



EVALUATION OF TEXTILE COMPOSITES MANUFACTURED BY INFUSION

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Abstract: The polymer composites provide physicochemical and mechanical properties which in many cases have advantages over structures made of steel and aluminum. Additionally, with the evolution of demand for new and challenging applications, manufacturing techniques are increasingly moving to the use of methods and equipments that man dependence is increasingly reduced to ensure quality and repeatability of manufactured material. Examples of this gradual development are the fiber placement (FP) and tape laying (TL) processes in addition to the already established BMC, SMC, RTM, filament winding and infusion processes. Considering, however, geometric shapes as well as amount and orientation of fiber, few of them can meet these requirements satisfactorily. Textile preforms manufacturing techniques allow to lay-up the desired amount of fiber in any position as well as guide them in the directions according to design, also allowing to create different geometric shapes and local reinforcement. In the present study unidirectional high strength carbon fiber preforms were manufactured by the Tailored Fiber Placement (TFP) process using nonwoven fabric substrates. Composite panels were manufactured by infusion and the geometry specimens followed the dimensions given by ASTM D-3039. Results of tensile test specimens in the longitudinal direction exhibited a strength of 2285 MPa, Young modulus of 137 GPa and strain around 1.47% for panels with 54% fiber ratio. In the transverse direction the results were respectively 37 MPa, 5 GPa and 0.60.

Keywords: Process, Tailored fiber placement, Carbon fiber, Textile composites, Infusion, Mechanical properties.

1. INTRODUCTION

The benefits that composite materials provide are widely known and are now applied in almost all industry segments, either as an auxiliary component, part of a structure or even composing the whole structure, as the Boeing 787 and Airbus A350.

It is true, however, that such success in high responsibility applications, requires a chain of knowledge very well mastered, which include, among others, the constituent raw materials, determination of elastic and mechanical properties, structural design, design and manufacturing.

Considering the reinforcing elements of a composite material, the fibers are provided in the form of chopped fibers and continuous tow and the last has arrangements, for instance, in the form of fabrics.

Processes such as filament winding, braiding and fiber placement, shown in Figure 1, use the basic form of the material, which are continuous filaments, that can generate structures such as pressure vessels, pipes and cylinders.

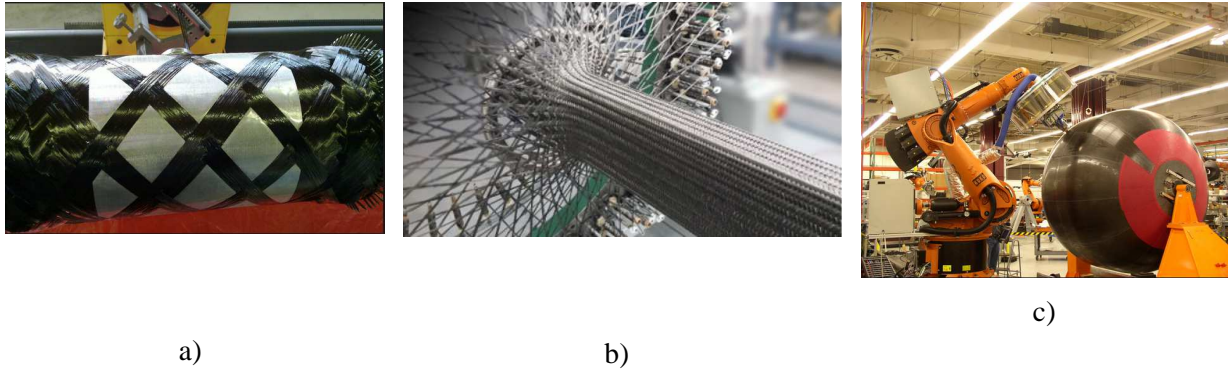


Figure 1- a) Filament winding [1], b) Braiding [2], c) Fiber Placement [3].

Lamination processes typically use reinforcement as fabrics and depending on how they are made, can be manufactured in plain weave, twill or satin architecture, as illustrated in Figure 2 [4]. In these fabrics, the directions of the fibers are perpendicularly to each other, forming the bi-directional fabrics, known as fabric 0/90, in reference to the orientation 0° (warp) and 90° (weft). This technique is widely used by the companies of fiber weaving, whether glass, carbon or aramid fiber.

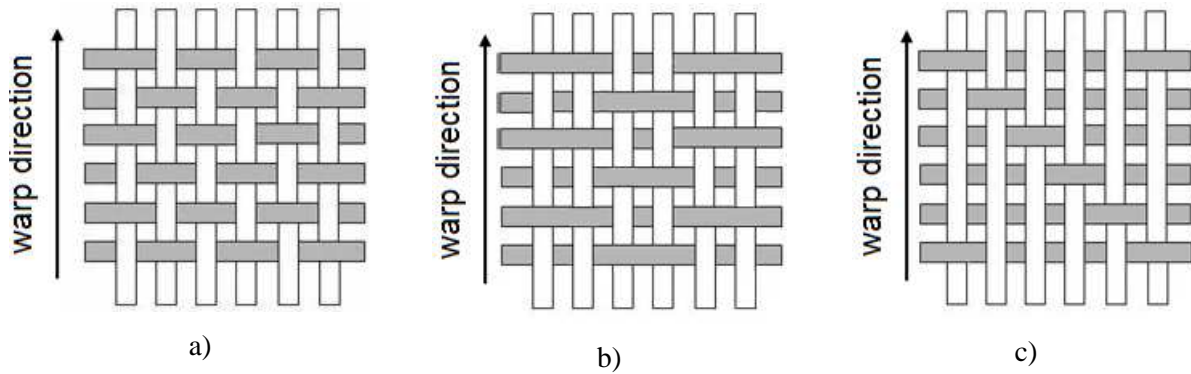


Figure 2- Fabrics architectures: a) Plain weave, b) Twill, c) Satin [4].

Due to loads that can act in a composite structure, the fabrics are also manufactured with the fibers in orientations other than 0° and 90° , as the triaxial and quadraxial fabrics, as shown in Figure 3 [5].

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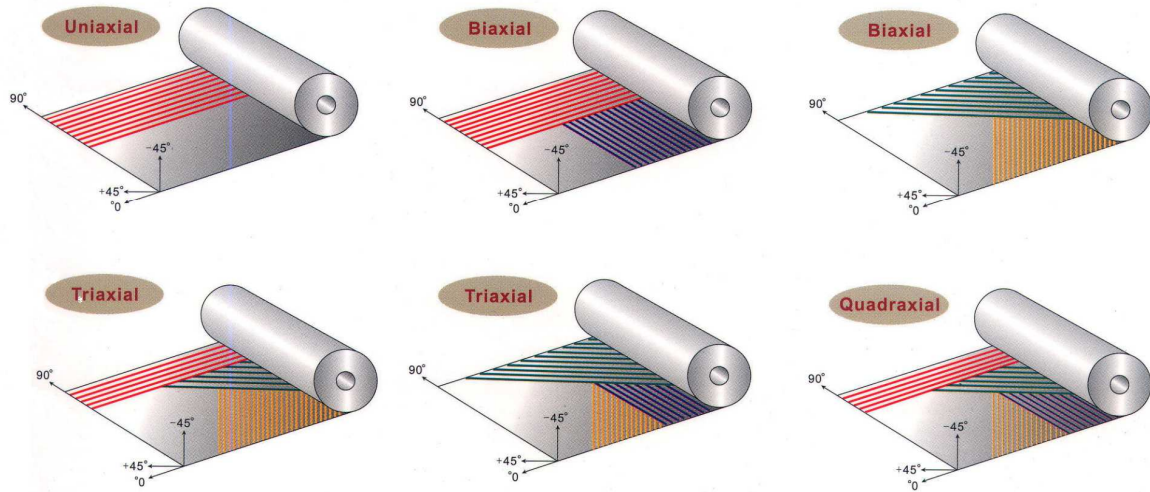


Figure 3- Multidirectional fabrics [5].

Even with this wide range of arrangements and fabrics forms, the expansion of composites, regarding new and challenging applications, has demanded for fibers position in directions that does not follows the fabric 0/90 array or multidirectional. To supply new design requirements, textile composites emerged as a constructive solution for composite structures production, as Tailoring Fiber Placement (TFP), for instance. In the textile process, the fiber may be placed in a pre-determined fiber path, making the manufacture more rational, economical and fast.

TFP process allows the consistent transfer of calculated locally optimum fiber quantities and orientations into fiber preforms [6]. This technology, uses a pre-determined fiber path designed, using suitable software, to accommodate the loading experienced by a fiber reinforced polymer composite, where a stitching head, a numerically controlled frame (with x-y movement) and a steering unit (with 360° movement) are used to orient fibers according to the designed path [7]. Preforms composite structures manufactured by TFP is still not widespread and not well known by the composite manufacturers and design engineers. A limitation that can be attributed to the textiles may be to build arrangements for a specific design. Figure 4 shows some preforms manufactured by TFP technology.

The process for manufacturing a component is finished with a suitable impregnation of the preform with a polymer matrix. Infusion and RTM are processes that ensure high fiber volumetric fraction and reduced voids volume and excellent surface finish.

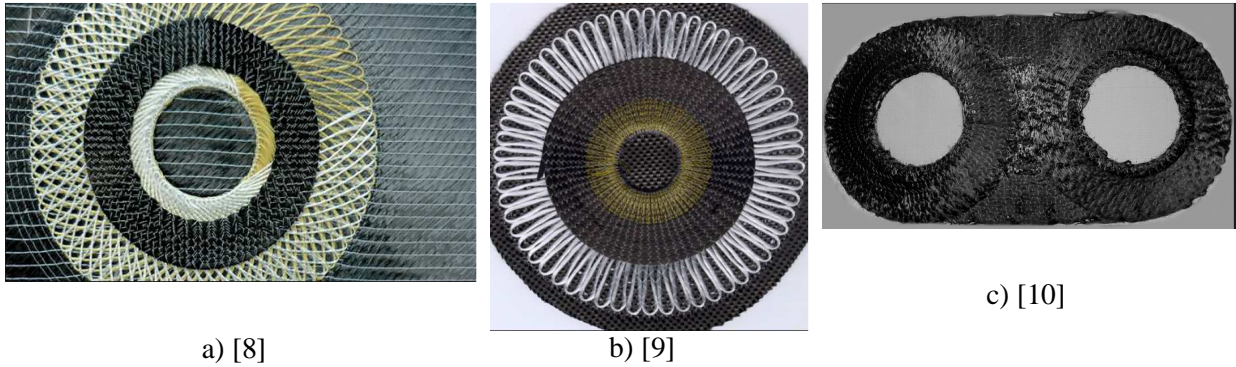


Figure 4- Preforms arrangements using the TFP technique.

A TFP machine has the basic features that a traditional sewing machine and has a great similarity to embroiderers machines. Besides the coordinated movement of the table in two perpendicular directions, a stationary embroidery head stitches a single carbon tow or a glass roving on to a thin backing fabrics (substrate) to provide localized in-plane and through-thickness reinforcement [11], as illustrated by Figure 5. Moreover with suitable softwares developed for the preforms fabrication purpose, make a TFP machine sophisticated and with high price. So, TFP composites could be a solution for some specific problems, for instance, for manufacturing composites in which the design requires orientations of the fiber that other process does not performed well.

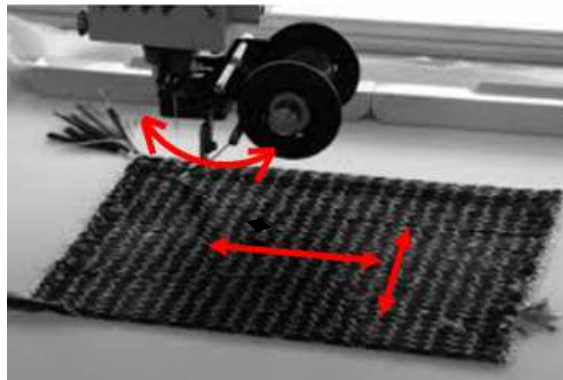


Figure 5- Movements of a TFP machine [11].

Applications involving localized reinforcement areas [12] allow that designs are made possible using the TFP technique, which otherwise would make the work costly and more heavy. One of the solutions that the TFP technique offers is in manufacturing structures with openings or holes, where drilling tools or cutting could damage the continuous fibers can create localized damage [13].

2. MATERIALS AND METHODS

In the present study the preforms were manufactured by a Tailored Fiber Placement (TFP) that used a Toray T700 12k carbon fiber and sizing for epoxy resin. The properties of this fiber are shown in Table 1 [14]. The preforms were 300 mm long and 160 wide, manufactured with 3 unidirectional layers.

The carbon fiber was stitched in a non-woven substrate using an upper and under polyester thread of 12 tex supplied by Coats. After the infusion, the resin system were thermal cured and the final

temperature was 130°C. After cooling, the plates were released from mold and the cut was performed using a diamond saw

Table 1- Toray carbon fiber T700 12k properties [14].

Toray T700 12k	Properties
Tensile Strength	4900 MPa
Tensile Modulus	240 GPa
Strain	2%
Density	1.80 g.cm ⁻³
Filament Diameter	7.0 μm

The composite panels were manufactured by infusion using the TFP preforms and an epoxy system as matrix (epoxy resin, anhydride curing agent and benzyl dimethylamine accelerator). The dimensions of the specimens followed the guidelines of ASTM D3039 and the cut was made using diamond rotating discs. Figure 6 illustrates a preform manufactured with a non-woven backing fabric.

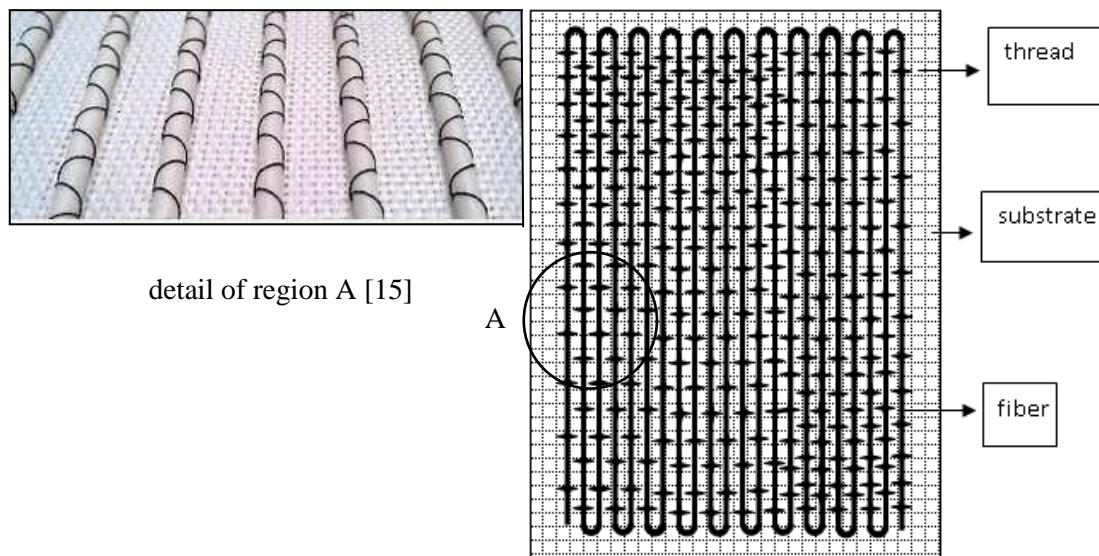


Figure 6- Illustration of a preform manufactured with a non-woven backing fabric.

At the ends of the specimens were bonded tabs, in accordance ASTM D-3039, which were made of glass fiber and polyester resin. The dimensions of the specimens in the longitudinal direction of the fiber were 250 mm long, 15 mm wide and 1 mm thick; while for specimens with fiber loading in the transverse direction the dimensions were 175 mm long, 25 mm wide and 2 mm thick. The tensile tests were carried out using an Instron universal testing machine with displacement of 1 mm/min and the loading is measured using a 150 kN cell.

In Figure 7 [16] is shown an equipment for manufacturing preforms by Tailored Fiber Placement in which the fibers are stitched onto a substrate which suit as support for the preform fabrication. It was used a non-woven backing fabric made of polyester.



Figure 7- Illustration of a Tailored Fiber Placement (TFP) [16].

3. RESULTS

This paper presents an experimental investigation of carbon fiber/epoxy composites stitched with polyester thread of Coats. In this work, tensile tests were performed to obtain the strength and Young modulus of the unidirectional (UD) infused TFP panels. For comparison, the results were compared with properties of UD specimens manufactured by a filament winding machine with the same fiber and polymeric matrix. The fiber content of each laminate was determined following the ASTM D-3171-99 Procedure A. The fiber volume fraction of TFP panels was 54% and filament winding panels was 65%.

It must be considered that the comparison with the filament winding process is quite appropriate since in this process there is a perfect integration of the polymer matrix with the fibers, condition which can not be achieved in the TFP process due to the presence of the thread within the composite. That is why it was decided to compare the properties obtained from TFP specimens with those obtained by the filament winding process.

Samples for microscopic analysis were taken out from the infused TFP plates and placed in moulding cups. Epoxy resin and hardener were mixed, poured into the moulding cups and cured at room temperature to provide an appropriate support for microscopic optical observations. To grind the samples it was used a grinding and polishing automatic equipment supplied by Struers with silicon carbide grinding paper 320, 500 and 800 grit. For final polishing, cloths with higher resilience and a lubricant with high viscosity were used. Diamond suspensions and spray were also used to obtain a constant removal rate.

A feature of the preforms manufactured by Tailored Fiber Placement is that the sewing thread remains as an integral part of the preform and the composite; and this causes an interference in fiber-resin matrix bonding. The presence of the sewing thread inside the matrix, which has a much larger diameter than the fiber, contributes for the formation of matrix veins (resin rich regions), as shown in Figures 8a and 8b, which may contribute for the occurrence of early failure in these regions. It remains to be noted that due to the resin veins there was a small reduction of the fiber volume fraction in the panels manufactured by TFP infusion compared to the filament winding panels.

Figure 9 shows a microscopic view of a specimen manufactured by filament winding. As can see, the monofilaments of carbon fibers of 7 μ m in diameter are covered by the polymeric matrix and no

rich region of resin was found. In this process there is no other fiber besides carbon fiber and the distribution of the reinforcement is more uniform. However, in this process there is a limitation of shape, because the winding equipment is designed for manufacturing mainly cylindrical and spherical structures.

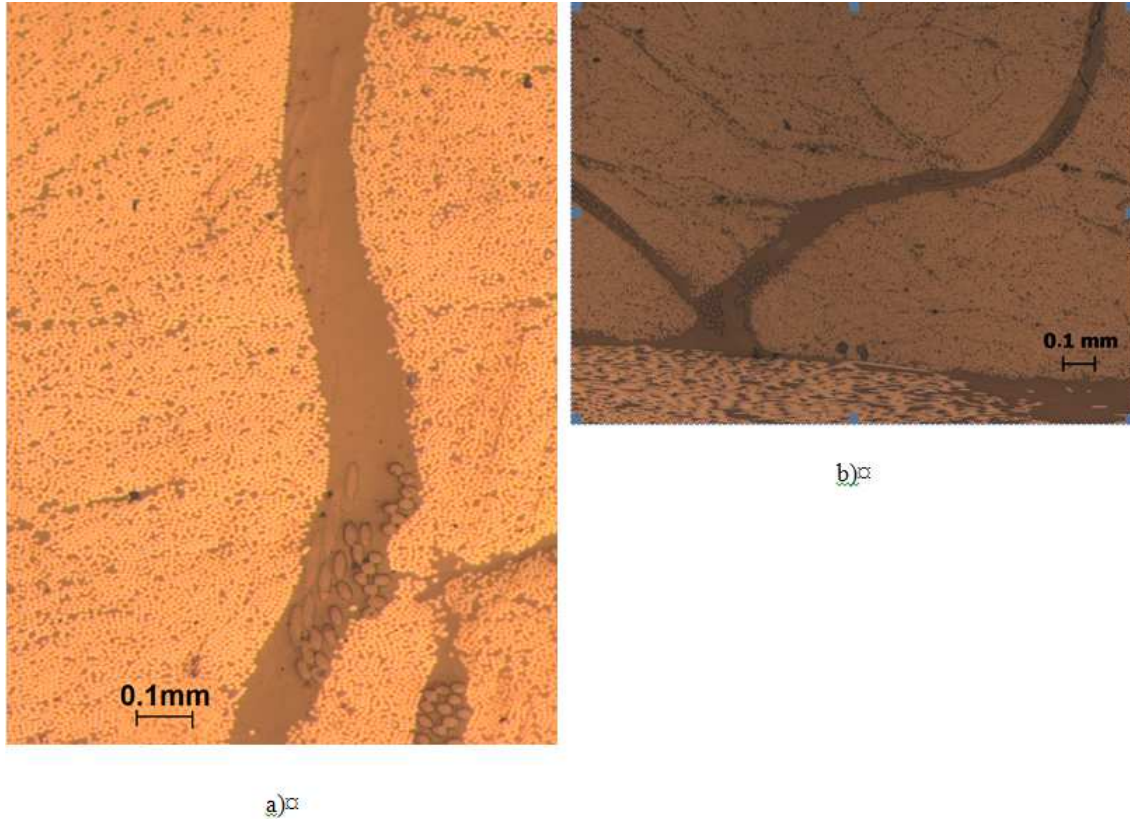


Figure 8: Polymer matrix composite veins.

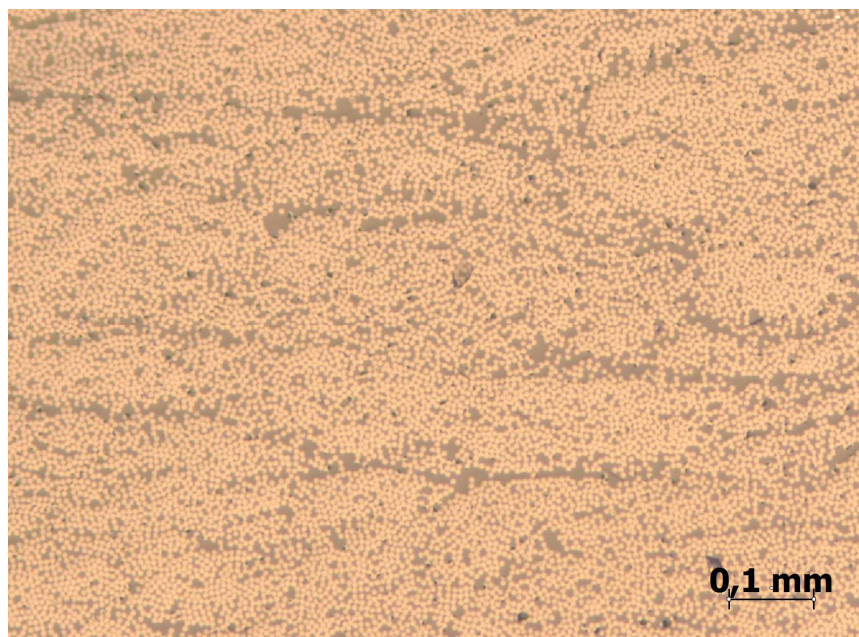


Figure 9: Transverse section of a specimen manufactured by filament winding.

3.1 TFP panels

3.1.1 Tensile tests in longitudinal direction

Table 2- Properties in the longitudinal direction-TFP.

Specimen	Strength (MPa)	Young Modulus (GPa)	Strain (%)
1	2270	132	1.60
2	2194	136	1.36
3	2303	139	1.45
4	2401	141	1.51
5	2241	138	1.41
mean value	2285	137	1.47
Standard deviation	89	3	0.09

3.1.2 Tensile tests in transverse direction

Table 3- Properties in the transverse direction-TFP.

Specimen	Strength (MPa)	Young Modulus (GPa)	Strain (%)
1	33	5	0.56
2	37	5	0.59
3	36	6	0.55
4	39	5	0.65
5	41	5	0.67
mean value	37	5	0.60
standard deviation	3	0	0.05

3.2 Filament winding panels

3.2.1 Tensile tests in longitudinal direction

Table 4- Properties in the longitudinal direction-filament winding.

Specimen	Strength (MPa)	Young Modulus (GPa)	Strain (%)
1	2870	148	1,92
2	2947	137	1,86
3	2883	146	1,84
4	3047	144	1,91
5	2912	140	1,84
mean value	2932	143	1,87
standard deviation	71	4	0.00

3.2.2 Tensile tests in transverse direction

Table 5- Properties in the transverse direction-filament winding.

Specimen	Strength (MPa)	Young Modulus (GPa)	Strain (%)
1	40	9	0.40
2	43	8	0.40
3	36	9	0.34
4	38	8	0.37
5	43	9	0.41
mean value	40	9	0.38
standard deviation	3	0	0.00

The significant effect that was observed on the longitudinal tensile tests was a reduction in the strength of the specimens manufactured by TFP relative to the filament winding ones. Thus, it appears that the presence of the thread and the resin veins play an important role in the composite mechanical behavior.

Analyzing the results shown in the Tables 2 through 5, the specimens taken from the TFP panels have longitudinal strength and Young modulus values, respectively 23% and 4% lower than the ones from filament winding, while in the transverse direction strength and modulus decreased respectively 8% and 55%.

The tensile strength in the transverse direction is given predominantly by the polymer matrix. The presence of the polyester thread in the epoxy matrix could behavior as “voids” and seems to damaged the matrix, decreasing the epoxy matrix strength, that is normally in the range of 65-70 MPa. Moreover, it is important to note that the adhesion between the fiber and the thread is not as good as between the fiber and epoxy matrix. The carbon fiber in the present study has a sizing compatible with epoxy resin, which favors the adhesion between fiber and matrix. The fact is that even with a less matrix volume fraction, the specimens from panels manufactured by filament winding resulted in higher transverse stresses.

CONCLUSIONS

The use of the TFP process opens new frontiers for composites, creating the possibility of new projects and use that could not be addressed using tapes and cross-ply fabrics.

The properties in the longitudinal direction of specimens manufactured by the TFP process, compared to the filament winding process, showed a reduction that could be attributed to the resin veins, although the volume fraction of the filament winding panels were higher than the ones manufactured by TFP. Also assign that the transverse strength of TFP specimens was lower because the thread has a poor adhesion to the polymer matrix.

However, this technique allows to reinforce some regions of a composite structure, following predetermined fiber orientation, without this can be done by other techniques.

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