BIO-COMPOSITES REINFORCED WITH 3D KNITTED PREFORMS

Saber Ben Abdessalem[1], **Samar Turki**[1]
Monastir University, National Engineering School of Monastir, Textile Materials and Process Research Unit, Monastir, Tunisia
e-mail: saber_ba@yahoo.fr

ABSTRACT:
Textile-reinforced-composites are widely used in composite applications where a lightweight and rigid structure is an imperative target. As reinforcement materials, spacer fabrics, especially flat-knitted preforms, are making a greater interest in composite materials field. This paper deals with the development of flat-knitted 3D spacer fabrics composites having cotton yarn as reinforcement material impregnated with polyester resin. Three-point bending and compression tests were carried for two consolidated spacer fabrics (with U and V-shaped cross-links). This study aims to evaluate the impact of the fabric connection shape on composite mechanical properties. It was found that composite material with U reinforcement has the best compression resistance whereas the best bending properties were obtained with V shaped connection.

KEYWORDS:
Spacer Fabrics, Flat knitting, Cotton preforms, Polyester Matrix, Mechanical properties.

1. INTRODUCTION

Face to environmental problems concerning CO_2 emissions and responding to high-tech demands, the main objective of aerospace industries is to reduce to half the consumed fuel amount by 2020. Consequently, the use of lightweight structures having the required mechanical performances becomes an imperative target (Laurenzi et al., 2014).

Conventionally, composite materials, especially sandwich structures, have been widely used in transport vehicles, aircrafts, infrastructure, high speed ships, etc. They are made of two stiff skins separated by a thick core which provides a sandwich composite with high bending stiffness with overall low density. However, their major weakness is the delamination problem which generates the disconnection of skins. Therefore, 3D textile preforms called spacer fabrics offer some of the most innovative solutions of today (Wang et al., 2014).

Spacer fabrics are 3D complex structures compounded of two surface layers bound vertically with pile yarns or fabric layers. They are obtained by weaving and knitting technology. In recent years, flat-knitted 3D spacer fabrics with connecting layers have made a breakthrough in textile reinforced composites field and are very promising to be used in lightweight engineering applications due to their high tensile, bending, impact and energy absorption properties. For instance, ballistic protection of combat vehicles or buildings can be an interesting future application area (Abounaim et al., 20010).

Being knitted together, surface and connecting layers form an integral sandwich structure that cannot delaminate so they can replace conventional sandwich panels and be used in lightweight applications such as spacecrafts, racing cars, marine applications, etc.

Abounaim et al. (Abounaim et al., 2010) was the first who developed this structure using hybrid yarn (GF/PP) and flat knitting machine for thermoplastic composites. Mountasir et al. (Mountasir et al., 2013) developed the same structure using modified double-rapier weaving machine.

Flat-knitted 3D spacer fabrics have attracted the interest of many researchers in order to develop 3D preforms with diversified structures for complex shapes composite reinforcements in one process step reducing waste and production time (Abounaim et al., 2010) but today, in literature, 3D-knitted composite characte-ristics have not been studied and the impact of the nature of the textile-knitted structure on the composite performance was not investigated.

The present work contributes to study further the mechanical properties of flat-knitted 3D spacer fabrics specifically the impact of connecting layers shape on consolidated composite performances.

2. MATERIAL AND METHODS

2.1. 3D Spacer fabrics development

Cotton yarn was used to produce two shaped 3D spacer fabrics with U and V connecting layers (cross-links) form as shown in ***Figure1***.

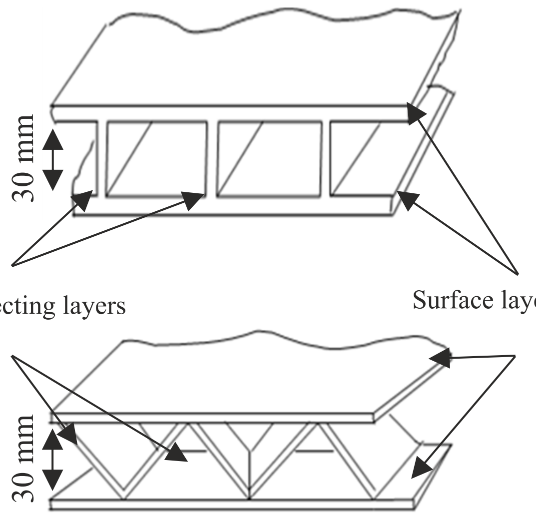


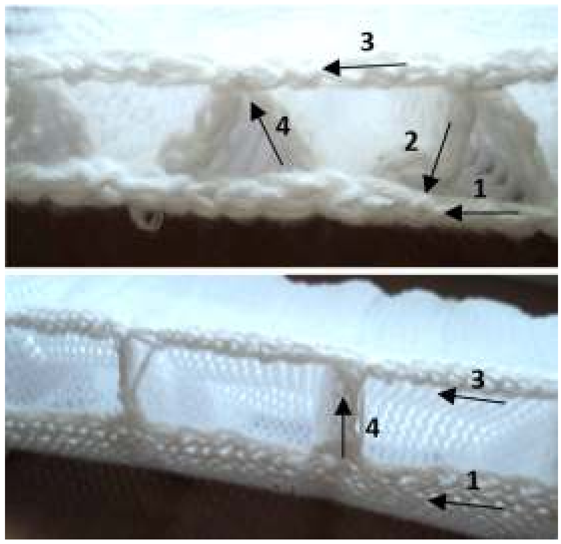
Figure 1 U (top) and V-shaped spacer fabrics

These preforms were produced on CMS 330 TC E5 flat knitting machine. The technical features of this kind of machine such as racking system, loop transfer and individual needle selection make it suitable for the production of diversified structures with complex shapes.

In order to obtain the U shaped preform, we used single jersey to knit the two surface layers with only uneven needles and two yarn carriers, one carrier for each needle bed in order to have an opened structure from the both sides to insert molds. Then, the first course of the cross-link is made by single jersey on front needle bed and connecting layers are knitted using only even needles. Finally, the last course of cross-links is linked to back surface layer by means of racking and loop transfer. We should notice that cycles must be added to have the desired thickness (connecting layers length).

The manufacturing technique of v-shaped spacer fabric is deduced from the previous binding. The only difference is to knit surface layers and cross-links on front and rear needle beds alternatively to avoid knitting troubles.

The obtained 3D structures are illustrated in ***Figure 2***.



→ : Knitting direction; 1, 3: surface layers; 2, 4: connecting layers

Figure 2. V (top) and U-shaped spacer fabrics

2.2. Manufacturing technique of composite materials

3D composite materials were obtained through a hand-worked process using an unsaturated polyester resin "Crystic®125 PA" supplied by SCOTT BADER. A stiff cardboard mold was embedded into the structure interspaces and the resin, mixed with an organic peroxide curing agent in the proportion of 2% of the resin volume, was applied on the surface and the connecting layers using a wide brush. The final consolidated sandwich structures are presented in ***Figure 3***.

Figure 3 U (top) and V-shaped 3D composites

2.3 Mechanical tests

In this current study, three-point bending and flat compression tests were performed by a Lloyd EZ 20 testing machine.

For the bending test, the size of the specimens was 200×35 mm at a loading speed of 2 mm/min and the distance between the two supporting points was 160 mm.

For the compression test, the specimens having an area of 80×80mm were subjected to a compressive force at a test speed of 1 mm/min.

3. RESULTS AND DISCUSSIONS

3.1. Bending properties

During bending test, the upper layer is subjected to a compression force while the bottom one is exposed to a tensile load. Due to these constraints, breaks and cracks occurs in the deformed shape of the specimens (*Figure 4*).

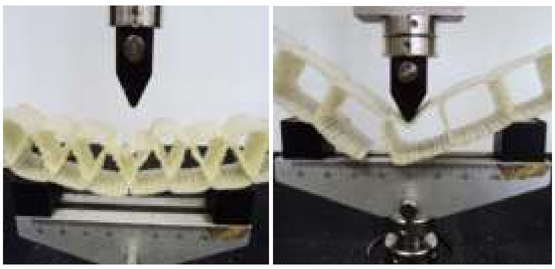


Figure 4 Deformed composites under bending test

Figure 5 illustrates the mechanical behavior of the 3D composites under three-point bending load. It can be seen from the stress-displacement curve (***Figure 5***) that the bending stress increases linearly with the displacement until the connecting layer starts to fail which causes the load's decrease.

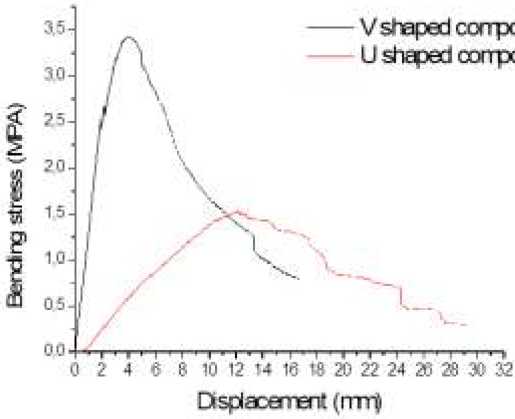


Figure 5. stress-displacement curves of bending tests on 3D spacer fabric composites

V-shaped composite has the highest bending strength and modulus as can be seen from ***Table 1***. Thus, V arrangement is more resistant under bending loads since it presents a higher number of bonding points between the outer layers which makes them strongly linked together. However, it presents the lowest displacement when flexural load reached the maximum so it is stiffer than the u shaped arrangement.

3.2. Compression properties

After compression test, deformed composites show cracks on external layers and a total crash of cross-links as shown in ***Figure 6.***

According to the experimental stress-deformation curves shown in ***Figure 7***, the U- and V-shaped composites show a linear elastic

Figure 6 Deformed 3D composites under flat compressive loads: (a) V and (b) U-shaped composites

behavior until the matrix cracking begins. Then, the load starts to decrease due to the destruction of the cross links. This phenomenon continues until the connecting layers fail completely.

Table 1

Bending and compression test results of 3D consolidated spacer fabrics

	Three-point bending test		Compression test	
Sample	Maximum stress (MPa)	Elasticity Modulus (MPa)	Maximum stress (MPa)	Elasticity Modulus (MPa)
V-shaped composite	3.42	4.96	2.8	2.86
U-shaped composite	1.49	2.75	3.68	4.56

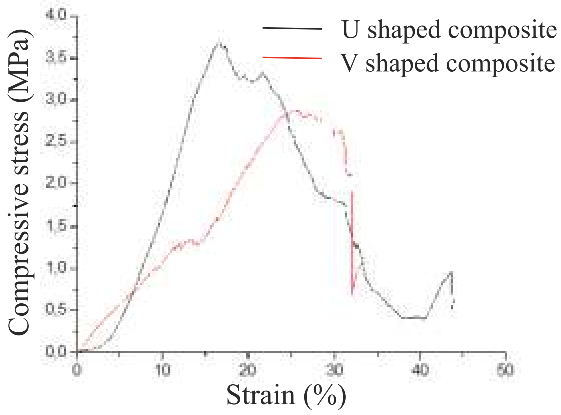


Figure 7. stress-displacement curves of compression tests on 3D spacer fabric composites

It can also be seen from table 1 that the U-shaped composite has the highest compressive stress and modulus. This could be explained by the vertical arrangement of cross-links, which is more resistant to compressive loads than V-connection since it allows a balanced distribution of load on composite surface layers.

We did not find similar tests made on knitted reinforced composites in literature given the scarcity of studies reporting on the development of such composites. Only U-shaped woven composite was developed and characterized by Mountasir et al. (Mountasir et al., 2013) and Wang et al. (Wang et al., 2014).

4. CONCLUSION

In this study, three dimensional flat-knitted spacer fabrics were produced for composite reinforcements.

The consolidated composites were characterized under compression and bending tests. Results show that sandwich panel having U-shaped cross-links is stiffer in compression whereas higher bending properties were obtained with the V-shaped arrangement.

Consequently, mechanical performances of knitted sandwich structures are greatly affected by the connecting layer's shape. Thus the selection of the spacer fabric according to its composite envisaged application is of primary importance.

Finally, the use of the cotton yarn as a reinforcement material can be seen as a trend to develop bio- composites in order to reduce the environmental impact of man-made fibers.

REFERENCES

[1] **Abounaim, Md., Hoffmann, G., Diestel, O., Cherif, C. (2010)**: Thermoplastic composite from innovative flat knitted 3D multi-layer spacer fabric using hybrid yarn and the study of 2D mechanical properties. *Composites Science and Technology*, 70, pp. 363-370

[2] **Laurenzi, S., Grilli, A., Pinna, M., De Nicola, F., Cattaneo, G., Marchetti, M. (2014)**: Process simulation for a large composite aeronautic beam by resin transfer molding. *Composites: Part B*, 57, pp. 47-55.

[3] **Mountasir, A., Hoffmann, G., Cherif, C., Löser, M., Műhl, A., Grobmann, K. (2013)**: Development of non-crimp multi-layered 3D spacer fabric structures using hybrid yarns for thermoplastic composites. *Procedia Materials Science,* 2, pp. 10-17.

[4] **Wang, M., Cao, H., Qian, K. (2014)**: Mechanical properties of three-dimensional fabric sandwich composites. *Journal of Engineered Fibers and Fabrics*, 9, pp. 1-7.