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RECYCLED PET FIBER AS REINFORCEMENT OF CEMENT-BASED MATERIALS

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Abstract. *This paper deals with an experimental study on the influence of recycled polyethylene terephthalate (R-PET) fibers as reinforcement of cementitious materials. The mixtures were produced using Portland cement, fly ash, silica sand, superplasticizer and different volumes of R-PET fibers (0%, 1.0%, 1.5% and 2.0%). Four-point bending and compressive tests were performed. The results indicated that the incorporation of R-PET fibers significantly improve the post-cracking behaviour of mortars with a major improvement in mortar toughness and deflection capacity. The maximum volume of PET fibers for a desired workability and performance of the composite was 2.0%, which showed a deflection hardening behaviour. Mixtures with 1.0% and 1.5% fiber volume content exhibited deflection-softening behaviour, with a single cracking formation.*

Keywords: *Cement based composite, FRC, PET fibers, mechanical properties*

1. INTRODUCTION

In recent years, several researches are being carried out on the utilization of recycled plastic in concrete as low cost lightweight aggregates (Frigione, 2010), and reinforcing fibers for eco-friendly cementitious material in the construction industry. The interest in the waste materials originates mainly from environmental reasons, due to the fact that post-consumer plastics are the most relevant wastes with a low rate of biodegradation, and in consideration of the severe environmental problems created by the scarcity of space for landfilling. Thus, the waste utilization has become an attractive alternative to disposal. Several researches have reported the effects of Recycled PET fibers (R-PET) as reinforcement of cementitious matrices (Fraternali et al, 2011; Ochi et al 2007; Fraternali et al 2013; Kim et al, 2008; Oliveira and Gomes, 2011; Siddique et al, 2008), since fibers can overcome the main disadvantages of the concrete such as low energy absorption and low ductility.

Kim et al (2010) studied compressive properties of R-PET fibers reinforced cementitious composites, and bending strength of prismatic concrete specimens reinforced with both recycled PET fibers and steel bars. R-PET fibers were produced in laboratory and used at different volume fractions (0.5% - 1.0%). They observed significant increases in flexural strength and ductility, and slight decreases in compressive strength and elastic modulus of composites, as compared to plain concrete. The density, workability, compressive and tensile strengths and the modulus of elasticity of the mixture added with PET fibers have been investigated by Foti (2011), Choi et al (2005) and Marzouk et al (2007). Silva et al (2004) analyzed the durability of recycled PET fibers used as reinforcement in cement-based materials and Betioli and Silva (2005) evaluated the durability of PET fibers under different aggressive environments.

In most of these studies, R-PET has been utilized in the concrete mix shaped as short or long strips or circular fibers obtained by cutting waste bottles orthogonally to their longitudinal axis. The R-PET fibers have a width ranging from 0.1 to 5mm.

Ochi et al (2007) described methods for manufacturing reinforcing fibers from recycled PET bottles, and evaluated their beneficial effects in terms of ductility and compressive strengths of concrete specimens. In the study by Kim et al (2008), PET fibers with different geometries (embossed, straight, and crimped) were employed to control shrinkage cracking in cementitious composites.

In this work an experimental program was conducted to evaluate the utilization of plastic fibers obtained industrially from recycled polyethylene terephthalate (PET) bottles as an eco-efficient mortar component. The R-PET fiber used in this study is produced by M&G Fiber Brazil S.A with a length of 32 mm and a 14 µm diameter. The PET filaments are extruded using recycled PET bottle flakes. The monofilaments can be manufactured either straight or crimped, with different profiles and diameters. Compressive and bending tests are used to analyze and characterize the mechanical properties of composite with different fiber volume contents (1.0%, 1.5% and 2.0%).

2. EXPERIMENTAL PROGRAM

2.1 Materials and composite manufacturing

The raw materials used to produce the mixtures were: Portland cement CPII F-32 composed with 6% of calcareous filler (NBR 11578, 1991), with 32 MPa of compressive strength at 28 days and a density of 3.08 g/cm³; fly ash with a density of 2.35 g/cm³; silica sand with a maximum diameter of 212 µm and a density of 2.60 g/cm³; and a superplasticizer, Glenium 51 (manufactured by MBT Brazil) based on modified polycarboxylic ether with 32.5% solid content and density 1.20 g/cm³.

The particle size distribution of the sand and cementitious materials can be seen in Fig. 1. The recycled PET fiber used in this study is produced by M&G Fiber Brazil S.A with a length of 32 mm, a 14 µm diameter, and density of 1.43 g/cm³. The fibers were produced by mean of an extrusion of plastic filaments from flakes of recycled polyethylene terephthalate (R-PET)

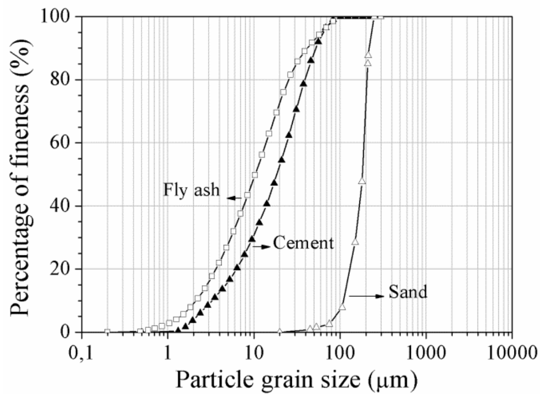

Figure 1. Particle size distribution of cement, fly ash and sand.

Unreinforced (plain) mortar and R-PET fiber reinforced composite specimens were prepared to study the influence of different volumes of the R-PET reinforcement (1.0%, 1.5% and 2.0%) on the bending properties of the final material.

In all composites, the water/cementitious material ratio and superplasticizer content were dosed such that all mixtures would have similar fresh properties measured by the flow table test (between 160-190 mm). A slight adjustment in the superplasticizer content in each mixture was made to achieve consistent rheological properties for better fiber distribution and workability. The mixture proportions are given in Table 1.

Table 1. Materials composition in the mixture.

Ingredients	Matrix	M02	M03	M04
Fly ash/cement	1.20	1.20	1.20	1.20
Water /(cement + fly ash)	0.36	0.36	0.36	0.36
Cement (Kg/m³)	505.00	505.00	505.00	505.00
Fly ash (Kg/m³)	605.00	605.00	605.00	605.00
Sand (Kg/m³)	404.00	404.00	404.00	404.00
Water (Kg/m³)	404.00	404.00	404.00	404.00
Superplasticizer (Kg/m³)	6.05	6.05	6.81	6.81
Fiber (Kg/m³)	-	14.33	21.50	28.66
Fiber content (%)	-	1.00	1.50	2.00

To produce the mixtures all dry raw materials were mixed for 3 minutes in a mechanical mixer with a 20 liter capacity. Water and superplasticizer were added to form the basic matrix. The mixture was stirred for another 8 minutes to allow adequate flowability and viscosity, both of which are necessary for good workability and uniform fiber distribution. In the last step, fibers were dispersed carefully by hand into the mortar mixture and the mixture was stirred for 5 minutes more.

A small flow cone for conventional flow table test was used to quantify the deformability of the fresh mix according to (NBR 13276, 2005). Then, the specimens were cast in steel molds and demolded 24 hours after casting, always covered with damp cloths. The specimens were cured for 28 days in a curing chamber with 100% relative humidity and 21 ± 1ºC of temperature.

2.2 Testing procedure

To determine the bending and compressive behavior of the studied composites, a Shimadzu Universal testing machine with a capacity of 100kN was used.

Three samples measuring 400 x 60 x 12.5 mm (length x width x thickness) were tested under four point bending loads at a span of 255mm and crosshead rate of 0.2 mm/min, as seen in Fig. 2. Deflections at mid-span were measured using an electrical transducer (LVDT). The loads and corresponding deflections were continuously recorded on a computerized data recording system.

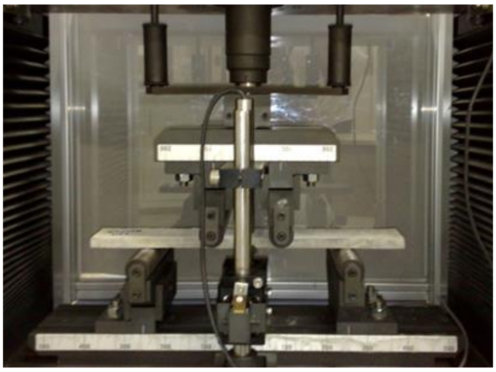

Figure 2. Bending test set-up

A compressive strength test was performed on cylindrical specimens of 50mm × 100mm (diameter x height) in a Shimadzu universal testing machine (UH- FI-1000KN) controlled by computer under strain control at a loading rate of 0.2%FS/min. The load and corresponding displacement were continuously recorded.

3. RESULTS AND DISCUSSION

3.1 Bending properties of the composites

The bending performance of the mixtures was assessed based on the four-point bending test in terms of first-cracking stress, first-cracking deflection, ultimate bending strength, ultimate midspan deflection at bending strength, which will be referred to as deflection capacity, and toughness. In this research, the toughness was computed as the total area under the bending stress - deflection curve while the first cracking point is defined as the point where nonlinearity in the bending stress-deflection curve becomes evident.

Equivalent bending stress - deflection curves obtained for experimental mixtures are shown in Fig. 3. The results of the evaluation of all curves are summarized in Table 2. Each result in Table 3 is the average of three specimens.

Fig 3a shows the curves from the bending tests on mortar mixture without reinforcement, where the maximum stress is at an average deflection of 0.304 mm (deflection at the maximum load point); following this, the load suddenly decreases. However, when the content of R- PET fiber increase from 1.0 to 2.0% (Fig. 3b-d), the bending behaviour is supposed to increase owing to the fact that a greater amount of fiber exists, which enables a greater capability of resisting the tensile stress, especially at the post-cracking stages.

Comparing the results from Table 2, it can be noticed that as the fiber volume content increases, the first cracking strength decreases from 4.06 MPa (Matrix) to 3.27 MPa (M04-2% fiber), in accordance with what was expected as the introduction of the fibers damage the matrix (Bentur and Mindess, 2007). However, the tests results have shown no differences in first-cracking deflection when the fiber volume content increases from 1.0 to 2.0%.

Concerning the post-cracking behaviour, Fig. 3b-d indicated that, even though the test series demonstrated a range of performance, both test series with 1.0% and 1.5% fiber volume content (Fig. 3b-c) exhibited deflection-softening behaviour, with a single cracking formation, while the test with 2.0% fiber volume content (Fig. 3d), generated a performance in the edge of the deflection-hardening behaviour (maximum post-cracking bending stress is similar or higher than first-cracking strength), with a single cracking formation surrounded by ramifications. According to Kim et al (2008), fiber reinforced cementitious composite showing deflection-hardening behavior generates a higher load carrying capacity after first cracking compared with normal concrete or composite with deflection-softening behaviour.

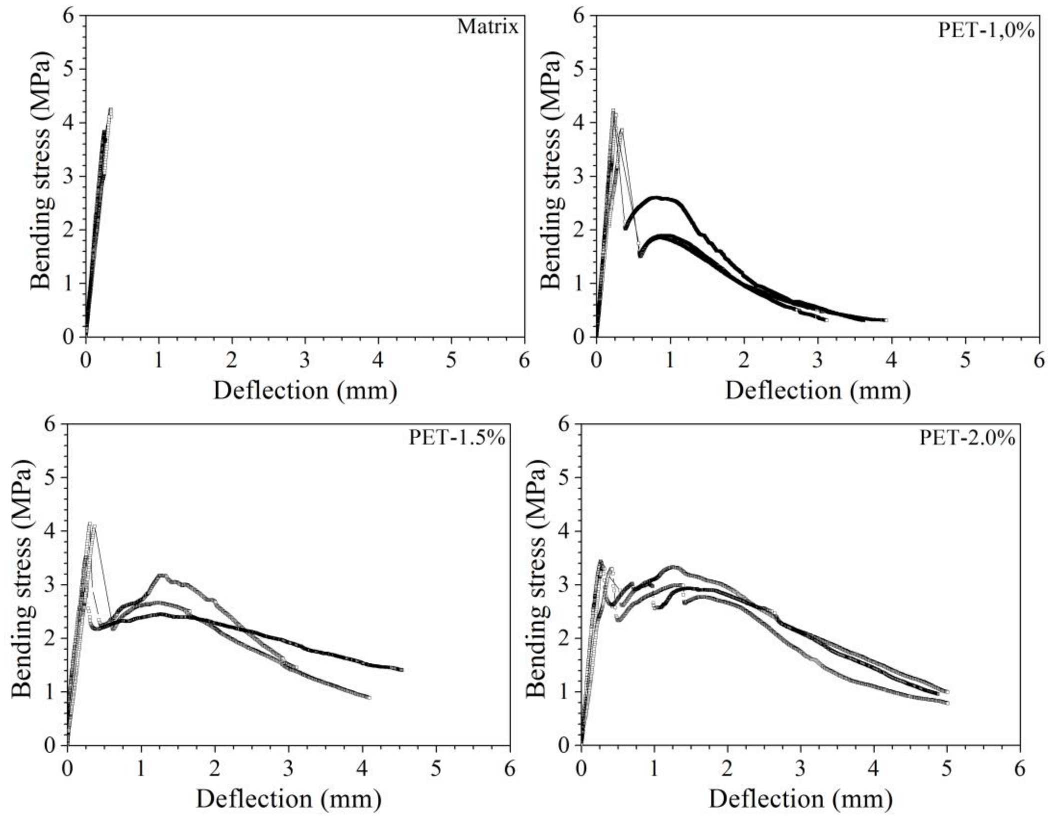

Figure 3. Equivalent bending stress-deflection curves of the matrix (no fiber) and composites reinforced with 1.0%, 1.5% and 2.0% at 28 days.

Table 3. Summary of bending tests of the mixtures at 28 days (standard deviation in parenthesis).

mixture	first-cracking deflection, (mm)	first-cracking stress (MPa)	ultimate bending strength (MPa)	deflection capacity (mm)
matrix	0.304 (0.047)	4.06 (0.21)	-	-
M02	0.277 (0.057)	4.09 (0.19)	2.58 (0.57)	0.94 (0.04)
M03	0.276 (0.041)	4.00 (0.72)	2.84 (0.54)	1.32 (0.03)
M04	0.275 (0.018)	3.27 (0.22)	3.03 (0.29)	1.43 (0.14)

Comparing the effect of fiber volume fraction on post-cracking value, it is evident the beneficial influence of the fiber in post-cracking behavior of fiber reinforced cementitious composites. The results indicated that when the contents of R-PET fiber increased from 1.0 to 1.5%, the ultimate bending strength increased from 2.58 to 2.84 MPa and deflection capacity increased from 0.94 to 1.32mm and when the content of R-PET fiber increased to 2.0%, the ultimate bending strength increased from 2.58 to 3.03 MPa and deflection capacity increased from 0.94 to 1.43mm. This represents an increase of up to 4.7 times in comparison to the deflection capacity of unreinforced matrix.

There is need for high energy absorbing materials that will mitigate the hazards for structures subjected to dynamic loads, such as seismic, impact and blast. Thus comparing energy absorption capacity provides useful information for such applications. The effect of fiber volume content on energy absorption capacity is determined by using toughness values, defined as the total area under the bending stress - deflection curve.

The results indicate that there are noticeable differences between specimens with different fiber contents. For example, samples reinforced with 1% of R-PET fibers showed toughness value of approximately 4.6 J/m^3, while samples reinforced with 1.5% and 2.0% of R-PET fibers showed 7.2 J/m^3 and 8.2 J/m^3, respectively. This indicates an increase of up to 76% on absorption capacity of composite reinforced with 2.0% of R-PET fiber.

3.2 Compression properties of the composites

The compressive behavior of the composites was determined at 28 days. Fig. 4 shows the typical stress – strain relationship measured from the compressive tests. The average and the standard deviation (in parenthesis) are summarized in Table 4. The reported data are the average values from three specimens.

Table 4. Summary of compressive tests of the mixtures at 28 days (standard deviation in parenthesis).

mixture	young's modulus (GPa)	compressive strength (MPa)
matrix	19.40 (0.61)	39.83 (0.58)
M02	14.43 (1.11)	37.73 (1.76)
M03	12.40 (1.44)	17.68 (0.36)
M04	10.73 (2.21)	18.65 (0.27)

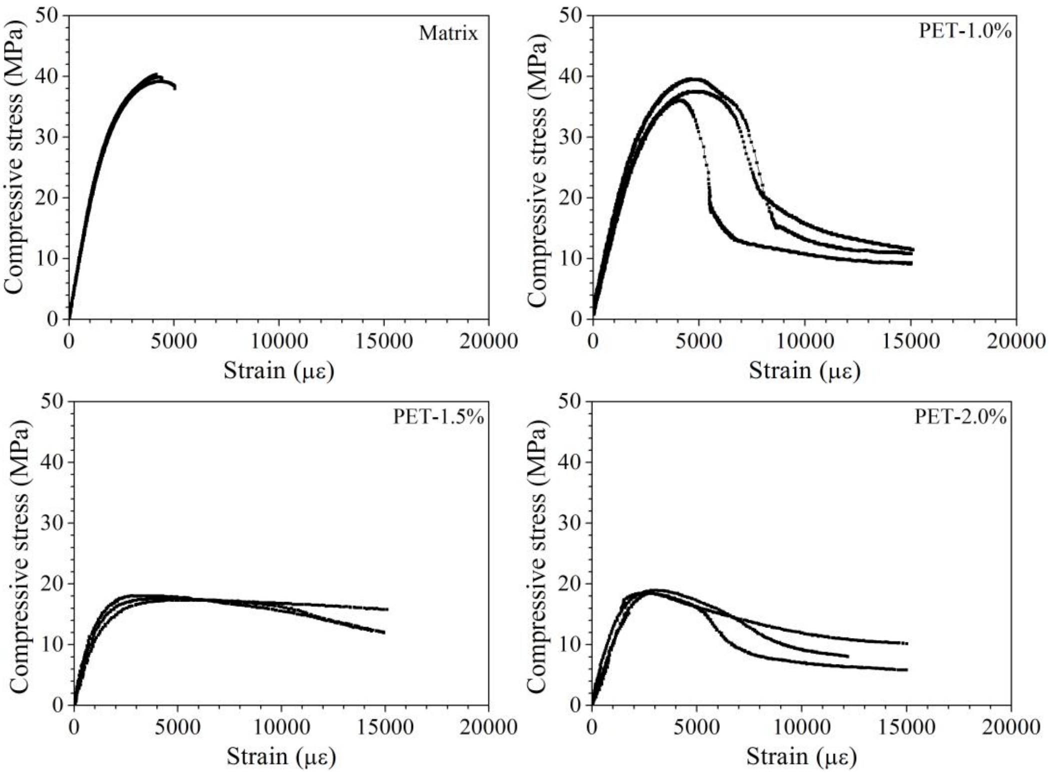

Figure 4. Compressive stress-strain curves of the matrix (no fiber) and composites reinforced with 1.0%, 1.5% and 2.0% at 28 days.

As seen from the results, the compressive strength and young's modulus of mixtures decreased with increasing of the fiber content. For example, both the compressive strength and young's modulus of the mixtures are reduced by approximately 53.2% and 44.7% respectively when 2% of fiber was added. However, the slopes of the descending branch of the compressive stress - strain curves (fig. 4), in post-peak region, indicate that the compressive ductility was increased.

4. CONCLUSION

Based on the results obtained in the present work it can be concluded that the use of recycled PET (R-PET) fibers, as reinforcement of cementitious materials, is a promising technique for developing sustainable materials to be applied in the civil construction industry.

Cementitious composites reinforced with 1.0% and 1.5% fiber volume content exhibited deflection-softening behaviour, with a single cracking formation, while the mixture reinforced with 2.0% R-PET fibers presented a deflection-hardening behaviour with an average ultimate bending strength of 3.03MPa, ultimate deflection at bending strength about of 1.43mm and toughness of 8.18 J/m³. In fact, the use of R-PET fibers as reinforcement of cement mortar can produce composites with appropriate mechanical properties allowing its use in semi-structural applications.

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE

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