A Review on Structure-Property Relationship of Knitted Composites

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Abstract- The tensile and compressive behaviors of knitted composites manufactured by resign transfer molding (RTM) process in the wale and course directions were discussed for their dependence up on knit structural parameters, such as loop length and stitch density. Strength, modulus and strain-to-failure Poisson's ratio of the composites under tensile loading was also discussed.

Index Terms- Knitted Composite, Structural Parameters, Resin Transfer Molding Composites.

1. INTRODUCTION

The adoption of traditional textile manufacturing techniques for the production of advanced three-dimensional (3d) composite reinforcements has gained considerable interest over the last couple of decades. One of such highly automated textile techniques that has been successfully tried is knitting, where the near-net-shape manufacture of knitted preforms and their excellent drapability hold particular promise for the cost-effective production of intricately-shaped composites.

Knitted composites, however, are generally considered to have inferior mechanical properties due to their highly looped fibre architecture. Whilst some recent researchers [1–7] have suggested that knitted composites could possess attractive properties for niche applications, such as those requiring high energy absorption or good impact resistance, or in cases where the component is complex in shape and demands exceptional formability, the lack of a comprehensive understanding of the way knitted composites behave still acts as an impediment to the wider acceptance of the material and, hence, expanded application. To extend the understanding of how the structure of knitted preforms can be manipulated and controlled for desired properties various research has been conducted. The present paper explored the effect of weft-knit architecture and knit/structural parameters on the tensile and compressive properties of knitted composites. These composites were fabricated from the knitted fabrics using the resin transfer molding (RTM) [5] process. The fabrics were placed into the RTM tool and injected with vinyl ester resin to produce flat composite panels.

2. STRESS-STRAIN CHARACTERISTICS

On the whole, all the knitted composites have very similar stress-strain behaviour. In fact, their stress-strain curves all have the same characteristics under both tensile and compressive loading. Basically, the composites exhibit linear behaviour at the early stages of loading and then transform to pseudo-plastic, coincident with a gradual degradation in the stiffness of the composite, before a maximum stress is reached. This is followed by an abrupt drop in stress corresponding to final failure of the composite. The point at which transition from linear-to-nonlinear behaviour happens is generally defined by a "knee" in the curve, which occurs at a tensile strain level of approximately 0.3%, and a compressive strain level of about 1.0%. [2]

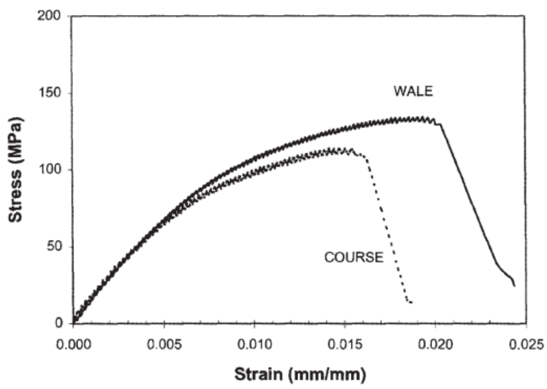

Fig. 1. Tensile stress-strain behaviour of plain and rib structure. [2]

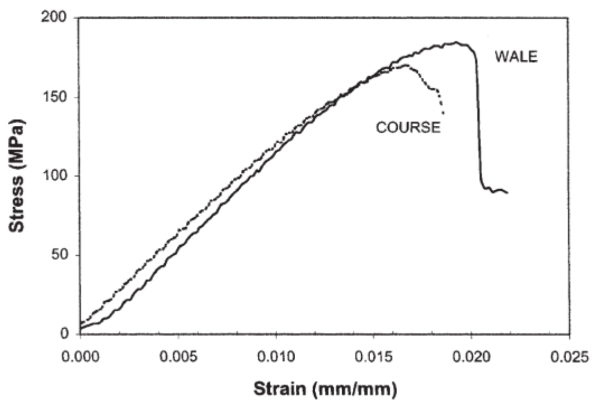

Fig. 2. Compressive stress-strain behaviour of plain and rib structure. [2]

3. MECHANICAL PROPERTIES

3.1 Tensile Properties

The rib structure gives the lowest tensile strength and strain-to-failure, and the plain knit structural design the highest. Extensive inter laminar nestling is expected in the plain knit composites due to the relatively high number of fabric layers used and this could contribute to their superior strength and ultimate strain [4].

The architectures, however, only differ slightly in tensile modulus, with the plain knit architecture being only marginally inferior to the rib, which are of almost equal stiffness. [2]

3.2 Effect of Changing Knit/Structural Parameters

By increasing loop length and decreasing stitch density a positive effect on the composite tensile strength. Therefore, any improvement in strength brought about by reduced stitch density could be due to the presence of fewer crossover points. It is believed that a relaxation of stresses at the fibre crossover points is also plausible with increased loop length. The radii of curvature of the loops are larger for longer loop lengths which would improve the fibre loading efficiency.
Manipulating the loop length and stitch density, on the whole, appears to have little effect on the tensile modulus of the composites. Whilst strength is mechanistically controlled, modulus is predominantly controlled by factors such as fibre content and fibre directionality. It is believed that the loop lengths considered for this study is not sufficiently different to bring about significant changes in those factors, and hence, modulus. It should be noted that knitting constraints had prevented the manufacture of fabrics with a greater range of loop lengths and stitch densities.

The effect of loop length and stitch density on ultimate tensile strain is not straight-forward. For the plain knit architecture tensile strain improve with increasing loop length, but the in rib architectures there could be an optimum loop length and stitch density where maximum ultimate strain is achieved. If the apparently irregular result along the wale axis is excluded, Poisson’s ratio, on the whole, is insensitive to loop length or stitch density. It is believed that the higher average net fibre content in the wale direction compared with that in the course direction, and the lower wale-to-course lineal loop density and, hence, the number of fibre crossover points and failure nuclei, both contribute to this anisotropy of knitted composites. [2]

4. COMPRESSIVE PROPERTIES

4.1 Effect of Knit Architecture

Similar loop length, and lineal and areal stitch densities shows that the compressive strengths are very similar. The compressive moduli are also almost identical, but only along the wale axis. In the course direction, the plain knit composite is clearly inferior to the rib composites, which have very similar moduli. [6, 8]

The apparent insensitivity of compressive strength and modulus to knit architecture is attributed to the strong dominance of the matrix properties which has resulted from the highly curved fibre architecture of the knits and, hence, poor fibre loading efficiency. In fact the strength and modulus values of the knitted composites are quite close to the values of results of continuous glass strand mat reinforced vinyl ester composite. It is interesting to note that, due to the three-dimensional nature of knits, the kinks are formed by fibre buckling in-plane as well as out-of-plane. [6, 8]

Whilst the wale-wise strength and modulus are superior to those of the course, the knitted composites clearly have higher strain-to-failure in the course direction. It is yet unclear as to the reason for this intriguing behaviour. [5, 8, 2]

4.2 Effect of Changing Knit/Structural Parameters

The composites are improved, by an increase in loop length. The radii of curvature of the loops are generally increased for the knits with longer loop lengths and this could mean higher fibre buckling loads and, hence, better compressive strength. The effect of loop length and stitch density on modulus in the wale direction is negligible, although, in the course direction, it improves with increasing loop length and decreasing stitch density for the rib composites, and deteriorates for the plain knit composites.[3]

As in the case of tensile loading, the effect of loop length and stitch density on ultimate compressive strain is not straight forward. The plain knit architecture appears to improve with increasing loop length and decreasing stitch density, but the results of the rib architectures imply that there could be an optimum loop length and stitch density for maximum ultimate strain. [2]

5. SUMMARY AND CONCLUSIONS

Effect of weft-knit architecture and structural parameters on the tensile and compressive properties of knitted composites was studied from various research papers.

Tensile failure initiates from the highly stressed crossover points in the knits. For this reason, the plain knit composites which have a relatively simple structure prove to be superior over the rib composites. Further, by increasing loop length and decreasing stitch density, better tensile strengths can achieved. This is coincident with a reduced number of, and an expected relief of stresses at, crossover points, as well as a relaxation of the overall bending stresses in the knitted loops. Therefore, a relatively simple structure with high loop radius of curvature and a small number of crossover points is preferable for good tensile strength. These characteristics can be enhanced with increased loop length and reduced stitch density.

Compressive strength is virtually insensitive to knit architecture as it is highly dominated by the properties of the matrix. Nevertheless, ultimate failure of the composites in compression is preceded by fibre tow collapse. Hence, better compressive strengths are achieved with longer loop lengths and smaller stitch densities which increase the radii of curvature of the knitted loops, thus enhancing fibre buckling loads. In other words, the "S" shape of the knitted loops that are susceptible to fibre collapse by micro buckling is minimised by an increased loop length and reduced stitch density, thus improving compressive strength of composite.

Tensile and compressive moduli of the knitted RTM composite are unaffected by varying loop length and stitch density. The ultimate tensile and compressive strains on the other hand react in a similar manner to loop length and stitch density variations for the plain knit composites, increasing loop length and decreasing stitch density are advantageous, but for the rib composites there is, apparently, an optimum loop length and stitch density for maximum ultimate strain to be achieved.

Tensile Poisson's ratio of the knitted RTM composites was found to be independent of the architectures.

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