Characterization of Polymer Concrete made with Recycled Aggregate

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ABSTRACT

The sustainable management of solid wastes stimulates metallurgic and metal mechanics industries to look for safety applications for these wastes. The proposal of this work is the recycling of foundry sand with organic pollutants to be used, as inert, in the manufacturing process of polymer concrete. Polymer Concrete (PC) is a composite material in which the binder consists entirely of a synthetic organic polymer. It is known as synthetic resin concrete, plastic resin concrete or simply resin concrete. PC consists of mineral filler (for example, an aggregate) and a polymer binder which it is normally thermosetting resin. In comparison with conventional Portland cement concrete, polymer concrete offers many advantages, such as higher strength, better chemical resistance and improved fracture toughness. In this present paper the mechanical characterization of epoxy polymer concrete made with foundry waste, i.e., recycled foundry sand is presented in comparison with epoxy polymer concrete made with fresh sand. The foundry sands are contaminated with polymer resin from the mould making process. It is found that the recycled sand does not influence the mechanical properties, i.e., the polymer concrete made with recycled sand has about the same mechanical characteristics of polymer concrete made with fresh sand. In fact a slightly increase is observed in terms of fracture toughness and flexural strength. Environmental acceptance of foundry sands in requires reliable knowledge of sand composition and sand residue composition variations especially regarding their environmental characteristics.

1. INTRODUCTION

The sustainable management of solid wastes stimulates metallurgic and metal mechanics industries to look for safety applications for these wastes.

The proposal of this work is the recycling of foundry sand with organic pollutants to be used, as inert, in the manufacturing process of polymer concrete and characterization of the produced material.

Polymer Concrete (PC) is a composite material in which the binder consists entirely of a synthetic organic polymer. It is known as synthetic resin concrete, plastic resin concrete or simply resin concrete. PC consists of mineral filler (for example, an aggregate) and a polymer binder which it is normally thermosetting resin.

In comparison with conventional Portland cement concrete, polymer concrete offers many advantages, such as higher strength, better chemical resistance and improved fracture toughness [1].

In this present paper the fracture energy characterization of epoxy polymer concrete made with foundry waste, i.e., recycled foundry sand is presented in comparison with epoxy polymer concrete made with fresh sand. The foundry sands are contaminated with polymer resin from the mold making process.

Environmental acceptance of foundry sands in PC requires reliable knowledge of sand composition and sand residue composition variations especially regarding their environmental characteristics.

Some potential results of the present work:

- Reduce the environment impact:
    - Reducing the consumption of finite natural resources
    - Reducing or eliminating the need to landfill disposal
- Reduce industry costs:
    - Reducing or eliminating foundries costs associated with waste disposal
    - Reducing raw material costs for polymer concrete manufactures
- Contribute to sustainable industrial growth
- Produce a high quality Polymer Concrete

2. SAND CHARACTERIZATION

Recycled foundry sand is high quality silica sand with uniform physical characteristics. It is a byproduct of the ferrous and nonferrous metal casting industry, where sand has been used for centuries as a molding material because of its thermal conductivity.

Sand is used in two different ways in metalcasting: as molding material, which forms the external shape of the cast part, and as cores, which form internal void spaces in products such as engine blocks. Since sand grains do not naturally adhere to each other, binders must be introduced to cause the sand to stick together and hold its shape during the introduction of the molten metal into the mold and the cooling of the casting.

Two general types of binder systems are used in metalcasting: clay-bonded systems (green sand) and chemically-bonded systems. Both types of sands are suitable for beneficial use but they have different physical and environmental characteristics.

The present paper describes the use of foundry sand impregnated with 1.5 % (in weight) of phenolic resin.

Chemically bonded sands are used both in coremaking, where high strengths are necessary to withstand the heat of the molten metal, and in mold making. Most chemical binder systems

consist of a organic binder that is activated by a catalyst, although some systems use inorganic binders.
Core sand with chemical binders and heavy metals, such as lead and copper, origin a danger residue that can cause serious problems to environment.

Environmental acceptance of foundry sands in new products requires reliable knowledge of sand composition and sand residue composition variations, especially regarding their environmental characteristics. This information together with an effective quality control system is also necessary for the promotion of sand residue utilization.

It is necessary to classify the foundry sand in terms of physical, chemical and grain sized characterization to define the best way to recycle.

These caractherisation include determination of the moisture content, particle size distribuition, density, porosity, specific surface area as well as the heavy metals content. A full test to evaluate the toxicity of these wastes also includes extensive leaching tests and determination of the total availability of the metallic elements.

In general, the foundry sand needs no pre-tretament to be used as inert in PC. The recycling methodology consists in the application of mechanical treatments, “shake out” process (dry and wet friction), to separete the sand grains and obtain a fine size aggregate (245 μm) .

3. MATERIALS AND TEST METHOD

3.1 Materials Used

The experimental program was designed to examine the durability and fracture behaviour of epoxy polymer concrete with recycled foundry sand.

Polymer concrete in essence consists of an aggregate blend mixed with a polymer resin in convenient proportions.
In this particularly study the aggregate was recycled foundry sand impregnated with 1.5 % (in weight) of phenolic resin.

The original foundry sand consists in siliceous sand, designed by SP55, from SIBELCO® used in the foundry industry, with a uniform granulometry, and average diameter of 245 μm, and the phenolic resin binder has a 90 cSt viscosity, pH of 12.5 and less than 0.3% of free phenol.

The epoxy resin system used was EPOSIL 551 SILICEM® based on a diglycidyl ether bisphenolA and an aliphatic amine hardener it processed with a maximum mix ratio to hardener of 2:1.

Considering previous research, in which the resin content and type of aggregate were studied, the Taguchi method was used to evaluate the best composition of Polymer Concrete. Ferreira and co-workers [2] found that the best composition was 20% of resin and 80% of aggregate in mass, where the resin content is the biggest factor of influence on flexural behaviour.

Thermal and mechanical properties of the epoxy resin are presented in table 1.

Table 1 – Thermal and mechanical properties of epoxy resins

Resin properties (After one week at 25ºC)	Epoxy resin
Glass transition temperature Tg (ISO 6721-5)	**45ºC**
Heat distortion temperature HDT (ISO 75)	**34ºC**
Tear Strength (ISO 527)	**40 MPa**
Flexural Strength (ISO 178)	**70 MPa**

Polymer concrete specimens to perform the fracture tests were mixed mechanically and compacted in a steel mold of dimensions of 30mm x 60mm x 280mm according to RILEM standard TC-113/PC2 [3].

The specimens were first cured at room temperature. A post-cure process of 7 hours at 60ºC was done.

Fig. 1 – Polymer concrete fracture specimen

Polymer concrete specimens to perform the flexural tests were compacted in a steel mould 40 mm x 40 mm x 160 mm to obtain the prismatic specimens in accordance to RILEM [3]. All specimens were allowed to cure, for seven days at room temperature and then post-cured at 80ºC for three hours.

3.2 Test Method

Beams for the fracture tests were notched with 20mm depth using a 2mm diamond saw. The specimens were subjected to three point bending test using a INSTRON machine with a cross head speed of 0,5 mm/min.

Specimens were tested under three point bending in a closed-loop servo-controlled testing machine with a 100kN load cell according to RILEM [7] with a cross-head speed of 1mm/min.

The fracture test set-up apparatus is presented in Fig 2.

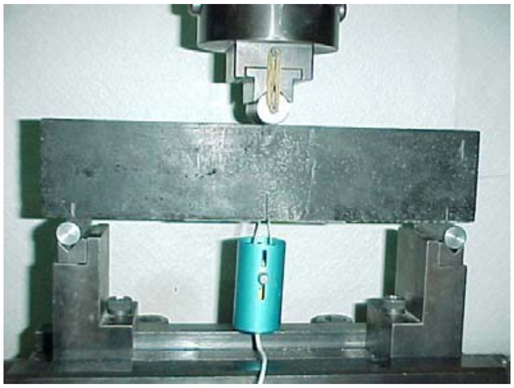

Fig. 2 – Test set-up apparatus

The Fracture Energy was determined according to RILEM recommendation [6]. RILEM, Réunion Internationale des Laboratoires et Experts des Matériaux, systèmes de construction et ouvrages, has been actively involved in developing test methods for the determination of fracture parameters necessary for the analysis of cracked structures. RILEM technical committee recommend a simple specific method for the determination of the Fracture Energy, G_f, in concrete. We use the same methodology to perform our calculations since Polymer Concrete has a very similar behaviour.

$$G_f = \frac{(W_0 + mg\delta_0)}{A_{lig}} \qquad (1)$$

Where
W_0 – Area under Load vs. Displacement diagram (Nm)
m – Corrected mass of the specimen and the attached equipment (kg)
δ_0 – Deflection (m)
A_{lig} – Area of the uncracked ligament (m^2)
g – Acceleration due to gravity (m^2/s)

4. RESULTS AND DISCUSSION

Fracture test results performed in the Polymer Concrete specimens made with fresh and recycled sand are presented in table 2.

Table 2 – Polymer Concrete Fracture Energy test results

Fracture Energy G_f (N/m)		
Specimen	Fresh Sand	Recycled Sand
1	8,206	9,989
2	8,575	9,525
3	8,738	9,043
4	9,361	8,356
5	9,205	8,535
6	9,019	9,037
Average	8,851	9,081
St Dev	0,429	0,608
COV	4,843	6,696
CI (95%)	0,44989056	0,63822986

Fig 3 represents the tests performed according to RILEM recommendation [6]. A comparison between Polymer Concrete made with Fresh sand and Polymer Concrete made with Recycled foundry sand.

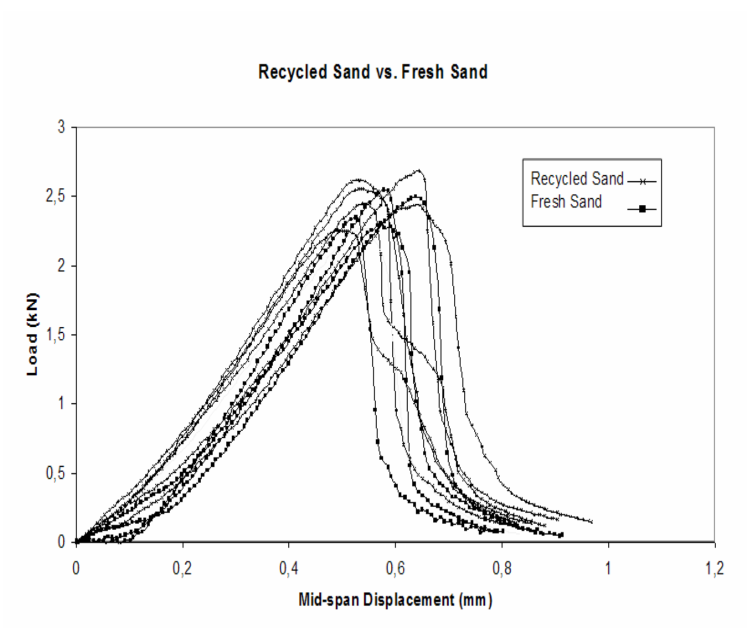

Fig. 3 – Load vs Mid-span Displacement of Polymer Concrete made with Fresh and Recycled sand

Flexural tests results performed in 3-point bending are presented in table 3.

Table 3 – Polymer Concrete flexural test results

Flexural Strength (MPa)		
Specimen	Fresh Sand	Recycled Sand
1	33,422	38,154
2	35,448	38,795
3	35,813	38,934
4	37,197	35,096
5	33,133	33,459
6	33,610	34,164
Average	34,771	36,434
St Dev	1,62974437	2,47291283
COV	4,68714677	6,78743881
CI (95%)	1,71059004	2,59558502

Fig 4 represents a comparison of results for fresh and recycled polymer concrete. 3-point bending tests were performed according to RILEM [7].

It is clear that recycled foundry sand influence as polymer concrete aggregate is positive. Results show that a slight increase is observed for both types of tests. In the Fracture Energy tests results an increase of 2,6% is observed and a 4,8% increase are reported from 3-point bending tests results. These results prove that recycled foundry sand can be used as aggregate with no prejudice to the composite itself.

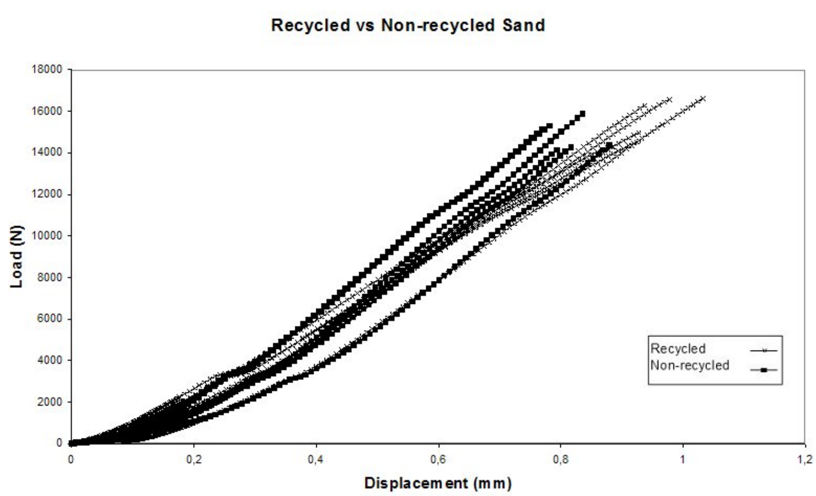

Fig. 4 – Load vs Displacement of Polymer Concrete made with Fresh and Recycled sand

5. CONCLUSIONS

The objective of this research was to analyse the influence of recycled foundry sand with phenolic binder in epoxy polymer concrete.

The results are reasonably consistent, showing good relation between specimens. The Statistics of the test results shows a low Covariance with a low Confidence Interval as well.

Long-term tests should be performed to verify the performance of recycled foundry sand as aggregate. Since the foundry industry uses acids in the composition of the moulds and the sand is impregnated with these acids, tests should be performed in the near future to analyse if this components affects the long-term performance or it is vanished from the composition.

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