1 Introduction

Composite materials have been used for a long time in various industrial fields such as aeronautic or automotive due to their excellent properties. Nowadays, they are also valorized within buildings and they turn to be of current applications as strengthening rods or plates. The new advanced technologies in textile industry has allowed the emerge of novel fabric geometries used for composites reinforcement in addition to those traditionally produced in the textile market such as woven, non-woven, knitted or braided [1,2]. Textile composites offer several advantages over unidirectional (UD) composites, such as lower production costs, better drapability, higher delamination and impact strength. However, their mechanical in-plane properties, stiffness as well as strength, are lower than those of UD-composites. The reason for this drawback is the generally higher fiber undulation, which is due to the textile fiber architecture and to the fabrication process [2].

The textile architecture posses another challenge on the design process, because different fiber directions are no longer separated, but somehow connected through weaving, braiding, stitching, or knitting. Separate layers with a homogeneous fiber direction as in unidirectional preimpregnated composites are seldom found in textile composites. This kind of textiles is named non crimp fabrics (NCF) or multiaxial textiles. The description of the geometry of multi-axial multi-ply stitched preforms includes the geometry of the stitching yarns and geometry of the fibrous plies [3].

Recently NCF have gained a place in composite materials manufacture as reinforcement in many structural applications. These textiles consist in two or more layers of unidirectional fibres held together by a secondary non-structural fine additional yarn commonly of polyester. This holding thread ideally should not interfere with the mechanical properties; however it has been demonstrated [4] that it affects the cracking propagation in the composites. The main fibers can be made of any structural fibers available in any combination. The textile manufacture process allows any orientations in the fires more complex than that observed in woven (0°/90°).

On the other hand non-crimp fabric (NCF) reinforced polymers have attracted a lot of attention because of their mechanism. Therefore, the knowledge of the viscoelastic behavior is of considerable interest in materials development and application [5]. The previous studies [6, 7] have investigated the effect of fiber content on the creep behavior of polycarbonate (PC) and glass fiber reinforced polycarbonate (GFRPC). The effect was shown to be equivalent to the strengthening of the resin matrix. The purpose of this study is to understand the effect of orientation of NCF composite on static bending and bending creep behavior.

2 Materials and Experimental

2.1 Materials

A composite material based on epoxy matrix reinforced with glass-fibre non-crimp fabric was evaluated in this research. The multi-axial E-glass reinforcement textile (provided by Italian industry Nastrificio Gavazzi) has a mass per unit area of 972 ±5% g/m² and a [0°,+45°,90°,-45°] stacking sequence as displayed in Fig. 1. The layers are stitched together with a polyester (PES) multifil binding yarn. 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.

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Samples were cut from several laminas having each of the four plies of unidirectional fibers orientations (0º, ±45º, 90º) parallel to sample length in order to test the effect of the polyester knit yarn on the damage initiation and propagation (Fig. 2). Samples with 60mm length, 20mm wide and 3mm thick were obtained to be tested in flexural mode, and 50mm length, 10mm wide and 3mm thick were obtained to be tested in creep mode.

2.2 Experimental

Four-point bending test was carried out. Composite samples were loaded to progressively higher strain at a cross-head speed of 0.5 mm/min in a Shimadzu Universal Machine AG-1000E. Tests were performed with the outer and inner span being 30mm and 10mm respectively in air atmosphere. To confirm the difference of the crack density, the Acoustic Emission Method was used during static bending tests. Acoustic emission sensors were attached at both sample’s extremes to obtain the signal in order to be related to the damage development and mechanisms of fracture. During the test, AE signals were monitored by 2 AE broad band sensors (NF Electronic Instruments: AE-900M) and baseline grease was used as a coupled agent. The AE signals were amplified 40 dB and the threshold level was set to the value of 26.8 dB at the input of the sensors. The AE signals were processed by an AE analyzer (Vallen Systems, AMSY-5). The threshold for the AE equipment was established by performing preliminary analysis in order to be able to record the AE signals from the tests without spurious noise.

To understand the effect of orientation on creep behaviour, three-point bending creep test was carried out in silicon oil surroundings using HDT VSPT Tester S-3M (TOYOSEIKI Co., Ltd.). The span length used was 40mm. The applied loads were 15% load of their static bending strengths measured by three points bending test. The test temperatures was 100, 120, 140 and 160ºC, and test time is 100 min. To remove the influence of the moisture, physical aging and residual stresses, the specimens were dried at test temperature for 10 times of test time by the fine oven YAMATO Science Co., Ltd., DH-60.

3 Results and Discussion

3.1 Static Bending Properties

A typical stress vs. time curve is shown in fig. 3. In this graphic the three curves at different textiles orientations (0º, 45º and 90º) can be compared. Samples at 0º exhibited better mechanical properties on the other hand 90º shown higher deformation. Higher Young’s modulus and bending strength was shown for 0º composites while results for 45º and 90º were not very dissimilar (Table 1). These behaviour are in agreement with previous work in which these materials were mechanically analysed under static tensile test [8]. For all samples, discontinuities on the curves appeared when a significant crack emerged. Materials at 90º were observed to have more serrations on its curve due to the higher crack density due to the reinforced textile geometry.

To confirm the amount of crack density, the AE measurements are carried out. There are AE counts during static bending tests on each material on fig. 4. As shown in this figure, 0º exhibited fewer AE counts than 45º and 90º. This AE counts shows how many cracks are there during bending tests, therefore, epoxy resin of 45º and 90º have many cracks since
the bending tests started, and that of 0° have few cracks until final fracture. That is to say, the outer layer of glass fiber of 0° absorbed the fracture energy, and the epoxy resins had few cracks until final failure. It is assumed that the 90° layer must be initiator of the matrix crack. That is to say, cracking developments seems to be affected by the PES thread which is stitched throughout the thickness of the textile. These sites can act as stress concentration zones.

### 3.2 Effect of Orientation on Creep Behavior

On static bending behavior, the cracks were affected by the fiber orientations. To understand the effect of orientation of fibers and their cracks on viscoelastic properties, creep tests were carried out. Figure 5 shows the creep test results on each fiber orientation tested at 100°C. As shown in the figure, the creep compliance of 0° and 90° are almost the same and lower than that observed at 45°. It is suggested that if there is 0° layer on outer and inner layer, creep compliance will be constricted by 0° layer. And the specimens that were already creep tested have no cracks on their inner and outer surface. It is different from the results of static bending behavior.

Figure 6 shows the creep test results on each fiber orientation tested at 140°C. The initial creep compliance of 0° is lower than 45° and 90°, and the creep behavior of 0° is similar to that of 45°. In early stage, the difference of Young’s modulus might
affect to the initial creep compliance, however, the 0º and 90º layers may absorbed the creep deformation. At 120ºC, similar results were obtained. Figure 7 shows the results of creep tests at 160ºC. As shown in this figure, the initial creep compliance is similar to the results at 140ºC, however, the later stage of creep behaviors are different. The creep behavior of 45º and 90º showed similar patterns. And the creep behavior of 0º was lower than those materials. It is assumed that the matrix resin was softened by the high temperature, then the fibers cannot absorb the creep deformation on 45º and 90º, because of their direction, and 0º layer can absorb it.

With those results it is demonstrated that the fiber orientation affected the creep behavior at higher temperature. Because epoxy resin loosened by high temperature, the 90º can move freely, so the creep behavior progresses more than 45º and 0º. The amount of creep deformation observed at 90º is larger than other two materials.

3.3 Effect of Orientation on temperature

To understand the properties of creep phenomena, creep compliance curves were drawn for each test temperature. As a typical example, the creep compliance curves for 90º are presented in Figure 8(a), which shows that a greater test temperature and increased creep test time cause higher creep compliance. To discuss the application of the time–temperature superposition principle, a master curve of the creep compliance for 90º is given in Figure 8(b), with a reference temperature of 100ºC. To produce a master curve of creep compliance, the creep compliance curves were shifted horizontally until they completely overlapped the curve of the reference temperature. With the curves overlapping, part of the curve at a short time interval as used, mainly because the parts of the curve at a long time interval sometimes are deviated from the smooth master curve. The master curve was obtained by replacing the real time t for each shifted curve by the physical time t' at the reference temperature $T_0$. Master curves were obtained for other materials with each fiber orientation. The amount of shifting required to create master curves is called the “time–temperature shift factor”. The shift factor curves for each of the fiber orientation of NCFs are plotted as an Arrhenius-type plot (Figure 9). These curves have
straight lines above 120°C for each orientation, and under 120°C for all materials.

Below 120°C, the shift factor value does not depend on the fiber orientation. Because the epoxy resin put the fiber layer constraint, the effect of fiber orientation was not seen in the time-temperature shift factors.

Above 120°C, the shift factor value may have been changed. The slopes of time-temperature shift factor represent the activation energy. In this case, however, the activation energy should be ignored, because the creep deformation of each fiber orientation has a big difference. The difference of the creep deformation makes the misunderstanding on the activation energy, since the appearance of the shift factors depends on the difference of creep deformation.

The results of section 3.2 and 3.3 were related each other, and it is possible to say that the fiber orientation of NCF affects materials creep behavior. Therefore, it is important to consider the fiber orientation on NFC.

4 Conclusions

In this paper, bending tests and bending creep tests are carried out. Finally, following conclusions were obtained.

1. Mechanical properties of textile reinforced composite materials are highly dependent of the fabric architecture and geometry.
2. In bending test, cracking developments seems to be affected by the PES thread which is stitched throughout the thickness of the textile. These sites can act as stress concentration zones.
3. An influence of the 0º layer was found during creep test. They seem to dominate the creep behavior.
4. The effect of temperature on creep behavior was affected by the fabric architecture and geometry.

References


