# Effect of the Fiber Density in the Mechanical Properties of Non-Crimp-Glass Fabric Reinforced Composite Materials

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## 1. Abstract.

The relationship between textile architecture and fiber density with the sequence damage under tensile loading has been investigated for a composite material reinforced with a non-crimp-glass fiber textile of configuration [-45º,+45º] based on epoxy resin matrix cured with high temperature hardener. Two textiles of different density were used (440 ±5% and 227 ±5% g/m$^2$). The system chosen for this work consists of a bifunctional epoxy, diglycidyl ether of bisphenol A (DGEBA), cured with a tetrafunctional amine, diaminodiphenyl sulfone (DDS). This system ensures the obtaining of a rigid material with excellent mechanical properties in order to observe, analyze and identify the process and progress of the generated damage and the failure mechanism which leads to the materials fracture.

## 2. Introduction.

Stitching technologies are considered to be one of the key technologies for the automated, cost-reduced manufacture of complex textile preforms subsequently used for liquid composite moulding (LCM) of high-performance fibre-reinforced polymer composites [1]. In contrast to the integral three-dimensional (3D) fibre structures typical of woven, knitted, and braided composites, the stitching process is characterised by the insertion of a through-thethickness yarn into traditional two-dimensional (2D) preforms as a secondary processing step following lay-up. Recently, multi-axial multi-ply fabrics have attracted much attention of the composites industry [2,3,4]. Combination of unidirectional placement of fibres in plies with consolidation of the preform by stitching leads to a highly advantageous combination of material properties and processing. This results in the full use of fibre modulus and strength in a ready part and allows the use of Resin Transfer Moulding (RTM) for the production. The advantages of such through-the-thickness stitching include not only the cost-effective joining of fabric cloths with an improved ease-of-handling of the dry perform and the joining of composite structures with the possible replacement of mechanical fasteners but also a potentially improved interlaminar fracture toughness and impact damage resistance and tolerance of the final composite part when appropriate threads are used [5,6].

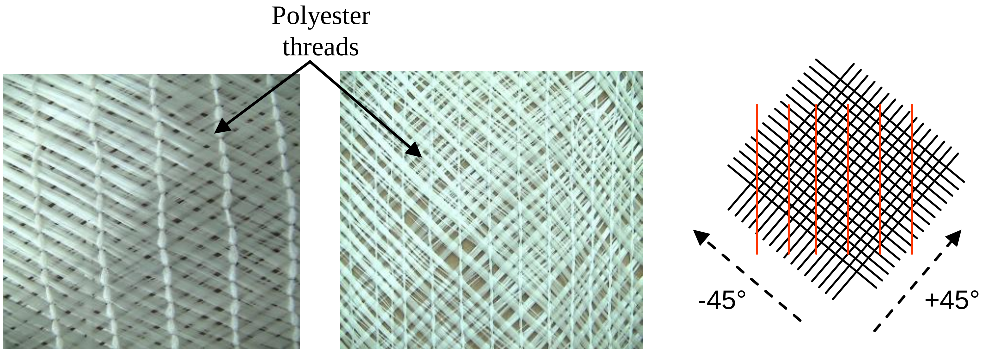
## 3. Experimental procedure.

Matter of the investigation is a glass-fibre non-crimp fabric reinforced epoxy composite. The bi-axial E-glass reinforcement textiles were provided by Italian industry Nastrificio Gavazzi, having a mass per unit area of 440±5% and 227±5% g/m$^2$ respectively and a stacking sequence of [-45º,+45º]. The layers have relative mass fractions as indicated in table 1 and are stitched together with a polyester multifil binding yarn. The unidirectional fiber bundles in the two planes are held together by a fine polyester thread in both sides. Figure 1 illustrates both multiaxial textiles where it is possible to observe the main difference between both cloths: the fibre density. Epoxy system chosen was constituted of resin D.E.R 331 from Dow Company which is a liquid resin of low viscosity and high content of epoxy groups. The hardener used was 4,4'-diamino-diphenylsulfone (DDS) from Aldrich which is an aromatic amine with functionality 4, molecular weight 248.3 gr/mol and melting point of 175-177ºC.

**Table 1.-** Technical specification of the textiles.

| Layer orientation | Weight g/m$^2$ | Composition |
|---|---|---|
| +45º | 217 | E- Glass |
| -45º | 217 | E- Glass |
| Knit yarn | 6 | Polyester (PES) |
| Total | 440±5% | |

| Layer orientation | Weight g/m$^2$ | Composition |
|---|---|---|
| +45º | 109 | E- Glass |
| -45º | 109 | E- Glass |
| Threads of stabilization | 4 | E- Glass |
| Knit yarn | 5 | Polyester (PES) |
| Total | 227±5% | |




a) b)

**Figure 1.-** Photos if both textiles a) 440±5% and b) 227±5%.

Using one layer of non-crimp fabric sheet and epoxy resin, composites with low fibre volume fraction (6.78% and 3.63% respectively) were manufactured by wet lay up process. Resin system was placed in a mould and then, the textile was laid in assuring a complete diffusion of the resin in the fabric filaments. The mould was placed in the oven for curing at 140ºC during 8 hrs. After this time, the lamina was cooled down to room temperature and finally it was withdrawn from the oven to get the samples for mechanical test. A Shimadzu machine was used for mechanical testing and crack development by using a loading cell of 5 KN. The cross-head speed for all tests was kept constant at 0.5 mm/min. The Iosipescu shear test (ASTM D5379) was investigated experimentally as a mean for determining the in-plane shear modulus and strength of multiaxial textile reinforced composite. The Iosipescu shear test uses a flat specimen that is easier to fabricate while achieving a pure and uniform shear strain-stress state over the test region. The ASTM standard prescribes V-notches with 90º opening angle, while the resulting stress field in the test region strongly depends on the material anisotropy, a feature present in many composite materials. Thus, the test performance depends both on actual material properties and on material orientation relative the test region. Due to an unusually small difference in the indices of optical refraction of the matrix-system and the glass-fibres, the obtained samples showed an extraordinary transparency Therefore, matrix cracks, voids, and inclusions could easily be detected by transmitted light photography. The glass fibres cannot be seen while the binding yarns remain visible.

## 4. Results

All manufactured composites appeared to be of a homogeneous good quality and surface finish; the procedure seams did not lead to any detrimental effects on either processability or general product appearance. Samples were cut from several laminas having each of the two planes directions (-45º,+45º) aligned to load direction in order to test the effect of the polyester knit yarn on the damage initiation and propagation. Figure 2 displays the tested orientations for each of the two types of textiles. Results for each orientation are discussed.

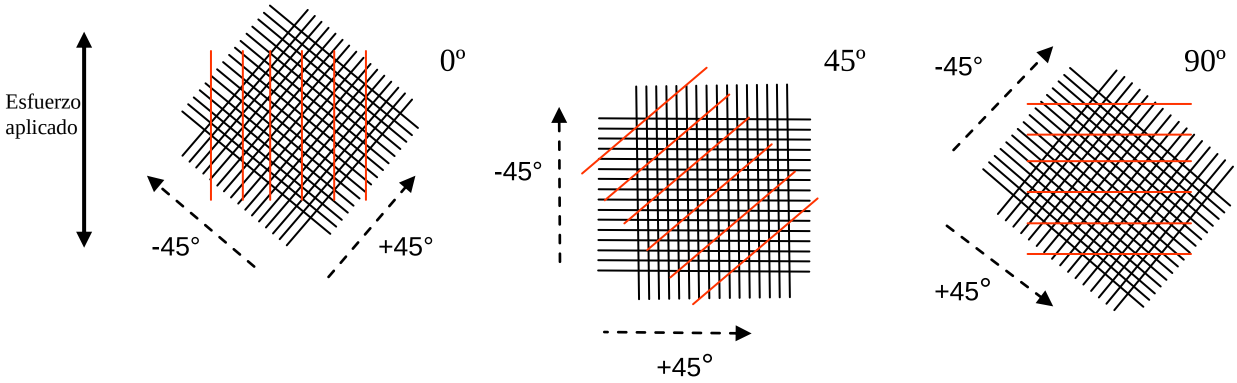



**Figure 2.-** Sketch of the direction tested I relation with the applied test (0º,45º and 90º).

Figure 3 shows typical stress-strain curves for textile 1 (440±5% g/m$^2$) where it is possible to visualize that, due to the fibre orientation to applied stress, 0º direction shows a smooth curve while for 45º and 90º some discontinuity or serrations appear because of the mayor amount of fibres oriented perpendicular to the applied stress. These discontinuities are intimately related to the appearance of significant cracks before total fracture of the sample. On the other hand, at 0º and 45º exhibited higher values for elastic modulus due to the effect of fibre reinforcing parallel to applied stress. Table 2 shows the numerical values.

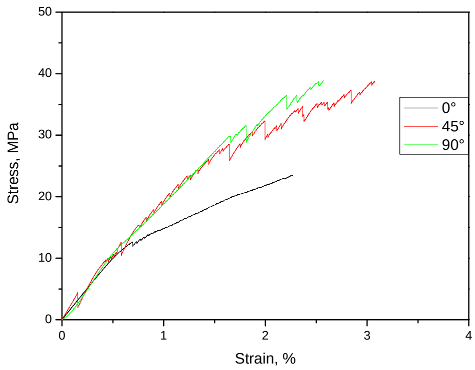



**Figure 3.-** Textile 1 tensile curves.

**Table 2.-** Mechanical parameters values.

| Angle | Elastic Modulus (MPa) | Max. Stress (MPa) | Max. Strain (%) |
|---|---|---|---|
| 0° | 2385.68 | 24.20 | 1.71 |
| 45° | 2324.56 | 35.41 | 3.21 |
| 90° | 1526.32 | 41.36 | 2.75 |

Figure 4 shows typical stress-strain curves for textile 2 (227±5% g/m$^2$). In this case 0º, 45º and 90º did not show distinctive drops related to damage development due to the sudden fracture when the first significant crack appeared. Only some samples at 45º exhibited some crack development along the samples. Table 3 shows the numerical values not to different to that found in textile 1. The resin system seems to be dominating the mechanical parameters.

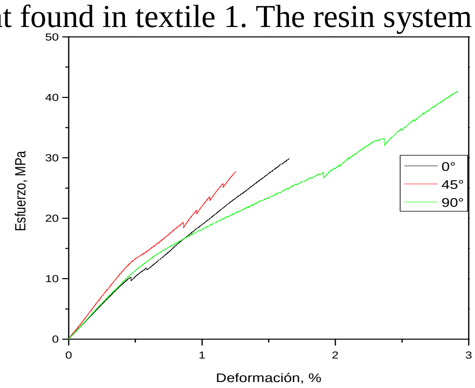
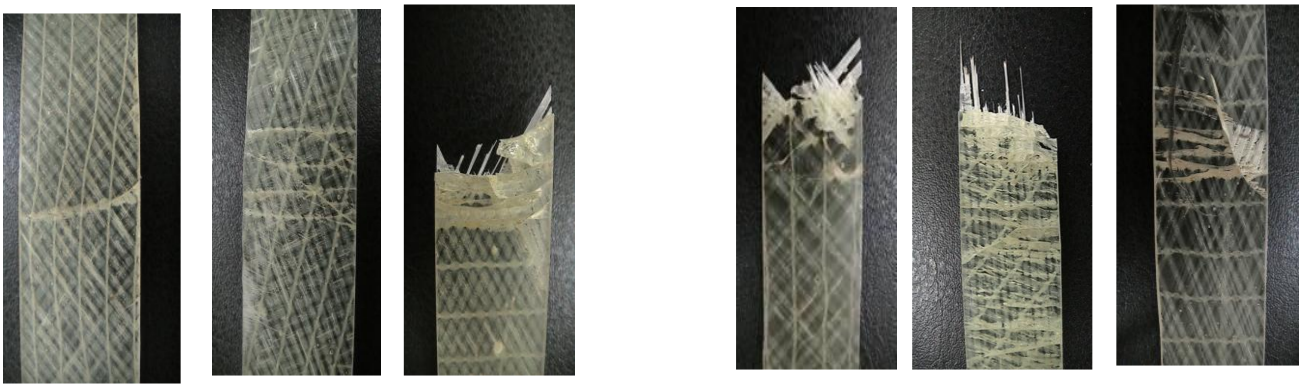



**Table 3.-** Mechanical parameters values.

| Angle | Elastic Modulus (MPa) | Max. Stress (MPa) | Max. Strain (%) |
|---|---|---|---|
| 0° | 2194.58 | 26.15 | 1.38 |
| 45° | 2495.44 | 22.24 | 1.19 |
| 90° | 2411.00 | 39.02 | 2.61 |

**Figure 4.-** Textile 2 tensile curves.

Figure 5 presents the damage development in the samples for each textile.

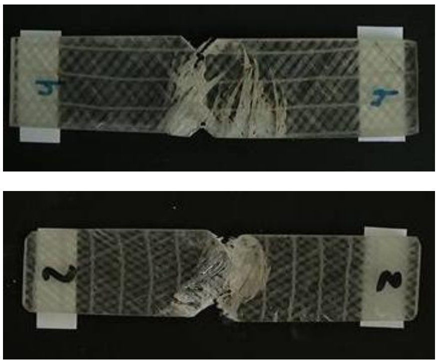


0º 45º 90º
Textile 1

0º 45º 90º
Textile 2

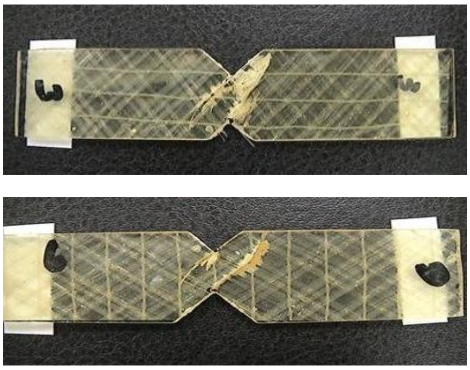
**Figure 5.-** Damage development in both textiles depending on fibre orientation.

Iousipescu test exhibited results that are not affected by the fibre orientation but the damage is influenced by fibre density. All the samples reinforced with both textiles were fractured in the middle, between the notches, in the stress concentration zones in accord to ASTM D5379 technique. Figure 6 displays the Iosipesu test fractured samples where it is possible to visualize the main crack with no additional damage in the sides.



0º

90



Textile 1 Textile 2

**Figure 6.-** Iosipecu test fractured samples.

## 5. Conclusions.

The mechanical properties of bi-axial glass-fabric textile reinforced epoxy composites were determined exhibiting a quasi-isotropic behaviour. Effects of reinforcement improving mechanical properties are not observed for low volume fraction composites. Damage development was observed to be higher in those cases were the major amount of fibres was perpendicularly oriented to the applied stress. Sudden fracture was also presented in samples having higher zones of rich resin zones where a significant crack could be formed generating a catastrophic failure. Iosipecu in-plane share demonstrated that there is not a significant effect of the textile orientation; however, density seems to influence the crack formation since samples reinforced with textile 1 (denser) exhibited higher amount of cracks surrounding the fracture zone in the sample.

## 6. References.

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