Polymer concrete reinforced with recycled-tire fibers: Mechanical properties

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Abstract. Polymer Concrete was reinforced with recycled-tire fibers in order to improve the compressive and flexural strength. Polymer concrete specimens were prepared with 70% of silicious sand, 30% of polyester resin and various fiber concentrations (0.3, 0.6, 0.9 and 1.2 vol%). The results show increment of 50% in average of the compressive and flexural strength as well as on the deformation when adding 1.2 vol% of recycled-fibers.

1. Introduction

The development of polymer concrete (PC) has been of scientific and technological interest around the world since last three decades due to the versatility of its applications. There are several important features in PCs such as fast curing, light weight, good linkage with steel reinforcements, high compressive and flexural strength as well as durability that make it a suitable material for the construction industry [1-5]. PC is formed by a thermoset resin used as binder of natural or artificial aggregates; it is known that polymer concrete has mechanical properties higher than those for Portland cement concrete (PCC) but with a little drawbacks associated to brittle behavior, which can be solved adding fillers as fibers or particles.

The final properties of PCs rely on several criteria: polymer binder, mineral aggregates, type of reinforcement as well as the concentration of each component. In the polymer concrete elaboration is common the use of polyester resin by its low cost compared to other polymeric binders. It is not common the use of fiber reinforcements on polymer concrete like the one presented in the Portland cement concrete (PCC), thus a lack of information of such reinforcements is evident. Some fibers have been used for this purpose as steel, glass, carbon, nylon, polyester, propylene, among others; however in order to reduce the environmental impact of industrial or postconsumer waste, recycled fibers has been used. They offer advantages in reducing waste and conserving resources [6]. Recycled fibers can improve the mechanical properties of PCs. Wood wastes from timber industry are used as reinforcement of epoxy-polymer concrete and the flexural strength, fracture toughness and fracture energy are improved; similar behavior are observed for PCs with glass fiber as reinforcement.

The recycling and reutilization of cross-linked elastomers are difficult due their 3-D formed network, nevertheless it is necessary to found wise-strategies for reuse and to avoid ground contamination [7]. Modifications have been made to PCC with recycled-tire-rubber particles due to the benefits on the tensile and flexural strength of the mixtures. The natural and synthetic rubbers such as styrene-butadiene-styrene (SBS) and styrene-butadiene-rubber (SBR) are the raw material in the
production of tires; the natural rubbers provide elastic properties while the synthetics provide thermal stability [8].

2. Experimental

2.1. Specimen manufacturing
Standard prismatic molds (40x40x160 mm) were used to formulate polymer concrete specimens according to CPT PC-2 recommendation. The polymer concrete specimens were elaborated with an isophthalic polyester resin (Aropol™ IS 4633) and a siliceous sand (SP55-Sibelco). The resin was accelerated by 1% of cobalt octoate, and the methyl ethyl ketone peroxide was used as initiator. The sand with granulometry uniform had an average diameter of 245 μm.

The polymer concrete specimens (taken as a control) consisted of 70 vol% of siliceous sand and 30 vol% of polyester resin. As reinforcements of polymer concretes were used recycled-tire rubber fibers at four different concentrations (0.3, 0.6, 0.9 and 1.2 vol%), these were taken into account in accordance to the sand concentrations. The recycled-fibers had a size distribution from 0.5 to 3.5 mm length. Before preparing specimens both aggregates, siliceous sand and fibers were dried in an oven for 3 hours at 60°C in order to guarantee the absence of water.

2.2. Mechanical tests
All specimens were cured for 24 hours at 30°C and post-cured at 80°C for three hours before being submitted to experimental testing. The mechanical tests of PC specimens were carried out in an Instron universal testing machine, with a load cell of 100 kN. The flexural testing was according to CPT PCM-8 standards at a rate of 1 mm/min for three-point bending tests. Load-displacement curves and the maximum load for the collapse bending were recorded. The compressive testing at a loading rate of 1.25 mm/min was done, following the UNE 83821:1992 test standard.

2.3. Morphological characterization
The surface of recycled-tire rubber fibers were observed with a scanning electronic microscope (SEM) in a JEOL model JSM-5200 machine, in the backscattering-electron mode.

3. Results and Discussion

3.1 Compressive and Flexural Strength
Compressive strength results of reinforced polymer concretes are shown in Figure 1a. It can be noticed two well-defined stages: a) In the first there is a diminution in compressive strength for polymer concretes with 0.3 and 0.6 vol% of recycled fibers, it means 54% of diminution respect to polymer concrete without fibers; b) Then the values increase for specimens with 1.2 vol% of recycled-fibers.

![Figure 1](image-url)

**Figure 1.** Polymer concrete with recycled-fiber: (a) Compressive strength, (b) Flexural strength.
With exception of specimens containing 1.2 vol% of fibers; all values are lower than those for polymer concrete without fibers. The highest value, namely 41 MPa means an improvement of 54% compared to polymer concrete without fibers.

The flexural strength behavior is similar when it is compared with compressive strength behaviour (see Figure 1b). The highest value, namely 15 MPa means an increase of 43%. We remind that the elastomeric fibers has a high Poisson ratio of approx. 0.5, this feature is noted when adding 1.2 vol% of fibers which is enough to "overcome" the poor interaction between tire-rubber fibers (an elastomer) and the polyester resin (matrix). A great quantity of different fiber sizes leads a greater distribution that can fill the interstitial spaces with smaller fibers.

3.1. Compressive Strain at Yield Point and Compression Modulus of Elasticity

As shown in Figures 2a and 3, a maximum compressive strain (20%) is obtained when 0.9 vol% of fibers are added, respect to plain polymer concrete, showing the influence of the elastomer on the strain behavior. A different behavior is observed for the elasticity modulus (see Figure 2b), which decreasing according to the fiber concentration increase. As we know a lower elasticity modulus implies a ductile material unlike a rigid material. In our case the lowest value is obtained for polymer concrete with 0.6% of fibers; which is 53% minor than polymer concrete without fibers, generating a more ductile material. An unexpected result is the increment of elasticity modulus for polymer concrete with 1.2% of recycled-fibers, which is 18% higher than that of polymer concrete without fibers.

![Figure 2](image2.png)

**Figure 2.** Polymer concrete with recycled-fiber: (a) Compressive strain at yield point, (b) Compression Modulus of Elasticity of polymer concretes.

![Figure 3](image3.png)

**Figure 3.** Compressive strength vs strain of polymer concrete with recycled-fiber.
In Figure 4 the fiber surface characteristics of the recycled-tire fibers are shown. Some fibers show roughness on their surface and others smooth surfaces. The average diameter of recycled fibers varies from 10 to 35 μm and the length from 500 to 3500 μm. The roughness surface can allow anchoring between the tire-rubber fibers (an elastomer) and the polyester resin (matrix). For the lowest concentrations a poor elastomer-matrix adherence is found, but when increases the volume fraction of fibers, mechanical interaction are augmented due to the higher amount of fibers, therefore improvements on the mechanical properties are obtained.

![SEM images of recycled-tire fibers at: (a) 1000x, (b) 180x.](image)

**Figure 4.** SEM images of recycled-tire fibers at: (a) 1000x, (b) 180x.

### 4. Conclusions

The flexural and compressive strength were modified with the addition of recycled fibers, these properties have a concentration dependence of reinforcements utilized. Mechanical properties of PC are improved when the fiber concentration is enough to decrease the negative effect of a poor elastomer-matrix adherence but with a percentage of reinforcement less than 1 vol%. A more ductile material is obtained at expense of the flexural and compressive strength.

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