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ORIGINAL PAPER

Mechanical properties of polymer concrete made with jute fabric and waste marble powder at various woven orientations

M. Rokbi[1] · **B. Baali**[2] · **Z. E. A. Rahmouni**[3] · **H. Latelli**[3]

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Abstract

The use of polymer concrete has been extensively developed over the last few years, and a growing attention is being paid to search for ways to strengthen their innovation processes. The object of this work is the valorization of natural resources, such as vegetable fibers and mineral wastes, to reduce the environmental impact and improve the mechanical properties of polymer concrete. More specifically, this investigation focused on the influences of woven fabric orientation on mechanical properties of polymer concrete laminates.

Keywords Polymer concrete · Mechanical properties · Vegetable fibers · Mineral wastes

Introduction

Fiber-reinforced polymers are composite materials that are made up of a polymer matrix reinforced with fibers such as glass, aramid and carbon. These composites materials display excellent mechanical performances, good oxidation resistance and chemical tenability. However, they create many environmental concerns. For example, when mineral fibers are used as a reinforcing agent they can create health problems. The study carried out by Sripaiboonkij et al. (2009) provides evidence that exposure to glass microfibers increases the risk of respiratory and skin symptoms, and has an exposure–response relation with breathlessness and skin symptoms. More recently, several authors have initiated investigations in order to develop vegetable fibers as reinforcements not only for polymer matrix composites but also for polymer concrete.

The use of natural fibers as reinforcement in building construction represents an environmentally friendly alternative to conventional reinforcing fibers, particularly the common glass fiber. Recently, natural fibers such as hemp, flax, jute and sisal are introduced into structural applications such as those in housing and building construction materials (Onuaguluchi and Banthia 2016; Coutts 2005; Kiruthika 2016). As a result, several advantages associated with mechanical, thermal and biodegradable properties are added. In the last years, extensive studies have been done on the effects of natural fibers in fiber-reinforced concrete composites. Mansur and Aziz (1982) conducted an investigation on the mechanical properties of cement paste and mortar reinforced with jute fiber. The experimental results showed that inclusion of jute fiber in cement-based composite imparted significant increase in flexural toughness, tensile, flexural and impact strengths, but had very little influence on the compression strength. Asasutjarit et al. (2007) determined the physical (density, moisture content, water absorption and thickness swelling), mechanical (modulus of elasticity, modulus of rupture and internal bond) and thermal properties of coir-based lightweight cement board after 28 days of hydration. Ramakrishna and Sundararajan (2005) tested sisal, coir, jute and hibiscus cannabinus (kenaf) fibers-reinforced cement mortars with different fiber lengths and fiber dosages. They found that the impact strength of mortars with fiber reinforcement is always higher than that of those without fiber reinforcement. In some cases, the impact resistance of the former is 18 times higher than that of the latter. Other

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✉ Z. E. A. Rahmouni
zineelabidine.rahmouni@univ-msila.dz

[1] Department of Mechanical Engineering, Faculty of Technology, University of M'sila, 28000 M'sila, Algeria

[2] URMPE/MESOnex Team, Faculty of Engineering, University of Boumerdès, 35000 Boumerdès, Algeria

[3] LDGM, Department of Civil Engineering, Faculty of Technology, University of M'sila, 28000 M'sila, Algeria

researchers have reported a cost-effective process methodology for manufacturing jute fiber-reinforced concrete sewage pipe. In that study, jute fibers were chopped and treated by chemicals in order to achieve homogeneous dispersion of jute fibers into cement matrix. It was found that the load bearing capacity of jute fiber-reinforced sewage pipes was significantly increased as compared to the concrete pipes made without fiber reinforcement, indicating that natural fibers, such as jute fibers, could be reasonably good reinforcement for cement-based materials (Kundu et al. 2012). Zakaria et al. (2015) investigate the effect of introducing jute yarn into the mechanical properties of concrete. An experimental investigation of the compressive, flexural and tensile strengths of jute yarn-reinforced concrete composites has been conducted. It was found that the addition of jute yarn contributes enriched results for mechanical properties of concrete composites for a particular yarn length and yarn content. More specifically, compressive, flexural and tensile strengths are found to enhance significantly for volume content of 0.1 and 0.25% and the yarn cut length of 10 and 15 mm. Chakraborty et al. (2013) investigated jute fibers as a reinforcing agent in improving the physical and mechanical properties of cement mortar and found that fracture toughness is significantly increased of jute fiber-reinforced cement mortar up to 1% by weight, with respect to cement, jute fiber loading, while, with the further increase in jute contents, the fracture toughness of cement mortar is gradually reduced. In this study, the jute fiber loading in concrete was 0.5% by volume, which is equivalent to 1.2% by weight, of cementitious binder close to the recommended fiber loading recommended by them.

The reinforcement of polymer concrete (PC), which is produced by mixing well-graded inorganic aggregates with a resin binder, with cellulosic fibers knew a fast development in recent years (Reis 2012; Barbuta and Harja 2008; Rokbi et al. 2017; Alam and Al Riyami 2018). It was shown that the fractures, compressive and flexural properties of PC reinforced with short cellulosic fibers were improved. Hence, natural fibers can be an alternative solution to synthetic fibers. Reis (2006) performed third-point loading tests to investigate the flexural strength, fracture toughness and fracture energy of epoxy polymer concrete reinforced with coconut, sugarcane bagasse and banana fibers. The investigation revealed that fracture toughness and energy of coconut fiber-reinforced polymer concrete were the highest, and an increase in flexural strength up to 25% was observed with coconut fibers. According to Ribeiro et al. (2010) when piassava fibers were used as reinforcement in polyester polymer mortars and tested in compression, an increase in strength was observed, 14.3% for 1% piassava fiber content and 10.5% when 2% of piassava fibers were used as aggregate replacement. On the other hand, waste marble powder (WMP) that results from the recycling process has been used as aggregate for assorted construction materials. WMP is a useful material obtained as a by-product of marble during sawing, shaping and polishing processes such that about 25% of the processed marble turns into dust or powder form (Güneyisi et al. 2009). Hebhoub et al. (2011) showed that the appropriate incorporation of marble waste aggregates can lead to interesting characteristics in terms of strength. The effect of substitution of quartz by different WMP contents on the mechanical properties of PC is investigated in Rokbi et al. (2017). The use of WMP in PC is shown as a filler effect. The use of 20% of WMP could be considered as the optimum content to enhance the PC properties (Rokbi et al. 2017).

This research is part of the framework of a new material's concept currently applied in Algeria and in many other countries based in externally GFRP polymer concrete which proved its efficiency in piping systems (Priniotakis et al. 2018). In this work, the glass fabrics were substituted by jute-woven fabric. As yet, very little work has been done on this subject. The purpose of this work is to investigate the influence of orientation plies (45°, 55°, 60° and 0°) of jute fabric on mechanical properties of PC laminate made up of an orthophthalic polyester binder, jute-woven fabric and natural aggregates.

Materials and methods

Materials

The aggregate used in PC was quartz fine sand. The grains have a homogeneous size with an average diameter between 200 and 500 µm. The quartz fine aggregate was produced by "Mostaganem" unit and has been used in the past as filler in polymeric composite pipes produced by Maghreb Pipe Industry (M'sila). The chemical compositions of quartz sand are given in Table 1. In addition, a very fine waste marble powder has been used in the PC as a mineral addition. The

Table 1 Chemical composition of quartz sand and WMP (Rokbi et al. 2017)

Chemical composition	Quartz sand (%)	WMP (%)
MgO	0.006	0.080
CaO	0.010	55.650
Fe_2O_3	0.215	0.000
Al_2O_3	0.769	0.05
SiO_2	99.02	0.040
TiO_2	0.078	–
K_2O	–	0.030
H_2O	0.020	–
LOI	–	43.47

recovered waste marble is sieved into marble powder using a fine sieve (5 microns). Table 1 also presents the chemical characteristics of white WMP.

As binder, the orthophthalic polyester is used. This resin is considered as the most cost-effective binder in polymer concrete systems. Additionally, polyester resin is the most used resin to produce polymer concrete due to its high performance, resulting in a high strength and durability against aggressive environments, with low permeability and lower cost when compared to epoxy resins (Reis 2011). Resin properties provided by Maghreb Pipe are presented in Table 2.

In this investigation, a bidirectional plain jute fabric with a surface density of 420 g/m^2 (warp and weft density 49 × 47 fiber/10 cm) was used. The jute fabric was kindly provided by "TDA Textiles Divers Algerie". It is a company specialized in manufacturing of jute fabrics, ropes, chemical fiber fabrics, plastic bags and sacks, etc. The fabrics were dried in oven at 70 °C for 6 h before being used. Physico-chemical and mechanical properties of jute yarns and fabric can be found in the early work of Bouguessir et al. (2018).

Table 2 Physical and mechanical properties of orthophthalic polyester (Rokbi et al. 2017)

Properties	Unsaturated polyester
Monomer (%)	30–35
Visco at 25 °C (mPas)	450
Gel time (min)	12–16
PIC (°C)	165–185
Tensile strength (Mpa)	60–80
Strain at break ξ (%)	2.5–3.5
Tensile modulus (GPa)	3.4–3.8

Manufacturing methods of PC laminate

In this study, four PC laminates were developed. The difference between these plates relates to the fibers orientation of jute fabric plies (±45°, ±55°, ±60° and ±0°). The laminate is composed of a central PC layer of thickness of 10 mm, and of two identical plies of jute fabric composites in both sides. The choice of jute fabrics as a reinforcing fiber is mainly due to its relatively low cost and commercial availability and also good specific mechanical properties upon comparing with plastic and is a good replacement for conventional fibers in many applications (Rana and Jayachandran 2000; Arju et al. 2015; Bledzki et al. 2015).

The jute fabric plies (±45°, ±55°, ±60° and ±0°) were cut (400 × 400 mm^2) from a jute roll in the desired orientation (Fig. 1), and usual instruments are used.

Figure 2 illustrates the experimental procedure for the preparation of different PC laminates. First of all, two identical plies of woven jute fabric composite were prepared in specially designed wood mold (400 × 400 × 20 mm^3) to give a uniform PC thickness (Fig. 2a). In parallel, an amount of PC based on quartz fine sand (2033 g), polyester resin (500 g) and waste marble (208 g) was prepared (Fig. 2b, c), thereby this mixture was poured into the mold in a uniform manner. Finally, two plies of woven jute fabric composite were added to mold and the obtained PC laminate was compressed using a roll and an insulating paper (Fig. 2d).

Figure 2e illustrates the final PC laminate. Four PC laminates were prepared using the same procedure mentioned above while respecting the orientation of jute fabric plies (±45°, ±55°, ±60° and ±0°). These laminates were initially cured at room temperature and then post-cured for 6 h at 70 °C (Rokbi et al. 2017). Bending test samples were prepared according to the ASTM D790. Figure 2f illustrates the obtained bending test samples.

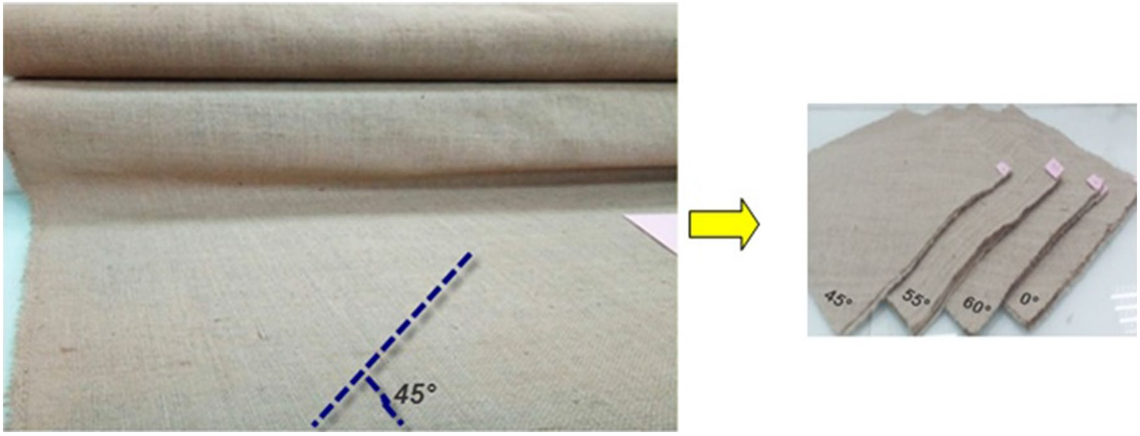

Fig. 1 Obtaining of jute plies

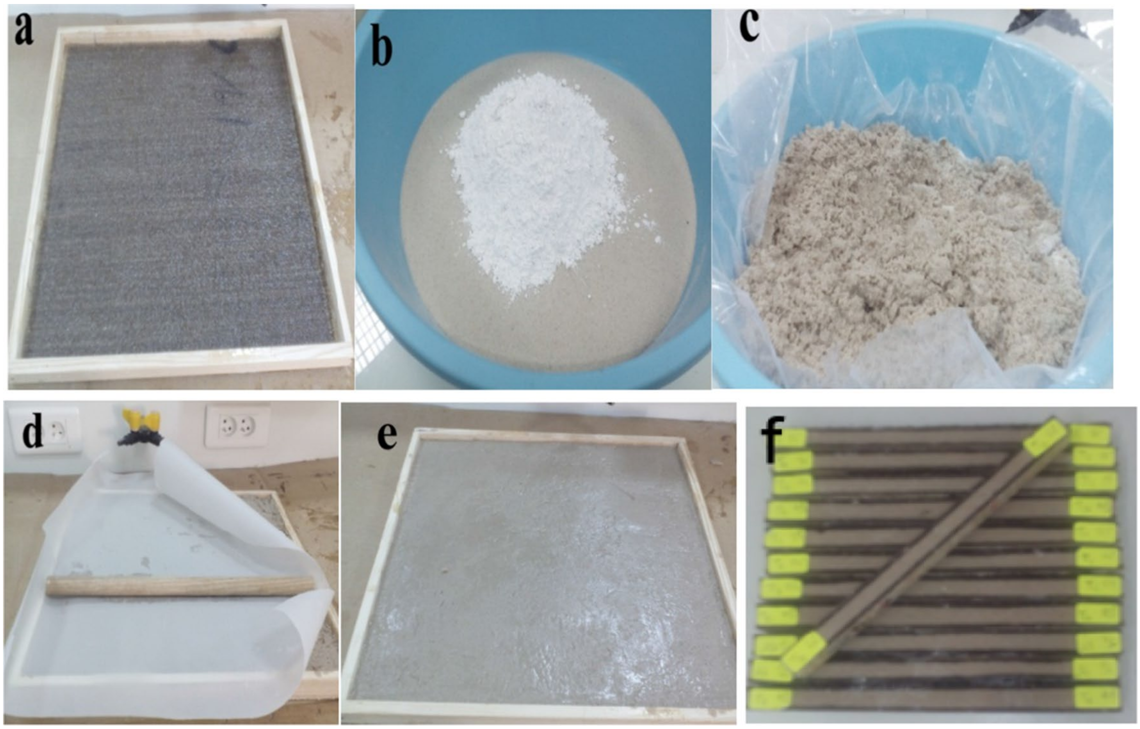

Fig. 2 Experimental procedure for the preparation of different PC laminates: **a** impregnation of plies, **b** quartz and WMP mix, **c** quartz, WMP and resin mix, **d** laminate compaction, **e** polymerization, **f** tensile and **g** flexure specimens

Table 3 Different manufacturing PC laminates

Orientation (°)	Composition	Designation
±45	[±45/PC/±45]	PC-45
±55	[±55/PC/±55]	PC-55
±60	[±60/PC/±60]	PC-60
0	[±00/PC/±00]	PC-00

Three-point bending tests had stopped automatically when the plastic deformation appeared in the tested PC laminates (Ozsoy et al. 2016). The tensile strength of PC laminates was determined using specimens of dimensions $250 \times 25 \times 14$ mm^3 in accordance with ASTM D3039. The different PC laminates are shown in Table 3. At least five specimens of each composition were tested.

Results and discussion

In this study, the PC laminates were monitored through the registration of the associated load–displacement curve (P–δ) using universal testing machines/20 kN with a cross-head speed of 1 mm/min. The studied PC laminates displayed a brittle behavior with a sudden load drop when failure occurs. The overlays of the (P–δ) curves of PC-00 specimens are illustrated in Fig. 3. The reproducibility of experiments is essential during the validation of results. It is an essential part of the scientific method and a very important to warrant the results credibility. Thus, in our work, the reproducibility of experiments can serve as a reliable measurement of tensile and flexural properties. The curves in Fig. 3 showed that the load–displacement behavior was well reproduced. The same reproducibility was observed for other laminates

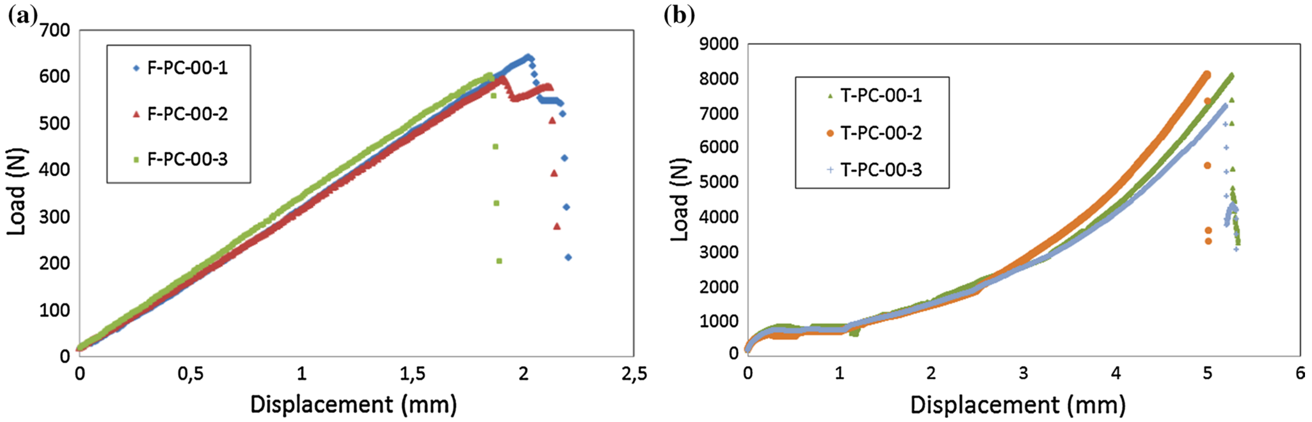

Fig. 3 Reproducibility of experiments: case of PC-00 in **a** flexural and **b** tensile tests

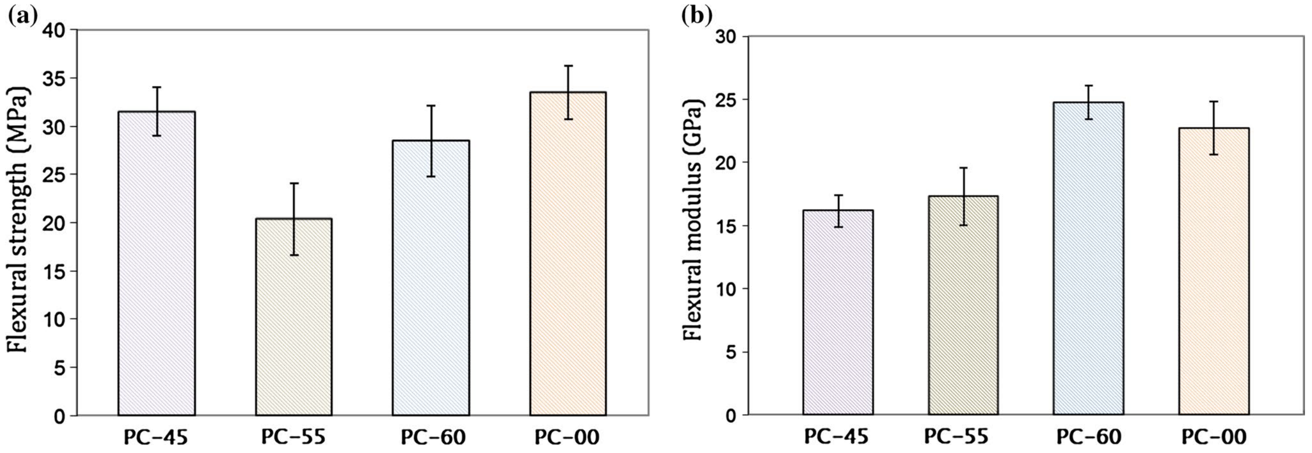

Fig. 4 Comparison of **a** flexural strength and **b** flexural modulus of different PC laminates

in flexural and tensile tests. These results suggested good reproducibility.

Bending test of PC laminates

The results of three-point bending tests are presented in Fig. 4. The strength and modulus values of the PC laminates were both significantly influenced by the plies orientation degree. This suggests that the fiber/matrix interactions were affected by the orientation degree of plies. The histograms in Fig. 4 indicate a significant effect of jute fabric orientation on flexural strength and modulus of different tested PC laminates. As indicated in experimental procedure, the difference between the tested PC laminates' response is conditioned by the different woven fabric orientation since the central PC layer (10 mm) for all laminates is similar. During three-point flexure test, the bottom surface is in tension, while the top surface of the specimen is in compression. This makes the behavior of the PC laminates rather complex, especially if it is a composite reinforced by woven fabric with various orientations. The best flexural strength

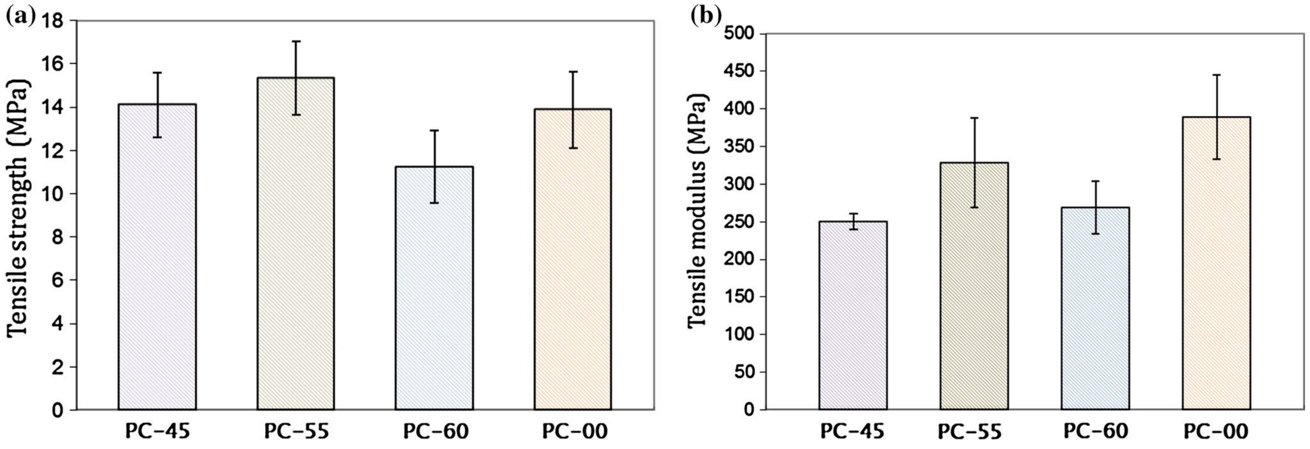

Fig. 5 Comparison of **a** tensile strength and **b** tensile modulus of different PC laminates

was obtained when the jute-woven fabric was orientated at 0° (33.50 ± 2.76 MPa) followed by the PC laminates PC-45 and PC-60 which have values close to that of PC-00 (Fig. 4a). The higher flexural strength of the laminate PC-00 than all other ones was probably due to the good interfacial bonding between the bundles fibers oriented at 0◦ and polyester matrix. When the fabric is oriented, that leads to occurrence of the interfacial separation between polymeric matrix and bundles fibers as a result to detach bonding between matrix and bundles (Abd-Ali and Madeh 2016). However, the lowest flexural strength value was observed for the PC laminates PC-55 (20.34 ± 3.70 MPa). The experimental results of Barbuta and Harja (2008) studies regarding polymer concrete with cellulose fibers show that the values of flexure strengths for PC vary between 13.55 and 17.57 MPa. In terms of flexural modulus, the material PC-60 offered the best value (24.75 ± 1.35 GPa), followed by the PC laminates PC-00 (22.74 ± 2.10 GPa). In contrast, very low values of flexural modulus were observed, as shown in Fig. 4b, for both materials PC-45 and PC-55 (16.16 ± 1.26 and 17.30 ± 2.30 GPa, respectively). From Fig. 4, the orientation of jute fabric at 60° seems to offer better performances when the PC is subjected to the three-point flexion.

More recent work by Benzannache et al. (2018) revealed that the best flexural modulus of PC obtained with a polyester resin matrix, marketed sand (quartz) and waste marble powder was 23.00 ± 1.40 GPa. The incorporation of woven jute fabric according to the orientation 60° in PC has considerable potential for improving the flexural modulus about 8%. In other article, Martinez-Barrera et al. 2011 reported that the addition of natural or synthetic fibers such as carbon or glass fibers can improve the mechanical performance of PC. The improvement in flexural strength and modulus of the PC-60 may be attributed to the increased interfacial adhesion between jute fibers and polyester matrix.

Tensile test of PC laminates

The effect of jute fabric orientation plies on the tensile properties of PC laminates is shown in Fig. 5. Results show that mechanical proprieties in tensile are strongly changed with plies orientations. From the histograms in Fig. 5a, it is clearly seen that the material PC-55 showed the highest properties in terms of tensile strength (15.34 ± 1.70 MPa), which is increased by ≈ 9%, compared to PC-00 and PC-45 materials (13.87 ± 1.49 and 14.10 ± 1.76 MPa), respectively. The lowest value was found for the PC laminate PC-60 (11.24 ± 1.69 MPa). From Fig. 4b, the material PC-00 was characterized by superior mechanical properties in terms of tensile modulus (389 ± 20.60 MPa), followed by the laminate PC-55 (328 ± 20.04 MPa). However, both materials PC-45 and PC-60 have presented the lowest values, respectively, 250 ± 10.50 MPa and 269 ± 30.03 MPa.

Conclusion

In this work, experimental results obtained for polymer concrete prepared with polyester resin, quartz, powder marble and woven jute fabric are presented. Four PC laminate configurations were considered under static tensile and flexural conditions. The results of the present study showed that the use of the jute-woven fabric as a reinforcement agent for the manufacture of PC laminate could successfully develop a new beneficial material, particularly in terms of strength and rigidity. This work is of paramount importance in understanding how the fabric orientation is affecting both tensile and flexural properties of PC laminates. Following conclusions have been made from this study:

- The best flexural strength was obtained when the jute-woven fabric was orientated at 0°. This material configuration was also characterized by superior mechanical properties in terms of tensile modulus.
- A considerable potential for improving the flexural modulus of PC laminate was provided by using woven jute fabric according to the orientation 60°.
- When the jute-woven fabric was orientated at 55°, this PC laminate provided the highest properties in terms of tensile strength.

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