared to woven fabric composites, knitted fabric composite exhibited a better impact resistance and bursting strength.

An attempt has been made to discuss the traditional and modified knitted structure suitable for industrial application and critically review the research work done by different researchers in this regard. An insight into the knitted structures with respect to their composite performing and their characteristics is presented in this article. Flexibility & adaptability of knitted structures and requirements of structural modifications for knitting process & parameters have been discussed. Contour ability, formidable net-shape preforming, high dynamic mechanical properties along with easy and rapid manufacturability are certain important features of knitted structures for development textile reinforced composites.

KEY WORDS: *Biaxial, 3D knitted structure knitting technology, mono axial, multi axial, spacer fabric*

1. Introduction

Knitted is process characterized formation of textile structure by interlooping of yarn, based on principle of making a loop and drawing the new loop through the previously formed loops i.e. pulling a new loop through the old loop.[1] These loops are interconnected to each other to form the knitted structure. The length of yarn used to form a loop is called the loop length which plays an important role in fabric characteristics. The longer the loop length the more elastic and lighter the fabric and poorer its cover and bursting strength. In knitted fabrics the loops are arranged in rows and columns roughly equivalent to weft and warp of woven structures termed as courses and wales. [2] The basic knitting types are weft knitting and warp knitting. Weft knitting is sequential in which loop formation takes place course wise, i.e. in horizontal manner. In warp knitting loop formation takes place in vertically upward direction and this unique feature of loop continuity in upward direction makes the warp knitted fabrics, more special with respect to their characteristics, production and applications. Knitted fabrics can be produced at high rates and for low costs. These fabrics are popular for apparel and garments due to their shape fitting properties softer handle bulkier nature and high extension at low tension. [1], [3]

Textile materials, specifically knitted structures, were supposed to be a basic necessity in form of clothing which forms a multidisciplinary team involving trained weavers, artisans and fashion designers. It describes an area of an art and design environment. Apart from the house hold significance nobody has thought about is relevance for industrial application as an engineering material due to its anisotropic nature, showing poor through thickness properties.[3] The practice of combining engineered design architecture and science-based processes is a current trend running through textiles. With the innovation of technical textile the knitted structures specially warp knitted structure got focus of attention for its relevance in industrial composite performs due to their elastic, open & closed structure and can be produced in flat, tubular or three dimensional sandwich type structure. Although the commercially available fabrics failed in many cases to satisfy the specifications set by the producers and the designers and textile engineers were involved to modify the tool, technique and methodology in existing form to create new structures with enhanced functionality to make it suitable for technical application. [4-9]

In recent years, knitted fabrics have attained focus of attention in the composites industry for structural reinforcement. This is attributed to their unique properties in comparison with other reinforcement fabric structures such as woven and braided fabrics. The loop structure of knitted fabrics creates high degree of deformability. This deformability has an added advantages, provides draepability, which makes them ideal for the reinforcement of complex-shaped preforms and liquid molding in the production of composite components. Moreover, some important mechanical properties of composites, such as resistance against impact and delamination, can be improved due to the energy absorption capacity of loop structures.[2],[10]

There is however no doubt that the loop structure will result in a reduction of the modulus of the resulting composites. However, this disadvantage may be overcome by inserting straight reinforcement yarns in the knitted structures. The directionally oriented structures (DOS) are examples of this, and yarn reinforcements may be inserted in one, two, three or multiple directions. [7],[11]

2. Structural Modification in Knits for Composite Application

Techniques of structural modifications in knitted structure can substantially change not only the physical structure but enhance the properties of knitted material. It is required that technique adopted must retain the cohesiveness of interloping which is an essential requirement of knitting process. Four of such main techniques are:

a) laying-in,
b) plating,
c) open work and
d) plush–pile constructions

Amongst which the laying in technique has been explored and proven successful [11]. An in-laid structure consists of a ground structure of knitted yarns which hold in position other non knitted yarns which were incorporated into the structure during the same knitting cycle to modify one or more of fabric properties like strength, stability, weight, handle, etc. [12],[13].

2.1 Directionally Oriented Knitted Preforms

Anisotropic and poor mechanical properties of knitted fabrics require structural modifications for its utility as technical textile. The stability of structures can be obtained by using standard stitches with inlay yarns and their combinations in length wise, width wise and diagonal directions. These structural modifications of developed preforms are suitable for the composite applications. They are generally categorized in three following categories:

2.1.1Unidirectional Knit Structures

UD knitted fabrics such as warp or weft knits with inlay yarn in any one particular direction are termed as mono axial structures. The width wise inlay insertion in knitted structure, also known as weft insertion, is a form of inlay extending over the entire width of the fabric. In weft knitting, inlaid yarns are trapped inside double needle bed fabrics. 1X 1 Rib structured inlaid preforms have been attempted and found that UD strength can be enhanced substantially in the inlaid directions [7],[9],[14] and composites in such cases with better tensile strength compared to standard woven counterparts have been reported [15],[16].

Magazine return weft insertion and single-end magazine weft insertion are the two principles on which weft insertion during warp knitting takes place. Weft inserted warp knit preforms have been characterized for composite applications [21]. Fig. 2.1 & 2.2. Illustrates the UD knit, in form of net and uniaxial, biaxial & multiaxial weft inlayed structures respectively.

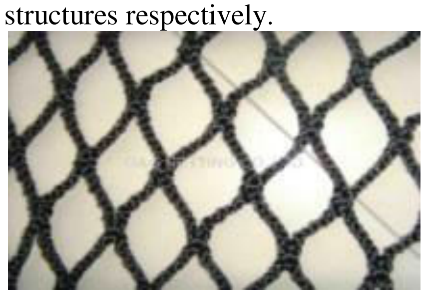
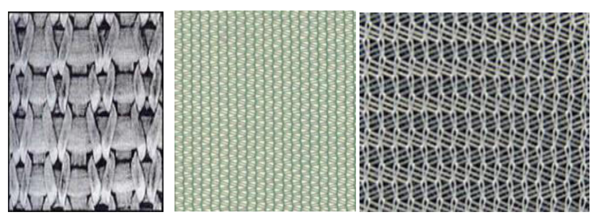


Fig 2.1 Uniaxial Net Shaped



Uniaxial Biaxial Multiaxial inlayed
Fig.2.2

2.1.2 Biaxial Knit Structures (2-D Knits)

Incorporation of additional yarns in two directions in the knitted structures is termed as biaxial knitted structures. Introduction of both weft or warp yarns and diagonal yarns into warp and weft knitted fabrics during knitting process combines the advantages of woven and knitted fabrics together [28].

Co-we-knits is a combined weaving and knitting technique, which is a modification of the warp knitting technique, wherein weft yarn is laid in front of warp threads to simulate woven and knitted structures together [11].

Warp laying in warp knits is either by miss lapping or with the use of the fall plate technique [14]. Figure 2.2 [7],[8] illustrates biaxial structures—warp and weft in-laid weft knit, warp and weft in-laid warp knits,

2.1.3 Multiaxial fabrics

The multiaxial fabrics are characterized by the presence of multiple layers of yarns disposed at preferential angles that are assembled in the knitted fabrics. These fabrics are produced on special warp knitting machines using high performance yarns like, glass or carbon for forming the layers. The incorporation of high performance yarn through traditional knitting operation is a stumbling block hence the warp knitting technology is best suited for this kind of structures with in-laid yarns [20]. Multiaxial fabrics are used mostly for the reinforcement of composite materials. The layers are united by the actual knitted fabric, using pillar or tricot stitches.[1] The preset angles correspond to the directions requiring higher strength and enhanced functionality imposed by the application. Currently, there are two main technologies adapted for the production of multiaxial fabrics: the Karl Mayer technology and the Liba technology.[8] These structures produces non-crimp technical textiles in presence of knitted loops is to perform. The function of holding layers of uncrimped inlay yarns are fabrics bonded by a knitted loop system, consisting of one or several yarn layers stretched in parallel. Yarn layers may have deliberately created different orientation and yarn densities. [21]

2.2 3D Knitted structures

Conventional knitted structures can be stitched together in layers to form In the case of knitted fabrics, the 3D architecture is facilitated by their high extensibility and formability that allow the production of complex shapes.[22] This is the reason why the knitted fabrics are regarded as a viable option for preforms for advanced composite materials. The main advantages of the 3D knitted fabrics are:

- 3D knitted preforms are more drapable
- Can produce more complex near-net-shape preforms
- Essay to produce on existing knitting machines (warp knitting) with little alteration.
- More versatile production offers opportunity to be produced on circular, flat and warp knitting machine.
- 3D knitted sandwich composites produces lightweight materials are multifaceted not only owing to its extremely light materials, but also because of exceptionally high stiffness to weight ratio.
- These composites have higher impact damage tolerance and energy absorption properties.

Apart from advantages there are certain limitations & issues impeding the use of 3d knitted composites such as:-

- Many 3D knitting machines cannot produce commercial quantities of fabric.
- It not feasible to produce thick perform on existing form of machine. Requires major modification and induction of sophisticated process.
- Production of inlayed structure in form of non crimp configuration is difficult through weft knitting process. Distortion and loop and end breakages are prominent during production process.
- In-plane properties and failure mechanisms of 3D knitted composites are not well characterized. Validated methods are not available for predicting many of the properties and long-term durability of 3D knitted composites
- Poor understanding of the influence of the knitting process parameters on the composite properties. Knitted composite components usually contain ‘soft spots’ and ‘hard spots’ caused by a change in the knit structure due to stretching of the fabric during prefoming

The 3D knitted fabrics for industrial application can be divided into: shaped or contour, multiaxial fabrics (multilayer), sandwich/spacer fabrics and tubular or multiple branched knitted fabrics.

2.2.1 Shaped knitted fabrics

The shaped knitted fabrics are based on the need to produce fabrics with complex shapes that are similar to the shape of the requisite product. The contour shape has great importance in industrial application. Certain degree of spatial geometry can be obtained by using modules of structures with different patterns or differential stitch configuration and dynamic stitch length, the technique of shape knitting is the only one that has no limitations with regard to the shape complexity and dimensions. Furthermore flexibility of knitted structure, easy manufacturing process and better adaptability with various perform shapes knitting process has been widely used in comparison with the woven perform. [23], [24]. This technique is based on knitting courses on all working needles and on a variable number of needles, formulating zones with different stitches configurations. The zones with the highest amount of stitches will have in the end a spatial geometry.

Shaped knitted structures can be divided in tubes (cylinders), spheres and hemispheres, cones and frustum of cones, ellipsoids, tetrahedrons, pyramids, parallelepipeds, etc.[2],[3]

Fig.2.3 Shaped Knitted fabric

2.2.2 Sandwich/spacer fabrics

Simplest form of spacer fabrics are complex three-dimensional (3D) constructions made of two separate fabric layers connected vertically with pile yarns or fabric layers. The conventional spacer fabrics composed of two surface layers bound with pile yarns are generally manufactured using warp or weft knitting technologies. However, such pile based sandwich form of construction has inferior mechanical properties, such as elasticity and deformability under applied loads; conventional spacer fabrics are not suitable for high-performance composite applications.

Moreover, the modified form of 3D spacer fabric made by warp knitting technique incorporates high performance yarns and knitted fabric layers instead of pile yarns. This type of 3D spacer fabric with multi-layer reinforcements in the fabric structures is expected to show superior mechanical properties and be especially suitable as textile preforms for lightweight composite applications.[28] A transformed of sandwich/spacer fabric is a 3D construction made of two complementary slabs of fabric with a third layer tucked in between. The inner layer can take a variety of shapes, including tubes,pleats or other engineering forms, which gives the entire three layer fabric a wide versatile range of potential applications [23]. The fabric thickness determined by length of the connecting yarns/layers. When produced on warp machines, these fabrics are known as spacers as shown at Fig. 2.4. They are obtained on double needle bar machines, with 4 to 6 guide bars. Single or two guide bars constitutes the top and bottom independent layers. The centrally formed layer contributes to connection of aforementioned layers on both beds (forming stitches or being in-laid). The fabric thickness depends on the distance between the two beds. There are many ways for connection of layers depending on preforms requirements some of such combinations are shown at Fig. 2.5

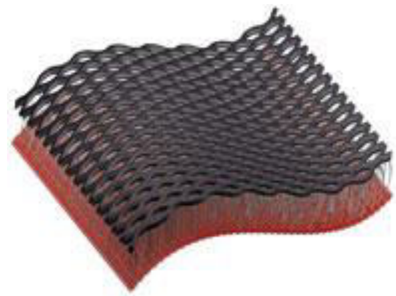


Fig.2.4 Warp knitted spacer fabric

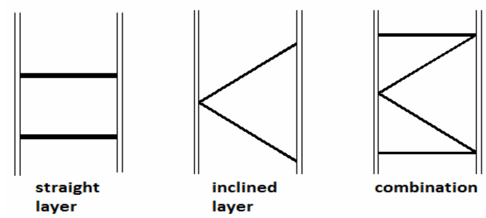


Fig. 2.5. Types of connecting layers

4. Properties of Knitted Preforms and their Composites

Knitted structure in general characterized by its bulkiness, high extensibility and low flexural rigidity. Different parameters like configuration of structural geometry, yarn strength, stitch density, pre stretch parameters and incorporation of different technique of structural modifications; mentioned earlier has significant importance for selection of knitted preform for composite applications. In knitting process, yarn properties like friction, stiffness, bending strength brittleness etc have influencing role on over all knitted structure. The 2D knitted structures owing to anisotropic nature requires structural modification for making it meaningful for composite applications. By certain proved techniques like laying in, plating, open work, plush–pile constructions etc, directional oriented structures can be made which enhances shear strength and other mechanical properties. Innovative development of 3D knitted structure in form of shaped, contour, tubular and sandwich type spacer fabric has offered enhanced functionality of knitted perform.

The properties of 3D warp & weft knitted multi axial preforms were studied by various researchers. The tensile and compressive properties of the knitted fabrics are poor in comparison with the woven and braided fabrics, but they are more likely to be chosen for their process ability and energy absorbing characteristics than their in-plane properties. It was found that the fiber content of weft knitted fabric composites can be increased by using the coarser yarns. In general, the coarser yarns are difficult to knit and the coarsest yarn knitability dependent on the yarn type and knitting needle size. The high performance yarns also encounter difficulty to knit and require modifications in existing form of machine. In addition, the maximum volume fraction is limited by the knitting needles used in the knitting machine. Hence, the maximum volume fraction can be achieved by more stitch density or the tightness of the knitted fabric. Aforementioned structural modifications in knitted structure do not require knitting of coarser or high performance yarns, but such type of yarn can be incorporated in the knitted structural configuration. The properties of different structures and their performance in composite applications were investigated by different researchers, which are being summarized as follows:

- The performance of weft knitted structures under tensile load was investigated; it was also found that impact and tensile performance was adversely affected by an increase in loop length or stitch density.
- In experimental study of Giri dev et al [29], effect of stacking sequence and the introduction of inlay fibre strands, on the mechanical properties of double layered rib knitted, glass fabric reinforced epoxy laminates was investigated. The results showed superior mechanical properties with the introduction of inlay fibres. Further, the impact property of stacking sequence [0º/90º] was found to be superior to that of [0º/0º] sequencing.
- There are a large number of potential sites for crack initiation in knitted composites. Weft knitted composites observed in wale direction shows that crack the initiate from debonds, which were formed around the needle and sinker loops in the knitted architecture. Furthermore, cracks developed in fabrics tested in tension in the course direction are believed to occur from the side legs of loops**.** It has been investigated that a higher percentage of impact energy is observed by the weft knitted glass reinforced composite than was observed by an equivalent woven fabric. Study indicated that the damage area was approximately six times larger for the knitted fabrics than for the woven fabric, presumably reflecting the increased availability of crack initiation sites in the knitted architecture. Compression after impact strengths were decreased by only 12% for the knitted fabrics, whereas the woven fabric compression after impact values fell by as much as 40% [25] [26].
- Composites are designed to achieve unique thermo-mechanical properties and superior performance characteristics, not possible with traditional knitted materials. The need for structural modifications in it in, has established high strength, high stiffness, and light weight materials for industrial applications. It is now possible to use such composites in high performance applications like aircraft, land-based vehicles and armour.[30]
- The mechanical properties of various weft knitted fabric and their thermoplastic composites as well as the energy absorption mechanisms have been studied. The knitted composites display superior tensile properties in the wale wise direction than in the diagonal and course wise direction. The knitted composite has an excellent combination of properties than its individual components in terms of energy absorption capacity.
- Impact properties of different knitted composite structure were investigated by many researchers. It was observed that in comparison with many woven structural composite, the knitted fabric composites have better delimitation resistance and absorbed more impact energy. [25], [26]
- Knitted preforms, compared to woven counterpart are considered thick, highly extensible, distribute the stress better throughout the structures, and have less flexural rigidity [27]
- The complex nature of the knitted structures generally do not exhibit distinct directions where the strength is at maximum, but the knit preform properties are greatly influenced by the fiber strength, modulus, knitted structure, stitch density, number of knitted fabric plies, pre-stretch parameters, inlays, and other knitting parameters. Although Strength and stiffness of the knit reinforced composite is considered relatively lower than woven and braided textile preformed composites.[11],[15]
- Knitted structures are highly compressible compared to wovens and it is observed that multilayered knitted preforms are easier to compress than the single layered, since the loops of different layers can mingle into each other in multilayered performs. Compression behavior of knitted composites are mainly governed by the reinforcing matrix, hence this property is much more isotropic and predictably knitted composites perform better in compression than in tension. In the case of knitted structures, because of the looped configuration of the reinforcing fibres, the structure is more isotropic. The variation in impact damage resistance of different knit structures with varying knit parameters is very minimal implying that knits in general greatly enhance the structural integrity of the composites, giving rise to an improved interlaminar fracture toughness value resulting in better impact energy absorption [25].

- The knitted preforms have high drapability and deformability under low load, the ability because of which complex contouring of shapes are possible with uniform fiber volume fraction throughout the composite material and in certain cases it is possible to develop truly 3-D fabrics that do not need any seaming when put in the mold. Formability studies on two-biased multiaxial warp knit during hemisphere-pressing process based on the deformation behavior has been done to predict possible wrinkles, local deformations, and the flat shape for hemisphere. The comparison between theory and experiment suggest that the model fit the results very well [28].
- Net shape performing is another way to knit the structure to the desired shape and size to fit the composite requirement. The property of deformability and net-shapability of knitted preforms is utmostly significant when composite panels with holes are to be designed. Such composites with holes display higher notch strength and bearing properties than drilled composites due to better dissipation of stresses away from the hole through looped network of knitted preforms [19] [21].
- The capability of biaxial or multiaxial extensibility of knitted structure to form 3-D shapes not only enables these knitted textile materials to be utilized for a wide variety of close fitting apparel garments but for shaped composite perform as well.
- Studies regarding the effects of deformation of knitted fabrics on the tensile and compressive properties of their composites have been investigated for the weft-knit Milano rib fibre architecture. The properties have been studied for both the course and wale directions for composites with fabrics deformed in either of the two directions. It was found that any change in the mechanical property of the deformed composites with respect to undeformed one solely depends on the changes in the knit configuration brought about by the induced deformation to the knitted fabric. Deformation in the knitted fabric also affects the tensile fracture mode whereby increased deformation, be it wale- or course-wise, transforms transverse fracture to shear fracture in either loading axis. [18] [22] [23]

5. Applications of Knitted Preforms for Composite Materials

Among many applications of knitted preforms for composites, major fields include automotive, aerospace, medical, geo textiles, protective, packing, sport and civil applications.

Malimo multiaxial is a high tech knitting machine with several weft insertion systems produce multiaxial fabric layers for various sport applications such as tennis racquets, skis, snowboards, surfboards, sport boats etc.

Multi axial warp knit preform for top shell composite and an interlock weft knit preform inlaid with additional yarn in horizontal direction for the wheel wells of an all-composite electrical vehicle was achieved by a combination of shaping techniques: holding, narrowing, widening, and binding off to obtain sufficiently high fiber volume fraction and mechanical strength from the curved fibers in the knitted loops [13].

Protective knitted textile includes flame and weather protection, protection against the sun, camouflage nettings, and nets with varying mesh openings and constructions.

In medical textile mattress covers, wheel chair cushions for bed sore prevention, prosthesis padding, branched artificial blood arteries are some of the prominent knitted structures widely used now a days.

Applications of knitted structures and its composite are widely used in geo textile sector prominent area of applications is: building foundation, drainage layers, railway construction, landscape protection. With respect to the properties such as tensile properties, tear strength, hydraulic properties, warp knitted geo textiles are advantageous when compared to others. [3]

Vehicular crash guards, composite helmet by net shaping, and contouring [25] and railway coaches of non crimped knitted reinforced composites [27] are the other major automobile applications.

The complicated nature of the short weft knitted preforms enhance bonding and mechanical anchoring to the cement matrix effecting higher efficiency factor of flexural strength [21]. T-joints and T-shape connectors, cones, pipes, and I-beams form supplementary civil applications.

Knitted ceramic composite jet engine vanes impregnated with silicone carbide by chemical vapor deposition radomes, rudder tip fairing for midsized jet engine aircraft [16], medical prostheses made from glass and Kevlar knitted composites [17],[18] and electrically conductive composites, made from copper wire/glass fiber knit fabric reinforced with polypropylene polymer matrix [11] are a few important composite applications worth mentioning.

6. Conclusions

Knitted fabrics are well known for their applications in the field of technical textiles, including composite materials with polymer matrices. Owing to certain deficiencies associated with regards to mechanical properties of knitted fabric as composite reinforcement, some structural modifications in form of use of inlaid yarns and knitting configuration is essential. Both weft and warp knitting technologies can be used to produce such reinforcements. Warp knitted fabrics are best suited for structures with in-laid straight yarns (multiaxial fabrics), whilst weft knitted ones allow structures with 3dimensional architecture, used as preforms for advanced composite materials. The complex 3D textile systems are being used mostly in defense and aerospace applications (for example, glider wings), where they can effectively replace conventional materials. A better understanding of the mechanism of fibers reinforcement in composite materials enables the design and production of new high performance textile-based composites for a wide range of applications. Technology optimization will yield in reduced production costs, while geometrical modeling and predictive calculations of the physical and structural properties of textile complex structures will result in preforms with tailored properties.

Knitted preforms are particularly suited for the rapid production of composite components with complex shapes due to their low resistance to deformation and minimum material wastage. At the same time knits consume more yarn for comparable fabric properties against wovens, which is of much concern since cost of yarn much exceeds cost of fabric production particularly for high performance fiber preforms for composite applications. Multidirectional knitted preforms are in its embryonic stage and would be preferred preforms due to better performance characteristics.

It is evident that the knitted preforms perform better than the existing ones in terms of cost, contour ability, and impact strength but tensile, bending strength lacks need to be compensated with structural modifications as mentioned earlier. With suitable structural modifications and very high versatile design potential, knitted preforms offer a good deal for composite applications.

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