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Investigations on the fabrication and the characterization of glass/epoxy, carbon/epoxy and hybrid composites used in the reinforcement and the repair of aeronautic structures

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This paper reports the fabrication and the characterization of glass/epoxy, carbon/epoxy and hybrid laminated composites used in the reinforcement and/or the repair of aeronautic structures. These composites were manufactured by the hand lay-up process. Their physical, thermal and mechanical behaviors are discussed in terms of moisture absorption, thermal stability, tensile strength, elastic modulus, flexural strength, flexural modulus and abrasive wear resistance. The impact of hygrothermal aging on the mechanical properties of each composite group has been also investigated.

The main results indicated that after water immersion, all composites showed significant moisture absorption especially for glass/epoxy composite. Thermogravimetric analysis showed that the hybrid composite presented the best thermal stability behavior while the glass/epoxy composite the bad behavior. The mechanical properties of the carbon/epoxy composites, in the bulk material, were considerably higher than those of the glass/epoxy; the hybrid structure presented intermediate mechanical properties. The same trend was also observed in terms of wear properties. Finally, a deleterious effect on the strength of all composites due to hygrothermal exposure was established. However, carbon/epoxy composites seem to be less susceptible to aging damage after 90 days at 90 °C.

1. Introduction

With advances in science and technology, there is increasing interest in polymer composites, both in scientific research and for engineering applications. In particular, glass and carbon fiber/epoxy composites are increasingly in demand for structural applications in the aerospace, automotive and marine industries due to their advantageous excellent specific mechanical performance (mechanical properties/density ratio) and design flexibility compared with conventional materials [1–6]. However, it is evident from the literature that polymer–matrix composites (PMCs) which used, for example, as aeronautical engineering structures and in other industrial applications may be generally subjected and exposed, in its service life, to different environments usually involving humidity, temperature and mechanical stress [2,7]. This may affect essentially the mechanical performance of aircraft composite parts and reduce their lifetime.

In this context, this work can be considered as an attempt to give a scientific response to a real industrial problematic proposed by the Tunisian aeronautical society. In fact, the latter aims to construct a database about the characteristic of various fabricated composites dealing with repairing and reconstructing aeronautic composite structures. In particular, it is worth to choose the appropriate composite structure (glass fiber/epoxy, carbon fiber/epoxy, or hybrid structure) for every damaged part which should be repaired.

From the literature review, there are many papers focusing on the fabrication of laminated composites using the hand lay-up processes and their characterization [8–14]. The performance of these composites was largely investigated and discussed in terms of several properties depending essentially on their use conditions. In addition, the composite performance is directly related to the performance of the fiber, the matrix and the interface. Schutte has reported on its work that the durability of glass fiber/polymer composites is dictated by the durability of the components: glass fiber, matrix, and the interface [15]. In fact, environmental attack by moisture, for example, can degrade the strength of the glass fiber; plasticize, swell, or microcrack the resin and degrade the fiber/matrix interface by either chemical or mechanical attack.

Many others researchers have used severe and accelerated conditions (different environments: water, saline water, acidic water, organic fuel, low and high temperatures) in order to predict the performance of the carbon or glass fiber reinforced polymeric composites [7,9–11,13,15–21].

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Considerable attention is presently being given to the water uptake behavior of composites, to their thermal stability and mechanical behavior. For this reason, various characterization techniques and methods were usually adopted. To investigate the sorption water of laminated composites, gravimetric measurements have been carried out [9,17,20,22,23]. Thermogravimetric analysis (TGA) has been used in order to evaluate the thermal stability for these composites [24,25]. To study the mechanical properties (in the bulk of the material), tensile, flexural and compression tests have been generally retained in many Refs. [9,11,12,26–29].

The wear performance was equally studied using a pin-on-disk configuration [10]. Suresha et al. have focused on a comparative study in terms of wear of glass and carbon fiber reinforced epoxy composites [10].

As retained results, the performance of fibers reinforced polymer composites (FRP) was directly related to the performance of the components: fiber, matrix, and the interface [30]. Also, it was shown that both physico–chemical and mechanical properties of composites are strongly affected during hygrothermal conditioning which eventually reduces the overall material performance. For example, Ray has reported that the importance of temperature at the time of conditioning plays an important role in environmental degradation of carbon/epoxy and glass/epoxy composites [9]. He has proved the harmful effect of temperature on shear strength of such composite materials during hygrothermal conditionings. Ray has equally shown a mechanism of deadherence and interfacial cracking in aged glass/epoxy laminated composites and, on the other hand, matrix cracking and fiber damage in carbon/epoxy composites.

The present paper outlines the fabrication and the characterization of carbon fiber/epoxy, glass fiber/epoxy and hybrid laminated composites. Moreover, thermal stability, tensile strength, elastic modulus, flexural strength, flexural modulus, abrasive wear resistance of the composite samples are determined. The impact of hygrothermal aging on composite performance has been also investigated.

2. Experimental procedure

2.1. Material processing and sample preparation

It is worth noting that the studied samples in this investigation are bidirectional laminated composites. Various composites were prepared such as carbon/epoxy (C–E), glass/epoxy (G–E) and hybrid through the composite-manufacturing technique of hand lay-up. The fabrication procedure has been carried with a contact molding (open mold), at room temperature and without pressure.

The used matrix consists of Hysol EA 9396 epoxy adhesive which is mixed with its hardener (30%). The used fibers are R-Glass fiber (1581) and carbon fiber (G814). The density of glass fiber, carbon fiber and epoxy resin is about 2.56, 1.83 and 1.157 g cm^{-3}, respectively. The surface mass of glass fiber and carbon fiber is about 295 and 193 g m^{-2}, respectively.

The laminated composites were manufactured into 160 mm × 130 mm panels with a thickness of 3.9–5 mm with varying the lay-up angle and the fiber volume fraction. Three series (types) were distinguished: first series (1A, 1B, 1C and 1D); second series (G–E) and third series (hybrid), Tables 1–3. The geometrical parameters of the fabricated beams are shown in Table 4.

The polymerization process of the composite material is carried out with the help of the GMI – ANITA NG apparatus (Fig. 1). After that, finished laminates are cured for 2 h at 80 °C.

The samples (both three-point flexural samples and tensile ones) were cut from the fabricated composite panels by using a water-cooled diamond saw.

Table 1
Geometrical parameters of the laminated composites (first series: 1A, 1B, 1C and 1D).

Ply No.	Material	Ply angle
1	GF 1581	+4°
2	CF G814	+45°
3	CF G814	0°
4	CG G814	+45°
5	CF G814	0°
6	CG G814	+45°
7	CF G814	+4°
8	CG G814	+49°
9	CF G814	+4°
10	CG G814	+49°
11	CF G814	+45°
12	CG G814	+49°
13	CF G814	+4°
14	CG G814	+49°
15	CF G814	+4°
16	CG G814	0°
17	CF G814	+45°

Table 2
Geometrical parameters of the laminated composites (second series: pure G–E).

Ply No.	Material	Ply angle
1	GF 1581	0°
2	GF 1581	+45°
3	GF 1581	90°
4	GF 1581	0°
5	GF 1581	−45°
6	GF 1581	0°
7	GF 1581	+45°
8	GF 1581	+45°
9	GF 1581	90°
10	GF 1581	0°
11	GF 1581	+45°
12	GF 1581	−45°
13	GF 1581	0°

Table 3
Geometrical parameters of the laminated composites (third series: hybrid).

Ply No.	Material	Ply angle
1	GF 1581	+4°
2	CF G814	+45°
3	GF 1581	0°
4	CG G814	+45°
5	GF 1581	0°
6	CG G814	+45°
7	GF 1581	+4°
8	CG G814	+45°
9	GF 1581	+4°
10	CG G814	+49°
11	GF 1581	+45°
12	CG G814	+49°
13	GF 1581	+4°
14	CG G814	+49°
15	GF 1581	+4°
16	CG G814	0°
17	GF 1581	+45°

2.2. Moisture sorption tests

Prior to the absorption experiments, all samples were thoroughly washed and then vacuum dried until a constant dry weight was attained. In order to evaluate the durability of the composites, an accelerated hygrothermal aging procedure that simulates severe conditions of climatic aging was adopted. Immersion of samples was performed in large tubs containing distilled water at a set temperature of 90 ± 1 °C. At predetermined time intervals, samples were taken out from the tubs, surface dried and weighed using an