MECHANICAL PROPERTIES OF POLYMER MORTAR CONTAINING PET WASTE AGGREGATES

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Abstract. *Non-biodegradable plastic aggregates made of polyethylene terephthalate (PET) waste from beverage containers are used as partial replacement of natural aggregates in mortar. Various weight fractions of sand 5%, 10%, 15% and 20% are replaced by the same weight of plastic. This paper investigates the mechanical properties of the obtained composites. The main results of this study show the feasibility of the reuse of PET waste aggregates materials as partial substitutes for aggregates in composite materials. Despite of some drawbacks like a decrease in flexural and compressive strength, the use of PET waste aggregates presents some advantages. A significant improvement in the modulus of elasticity is observed. The present study has shown quite encouraging results and opened new ways for the recycling of PC waste aggregate in polymer matrix composites.*

Keywords: *Polymer Mortar, Recycled PET, Mechanical Properties*

1. INTRODUCTION

From the beginning of synthetic polymers industrial production in the early 1940's, the manufacturing, consumption and waste generation has increased considerably.

Recent work by Glen (2007) showed that polyethylene terephthalate (PET) bottles have experienced rapid growth since the 1970s when the technique of blow molding was introduced. According to Simon and Schnieders (2007), in 2007, the worldwide consumption of bottle grade PET was 15 million metric tons representing 8% of the total demand of standard plastics. PET bottles are characterized by high strength, low weight, and low permeability of gases (mainly CO_2) as well as by their aesthetic appearance (good light transmittance and smooth surface).

PET does not create a direct hazard to the environment, but due to its substantial fraction by volume in the waste stream and its high resistance to the atmospheric and biological agents, it is seen as a noxious material. Ecological as well as economic considerations advocate the introduction of wide-scale PET recycling, similar to the recycling of traditional materials such as glass, paper or metals.

There is many ways to recycle waste polymers including PET. A very attractive form of recycling used polymer materials is the so-called, "materials recycling", which consists of the collection, disintegration and granulation of waste polymer and then their recirculation into production (La Mantia and Vinci, 1994a; 1994b). Another way is the chemical recycling, which produces unsaturated polyester resin based on the concept of depolymerizing the condensation polymer through solvolytic chain cleavage into low molecular-weight products, which can be purified and reused as raw materials (Carta *et al.*, 2003).

For the last decades researchers have focused their studies in the use of plastic waste as an alternative to natural resources as raw materials. Pet waste was used as polyurethanes, coating materials, unsaturated polyester resin, binder (Rebeiz, 1996; Byung-Wan *et al.*(2008) and Abdel-Azim, 1996) and as fiber reinforcement (Choi *et al.*, 2005; Frigione, 2010; Akçaözoglu, 2010 and Hannawi *et al.*, 2010).

Recycling is a relatively new activity in Brazil initiated only in 1994. Despite the short time, the recycling industry established itself throughout the country encouraging this important sector which is responsible for adequate disposal of recyclable products. Recycling, in addition to its environmental importance, is also contributing to the lower-class of the Brazilian economy creating job opportunities.

The latest edition of the Census of PET, released in December 2010 by ABIPET, demonstrated that Brazil is one of the largest PET recyclers in the world and the most effective in finding applications for the recycled material. The recycled PET in Brazil has various applications; being distributed mainly in the textile industry and in the manufacture of unsaturated and alkyd resins. Laminates, metal sheets, food and nonfood packages also represent a significant proportion of reused PET. The application of PET fiber in building materials helps the search for alternative materials (composites) in a way to reduce costs and encourage the use of aggregates that are environmentally less aggressive.

The aim of this work is to investigate the fracture properties, including elasticity modulus of recycled-PET polymer mortar with shredded PET waste from beverage containers by mixing fragments in polymer mortar to be used as lightweight waste aggregate as a function of the ratio of natural and recycled aggregate. Besides using PET waste as substitute of natural aggregate, unsaturated polyester resin from recycled PET was also used as binder and compared to epoxy resin.

2. MATERIALS AND METHODS

2.1. Materials

Mortar formulations were prepared by mixing foundry sand and shredded PET waste as aggregates with epoxy resin as binder. Resin content was 12% by weight and no filler was added in both formulations. Previous studies carried out by Reis (2009) considering an extensive experimental program, allowed an optimization of mortar formulations that are now being used in the present work.

The epoxy resin system was based on a diglycidyl ether of bisphenol A and an aliphatic amine hardener. This system has low viscosity and is processed with a maximum mix ratio to the hardener of 5:1. Epoxy properties are presented in table 1.

Table 1 - Epoxy matrix properties

Property	Epoxy
Viscosity at 250C μ (cP)	12000-13000
Density ρ (g/cm^3)	1.16
Heat Distortion Temperature HDT (^{o}C)	100
Elasticity Modulus E (GPa)	5.0
Flexural Strength (MPa)	60
Tensile Strength (MPa)	73
Maximum Elongation (%)	4

The aggregate was foundry sand with a homogeneous grain size, uniform grains, a mean diameter of 300 µm and with finesses modulus between 3 and 5. The specific gravity of the fresh sand was 2.63 g/cm^3. The foundry sand was previously dried before added to the polymeric resins to reduce moisture content, insuring a good bond between polymer and inorganic aggregate.

The shredded waste PET bottle granules used as aggregate were obtained by picking up waste PET bottles and washing them and then crushing in granules by a shred machine. Polyethylene terephthalate (PET) is a thermoplastic polyester with tensile and flexural elasticity modulus of about 2.9 and 2.4 GPa, respectively, tensile strength up to 60 MPa and excellent chemical resistance. It is a semi-crystalline polymer, with a melting point of about 260 °C and a glass transition temperature ranging from 70 to 80 °C, in relation to the amount of crystalline region enclosed in the amorphous phase. Its density (specific gravity) is around 1.3–1.4 g/cm^3 according to Van Krevelen (1990). The granulometry of the fine aggregates to be used are reported in table 2.

Table 2 – Characterization of aggregates

Sieve	Cumulative passing %	
	Foundry sand	PET waste
4.76 mm	-	100
2.38 mm	-	45.9
1.19 mm	100	16.3
590 µm	84.8	6.9
297 µm	6.7	0.8
150 µm	0.5	-

In order to achieve a more homogeneous material the mixture was performed mechanically. With those mix proportions, polymer mortar specimens were cast to prismatic (40 x 40 x 160 mm^3) and cylinder (ϕ50 x 100 mm) specimens according to RILEM TC113/PC-2 (1995). For each formulation five cylinder and three prismatic specimens were cast. All specimens were allowed to cure for 7 days at room temperature and then epoxy specimens post-cured at 80 °C for 3 h and unsaturated polyester mortars post-cured for 3 h at 60º C before being tested for flexural and compression.

2.2. Methods

To determine the influence of temperature on the mechanical strength of PM, flexural and compressive tests were performed at different temperature levels. The test temperatures range from room temperature to 90ºC. To perform this research an universal testing machine, with a thermostatic chamber attached, was used.

Prismatic polymer mortar beams were tested in three-point bending up to failure at the loading rate of 1 mm min^{-1}, with the span length of 100 mm, according to RILEM TC113/PCM-8 (1995) specification. The specifications of this standard, in terms of specimen geometry and span length, are similar to those specified in ASTM C348-02 (2002), standard test method for flexural strength of hydraulic cement mortars. In both mentioned standards, shear effect is not taken into account on calculation procedure of flexural strength. Despite the very short span compared to the thickness, shear effect is disregarded. Polymer mortar is considered an isotropic material and the theory of plane cross-section is used.

Cylinder polymer mortar specimens were tested in compression at the loading rate of 1.25 mm min^{-1} according to ASTM C39-05 standard (2005).

Both flexural and compressive test set-up are presented in figure 1.

Figure 1. Flexural and compressive test set-up

3. RESULTS AND DISCUSSION

The flexural and compressive test results of polymer mortar containing shredded PET in substitution of aggregates are presented in table 3.

Table 3. The flexural and compressive test results of polymer mortar containing shredded PET

PET content (%)	Flexural Stress (MPa)	Flexural Elasticity Modulus (GPa)	Compressive Stress (MPa)	Compressive Elasticity Modulus (GPa)
0	15.87 ± 0.57	14.10	38.73 ± 1.82	14.72
5	15.22 ± 0.33	25.16	30.43 ± 1.39	26.25
10	11.21 ± 0.33	18.68	25.62 ± 0.93	22.31
15	11.08 ± 0.65	10.50	24.63 ± 1.01	17.99
20	8.28 ± 0.46	6.01	15.75 ± 1.99	15.03

From table 2 it can be analysed that the substitution of shredded PET waste by aggregates in polymer mortars mixture contributes to a decrease in both flexural and compressive ultimate stress. For flexural results, 5% content contributes to a decrease of 4.1%. This result is not significant since the standard deviation for plain polymer mortar is in that range. Higher decreases are observed when the substitutions are increased in the mixture. For 10% of shredded PET content a 29.4% decrease is reported, 30.2% for 15% content and 47.8% are computed for 20%. Evaluating the compressive ultimate stress, elevating the shredded PET waste content also contributes to its diminish. When 5%

content are analysed a 21.4% decrease is reported. Elevating 10%, 15% and 20% the content of shredded PET, the ultimate compressive stress lowered 33.85%, 36.4% and 59.3% respectively. This overall decrease is related to a poor bond between shredded PET waste and the epoxy matrix.

Nevertheless, the elasticity modulus for both flexural and compressive increase with the substitution of shredded PET waste in the polymer mortars aggregates. In flexion an increase is observed for 5% content of shredded PET waste, from 14.10 to 25.16 (GPa), 78.4% and for 10% content the flexural elasticity modulus raises 32.5%. For compressive elasticity modulus, shredded PET waste contributes to elevate its values. 5% content is percentage the higher content contributing to this increment, 78.2%.

The flexural stress vs. strain test results of polymer mortar containing shredded PET as aggregates are displayed in figure 2.

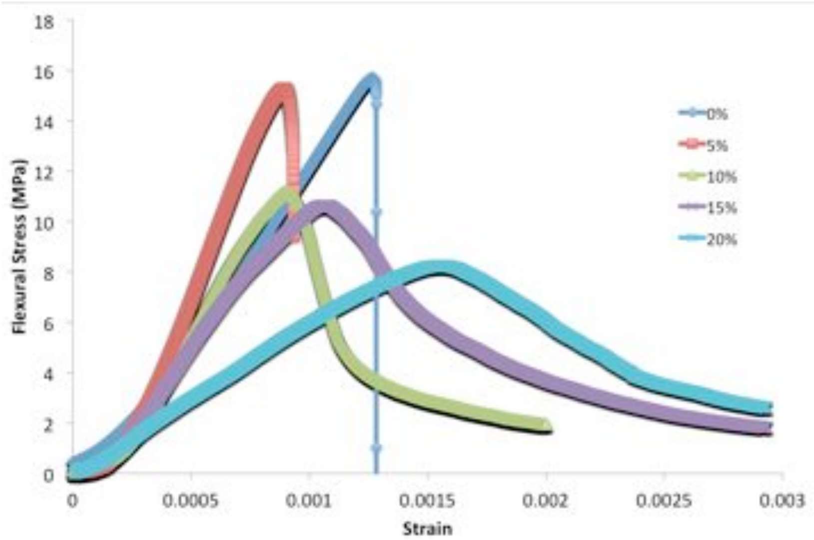

Figure 2. Flexural stress vs. strain polymer mortar containing shredded PET waste as aggregates test results

Analysing figure 2 it can be seen that substitution of aggregates by shredded PET waste in the polymer mortar mixture contributes to the decrease of the ultimate flexural strength of the composite material. However, the addition of 5% of PET waste clearly contributes to an increase of the flexural modulus of elasticity modulus, E. Also, by increasing PET waste content in the admixture less brittle behaviour is observed.

Figure 3 presents the compressive stress vs. strain of polymer mortar containing shredded PET waste as aggregates results.

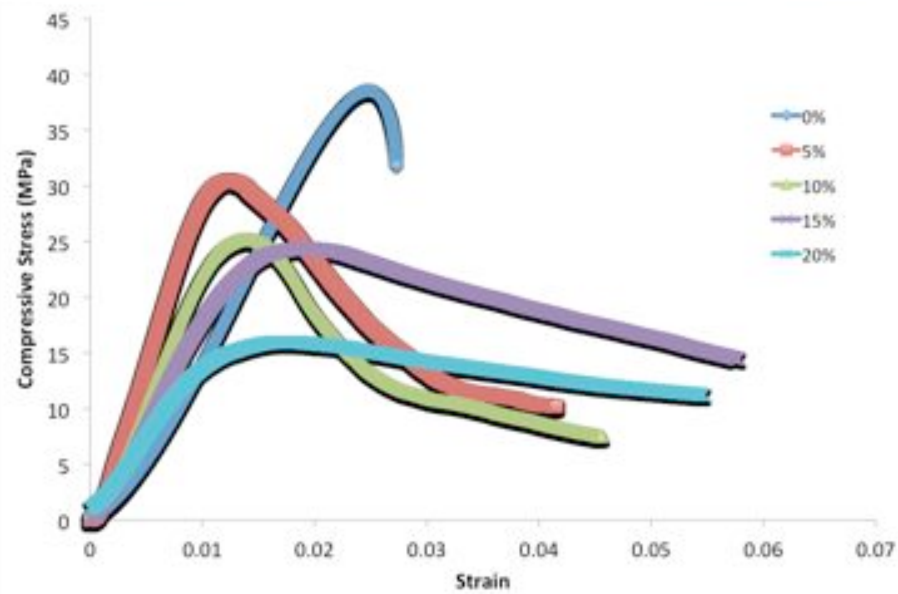

Figure 3. Compressive stress vs. strain polymer mortar containing shredded PET waste as aggregates test results

Again, the substitution of shredded PET waste by aggregates in the polymer mortar mixtures contributes to lower the compressive stress. For the compressive elasticity modulus the increment is higher than the one reported in the flexural tests. The shredded PET waste significantly increases the elasticity modulus as can be seen from figure 3.

4. CONCLUSIONS

This research presents that by substituting foundry aggregate with shredded PET waste, without any particular treatment except the washing and shredding, its possible to produce a composite material that brings economical and energy saving benefits from an ecological point of view.

The addition of shredded PET waste contributes to reduce the specific weight of the polymer mortar for epoxy polymer mortars.

Shredded PET alters the flexural and compressive behavior of polymer mortars. As content rises throughout each test series, the elasticity modulus increases until a certain level of shredded PET waste content is reached. The material becomes more ductile and shows less brittle failure.

Flexural and compressive ultimate strength, in epoxy polymer mortars, are adversely affected by the introduction of any level of shredded PET considered in the present work, except for 5% content which presents to be the best formulation tested.

Comparing to ordinary concrete with PET waste as aggregates similar behavior is observed. The substitution of aggregates by PET waste contributes to a decrease of flexural and compressive strength, but the opposite is reported when elastic modulus is analyzed when compared to polymer mortars. Shredded PET waste contributes to lower the elastic modulus in ordinary concrete mixtures (Byung-Wan et al., 2008, Frigione, 2010).

5. ACKNOWLEDGEMENTS

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