3D WEAVING OF NEAR NET PREFORMS

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Abstract

3D weaving is a convenient method of creating relatively thick blocks of as well as inter-connected layers to create T,PI,H sections. In this paper, 3D weaving techniques on conventional Jacquard looms and purpose-built multi-shed looms have been compared. Conventional looms offer the flexibility to create complex weave styles as well as the ability to drop an end or part of a pick, to be trimmed afterwards. In purpose built, multi-insertion looms, it is not always possible to bring a selected tow to the surface and hence ply-drops will have to be created using novel cutting mechanisms. However, multi-weft insertion systems offer the advantages of minimized fibre damage as well as enhanced preform thickness.

1 Introduction

Textile preforms can be generally categorized as two or three dimensional, based on the degree of reinforcement in different directions. Properties to get better performance can be achieved with continuous fibres rather than short fibres or whiskers [1]. Currently these composite structures are produced from two dimensional laminated structures, however such 2D laminates have certain drawbacks such as poor damage tolerance, poor out-of plane properties, expensive etc. It has been proven at many instances that it is easier to manufacture 3D preforms than 2D laminates particularly for complex shapes. A 3D fabric generally consists of fibres extending along a direction in the X, Y and Z directions.

Development of 3D composites has been driven by the need to reduce fabrication cost, increase through-thickness mechanical properties and improve damage tolerance. Basic textile techniques such as weaving, knitting, braiding and stitching are utilised to produce 3D textile preforms [2,3]. Weaving is the most common amongst these processes as it allows 3D composites to be fabricated at high production speeds and offers flexibility to produce a diverse range of 3D fibre structures. Three-dimensional woven preforms can be produced using almost any type of reinforcement yarn, and the proportions of the yarns in the plane and through-thickness directions can be controlled to tailor the properties of the composite for a specific application [4].

In conventional weaving methods, weaving of multilayer reinforcements has developed into a complete process, utilising modified weave structures and lifting plans, with through-the-thickness yarns incorporated as part of the weave design [5]. Three dimensional multilayer woven composites have shown to be effective in improving inter-laminar properties of laminated composite structures with the introduction of reinforcing fibres in the thickness direction of the laminate. 3D weaving also has an added advantage of producing complex shapes in one piece. Apart from conventional weaving methods, several methods have been developed and patented to manufacture 3D woven preforms. In this research, both routes of manufacturing near net shape 3D woven preform (conventional weaving and purpose built machines) have been considered and analysed for various aspects such as weave architecture, production time and cost.

2. 3D Weaving on Conventional Looms

There are a number of weaving methods that can be used to produce multilayer preforms. Standard weaving machines, with minor modifications, if required, can be used to weave high modulus carbon and glass fibres. Specific proportions of yarns can be arranged in the three mutually perpendicular directions referred to as warp (X), weft (Y), and through-the-thickness (Z) directions [6-8]. Yarns in the third direction which bind the structure can either belong to warp or weft yarn set. Secure selvedges and near-net shaped performs can be produced with relatively little waste by using a shuttle for weft insertion; however it is difficult to handle high modulus yarns using this technique. Alternatively, leno selvedges can be employed to assist in the production of near-net shapes. Manufacturing 3D fabrics make use of a more complex shedding technique as compared to 2D fabrics. For a 2D fabric, the shed is created to insert one weft layer, whereas in a 3D fabric, wefts are laid one above the other, hence several sheds need to be created to accommodate wefts at different levels. The warp tension, which is an essential weaving parameter, varies because of multiple layers in the 3D fabric; multiple warp beams are used to maintain desired warp tension in the layers.

Conventional looms are traditionally set-up to produce fabrics comprising of limited number of layers. Normally, simple rectangular or circular 3D woven preforms can be produced without much modification with 3D weaves. However preforms for composite applications sometimes are required to offer variation in thickness. In addition to this, warp or weft density is required to vary accordingly with near-net shapes. Weaving multilayer fabrics on conventional looms can become very complicated if a multilayer shaped reinforcement is required. These factors impose restrictions for using standard looms for near-net shape performs, but they can be overcome by carrying out some loom modifications. Another approach taken for fabrication of shaped reinforcements on conventional looms concerns weaving the shaped reinforcement in a flat multilayer form, and then folding or opening it to the desired shape after removal from the loom [6,9]. One of the key advantages of using conventional looms is that 3D woven structures can be produced without incurring vast expense of specialised weaving machinery. Several types of weaving machines such as rapier, projectile, shuttle, air jet and water jet are available to manufacture woven fabrics. These machines have their own advantages and disadvantages but amongst these, both rapier and shuttle weaving machines are used to produce multilayer fabrics in this research. Rapier loom offers better control of weft yarn and allows weaving with any type of yarn.

2.1 Design approach

There are several patents and methods to produce different 3D woven structures on conventional weaving machine, but relatively limited information on varying thickness laminates. In aerospace, automotive and engineering industries, there is high demand for composites with complex part geometry. Near-net-preforms are hence required. There are certain structures which can replace the damaged part and avoid replacement of the whole structure. Many complex structures also comprise of joints such as lap joint, scarf joint, double lap joint etc. These joints, either adhesive or mechanical, do have certain drawbacks. Such joints can be designed and manufactured in the weaving machine according to design requirements. In the work presented in this thesis, multiple step fabrics have been designed and produced on a conventional weaving machine as shown in Fig. 1. Different 3D weaves have been employed to get the desired end product with better mechanical properties in comparison to 2D laminates. A drawback of 3D woven composites is that the load bearing fibres may be damaged and distorted during weaving operations. Fibre damage appears to occur during weaving due to repetitive abrasion and bending of the yarns. This damage can be minimised by modifying some loom parts or with the purpose built machines. Proceeding with this concept a 3D weaving machine was designed and developed to fabricate a similar product, but with enhanced quality and higher production rate.

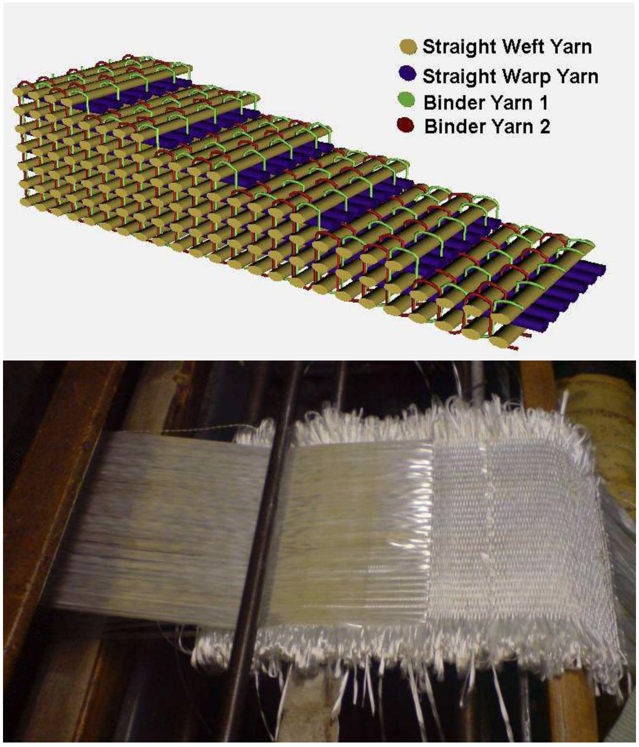
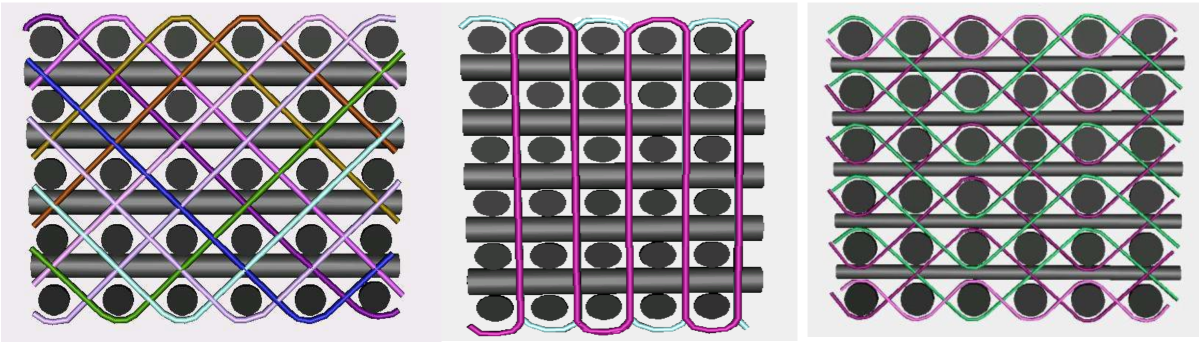


Fig: 1 Multistep preform on a conventional loom

The project aims to develop an approach to overcome the problem of weaving 3D preforms on a conventional weaving machine. Along with the near net shape of stepped lap joints, the weaving machine can also be used to produce double lap step joints and taper 3D structures. Research efforts on modifying traditional weaving methods to introduce through the thickness or 'z' direction yarns for the production of such multilayer woven preforms are discussed.

A large number of 3D woven structures can be achieved by modifying weave pattern, number of layers, yarn type, and yarn count, etc., thus allowing large number of variables to predict structural and mechanical properties under applied loads [6]. Weave architectures such as angle interlock, orthogonal and layer to layer are generally applied in order to produce 3D woven preform. In Angle-interlock fabrics, the warp yarns can enter one or more layer of weft yarns (layer to layer angle interlock), or go through all layers of weft yarns (through-the thickness angle interlock). When yarns are placed in three mutually orthogonal directions, they form an orthogonal woven fabric. The yarns are interlaced uniformly in all three directions to provide quasi-isotropic properties or alternatively the interlacements can be allowed to vary in each direction when anisotropic properties are required. The layer-to-layer is a multilayered woven fabric in which binding warps travel from one layer to the adjacent layer and back. A set of (non-interlacing) warp yarns is introduced to reinforce all the layers of the preform. In multilayer fabrics, binder yarn path may vary according to design. These weave structures can be modified accordingly; by altering the lifting plan it is possible to create different binding points and hence distinct near-net shape structures.



(a) (b) (c)

Figure 2. (a) Angle interlock (b) Orthogonal (c) Layer to layer

The concept of weaving step joints can be taken forward to produce taper laminates. If several warp beams are used, thick structure can be produced. The thickness of the structure can be reduced gradually by removing warp layer at regular intervals. In addition, step structures can be joined together to form uniform lap joint configuration. Fig 3 illustrates joint area between two step preforms.

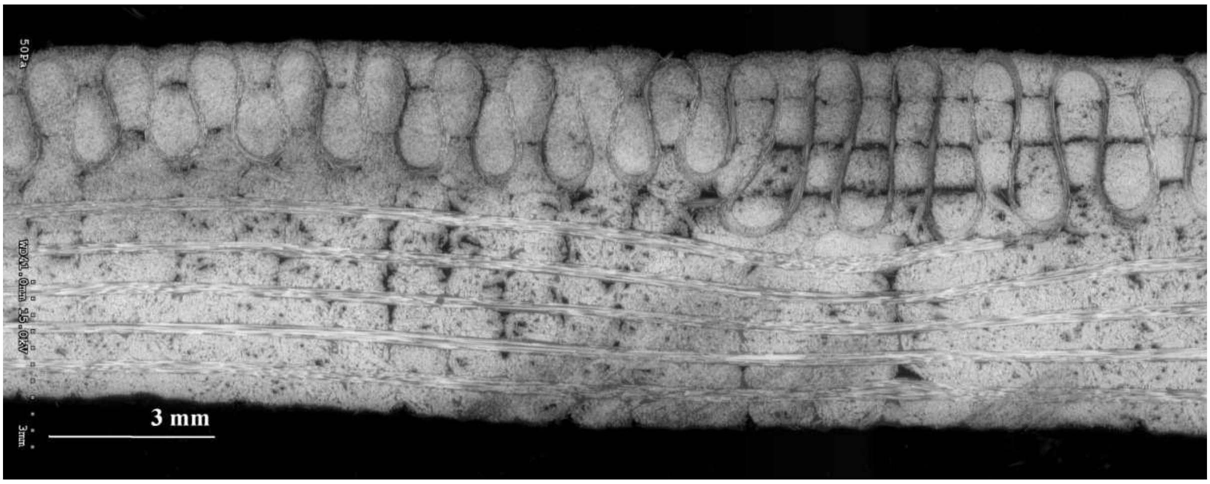


Figure 3. Lap joint between step preforms

3. 3D Weaving on a purpose built machine

3D woven composites were first developed nearly 30 years ago in an attempt to replace expensive high-temperature metal alloys in aircraft brakes [10]. Although standard industry looms can be modified to produce 3D woven preforms, investigations into 3D weaving processes has led to the development of a number of specialized looms that are capable of weaving complex preforms.

Despite the current methods and advances, 3D woven fabric has not been used widely in the composite industry. Two of the main drawbacks with current technologies are near net shape preform manufacturing and lack of fibres in direction other than 0 and 90 degree. There are certain specialised looms which can produce the fabric with the bias yarns, but overall cost is very high. In order to achieve goals of this research, it is required to design and develop machine which can produce near net shape preform with fibres in 0, 90 and bias direction with through thickness fibres. This machine needs to be economical, efficient and flexible in terms of structure configurations. The proposed machine can solve the problems stated in the above. In the present work we have made an attempt to make a 3D weaving machine based on work described by several patents and methods. The drawbacks of the existing methods are already mentioned earlier. The primary object of this research is to develop a machine which can produce the 3D structure to replace the current 2D laminate and its deficiency. We have considered different mechanisms involved in weaving to overcome the problems related to 2D fabrics in order to create near net shaped preform. The key criteria for the machine design are stated below.

- Multiple weft yarn insertion
- Permanent shed creation
- Uniform warp yarn tension
- Flexible binder yarn arrangement
- Linear take-up
- Open needle beat-up
- Knitted selvedge formation
- Automatic cutting system for taper creation

Figure 4:multi-shed weft insertion

Figure 4 shows the basic multi-weft insertion concept.   Since the shed are

A detailed development of near-net preforming on multi-insertion system will be presented.

References

1 Cox B.N. and Flanagan G., Handbook of Analytical Methods for Textile Composites
2 Dow M.B. and Dexter H.B., Developments of stitched, braided and woven composite structures in the ACT program and at Langley research centre,1985-1997, NASA/TP-97-206234
3 Masters J.E. and Portanova M.A., Standard test methods for textile composites, NASA Contractors Report 4751
4 Bannister M.K., Development and application of advanced textile composites,Journal of Materials: Design and Applications, 2008, Vol 218, pg 255-260
5 Soden J.A and Hill B.J., Conventional weaving of shaped preforms for engineering composites, Composite Part A , 1998, 29A, pg 757-762
6 Yi H.L. and Ding X., Conventional approach on manufacturing 3D woven preforms used for composites, Journal of Industrial Textiles, July 2004, 34, No.1.
7 Goering J., Design Consideration for 3D Woven Preforms, Society for the Advancement of Material and Process Engineering, 2003, 39.
8 Soden J.A., Weissenbach G., Hill B.J., The Design and fabrication of 3D multilayer woven T section reinforcements, Composites Part :A,1999, 30, pg 213-220.
9 Zhang C., Characterization and modelling of 3D woven composites, PhD thesis, North Carolina State University
10 Chiu C.H. and Cheng C.C, Weaving method of 3D woven preforms for advanced composite materials, Textiles research journal,2003, 73(1), 37-41