MECHANICAL CHARACTERIZATION OF CARBON FIBRE COMPOSITES WITH THE REINFORCEMENT AT DIFFERENT ORIENTATION

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ABSTRACT

The aim of this study was to obtain mechanical properties of angle-ply composites manufactured by filament winding. The carbon/epoxy angle-ply composite was manufactured considering different reinforcement orientation. The coupons were manufactured in the directions of 0º, ±10º, ±20º, ±30º, ±60º, ±70º, ±80º e 90º, related to the loading direction. Results showed that for coupons with the fibre in the ±10º direction the mean strength and the mean modulus of elasticity were respectively 854 MPa and 134 GPa, while for coupons with the fibre in the ±80º direction the mean strength and the mean modulus of elasticity were respectively 68MPa and 9,3 GPa. The results indicated that mechanical strength decreases abruptly at orientations above ±10º. The fibre volumetric fraction was also obtained for all manufactured plates.

1-INTRODUCTION

Technological progress reached by several areas of engineering leads to a growing demand for new materials able to be applied in extreme conditions of temperature, pressure, chemical attack and mechanical loading, aiming at more profitable new projects.

Polymeric composites have several advantages when compared to metallic materials. Its resistance to corrosive atmospheres, associated to its high strength-to-weight and stiffness-to-weight ratios have increased their application in structures that demand low specific weight without changes of properties.

For an effective use of the polymeric composites in structural applications, considering the countless possibilities of composite construction, a proper knowledge of tension and strain analysis and production techniques, as well as mechanical characterization and thermal analysis are necessary tools for engineers working with these materials.

As mechanical strength and rigidity can be changed as a function of reinforcement type and orientation, matrix and their contents, it becomes important to know the composite properties to assist important applications.

This work presents a study of carbon/epoxy angle-ply composites in which mechanical properties were determined in specimens manufactured by filament winding with orientation of 0º, ±10º, ±20º, ±30º (low angles), ±60º, ±70º, ±80º and 90º (high angles).

2- MATERIALS AND METHODS

Filament winding is one of the most efficient methods to manufacture composites, because it allows placing reinforcement in different orientations. It also allows pulling the fibre at an appropriate tension as well as to control the content of the constituent materials (fibre and matrix) in the composite. It is a common method employed to manufacture cylindrical structures, mainly for the aerospace, nautical and chemical and petrochemical industries[1].

The material chosen for this study is a carbon fibre T300. The fibre is a PAN-based high tensile carbon fibre of 6000 filaments per bundle, impregnated with an epoxy resin-anhydride system.

The manufacturing process is usually the one that produces fiber crossovers. This means that helical pattern is characterized by fibres crossovers at certain points along the mandrel and the layers are wound in pairs, in other words, one layer is wound at $+\theta$ and the other one at $-\theta$, in two simultaneous layers. Depending on the winding pattern it is possible to have one or more fiber crossovers. In this process, end closures can be incorporated to the mandrel.

In order to avoid any other kind of stress in the specimens besides the tensile stress, it was chosen a symmetrical lay-up. So, instead of laying-up according to the sequence $[\pm\theta/\pm\theta]$ that is obtained by the cross process, it was developed a process in which the layers are wound independently, layer by layer, that was called overlap process. The lay-up sequence was $[+\theta/-\theta/-\theta/+\theta]$.

In the overlap process, each complete layer is placed just forming an angle with the longitudinal mandrel axis, for instance, $+\theta$ [2]. The advantage provided by this method is to make possible the manufacture of symmetrical composites by the filament winding process, which would be extremely difficult by another process, with the exception of the prepreg process.

The 1 mm thickness plates were laid with $[0_4]_T$, $[\pm 10]_S$, $[\pm 20]_S$, $[\pm 30]_S$ and the 2 mm ones with $[\pm 60]_{2S}$, $[\pm 70]_{2S}$, $[\pm 80]_{2S}$ and $[90_8]_T$. The plates were thermal cured with the last step at 130ºC. Specimens were saw cut from the plates to a final dimension of 250 x 15 x 1 mm for 0º, 10º, 20º and 30º and of 175 x 25 x 2 for 60º, 70º, 80º and 90º. A sketch showing the positions of the specimens on the plates where they were cut off can be seen on Figure 1, for a plate manufactured with 70º. Both mandrel and resin bath were kept at the same temperature during the winding process.

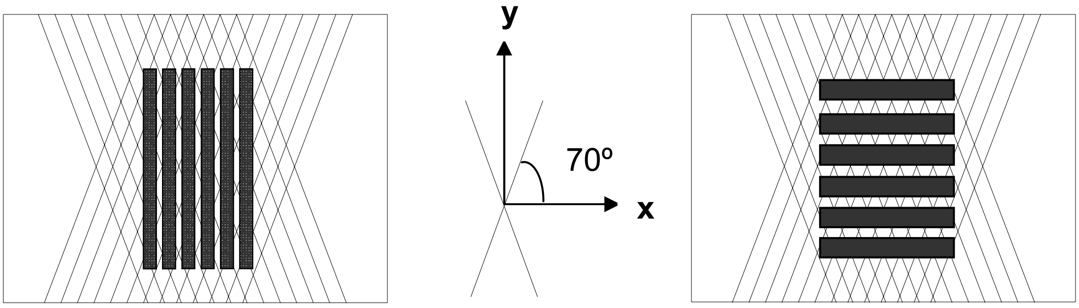


Figure 1: Sketch of the specimens cut for a plate manufactured with 70º.

To obtain the Poisson ratios for the specimens manufactured with low angles, the strains in the longitudinal and in the transverse directions were determined by means of strain gages, as shown in Figure 2. A data acquisition system was employed in order to obtain the values of strains as the loading was increased. For high angles, the strains in both directions were determined by means of bi-directional extensometer.

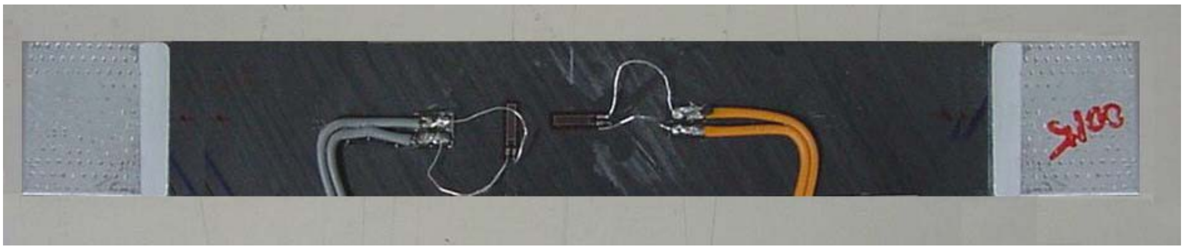


Figure 2: Strain gages bonded to the specimens.

The winding machine used in the present work is the one that fastens the mandrel in the horizontal position while the feed carriage shuttles backward and forward at a speed to generate the desired helical angle or winding angle [2]. Figure 3 illustrates a filament winding machine that has two degrees of freedom [3]. In this figure, one of the axes rotates the mandrel and the other moves the feed carriage parallel to the mandrel.

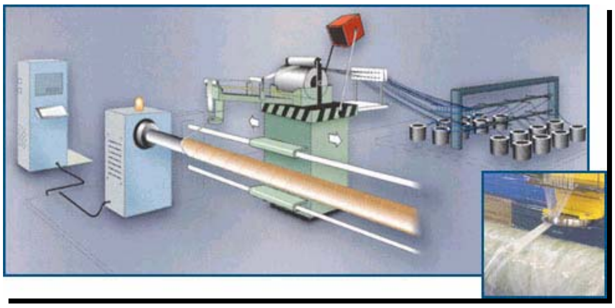


Figure 3: Illustration of a filament winding machine.

3- RESULTS AND DISCUSSION

ASTM D3039 [4], that guides tensile test procedures, defines the specimens dimensions for reinforcement wound at 0º and 90º directions, but it does not define clearly specimen dimensions for angles between 0º and 90º. So, for specimens that were manufactured with ±10º, ±20º and ±30º the dimensions adopted corresponded to that in the 0º direction: length of 250 mm and width of 15 mm. For angles at ±60º, ±70º, ±80º the specimen dimensions corresponded to that at 90º direction, with length of 175 mm and width of 25 mm. The differences between specimen's dimensions take into account that more close the filaments are of the applied load direction larger resistance the material will have.

In the Figures 3 to 10, typical curves of tensile strength versus strain are shown and mechanical properties were obtained for each of the angles proposed in this study. As it was mention, for low angles (0º, ±10º, ±20º, ±30º) it was used strain gages and for high angles (±60º, ±70º, ±80º, 90º) a bi-directional extensometer. There is a decrease of the tensile strength with the increase of the winding angle. This behavior is due to the fibres deviation from the loading direction when the winding angle is increased, which reduces the composite strength as can be seen in Table 1.

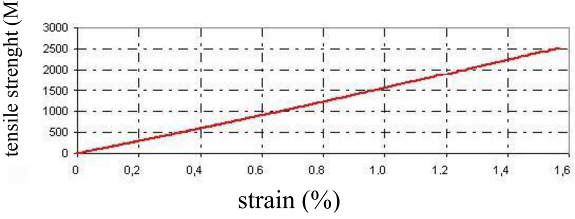
The effect of fibre orientation on the tensile strength, modulus of elasticity and Poisson ratio is shown respectively in Figures 11, 12 and 13 for a typical carbon/epoxy angle-ply composite. It is seen that for low angles a change of just ±10º in the fibre direction, related to the loading direction, the tensile strength decreased 30% in comparison to the 0º direction. The modulus of elasticity showed a less accentuated reduction for the same change in winding angle. It decreased of about 10%.

The Poisson ratio was the property that showed a non expected behavior, as its maximum value was around 35°.

For winding angles of ±60º/±70º/±80º/90º no significant change in properties were obtained. The tensile strength and modulus of elasticity presented equivalent values to a net epoxy specimen.

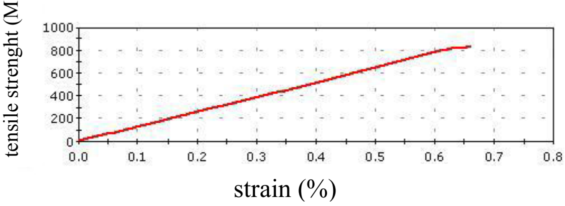
The average value of fibre volume, obtained by ignition loss procedure [5], was 66% and the average voids fraction was 1.4%.

The experimental and the theoretical properties are given, respectively, by Table 1 and Table 2 and the results show a close agreement. The theoretical properties were obtained from Classical Laminated Theory [6].



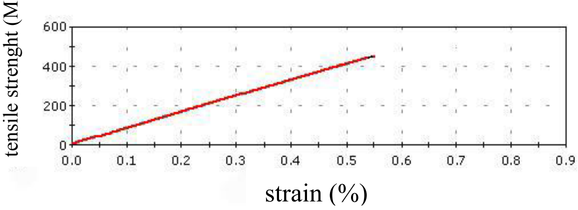
(0º)

Figure 3: Typical tension versus strain curve for carbon/epoxy composite specimens with 0º winding angle.



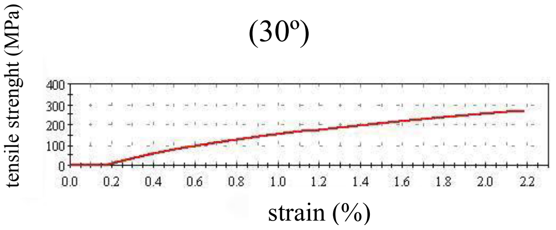
(10º)

Figure 4**:** Typical tension versus strain curve for carbon/epoxy composite specimens with ±10º winding angle.



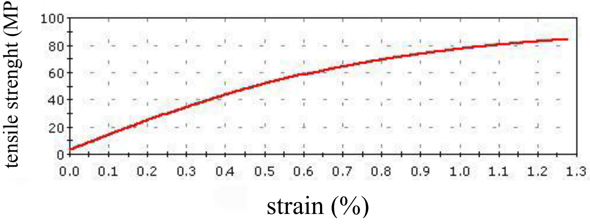
(20º)

Figure 5: Typical tension versus strain curve for carbon/epoxy composite specimens with ±20º winding angle.



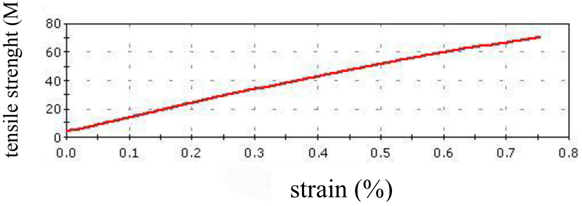
(30º)

Figure 6: Typical tension versus strain curve for carbon/epoxy composite specimens with ±30º winding angle.



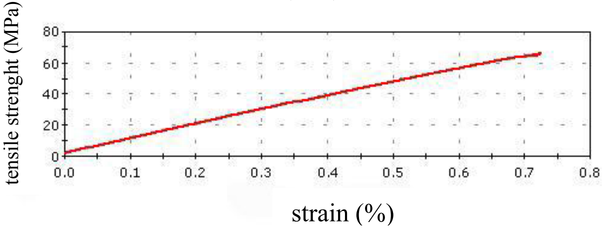
(60º)

Figure 7: Typical tension versus strain curve for carbon/epoxy composite specimens with ±60º winding angle.



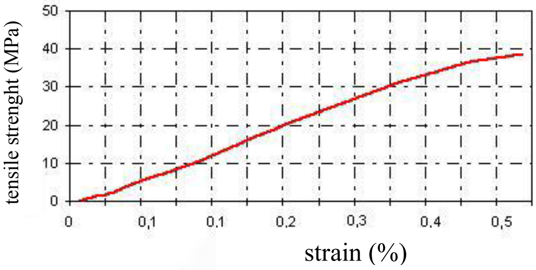
(70º)

Figure 8: Typical tension versus strain curve for carbon/epoxy composite specimens with ±70º winding angle.



(80º)

Figure 9: Typical tension versus strain curve for carbon/epoxy composite specimens with ±80º winding angle.



(90º)

Figure 10: Typical tension versus strain curve for carbon/epoxy composite specimens with 90º winding angle.

It is important to mention that for specimens with 90º, the extensometer was removed when the load reached 60% of the rupture load, in order to avoid damage in the device due to the specimen rupture. This is the explanation for the difference in the tensile stress between that is shown in the Figure 10 and that of the Table 1.

Table 1: Experimental properties of carbon fibre composites as a function of winding angle.

winding angle	**Tensile strength (MPa)**	**Modulus of elasticity (GPa)**	**Poisson ratio**
0º	2509 ± 100	153,0 ± 4,0	0,30 ± 0,01
± 10º	854 ± 45	134,0 ± 4,0	0,60 ± 0,02
± 20º	537 ± 8	83,0 ± 2,0	1,44 ± 0,02
± 30º	292 ± 3	34,0 ± 1,0	1,62 ± 0,02
± 60º	83 ± 3	10,9 ± 0,3	0,48 ± 0,04
± 70º	64 ± 1	9,7 ± 0,8	0,15 ± 0,04
± 80º	68 ± 3	9,3 ± 0,3	0,05 ± 0,02
90º	73 ± 6	10,5 ± 0,6	0,02 ± 0,01

Table 2- Theoretical properties of carbon fibre composites as a function of winding angle.

winding angle	**Tensile strength (MPa)**	**Modulus of elasticity (GPa)**	**Poisson ratio**
0º	2510	153,0	0,30
± 10º	855	141,3	0,64
± 20º	536	102,8	1,23
± 30º	292	57,2	1,29
± 60º	84	13,3	0,30
± 70º	57	11,4	0,14
± 80º	59	10,7	0,05
90º	73	10,5	0,02

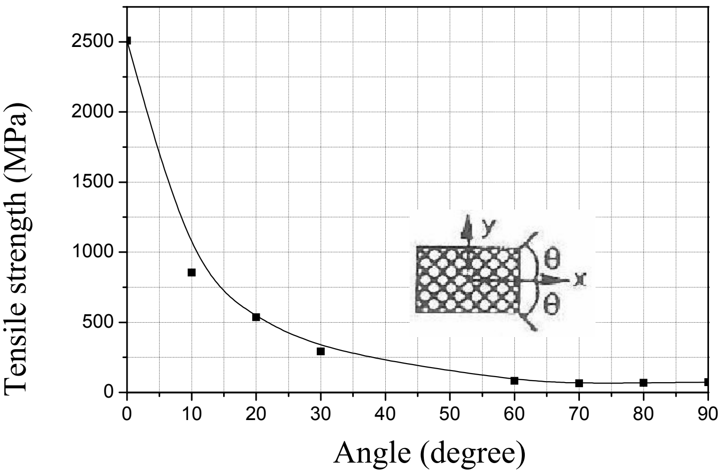


Figure 11: Tensile strength (σ_x) of carbon fibre angle-ply composite as a function of winding angle.

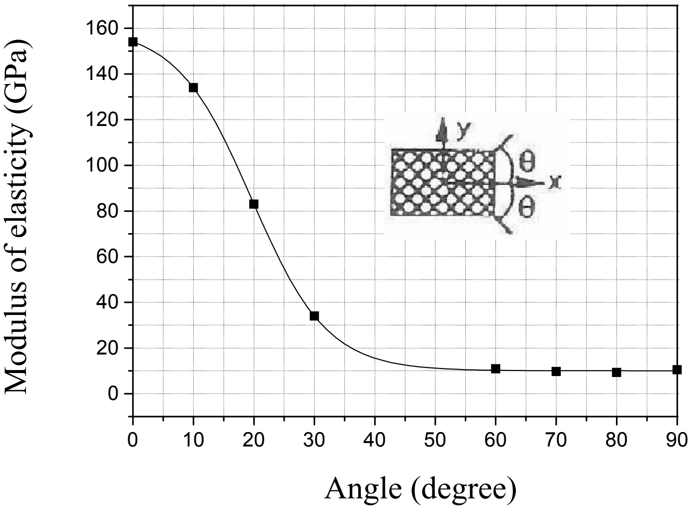


Figure 12: Modulus of elasticity (E_x) of carbon fibre angle-ply composite as a function of winding angle.

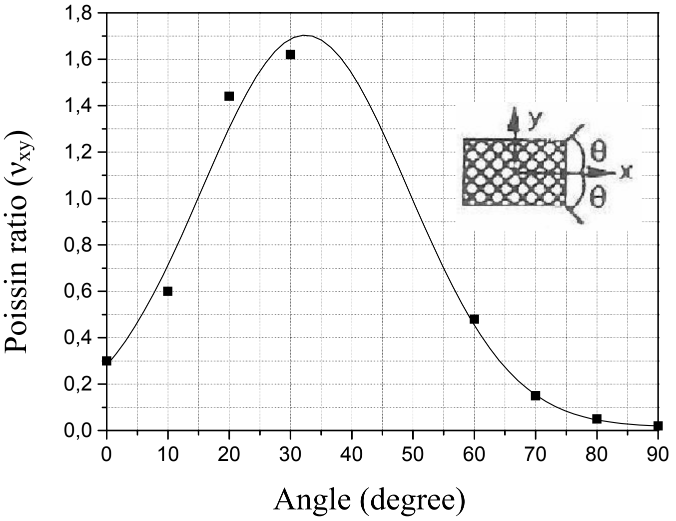


Figure 13: Poisson ratio (ν_{xy}) of carbon fibre angle-ply composite as a function of winding angle

6- CONCLUSIONS

Tensile tests results showed that the strength and the modulus of elasticity are strongly dependent on the reinforcement orientation. This dependency is more accentuated for winding angles 0º, ±10º, ±20º and ±30º, in which the fibres are closer to the loading direction.

The results obtained for specimens wound with ±60º, ±70º, ±80º and 90º, showed that these composites properties were less affected by their orientation, relapsing over the matrix the material strength. This may be due to the fact that for winding angles above 60º in relation to loading direction, the contribution of fibre strength is very low and there is no improvement to the composite performance.

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