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MECHANICAL PROPERTIES OF POLYESTER POLYMER CONCRETE MADE WITH RECYCLED MATERIALS

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Abstract. *This research work presents an assessment of polymer concretes made with recycled materials. PC origins from mixing fine aggregates to a polymeric resin as binder, instead of ordinary cement and water. In this study, recycled textile fibers from garment industry and unsaturated resin obtained from the PET chemical recycling was used as recycled materials. In total, four compounds of polymer concretes were generated, with different fiber and resin content. The samples were studied through compressive strength, flexural strength. The results show that polymer concretes made with recycled materials can present great values in strength, when compared to original materials and ordinary cement concrete.*

Keywords: *Textile Fibers; Recycled Resin; Composite*

1. INTRODUCTION

The development of high strength, durable and elevated life cicle new materials are demands of the new growing manufacturing sustainable market. According to EPA (Environmental Protection Agency) the evaluation of a product life cycle is one of the main tools to analyze the entire process, from extracting raw material, manufacturing, distribution, intake, usage to transformation into residue (Vigon *et al.* 1993). This analysis evolves not even the product impact at its usage but even though the energy demanded to manufacture and transport. (Carmody *et al.* 2007). Therefore, this new global process point of view can evaluate the impact generated and adapt to a new market demand. Polymer Concrete, PC, can be considered a high durable composite material due to its high performance when submitted to mechanical strength aggressive and outdoor environments (Reis and Ferreira, 2006). Reducing the maintenance need frequently require by ordinary portland cement concrete. Polymer Concrete is a composite material which uses polymeric materials, i.e., thermoset resins to bind the aggregates, similarly to the action of Portland cement concrete. PC rapidly proved to be an excellent repair for concrete. Today, PC is used very effectively in precast components for bridge panels, buildings, machine bases, and transportation components (Fowler, 1999 and Czarnecki, 2001) Although three to five times stronger than conventional concrete, PM does display brittle characteristics that have limited its usefulness for load-bearing applications (Letsh, 2002).

Synthetic fibres were developed mainly to supply the high demand for textile products. Rayon and Nylon were the first ones to be developed and commercialized. Today, textile fibres are manufactured from a unique type of fibre or from a combination of several fibres, natural or synthetic, providing a huge variety of final products (Rowell, 2000). Brazil is an important manufacturer of textile products worldwide, according to previous studies (Filho e Santos, 2002). The textile cuttings waste from this industry is usually disposed of as a waste product whose non-biodegradability impacts and environment, or it is burned in heaps, releasing highly toxic fumes into the surrounding air.

The practice of disposal requires constant creation of new landfill spaces, which is in direct contradiction to environmental goals and the preservation of ecosystems. Significant efforts have been devoted to the reduction, reuse, and recycling of waste materials. Recycling technologies are typically divided into primary, secondary, tertiary, and quaternary approaches. Primary approaches involve recycling a product into its original form. Secondary recycling involves processing a used product into a new type of product that has a different level of physical and/or chemical properties. Tertiary recycling involves processes, such as pyrolysis and hydrolysis, which convert the waste into basic chemicals or fuels. Quaternary recycling refers to waste-to-energy conversion through incineration. All four approaches exist for textile, plastic, and paper recycling. Studies have indicated that many forms of fibres recovered from various types of waste are suitable for mortar reinforcement (Wang *et al.* 1994 and Peled *et al.* 2008) The advantages of using such recycled fibres generally lower processing costs than virgin fibres and the elimination of the need for waste disposal in landfills.

A significant amount of fibrous waste from the textile industry and post-consumer products is disposed worldwide. This is not only a cause for environmental concern, but also represents a waste of useful resources. This paper contributes to understand the characteristics of polymer mortar made with recycled textile fibres from the clothing industry. It is expected that this research will stimulate further full-scale studies on waste fibre reinforcement and promote the use of such material in civil construction.

These textiles are generally the ones that most effectively translate yarns into stiff, strong composites. The textile cuttings are usually discarded as waste product, whose non-biodegradability impacts and environments, or burned in heaps, releasing highly toxic fumes into the surrounding air. Due to the influx of these voluminous wastes into our environment, manufacturing polymer mortar reinforced with textile fibres has a double function: elimination of wastes, and introduction of a new product. This study explores the technical properties of a new product produced from textile cuttings in order to determine its usefulness as a new building material.

2. MATERIALS

The textile cuttings waste used in this study came from the largest lingerie manufacturer in Brazil, located in the industrial centre of Nova Friburgo in Rio de Janeiro. The textile cuttings consisted of cotton, polyester, silk and rayon. A homogenous single type of textile usually consists of a combination of these materials in various percentages. In the textile polymer composite material under study, foundry sand was mixed with thermosetting resin, epoxy, which served as binder. Textile cuttings should not be considered either aggregates or reinforcement. Due to their fibrous nature, they contribute to increase the volume of the mixture (which is the major function of an aggregate), and their purpose is to contribute toward the flexural and compressive resistance (which is the main function of reinforcements). Textile-reinforced polymer mortar was prepared in the same way as plain polymer mortar, by incorporating 1% and 2% in weight of chopped textile fibres. These percentages were chosen based on previous studies on fibre-reinforced polymer mortar (Reis, 2006, Aspiras and Manolo, 1995). The textile cuttings waste was provided by the manufacturer, cut into 5 mm lengths, with a specific weight of 1.22 to 1.38 g/cm^3.

The aggregate was foundry quartz sand with a homogeneous grain size, employed in a 40/50 design, produced by JUNDU® and used in the foundry industry. The resin used as binder was unsaturated polyester obtained from recycling PET. 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. Polyester resin from PET showed similar results when used as binder to polymer concrete when compared to ordinary polyester resin, with the advantage of low manufacturing cost and processing energy and, of course contributing to reduce the plastic waste. (Mahdi *et al.,* 2007, Karayannidis *et al*., 2005). Resin properties are presented in table 1.

Table1. Recycled Resin from Pet Properties

Property	
Brookfield Viscosity at 25ºC (CP)	250-350
Density (g/cm^3)	1.0955
Heat Distortion Temperature HDT (ºC)	85
Acid value (mgKOH/g)	25

Two series of PC formulations were studied, using different resin-to-sand weight ratios. The resin content varied from 10 to 12% by weight.

With these mix proportions, polymer mortar samples were cast into prismatic (40 x 40 x 160 mm^3) and cylindrical (ϕ50 x 100 mm^2) specimens, as illustrated in Fig. 1, following the specifications of RILEM TC113/PC-2 (Rilem, 1995). Five cylindrical and five prismatic specimens were cast in each formulation. All the specimens were cured at room temperature for 7 days.

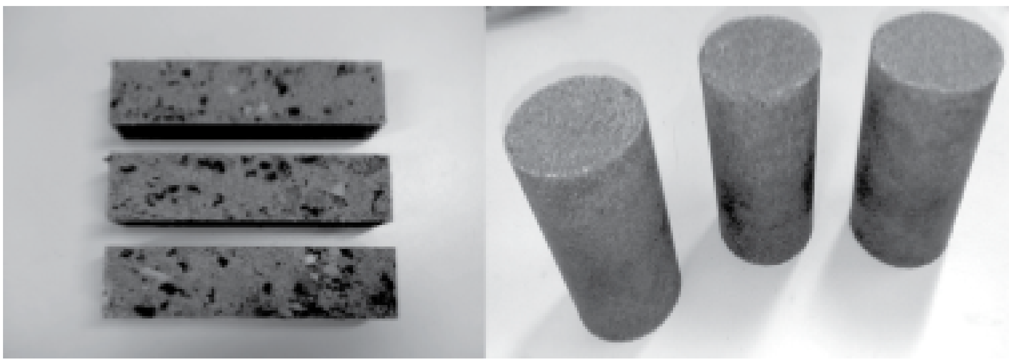

Figure 1. Examples of Flexural and Compressive Specimens

3. Flexural and Compressive Strength

Measurements of textile fibre-reinforced polymer concrete under different loading conditions were taken under flexion and compression. Prismatic polymer mortar beams were tested by three-point bending up to failure at a loading rate of 1 mm min^{-1}, with a span length of 100 mm, according to the RILEM TC113/PCM-8 specifications. In terms of specimen geometry and span length, the specifications of this standard are similar to those of the ASTM C348-02 standard testing method for flexural strength of hydraulic cement mortars. Neither of the aforementioned standards takes into account the shear effect in the calculation of flexural strength. Despite the very short span compared to the thickness, the shear effect was disregarded. Polymer concrete is considered an isotropic material and the plane cross-section theory was used here. Flexural strength, i.e., strength under normal stress, was determined from the following equation:

$$\sigma_f = \frac{3Pl}{2bh^2} \tag{1}$$

where σ_f is the flexural strength; P is the maximum load recorded, l is the span length; b is the width and h the height of the prismatic specimens.

Cylindrical polymer mortar specimens were tested under compression at a loading rate of 1.25mm/min^{-1}, according to the ASTM C39-05 standard.

Compressive strength was calculated from the following equation:

$$\sigma_c = \frac{F}{A} \tag{2}$$

where σ_c is the compressive strength; F is the maximum load recorded; and A is the cross-sectional area of cylindrical specimens.

The flexural and compressive test setups are depicted in Fig. 2.

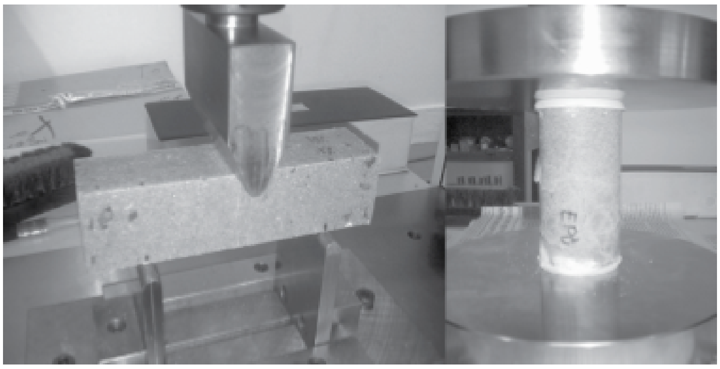

Figure 2. Flexural and Compressive Test Set-up.

4.Test Results and Discussion

The flexural and compressive tests conducted at the Universidade Federal Fluminense (UFF) and the Instituto Politécnico do Rio de Janeiro (IPRJ) are presented in the tables below. Table 2 displays the flexural test results and Fig. 3 plots the flexural strength comparison between specimens.

Table 2. Flexural Strength of PET Polymer Concrete (MPa)

Specimen	FLEX100	FLEX101	FLEX120	FLEX121
1	10.74	7.33	12.39	9.55
2	9.92	7.55	12.34	9.09
3	10.44	7.88	13.02	9.92
Average	10.37	7.59	12.58	9.52
Std.Dev.	0.415	0.277	0.379	0.416
COV	4.002	3.649	3.012	4.368
CI (95%)	1.031	0.687	0.941	1.033

The results listed in Table 2 indicate a reduction in the flexural strength of polymer mortar containing 10% of recycled PET resin when textile fibres were added to the formulation. The average loss of flexural strength was 26.8% for 1% textile fibre content when compared with plain PET polymer concrete. The decline in flexural strength was lower when plain PET polymer concrete with 12% resin content was compared to 1% textile fibre-reinforced PET polymer concrete. Specimens containing 1% of fibre showed a 24.3% loss of flexural strength. In a comparison of plain polymer mortar, 12% resin content plain polymer concrete showed almost 22% higher flexural strength than did 10% resin content plain PET polymer concrete.

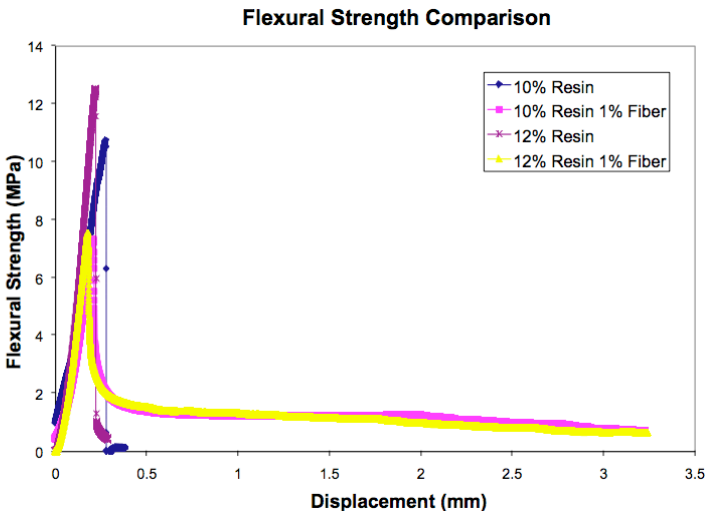

Figure 3. Flexural Strength Test Results Comparison

In bending, failure becomes less brittle as textile fibers content is increased in the polymer concrete mixture. Ultimate failure load decrease is observed in all cases and failure becomes even less brittle. When specimens reach 30% of the failure load, textile fibers retain the strength avoiding collapse.

Table 3 compares the compressive strength of all the plain and textile-reinforced PET polymer concrete formulations tested here and Fig.4 displays the compressive test results comparison. The compressive tests also demonstrated that the addition of textile fibres reduced the stiffness of PET polymer concrete.

Table 3. Compressive Strength of PET Polymer Concrete (MPa)

Specimen	COMP100	COMP101	COMP120	COMP121
1	17.18	11.94	33.57	20.51
2	17.49	11.01	29.24	20.57
3	17.31	11.83	31.77	20.33
Average	17.33	11.59	31.53	20.47
Std.Dev.	0.156	0.508	2.175	0.125
COV	0.898	4.383	6.900	0.610
CI (95%)	0.387	1.262	5.404	0.310

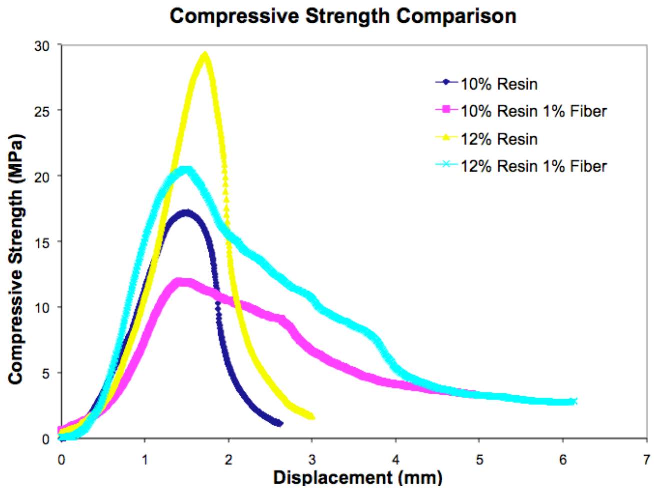

Figure 5. Compressive Strength Test Results Comparison

Analyzing the results of 10% PET resin content, it was found that the compressive strength of polymer mortar declined with the addition of textile fibres. The compressive strength of textile fibre-reinforced PET polymer concrete decreased by 33.1% with 1% of textile fibre content in relation to plain non-reinforced PET polymer concrete. Comparing 12% resin content plain polymer concrete and 1% of textile fibre-reinforced PET polymer concrete revealed a loss of 35.1% of compressive strength. In fact, even 12% resin content polymer concrete made with 1% of textile fiber content has a high compressive strength than plain 10% polymer concrete.

Textile fibers reinforcement characteristics are observed during the compressive test. Increasing fiber content failure become less brittle in both cases of resin content. Unreinforced polymer concrete specimens failed in a brittle manner and shattered into pieces as the load dropped instantly to zero. In contrast, all textile fiber reinforced samples after reaching the peak load could still remain as an integral piece, with fibers holding the polymer matrix tightly together.

Comparing test results from previous studies perform by the authors (Reis, 2009) with epoxy resin as binder decreases in both flexural and compressive strength were observed. The decrease reported comparing flexural test results were aproximally the same. Using epoxy resin as binder flexural strength decrease 27.1% and 18.5% respectively for 10 and 12% epoxy resin content. Lower compressive strength were reported analysing 10 and 12% resin content reinforced with 1% of textile fibers, 30.3% and 41.8%.

5. CONCLUSIONS

This research work produces response to manufacture a unique composite material. Textile fibers from industrial waste and recycled resin from PET were used intending to produce a polymer concrete from recycled components. The aim of using textile fibers as reinforced was not achieved. Textile fibers degrades polymer concrete microstructure producing a weak composite material, even though the results of textile polymer concrete were quite high when compared to ordinary cement concrete.

Textile fibers do not increase polymer concrete flexural and compressive strength but their addition to the mixture eliminates the signs of brittleness behavior of unreinforced polymer concrete. The use of those fibers, in specific applications, may solve two problems, namely, elimination of an environmental pollutant and provision of an alternative material for the construction industry.

6. ACKNOWLEDGEMENTS

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