Multiaxial Compound Weave Method for Preforms

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SUMMARY: This paper discloses a novel method and apparatus for integrally weaving a dense sheet of parallel ±45° fibre on the surface of woven structures. The additional ±45° fibre has been incorporated onto a range of compound three-dimensional structures by means of a new device, which was developed for use with conventional weaving looms. The additional fibre forms a contiguous plane of ±45° fibre, while the configuration of the underlying structure remains substantially undisturbed. Three-dimensional multiaxial structures have been successfully produced using high performance fibres including carbon and glass, which require special processing considerations.

KEYWORDS: Textile preform, multiaxial, weave, lappet, bias

INTRODUCTION

This paper describes a method and device for introducing a sheet of parallel ±45° fibre to the surface of woven structures, which is additional to the warp and weft of conventional woven fabrics [1]. Using the specially developed add-on mechanism, additional fibre can be integrally woven onto a range of compound three-dimensional structures.

BACKGROUND

A number of groups working in the field of woven textile composites have identified the benefit of having fibre at angles other than the primary weaving axes, and have made some very interesting advances to this end. Some are appropriate for flat plate structures, and others applicable to more advanced 3-dimensional woven structures. Other solutions have been found using alternate fabric forming technologies, such as multiaxial warp knits.

Some of these developments are based on modified lappet weaving technology. The base weave structure can be produced using conventional weaving equipment, with the additional fibre introduced using an add-on lappet device and associated driving mechanisms [2]. Farley [3] and Ruzand & Guenot [4] have described lappet based methods that introduce 45° fibres. These systems do not allow for individual control of the additional bias yarns, requiring all yarns on a set of lappet needles to be incorporated into the base structure at the same time. This results in

significant distortion to the base structure. The systems described also require special consideration for yarns at the edges of the fabric. The authors have developed a system that allows for the interlacing of the additional bias yarns on a freely selected basis. The intermittent, selective binding of the extra yarns allows for a very high density of these yarns without detriment to the base structure at the interlacing points. In addition, this selectivity allows for all yarns to be successively incorporated into an edge if required. This system can produce quartaxial structures via a conventional loom, as distinct from those which require special additions to a triaxial loom, as described by Iida, *et. al.* [5].

There are a number of examples of multiaxial multilayer preforms, some using conventional weaving equipment, and others requiring custom-built machines. Greenwood *et. al.*[6] have produced a range of flattened '2-dimensional' structures on conventional equipment, which are subsequently folded and sections of the fabric re-oriented using a shearing motion to achieve 3-dimensional structures with fibre direction appropriate to loading conditions. The very nature of achieving multiaxial sections by shearing results in sections of the structures having no through-the-thickness strength. These structures are also unstable between the preform and consolidation processes. Similar structures, such as I-beams with ±45° in the web, have been produced by Bompard & Lamarie [7] and Edgson & Temple [8], with the final shape produced on the loom. They use compound weave technology to form two distinct layers of fabric (which could be the flanges of an I beam), joined by warp yarns in an 'angle interlock' path to achieve ±45° in the web joining the two layers. To manufacture these structures a high level of loom control is needed. Consideration must also be given to maintaining the shape of the preform during take-up. The angle interlock principle has also been used by Yamamoto *et. al.*[9] to produce multiaxial thick woven fabrics, with the same manufacturing considerations as previously described.

Anahara, *et. al.* [10] have built a complex machine to produce flat plate structures, and have made further developments to improve the preform properties [11]. Addis [12] has patented a bias yarn forming assembly, used in conjunction with a jaquard shedding mechanism. Mood & Mahboubian-Jones [13] have developed a method for multi-axial weaving using a two-part or split reed to traverse warp yarns across the weft direction. These machines are very complex and produce only a limited range of structures.

MULTIAXIAL COMPOUND WEAVE METHOD

The authors aim was to develop a system to incorporate a sheet of additional fibre at an angle to the warp and weft. The main design considerations for this system are that sufficient additional fibre is supplied so the ±45° fibre is very dense, the additional fibre does not impede the base structure, and that the system be suited to existing weaving equipment.

We have produced a device that consists of a guide plate (1), tube guide (2), tube (3) and depression plate (4) as illustrated in Figure 1. The bias fibre is passed through the tube, which in turn telescopes through the tube guide. The bracket on the tube guide fits onto the guide plate. The depression plate fits around the upper end of the tube to engage the depression collar. Figure 1 shows only one tube assembly on the guide plate; in practice, the guide plate is tightly packed with many tube assemblies.

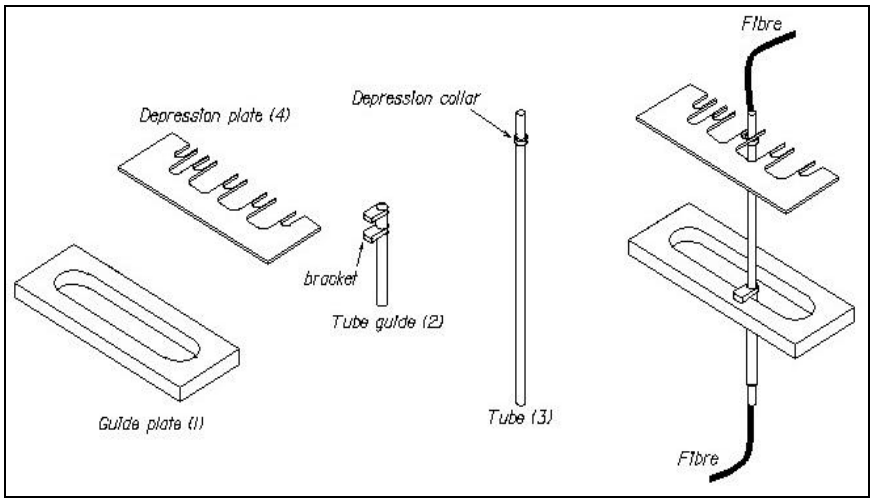

Figure 1: Components of the bias device & assembled device showing only one tube

Each tube can be selectively lowered into the upper shed of the base structure by engaging the depression collar using the depression plate (which can have a variety of profiles depending on the desired tie-in sequence). The additional yarn in the lowered tube is bound into the base structure using weft yarn. The tubes are then lifted and weaving takes place while the tubes progress laterally around the guide plate. This has the effect of moving the additional yarn across the warp. The sequences in this process are illustrated and described in more detail below:

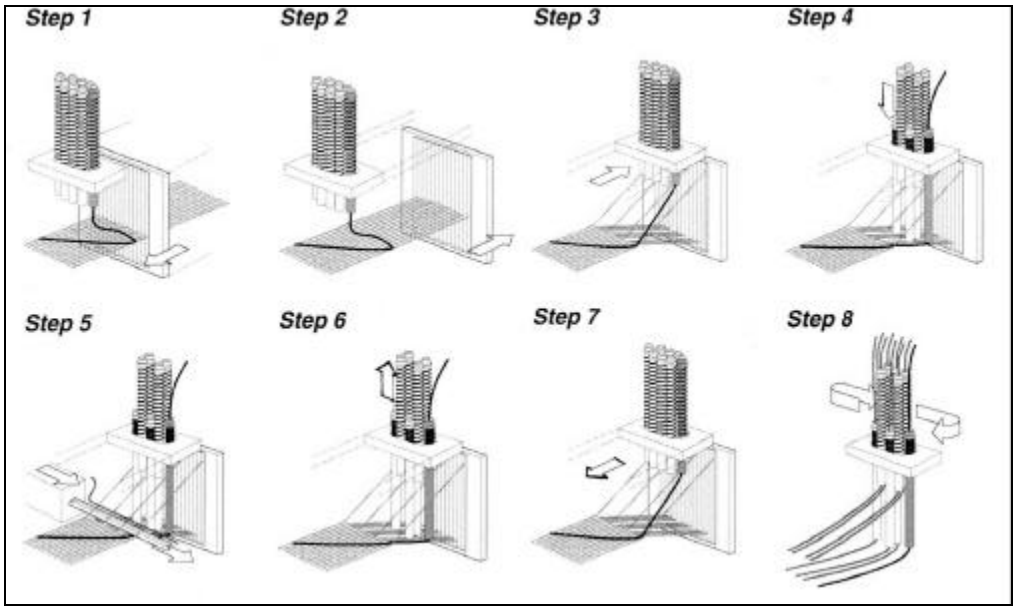

Figure 2: Schematic of bias forming sequence; steps 1 to 8

Step 1

The reed beats up to the fell position to consolidate previously inserted weft. The tubes, tube guides and guide plate are held forward of the fell position so as to be clear of the forward motion of the reed, this is known as the rest position. This position may be held for several weaving cycles that do not involve binding of the bias reinforcement.

Step 2

The reed is withdrawn from the fell position. The tube guides and guide plate are held in the rest position.

Step 3

With the reed at back centre, a shed is formed from the warp yarns. A special selection of warp yarns is made to accommodate the selected tubes. The guide plate and accompanying tube guides and tubes are moved away from the rest position toward the reed and coming in close proximity to, but forward of the reed. The tubes remain above the upper shed.

Step 4

Using the depression plate, selected tubes, or all tubes, depending on the desired structural characteristics, are lowered between the upper shed warp yarns previously positioned in Step 3.

Step 5

Weft is inserted into the shed now formed, which includes at least some bias reinforcing fibre in the lower shed position. Figure 3 is a photograph of the apparatus at this stage of the weaving sequence.

Step 6

The previously lowered tubes, as in Step 4, are now raised to the neutral position where the bias reinforcing is above the upper shed position of the warp yarns.

Step 7

The guide plate including guide tubes and tubes, is moved towards the rest position and the reed moves forward to beat the weft into the fell position. The beat-up of weft yarn may occur in the open shed, closed centre or closed bottom shed positions.

Step 8

The guide tubes are moved around the guide plate to the next position. This position is determined by the desired binding pattern. To achieve a binding of each yarn at the edge of the bias zone of the fabric, it would be necessary for each tube to dwell for one cycle at the extremities of the guide plate.

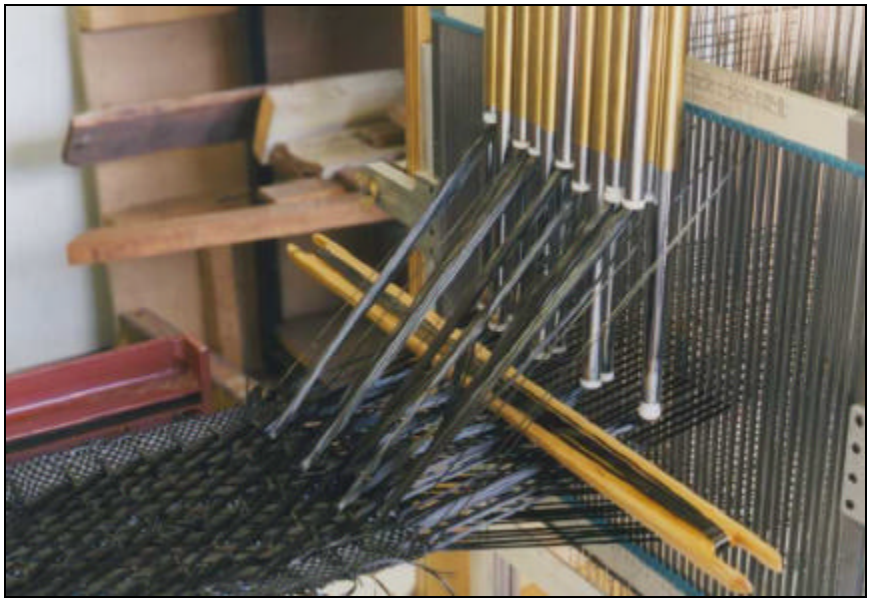

Figure 3: The device in use, processing carbon fibre (Step 5)

APPLICATIONS

In its most obvious application the bias reinforcement would be incorporated across the full width of the base fabric. However, the system is also capable of confining the zone of additional fibre within these boundaries, and even allowing variable positioning of the zone during production of a particular product, a feature which may be useful for curved components. Similarly, the rate of binding of the additional yarns into the base structure can be altered during production, resulting in

variation in the angle of the additional reinforcing, as shown in Figure 4, which can range from close to the weft direction through to the warp direction.

Individual bias reinforcement yarns may be stopped short of the edge, while others may continue to the full extent of the zone. This would allow tapering of the bias yarns at the edges of the structure, and would be useful in optimising fibre placement for an I-beam where less ±45° fibre is required on the flanges compared to the web. This is achieved through selective tube control by altering the profile of the depression plate, or using different plates in the one design.

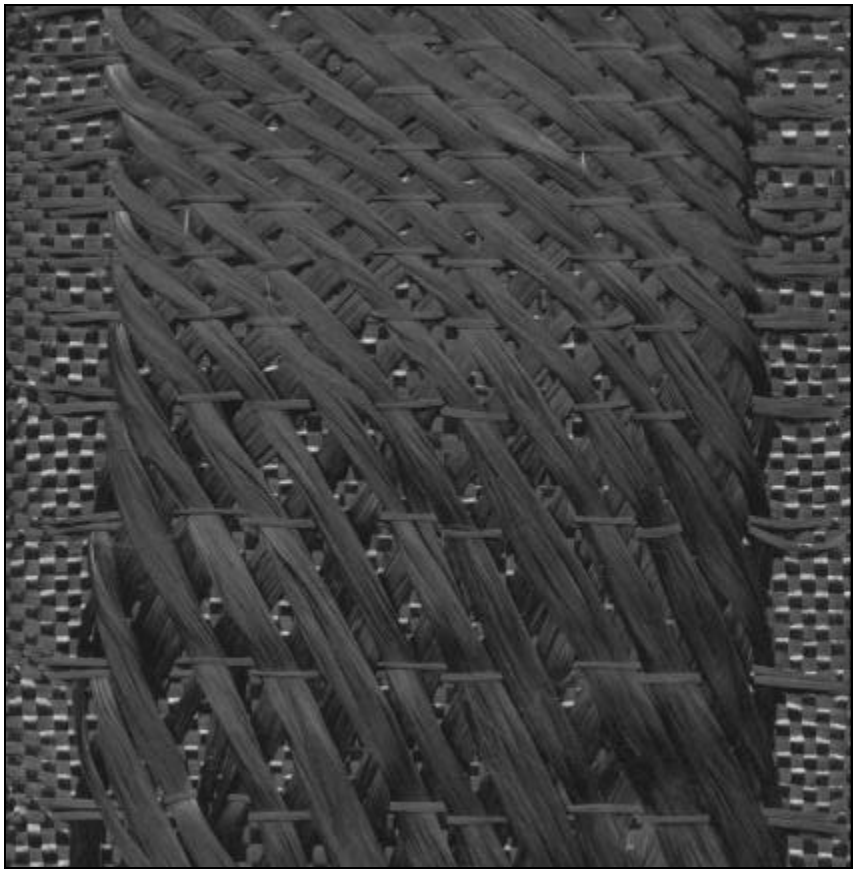

Figure 4: Example of the weave structure produced using bias forming device where the angle of the bias fibre changes along the sample. Each bias yarn proceeds to the edge of the bias-forming zone. The plain weave of the base structure is largely undisturbed.

Additional fibre has been added to customary two-dimensional orthogonal woven structures, compound or multilayer woven structures and complex three-dimensional woven structures such as I-beams and sandwich structures. The additional fibre can form a contiguous plane, while the configuration of the underlying structure remains substantially undisturbed.

DISCUSSION

A needle is traditionally used in lappet weaving mechanisms to control the additional fibre [2] and also in the inventions by Farley [3] and Ruzand & Guenot [4]. Using tubes to carry the fibre, rather than needles, has allowed large bundles of carbon fibre (up to 16 x 12K) to be manipulated with negligible abrasion. The primary consideration when designing this add-on device was to accommodate a number of fibre bundles in close proximity to each other. The size and number of tubes were chosen with attention to the materials available; in particular the internal diameters,

wall thicknesses and ease of working. Further, the overall dimensions of the add-on device, particularly in the warp direction, were integral to the ease of adaptation to existing equipment and therefore were kept to a minimum.

In the lappet process, all the needles are introduced through the base structure at once, requiring clearance between the needles to accommodate warp yarns. The equivalent process using our add-on device would require a similar clearance between tubes. However, individual selection of the tubes, by using various depression plate profiles, has allowed close proximity of tubes and therefore a high density of bias yarn.

Other multiaxial weaving methods require special considerations to achieve continuous bias reinforcing to the edges of the structure. A solution to this obstacle is integral in the add-on device by virtue of its design and operation, with the additional capability of tapering the bias reinforcing at the edges when desired.

We have used the add-on device on only one surface of the structures we have produced, which is the upper side during production. It is conceivable that a similar device be operated simultaneously on the under side of the structure, allowing far greater range of reinforcing configurations.

In its current form, the device is an add-on to a purpose built hand-operated loom. This loom performs all the primary and secondary weaving motions (shedding, weft insertion, beat-up, let-off and take-up) using standard weaving technologies. To facilitate manufacture of 3D preforms using high performance fibres, there are features additional to a standard loom that allow a high level of operator control over weaving parameters, including multiple shed heights using 620mm heddles, linear take-up and individual warp yarn tension.

The bias forming device is also manually operated, and employs mechanisms that are convenient to its current application, such as a range of depression plates, which would require redesign for adaptation to a production loom. There are a number of possibilities for electronic control of the position of the tubes, including linear actuators or linear stepper motors. Incorporation of a similar device on an automated loom also requires the ability to intervene in the normal weaving cycle to add the steps involved in controlling the tubes and binding the additional yarns to the base structure.

CONCLUSIONS

The aim of integrally weaving two layers (for example +45° and −45°) of highly concentrated bias yarn to a conventional orthogonal structure has been achieved. Moreover, this has been successfully done with fibres which require special processing considerations, including carbon and glass.

The authors are keen to continue this work by optimising fibre placement for structures suitable to the invention; and then consolidating and testing the resulting structures.

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