3D WEAVING POSSIBILITIES ON AN 8 SHAFT LOOM

D N Sandeep, B.S Sugun*

Centre for Societal Missions and Special Technologies, CSIR – National Aerospace Laboratories, PB No 1779, Old Airport Road, Bangalore – 560 017, India.
** sugun@nal.res.in*

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Abstract

This work's focus is towards exploring the possibilities of weaving select type of 3D reinforcements on the commercially available 2D weaving looms of the textile industry. In this context, two classes of 3D reinforcements were developed using 6K Carbon rovings of 400 Tex on an 8 shaft handloom. The first class comprised of weaving single layer profiles wherein, 'T' and 'π' profiles were woven. The second class comprised of weaving planar multilayer (angle interlock structure) samples of two types viz., layer to layer and through-thickness. In this class, a 'T' profile was also woven. Weave Design Plan for these structures were developed using the warp(for single layer profiles) and weft (for angle interlock structures) yarn cross-sections. It has finally been inferred that, woven cloth construction design and 2D weaving technology can be successfully utilized to develop select class of 3D reinforcements for composite applications.

1. Nomenclature

Roving: Bunch of untwisted filaments
Tex : Designation for thread count (weight in gms per 1000 mtr length of the yarn)
Warp : Longitudinal threads in a fabric
Weft or Pick : Transverse threads in a fabric
Shuttle : Weft insertion device
Loom : Weaving device
Let-off : Letting off of the warp yarns for the formation of shed
Shedding : Separation of the longitudinal threads by a suitable mechanism
Tappet/Dobby / Jacquard looms : Types of looms
Picking : Insertion of transverse threads by suitable mechanism
Beat-up : Moving the previously inserted weft to the cloth formation edge called fell
Take-up : Taking up of the cloth onto the cloth roller
Interlacement pattern : The manner in which the warp and weft interweave
Weave design plan : comprises of design, drawing-in-order, lifting plan and denting order of requirement to the weaver to weave the structure on the loom

2. Introduction

Laminated composites today, being used in aircraft and automobile structures, have good in-plane properties but very poor out-of-plane properties due to lack of reinforcement in the third direction. Researchers are exploring various 3D technologies[1-3] for possible exploitation. Of the varied 3D technologies, 3D weaving is an important class. The versatility and usefulness of 2D weaving has made it all the more promising to explore it in the 3D arena as well. It is expected that, these 3D weaving technologies for composites would enhance the properties for complex profiles such as 'T' sections, 'Pi' sections, wing root- fittings etc., wherein, they render the much required structural continuity in the third direction. 3D weaving can be categorized into two classes (Figure 1) viz., 3D woven 3D fabrics (involving special machinery development) and 2D woven 3D fabrics (using the existing 2D looms) for use in composites. While the former class would be preferable for the above stated applications, these machineries today, are in their early stages of development, and as such, are not, as yet commercially viable like the 2D weaving machines. The latter, being commercially available, can be thought of for prospective development of select class of 3D reinforcements which is also required to be explored for their potential usefulness and prospective applications in composites. Moreover, the prevalent 2D weaving looms of the textile industry have undergone step-by-step advancements by way of automation and perfection, to the extent, that, today they are able to weave hundreds of meters of cloth with minimum stoppages and downtime. For the aircraft designers, there is also the ease of meeting the qualification and certification needs as the base machinery and 2D weaving technology have already undergone these phases.

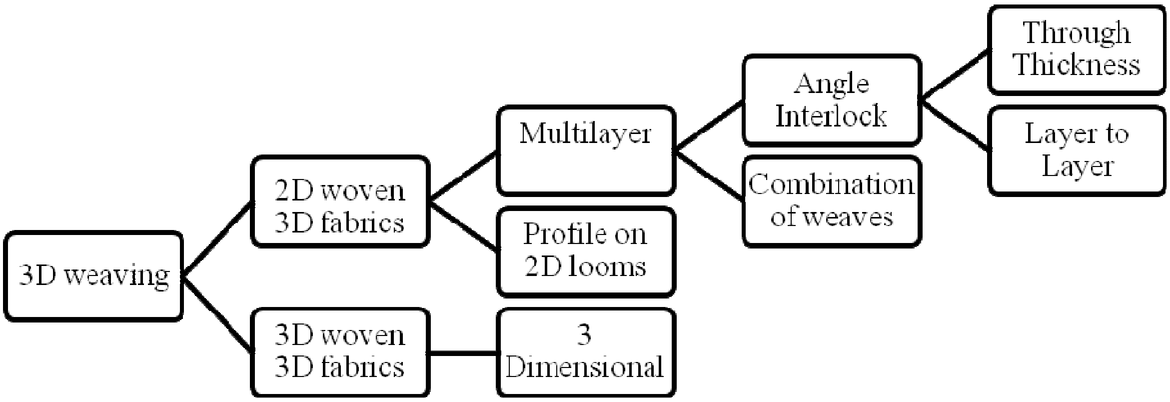


Figure 1: Classification chart for 3D weaving[4-6]

With this backdrop, the theme of this paper, therefore, is to explore the possibilities of developing select 3D reinforcements using 2D weaving machinery and the woven cloth construction design [7] technology. The work focuses on the conceptual development of single and multilayer 3D woven (angle interlock)structures using carbon roving on a conventional handloom which can be easily scaled to production on a multiple box loom (suitable for carbon weaving) with dobby or Jacquard attachment (as per the requirement). The scope of this paper is limited to the technicalities of textile structure development. The envisaged applications for these reinforcements are in composites for aerospace and automobile applications, which to some extent is already being looked-into by the composites community [8].

3. Single layer profile weaving

The 2D weaving looms such as the tappet, dobby or the jacquard can weave a wide range of cloths and furnishing fabrics with small and large designs on them. Depending on the complexity of the design, the type of loom changes from tappet to dobby to jacquard. Examples would be a plain shirting material for the tappet loom and small, large furnishings for a dobby, jacquard loom. The starting point of weaving all of these is in the development of design. From these designs, the arrangement of the warp threads on the loom through the lifting devices (termed heald shafts, heddles, lingoes) and the sequence of lifting these devices for weft insertion will be decided by well established procedures in the textile industry. This whole process is termed woven cloth construction design or to be more specific, weave design plan which ensures the cloth formation as per the required design. There are more detailed requirements on the weaving aspects that can be obtained in the literature domain. [7,9]. In the course of development of varied types of designs, the double cloth and treble cloth construction has also evolved in the textile industry for utilitarian requirements of the furnishing segment. This concept of cloth construction has promising potential for the development of single layer profiled reinforcements for use in composites. The profile is woven in folded form on the loom using the above principles of double cloth/treble cloth.

3.1Weaving of the ‘T’ profile

The warp threads would be arranged in a folded manner as per the shape of the profile. The arrangement of warp threads for developing a ‘T’ profile is shown in figure 2. The warp threads are all parallel. It may so happen that in some portions one warp thread is above the other as can be seen from the figure. These threads are maintained in their positions by spaced metal wires called reed. It should be noted that each dot in the figure represents one warp thread and these warps can be of hundreds of meters of length which are prepared (by a preparatory process) on a beam.

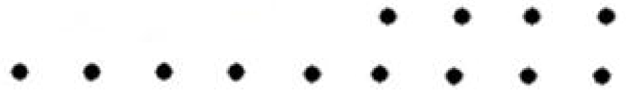


Figure 2 : Arrangement of warp threads for ‘T’ Formation

Now to get the profile in question, the warp threads need to be interlaced in a continuous manner with the weft. This is done by devising the path the weft needs to take. In the case of ‘T’ profile (Figure 3), the weft path devised, constitutes 4 steps (a, b, c, d) from the start to finish (one cycle) which runs continuously to the required length of the warp. Once these steps are defined, it would be required to develop the weave design plan as per defined procedure [10] which serves as input for the weaver to develop the profile. In the figure, the dots are the warp threads (and the lines (continuous/dotted) are the weft. For clarity, the previously inserted weft is shown using dotted lines, however, they are continuous running threads in the preform till the required length of the profile. It is to be noted that, added to the above, there are the other regular weaving requirements such as pushing the weft to the fell of the profile, take-up of the woven profile etc., which would be required to complete the profile forming process.

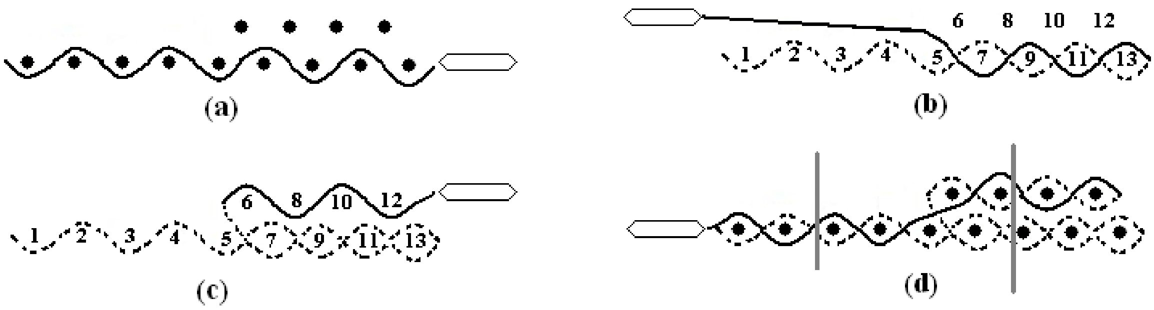


Figure 3 : Weft path for developing the ‘T’ profile

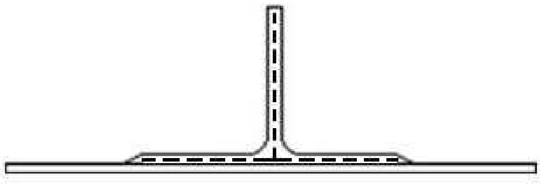


Figure 4 : ‘T’ Stiffener with a single layer ‘T’ insert (dotted line)

From the initial studies on the composite properties with these inserts, It has been observed that the failure modes in composites incorporating them has changed from that of catastrophic to progressive which is a step improvement in damage tolerance of the structure in question. This is currently under evaluation stage by the composites group.

3.2 Weaving of the ‘π’ profile

The ‘π’ profile was developed folded outwards using the following weaving approach in sequence. single layer (Zone 1) – double layer (Zone 2) – single layer (Zone 3) – double layer (Zone 4) – single layer (Zone 5). Figure 5 gives the warp arrangement and the six pick repeat (one cycle) for ‘π’ weaving. The approach adopted and the explanations are similar to that of the ‘T’ profile development ,wherein, from the cross-section diagram, the weave design plan would be developed and then weaving of the profile would be carried out. The boxes in figure 5 indicate repeat units in each zone. Here again, it should be noted that the weft would be continuously woven till the required length of the profile is developed. Table 1 gives details about the dimensions of the preform, thread density, linear length woven and thickness of each layer in the profile. In the case of profiles, weight in grams per linear meter (depicted in the table), can be notated instead of the usual grams per square meter (used for fabrics). The samples were woven using untwisted carbon rovings of TC33 6K (6000 filaments) and 400 Tex. Figure 8 shows the photograph of the single layer ‘T’ profile and the ‘π’ woven on the handloom.

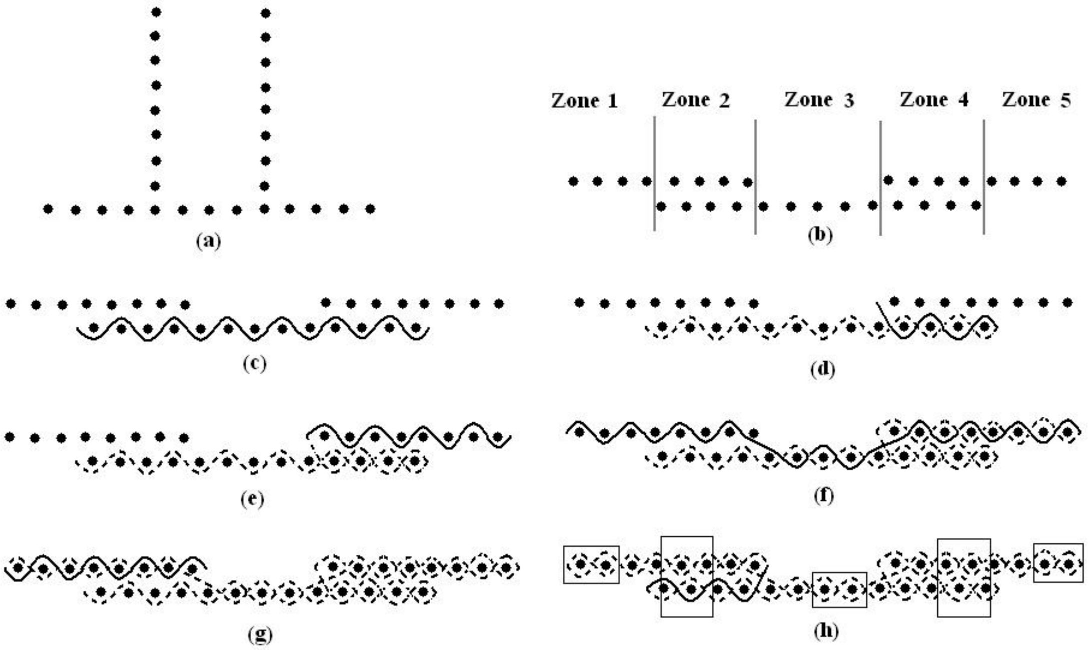


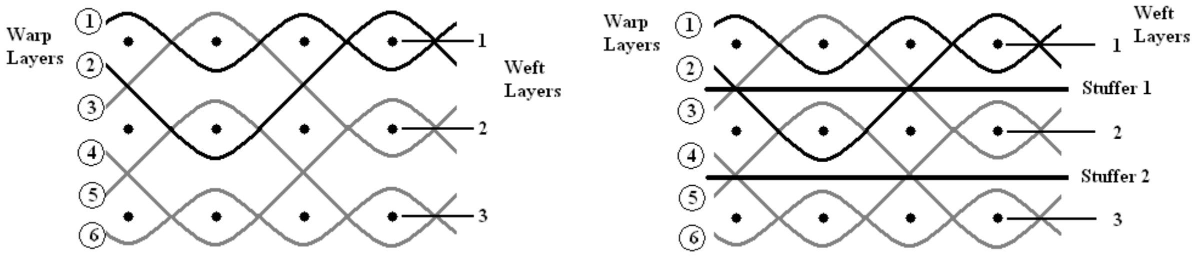
Figure 5 : Warp arrangement and the six pick repeat (one cycle) for ‘π’ weaving

Profile	Thread density (per cm) Warp	Weft	Linear length woven (mm)	Width of each section (mm)	Thickness of each layer (mm)	Weight per linear meter (gm)
T	5	5	125	25	0.7 ± 0.05	50.48
π	5	6	350	Zone 1 – 78 Zone 2 – 52 Zone 3 – 31 Zone 4 – 52 Zone 5 – 78	0.7 ± 0.05	187.80

Table 1: Specifications of the single layer woven profiles

4. Multi-layer (angle interlock) weaving

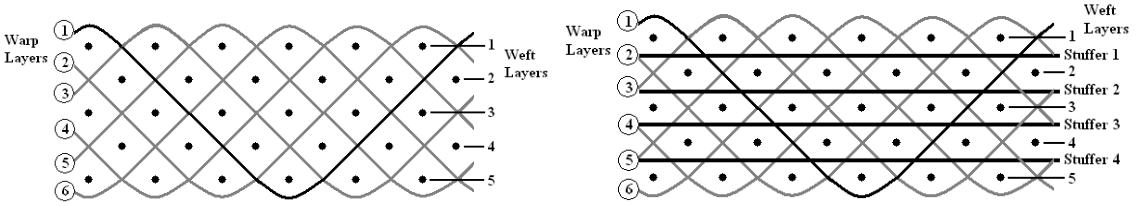
Multi-layer weaving is alternatively termed as angle-interlock weaving and in simple terms is about weaving several layers of warp with several layers of weft and interlocking them together to form one bulk preform of defined-thickness. It is similar to stacking several layers of cloth one over the other (to achieve the desired thickness), but woven on the loom wherein the weave design locks the layers together. They are expected to have improved impact damage tolerance, fracture toughness, delamination resistance, balanced in-plane and out-of-plane properties. Some of the envisaged applications for this technology are wind mill blade preform, exhaust nozzles in missiles, brake discs, and high temperature fasteners. There are two types of angle-interlock structures viz., Layer-to-Layer and Through-Thickness. In the Layer-to-Layer angle interlock structure, each warp thread traverses to some intermediate layer in the architecture. The linking of these layers are achieved by this traverse (which happens in a definite pattern) as shown in figure 6. Here, the dot represents the weft. As detailed in profile weaving, once the cross-section is developed, the weave design plan and other procedures follow for the realization of the preform. The difference being, in that, for profile weaving the warp cross-section is used, whereas for multilayer weaving, the weft cross-section is used and accordingly the development of the weave design changes.



6(a) 6(b)

Figure 6 : Layer-to-layer angle interlock structure

Due to complex warp path, it would be required to improve the strength properties in the (warp) loading direction . This is done by adding stuffer yarns (straight threads running along the warp), which are locked into the structure by the weave (Figure 6(b)). In the Through-Thickness angle interlock structure, each warp thread traverses from the top to the bottom and back to the top of the structure. Here again, the linking of the layers is achieved by the traverse of the warp threads and happens in a definite pattern as shown in figure 7(a). The other explanations are similar to that of the Layer-to-Layer structure. The provision of including stuffer yarns exist here also (Figure 7(b)). The addition of the stuffer yarn also aids in increasing the fibre content.



7(a) 7(b)

Figure 7 : Through-Thickness angle interlock structure

Although the samples were produced on the handloom, this is very much possible to be woven on a conventional (shuttle) loom. Table 2 gives the specifications of angle interlock structures.

4.1 Multilayer ‘T’ weaving

‘T’ profile was woven using Layer-to-Layer concept warp way. The cross-section was so devised (figure 9) that at an intermediate point, the single planar preform would split into two planar preforms. When taken out of the loom, the two planar preforms (of half the thickness) would spread out and form the base as shown in the photograph of figure 8 thus forming the ‘T’.

'T' Profile **'π' Profile** **Multilayer 'T' Profile**

Figure 8 : Photograph of profiles woven on handloom

It should be noted that this paper gives an outline of the possibilities of developing select class of 3D reinforcements using 2D weaving looms. For actual use and evaluation in the composite, it would be required to get into finer details such as specific dimensions required, cloth construction details, etc., However, the method would be similar to that outlined in this paper.

Particulars	8 warp Layer(no stuffer) Through Thickness	8 warp Layer(no stuffer) Layer to Layer
Dimensions L X W	40mm X 27mm	38mm X 27mm
Thickness	3.88mm	4.08mm
Specimen Weight	2.4596g	2.0326g
GSM	2277	1981
Carbon Fibre Density	1.7g/cc	1.7g/cc
Carbon Fibre Volume in the Specimen	1.447cc	1.196cc
Total Volume of the Specimen	4.1904cc	4.1860cc
Fibre Volume Fraction	34.53%	28.57%

Table 2: Specifications of Angle interlock woven preforms

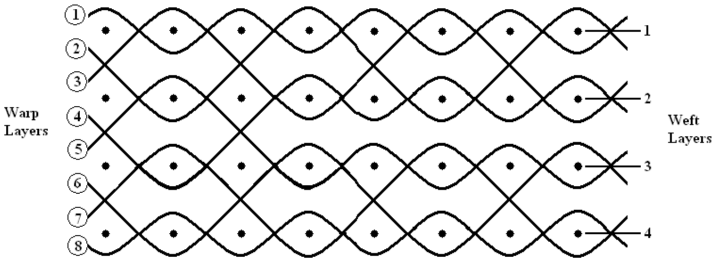


Figure 9 : Cross-section of multilayer ‘T’ profile

5. Conclusion

From the above work, it is demonstrative that select type of 3D reinforcements especially single layer profiles and thin angle interlock structures can be developed on the existing 2D weaving looms for use in composites. In the case of single layer profile weaving , the warp cross-section diagram is required to develop the weave design plan and in the case of angle-interlock structure, the weft cross section diagram would be required to develop the weave design plan from which the reinforcements can be developed. It is finally concluded, that the commercially available 2D weaving machinery of the textile industry can be further exploited (in addition to the development of planar fabrics) to develop special type of reinforcements for use in composites.

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