BIAXIAL KNITTED PREFORMS FOR STRUCTURAL COMPOSITES

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Abstract

Biaxial knitted structures consisting of a stitching yarn system that holds high performance inlay yarns in the 0° and 90° machine directions have been developed for structural composite applications. The manufacturing method for biaxial weft knitted structures was refined with the inclusion of a warp insertion device and warp yarn delivery system to a 10 gauge (E10) dubied hand flat v-bed knitting machine. The machine modifications allowed for easy processing of biaxial knitted preforms at low cost with E-glass fibre as the reinforcement yarn. Through maximizing the mechanisms of the machinery, high quality biaxial knitted preforms and composites were manufactured. Two different knitted binding structures of half milano and half cardigan were investigated to identify their effect on the mechanical properties of the resultant preforms. It was found that the knitted binding structure impacts the inlay density, stiffness and formability of the preform. Tensile and bending tests showed that the use of half cardigan as a knitted binding structure yields a higher weft inlay density, thus increasing the breaking load and bending stiffness of the preform.

1. Introduction

Textile composites are fast replacing metal and wood used in a range of applications and industries including: aerospace, civil engineering, sporting goods and automotive [1]. The replacement of metal with high performance fibres such as glass or carbon, can reduce weight whilst maintaining high mechanical properties. The use of knitting technology for the manufacture of textile composite has seen increased interest due to its design flexibility and machine capabilities. The nature of the loop structure means that knitted structures have lower stiffness and Young's modulus compared to woven structures [2, 3]. However, to improve the in-plane properties such as strength, resistance to surface deformation and directional reinforcement, inlay yarns have effectively been added to knitted structures in the wale, course and bias directions [4-6].

The insertion of inlays in the wale and course directions (using warp and weft insertion respectively), held together by a stitching yarn system creates biaxial knitted structures [7]. The stitching yarn system, also referred to in this paper as the knitted binding structure, supports the inlaid reinforcement yarns, as shown in Fig. 1.

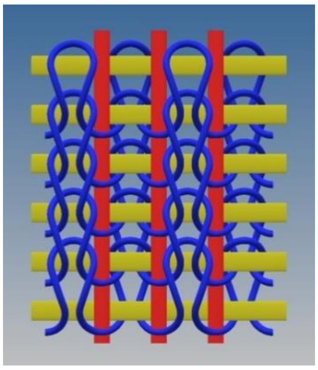

Figure 1. CAD drawing of biaxial knitted structure.

In the late 20th century, interest grew in the use of biaxial knitted structures for composites [8-10], starting with incorporation of weft inlay only, before integrating warp inlay also. At Dresden University a method to produce a multilayer knitted structure with multiple sets of warp and weft inlays was developed [10]. This is only capable on an electronic weft knitting machine due to the availability of more feeders to deliver the multiple layers of weft inlay. The technology produces highly drapeable semi-finished structures for fibre composites, with the capability to absorb tensile, compressive and bending forces.

The reinforcement yarns in biaxial knitted structures experience zero damage, as the binding yarn is knitted around the inlays, rather than puncturing through it (as seen in NCF's). Biaxial knitted structures can be produced using both warp and weft knitting technology, however, the use of weft knitting machinery enables shaping directly on the machine, through transferring of stitches and individual needle selection.

Modifications to a 10 gauge (E10) dubied hand flat v-bed machine have been made to allow for biaxial knitted structures to be produced with low capital investment and easy machine set-up. In this study, the effect of the knitted binding structure on the tensile and bending properties of the preform have been investigated, comparing half milano with half cardigan.

2. Materials and machine design

2.1. Development of warp insertion device

The creation of biaxial knitted structures using a dubied hand flat v-bed machine required four main components: warp insertion method, correct feeder set-up and positioning, warp yarn delivery set-up and weft insertion set-up.

For the warp insertion method, a warp insertion device consisting of warp guide eyelets was developed. The spacing of the warp guide eyelets is equivalent to the needle gauge of the machine, and delivered warp yarns taught and evenly spaced between the needles. The width of the warp insertion device defines the maximum width of the warp insertion structure.

In this study, three feeders were used to produce the biaxial knitted structures using two needle beds. The warp insertion device was positioned on the middle feeder position, with the back feeder used for the weft inlay, and the front feeder used for the knitted binding structure. This positioning of the feeders ensured the warp inlay yarn was integrated within the biaxial knitted structure.

Individual yarn packages for the warp inlay were positioned on a creel to the side of the machine. The yarns travelled parallel to the needle bed underneath the cambox arm before reaching the warp insertion device. Tension was applied to the warp yarns below the needle bed to ensure the yarns remained taught as the needles passed between them. The streamlined design of the warp insertion device prevented contact between itself and the two feeders which traversed the needle bed.

Multiple ends of yarn can be inserted in the weft direction in one inlay, with the maximum number and width depending on the yarn type and stitch size chosen. The weft inlay was threaded through a standard yarn feeder that traversed along the needle bed: delivering inlay yarn in-between the front and back bed stitches.

2.2. Manufacture of biaxial knitted preforms

The biaxial knitted preforms in this study were manufactured using the mentioned dubied knitting machine and developed warp insertion device. Polyester thread was used for the knitted binding structure, whilst E-glass fibre was used as the inlay yarns. Half milano and half cardigan were used as the knitted binding structure, the biaxial knitted preform using half milano structure is shown in Fig. 2.

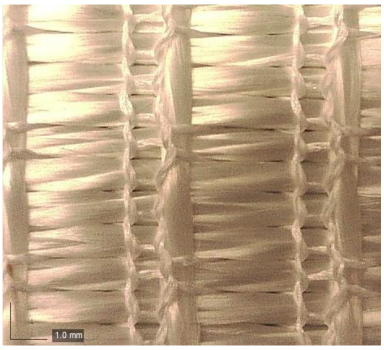

Figure 2. Biaxial knitted prefrom (knitted binding structure of half milano).

3. Methods

3.1. Three-point bending

A three-point bending test was carried out according to test standard BS ISO 5628:2012 [11], the set-up is shown in Fig. 3. The test was carried out to observe the effect of the knitted binding structre on the bending properties of the preform, with the bending stiffness indicating the preforms capability to assume the curve of complex shaped moulds. The bending stiffness, Sb (Nm.mm) was calculated given by the following equation:

$$S_b = \frac{F}{f_{max}} \cdot \frac{l^3}{3b} \tag{1}$$

where

F	Force (N),
f_{max}	Maximum linear deflection (mm), calculated by 0.132*l*.
l	Bending length (mm),
b	Specimen width (mm).

The maximum force was recorded at a predetermined linear deflection of the anvil, and was used to calculate the bending stiffness.

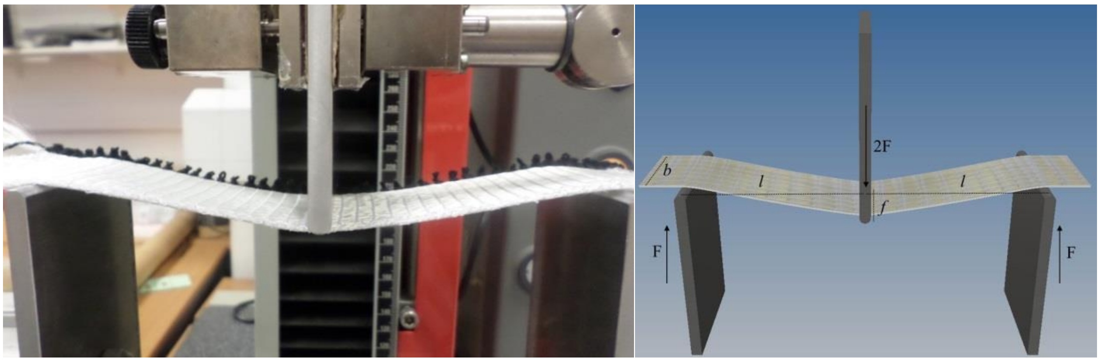

Figure 3. Bending test set-up.

3.2. Tensile testing

The biaxial knitted preforms were subjected to tensile tests on an Instron 5569 machine, according to test standard EN ISO 4606: 1995 [12]; the set-up is shown in Fig. 4. Paper tabs of 40mm x50mm were attached to the ends with resin to prevent slippage of the samples, and promote failure in the centre of the gauge section.

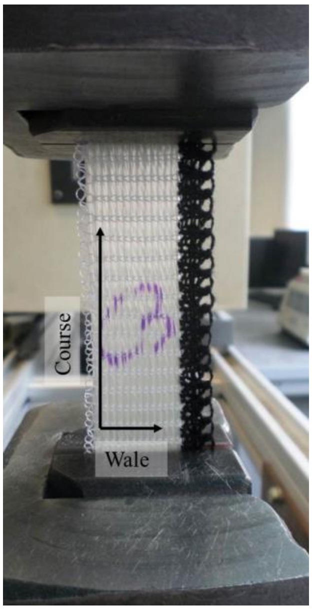

Figure 4. Tensile test set up.

Since uniaxial tests are affected by the fibres oriented in the load bearing direction, where yarns oriented perpendicular to the tensile direction do not bear any load [13], only course wise direction was analysed. Wale direction testing is affected by the warp inlay density, which does not change when altering the knitted binding structure, and therefore no difference in tensile strength would be seen across the two types of samples. Conversely, the weft inlay density changes from 8 inlays/cm to 12 inlays/cm for knitted binding structures of half Milano and half cardigan respectively.

4. Results and discussion

The bending and tensile properties of the preform samples are shown in Table 1.

Table 1. Tensile and bending properties of preform samples.

Knitted binding structure	Thickness (mm)	Average breaking force (N)	Average tensile strength (MPa)	Average force at maximum deflection, f_{max} (mN)	Average bending stiffness (Nm.mm)
Half Milano	1.3	12,800	419	170.5	36.3
Half Cardigan	2	18,750	390.6	334.8	65.2

As expected half cardigan required more force than the half milano for equivalent bending deformation. Half cardigan increases the density of the preform, through the compaction of weft inlays by tuck stitches, and as a result creates a stiffer preform, with the bending stiffness (Nm.mm) nearly twice the value of the half milano structure.

Tensile tests showed that the force required to rupture the weft inlay yarns (average breaking force, N) was higher in the half cardigan samples than the half milano samples. This is a result of half cardigan having a higher weft inlay density. However, when cross-sectional area is taken into account, the half milano demonstrated higher tensile strength (MPa). These results are valuable during the composite design process, when the weight of the material is an important parameter.

5. Conclusion

A key advantage of biaxial knitted structures is their ability to drape and conform to the surface of complex shaped moulds, where they are less susceptible to wrinkling compared to woven preforms. The ease of deformation is owed to the lack of joints (such as cross-over points present in weaving), where there is free movement and slippage of yarns. The knitted binding structure can impact the drapeability, with bending stiffness reported as higher for the half cardigan samples. A higher stiffness indicates it’s less able to drape and assume the shape of complex shaped moulds. Results suggest that the use of half milano will provide better surface for moulding to complex shapes in composite manufacture.

Further results have shown that using a knitted binding structure which increases the density of the weft inlay yarns, will increase the maximum breaking load of the preform. The samples with half cardigan structure increased the breaking load by aproximately 150% compared to half milano. However, when taking into consideration the cross-sectional area of the samples, half milano exhibits higher tensile strength (MPa).

Within the scope of the research, further development of the biaxial knitted structures will be carried out to fully comprehend the capabilities of the structure. The biaxial knitted preforms will be converted to composites and will undergo full mechanical characterization.

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