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MECHANICAL BEHAVIOR OF DOUBLE-LAP JOINTS ADHESIVELY BONDED POLYMER CONCRETE

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Abstract. *This work presents an experimental investigation of mechanical behavior of composite. Double lap joints adhesively bonded polymer concrete specimens submetted to compressive loads are analyzed. These specimens are made with rectangular blocks of polymer concrete bonded with epoxi resin. The polymer concrete is a composite material in which the binder consists entirely of a synthetic organic polymer. The principal main of this test method is to determinate the compressive load and the shear strength of adhesives for bonding polymer concrete when tested on a standard double-lap joints as well as to study some important mechanical characteristcs such as failure models.*

Keywords*: polymer concrete, double lap joints, shear testing*

1. INTRODUCTION

Polymer Concrete was widely used from the middle of the last century produce building cladding [1]. In recent years, technical innovations in the construction industry have progressed considerably, and the research and development of high-performance and multifunctional construction materials have been actively pursued to cope with the innovations. In particular, this trend is marked in the new frontiers of the construction industry, i.e., superhigh- rise building, very deep underground space, ocean, and lunar base developments in advanced countries. Current development of construction materials should be ecologically safe and energy-saving from the viewpoint of global environment protection, apart from conventional development. A worldwide interest in concrete- polymer composites has become stronger [2].

Polymer Concrete is a concrete-like composite, in which resin binders, in this case epoxy resin, substitutes the cement binder. The composition of PC is determined by its applications, and is used very efficiently in precast components such as manholes, pipes and chemical vessel, also has important application including concrete repair and anti- corrosion protection, including industrial flooring [3,4]. It exhibits brittle failure behavior and therefore it is important to improve its post-peak stress-strain behavior [5].

Adhesively bonding is a well established joining method which has a long and successful track record, for example, in aircraft and aerospace structures. Design and fabrication procedures and procedures to assess stresses and resistance have been established such that reliable bonded joints can be obtained [6] Classical bonded joints are made by bringing two adherends together with an adhesive between them thereby creating a distinct (sometimes very thin) adhesive layer.

The inherent advantage of adhesive bonding is that stress can be distributed, rather than concentrated. Adhesive bonding is also attractive from the standpoint that reduction in weight can be achieved, smooth external surfaces can be obtained, and assembly costs, can be reduced since adhesive bonding is less costly than mechanical fastening on large areas bond. Disadvantages of adhesive bonding are that special adherend surface preparation is required, non- estructive inspection is difficult and the effects of thermal cycling and high humidity are not yet well understood.

A reliable prediction of stresses at locations where a high risk of crack initiation exists is thus a necessary step in designing mechanical structures. Simplified models [7] shows that in an adhesive joint, both shear and normal stresses reach their maximum value in the vicinity of the bond edges. These stress concentrations often lead to the joint failure. In an adhesive joint, three kinds of failure are possible. The first is adhesive failure, which occurs at the adherend/adhesive interface. The second is cohesive failure, which occurs in the adhesive. The last kind of failure is mixed: it starts out as an adhesive crack and hen quickly becomes a cohesive failure.

The objectives of this investigation are to study the mechanical behaviour of polymer concrete adhesively bonded and to analyze the adhesive and adherend failures.

2. MATERIALS USED

2.1 Adherend

To perform this research PC formulations were prepared by mixing aggregates with thermosetting resins. The aggregate used was foundry sand, which consists in quartz sand, designed by 40/50, used in the foundry industry, with a uniform granulometry.

The epoxy resin system used is based on a diglycidyl ether bisphenol A and an aliphatic amine hardener, it processed with a maximum mix ratio to hardener of 2:1 with low viscosity (500- 700 MPa s), which cluster the sand, giving high strength and cohesion. Epoxy resin produces a high performance polymer concrete, which results in durability, low permeability and fast cure. Resin content used was 12% by weight. Previous studied performed by the author showed the lowest binder concentration that would deliver an optimal cost/performance ratio [8,9].

2.2. Adhesive

The adhesive used is a two-component paste grade system based on a silicon steel alloy blended with high molecular weight reactive polymers and oligomers. Some important characteristics are the flexural modulus equal to 0.073 GPa, the compressive strength equal to 8.9 kPa and the flexural strength equal to 6.2 kPa.

3. DOUBLE-LAP JOINTS

The first analysis proposed by De Bruyne is a adaptation of Volkersen's single-lap joint theory for the double-lap joints. Tsai et. al. improved this model by including the adherend shear deformations.

Consider a double-lap joint with geometry and material characterizations, shown in Fig. 1. The length of the overlap is 2*c*. The thickness of the outer and inner adherends is equal to *t*. *E* and *G* are the elastic modulus and shear modulus for the adherends, and G_c and η are the corresponding adhesive shear modulus and thickness. *T* is the applied force *F* per unit width *w*.

The classical solution of the shear stress for a balanced double-lap joints proposed by Tsai *et al.* is given by

$$\tau_c(x) = A\sinh(\gamma x) + B\cosh(\gamma x) \tag{1}$$

where the constant coefficients are determined from the boundary conditions and are expressed as

$$B = \frac{\gamma c T}{\sinh(\gamma c)} \quad \text{and} \quad A = \frac{\gamma c T}{3\cosh(\gamma c)} \tag{2}$$

In addiction, the parameter γ is defined by

$$\gamma^2 = \frac{\frac{G_c}{\eta}\left(\frac{3}{Et}\right)}{\left[1 + \frac{G_c}{\eta}\left(\frac{t}{2G}\right)\right]} \tag{3}$$

and the average shear stress along the entire bonded line is $\tau_c = \frac{T}{4c}$

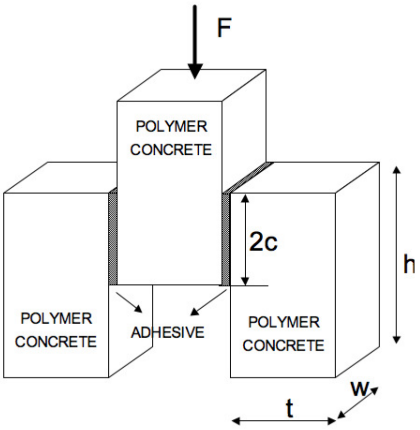

Figure1. Geometry configurations of double-lap joints with polymer concrete and epoxi.

In order to obtain the experimental results, the geometry model for the double lap joint, schematically illustrated in Fig. 1, was made of polymer concrete bonded with epoxy resin, for this was considered the following data: adherend (polymer concrete) with dimensions thw = 30x60x30 mm^3; adhesive (epoxy resin) thickness equal to 3 mm. The material proprieties of adherends and adhesive are shown in Tab.1.

Table1. Material Proprieties of adherend and adhesive.

Propriety	**Epoxy PC**	**Polyester PC**	**ARC 858**	**Belzona**
Modulus of elasticity, E (GPa)	13.7	16.7	6.8	7.3
Flexural Strength (MPa)	24.7	13.0	60.7	62.0
Compressive Strength (MPa)	51.9	31.8	89.6	89.6
Hardness (Shore D Durometer)	-	-	88	89
Tensile Shear Adhesion (MPa)	-	-	14.5	18.6

4. EXPERIMENTAL SETUP

The experimental test of double-lap joints subjected to compressive load was performed using a tensile testing machine. The polymer concrete test specimen fixed to wedge grip assembly is illustrated in Fig 2. In order to obtain the mechanical behavior of polymer concrete bonded, the tests were carried out considering a load velocity equal to 5mm/mim.

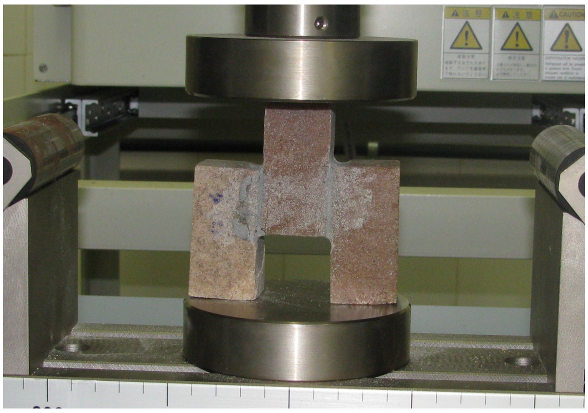

Figure2. Experimental arrangement of the polymer concrete specimen under compressive force

The tested specimens of polymer concrete are illustrated in Fig 3. It is possible to observe the failure model.

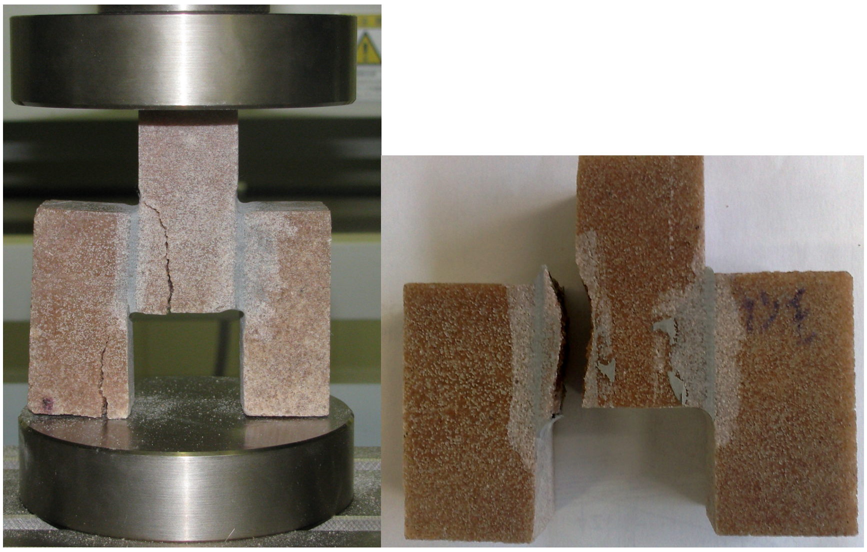

Figure3. Cohesive failure.

There are two types of information that can be obtained from this test. The first is qualitative, deriving from an analysis of the resulting fracture illustrated in Fig 3. Some idea of the integrity of the polymer concrete joints can be obtained by noting whether failure tends to be mainly cohesive in the polymer concrete itself, as shown in Fig 3. It has been hypothesized that, in this cases, the failure mode in the double-lap joints test experiment is determined by a preexisting distribution of flaws in the sample. A second one is the quantitative information derived from the double-lap joints test.

Tests were made with Exopy PC with Belzona 1111, Polyester PC with Belzona 1111 and Polyester PC with ARC 858, and the result of these experiments are show in table 2. The average are respectively 8.65, 2.47 and 2.78 MPa and the variance are respectively 1.19, 0.48 and 0.09.

Table2. Tests and results.

	Epoxy PC with Belzona 1111	**Polyester PC with Belzona 1111**	**Polyester PC with ARC 858**
Tests	**Load (kN)**	**Load (kN)**	**Load (kN)**
1	8,45197	1,64863	2,82261
2	8,67947	2,88863	3,15471
3	8,64250	2,57382	2,64670
4	7,20002	3,32721	2,93033
5	10,26750	1,88675	2,34324
Average	8,65	2,47	2,78
Variance	1,19	0,48	0,09

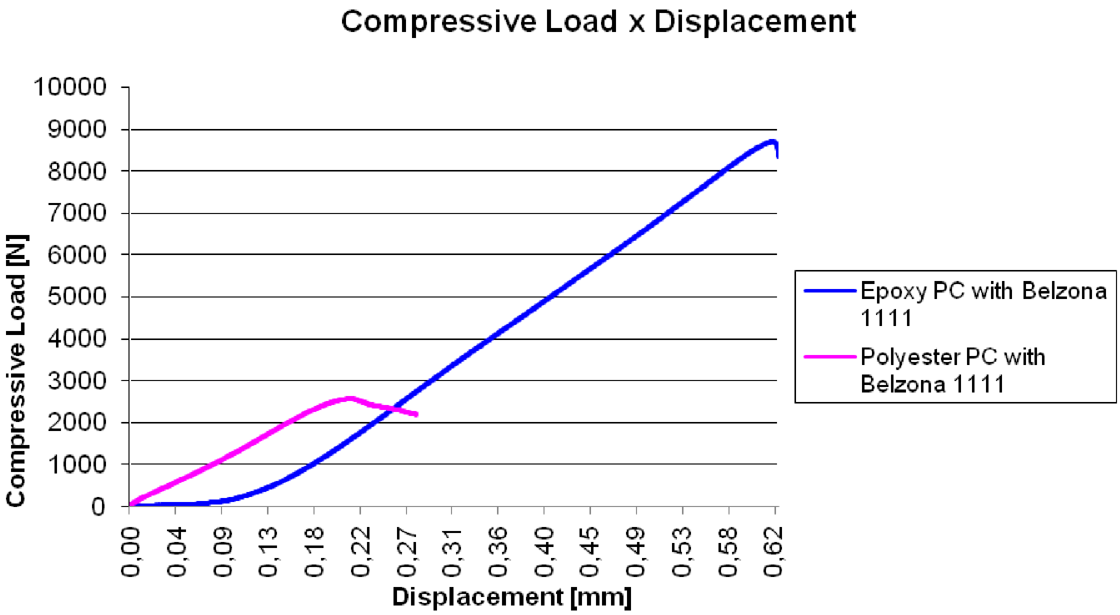

Figure4. Compressive load versus displacement in the double-lap joints test.

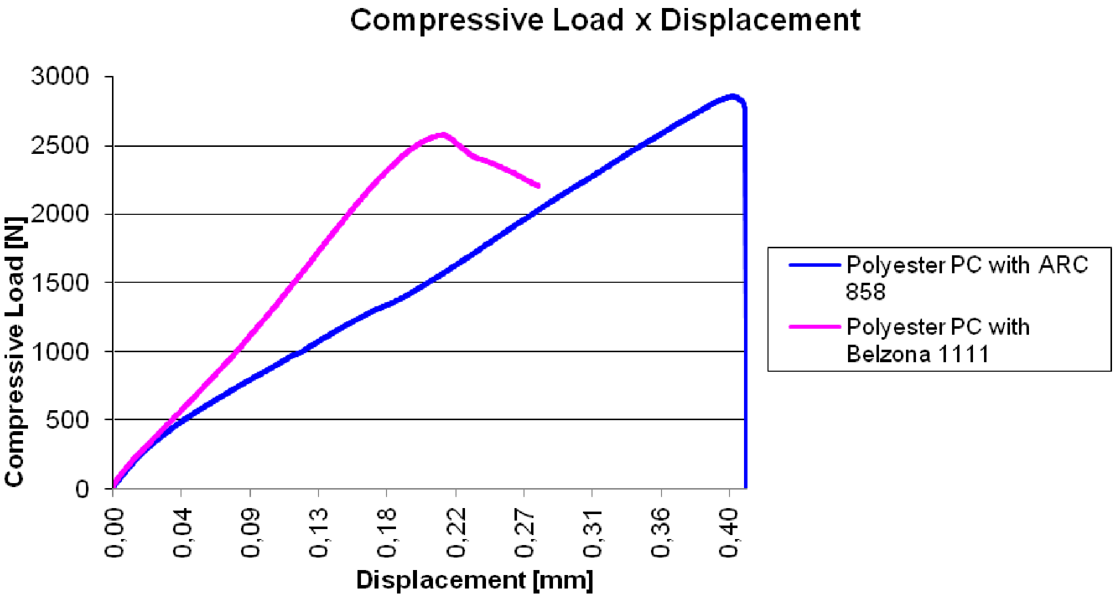

Figure5. Compressive load versus displacement in the double-lap joints test.

Figure 4 show a line chart comparative Epoxy PC and Polyester PC with Belzona 1111 and the figure 5 show a line chart comparative Polyester PC with Belzona 1111 and ARC 858. Both charts present experimental results of compressive load versus displacement obtained by means a simple compressive test in the double-lap joints concrete specimens. The failure are observed in the tests, where occur cohesive failure the maximum compressive load for Polyester with Belzona 1111 is 2.57 kN or 30% of the Epoxy with Belzona 1111 (8.68 kN) and the Polyester with ARC 858 is 2.85 kN, and this result as expected because the materials propriety.

5. CONCLUTIONS

This study was designed to analyze the mechanical behaviour of polymer concrete adhesively bonded. The experimental results present qualitative and quantitative information. It was possible to observe that the polymer concrete specimens present one type of failure. In addiction, using the information of maximum compressive load was determinate the tensile shear in bonded joint.

For the next step the authors aim to continue to compare the polymer concrete adhesively bonded with metal adhesively bonded and finalize with a theorical analisys adding an experimental methodology to obtain the full-field displacements.

This next step will be completed until the date of the congress.

6. ACKNOWLEDGEMENTS

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8. RESPONSIBILITY NOTICE

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