Visual Abstract

Valorization and recycling of packaging belts and post-consumer PET bottles in the manufacture of sand concrete

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ABSTRACT. The valorization of local by-products in the manufacture of a new range of sand concrete and the improvement of their properties, will lead to seek an arrangement between performance and cost in order to achieve a resistant material. Waste recycling affects two very important affect namely the environmental impact and the economic impact. The main objective of our work is to contribute to optimize the formulation of sand concrete as part of the recovery of waste, which is harmful to the environment given its bulky and unattractive nature, it is waste plastic. Most PET bottles become waste after use, causing environmental problems. To solve this problem, a method for recycling PET bottles as fibers to strengthen concrete is proposed.
Two types of plastic waste are added to sand concrete; the first concerns the recycling of post-consumer bottles in PET, in the form of polyester fiber supplied by the company RET-PLAST and the second type concerns the packaging belts made of polyethylene terephthalate (PET). The properties in the fresh state (workability and density) and in the hardened state (compressive strength, tensile strength and water absorption) of the various

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produced concretes are analyzed and compared against their respective controls. From the experimental results, it can be concluded that the reinforcement of the cement matrix with PET fibers with a rate of 1% improves the mechanical properties of sand concrete as well as a remarkable decrease in its water absorption capacity.

KEYWORDS. Sand concrete; PET fiber; Mechanical behavior; Water absorption; Environment.

INTRODUCTION

The promotion of local materials in construction has now become a necessary solution to the economic problems of developing countries. It is in this context that the reflection on the search for new materials begins. Various types of recyclable materials are currently used in civil engineering applications [1–5].

Currently, composite materials are widely used, because they allow, by the choice of the nature, the geometry and the distribution of the constituents, to obtain the best compromise in terms of desired properties such as specific rigidity, mechanical resistance or dimensional stability.

The most commonly used reinforcement in this case is glass fibers, which can produce composites with good corrosion resistance, high mechanical properties, low weight, good chemical resistance, and better insulation qualities electrical and thermal. However, the disadvantage of these fibers is the expensive price and the unavailability in our country. It is in this context the objective of our work is interested in the use of recyclable waste in civil engineering applications, which is the plastic material. This material has the advantage of being inexpensive (raw material). It is recyclable, which will make it possible, after the development of recycling channels, to avoid their accumulation in public landfills and therefore to offer a second life to plastic and for the development of new construction materials such as cementitious composites based on PET fibers [3–5].

The recycling of plastic waste for the development of new building materials such as cementitious composites appears to be one of the best solutions for the disposal of plastic waste, due to its economic and ecological advantages. Extensive work has already been done on the use of wastes such as polyethylene terephthalate (PET) [6–8], polyvinyl chloride (PVC) [9], high density polyethylene (HDPE) [10]], thermo plastic [11], shredded and recycled plastic waste [12–14] and rigid polyurethane foam [15,16]. Thus, several previous studies have shown that it is possible to use plastic waste in concrete. In particular, PET from packaging has been used as a binder for the production of a high-performance composite material, polymer concrete [17]. PET is one of the plastics known for its use in the manufacture of fibers. It is a ubiquitous material. Its advantage is that it has good mechanical and chemical properties, as well as good thermal stability, excellent transparency associated with good barrier properties (permeability to gases, to contaminants) [18].

So far, four major processes have been identified for recycling used PET bottles into building materials [19]. The first method consists of depolymerizing the used PET into unsaturated polyester resin to produce polymer-mortar or polymer-concrete [20]. The plastic is transformed in the presence of glycols, into unsaturated polyester resin, which is then mixed with sand and chippings. The polymer concrete obtained is very resistant in compression and in bending compared to conventional Portland cement concrete [21]. It also has the advantage of reaching 80% of its mechanical strengths from the first days of setting, but their physical and mechanical properties are sensitive to temperature and the cost of producing the latter from plastic waste is high [1,22,23].

The second method consists of reinforcing the concrete with PET fiber to improve the ductility of the concrete and reduce the cracking caused by plastic shrinkage [5, 23]. The third process consists of replacing part of the aggregate with PET waste in the form of aggregates in the production of lightweight concrete or asphalt concrete [6,19,21,24]. A fourth method has been tried is to recycle flakes from PET bottles and use them directly as a binder. Another study by Ge et al [19] who recycled PET bottles to produce recycled PET mortar, and the results are promising.

In Algeria, as in many countries of the world, the amount of plastic waste is increasing and occupies a large part of solid waste. This type of waste is a serious problem for the environment due to its non-biodegradable nature. Recycling this type of waste to produce new materials such as concrete or mortar appears to be one of the best solutions, due to its economic and ecological advantages.

The aim of this work is to present the results of a first experimental study on the possibility of using PET in the formulation of sand concrete. For this purpose, we used two types of fibers, the first is a synthetic fiber supplied by the Algerian company RET-PLAST. Post-consumer bottle recovery workshops, the regeneration of which provides a product intended, essentially, for padding, textiles, the regeneration of which provides a product intended, primarily, for padding, and textiles produce these fibers. The use of fibers from recycling as reinforcement thus constitutes a significant contribution to the material recovery of PET waste.
The second type of fibers are the PET packing tapes from which we have recovered this waste material which is available in huge quantity and is harmful for environmental pollution and landfill depletion. The use of these fibers from the recycling process as reinforcement thus constitutes a significant contribution to the material recovery of PET waste and the application of mortar-polymer composites based on PET waste in the field of construction seems possible. In view of the results obtained by the analysis of its properties. We have made a laboratory cut of these belts in two lengths which are 1cm and 2cm.

MATERIALS AND METHODS

Materials: Binders

The binders used were Portland Cements CEM I 42.5/A as classified by the European Standard EN 197-1 [25] and the Algerian blast furnace slag(GGBFS) mineral admixture according to Standard NF EN 15167-1[26]. Tabs. 1 and 2 describe the various chemical and physical properties of cement and mineral admixture.

Binders	Elements	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	Cl^-	P.A.F
Cement	Content (%)	19.97	5.18	3.34	61.38	0.99	0.20	0.44	2.90	0.19	3.71
Blast furnace slag		34.41	8.17	4.15	40.69	4.56	0.10	0.89	0.36	0.01	-

Table 1: Chemical compositions of cement and mineral admixture.

Binders	Fineness (cm^2/g)	Bulk density (g/cm^3)	Absolute density (g/cm^3)
Cement	4120	1.02	3.00
Blast furnace slag	3800	1.22	2.91

Table 2: Physical properties of cement and mineral admixture.

Materials: Aggregates

Two different size fractions of 0/2 mm (fine siliceous sand) and 1.25/5 mm (limestone crushed sand), of aggregates were used. Tabs. 3 and 4 describe the physical and chemical properties of aggregates. The grain size curve is shown in Fig. 1.

Aggregates	Absolute density (g/cm^3)	Sand equivalent (%)	Fineness modulus	Water absorption coefficient (%)
Siliceous sand	2.53	75	1.85	3.00
Limestone crushed sand	2.60	80	2.70	2.91

Table 3: Physical properties of aggregates.

Aggregates	Elements	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	TiO_2	MnO	P_2O_5	Loss on ignition
Siliceous sand	Content (%)	0.30	0.44	0.29	53	1.60	0.10	0.30	-	-	-	-	42.90
Limestone crushed sand		93.88	2.13	1.60	0.43	0.12	0.24	0.38	0.39	0.13	-	0.03	0.67

Table 4: Chemical properties of aggregates.

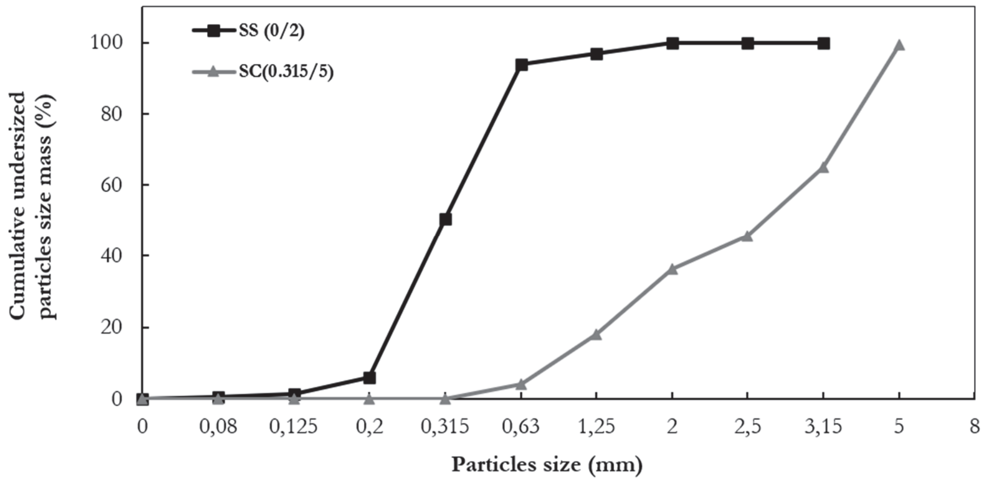
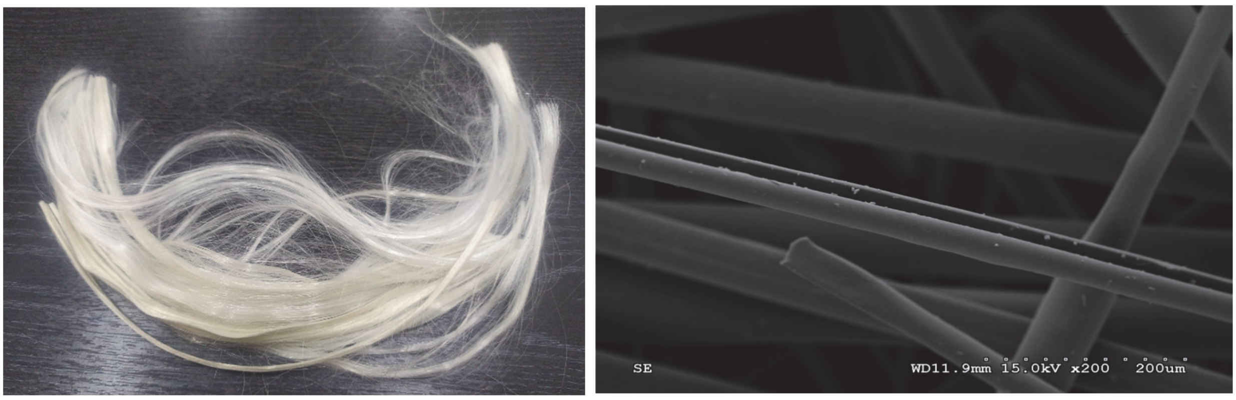


Figure 1: Particle size analysis of the different sands used.

Materials: PET fibers

The PET fibers used in this study were provided by the company RET-PLAST, located in the region of Mezloug/Sétif (Algeria), specialized in the recycling of post-consumer PET bottles.

The observations of the PET fiber using the optical microscope and the scanning electron microscope are presented in Figs. 2a and 2b, respectively.



(a) (b)

Figure 2: PET fibers: (a) optical photo and (b) SEM photo.

Fig. 2b shows that the PET fiber has a smooth surface and a hollow cylindrical shape. The average diameter of the fibers is between 60-70 µm.

Figure 3: Optical photo of polyethylene terephthalate (PET) packaging belts.

The physical-mechanical characterization of the PET fiber (Fig. 3), obtained from the shredded packaging tapes, were carried out at the MediFil company in Hammam Guergour/Sétif, Algeria. The corresponding results are given in Tabs. 5 and 6.

Physical and mechanical properties	Values
Density at 20 ° C	1.16
Cutting length (mm)	70.00
Metric number (Nm)	557.00
Title (DTex)	18.00
Size (Denier)	16.16
Pressley Index (Pound/mg)	6.97
Pressley (Pound/Thumb²)	73.00
Breaking length (gf/Tex)	37.39
Relative Tenacity (gf/Denier)	4.00
Tensile strength (MPa)	70
Young's modulus (MPa)	2.00

Table 5: Physical and mechanical properties of PET fiber.

Physical and mechanical properties	Values
Regular color	Green
size	1200 to 1900 mm
Width	9 to 16mm (± 0.5mm)
Thickness	0.5 to 0.8 mm (± 0.05 mm)
Size (Denier)	16.16
Thickness	6.97
Elongation at break	5 to 21%

Table 6: Physical and mechanical properties of PET wrapping belt fiber.

Materials: Mixing water

The mixing water used for making the various mixtures comes from the public drinking water distribution network in accordance with standard NF EN 1008 [27–31].

Materials: Formulation of sand concrete

In our study, the formulation approach used is that defined in the SABLOCRETE project of the revised standard P 18-500 "sand concrete" exposed in the work entitled "sand concretes: characterizations and practical use" [32–36].
The composition of different mixtures is summarized in Tab. 7. All compositions are based on the use of a mixture (cement + granulated slag) as binder and a fixed W/C ratio.

Denomination of sand concretes	Constituent assays (Kg/m³)							
	CPA Cement	Water	Silica Sand (SS)	Quarry Sand (QS)	Granulated slag filler (LG)	PET fiber	PET PB fiber	Water/Cement
Sand concrete	311,25	176	858,34	790,43	161,85	-	-	0,57
Sand concrete with 1% of PET	311,25	176	853,34	785,43	161,85	10	-	0,57
Sand concrete with 2% of PET	311,25	176	848,34	780,43	161,85	20	-	0,57
Sand concrete with 1% of packaging belts	311,25	176	853,34	785,43	161,85	-	10	0,57
Sand concrete with 2% of packaging belts	311,25	176	848,34	780,43	161,85	-	20	0,57

Table 7: Formulation of study concretes.

Methods: Preparation and conservation of test specimens

The physic-mechanical characterization of sand concretes is obtained by exploiting the measurements of the tensile strength by bending and compression on specimens 4×4×16 cm³ conforming to standard NF EN12390-1 [37]. The preparation of the test specimens is carried out according to standard NF EN 12390-2 [38], the mixing is carried out using a concrete mixer with a capacity of 25 L with a total mixing time of around 5 minutes.

Vibration is the most common way to give concrete its maximum compactness and to eliminate as much voids as possible. Compaction is carried out on a vibrating table for a total duration of one minute. The specimens are removed from the mold after 24 hours and stored at saturating humidity RH = 100% and at a temperature of 20 ± 2 ° C until the end of the various tests.

RESULTS AND DISCUSSION

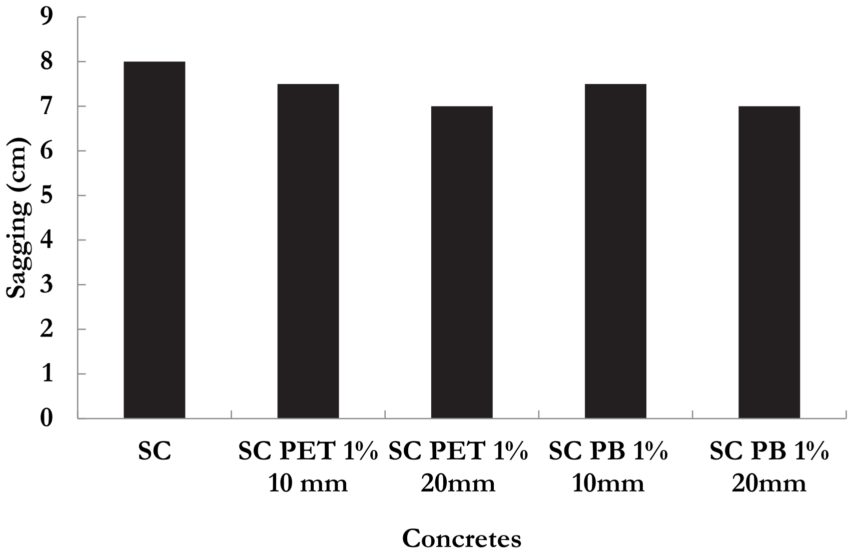
Fresh concrete: Workability

The consistency of the fresh concrete was characterised by measuring the slump using the Abrams cone according to NF EN 12350-2 [38-39]. Slump cone used (Fig .4) is a metal cone with form with the base 200 diameter and 300 mm height with the top diameter 100 mm. The cone must be placed on a horizontal metal plate slightly moistened beforehand. The filling of the cone is done in three layers of equal height, each layer being pricked by 25 strokes with a standardized pricking rod. Once filled, the mold must be removed vertically regular performed in 5s to 10s. The slump h is measured after the slump has stabilized using a ruler.

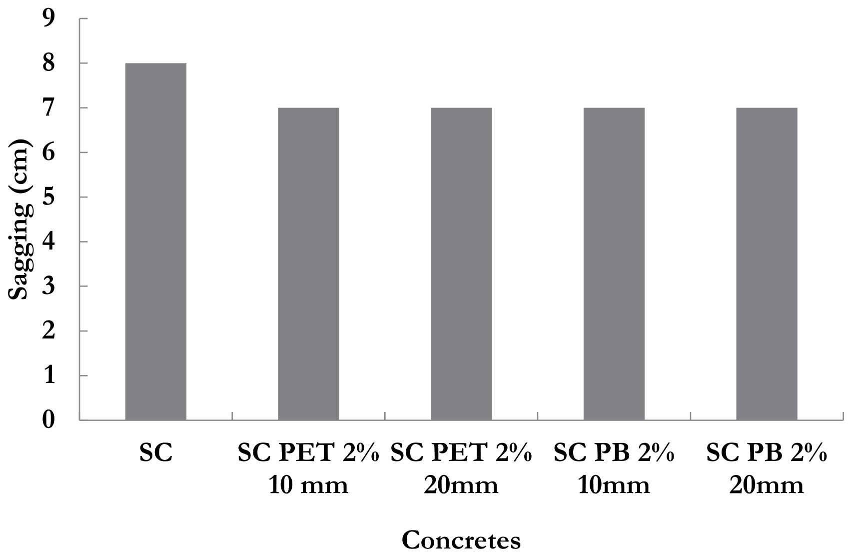
Figure 4: Slump test.

Effect of the length and rate of PET fibers on the workability of sand concrete

The workability results of sand concretes with different PET fibers ratios characterized by the Abrams cone sag test are shown in Fig. 5.



(a)



(b)

Figure 5: Workability variation of concrete as a function of fibers contents.

Fig. 5 shows that the incorporation of PET fibers gives a slight decrease in sag by wearing to the control concrete. This is explained by the improvement in the cohesion of fresh concrete with the increase in the fiber content of PET. It can be considered that the influence of the fiber dosage on the workability characterized by sagging is negligible, the decrease in sagging recorded is less than 1 cm, and the concretes always remain in the plastic domain. Several papers reported that the introduction of any kind of fibers in the composite, involves a significant reduction in the workability of the concrete [5].

The Comparison of workability results for the same type of PET fiber and two different lengths and rates shows that, the effect of introducing fibers is negligible. We have the maximum dimension of the aggregates used for the preparation of sand concretes is less than 5 mm, the introduction of PET fibers in these concretes does not raise any problem and difficulty as well as their distribution being done easily and not requiring any precaution particular during mixing.

Density

It is estimated from the determination of the density of fresh concrete mixes according to standard NF EN 12350-6 [39]. The latter characterized by the mass of a quantity of fresh concrete relative to its volume after vibration.

Effect of the length and rate of PET fibers on the compactness of sand concretes

The effect of the PET fiber rate on the compactness of the concretes is estimated from the determination of the density of the fresh concrete mixes. The experimental results of this density are given in Fig. 6.

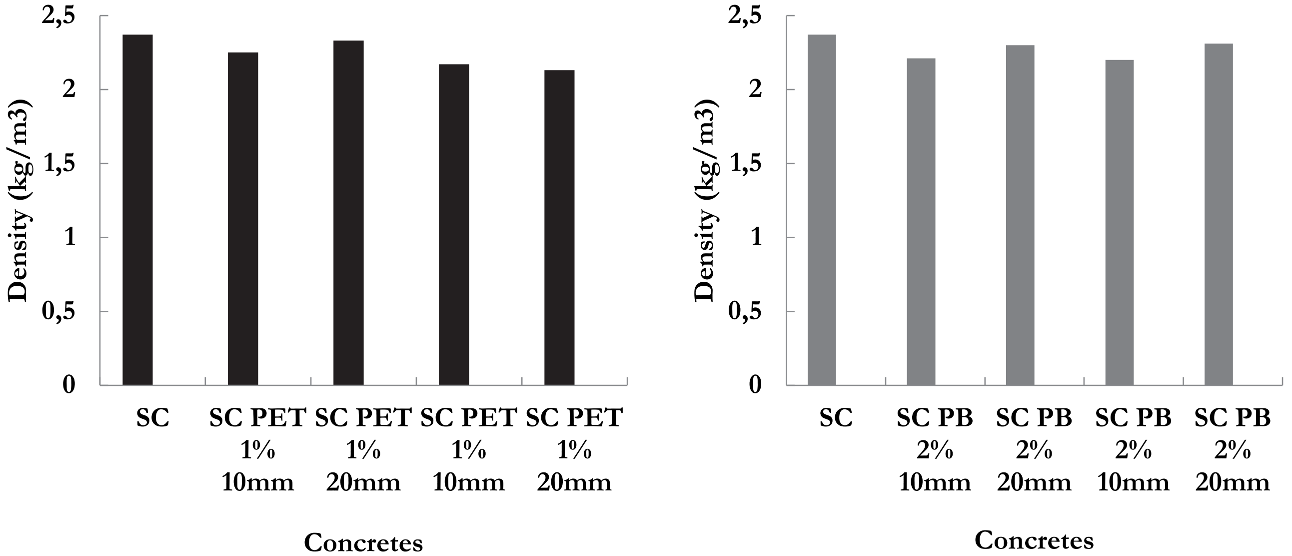


Figure 6: Variation in concretes density as a function of fibers contents.

All the samples of the study in the fresh state have values higher than 2.17 g/cm³, against a value of 2.25 g/cm³ of the control sand concrete, which can be explained by the intrinsic density of the sands and the good grading of the dune and quarry sand.

According to Fig. 6, we note that the effect of the addition of PET fibers on the density of sand concretes as the effect on workability is negligible. A slight decrease is recorded for a PET fiber content of 1% and 2%. This slight decrease can be explained by the low density of the PET. The hollow structure of PET fibers gives them a low density, which allows the design of lightweight composite materials that can find many applications.

This observation confirms the density measurements, which showed that even at a high rate of PET fibres, the density of the composite remains constant and comparable to that of the control sand concretes.

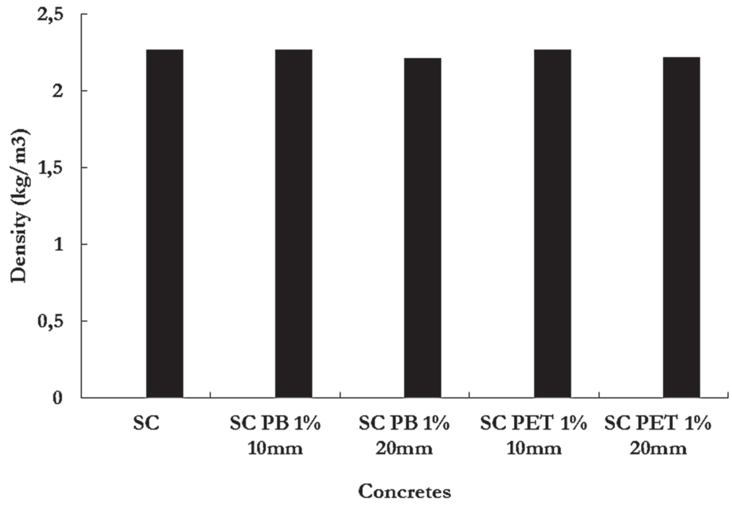
MECHANICAL PROPERTIES OF HARDENED CONCRETE

Density

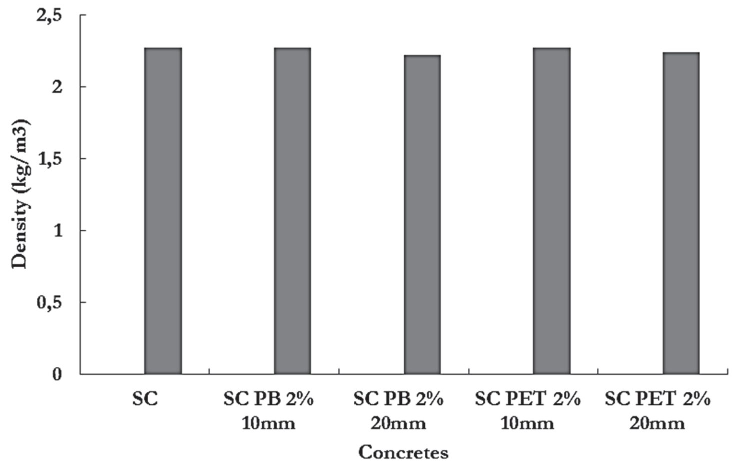
The density of the concrete in the hardened state is measured from the mass of the specimen compared to its volume after 28 days of hardening according to standard NF EN 12390-7 [40]. The density tests were carried out on cubic specimens 4×4×16 cm³.

According to Fig.7, which shows the effect of rate and length of PET fibers on the density of sand concretes in the hardened state and with the aim of improving certain characteristics of sand concrete, we aimed to study the effect of the fiber content of PET.A slight variation in the densities was recorded for the different dosages of PET.

The analysis of the results related to the density parameter of the concretes in the hardened state showed a behaviour similar to that of the density of the concretes in the fresh state where the density values of all the samples were around 2.2 g/cm³ ‘ against values of approximately 2‘27 g/cm³ for the control sample. This light recorded can be explained by the low density and the small dimensions of PET (L = 10mm and 20mm) added to the concrete with low dosage.



(a)



(b)

Figure 7: Effect of rate and length of PET fibers on the density in the hardened state.

Bending tensile test

The specimens used in the tensile test by bending are prismatic specimens 4×4×16 cm^3. The test consists of breaking specimens at two points using a ZWICK Roel press bending tensile device with a maximum capacity of 20 kN (Fig. 8). The value of the resistance and the breaking load is recorded directly during the test according to the standard [41].

Effect of length and rate of PET fiber on tensile strength

The mechanical strength results, which are represented by the average of three specimens for flexural tension. These results are illustrated in Fig.9. From Fig. 9, giving the effect of PET fiber rate on tensile strength.
According to Fig. 9 giving the variations of the tensile strength according to the rate and the length of the PET fibres, we noted a reduction in the tensile strength with the increase in the rate of fibres. When the stress reaches the tensile strength of the concrete, it is transferred to the PET fibers. The addition of fibers can stop the propagation of macrocracks by improving the tensile strength. It has been shown that normal sand concrete failed abruptly once the concrete cracked, while recycled PET fiber concrete could retain its shape even after the concrete cracked. This shows that concrete reinforced with plastic macrofibers has the ability to absorb energy in the post-cracking state [43-46]. In general, samples containing PET fibers were found to be more able to withstand tensile load after rupture without complete disintegration.
We noted also a notable increase in tensile strength for sand concretes reinforced with 1% PETCPB and 1% PET followed by a decrease for the highest rates, notably 2% of PET and 2% of PET PB. When the fibers are present in low levels, they are well dispersed in the matrix, which provides a larger matrix/fiber contact surface and stronger interactions, thus ensuring better stress transfer between the two phases of the composite.

However, when PET fibers are introduced at higher concentrations, they tend to clump because fiber/fiber interactions are promoted. Due to the lack of wettability of the fibers by the matrix, defects appear in the material and are responsible for poor stress transfer and brittle failure of the composites, as shown in Fig.9.
The reinforcement rates 1% and 2%, we noted an increase for the sand concretes having fiber lengths of 10mm compared to the pure matrix, followed by a reduction for the concretes reinforced by longer fibers (20mm). This is attributed to the fact that the fibers are all the better oriented in the liquid matrix as they are shorter. Also, the longer the fibers, the more flexible they become and the greater the likelihood that they can fold and roll up on themselves. These facts are responsible for the appearance of microvoids showing poor impregnation by the matrix and forming sites of local stress concentration. All these defects constitute weak points within the matrices and are at the origin of the reduction in the stress and the deformation at break.

Figure 8: Bending tensile test on concrete specimens.

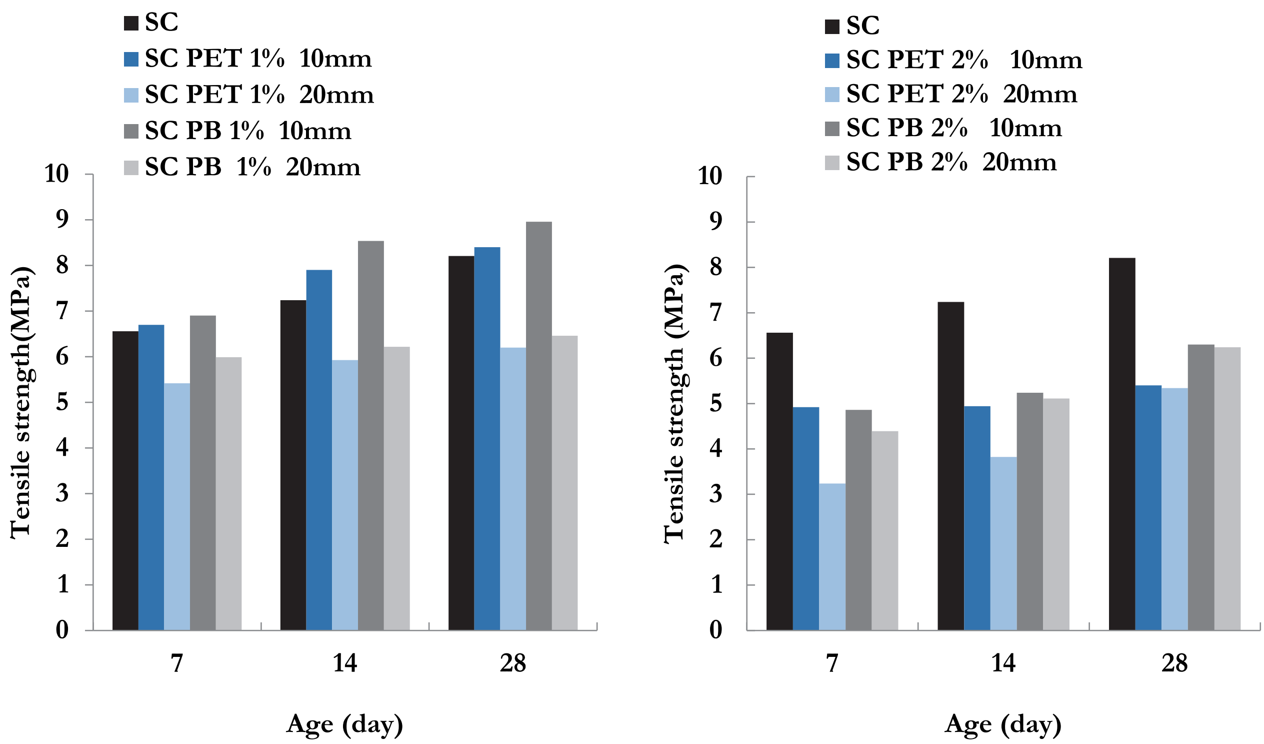


Figure 9: effect of length and rate of PET fiber on tensile strength.

Compressive strength

The specimens used for the compression test are prismatic specimens 4x4x4 cm^3 obtained after the bending tensile test [41]. The test machine is a hydraulic press with a maximum capacity of 2000 kN at constant speed, the compression test is carried out until the specimen breaks according to standard [42].

Figure 10: Compression test device.

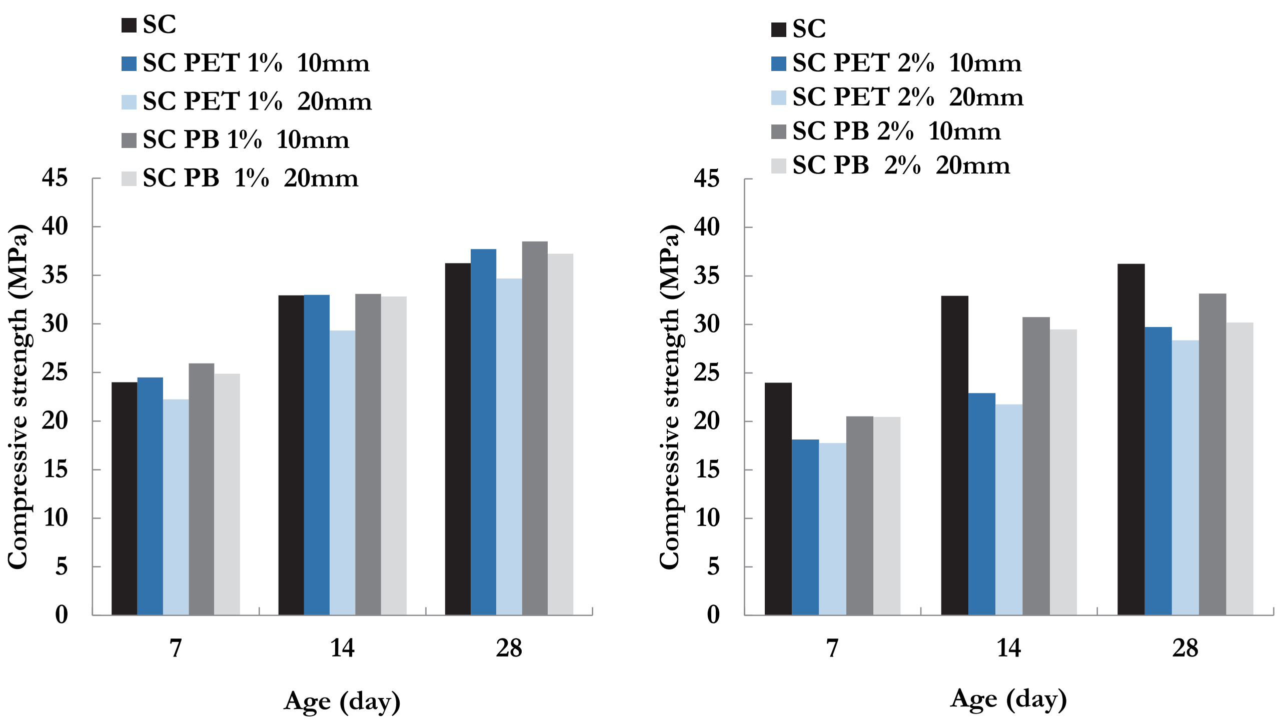


Figure 11: Effect of length and rate of PET fiber on compressive strength.

Effect of length and rate of PET fiber on compressive strength

The mechanical compression and tensile tests by bending were carried out on the test specimens of the sand concrete. The tests were carried out at different ages of the concrete: 7, 14 and 28 days. The mechanical strength results, which are

represented by the average of six specimens for compression and three specimens for tensile bending. These results are illustrated in Fig. 11.
According to Fig. 11, the best compressive strengths are obtained by adding PET PB and PET fiber with a rate of 1%. Fig. 11 shows that the mechanical strengths in compression and in tension by bending are little affected by the addition of PET. The influence of the rate of PET fiber up to a rate of 1% does not significantly modify the compressive strength, on the other hand with a high rate of PET fiber (2%) there is a drop in resistance. in compression, this may explain why the high dosage of PET fiber disturbs the crystal lattice of the cementitious matrix.
The mechanical strength is expressed by the power of sand concrete to resist destruction under the action of stresses due to different compressive loads. Each value of the compressive strength is equal to the average of the measurements on three specimens. It can be seen that the strengths of all concretes increase steadily with the age of the specimens and do not show any drop in strength. The compressive strength decreases with the increase of the percentage of PET in the composites such as:
- at 7 days, it goes from 24MPa to 25.94 MPa for SC and SC PET PB concretes respectively.
- at 14 days, it increases from 32.94 to 33.09 MPa for SC and SC PET PB concretes respectively.
- at 28 days, it increases from 36.25 to 38.49 MPa for SC and SC PET PB concrete respectively.

The Fig.13, shows that the best compressive strengths are obtained by SC PET PB with a rate of 1%. This is explained by the better distribution of fibers, but the addition of fibers with a high ratio disturbs the crystal lattice of the cementitious matrix.
The addition of fibers tends to cause bundling during mixing and pouring, also known as fiber balling. This phenomenon weakens by the high possibility of fiber surfaces coming in contact with one another. The area between fiber surfaces is the weakest point in concrete; microcracks and macrocracks caused by compression loading easily appear in this area [43-44].
It is also observed from the results that the length of the fibers reduces the compressive strength, the shorter the fibers the higher the strength.
The best compressive strengths are obtained by adding PET PB and PET fiber with a length of 10mm. The influence of the length of the PET fibers is remarkable. There is a drop in the compressive strength of sand concretes for sand concretes with fiber lengths of 20mm compared to the pure matrix. This is attributed to the fact that the fibers are all the better oriented in the liquid matrix that are shorter.

Effect of fiber content on water absorption by capillarity

The results of the water absorption coefficient of sand concretes with different rates of PET fiber are presented in Fig. 12.

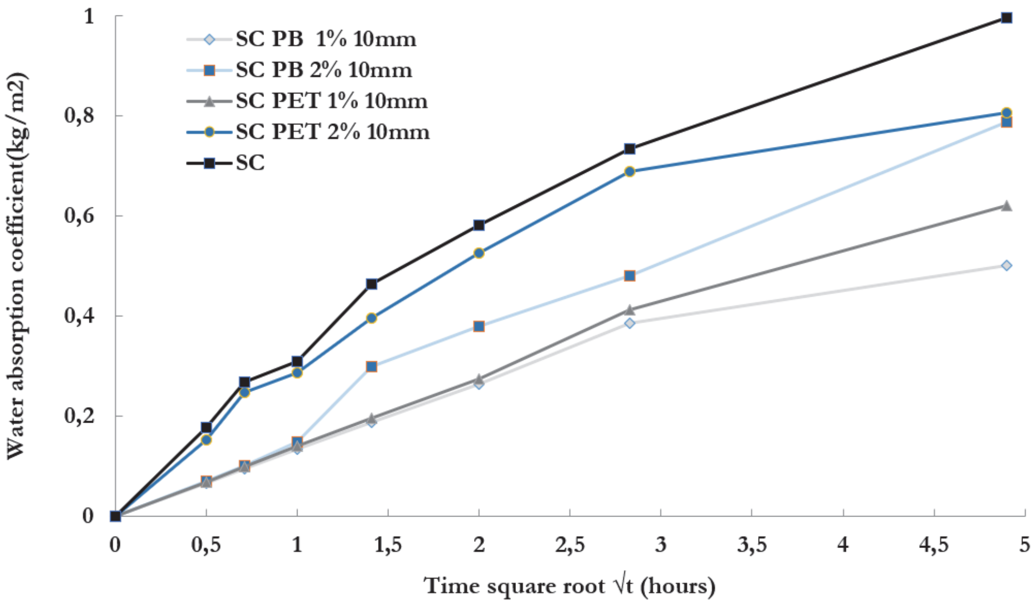


Figure 12: Effect of fiber content on water absorption by capillarity.

From Fig. 12, it can be seen that the water absorption coefficient of sand concretes increases with increasing square root of time. Sand concretes have a higher number of voids than conventional concretes, but the distribution according to the size

of the voids differs from that of conventional concrete. The voids in sand concretes are more numerous, smaller and more one-dimensional[32].Sand concretes are characterized by a fine capillary network with very small pore dimensions, in this case the capillary rise in this network justifies the slowing down of the water absorption kinetics of these concretes.
From the appearance of Fig. 12, it is clearly visible that the process of water absorption by capillarity of the sand concretes with PET fiber is similar to that of the control sand concrete. The introduction of PET fibers further reduces the water absorption of concrete.

Bending failure mode
The general failure mode of sand concrete without fibers specimens is brittle. The rupture is sudden with the separation of the specimen into two parts. The fiber sand concrete specimens represent a ductile failure mode. It is observed that after the three-point bending test the non-separation of the specimen in two, as is the case with the specimens of sand-free concrete. The fibers retain the cementitious matrix even with the appearance of cracks as shown in Figs.13 and 14.

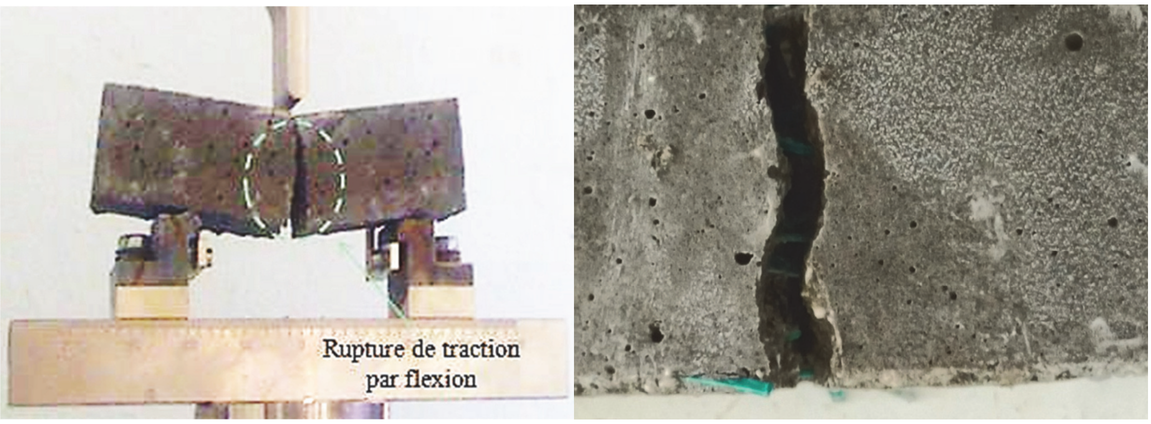


Figure 13: Failure mode of control sand concretes with 2% PET PB after the three point bending test.

Figure 14: The failure mode of sand concretes with 2%PET after the three point bending test.

Conclusions

The work addressed focused on the study of the physico-mechanical behavior of a sand concrete reinforced with PET fiber, from packaging bands. This study carried out focused on two parameters: the effect of the rate and the length of the PET fibres.
At the end of this study, we can conclude the following:

- The introduction of PET fibers does not significantly affect the characteristics of concretes in the fresh state, namely workability and density.
- The effect of the content of PET fiber content on the density in the hardened state is negligible.
- The rate effect of PET fibers on tensile strength is remarkable; we noted a noticeable increase in tensile strength for sand concretes reinforced with 1% PET PB and 1% PET.

- The effect of PET fiber length on tensile strength for 1% and 2% reinforcement rates, shows an increase for sand concretes having fiber lengths of 10mm compared to the pure matrix, followed a reduction for concrete reinforced with longer fibers of 20mm.
- The best compressive strengths are obtained by adding PET PB and PET fiber at 1%.
- The best compressive strengths are obtained by adding PET PB and PET fiber with a length of 10 mm.
- The comparison of the failure mode of the fiber sand concrete shows that the latter have a ductile character during the break, that is to say that the specimen remains attached by the PET fibers after the break and no glow.

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