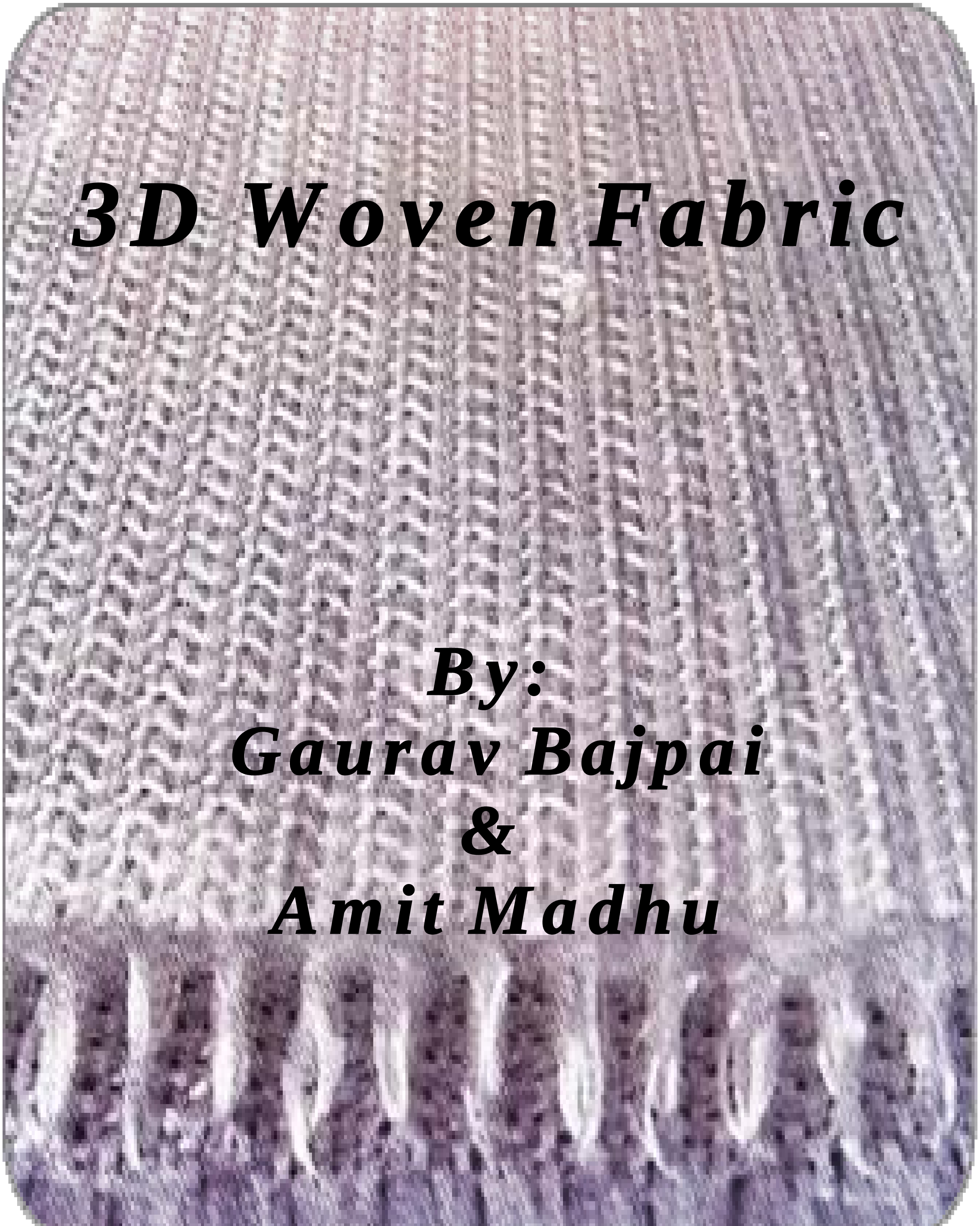


3D Woven Fabric

By:
Gaurav Bajpai
&
Amit Madhu

3D Woven Fabric

By: Gaurav Bajpai & Amit Madhu

Panipat Institute of Engineering & Technology, Panipat

Abstract

3D fabrics are the focus of rapid development due to their versatile physical, structural attributes and application scopes. These fabrics can be produced in various architectures which offers a great deal of opportunity to modify the weight, aesthetics, properties and cost of the various products. 3D fabrics have wide methods in terms of manufacturing. This paper will discuss about various manufacturing techniques for 3D fabric and their potential end uses in the market.

Introduction

Three dimensionally woven textiles are not only beautiful, they also have the potential to change the way aircraft and other complex structures are built. Different authors define 3D fabrics in different ways. Greenwood[1]- 3D fabrics are those fabrics which have substantial measurement in three dimensions as compared to the conventional fabrics, which will have measurement in two dimensions only. According to Khokar[2]-3D fabric is defined as a single-fabric system the constituent yarns of which are supposedly disposed in a three mutually perpendicular plane relationship; this definition doesn't consider multilayer and some other type of fabrics to be of 3D type. Hearle [3]gives definition of 3D fabrics as- 3D fabrics are thick planar sheets or shaped solid forms with multiple layers of yarns, hollow structures and thin 3D shells.

2D and 3D Weaving

The conventional 2D weaving process involves the two sets of orthogonal yarns, warp and weft, intersect and interlace at right angles (see fig-1a) whereas the process of 'true' 3D weaving (see fig-1b) may be described as the action of three orthogonal set of yarns, in-plane warp and weft yarn layers interlaced in thickness direction by binder warp or weft yarns.

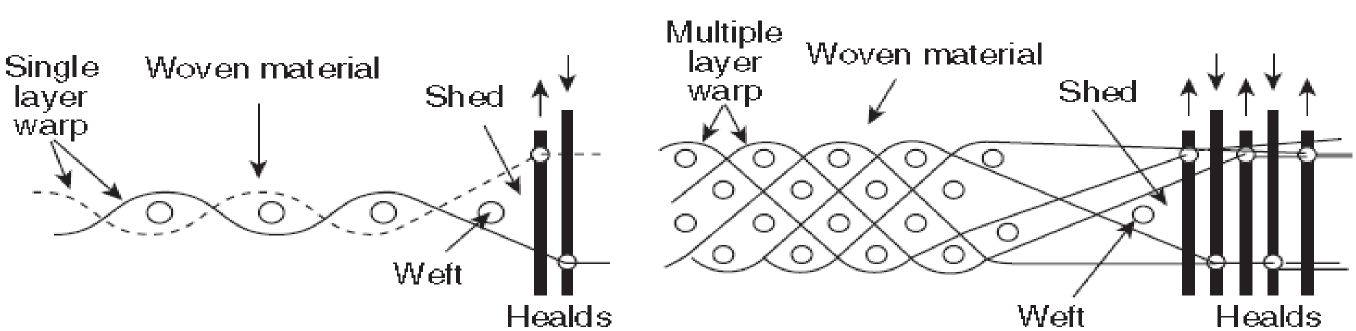


Fig 1 (a) 2D weaving and (b) 3D weaving process[2, 14]

The 2D weaving employs the mono-directional shedding which involves either single or multi layered warp yarn to be displayed to form only row-wise shed whereas 3D weaving involves dual directional shedding mechanism. The basic differences between the two weaving processes are shown in figure 2. [2, 4, 5, 6, 14]

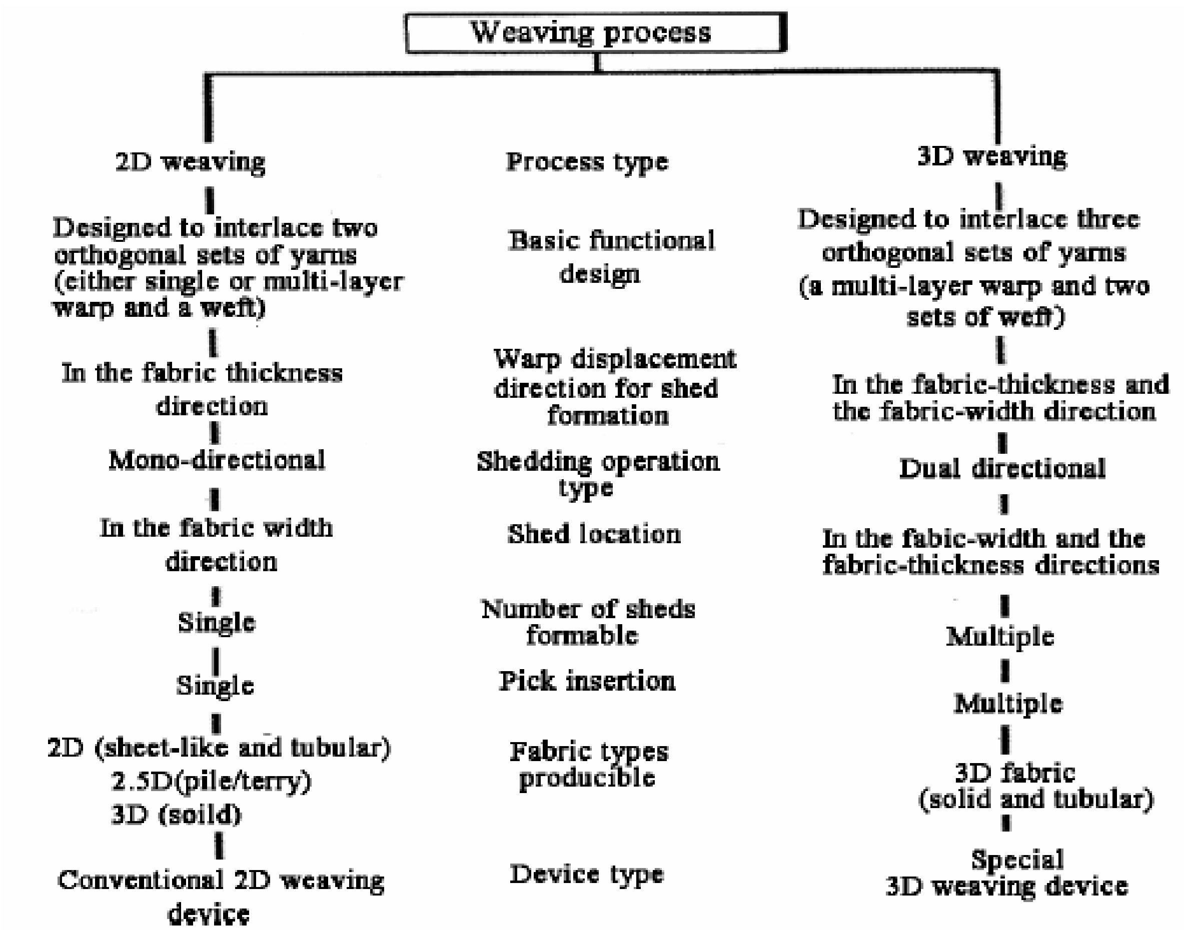


Fig 2 Classification on the basis of weaving process[4]

Why To Go For 3DWoven Fabrics?

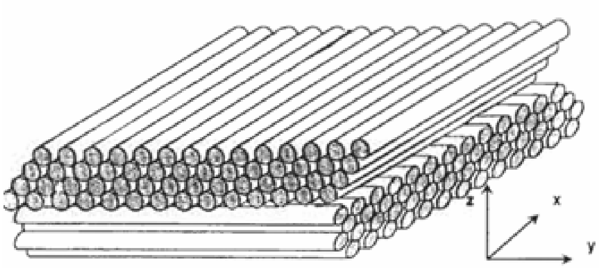


Fig 3 Schematic structure of 2D laminate[8]

Textile assemblies already play an important role for technical applications, most notably as reinforcements and preforms for advanced fibre composites for aerospace, automotive and other applications. Unidirectional and 2D woven textiles have been widely used in creating composite components and the have demonstrated clear advantages over the

traditional metallic materials in performance to weight ratio. [5, 7, 8]
A two-dimensional (2D) laminated structure is characterized in which the fibres are aligned along the plane (x- & y-directions) of the material, as shown in Figure 3**.**

A distinguishing feature of 2D laminates is that no fibres are aligned in the through-thickness (or z-) direction and this can be a disadvantage in terms of cost, ease of processing, mechanical performance and impact damage resistance. Also the processes require a high amount of skilled labor to cut, stack and consolidate the laminate plies into a preformed component. [5, 8]

To overcome the disadvantage of 2D laminates, 3D fabrics have been developed that can provide through the thickness mechanical properties in the structure. Compared with 2D laminates, 3D woven composites have the following advantages: [5, 8, 14]

1. 3D weaving can produce complicated near-net-shape preforms. This greatly reduces the material cost and handling time and ultimately gives better mechanical properties.
2. Through-thickness properties can be adjusted by controlling the amount of z yarns.
3. 3D woven composite has high ballistic and low velocity impact damage resistance.
4. 3D composite provides better post impact mechanical properties than 2D laminates.
5. 3D woven composites have a higher failure strain than that of 2D laminates.
6. Woven fabrics have a very low shear rigidity that gives a very good formability.

Classification Of 3D Fabrics

According to geometrical details 3D woven architectures can be classified as: [2, 3, 4, 7, 14]

- 3D Solid
  Multilayer, Orthogonal, Angle-interlock
- 3D Hollow
  Flat surface, Uneven Surface
- 3D Shell
  By weave combination, By differential take-up, By moulding
- 3D Nodal

3D Solid Structures

3D solids refer to those woven architectures that have solid cross-sections either in a broad panel or in a net shaped preform shown in figure 4. It is a structure comprising integrated multiple-walled sections in the directions of fabric-width and thickness defining a cross-sectional shape without any tunnel-like opening in fabric-length direction. [2, 7]

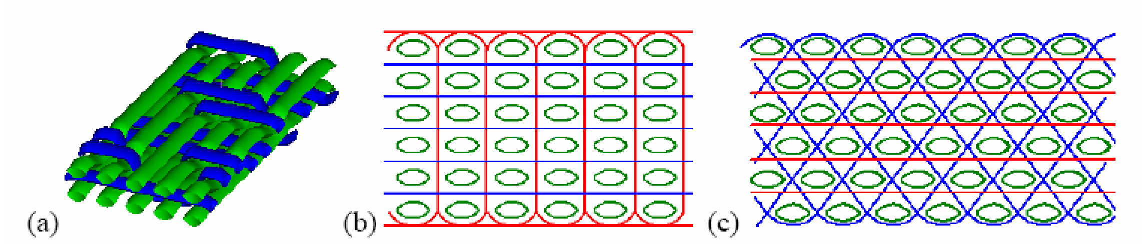


Fig-4 Cross sectional views of 3D solid architectures[7]

3D Hollow Structures

3D hollow architectures in this context refer to those having tunnels running in warp, weft, or any diagonal directions in the thickness of the 3D architecture. There are two different types of 3D hollow architectures- one with flat surfaces and the other with uneven surfaces[7] shown in figure 5.

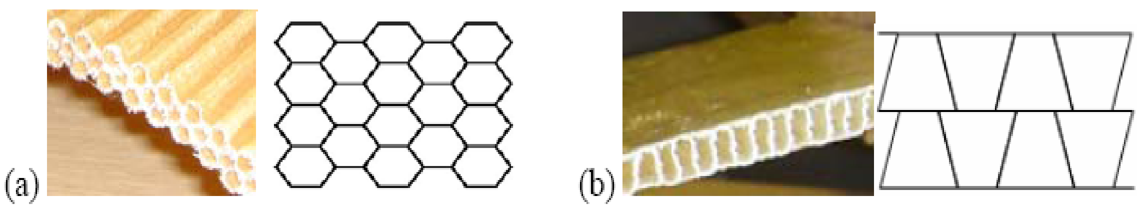


Fig-5 3D hollow structures with (a) uneven and (b) flat surfaces[7]

3D Shell Structures

It is a structure comprising integrated single-walled sections in the directions of fabric-width and thickness defining a cross-sectional shape without any tunnel-like opening in fabric-length direction [2, 7]. 3D shell architectures shown in figure 6, can be achieved by weave combination, discrete take-up, and moulding with fabrics which have low shear rigidity.

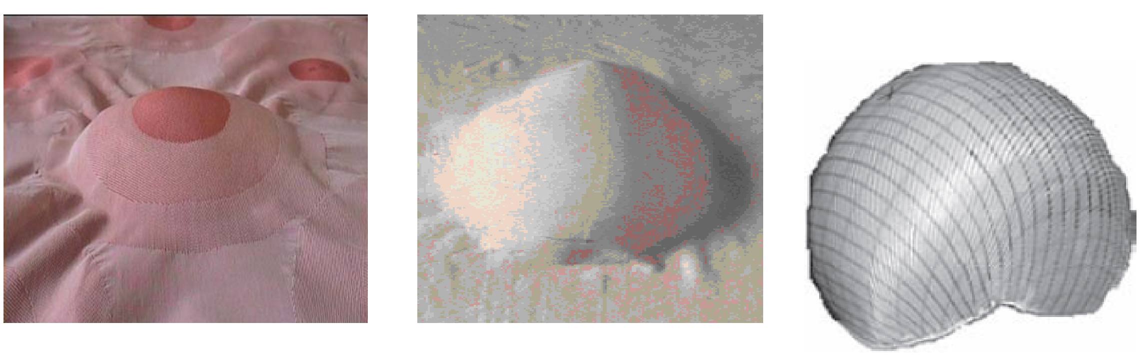


Fig-6 3D shell architectures by (a) Different weave (b) Discrete take-up (c) Moulding[7, 14]

3D Nodal Structures

3D nodal architectures basically refer to woven tubes, which are joined together. It is a structure comprising either integrated single-walled or multiple-walled sections in the directions of fabric-width and -thickness defining a cross-sectional shape with either one or more tunnel-like openings in fabric-length direction. [2, 7, 14]

Fig 7- 3D nodal architecture[7, 14]

Manufacturing Methods

3D fabrics can be produced by following methods/ principles: [2, 3, 4, 6, 7, 8, 9]

- Stitching Operation
- Multilayer Principle
- Orthogonal Principle
- Angle interlock Principle
- Dual Direction Shedding method

Stitching Operation to produce 3D fabric

Basically the stitching process consists of inserting a needle, carrying the stitch thread; through a stack of fabric layers to form a 3D structure (see Fig 8). The main requirement for a suitable stitching machine is that the needle be capable of penetrating through the number of fabric layers to be stitched together in a precise and controlled manner. [8, 9]

Aramid yarns have been the most commonly used for because of easy to use in stitching machines and are more resistant to rough handling than glass and carbon. However in certain situations reduction in mechanical properties of components can occur because of tendency of aramid yarns to absorb moisture. Glass and carbon yarn are significantly more difficult to use in stitching machines due to their inherent brittleness, which can lead to yarn breakage when stitch knots are being formed and fraying of the yarn in its passage through the stitching machine.[8]

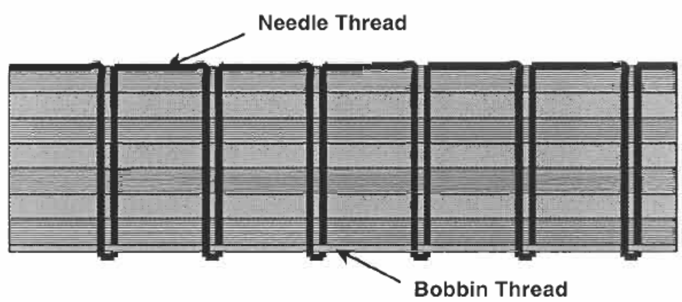


Fig 8- Stitch pattern through a composite laminate[8]

Multilayer Principle

In multiplayer principle, there are multiple layers of distinctive woven fabrics being stitched during the weaving process. 3D weaving of multi-layer preforms is done on conventional weaving machines equipped with an electronic dobby or a Jacquard system: this is a well-established textile technology and very cost-effective. [7]

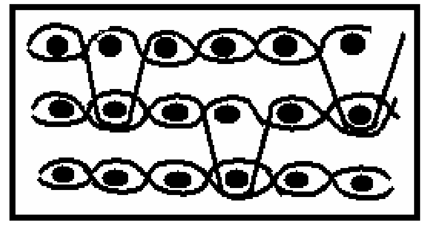
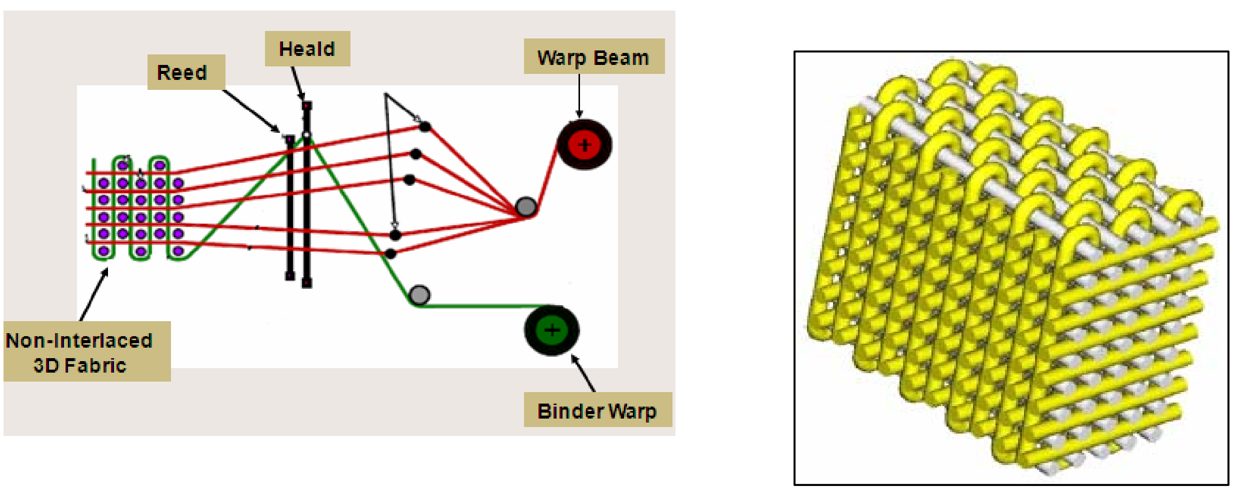


Fig 9- Cross-sectional view of multilayer 3D fabric[8]

Orthogonal Principle

3D orthogonal woven fabric is manufactured with a multi-warp yarn system. [7] In this system we use two series of warp yarns (Ground warp and Binder warp). The main concept of the fabric is to bind straight warp yarns and weft yarns (along 1- and 2-direction) together using binder yarns (along 3-direction). The warp and weft yarns provide high in-plane stiffness and strength, and the binder yarns run through the thickness direction to stabilize the woven structure. 3D orthogonal woven composites have higher inter-laminar fracture toughness and impact damage resistance than laminated composites. [1, 4, 5, 7, 8, 9, 10]



(a) **(b)**

Fig 10- (a) Formation of orthogonal 3D fabric, (b) orthogonal 3D fabric structure [2, 12]

Angle-Interlock Principle

Woven preforms have two sets of yarns perpendicular to each other interlaced by weaving process. In such type of structures weft yarns are laid straight and warp yarns travel diagonally as shown in figure 11. The Angle-interlock woven fabrics are widely used in the fabrication of composite materials because of higher interlaminar shear strength. Tensile, bending and permeability properties in either direction of the woven reinforcement is primarily a function of the yarn property, but is also influenced by the fabric weave.[7, 11, 13]

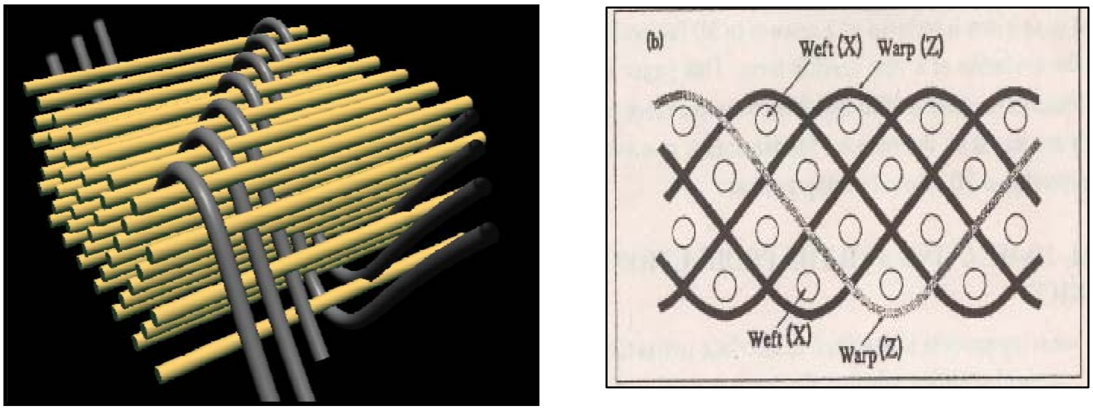


Fig 11- Angle-interlock 3D fabric[7]

Dual Direction Shedding Method

In dual direction shedding principle, multiple concurrent sheds of the vertical and horizontal directions are formed alternately. As shown in figure 12, the warp yarns are arranged (Z direction) and supplied in a grid-like arrangement, warps are displaced in the horizontal direction to create multiple vertical sheds, corresponding number of vertical wefts (Y direction) are inserted into the created sheds, the multiple vertical sheds are then closed, whereby the warp yarns become interlaced with the vertical weft yarns. The warps are at their level positions in the weaving cycle.

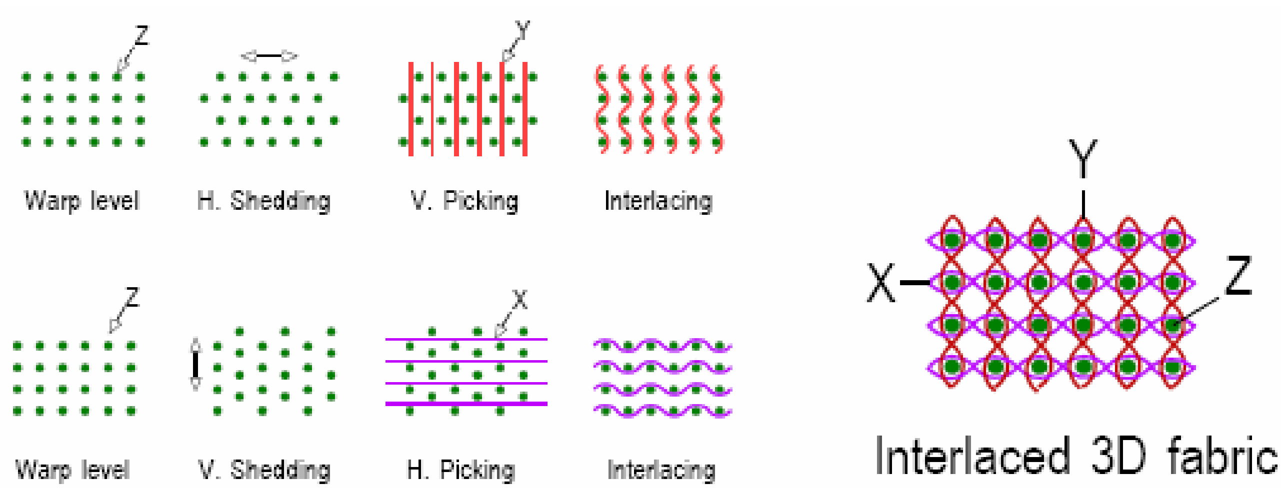


Fig 12-Dual direction shedding operation and 3D fabric formed

Next, the warp yarns are displaced in the vertical direction to create multiple horizontal sheds corresponding number of horizontal wefts (X direction) are inserted into the created sheds, the multiple horizontal sheds are then closed, whereby the warp yarns become interlaced with the horizontal weft yarns. These sequences of operations are repeated once more to insert the wefts in the respective opposite directions to complete one cycle of the 3D-weaving process to obtain the woven structure. [2, 4, 5, 10, 14]

Applications

Recently 3D woven fabrics have been finding increased usage in textile composites for commercial structural applications. 3D woven fabrics are being used in a number of applications as composite reinforcements for construction, automotive, ballistic and various industrial uses: for marine applications like carbon fibre performs for high performance powerboats; in medical technology like artificial veins, arteries, orthopedic tubes, scaf-folds, artificial joints and organs etc; lightweight constructions like reinforced section in automotive engineering and aeronautics; pipeline construction; in sports like shin guard for soccer, protective headgear for sky diving, high speed water sports etc. [4]

Woven composites have been provided ideal for security applications, where a high level of protection is expected from the lightest possible components. In transport application and vehicle construction composites have major advantages because lower weight of composites result in higher payload and lower fuel consumption[4]. In automotives, these are used as drive shafts, doors, oil pans, suspension arms, leaf springs, wheels, quarter panels, trunk decks, hoods, hinges, bumpers, seat frames and wheels.

3D woven fabric composites are ideal material for aircraft and aerospace applications where high-strength to weight ratio is required[8]. These are used in space structures such as missiles, rockets and satellites. Space structures require low weight, high stiffness, a low coefficient of thermal expansion and dimensional stability, which are the main properties offered by the 3-D fabrics. The application areas of 3-D woven composites in missile systems include rocket motor cases, nozzles, skirts and interstage structures, control surfaces and guidance structural components. Structural components used in space include trusses, platforms, shells, pressure vessels and tanks.

Instead of that their use is also increasing in sporting goods like hockey sticks, snow and water skis, bows, arrows, skateboards, bats, tennis rackets, helmets etc[8].

Conclusion

It is found that a number of 3D weaving processes are available which are suitable for engineering 3D fabric composites for load bearing applications. Stitching operation is suitable for complex 3D shape structure but this process is not regarded as a ‘true’ 3D weaving process. The new developments of dual direction shedding acquire relevance as these methods can produce a network like fabric construction.

References

1. K. Greenwood; United state patent 3818951; June 1974.
2. N. Khokar; "Second generation woven profiled 3D fabrics from 3D weaving"; Paper presented at the first world conference on 3D fabrics and their application; 10-11 April 2008.
3. W.S. Hearle; "Innovation for 3D fabrics"; Paper presented at the first world conference on 3D fabrics and their application; 10-11 April 2008.
4. B. K. Behera, R. Mishra; "3-Dimensional Weaving"; Indian Journal of Fiber and Textile Research; vol 33; Sept 2008; 274-287.
5. F. Stig; "An introduction to the mechanics of 3D-woven fibre reinforced composites"; Ph. D. Thesis; KTH School of Engineering Sciences, Stockholm, Sweeden; 2009
6. N. Khokhar; "3D fabric forming processes: Distinguish between 2D weaving, 3D weaving and an unspecified non interlacing process"; 1754-2340; Vol 87; issue 1, 1996, 97-106
7. X. Chen; "CAD/CAM of 3D woven fabrics for conventional looms"; Paper presented at the first world conference on 3D fabrics and their application; 10-11 April 2008.
8. L. Tong, A. P. Mouritz, M. K. Bannister; "3D Fibre Reinforced Polymer Composites"; Elsevier Publication; 2002
9. M.H. Mohammed; "Recent advances in 3D weaving"; Paper presented at the first world conference on 3D fabrics and their application; 10-11 April 2008.
10. N. Khokhar; "3D-weaving: Theory and Practice"; J. Text. Inst.; 92; 2001; 193.
11. N.V. Padki; R. Alagirusamy; B.L. Deopura; R. Fangueiro; "Multilayer interlocked 3D woven structures- fabric construction and properties"; The first world conference on 3D fabrics and their application; 10-11 April 2008.
12. X. Chen; P. Potiyaraj; "CAD/CAM of the Orthogonal and Angle-interlock Woven Structures for Industrial Applications"; Text. Res. J; 69(9); 1999; 648-655
13. Y. Luo , Lihua Lv, B. Sun, Y. Qiu, B. Gu; "Transverse impact behavior and energy absorption of three-dimensional orthogonal hybrid woven composites"; Composite Structures; 81 (2007); 202-209.
14. H. U. Jinlian; "3D Fibrous Assemblies" Woodhead Publishing Limited, England; 2008.