Advances in Concrete Construction, *Vol. 5, No. 4 (2017) 331-343*
DOI: https://doi.org/10.12989/acc.2017.5.4.331

Performance of polymer concrete incorporating waste marble and alfa fibers

Rokbi Mansour*[1], Rahmouni Z. El Abidine[2a] and Baali Brahim[3,4b]

[1]*Department of Mechanical Engineering, Faculty of Technology, University of M'sila, 28000, Algeria*
[2]*Department of Civil Engineering, Faculty of Technology, University of M'sila, 28000, Algeria*
[3]*Sarl Maghreb Pipe, industriel Zone, M'sila 28000, Algeria*
[4]*URMPE/MESOnexTeam, Faculty of Engineering, M.Bougara University, Boumerdes 35000, Algeria*

(Received May 8, 2017, Revised June 27, 2017, Accepted June 28, 2017)

Abstract. In this study a polymer concrete, made up of natural aggregates and an orthophthalic polyester binder, reinforced with natural Alfa fibers has been studied. The results of flexural testing of unreinforced polymer concrete with different rates of charges (marble) showed that the concrete with 20% of marble is stronger and more rigid compared to other grades. Hence, a rate of 20% of marble powder is selected as the optimal value in the development of polymer concrete reinforced Alfa fibers. The fracture results of reinforced polymer concrete with 1 and 2 wt% of chopped untreated or treated Alfa fibers showed that treated Alfa (5% NaOH) fiber reinforced polymer concrete has higher fracture properties than other composites. We believe that this type of concrete provides a very promising alternative for the building industry seeking to achieve the objectives of sustainable development.

Keywords: polymer concrete; quartz; waste marble; natural fibers; fracture

1. Introduction

Polymer Concrete (PC), as the name suggests, is a composite material consisting essentially of a mixture of carefully graded aggregates and fine fillers bound together by means of an organic resin system. In the ordinary cement concrete, the gravel is the aggregate, sand is the filler and Portland Cement is used as the binder (Pratap 2002). Polymer concrete was first developed in the 1950s and then became widely known in the 1970s. Today, the PC is used very efficiently in precast components for buildings, bridge panels, hazardous waste containers, machine bases, industrial flooring, retouching of damaged concrete structures, underground pipes and in various utility and transportation components (Abdel-Fattah and El-Hawary 1999, Reis and Ferreira 2004).

The use of polymer resins instead of Portland cement in the concrete mix improves the mechanical behavior in general and produces desirable properties for durability such as high abrasion resistance and impermeability to water and salts (Fontana and Bartholomew 1980). In

*Corresponding author, Ph.D., E-mail: rokbiman@yahoo.fr
[a]Professor, E-mail: rahmouniz@yahoo.fr
[b]Ph.D. Student, E-mail: b.baali@univ-boumerdes.dz

http://www.techno-press.org/?journal=acc&subpage=7 ISSN: 2287-5301 (Print), 2287-531X (Online)

addition, some natural powder stones such as marble and granite waste were used as a mineral addition in the production of civil engineering material (Almeida *et al*. 2007, Ergün 2011, Corinaldesi *et al*. 2010). Marble waste has a high calcium oxide content which is cementing property but it creates many environmental hazards too if left in environment or in water (Ashish *et al.* 2016). Almeida *et al.* (2007) suggested that improvements in the performance of concrete are related to dust particles filling the matrix interstices (transition zone and capillary pores), thus reducing the permeability. Hence, there is a consensus that the replacement of fine aggregates by waste marble powder enhances the material properties (Ashish *et al.* 2016, Ergün 2011, Almeida *et al.* 2007, Hebhoub *et al.* 2011).

On one hand, fiber reinforced polymer concrete (FRPC) with mineral fibers has generated considerable interest for retrofitting existing concrete structures. Although the incorporation of mineral fibers in the PC can make improvements to its composites (extremely high strength to weight ratios, versatility, better resistance to corrosion, fire, acids, and natural hazardous environments), but on the other hand , there may be health problems when these fibers are used as a reinforcing agent. 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. Recently, several authors have initiated investigations in order to develop vegetable fibers as reinforcements for PC (Reis 2006, Reis and Carneiro 2013, Barbuta and Harja 2008, Reis 2012). A number of works have been also conducted on the development of short natural fibers reinforcing inorganic matrix (Ali *et al.* 2012, Jarabo *et al.* 2012, Li, Wang and Wang 2004). In both cases, vegetal fibers were considered to substitute mineral ones. Replacing mineral fibers by natural ones has many advantages. Some of the most important are: sustainability, low density, non-toxicity, low cost, high specific properties, no abrasion during processing, easy availability and ease of chemical and mechanical modifications. Compared to steel fibers, vegetal fibers are also easy to use or handle because of their flexibility, especially when high percentage of fibers is involved (Ali *et al.* 2012). Natural fibers are readily available from natural sources such a stem (bamboo, flax, hemp, jute, Alfa and kenaf), a fruit (oil palm, coir and kapok), a leaf (abaca, banana, pineapple and sisal), and a root (broom root). To utilize natural fibers as reinforcement in concrete, it is important that the fiber reinforced concrete has appropriate physical and mechanical properties for a targeted application (Li *et al.* 2004). Furthermore, the incorporation of lignocellulosic fibers into polymeric or inorganic matrix can involve an interface incompatibility between fibers and matrix. This weakness can be overcome through the chemical pretreatment of fibers, with the aim of modifying either the chemical nature of the fiber surface or the surface properties (Jarabo *et al.* 2012). The interfacial properties can be improved by giving appropriate modifications to the components, which gives rise to changes in physical and chemical interactions at the interface level (John and Anandjiwala 2008). There are many different methods to improve the interfacial adhesion between fiber and matrix by modifying fiber surface, such as mercerization, acetylation, etherification, peroxide treatment, graft copolymerization, benzoylation and coupling agent. These treatments are described in detail by Kalia *et al*. (2009). Alkali treatment of natural fibers, also called mercerization, is the common method to produce high-quality fibers (Rokbi *et al.* 2011, Cao *et al*. 2006, Kalia *et al.* 2009).

The main objective of this study was to verify the feasibility of using naturally available materials such as Alfa fibers and waste marble powder (WMP) in PC material. Based upon the mechanical properties, the optimum content of waste marble powder addition by weight has been identified and reported. The fracture behavior of PC prepared with polyester resin, quartz fine

Table 1 Chemical composition of quartz sand and WMP

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%

Table 2 Physical and mechanical properties of unsaturated polyester used as binder

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

sand, waste marble addition and chopped Alfa fibers has been investigated and compared to PC reinforced with chopped glass fibers. Moreover, the effects of the NaOH treatment concentration (1, 5 and 10%) during 24 h and Alfa fibers reinforcement on the fracture toughness of PC were analyzed and discussed in this paper.

2. Materials and procedures

2.1 Materials

2.2.2 Mineral fine aggregate and resin binder

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 "Mostaghanem" 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 shown in table 1.

Orthophtalic polyesters are considered the most important binder in polymer concrete systems (Varughese and Chaturvedi 1996). 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. Consequently,

Table 3 Different manufacturing unreinforced PC

PC		
Content of quartz fine sand (%)	Content of WMP (%)	Designation
100	0	PC100-00
97	3	PC097-03
95	5	PC095-05
90	10	PC090-10
80	20	PC080-20
70	30	PC070-30

the choice of an orthophtalic polyester resin for this study is related to the important worldwide market for the production of PC materials due to the low cost and easy processability of general purposes unsaturated polyester resin (Soraru and Tassone 2004).

2.2.3 Raw alfa fibers

The natural fibers used in this research are Alfa fibers. They were collected from Hodna region (Algeria). Alfa grass (Stipa tenacissima L.) is constituted of stems with a cylindrical shape which have a maximum height of about 1 m. Once the Alfa fibers were harvested, they were washed with water (2% detergent solution) to remove the contaminants and adhering dirt. Thereafter, Alfa stems were cut into 6 cm lengths. These cut Alfa stems were milled using a vertical axis wheat mill. Its principle is to crush the chopped Alfa stems without destroying the fibrils. This is achieved by adjusting the distance between the grain grinders (Rokbi *et al.* 2011). The obtained fibers were then sieved to remove volatile compounds. Finally, the Alfa fibers are carded to make them soft and separated. After this Alfa pretreatment, the lengths of fiber varied from 0.4 to 6 cm. The resulting fibers were denoted as untreated Alfa fibers.

2.2.4 Alkali treatment of fibers

The Alfa fibers were soaked in a 1, 5 and 10% NaOH solution at 28°C. The fibers were kept immersed in the alkali solution for 24 h. The treated Alfa fibers were then washed several times with distilled water. Any traces of NaOH, remaining on the fiber surface, were neutralized with 2% sulfuric acid during 10 min. The fibers were washed again with distilled water until obtaining a pH=7. Subsequently, the fibers were dried at 60°C for 6 hours.

2.2.5 Mineral addition

In this study, very fine waste marble powder has been used in the PC as a mineral addition. WMP is a useful material obtained as a by-product of marble during sawing, shaping, and polishing process such that about 25% of the processed marble turns into dust or powder form (Güneyisi *et al*. 2009). The recovered waste marble is sieved into marble powder using a fine sieve (5 microns). Table 1 also presents the chemical characteristics of white WMP.

2.3 PC manufacturing methods

To determine the optimum of content of the WMP addition in PC, static flexural test PC specimens with varying contents of WMP (0%, 3%, 5%, 10%, 20% and 30% by weight of quartz

Table 4 Different manufactured notched PC

PC	Fibers	Fibers treatment	Content of fibers (%)	Designation
PC-1	Unreinforced	-	-	PC-marble
PC-2	Alfa	Untreated	1	PC-0000-1%
PC-3	Alfa	Untreated	2	PC-0000-2%
PC-4	Alfa	01% NaOH at 24 h	1	PC-0124-1%
PC-5	Alfa	01% NaOH at 24 h	2	PC-0124-2%
PC-6	Alfa	05% NaOH at 24 h	1	PC-0524-1%
PC-7	Alfa	05% NaOH at 24 h	2	PC-0524-2%
PC-8	Alfa	10% NaOH at 24 h	1	PC-1024-1%
PC-9	Alfa	10% NaOH at 24 h	2	PC-1024-2%
PC-10	Glass	Untreated	2	PC-Glas-2%

fine sand) were prepared as recommended by RILEM TC113/PC-2 (Committee 1995) specification. First, WMP is mixed with quartz fine aggregate, after that the resin is added to the mixture. The obtained PC was compacted in a steel mold of 40×40×160 mm dimensions. The composition of PC used was a mass of 80% of quartz fine sand and 20% of resin (Reis and Ferreira 2004). The mixtures proportions are reported in Table 3.

For the fracture tests, PC was obtained by mixing quartz fine sand, unsaturated polyester resin, WPM and chopped Alfa fibers. The used content of WMP was the optimum of WMP addition by weight of quartz fine sand determined by flexural tests. Ten concrete mixtures were prepared using the same methodology cited earlier. Two weight percentages of Alfa fibers (1% and 2%) out of the total mix (Quartz fine sand and WMP) were used.

The Alfa fibers were added in small increments by sprinkling them onto the surface of the mix until all the Alfa fibers will be absorbed by the mixture. This technique was performed to prevent ‘balling’ or interlocking of the fibers (Al-Oraimi and Seibi 1995). PC fracture specimens were compacted in a steel mold of 30×60×280 mm dimensions. The proportions of these mixtures are shown in Table 4.

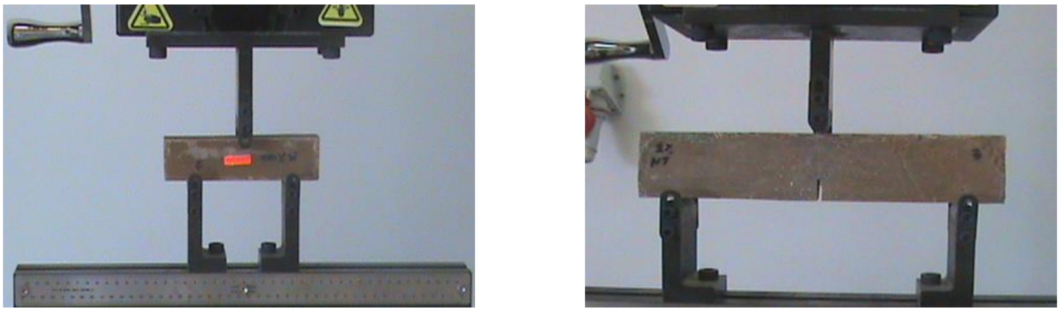
The fracture samples were notched using a 2 mm diamond saw to a 20 mm depth. For comparison, identical PC flexure and fracture specimens reinforced with 2% of chopped E-glass fibers were also prepared and tested. The flexure and fracture specimens were initially cured at room temperature and then post-cured for 6 h at 70℃.

2.4 Testing methods

The flexural tests were performed using a mechanical testing machine (YLE Universal Testing Machines/20 kN), at a crosshead movement rate of 1 mm/min (Fig. 1(a)), according to the RILEM norm TC-113/PCM-8 (RILEM 1995). Five specimens were tested for each PC formulation. The flexural strength, considered as the strength under normal stresses, was determined by applying the following standard equation known as the strength of materials

$$\sigma_f = \left(3Pl / 2bh^2\right) \tag{1}$$

where σ_f is the flexural strength; P is the maximum load recorded; B and W are, respectively, the



(a) (b)

Fig. 1(a) PC flexural test set-up, and (b) PC fracture test set-up

width and the height of the prismatic specimens; and l is the span length.

After the flexure testing, cubic specimens were used for each concrete mixture and were tested for the determination of compression strengths. The loading machine was STRASSEN TEST type its capacity in compression is 2000 kN. The compression load was applied at a rate of 2.4 kN/s.

To determine the fracture properties, three-point bending tests were conducted using YLE Universal Testing Machines/20 kN with a cross-head speed of 0.5 mm/min (Fig. 1(b)). Fracture toughness, K_{Ic}, is determined according to RILEM TC89 (TC89-FMT 1991) as follow

$$K_{Ic} = \frac{3P_{\max}S}{2W^2b}\sqrt{\Pi a}F(\alpha) \tag{2}$$

where α is (a/W), P_{max} is the necessary peak load for crack propagation, a is the notch depth, S is the bottom length of the beam, b is the specimen width, and W is the specimen thickness. In this expression (Eq. (2)), $F(\alpha)$ is a polynomial in notch ratio which takes into account the effects of finite sample size on the crack tip stress field. It is given by the following expression

$$F(\alpha) = \frac{1}{\sqrt{\Pi}}\frac{1.99-\alpha(1-\alpha)(2.15-3.95\alpha+2.7\alpha)^2}{(1+2\alpha)(1-\alpha)^{3/2}} \tag{3}$$

The total fracture energy, G_f, of each specimen was determined by means of three-point bend tests according to the RILEM TC50-FMC recommendation (Recommendation 1985)

$$G_f = \frac{W_0 + mg\delta_{\max}}{A_{lig}} \tag{4}$$

where W_0 is the area under the load-deflection curve (N/m), mg is the self-weight of the specimen between the supports (kg), δ_{max} is the maximum displacement (m), and A_{lig} is the fracture area ($d(b-a)$) (m^2); b and d are the height and width of the beam, respectively; a is the depth of the notch.

Finally, the analyses of the morphologies of the fractured PC surfaces were performed using optical microscopy.

3. Results and discussion

3.1 Effect of WMP replacement

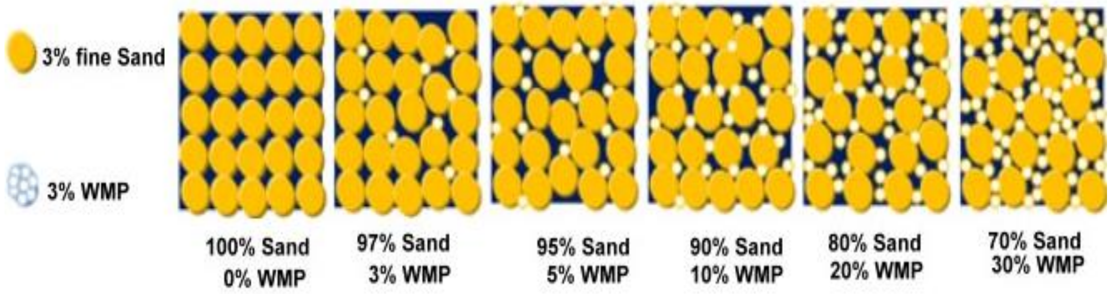


Fig. 2 Graphical distribution of different contents of WMP in 1 mm^2 of PC

Table 5 Flexural and compressive test results of PC

PC	Maximum load (kN)	Flexural strength (MPa)	Flexural strain (%)	Compressive strength (MPa)
PC100-00	12.15±0.83	27.9 ±0.85	2.41±0.15	51.86±2.44
PC97-03	9.67±1.33	21.20±1.23	1.45±0.30	55.73±1.84
PC95-05	9.90±1.97	21,60±1.05	1.47±0.22	64.04±1.88
PC90-10	11.89±0.43	27.10±1.23	1.53±0.14	65.20±1.89
PC80-20	14.63±0.37	31.80±0.42	1.88±0.28	67.42±1.25
PC70-30	14.72±0.20	31.10±0.62	1.70±0.31	67.30±1.60

The effect of replacement of fine sand by different WMP contents on the mechanical properties of PC is investigated in this section. The aim of this section is to optimize the content of WMP added as replacement of fine sand in PC. The related results can be discussed through Table 5. The usage of WMP in PC showed as a filler effect. The reason could be said as that the filler was an inert addition and it could be assumed as ultrafine aggregates filling voids in PC (Ergün 2011). When the PC specimens were tested in flexure, both materials PC80-20 and PC70-30 have shown an improvement in flexural strength of about 12% and 10%, respectively, compared to the materials PC100-00. The flexural strength of the material PC90-10 has not undergone a remarkable change (Table 5). However, the flexural strengths of PC97-03 and PC95-05 materials were decreased when small contents of WMP were used (about 24% compared to the materials PC100-00). This reduction can be explained by the fact that the use of a small content of WMP has somehow created microscopic defects, and the materials yield a higher possibility of failure, all promoting this destruction (Fig. 2). Aggregate is shown to cause stress variation on a local basis, which may aid crack formation close to aggregate particles. It is concluded that cracks are initiated at flaws such as pores or voids (Shrive 1983).

For the compression test results of PC tested specimens with five different content of WPM, an increasing in the compressive strength values were observed in all PC compared to the PC 100-00. The maximum improvement was attributed to materials PC80-20 and PC70-30, and it was about 23%. These can be explained by the fact of: (i) the usage of WMP reduced the porosity in PC physically; (ii) the chemical analysis of WMP indicated that the main component of WMP is calcia, and (iii) WMP has a higher surface area than fine sand because of the fineness of WMP used (Ergün 2011). Test results indicated that the replacement of 20% fine sand by WPM gave the best flexural and compressive strength. The use of 20% of WMP could be considered as the optimum content to enhance the PC properties.

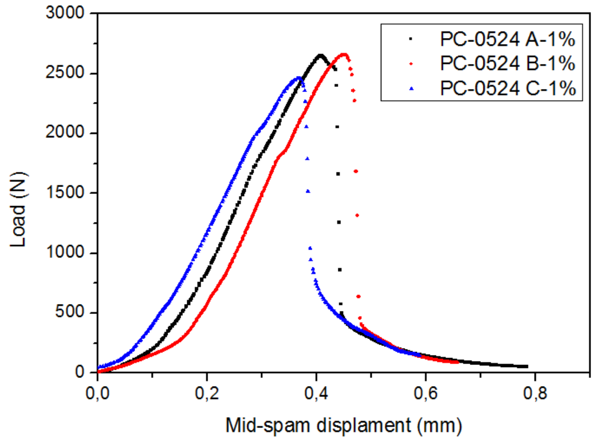


Fig. 3 Reproducibility of experiments: case of PC-0524-2%

3.2 Fracture test results

3.2.1 Load-deflection behavior

In this study, the PC experiments were monitored through the registration of the associated load-displacement curve (P-δ). The overlay of the (P-δ) curves of PC-0524-1% specimens are illustrated in Fig. 3. These curves showed that the load-displacement behavior was well-reproduced, and that the observed crack initiation occurred at roughly the same load and displacement in all three tests. The same reproducibility was observed for other PC. These results suggested good reproducibility. Thus, they can serve as a reliable measurement of fracture toughness during quasi-static loading.

For different tested PC, the (P-δ) curves were not similar (Figs. 4 and 5). Results showed that the (P-δ) behaviors were strongly influenced by the content and treatment rate of Alfa fibers. Three types of evolution in (P-δ) curves were observed. The (P-δ) curves of PC reinforced with untreated fibers showed a semi-controlled fracture (Fig. 4). This behavior was explained by fiber pull-out from a matrix (Fig. 6(a)). As shown in this figure, a partial adhesion of Alfa fiber is provided leading to a weak fiber-matrix adhesion. In addition, plain PC (PC-Marble) seems steeper than that the reinforced ones. However, in the case of PC reinforced with 1% treated fibers, generally, specimens failed in a brittle manner in which the load increased linearly with displacement, upon reaching the peak load, there was a sudden drop in load. Further reduction in load occurred gradually (Fig. 4). The change in the behavior of the 1% treated Alfa fiber reinforced PC was probably the results of the alkali treatment on these fibers. As known, alkali treatment improves the quality of the fiber/matrix interface: it modifies and improves fibers quality by the partial removal of lignin, hemicellulose, and adhering non-fibrous materials that link the elementary fiber (Zannen *et al.* 2014). Indeed in the optical microscope image, Fig. 6(b), of the (fractured) chemically modified Alfa fiber reinforced PC (case of PC-0524-1%), good adhesion between the fiber and the surrounding matrix can easily be identified. This makes the load transfer between the matrix and the reinforcing fibers more efficiently resulting in high mechanical properties (Huang and Netravali 2009).

On the other hand, a controlled fracture was observed when the PC was reinforced with 2% of treated Alfa fibers or glass fibers (Fig. 5). The content of treated Alfa fibers seems the meaning of

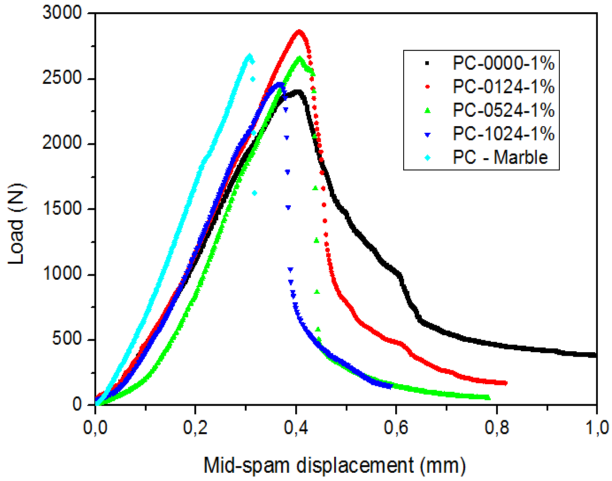


Fig. 4 Typical load vs. mid-span displacement test results of PC reinforced 1% Alfa fibers

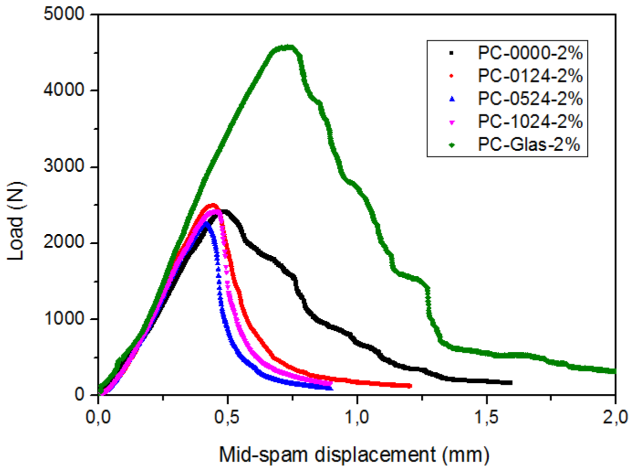
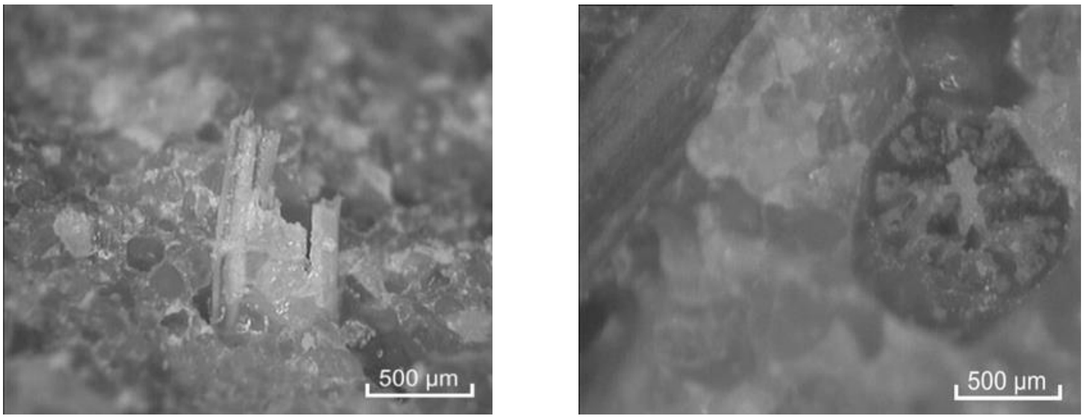


Fig. 5 Typical load vs. mid-span displacement test results of PC reinforced 2% Alfa fibers



(a) (b)

Fig. 6 Optical micrographs of PC fractured surfaces: (a) PC-0000-1%, and (b) PC-0524-1%

Table 6 Fracture results of the PC specimens

Polymer Concrete	Specimens	Break force, P(N)	Mean Break force, P(N)	Strain (%)	Mean Strain (%)	Critical Kic (MPa-$mm^{0.5}$)	Mean Kic (MPa-$m^{0.5}$)	Fracture energy, Gf (N/m)	Mean Gf (N/m)	References
	1	2368		0.370		1.851		498.13		
PC-marble	2	2314	2323	0.223	0.264	1.832	1.829	473.51	457.72	
	3	2287		0.201		1.804		401.53		
	1	2321		0.381		1.871		850.30		
PC-0000-1%	2	2252	2280	0.181	0.283	1.684	1.784	723.60	800.31	
	3	2267		0.287		1.799		827.01		
	1	2469		0.386		1.911		1329.75		
PC-0000-2%	2	2495	2384	0.480	0.384	1.980	1.857	1365.28	1315.28	
	3	2188		0.286		1.680		1250.82		
	1	2567		0.319		1.975		768.52		
PC-0124-1%	2	2332	2402	0.326	0.322	1.895	1.907	756.03	727.53	
	3	2309		0.322		1.851		658.04		
	1	2303		0.194		1.811		710.83		
PC-0124-2%	2	2351	2313	0.182	0.191	1.884	1.804	585.25	662.64	
	3	2285		0.198		1.755		691.84		Current work
	1	2486		0.179		1.982		773.14		
PC-0524-1%	2	2454	2469	0.192	0.192	1.941	1.957	691.34	731.53	
	3	2468		0.205		1.946		730.12		
	1	1853		0.186		1.588		592.07		
PC-0524-2%	2	2281	2139	0.229	0.229	1.697	1.656	684.15	642.08	
	3	2283		0.273		1.683		650.00		
	1	2667		0.294		2.087		643.91		
PC-1024-1%	2	2470	2469	0.263	0.256	1.937	1.951	617.85	614.01	
	3	2331		0.211		1.829		580.27		
	1	2212		0.263		1.657		568.50		
PC-1024-2%	2	2272	2257	0.278	0.280	1.707	1.699	523.49	560.95	
	3	2289		0.299		1.732		590.85		
	1	3417		0.941		2.718		2626.92		
PC-Glas-2%	2	3428	3422	0.739	0.804	3.333	2.960	2861.01	2771.00	
	3	3422		0.732		2.828		2825.08		
Epoxy/Sisal polymer mortars (untreated) (1% in weight)							2.380		1111.07	
Epoxy/Sisal polymer mortars (5% NaOH for 24 h) (1% in weight)							2.270		928.76	
Epoxy/Sisal polymer mortars (10% NaOH for 24 h) (1% in weight)							1.840		788.91	
Polyester/Sisal polymer mortars (untreated) (1% in weight)							1.120		669.89	(Reis 2012)
Polyester/Sisal polymer mortars (5% NaOH for 24 h) (1% in weight)							0.940		385.91	
Polyester/Sisal polymer mortars (10% NaOH for 24 h) (1% in weight)							0.890		349.29	
Polyester/Sisal polymer mortars (20% Acetic acid for 24 h) (1% in weight)							1.090		575.06	

the change in the 2% treated Alfa fiber reinforced PC behavior. In addition, it can be seen that 1% Alfa fiber reinforced PC displays similar stiffness compared to 2% Alfa fiber reinforced PC. The same observation is reported by Reis and Motta (2014). Overall, PC reinforced with treated fibers would seem steeper than that reinforced with untreated ones. This behavior was expected because the alkali treatment led to significant differences in the fiber surface morphology and then created a good interlocking mechanism with the surface of matrix (Rokbi *et al.* 2011).

3.2.2 Fracture parameters

Fracture properties test results from Alfa fiber reinforced PC with different content and treatment rate of Alfa fiber are presented in Table 6. The value of the fracture toughness indicates the magnitude of the stress concentration in front of the crack tip when the crack starts to propagate (Sarker *et al*. 2013). The maximum load for each test specimen is given in Table 6. At least, five fracture tests were performed and the closest three trends are selected and presented in the current study. From this table, it seems that 5% Alfa treated fiber reinforced PC has recorded the highest value. In contrast, when the content of treated fiber increases to 2%, the fracture toughness decreases. The values were 5%, 15% and 12% respectively for 1%, 5% and 10% of NaOH concentration.

The fracture energy is associated to the area under the load vs. displacement curve, as well as specimen weight, fracture area and maximum displacement (Reis 2012). Analyzing the fracture energy, G_f, it is clear that untreated Alfa fiber reinforced PC has the highest area compared to the others PC. Furthermore, the fracture energy of PC reinforced with 2% untreated Alfa fiber (PC-0000-2%) is much higher than that reinforced by 1% untreated Alfa fiber (PC-0000-1%). For the PC reinforced by untreated Alfa fiber, the untreated Alfa fiber reinforced polymeric concrete has the highest area under the curve, followed by Alfa treated fiber reinforced PC.

4. Conclusions

The main purpose of this paper lies in the feasibility of the use of naturally available materials: waste marble powder and Alfa fibers in PC material. The use of 20% of WMP could be considered as the optimum content to enhance the flexural and compressive properties of polymer concrete. The use of 1% Alfa fiber in reinforcement of PC displays similar stiffness compared to 2% Alfa fiber reinforced PC. However, the use of 1% Alfa fiber in reinforcement of PC can improve the fracture toughness better than 2% fiber reinforcement. Alkali treatment improves the quality of the fiber/matrix interface; best result is obtained when Alfa fiber was treated with 5% NaOH. The results of this experimental study have shown that waste marble powder and Alfa fibers can be used to enhance the properties of PC.

Acknowledgments

The authors gratefully acknowledge the support from Maghreb Pipe Industry. Special thanks are for Dear Kheir Baali president of Maghreb Pipe Industry for his valuable support and help. We thank also Prof Mostefa Bourchak from Aeronautical Engineering Department, Faculty of Engineering, King Abdulaziz University KSA for his help.

References

Abdel-Fattah, H. and El-Hawary, M.M. (1999), "Flexural behavior of polymer concrete", *Constr. Build. Mater.*, **13**(5), 253-262.

Al-Oraimi, S.K. and Seibi, A.C. (1995), "Mechanical characterisation and impact behaviour of concrete reinforced with natural fibres", *Compos. Struct.*, **32**(1-4), 165-171.

Ali, M., Liu, A., Sou, H. and Chouw, N. (2012), "Mechanical and dynamic properties of coconut fibre reinforced concrete", *Constr. Build. Mater.*, **30**, 814-825.

Almeida, N., Branco, F. and Santos, J.R. (2007), "Recycling of stone slurry in industrial activities: Application to concrete mixtures", *Build. Environ.*, **42**(2), 810-819.

Ashish, D.K., Verma, S.K., Kumar, R. and Sharma, N. (2016), "Properties of concrete incorporating sand and cement with waste marble powder", *Adv. Concrete Constr.*, **4**(2), 145-160.

Barbuta, M. and Harja, M. (2008), "Properties of fiber reinforced polymer concrete", *Buletinul Institutului Politehnic Iaşi., Sectia Constructii, Arhitectura*, **54**(3), 13-21.

Cao, Y., Shibata, S. and Fukumoto, I. (2006), "Mechanical properties of biodegradable composites reinforced with bagasse fibre before and after alkali treatments", *Compos. Part A-Appl. S.*, **37**(3), 423-429.

Committee, R.T. (1995), "Method of making polymer concrete and mortar specimens", *Proceedings of the Symposium on Properties and Test Methods for Concrete-Polymer Composites*, Oostende, Belgium.

Corinaldesi, V., Moriconi, G. and Naik, T.R. (2010), "Characterization of marble powder for its use in mortar and concrete", *Constr. Build. Mater.*, **24**(1), 113-117.

Ergün, A. (2011), "Effects of the usage of diatomite and waste marble powder as partial replacement of cement on the mechanical properties of concrete", *Constr. Build. Mater.*, **25**(2), 806-812.

Fontana, J.J. and Bartholomew, J. (1980), *Use of Concrete Polymer Materials in the Transportation Industry*, Federal Highway Administration, Office of Development, Brookhaven National Lab., Upton, New York, U.S.A.

Güneyisi, E., Gesoğlu, M. and Özbay, E. (2009), "Effects of marble powder and slag on the properties of self-compacting mortars", *Mater. Struct.*, **42**(6), 813-826.

Hebhoub, H., Aoun, H., Belachia, M., Houari, H. and Ghorbel, E. (2011), "Use of waste marble aggregates in concrete", *Constr. Build. Mater.*, **25**(3), 1167-1171.

Huang, X. and Netravali, A. (2009), "Biodegradable green composites made using bamboo micro/nano-fibrils and chemically modified soy protein resin", *Compos. Sci. Technol.*, **69**(7-8), 1009-1015.

Jarabo, R., Fuente, E., Monte, M., Savastano, H., Mutjé, P. and Negro, C. (2012), "Use of cellulose fibers from hemp core in fiber-cement production. Effect on flocculation, retention, drainage and product properties", *Ind. Crops Prod.*, **39**, 89-96.

John, M.J. and Anandjiwala, R.D. (2008), "Recent developments in chemical modification and characterization of natural fiber-reinforced composites", *Polym. Compos.*, **29**(2), 187-207.

Kalia, S., Kaith, B. and Kaur, I. (2009), "Pretreatments of natural fibers and their application as reinforcing material in polymer composites-a review", *Polym. Eng. Sci.*, **49**(7), 1253-1272.

Li, Z., Wang, L. and Wang, X. (2004), "Compressive and flexural properties of hemp fiber reinforced concrete", *Fibers Polym.*, **5**(3), 187-197.

Pratap, A. (2002), "Vinyl ester and acrylic based polymer concrete for electrical applications", *Prog. Cryst. Growth Charact. Mater.*, **45**(1-2), 117-125.

Recommendation, R.D. (1985), "Determination of the fracture energy of mortar and concrete by means of three-point bend tests on notched beames", *Mater. Struct.*, **18**(106), 285-290.

Reis, J.M.L. (2006), "Fracture and flexural characterization of natural fiber-reinforced polymer concrete", *Constr. Build. Mater.*, **20**(9), 673-678.

Reis, J.M.L. (2011), "Effect of aging on the fracture mechanics of unsaturated polyester based on recycled PET polymer concrete", *Mater. Sci. Eng. A*, **528**(6), 3007-3009.

Reis, J.M.L. (2012) "Sisal fiber polymer mortar composites: Introductory fracture mechanics approach",

Constr. Build. Mater., **37**, 177-180.
Reis, J.M.L. and Carneiro, E. (2013), "Effect of piassava lees in the fracture behavior of polymer mortars", *Compos. Struct.*, **95**, 564-568.
Reis, J.M.L. and Ferreira, A. (2004), "Assessment of fracture properties of epoxy polymer concrete reinforced with short carbon and glass fibers", *Constr. Build. Mater.*, **18**(7), 523-528.
Reis, J.M.L. and Motta, E. (2014), "Mechanical behavior of piassava fiber reinforced castor oil polymer mortars", *Compos. Struct.*, **111**, 468-472.
Rilem, P. (1995), "Technical committee TC-113, method of test for flexural strength and deflection of polymer-modified mortar", *Proceedings of the Symposium on Properties and Test Methods for Concrete-Polymer Composites*, Oostende, Belgium.
Rokbi, M., Osmani, H., Imad, A. and Benseddiq, N. (2011), "Effect of chemical treatment on flexure properties of natural fiber-reinforced polyester composite", *Proc. Eng.*, **10**, 2092-2097.
Sarker, P.K., Haque, R. and Ramgolam, K.V. (2013), "Fracture behaviour of heat cured fly ash based geopolymer concrete", *Mater. Des.*, **44**, 580-586.
Shrive, N. (1983), "Compression testing and cracking of plain concrete", *Mag. Concrete Res.*, **35**(122), 27-39.
Soraru, G.D. and Tassone, P. (2004) "Mechanical durability of a polymer concrete: A vickers indentation study of the strength degradation process", *Constr. Build. Mater.*, **18**(8), 561-566.
Sripaiboonkij, P., Sripaiboonkij, N., Phanprasit, W. and Jaakkola, M.S. (2009), "Respiratory and skin health among glass microfiber production workers: A cross-sectional study", *Environ. Health*, **8**, 36.
TC89-FMT, R. (1991), "Fracture mechanics of concrete test methods", *Mater. Struct.*, **23**, 457-460.
Varughese, K. and Chaturvedi, B. (1996), "Fly ash as fine aggregate in polyester based polymer concrete", *Cement Concrete Compos.*, **18**(2), 105-108.
Zannen, S., Ghali, L.M., Halimi, T. and Hssen, M.B. (2014), "Effect of chemical extraction on physicochemical and mechanical properties of doum palm fibres", *Adv. Mater. Phys. Chem.*, **4**(10), 203-216.

CC