EFFECT OF THE MESO-SCALE GEOMETRY ON THE MECHANICAL PROPERTIES OF TEXTILE COMPOSITES

Rishad Rayyaan[1], William Richard Kennon[1], Prasad Potluri[2]
[1]*Department of Textiles, School of Materials, The University of Manchester*
[2]*Department of Textiles, School of Materials and Aerospace, The University of Manchester*
Corresponding author Email: rishad.rayyaan@manchester.ac.uk

Abstract:Disorientation of the fibres from the load direction in a composite panel results in poor translation efficiency of the fibre strength to the composite strength. This disorientation which occurs during preform manufacturing can be attributed to the 'twist' and the 'waviness' of those fibres within the preform. In this project, glass fibre has been examined to see the effect of twist and different types of flax fibre performshave been chosen to examine the effect of waviness.By using vacuum bagging method, glass-fibre reinforced epoxy and flax fibre reinforced epoxy composites have been manufactured. It has been found that the longitudinal modulus decreases with the increase of twist. And when the waviness has been taken into account, it has been found that longitudinal modulus decreases with the increase of waviness.

Key words: Twist, waviness, textile composites, epoxy, longitudinal modulus.

1. INTRODUCTION

Composite materials are now being extensively used in various fields including aerospace and automobiles. In comparison with the materials made from steel or aluminium, composites exhibits better specific strength modulus [1].

The term 'Textile Composite' refers to a multi-component material fabricated around an arrangement of reinforcements or preforms structured by textile processes such as weaving, knitting, winding or braiding.

'Preform' creation is the step immediately preceding that of polymer matrix impregnation. Preforms are the structural backbone of a composite similar to the structural steel frame-work around which an architectural structure may be built. Textile performing means the process of fibre placement by utilising textile processes. The desired orientation of fibres can be achieved in different ways and thus the micro – fibrous structure can be organised with one, two or three – dimensional structures by utilising various textile oriented processes such as interlacing, interlooping, intermingling, intertwining or twisting. This results in a specific arrangement of the fibres through a pre-determined geometric placement of the fibrous structures and yields a desired preform architecture. Consequently the structural properties of the resulting composites can be predefined and tailored accordingly. Highly stressed regions of a composite material can be provided with strong and stiff fibres with a precisely predetermined fibre volume fraction with appropriate fibre orientation. This in turn results in enhanced design flexibility and reduction of weight per unit volume. And thus textile performing offers the composites industry almost unlimited potential from the design point of view and in respect of mechanical properties [2].

By the term 'meso-scale geometry' of textile fabric, mainly the different orientations of the filaments or fibres in a yarn or the existence of waviness over a yarn are refereed. In this research, both the effects of twist and waviness have been attempted to characterise, particularly when they are evident within composites.

Waviness is the amplitude of the fibres in angle, shifting away from the plane of the fabric. In a piece of woven cloth, this can also be termed as 'crimp' which is the bending of a yarn that happens due to the interlacement with another yarn that goes along in a different direction. Waviness directly influence several mechanical properties of composites including tensile, compressive, vibration and damping properties [3, 4]

To manufacture preforms by textile processing, twisting the strands of fibres or filament is usual. The 'twist' of yarn is a term which refers to the number of turns amongst the constituent fibres and/or filaments of a yarn. A strand of filaments or fibres turns into a yarn because of the introduction of twist. Twist assists the adherence of the fibres and thus increases the compactness and hence the strength of the yarn. Twist increases the lateral cohesion of the constituent fibres and helps to make the strand of fibres more monolithic. Another important feature of twist is that it eases the handling of fibres during the manufacturing of preforms by weaving or knitting. Getting the yarns through the reeds and dents of a weaving machine becomes very troublesome if the yarn is a non-twisted strand of continuous filaments. Due to the incidence of friction against the various guides within a weaving machine, non-twisted strands of filament tend to be pulled away from the filament axis and fibre damage occurs. The insertion of certain a certain amount of twist counteracts that effect to a significant extent [5, 6].

There are some voids still as far as the empirical characterisations of the influence of twist and waviness on textile composites are concerned. In this paper, firstly the role of waviness in flax-fibre reinforced epoxy composites has been characterised and secondly, the effect of twist on the glass-fibre reinforced epoxy composites have been analysed.

2. EXPERIMENTALS

Glass filaments of 661 tex manufactured by AGY has been used and the twist has been introduced by hand twister of James H Heal. Then 8-end satin fabric has been manufactured with twisted and non-twisted strand using shuttle loom.

Four types of materials made of flax fibre have been used namely warp knitted flax UD fabric, flax matt fabric, non-woven flax tape and flax tape with a glass veil.

(a) (b)

(c) (d)

Fig. 1 (a) UD fabric; (b) Matt fabric; (c) UD tape; (d) Glass-veil UD tape

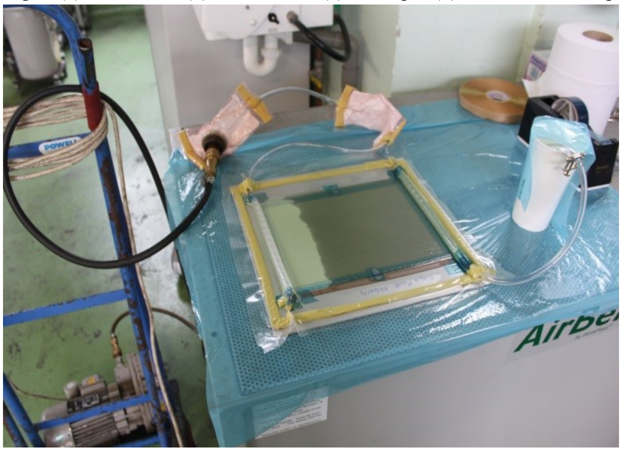

Fig. 2 Resin infusion using vacuum bagging

Then composite panels have been made using thermoset epoxy resin and finally longitudinal modulus have been examines using an Instron5982 machine using ASTM D3039 standard.

3. RESULT AND ANALYSIS

In this paper, the moduli of different types of glass-fibre reinforced composites and flax-fibre reinforced composites have been presented.

In Fig.3 we can see that the modulus of non-twisted glass fibre composites is 8.72% higher than that of the twisted glass fibre reinforced composites. the main reason behind the decline of modulus is that the axis of filaments is at an angle

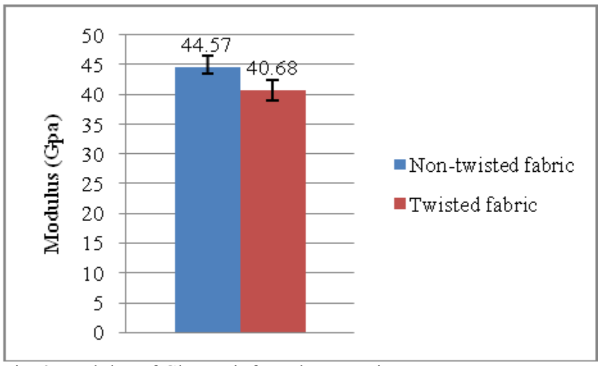

Fig. 3 Modulus of Glass-reinforced composites

to the yarn axis and consequently, also the loading axis. The geometrical effect of applying twist to a yarn is to cause the off-centre fibres to assume a helical path which deviates from the axial direction of the yarn.

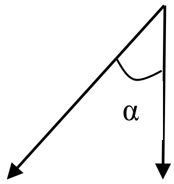

Fig4. Relationship between Filament Strength and Yarn Strength

From the Fig. 4, it may be seen that, Yarn Strength = Filament strength × cosα; where α is the twist angle.

Thus the contribution of the filament strength to the yarn strength is reduced. An increase in the twist angle 'α' leads to a decrease of the yarn strength, i.e. a reduced filament strength contribution to the yarn direction (and therefore to the load direction) occurs.

Another reason for the decrease of the modulus is that, the twist imparts some pre-strain to the filaments of yarn and the higher the twisting angle, the higher is the pre-straining [6]. Due to this pre-straining, twisted yarn can withstand lower strain and therefore lower load. Thus, the failure strain and the failure strength decrease when the degree of twist is increased.

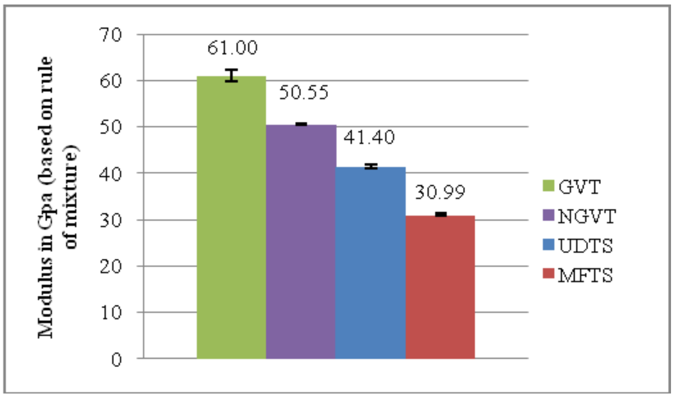

Fig. 5 Moduli of flax composites

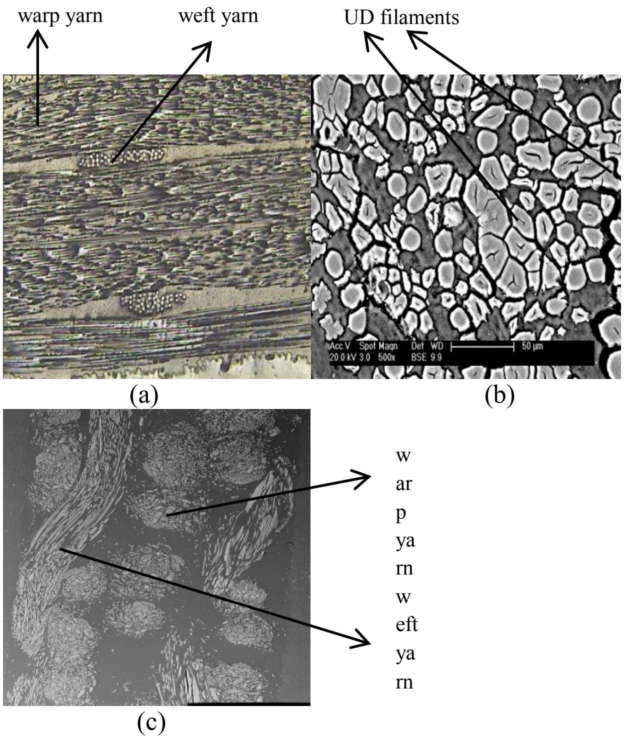

Fig. 6 Microscopic image of different composites; (a) glass fibre composite; (b) UD tape flax; (c) matt fabric flax

In fig. 5 we see the different moduli of flax fibre reinforced composites. The strain region taken into consideration is 0% up to the point where modulus curve flexes. A unique phenomenon of flax fibre and flax reinforced composites is that they show two plateau of strain region due to the intrinsic property of flax fibre [7-9]. All the moduli have been calculated using rule of mixture and only variable of different composite panels was the orientation of the yarns. In matt fabric (MFTS), due to invariable crimp of the warp and weft, there was waviness which resulted in the lowest modulus. Unidirectional fabric (UDTS) had no crimp as there very little interlacement between warp and weft due to weft yarn being very fine in comparison with the warp. So it showed higher modulus than the MFTS. Finally, two kinds of flax tapes (with and without glass veil) have been introduced (GVT and NGVT) where the packing fraction was higher than that of MFTS and UDTS. There was no waviness at all in those two panels which also has resulted in less resin rich area and better homogenous distribution of filament across the cross-sectional area. Analytical model and empirical research show that for the unidirectional laminates, the major young's modulus degrades seriously as the fibre waviness increases[10, 11]. Thus those two panels show better longitudinal moduli than the aforementioned two panels and these results are in line with the existing literature. The inclusion of glass veil to the tape adds some extra strength but main reason of that inclusion is to get better impact properties. The discussion regarding impact properties is beyond the scope of this research.

Fig. 6(a) shows very coarse glass yarn and very fine polyester yarn which has kept the warp yarn almost with no crimp/waviness. Fig. 5 (b) shows UD flax tape with better packing density than (c)-matt fabric flax composite.

4. CONCLUSION

Meso-scale geometry refers to the contour of the constituent filaments and yarns in a textile preform which directly influences the mechanical properties of the composites. Twist and waviness are two major denominators of the meso-scale geometry of textile perform. Twist enhances the monolithic property of a yarn by adding lateral forces among the fibres but it also shifts the fibre from the axis of the yarn. Thus it decreases the modulus. Experimental results for glass-fibre composites for longitudinal modulus also showthat with the inclusion of twist, longitudinal modulus decreases.

In case of waviness, flax fibre composites show that the modulus decreases with the increment of waviness. Also with the higher magnitude of waviness, packing density decreases that also works as an effective parameter to reduce the modulus. Thus matt fabric composite panel shows lowest modulus and UD tape with glass veil shows the highest modulus.

For the future works of this project, X-ray computer tomography will be used to quantify the waviness precisely and finite-element modelling will be carried out to predict the moduli as a function of twist and waviness.

REFERENCES

1. Zoghi, M., *The International Handbook of FRP Composites in Civil Engineering*. 2013: CRC Press.
2. Potluri, P. *Recent Advances in 3D Textile Composites*. in *Proceedings of the International Conference and exhibition on Reinforced Plastics*. 2002. FRP Institute.
3. Duc, F., P. Bourban, and J.-A. Månson, *The role of twist and crimp on the vibration behaviour of flax fibre composites.* Composites Science and Technology, 2014.
4. Potter, K., et al., *Variability, fibre waviness and misalignment in the determination of the properties of composite materials and structures.* Composites Part A: Applied Science and Manufacturing, 2008. **39**(9): p. 1343-1354.
5. Naik, N.K., *Twisted Impregnated yarn; Transverse tensile strength.* The Journal of Strain Analysis for Engineering Design, 2001. **36**(4): p. 347-357.
6. Naik, N.K. and R. Kuchibhotla, *Analytical study of strength and failure behaviour of plain weave fabric composites made of twisted yarns.* Composites Part A: Applied Science and Manufacturing, 2002. **33**(5): p. 697-708.
7. Kersani, M., et al., *Damage in flax/epoxy quasi-unidirectional woven laminates under quasi-static tension.* Journal of Composite Materials, 2014: p. 0021998313519282.
8. Baets, J., et al., *Determination of the optimal flax fibre preparation for use in unidirectional flax–epoxy composites.* Journal of Reinforced Plastics and Composites, 2014.
9. Zhu, J., et al., *Recent Development of Flax Fibres and Their Reinforced Composites Based on Different Polymeric Matrices.* Materials, 2013. **6**(11): p. 5171-5198.
10. Chun, H.-J., J.-Y. Shin, and I.M. Daniel, *Effects of material and geometric nonlinearities on the tensile and compressive behavior of composite materials with fiber waviness.* Composites science and technology, 2001. **61**(1): p. 125-134.
11. Tsai, C.-h., et al., *The effect of inclusion waviness and waviness distribution on elastic properties of fiber-reinforced composites.* Composites Part B: Engineering, 2011. **42**(1): p. 62-70.