Mechanical and durability characteristics of externally GFRP reinforced unsaturated polyester polymer concrete

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Abstract. The last decades of the XXe century cognized a huge extent of composite materials uses to almost all everyday life’s applications, replacing the conventional materials, due to their outstanding properties especially highest strength-to-weight ratio and the ability to be designed to satisfy specific performance requirements. To get the most out of these wonder materials, a new concept, combining polymer concrete and composite laminates, is currently used in Algeria. This research work has the aim to investigate applicability of this concept in civil engineering through tensile and bending tests. On the other hand, the influence of various chemicals (Sodium hydroxide, Potassium Hydroxide and Calcium Carbonates) on our material and its tensile properties retention over long-time exposure was examined. The mechanical properties obtained indicate the convenience of this material for use in civil engineering thanks to its very good tensile and flexural performances in addition to its sufficient residual strength after theoretically 56 years.

1. Introduction:
The composite materials have been imposed since the second half of the past century thanks to their specific mechanical characteristics [1]. These materials are emerging quickly in number of applications including: automotive, aerospace, marine, sporting goods, electronic industries and for retrofitting the corrosion-damaged reinforced concrete elements [2, 3]. These wonder materials with lightweight, high strength-to-weight ratio and stiffness properties have come a long way in replacing, technically and economically, the conventional materials like metals, wood etc. Moreover, their cost has significantly decreased over the past years due to improvement of manufacturing [4].

The most used fibers are: Carbon, aramid and glass ones. Although strength characteristics of Glass fibers are somewhat lower than carbon fiber and it is less stiff, the material is typically far less brittle and its raw materials are too much cheaper [5].

Polymer concrete (PC) is a composite material formed by combining mineral aggregates with a thermoset resin mixed with a hardener. Since late 70s, epoxy and acrylic polymer concrete have been used to replace traditional materials due to rapid curing and excellent bond to cement concrete [6-8].

The polymer concrete has widespread applications owing to its remarkable qualities in comparison with conventional cement concrete [9]. Among the advantages offered: fast hardening, very good adhesion with the aggregates and great resistance to chemical aggressions [10] excellent mechanical strength and good corrosion resistance [11], resistance to abrasion and weathering [12],
waterproofness and good sound and thermal insulation properties [13] fatigue resistance [14] and excellent bonding with steel reinforcement and to old concrete [15].

Although 3-5 times stronger than ordinary Portland cement concrete, polymer concrete (PC) displays brittle characteristics that have limited its usefulness for load-bearing applications [16] and due to the limited tensile strength values and its brittle failure [17], these concretes have been often reinforced with GFRP or CFRP rods [18], [19].

Pipe systems have presented to improve human beings’ standard of living since the dawn of civilization. Nowadays, there are many types of piping materials ranging from rigid concrete to flexible thermal plastic. Pipes must have adequate strength to perform their intended function and, also, must be durable enough to last for their lifetime. The steel pipes are detrimentally affected by corrosion phenomena [20]. In the other hand, the concrete pipes are exposed to various harmful effects during their service life. The high cost of structures repair due to aging and corrosion of steel has led to a worldwide interest in the feasibility of using alternative fiber reinforced polymer (FRP) materials [21].

To avoid these disadvantages, a new concept is currently used in Algeria combining polymer concrete and composite materials. Typically polymer concrete has a longer maintenance-free service life and possesses also other aforementioned advantages compared to Portland cement concrete. This new concept assembles many advantages: (a). Satisfactory mechanical tensile and bending characteristics. (b). better durability than steel and ordinary concrete pipes attending even 100 years of guarantee. (c). the middle layer made with polymer concrete is up to decrease significantly the whole price and to ensure sufficient characteristics.

However, researches show that GFRP composites are not immune to long-term environmental degradation and are susceptible to varying amounts of strength and stiffness changes in the presence of environments such as water, ultraviolet exposure, elevated temperature, alkaline or acidic solutions and saline solutions. Beyond the cost issues, the most significant technical obstacle preventing the extended use of this concept of materials in civil engineering is a lack of long-term and durability performance data comparable to that available for traditional construction materials. That is why the long-term performances have to be investigated before they can be widely applied to the field [22].

This research work investigated the applicability of this concept in civil engineering through tensile and bending tests. Furthermore, the influence of various chemicals (Sodium hydroxide, Potassium Hydroxide and Calcium Carbonates) on our materials and its tensile properties retention over long-time exposure was examined.

2. Experimental Procedure
2.1. Materials
2.1.1. Polymer Binder. The thermosetting Isophtalic unsaturated polyester UPE resin has a density of 1200 kg/m3, viscosity at 25° equals 426 mPas and a gel time at 25° equals 14’30’’. The UPE are the most frequently used thermosetting matrices owing to their low cost and adaptability to be transformed into large composite structures. The Catalyst and accelerator used for this investigation are Methyl Ethyl Ketone Peroxide (MEKP) and Cobalt in weight ratios 1:0.03:0.2 respectively.

2.1.2. Combined Mat/Woven fabric E-Glass: Fiber glass is a lightweight, extremely strong and robust material. Its bulk strength and weight properties are also very favorable when compared to metals and it can be easily formed using molding process.

The reinforcement fibers type was E-Glass combined stitched mat/woven fabric with a mass per surface unit of 600g/m2. Also we used chopped mat E-glass to reinforce the inner polymer concrete layer with 1% per weight.

2.2. Fabrication Method
The composite laminates used for the present investigation were fabricated by hand lay-up process. The plate was constituted of 4 layers of reinforcement fabrics impregnated in pre-catalyzed binder
between them a medium layer constituted of polyester polymer concrete. This latter, was reinforced by chopped E-Glass fibers of 50-70 mm length. Before Hand lay-up process begins, it is important to treat the mold surface with a release to ease removal of the fabricated laminates after their hardening. Release agent in a form of sheet (commercial name is Mylar sheet) painted with lubricant was used in order to avoid the above mentioned problem. After manufacture, the composites stayed 24 hours to have a total polymerization [23]

![Image of composite material](image)

**Figure 1.** GFRP tensile and flexural specimens

After curing, the GFRP specimens sawn with a water-cooled diamond saw were characterized for their tensile and flexural mechanical properties ‘Figure.1’ according to universal standards as described in the table below:

| Table 1. Trials and their Standards. |
|--------------------------------------|
| Trial Type                  | ASTM Standard |
|-----------------------------|----------------|
| Tensile test                | D 3039         |
| 3 Pts Bending               | D 790          |

2.3. Mechanical Characterization

A larger number of tests give a higher confidence in data that is why at least four samples have been taken for each test to obtain average value. All the tests were done at an ambient temperature.

2.3.1. Equipment: The manufactured GFRP composites were subjected to tensile and flexural quasi-static tests performed on a computerized Universal Testing machine UTM YLE 25 capable to loading to 250 KN with displacement control.

2.3.2. Tensile strength test. The tensile strength of virgin and harsh liquid aged composites were determined with a crosshead speed of 1.5 mm/min. The specimens of dimensions 250mmx25mmx14mm were used for analysis in accordance with ASTM D3039 for constant head-speed tests ‘Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials’ [24] As shown on Figure.2

The force was applied until the failure of the sample and stress-strain curve was obtained. The tensile strengths were calculated through the formula:

\[ R_t = \frac{F_u}{A} \]  

(1)

Where: \( F_u \): ultimate load (N).
\( A \): Transverse section.
2.3.3. Flexural strength test. The Flexural properties of samples were measured according to ASTM D790 at a cross head speed of 2 mm/min Fig 3. Flexural strengths are determined from the formula given below:

\[ R_f = \frac{3FL}{2bd^2} \]  

(2)

Where: F: Ultimate load (N), L: Span length (mm), b: wide (mm), d:Thickness (mm).

3. Results and discussion
Generally, the mechanical properties of composites are mainly governed by: number of layers, fiber direction, mass per area of fabric, strength and modulus of the fibers and the effectiveness of the bonding strength between matrix and fibers in transferring stress across the interface.

3.1. Tensile strength test
The tensile load for a composite is very much dependent on the strength properties of the reinforcement fibers since they are high compared to the resin system on its own.

The tensile strengths were assessed of the developed GFRP composites and average properties values are presented in Figure 4. From the behavior observed the material shows a linear response proportionally to the load applied and the strain increases till reaching the maximum load where it exhibits a little non-linearity before its failure by progressive breaking of the fibers.
During the tensile test, the GFRP composites had a width-wise failure perpendicular to the force application axis. Tab failure is likely to occur [25] that is why we took into consideration only specimens values with acceptable failure, i.e. failure occurring in (or near) the center of the specimen. Specimens showed a violent release of elastic energy exhibited by catastrophic failure i.e. explosion of the specimens in their centers figure 5.

![Figure 5. Failure of specimen in tension](image)

3.2. Flexural strength test
The average stress-strain relationship results of the flexural quasi-static tests are shown in Figure 6. These tests were carried out on samples with a span ratio of 1:16. It can be easily seen that flexural deflection increased as a function of the applied load. The flexural properties of the composites are mainly depending on the yarn geometry and fiber orientation which have important microstructural features [26]. It is evident from ‘figure 6’ that the samples could bear a maximum stress of 206±26 MPa and have a strain of 2.67±0.46 %.

![Figure 6. Flexural Stress versus strain diagrams of the samples](image)

4. Durability characterization
The long-term durability of the GFRP composite specimens elaborated above has been investigated with special focus on the effects of alkaline liquid ageing. For this end, we followed the procedure described by Francesco Micelli et al. [27]. Four specimens for each immersion period were tested.

![Figure 7. Effects of alkaline environment conditions on tensile performance of the samples](image)

As it was expected, the initial slope of curves was decreased as the exposure proceeds in accelerated ageing, which was clearly an indication on the deteriorating role of the alkaline solution on
the mechanical properties. However, the reduction in tensile strength was not very significant. The loss of composites in tension upon exposure was ≈ 3%, 5%, 10% and 11% respectively over control samples as it is showed on the histogram below:

![Histogram showing the loss of composites in tension](image)  

**Figure 8.** Residual apparent tensile strength of tested GFRP composites

One early effect of this alkaline aqueous environment was the appearance of a milky colour on the surface of composites as reported elsewhere [28].

5. Conclusion:  
This paper assessed the use of a new GFRP composite material concept in civil engineering through tensile and flexural mechanical tests. In the other hand, the long-term performance of this composite material under alkaline exposure was evaluated. The results indicate the convenience of this material for use in civil engineering thanks to its very sufficient mechanical performances; tensile strength 108±5 MPa and flexural strength 206±26 MPa; and also its good residual strength after theoretically 56 years.

A concerted effort is still needed study the long-term performance with respect to biological attack, fire and user habit conditions.

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