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EFFECT OF ALTERNATING HYBRIDISATION OF FIBRES ON THE PHYSICO - MECHANICAL BEHAVIOUR OF COMPOSITE MATERIALS

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Abstract

The performance/weight ratio of fiber reinforced polymer matrix composites makes them the material of choice for structural applications in many fields such as aerospace, aeronautics, automotive and civil engineering...etc. In polymer matrix composites, the fibers used as reinforcement are mainly synthetic fibers such as carbon and/or glass fibers. To ensure the low cost of using fiber-reinforced materials in motor vehicles, it is proposed to selectively incorporate carbon fibers to enhance glass fiber composites along the roadway, and to enhance glass fiber composites along the main load path. For this purpose, we conducted a behavioral study of hybrid epoxy thermoset polymer matrix laminates to highlight the influence of alternate hybridization of glass and carbon fibers on the physical-mechanical behavior of the materials.The results obtained show that the alternated hybridation of the fibers has a significant influence on the tensile properties ; and it affected the density, hardness and flexural properties significantly.

Keywords:

Hybridization;
Laminate;
Hardness;
Flexure;
Traction.

1 Introduction

Because of the week cross-sections of the fibers, they cannot be used directly in mechanical applications. Hence the idea of incorporating them in a polymer matrix to form a fiber composite. The matrix has various functions: to bind the fibers together, to transfer mechanical loads to the fibers, to protect the fibers from the external environment etc [1]. During the last decade, industrialists have taken a great interest in the development of polymer matrix composites such as thermosetting epoxy, materials that provide many functional advantages: freedom of shape, reduced maintenance, lightness, mechanical and chemical resistance [2, 3]. They allow to increase the life span of some equipments, they resist to corrosion, they offer a better thermal or sound insulation and for some of them a good electrical insulation [4, 5]. Hawever, Polymer matrix composites have defects that are mainly due to the method of elaboration and the nature of the fibers and the matrix used.

Various fibers can be used as reinforcement of composite materials. For geopolymer concrete fibers do not cause any negative effects on the mechanical properties of concrete but they improve the behavior of concrete during dry shrinkage [6]. And geopolymer mortar panels reinforced with textile fibers show flexural hardening and multiple cracking behavior. The deflection values at the same load levels decrease when the number of scrims is increased, the toughness values of the specimens are significantly improved with the increase in the reinforcement ratio of the glass fiber textile scrims [7].

The fibers used in polymer matrix composites are mainly synthetic fibers such as carbon and/or glass fibers, these fibers have very good mechanical and geometric properties [8, 9]. The architecture of the material such as the orientation of the reinforcements and the geometry creates directional effects that influence the nature of the damage [10-12].

This work inse to study the effect of alternating hybridization of fibers on the physical and mechanical behavior of composite materials.

2 Experimental procedure

2.1 Materials used

2.1.1 Epoxy resin

Epoxy resin is a thermosetting polymer, widely used in high performance composites in many industrial and aeronautical applications. Thermosetting resins are polymerized only after their final shaping .Their main advantages are: very low viscosity before shaping and very high thermal resistance [13].

The epoxy resin used in this study is MEDAPOXY 812 INJ from Granitex (Algeria). The mass ratio supplied by the supplier Granitex (Algeria) between the epoxy monomer A and the diamine hardener B is *MR* = 2.

The characteristics of the MEDAPOXY 812 INJ resin are presented in Table 1.

Table 1: Characteristics of epoxy resin.

Characteristics of epoxy resin	
Weight Ratio A/B	2/1
Density ISO 758 [g/cm^3]	1.1± 0.1
Viscosity CF4/20 º, NFT30 014	17 sec (±2)
DPU: NFP18 810	30 mn à 20 º
Resistance to compression RC	> 70 MPa
Tensile strength Rt	> 57 MPa

2.1.2 Reinforcements: carbon fibers, glass fibers

The reinforcements used are the unidirectional carbon fiber fabric provided by the company Sika (Algeria) under the trade name SikaWrap®-230 C/45, used in civil engineering for the reinforcement of reinforced concrete structures; and the architectural E-glass fiber fabric Taffeta GWR225 under the standard BMS (Boeing Materials Specification) 9-8 type 1 class 2 used for the nautical construction, provided by the laboratory of composite materials and plastic maintenance base of Air Algeria (Algeria). The characteristics of the reinforcements used are presented in Table 2.

Table 2: Characteristics of carbon fiber and glass fiber fabrics.

Characteristics	**Carbon fiber**	**Fiberglass**
Geometry	Unidirectional	Taffeta
Color	black	white
Density [g/cm^3]	1.76	2.54
Thickness [mm]	0.3	0.25
Tensile strength [MPa]	4300	3100
Traction Elasticity Module [GPa]	234	73
Elongation [%]	1.8	4.4

2.2 Method of elaboration

The composite materials studied in this work are laminated plates reinforced by 12 plies of glass fibers and laminated plates reinforced by 12 plies of carbon fibers, as well as hybrid laminated plates reinforced by 6 plies of glass fibers / and 6 plies of carbon fibers alternated, with dimensions of 300 x 300 mm, are developed by the vacuum method in the laboratory of composite materials and plastics of the maintenance base of Air Algeria. These laminates are dried in the oven at 80°C for 8 hours after their elaboration. Then, the specimens are cut with a diamond saw and lubricated according to the AFNOR NF T 57-105 [14], ISO 178 [15] standards corresponding to the Mechanical tests.

3 Physical-mechanical characterization

3.1 Tensile testing

Tensile tests are performed to determine the tensile properties of the materials, namely the ultimate tensile stress and the Young's modulus. They are carried out on a machine of mark IBERTEST, equipped with a cell of maximum force of 200 kN. The machine is controlled by microcomputer on which a software of control and treatment of the results is installed. This allows to give stress/strain diagrams with a good accuracy. It is equipped with self-clamping jaws, allowing a good holding of the laminated specimens. The test is performed at room temperature. The machine is driven at a constant traverse speed of 10 mm/min. To ensure good reproducibility of results according to NF EN ISO 527-4 [16] and ASTMD 790 [17], at least three to five specimens are tested for each series of tests.

The tensile test carried out on laminated specimens with glass fibers, carbon fibers and hybrids, allows us to record the results summarized in Table 3 and Fig. 1.

3. 2 Static bending test

The tests are carried out in three-point bending, they are carried out at room temperature on samples developed according to ISO 178 [15], ASTMD 790 [17], which specifies the dimensions of the test specimen, ie, L = 16h + 20 (± 1) mm, 10 ≤ b ≤15 mm, h ≤ 5 mm. L_0: length of the specimen [mm] ≥ 08 mm, b section width [mm], h thickness of test piece [mm], f the arrow of the specimen [mm].

The tests are carried out on a Zwick / Roell machine equipped with a 2.5 kN force sensor and controlled by the testxpert 9.0 software. The test speed is 2 mm/min.

The results obtained show the evolution of displacement according of the load applied until the rupture. The bending σ_f stress, E_f Young modulus, the shear stress hear σsh are calculated respectively according to the following formulas

$$\sigma_f = 3FL/2bh^2 \quad \text{[MPa]}, \tag{1}$$

$$E_f = L^3/4bh^3m \quad \text{[MPa]}, \tag{2}$$

$$\sigma_{sh} = 3F/4bh \quad \text{[MPa]}, \tag{3}$$

$$m = (F_2 - F_1)/(f_2 - f_1) = \text{tg}\alpha \quad \text{the slope of the elastic portion.} \tag{4}$$

σ_f and E_f are respectively the stress and bending modulus [MPa], σ_{sh} shear stress [MPa], F the maximum force [N], L distance between supports [mm]. The 3-point bending test performed, allows us to record the results presented in Fig. 2 and Table 4.

3. 3 Calcination test

The mass rate or the weight fraction of the fibers are determined by the method of loss on ignition, in accordance with standard NF T 57-102 [18] (applicable to strata, wires and laminates). The test specimen is of prismatic shape; the latter is weighed a first time at room temperature Mc. Then, it is placed in an oven at 600 °C for 1 hour to burn the resin. The remaining reinforcement is then weighed Mf. The reinforcement mass ratio is determined by the formula (5) and presented in Table 5.

$$Tf = Mf/Mc. \tag{5}$$

3.4 Determination of the density

To determine the density of different materials, we use an analytical balance equipped with measuring devices and software which allows to give directly the density of the sample, introducing the mass values in the open air and under water.according to ISO 1183-1[19]. The densities are determined on an average of five samples. The samples are immersed in a liquid with a good wetting power and a known density such as water ρ = 0.998 g/cm^3 at 23℃ and 1 atm. The density is obtained from equation (6)

$$\rho r = (\rho E.mr)/mr - (mf - mE), \tag{6}$$

with ρr in g/cm³ the density of the sample, ρ_E in g/cm³ the density of the immersion liquid. As immersion liquid, water at 23 °C is used; mr: the mass of the sample in the open air.m_f the mass of the test-tube holder and test-tube assembly in the immersion liquid (at the end of the residence time). m_E the mass of the test-tube holder in the immersion liquid. The experimental results are presented in Table 5.

3.5 Hardness test

Hardness can be defined as a measure of resistance to localized plastic deformation. Hardness measurement methods (Brinell, Vickers and Rockwell tests, etc.) are based on the penetration of an indenter into the material surface. A hardness value is determined by measuring the size of the indentation made by the indenter under controlled loads and application speeds. The results obtained with the microdurometer type NOVA 130 HV0.1 are shown in the Table 5.

3.6 Morphological analysis

A morphological analysis of the structures of different materials is studied by scanning electron microscope (SEM) observations. The purpose of these observations is to see the fracture surface and highlight the heterogeneity of the microstructure. Fig. 3a, b and c show the microscopic observations of the flexural fracture surfaces of the laminates.

4 Results and discussion

4.1 Tensile test results

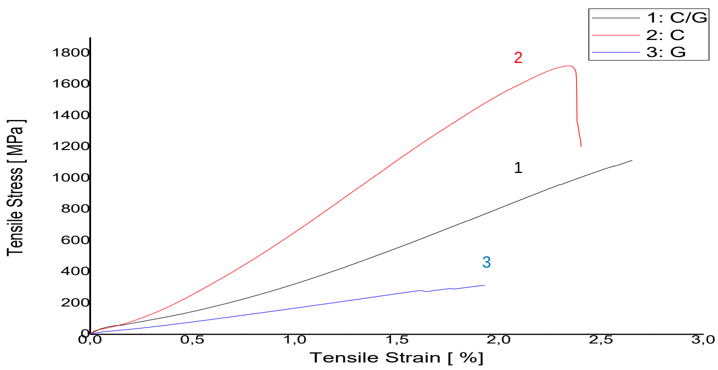

Fig. 1: Tensile behavior of glass, carbon and hybrid fiber laminates.

Table 3: Tensile characteristics of different materials.

Materials	Stacking sequence	$б_{max}$ [MPa]	$ε_{бrup}$ [%]	*E* [GPa]
glass fiber laminate *G* (12 layers of glass fiber)	G12	307.48	1.88	18.138
carbon fiber laminate *C* (12 layers of carbon fiber)	C12	1718.90	2.40	44.980
hybrid laminate *C/G* ; (6 layers of carbon fiber, 6 layers of glass fiber) in alternation.	C/G]6	1112.77	2.65	39.250

The results of the figure 1- table 3, allows us to conclude that The different laminates show a fragile behavior, we note a significant variation in tensile behavior depending on the nature of the fibers.

The carbon fiber laminate *C* has the highest tensile strength 1718.90 MPa, the highest Young's modulus 44.98 GPa with a strain of 2.4 %. On the other hand, the glass fiber laminate *G* has the lowest strength 307.48 MPa, the lowest Young's modulus 18.138 GPa with the lowest strain 1.88 *%*. The addition of carbon fibers to glass fibers in the *C/G* laminate improves the tensile strength and reaches the value of 1112.77 MPa, and the Young's modulus reaches the value of 39.25 GPa and the strain at break 2.65 *%*.

According to [20], the hybrid effect results from a failure to fully exploit the potential strength of the fibers in all-carbon fiber composites rather than an increase in their strength in the hybrid. And [21] found that in hybrid composites, the weaker, low-elongation fibers break first to form cracks that are bridged by the surrounding high-elongation fibers, allowing the stronger, low-elongation fibers to reach their ultimate strength.

4.2 Results of static bending test

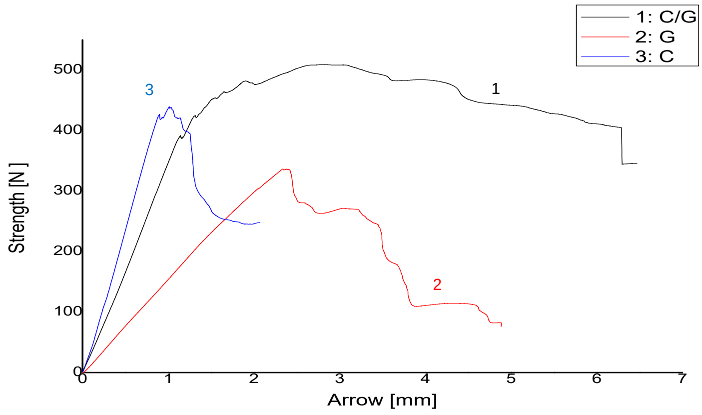

Fig. 2: Influence of the nature of the fibers on the flexural behavior of the laminates.

Table 4: Flexural characteristics of laminates.

Materials	Stacking sequence	Thicknes [mm]	F_{max} [N]	$f_{F.max}$ [mm]	Bending stress σ [MPa]	*E* flexural modulus [MPa]
glass fiber laminate *G* (12 layers of glass fiber)	G_{12}	2.83	287.67	2.34	286.26	29.74
carbon fiber laminate *C* (12 layers of carbon fiber)	C_{12}	2.70	458.72	1.04	411.50	61.99
hybrid laminate *C/G* (6 layers of carbon fiber, 6 layers of glass fiber) in alternation	$C/G]_6$	3.36	520.77	2.98	465.33	60.92

According to the results in Fig. 2, Table 4, the carbon fiber laminate *C* has the highest flexural strength 411.50 MPa and flexural modulus 61.99 GPa and the lowest maximum force deflection 1.04 mm, compared to the glass fiber laminate *G* which has the lowest flexural strength 286.26 MPa and flexural modulus 29.74 GPa. The hybridization of glass fibers with carbon fibers by alternate stacking increases the flexural properties of *C/G* laminate, the flexural strength reaches the value of 465.33 MPa which even exceeds the flexural strength of carbon fiber laminate, as well as the flexural strength increases up to 2.98 mm, and the flexural modulus 60.92 MPa which is close to the flexural modulus of carbon fiber laminate.

The flexural mechanical properties of hybrid composites are significantly improved, and are influenced by the composition of the hybrids and the stacking sequence, which is proved by other researchers [8, 11, 22]. The improvement in flexural strength may be due to the bridging effect of the carbon fiber layer between the glass fiber layers.

4. 3 Physical characterization

The calcination, density and hardness test results are summarized in the Table 5.

Table 5: Physical characterization.

Materials	Stacking sequence	Fiber mass fraction T_f [%]	Density [g/cm^3]	Microhardness HV0.1
glass fiber laminate (12 layers of glass fiber)	G_{12}	71.97	1.7711	29.13
carbon fiber laminate (12 layers of carbon fiber)	C_{12}	71.41	1.4328	35.71
hybrid laminate (6 layers of carbon fiber, 6 layers of glass fiber) in alternation.	C/G_6	65.06	1.5563	37.94

The density of the three laminates ranges from 1.7711 g/cm^3 for the glass fiber laminate *G*, to 1.5563 g/cm^3 for the hybrid laminate *C/G* and 1.4328 g/cm^3 for the carbon fiber laminate *C*. The incorporation of carbon fibers with glass fibers reduces the density of the composites.

The microhardness varies from 29.13 HV0.1 for the glass fiber laminate *G* to 35.71 HV0.1 for the carbon fiber laminate *C* and 37.94 HV0.1 for the hybrid laminate *C*/*G*.

These results in Table 5 indicate that the hybridization of carbon fibers with glass fibers has a very significant influence on the hardness and density of epoxy matrix laminates.

4. 4 Microscopic observation

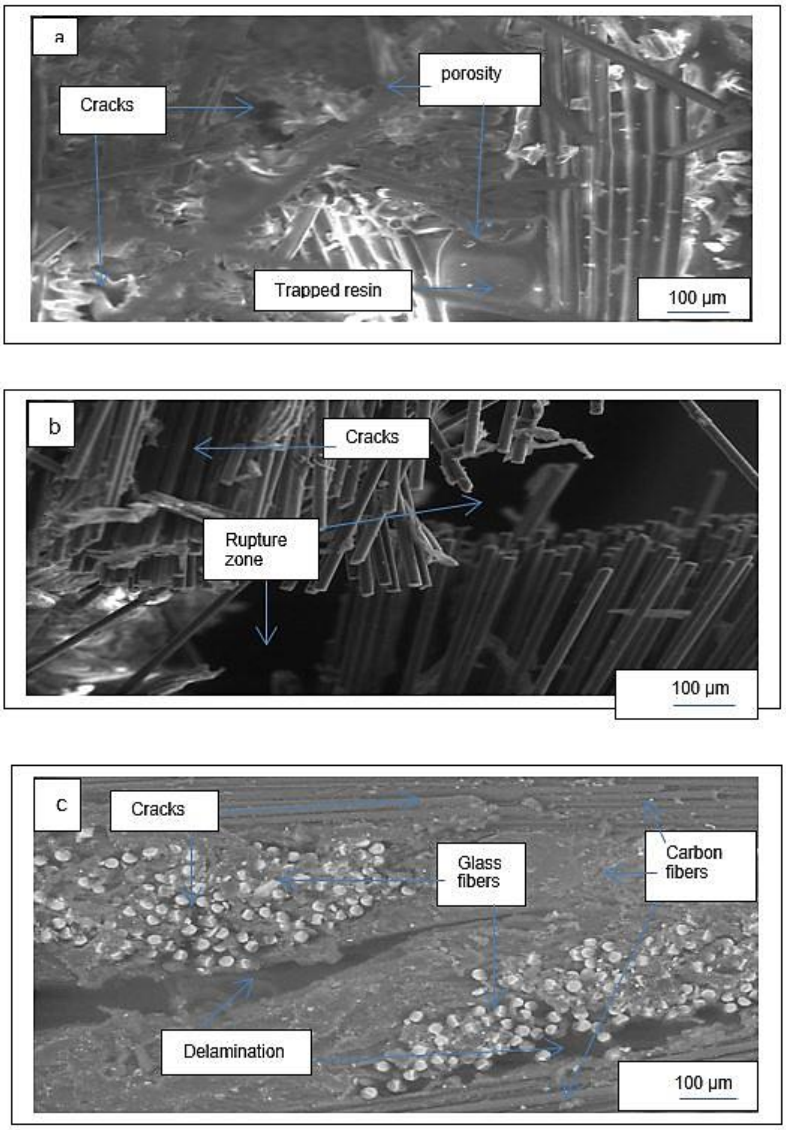

Fig. 3: Facies of the rupture of laminates: a) glass fiber laminate, b) carbon fiber laminate, c) hybrid carbon fiber/glass laminate, SEM observations.

In bending, the microscopic observations in Fig. 3a, b, c allow to highlight the alternation of the folds as well as the irregular distribution of the fibers in the matrix, characterized by zones rich in fibers and others rich in matrix. On the other hand, the microscopic observations reveal the presence of defects resulting from the elaboration of the laminates. These defects are essentially porosities which are mainly located in the resin-rich zones.

It is found that these materials present a heterogeneous morphology, whatever the scale of analysis, characterized by the presence of aggregates and isolated glass and carbon fibers. Each aggregate consists of a variable number of fibers and a trapped or occluded polymer fraction.

The crack generally follows a plane perpendicular to the load, loosening of the glass and carbon fibers, fiber breaks, delamination as well as cracks in the matrix were observed. This allows the determination of three types of damage resulting in the lower tensile failure zone, the intermediate shear failure zone and the uppercompressive failure zone. This has already been observed by Jin

Zhang [8], on glass/epoxy, carbon/epoxy and hybrid glass/carbon/epoxy laminates as well as by A.R Bezzazi [23], on glass/epoxy and kevlar/epoxy composites.

5 Conclusion

The effect of alternated hybridization on the physical and mechanical behavior and properties of the laminated composites with polymer matrix/ (carbon fibers / glass fibers) are studied. The main findings results are summarized as follows:

- The laminated composite wich alternated hybridization carbon fibers / glass fibers showes a better physical performance (hardness) than the laminated composite with glass fiber and laminated composite with carbon fiber.
- The influence of hybridization on the properties reduces the density of the composites.
- The tensile strength of glass fiber laminates is improved due to the alternated hybridization.
- The flexural strength and the elastic modulus of the hybrid composite are significantly increased due maybe to the bridging effect of the carbon fiber layers between the glass fiber layers.

This bridging effect between carbon fibers, glass fibers and epoxy resin, is opened to more research in the future to analysis of the chemical characteristics of these materials.

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