Environmental durability of externally natural fabrics reinforced polymer concrete

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Abstract. The quick emergence of composites since their invention due to their high specific properties do not gainsay the health problems associated with the use of synthetic fibers as reinforcing agent of almost all commercially available polymer composites. To avoid those hazardous effects, the current global tendency is the incorporation of lignocellulosic fibers instead of these mineral ones owing to their biodegradability, low cost and low density, renewability and aspect ratio in addition to their high mechanical properties. A new material’s concept currently applied in Algeria, based on an externally GFRP polymer concrete, proved its efficiency in piping systems. The design merging composite materials with polymer concrete in laminated form is used to get the most out of these two materials such as: more economic final material with high mechanical properties in tension also in bending in addition to a better durability properties. The aim of the present work is the substitution of glass fabrics and short fibers reinforcing the polymer materials in the current material concept by natural fibers and fabrics made up of jute plant. To assess the possibility of using this new concept reinforced with jute fabrics in civil engineering applications, we carried out tensile and interlaminar shear strength tests. Then, in the second part of this research work, mechanical properties durability of this new material was followed up through its immersion in a harsh environment simulating theoretically 56 years of aggressive exposure. The obtained results evidence high tensile and interlaminar shear properties. On the other hand, the residual tensile and ILS strengths allow the consideration of this new material’s concept reinforced with natural jute fabrics as suitable for civil engineering applications for non-bearing load elements.

Key words: natural fibers, BPREX, eco-friendly laminate, SFR polymer concrete, environmental durability.

1. Introduction

Developed from a laboratory curiosity in the time since the Second World War, fiber reinforced composites became the cornerstone of a colossal industry delivering millions of tons every year worldwide [1]. Composite materials find their use in more and more applications, from the manufacture of aircrafts, cars, and bicycles to superconductor components. They have been proven to be stronger yet more flexible than steel and other widely used materials [2]. Nowadays, Fiber
reinforced Polymers (FRPs) invade almost all of our daily life applications thanks to their specific characteristics. FRPs have a versatility concerning their bonding to different complex shapes, the highest strength-to-weight ratios, good mechanical characteristics especially in tension. In addition, they are lightweight and are resistant to corrosion, ultraviolet rays and the phenomenon of fatigue. Furthermore, they also offer the reduction of mandatory work and downtime to their implementation; their free shapes and adaptable design capability and chemical inertia exceeding that of all conventional materials [3], [4], [5], [6]. The lightweight of composite materials made them attractive for applications in any region of the world especially where construction cost penalties increase tremendously with remoteness of the locations and heaviness of the construction materials and equipment [7].

However, the quick emergence of composites since their invention due to their high specific properties does not gainsay the health problems associated with the use of synthetic fibers as a reinforcing agent of almost all commercially available polymer composites. To avoid these hazardous effects, the current global tendency is the incorporation of lignocellulosic fibers instead of these mineral ones owing to their biodegradability, low cost and density, renewability and aspect ratio in addition to their high mechanical properties. Recently, there has been an increase interest in the use of bio-composites due to environmentally aware consumers to preserve the world [8]. Natural fibers are low-priced and sustainable natural resources. With increasing environmental protection consciousness, natural fibers as a relatively new group of environmental friendly materials are in considerable demand in recent years by unifying technological, economic and ecological aspects [9].

A new material’s concept currently applied in Algeria and in many other countries, based on an externally GFRP polymer concrete, proved its efficiency in piping systems. We have already presented the concept of BPREX combining the polymer concrete with Glass fiber reinforced laminates. The design merging composite materials with polymer concrete in laminated form is used to get the most out of these two materials in the same time such as: more economic final material with high mechanical properties in tension also in bending in addition to a better durability properties. The applicability of this new concept in civil engineering in addition to its durability tracking in harsh environment was previously studied [10].

The aim of the present work is the substitution of glass fabrics and short fibers reinforcing the polymer materials in the current material concept by natural fibers and fabrics made up of jute plant. Keeping the same concept would ensure high level strengths and manufacture easiness in addition to the most important aim which is getting a more eco-friendly material and so, to have a compromise between sufficient performances and environmental protective aspect. The material constitution is shown on the figure below:

![Figure 1](image)

**Figure 1.** The concept of BPREX developed during our current project; two skins made of JFRP and an SFR polymer concrete core.

Where: JFRP: Jute fabric reinforced polyester resin

SFR polymer concrete: Short fibres reinforced polymer concrete

Although composite materials exhibit superior performances compared to conventional materials because they possess the potential to revolutionize engineering materials and technologies [11], previous researchers have proven that harsh environmental factors adversely affect the material properties of these polymer based materials [12]. The vulnerability of FRPs to such environmental factors has created a critical need for cost-effective and durable materials [13]. In order to use
efficiently this concept reinforced with natural fibers in civil engineering, a detailed mechanical characterization accompanied with a durability assessment is imperative.

To assess the possibility of using this new concept reinforced with jute fabrics in civil engineering applications, we carried out tensile and interlaminar shear strength tests upon specimens cut from its laminates. Then, in the second part of this research work, because durability properties of materials are crucial for its consideration as sustainable construction material, mechanical properties durability of this new material was followed up through its immersion in a harsh environment simulating theoretically 56 years of aggressive exposure as recommended by Francesco Micelli et al [14]. The obtained results evidence high tensile and ILSS properties. On the other hand, the residual tensile and ILS strengths allow the consideration of this new material’s concept reinforced with natural jute fabrics as suitable for civil engineering applications for non-bearing load elements.

2. Experimental procedure
2.1. Materials
2.1.1. Jute woven fabric. A bidirectional Commercial Jute yarns fabric was used for the reinforcement of our BPREX in the current research work. According to the specifications provided by the supplier, the mass per unit area of the fabric is 460 g/m2 and it was produced by 100% Jute yarns in both warp and weft direction with similar yarns. Before its use as a reinforcing agent, we carried out a full characterization of it in our previous work [15]

Figure 2. Jute bidirectional fabric used as reinforcing agent

2.1.2. Polymer Binder. The thermosetting Isophthalic 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.

2.1.3. Silica sand. The mineral fillers consist of standardized silica sand 200-500 μm. It is specially treated for the manufacture of the polymer mortar. This sand is produced by the Algerian company Adwan Chemical Industries Co. Ltd.

Figure 3. BPREX specimens developed and characterized during the current research work

2.2. Methods
All the quasi-static and durability tests were done at an ambient temperature on a computerized Universal Testing machine UTM YLE 25 capable to loading to 250 KN with displacement control. The long-term durability of the elaborated BPREX material was characterized by following the detrimental effects of its immersion in an alkaline liquid previously used by Francesco Micelli et al. [14] for which the formulation will be presented below.
3. Results and discussion
Experimental results of both virgin and immersed specimens are presented and discussed hereafter. It is well known that the performances of natural fibers reinforced composite materials are governed by the properties of lignocellulosic material and those of the polymer binder [16].
Figure 3 presents average virgin BPREX tensile curves. It is easily observable that BPREX specimens exhibit a brittle behavior till reaching their maximum bearing load before encountering an abrupt failure i.e. a linear proportionality between stresses applied and their corresponding strains followed by a fall of strength without showing any plastic deformations. This behavior is typical for almost all FRP materials and it is governed by the brittleness of its basic constituents; fibers and polymer binder.

![Figure 4. Tensile stress-strain curves of virgin BPREX specimens](image)

Due to the relatively weaker interfaces among the layers of polymer composite laminates compared to the interfaces in their plane, the interlaminar shear strength test (ILSS) is typically an important design factor [17]. Thereupon, it is of great importance to understand comprehensively the ILSS behavior of our developed BPREX material. Typical ILSS curves of BPREX test samples are shown on the figure 4. The brittle behavior is reproduced during ILSS tests for all BPREX characterized test samples.

![Figure 5. Interlaminar Shear Strength curves of virgin BPREX specimens](image)

The small non-linear regions in tensile and ILSS curves of laminates made from fragile materials, similar to those of our work, occurs from the development of damage from pre-existent defects in the matrix (polyester resin) and in the fiber / matrix interface. These microscopic defects become, with the loading increments, macroscopic order cracks causing the total failure of specimens subjected to the tests [18].

The second step in the presentation of our elaborated BPREX material reinforced with natural jute fabrics as a construction material for civil engineering applications is its long term behavior. For this purpose, the BPREX laminates were immersed in a harsh liquid environment for 84 days which theoretically equals 56 years in natural conditions.

The alkaline liquid has a pH = 13 and it is obtained following the equation below:

\[ \text{Distilled water} + 0.16\% \text{Ca (OH)}_2 + 1\% \text{Na(OH)} + 1.4\% \text{K(OH)} \]

After the immersion period, BPREX laminates should be carefully washed with distilled water to remove any chemical traces. Afterward, the composite laminates were cut into standardized dimensions prescribed in ASTM D3039 and ASTM D2344 for tensile and ILSS tests respectively.
A comparison between virgin and aged BPREX specimens, similar curve patterns are obtained further to interlaminar shear strength tests. On the figure 7 the reduction in the slope of the stress-strain curve for aged samples evidences a loss in the ILSS. This drop in interlaminar shear strength is of the order of 17% with respect to reference values reached with virgin BPREX samples.

It is clear that the alkaline liquid environment has deteriorating effects on the mechanical performances of the developed BPREX. Nevertheless, the tested specimens have significant residual stresses as shown on the following histogram:

Even though the fact that the environmental tolerance and overall durability of the composites are dominated by the polymer matrix while the reinforcing fibers are responsible for carrying the structural loads [20], for the particular case of bio-composites, the major sources of degradation amidst ageing process come from the degradation of the natural fibers and the weakening of their interface with the polymer binder [21]. Natural fibers degrade by decomposition into thin fibrils and detached layers. Thwe et al. [22] presumed that the drop in tensile strength is attributed to the breaking of the Si-O-Si bonds on the fibers surface as a result of their attacking by alkaline solution molecules. Taking into account the aforementioned assumptions, we could assume that the tensile curve layout change in addition to the loss of the ILSS after immersion period could be hypothesized to be associated mainly with the degradation of the jute fabrics. This natural reinforcement necessitates its chemical treatment prior to their insertion in polymer composites in order to improve the waterproofness without altering its surface wettability by polymer matrices [23]. Moreover, the inclusion of a compatibilizer in the polymer matrix improves its interfacial bonding with the fibrous phase and, hence, enhances significantly the mechanical properties [24].
4. Conclusion
The present paper sets out an investigation on the mechanical properties along with the durability performances of an elaborated polymer concrete reinforced with natural jute fabrics to which we have given the name BPREX. Based on the experimental campaign conducted during this study, the following conclusion could be made:

- The substitution of glass fibers by natural jute fabrics for BPREX reinforcement allowed attaining good mechanical properties in terms of tensile and interlaminar shear strengths which have values equal to 21±0.9 MPa and 44±0.6 MPa respectively.
- Ageing in alkaline solution induced a drop in BPREX performances for both tensile and interlaminar shear strengths.
- After immersion period simulating theoretically 56 years in natural environmental conditions, the BPREX laminates have important residual stresses percentages of 82% for tensile strength and 81% for ILSS.

The good mechanical properties achieved with the developed polymer laminates in addition to their ecofriendly aspect thanks to their reinforcement with natural jute fibers make the natural fibers reinforced BPREX a low energy and low cost construction material useful in applications requiring sufficient mechanical strengths and good durability concomitantly.

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References
[1] Summerscales, John. Non-Destructive Testing of Fibre-Reinforced Plastics Composites. London: Elsevier Applied Science, 1990.
[2] Isaac M. Daniel, Ori Ishai. Engineering mechanics of composite materials. 2nd edition. ISBN 978-0-19-515097-1.
[3] Mohammad Reza Aram, Christoph Czaderski, Masoud Motavalli. Debonding failure modes of flexural FRP-strengthened RC beams. Composites: Part B 39 (2008) 826–841.
[4] J.F. Chen, J.G. Teng. Shear capacity of FRP-strengthened RC beams: FRP debonding. Construction and Building Materials 17 (2003) 27–41.
[5] M. Maalej, K.S. Leong. Effect of beam size and FRP thickness on interfacial shear stress concentration and failure mode of FRP-strengthened beams. Composites Science and Technology 65 (2005) 1148–1158.
[6] Lelli Van Den Einde, Lei Zhao , Frieder Seible. Use of FRP composites in civil structural applications. Construction and Building Materials 17 (2003) 389–403.
[7] Piyush K. Dutta. Low temperature and freeze-thaw durability of thick composites. Composites: Part B 27B (1996) 371-379.
[8] A. Atiqah, M.A. Maleque, M. Jawaid, M. Iqbal. Development of kenaf-glass reinforced unsaturated polyester hybrid composite for structural applications. Composites: Part B 56 (2014) 68–73.
[9] Andrzej K. Bledzki, Wenyang Zhang, Andrés Chate. Natural-fibre-reinforced polyurethane microfoams. Composites Science and Technology 61 (2001) 2405–2411.
[10] H Bougessir et al 2017 IOP Conf. Ser.: Mater. Sci. Eng. 254 022002.
[11] Houssam A. Toutanj. Durability characteristics of concrete columns confined with advanced composite materials. Composite Structures 44 (1999) 155-161.
[12] José P. Gomez, Casto B. Freeze-Thaw durability of composite materials. Proceedings of the 1st international conference on composites in infrastructures, ICI, Tucson, Aris. 947-955.
[13] V.M.Karbhari, M.Engineer, D.A.Eckel. On the durability of composite rehabilitation schemes for concrete: use of a peel test. Journal of materials science 32 (1997) 147D156.
[14] Francesco Micelli, Antonio Nanni. Durability of FRP rods for concrete structures.Construction and Building Materials 18 (2004) 491-503.
[15] Bouguessir Hamza, Harkati ElHadi, Rokbi Mansour, Georgios Priniotakis, Savvas Vassiliadis, Sozon Vasilakos, Hadjer Boughanem and Lahcene Fellah. *Physico-chemical and mechanical characterization of Jute fabrics for civil engineering applications*. Journal of Computational Methods in Sciences and Engineering -1 (2018) 1–19.

[16] Ryszard Kozlowski, Maria Wladyka-Przybylak. *Flammability and fire resistance of composites reinforced by natural fibers: Review*. Polymers for advanced technologies 2008; 19: 446–453.

[17] Xin Wang, Xing Zhao, Zhishen Wu, Zhongguo Zhu and Zihao Wang. *Interlaminar shear behavior of basalt FRP and hybrid FRP laminates*. Journal of Composite Materials 0(0) 1–12.

[18] R.G. Cuntze, A. Freund. *The predictive capability of failure mode concept-based strength criteria for multidirectional laminates*. Composites Science and Technology 64 (2004) 343–377.

[19] Paul Böer, Lisa Holliday, Thomas H.-K. Kang. *Independent environmental effects on durability of fiber-reinforced polymer wraps in civil applications: A review*. Construction and Building Materials 48 (2013) 360–370.

[20] Omar Faruk, Andrzej K. Bledzki, Hans-Peter Fink, Mohini Sain. *Biocomposites reinforced with natural fibers: 2000–2010*. Progress in Polymer Science 37 (2012) 1552–1596.

[21] Moe Moe Thwe, Kin Liao. *Effects of environmental aging on the mechanical properties of bamboo-glass fiber reinforced polymer matrix hybrid composites*. Composites: Part A 33 (2002) 43-52.

[22] Moe Moe Thwe, Kin Liao. *Durability of bamboo-glass fiber reinforced polymer matrix hybrid composites*. Composites Science and Technology 63 (2003) 375–387.

[23] Yanjun Xie, Callum A.S. Hill, Zefang Xiao, Holger Militz, Carsten Mai. *Silane coupling agents used for natural fiber/polymer composites: A review*. Composites: Part A 41 (2010) 806–819.

[24] A. K. Rana, A. Mandal, B. C. Mitra, R. Jacobson, R. Rowell. A. N. Banerjee. *Short Jute Fiber-Reinforced Polypropylene Composites: Effect of Compatibilizer*. Journal of Applied Polymer Science, Vol. 69, 329-338 (1998).