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Full Length Research Paper

A comparative study of the creep behavior of laminated composites: Effect of type of fiber and matrix

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This paper presents the effect of matrix type on creep behavior at 80% loads of ultimate tensile strength of two laminated composites at different fiber and matrix system. For this, two types of laminated composites were manufactured based on two types of fibers (carbon fabric and glass fabric) with different matrix systems EPOCAST 50-A1 (EP50-A), Epoxy STR (STR) and Epoxy INJ812 (INJ). The tensile and creep behavior of each laminated composite was studied in the same test conditions. A microstructural study was also investigated by SEM-microscopy on the morphology of composite specimens after creep rupture failures at 80% of applied load. The obtained results showed clearly the influence of matrix type used on the tensile and creep behavior of studied composites. Indeed, it was noted that no creep rupture failures were observed in short-term (less than 4 h) for INJ/Carbon composite at tensile creep tests at 80% loads of ultimate tensile strength. At the same ultimate tensile strength, EP50/Carbon composite showed a best creep behavior up to 30 h and had a creep modulus higher than other laminated composites. The observation of rupture facets of all composite samples showed clearly that the rupture will take place in the direction of loading, creating voids at the interface resin/fiber. These are observed based on the nature of the matrix used.

Key words: Epoxy, aliphatic amine, cross-linked, carbon fabric, glass fabric, creep test, cyclic tensile test.

INTRODUCTION

Technological evolution of composite materials in aeronautics sector continues to lead to the development of new designs for technical and economic purposes, which include mechanical performances and cost reduction for best operation of aircrafts (Asundi and Choi, 1997; Soutis, 2005; Botelhoa et al., 2006; Botelho and Rezende, 2000). Firstly, more efficient materials are used in order to obtain lighter parts having same level of performance. On the other hand, it is desired to use composite materials whose specific properties are superior to those of conventional materials (Botelho and Rezende, 2000; Tarpani et al., 2006a, b). The advantage of associating performances with reduced weight of aircraft structural elements was one of the main purposes of aviation composites development. Laminated composites are selected for weight critical applications and have the best behavior as far as fatigue failure is concerned (Tarpani et al., 2006b). Actually, research

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Table 1. Mechanical properties of used matrix obtained by tensile tests.

Nb \ Matrix type	EPOCAST 50-A1			STR			INJ 812		
	ε_{rep} (%)	σ_{rep} (MPa)	E (GPa)	ε_{Frep} (%)	σ_{rep} (MPa)	E (GPa)	ε_{Frep} (%)	σ_{rep} (MPa)	E (GPa)
Specimen 1	1.97	63.69	3.49	0.55	31.12	2.530	15.7	9.98	0.4656
Specimen 2	1.75	58.95	3.44	0.58	32.20	2.532	17.3	10.3	0.4617
Specimen 3	1.72	58.65	3.47	0.60	32.20	2.528	14.8	10.1	0.4792
Av.	**1.81**	**60.43**	**3.47**	**0.58**	**31.84**	**2.530**	**15.93**	**10.13**	**0.4688**

studies aim to analyze the mechanical behavior of each laminate under tensile condition. The basic concepts of laminated composites were mainly studied by several authors (Tarpani et al., 2006a, b). According to the literature, there are some technologies that have been employed by some researchers to evaluate the mechanical properties of composite materials under tensile and impact loading. Research works were carried out to determine the mechanical properties of composite materials using tensile tests (Kalthoff, 2008; Chang et al., 2008). Other works have predicted the elastic behavior of laminated composites based on plain weave fabrics with different materials and undulations in the warp and weft directions by formulating a 3D analytical micromechanical model (Cortés and Cantwell, 2006; Cortes and Cantwell, 2004; Carrillo and Cantwell, 2007). Concerning creep tests performed till date, it was reported that all works use the creep tensile tests at maximum load (50%) of ultimate tensile strength. Researchers have studied non-linear viscoelastic model in a wide range of stress between 20 and 60 MPa under temperature of 90°C (Kouadri et al., 2009; Dasappa et al., 2009). These authors concluded that studied materials have a non-linearly behavior on all stresses applied. Another work was performed on the creep behavior of a carbon/epoxy composite by using tensile and flexural creep testing. It was observed by these authors that there is no creep rupture failure of studied composites under 77% loads of ultimate tensile strength (UTS) for 1600 h at room temperature (Goertzen and Kessler, 2006).

However, it is clearly known that the performances and in particular the creep behaviors of laminated composites are also influenced by the properties of used matrix. The latter not only maintains the form desired and protects the reinforcements against the external attacks but also has an important role to play in the creep of composites. In the literature, it was noted that the works on the characterization of laminates are based on types and architecture of reinforcements, on one hand (Dal Maso and Meziere, 1998), and of the epoxy matrix influenced by his properties of another shares (Gillham and Curing, 2006; Barrere and Dal Maso, 1997), on the other hand. In this context, the creep behavior is strongly influenced by the viscoelastic properties of resin and the characteristics of fibers. In the case of the Glass-Fiber Reinforced Plastic (GFRP), the creep limit is 0.3UTS; in the case of the CFRP and aramid (AFRP), it is the rupture limit to the creep of 0, 70 UTS according to recommendations of the ACI 440.4R04 (American Concrete Institute - ACI 440.4R-04, 2004).

According to this literature review, it is noted that few studies have been performed on the effect of type of matrix used on creep behavior of fabric-based laminated composites in two cases (carbon and glass), in particular at 80% load of ultimate tensile strength. The present work gives more information on the effect of the types of matrices on mechanical performances of laminated composites.

EXPERIMENTAL STUDY

Materials used

Two groups of laminated composites were manufactured using two types of fibers of different nature (Carbon fabric and glass fabric; Figure 2) and different matrix systems. In order to see the effect of matrix, three matrix types were chosen: EPOCAST 50-A1, Epoxy STR and Epoxy INJECT-812.The mechanical properties of the raw materials used are given in Table 1. Figure 1 gives the tensile behavior of the chosen resins. In this figure, it was reported that the resins used have different nature and mechanical behavior. It was observed that INJECT-812 (INJ-Matrix) has a ductile behavior while both resin EPOCAST 50 (EP50-A) and Epoxy STR (STR-Matrix) have a fragile behavior. However, EP50-A presents better mechanical performances having a very high elastic modulus compared to the other matrices.

Specimen preparation and fabrication

Manufacturing of laminated composites was carried in eight-ply (8-ply) using the vacuum method (Figure 3). The laminate plates were depressed by the pump until the matrix was cross-linked. Then, it was put in an oven at 80°C for eight hours. Later, specimens of carbon/resin fabric laminates and glass/resin fabric laminates were cut with a normalized size of 25x250x2.2 (mm) for tensile and creep tests (Figure 3). For the smooth running of the mechanical tests, all studied samples were provided with aluminum heels.

Mechanical test methods

Tensile tests

The tensile tests were carried by using a universal machine Zwick/Roelltype 250, equipped with a sensor force of 250 kN

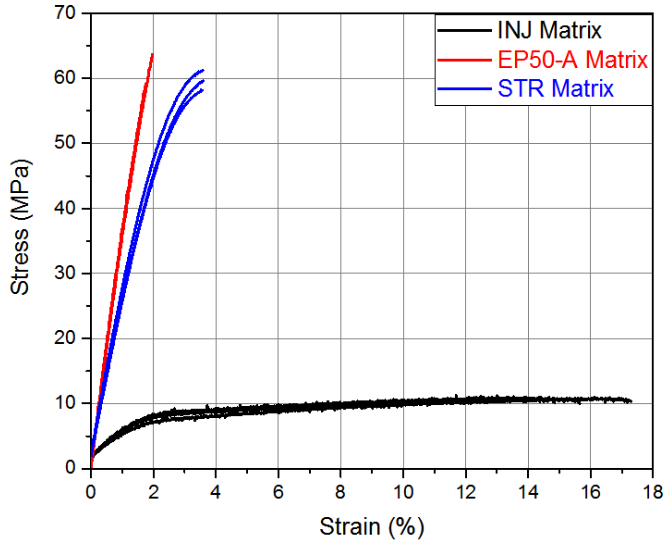

Figure 1. Tensile behavior of used resins.

Figure 2. Carbon and glass fabrics used.

capacity and with an extensometer. This machine is controlled by computer using the software TestXpert version9.0 (Figure 4). The tensile tests were conducted at room temperature in a relative humidity controlled laboratory (22 ± 0.5°C). In order to evaluate the effect of resin type on the mechanical performances of laminates, mechanical characterization tests were done in traction on the chosen matrices in this work. A tensile test was carried out using a universal machine Zwick/Roll type10 kN equipped with a sensor extensometer and controlled by computer (software TestXpert version 12.0).

Creep tests

The creep tests were performed on laminated composites studied at imposed stress by applying a constant 80% load of ultimate tensile strength. The machine is equipped with a high-resolution strain gauge which makes it possible to calculate the deformation over time without the useful zone, thus avoiding the effects of Clamping jaws which can distort the deformation measurements.

Microstructural study of laminated composites

After testing, all fracture specimens were observed with the scanning electronic microscope SEM (work without metallization), which makes it possible to observe the sample without making the preparation that can modify the rupture fasciculation. To see the breaking and failure mode of studied composites, delamination phenomena were observed in an interfacial zone of fiber/ resin.

RESULTS AND DISCUSSION

Mechanical behavior of laminated composites

Stress - strain curves of all studied laminated were obtained and given in Figure 5. As shown in Figure 5a, glass-based laminated composites present a ductile behavior in the case of STR and INJ matrix; however, an elastic fragile behavior was observed for glass-based laminated with EP50-matrixup to the failure. Concerning Carbon-based laminates, whatever the type of matrix used, an elastic fragile behavior was obtained because the material will fail immediately once the elastic limit is reached. It is also possible to specify that the ductile behavior of STR and INJ matrix does not amplify in Carbon-based laminates case (Figure 5b). Thus, the stacking of plies is an important parameter making it possible for the matrix to contribute to the overall

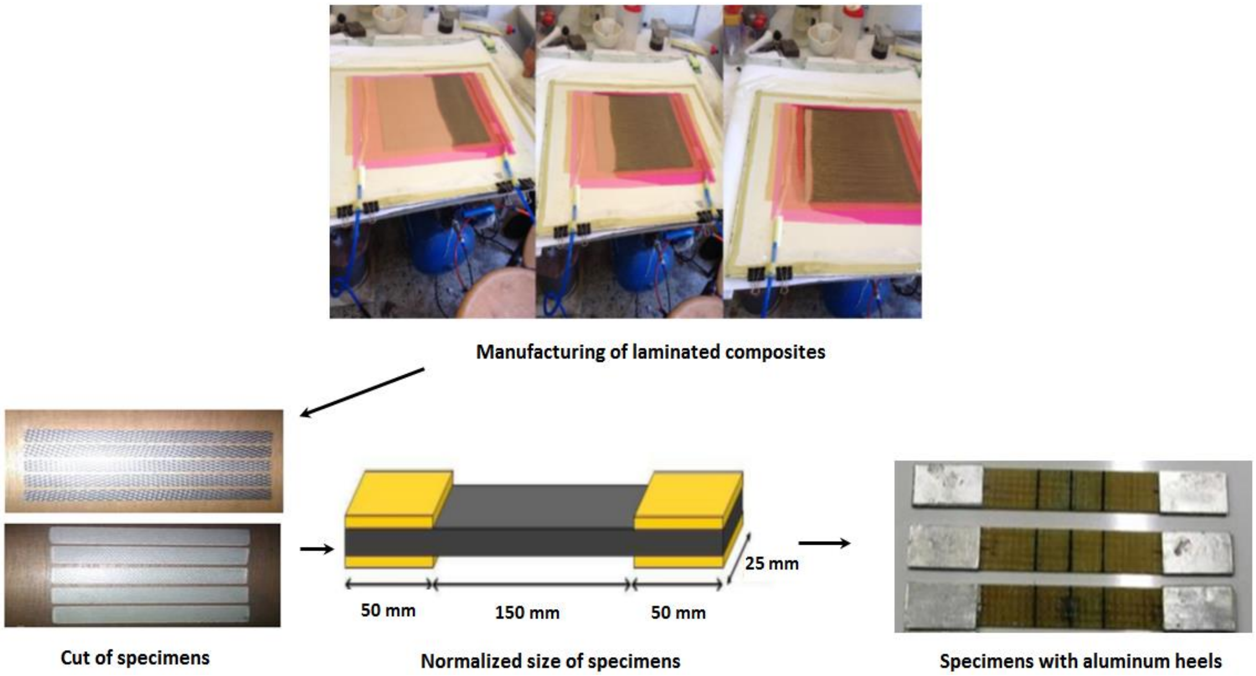

Figure 3. Specimen preparation and fabrication.

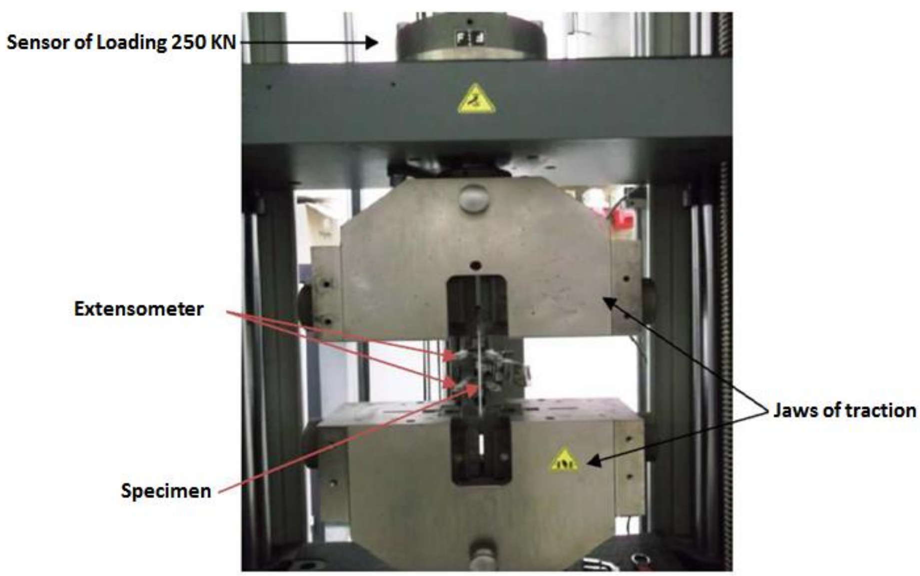

Figure 4. Universal machine of Zwick/Roell type 250KN.

behavior of the laminate.

Mechanical properties of laminated composites

From the TestXpert software of the machine, tensile properties such as modulus of elasticity, tensile strength and elongation at failure are evaluated and are given in Figures 6 and 7. According to the obtained results and as also previously proved by several studies (Deng et al., 1999; Kaleemulla and Siddeswarappa, 2009), the Carbon-based laminates present better mechanical performance compared to those elaborated with glass fabric (Table 2).

Comparatively with carbon-based laminates for three cases of matrix, it should be signaled that glass fabric-

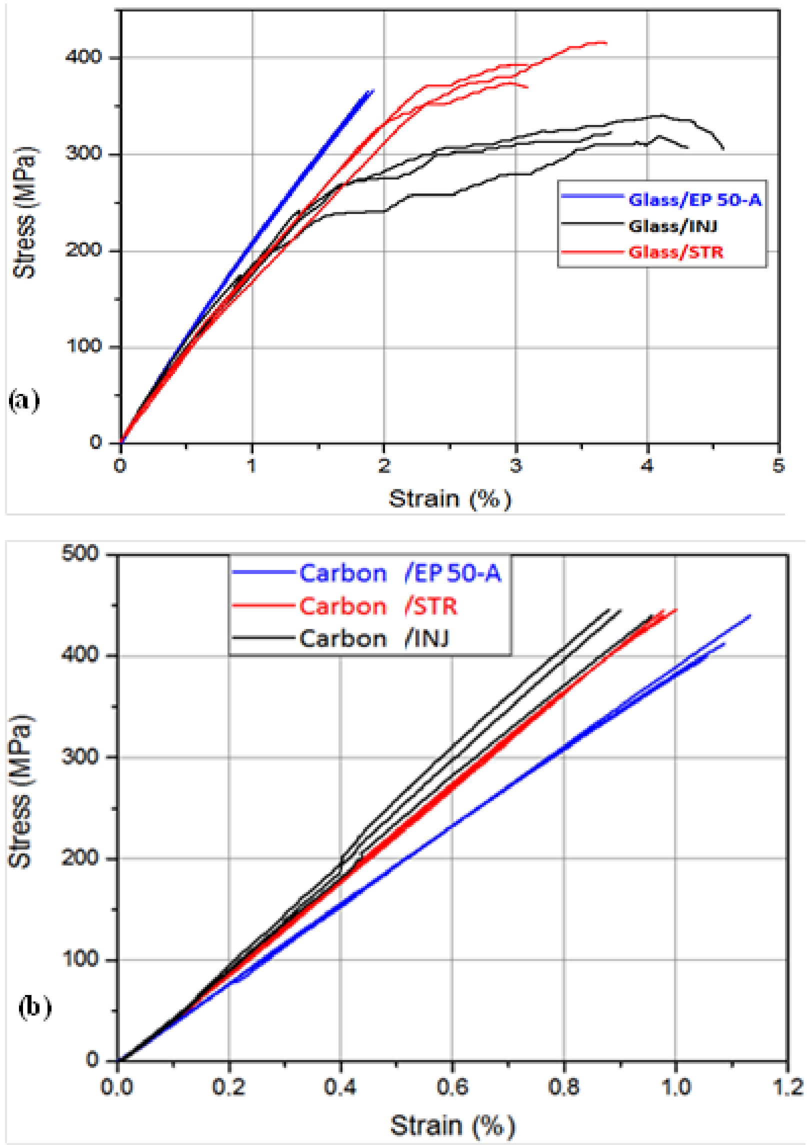

Figure 5. Stress-strain curves of different laminated composites (a) Glass-based (b) Carbon-based.

based laminates possess higher strain-to-failure, although they present a lower tensile strength. This is due to their lower modulus compared to those obtained with Carbon fabric (Abdel-Magid et al., 2003).

The obtained results show remarkable discrepancies. In fact, the elasticity of the STR-based laminate is between 0 and 2%. This value represents the deformation at failure of the reinforcement used, with the Young's modulus being 17.85 GPa and a strain value of 3.3%. The failure age limit of the EPOCAST-based laminate is average deformation of 2.1%, and Young’s modulus of 20.91 GPa. The maximum stress of the S-STR laminate is 395 MPa. This value is greater than the other two stratified values which have the values of 328 and 256 MPa for G-INJ812 and G-EPOCAST. On the other hand, the Young's modulus of the Carbon-EPOCAST laminate has a greater value of the order of 20.91 GPa, which shows a better transmission of the forces for the reinforcement in the case of this resin. Furthermore, it can be noted that there is non-identical failure modes for each type of laminate (Figure 8).

Creep behavior

The tensile modulus of laminated composites can be thought of as an instantaneous response (at zero-time). But, it would be very interesting to evaluate the creep modulus of our studied laminates at UTS chosen, in order to know the material behaves if this constant stress is

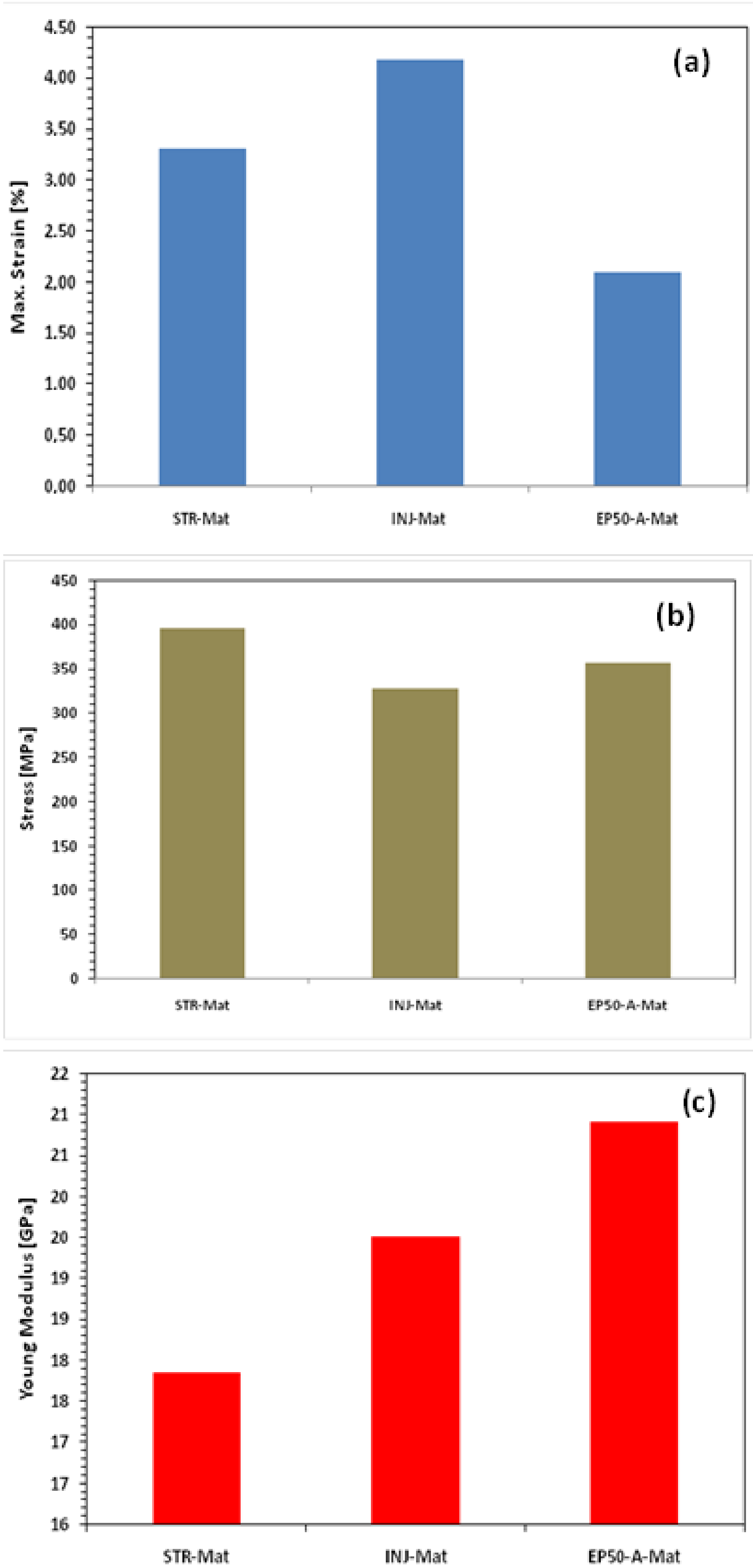

Figure 6. Mechanical properties of Glass-based laminates (a) Max. Strain (b) Stress (c) Young modulus

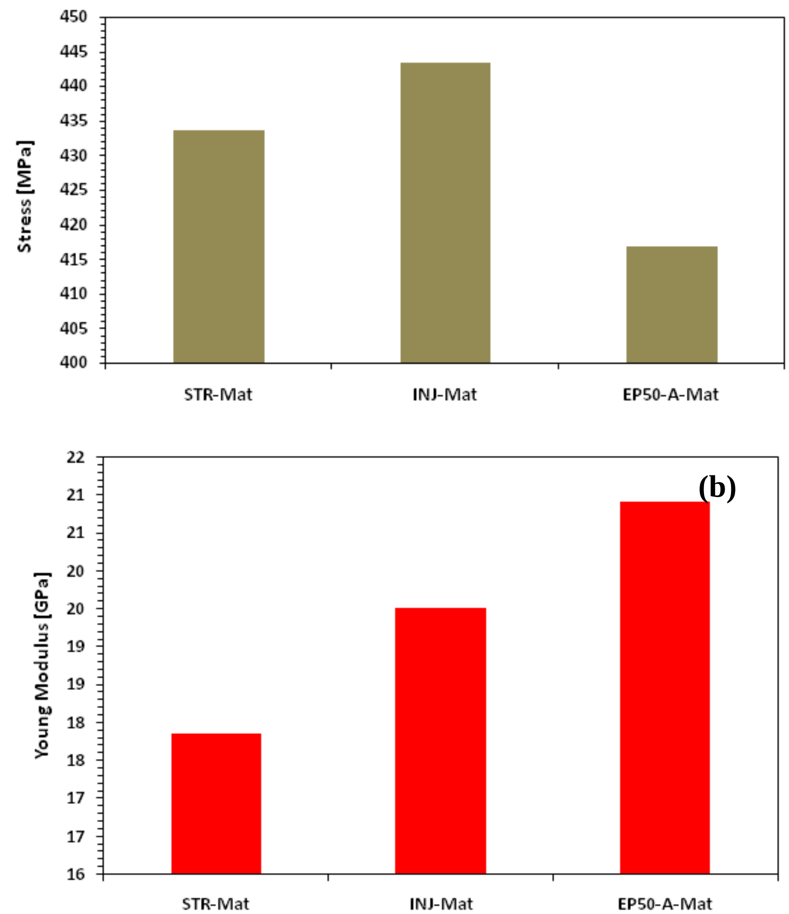

Figure 7. Mechanical properties of Carbon-based laminates (a) Stress (b) Young modulus

Table 2. Mechanical properties of Glass-based laminated composites.

Matrices / Measures	Matrice STR			Matrice 812INJ			Matrice EP 50 -A		
	ε_{Fmax} (%)	σ_{max} (MPa)	E (GPa)	ε_{Fmax} (%)	σ_{max} (MPa)	E (GPa)	ε_{Fmax} (%)	σ_{max} (MPa)	E (GPa)
Specimen 1	3.11	394.35	18.120	4.08	318.82	19.127	2.01	363.79	21.69
Specimen 2	3.10	374.57	17.447	4.34	340.78	20.149	2.09	347.23	21.06
Specimen 3	3.69	416.55	17.997	4.11	325.74	19.246	2.21	358.78	19.97

maintained. For this, Figure 9 shows the creep modulus-time curves of laminated composites studied at 80% of ultimate tensile strength (UTS) for two reinforcement and matrix types.

In Figure 9(a), it should be noted that a rupture of glass-based laminates was observed after 1 h of 80% load of UTS (case of Glass/EP 50). However, Carbon/EP50 has a kept modulus for 30 h. For this laminate, the rupture was obtained after 30 h of same loading applied to Glass/EP50 laminate (Daghigh et al., 2016; Raghavan and Meshiib, 1997; Rees et al., 2007; Chang et al., 2008; Goertzen and Kessler, 2006).

Also, at an identical loading and plies, the matrix type effect used was amplified and clearly observed in this figure 9(b). It was reported that EP50-based laminates behave better than the laminates elaborated with other matrix regardless of used fabric nature. This finding reflects the beneficial effect of the matrix nature as well as its role in the transfer of charges to the reinforcement.

Microstructural study of laminated composites

After testing of specimens, analysis microstructural was

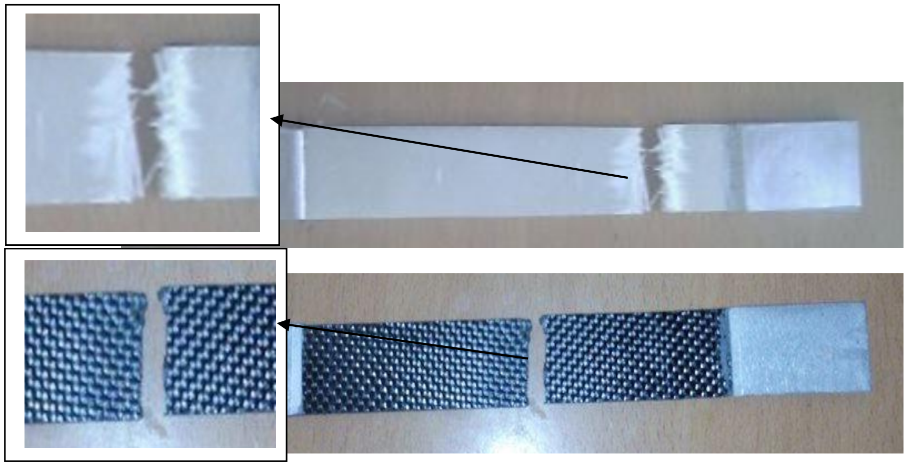

Figure 8. specimens after rupture (a) Glass-based laminate (b) Carbon-based laminate

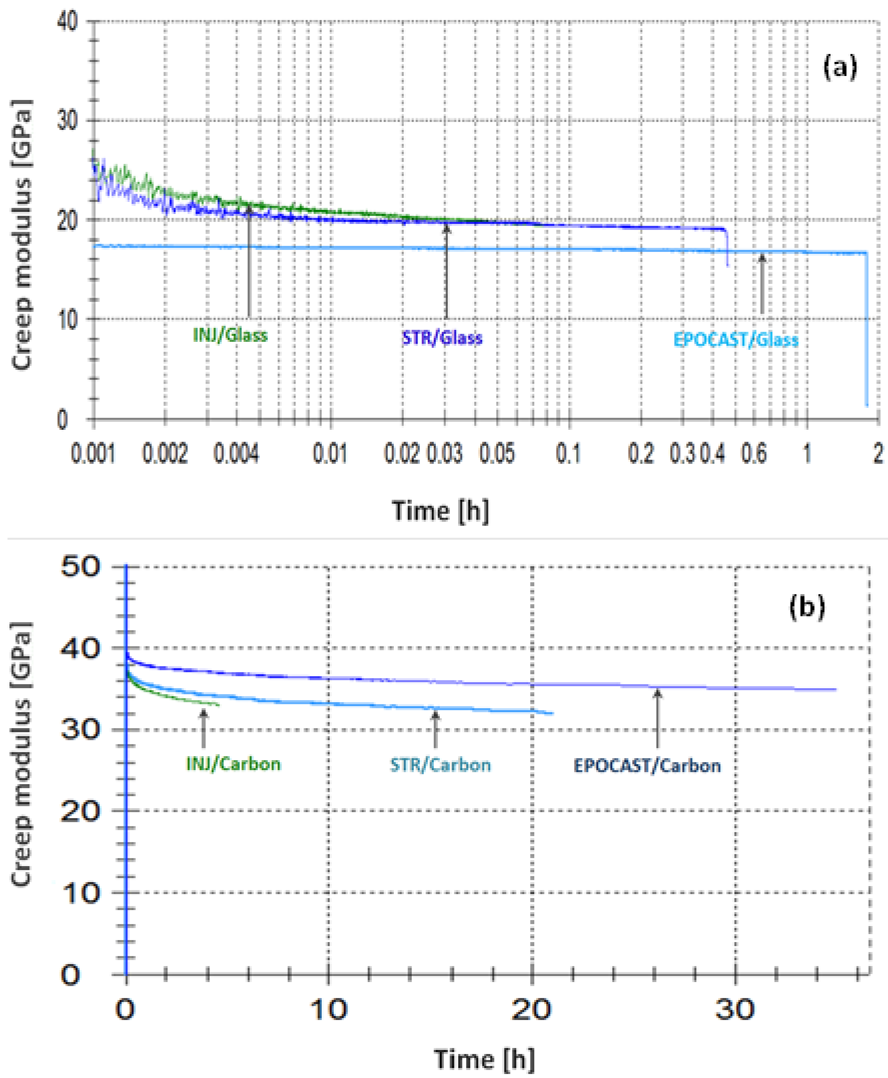

Figure 9. Creep testing of different laminated composites (a) Glass-based (b) Carbon-based

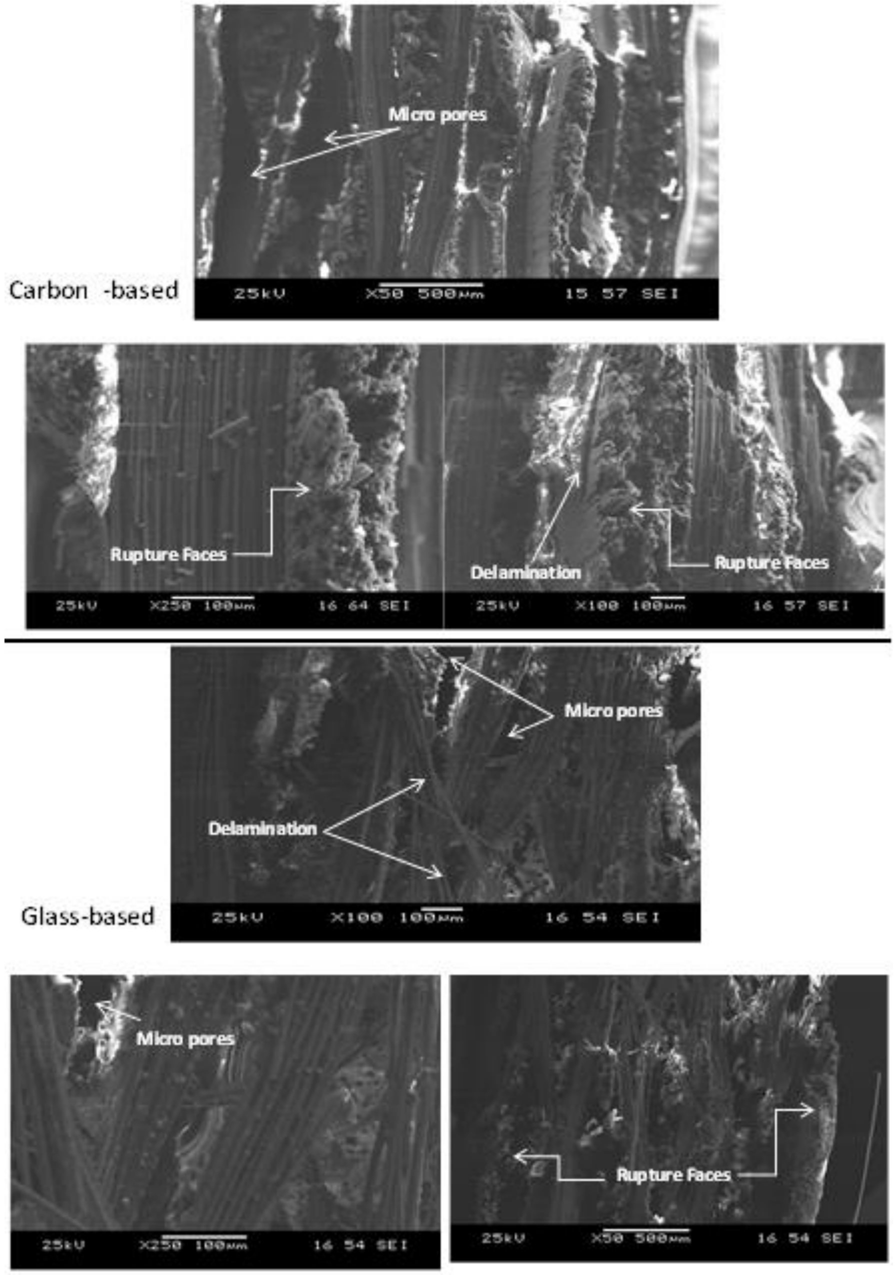

Figure 10. SEM micrographic of laminated after failure.

carried out. The SEM morphologies of fracture surfaces of the studied laminated composites are shown in Figure 10. In the figure, it was remarkable that the delamination occurred in the two studied cases of laminates with presence of cracks at the fiber-matrix interface. However, the delamination of EP50/Carbon laminate is not intense enough compared to that observed by STR/Carbon laminate. Also, it should be noted that the presence of microspores in the EP50/Carbon laminate is not important compared to that obtained by STR/Carbon (Goertzen and Kessler, 2006; Yan et al., 2017).

Conclusion

The objective of this work is to study the effect of matrix type on creep behavior at loads up to 80% of ultimate tensile strength of two laminated composites at different fiber and matrix system. The conclusions drawn from this work are summarized below;

1) The Carbon-based laminates present better mechanical performance compared to the elaborated ones with glass fabric;

2) At same matrix, the Young's modulus of the Carbon-EPOCAST laminate has a greater value in the order of 20.91 GPa compared to Glass-based laminate;
3) Concerning creep testing, the rupture of glass-based laminates was observed after 1 h of 80% load of UTS (case of Glass/EP 50) but for Carbon/EP50, it has a kept modulus for 30 h. For this laminate, the rupture was obtained after 30 h of same loading applied to Glass/EP50 laminate;
4) The microstructural analysis of laminated composites shows that the delamination of EP50/Carbon laminate is not intense enough compared to that observed by STR/Carbon laminate. Also, it should be noted that the presence of microspores in the EP50/Carbon laminate is not important compared to that obtained by STR/Carbon.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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