STATIC FLEXURAL STRENGTH CHARACTERIZATION OF POLYMER CONCRETE

Delfim Ferreira Monteiro
ISMAG - Institute Superior of Mathematics and Management of Fundão, 6200 - Fundão - Portugal
rafm@ismagf.pt

Eurico Augusto R. Seabra
Mechanical Engineering Department - University of Minho - Campus de Azurém - 4800-058 Guimarães - Portugal
eseabra@dem.uminho.pt

Abstract. *The polymer concrete is a composite material that results from combination of a mineral aggregate such as a silica sand or gravel with a polymer resin bond.*
The resins more frequently used are the polyester, epoxy, vinyl ester or acrylic and the advantages of the resin concretes, comparatively to the traditional cement concretes, are their high resistance, good durability, low permeability and very fast times of cure.
The typical versatility in the formulation and processing of the concrete polymeric results in a very large applications, namely in coverings of highways pavements, coverings of bridges boards, pavements of buildings mainly in the industrial ones and pre-moulded components of several classes.
Therefore, for the application in large scale of this new family of construction materials it is necessary to prior carry out a better characterization of the behaviour of these materials, namely concerning with their normalization and tests specifications.
This paper presents and discusses the results of several flexural experimental tests performed in four points in specimen's of polymeric epoxy concretes with foundry sand, with the purpose of to obtain the influence of the proportion of resin on the rupture strength to the tension, to the compression and to the flexing, on the elasticity modulus and on the Poisson's ratio. The mechanical and static characterization of these properties, in these new formulations is of crucial importance to study the fracture toughness and to parametric analysis of the fracture behaviour of the polymer concrete.

Keywords: *Polymer concrete / Composite materials / Flexural tests / Fracture mechanics*

1. Introduction

It is well known that the concrete polymer is a composite material made with a mineral aggregate, for instance silica sand, and a polymer resin bond. The versatility and processing on its formulation are fundamental characteristics on the wide variety of applications, namely in highways coverings, bridges boards covering, building pavements, just to mention a few (Fontana and Bartholomew, 1981, Fowler, 1987, Fowler, 1990 and ACI, 1986).

The main thermosetting resins used are the polyester, epoxy, vinyl ester or acrylic, being the advantages of resin concretes, when compared to the traditional cement concrete, the high resistance, durability, low permeability and very short cure times.

The polymer concrete is, therefore, a material with high resistance that is easy to apply, being its application in mortars of fine aggregates (Czarnecki, 1985). This new family of materials of construction requires the necessity to best characterize its behaviour, standardization and test procedures (Fowler, 1990).

Thus, the present experimental procedure has the main goal to characterize the static mechanical behaviour of concrete polymer which is based on epoxy resin, foundry sand, without load and optimized mixture. For that, an Instron facility machine was used to perform flexural tests using standard specimens. The static flexural strength curves versus deformation were obtained. The diagrams that relate the relation between deformation and time were also obtained in traction and compression zones of specimens. The specimens were adequately instrumented in order to acquire the data produced in a continuous form. The experimental program allows to quantify the traction and compression tensions, the respective elasticity modulus and the Poisson coefficients of the polymer concrete, which constitutes a new formulation. The determination of these mechanical properties is of primordial importance in the studies of fracture tenacity, as well as on the establishment of models to predict the fracture behaviour, based on finite elements method. A hybrid approach is also possible, that is to combine the finite element methodology together with experimental methods.

2. Experimental procedure

2.1. Material properties

The formulation of the polymer concrete and its components percentage are listed in Tab. 1. The epoxy resin selected is the EPOSIL 551, which has low viscosity (500 – 600 mPa.s), being its flexural strength equal to 70 MPa.

Table 1. Polymer concrete formulations.

Resin	Epoxy type - EPOSIL 551
Sand	Foundry type
Composition (Resin + hardener)	14%
	16%
	18%
	20%
Hardener	EPOSIL 551
Charge composition	0%

The foundry sand used in the present work has a uniform mesh, being D_{50} of 342µm, which corresponds to half of the sand particles having a diameter equal to 342µm. The foundry sand has silicate sand designated by SP55, which is used in foundry industry with average diameter 245µm. The resin EPOXIL 551 allows agglomerating the foundry sand resulting in aggregates with high stiffness and cohesion. In Tab. 2 the main characteristics of the mixture resin with catalyzing agent or hardener are presented.

Table 2. Main characteristics of the mixture.

Mixture characteristics	*Resin + hardener*
Mixture composition [g]	100 + 50
Viscosity [mPa.s]	500-700 + 300-400
Useful time of the mixture to 25°C [min]	27
Hardening time [h]	6

2.2. Specimens and instrumentation

In this work a total of 12 specimens were used, being three specimens for each percentage of resin and referenced with letter R (R14, R16, R18 e R20) when the data obtained for static flexural strengths curve, i.e., load versus displacement. When the data is relative to deformation versus time, the letter E is used as reference (E14, E16, E18 e E20), being this procedure used to quantify the traction and compression tension, elasticity modulus and Poisson's coefficients. It should be noted that both procedures are obtained at the same time.

In order to prepare the concrete polymer beams used in this work, a mixture of Resin 551/Hardener 551 in a proportion 2:1 was added to dry sand, which was introduced in an oven at 80°C during 30 minutes. This procedure was repeated for all different percentages mentioned above. After that, a mixer machine was used to promote the mixture, during 2 minutes. Finally, the obtained mixture was put in prismatic moulds. The specimens were prepared according to standard RILEM PC-2 (1995) and have a prismatic configuration with the following dimensions 160mm x 40mm x 40mm.

After 24 hours, the beams were desmolded and subjected to a thermal treatment of cure at 60°C during 7 hours, in order to improve their characteristics. The surface of the specimens was prepared to facilitate the assembly of the strain gages. As it is known, the concrete polymer, similarly to the traditional concretes, presents rugose and porous surfaces, and then it is necessary to apply an adequate substrate in order to facilitate the assembly of strain gages. For that purpose, a layer of adhesive epoxy was applied to the specimen's surface.

Thus the initial preparation of the zones to adhesive attaches the strain gages was carried out based on the following steps (Measurements Group, Inc., 1999a, 1999b and 1999c):

1- Water washes with a brush and detergent, followed by water passage and cleaner with paper. This operation is the degreasing phase.
2- Grinding with a wet silicon carbide paper TG5-3M-400 in order to remove irregularities of the surfaces using M-Prep-Neutrir 5A, which has the function to reduce the acidity surface.
3- Simple water distilled passage to remove the residual marks due to cleaner process, and dry in an oven.

The next phase consists of an application of an epoxy adhesive M-bond AE 10, composed by a proportional mixture of cure agent M-bond 10 plus Resin M-bond AE.

The adhesive was applied with a round rod made with glass, being manipulated with the purpose of cover the concrete surface pores. The specimens were, then, introduced in a Venticell oven during 3 hours at 80°C, in order to cure the adhesive. After this process, in the zones where the adhesive was drop, a new grinding procedure was performed. The sandpaper calibre is a NBR220 until the concrete is visible, followed by a new grinding using a wet silicon carbide paper TG5-3M-400. Finally, the conditioning A was used then the neutral 5A was employed, being the cleanness process performed with paper.

After these procedures, several strain gages were put at middle distance of the specimens, followed by welding the strain gages cables.

2.3. Test scenarios

The specimens were subject to flexural tests in four points according to the standard RILEM PC-7 (1995). Figure 1 shows the experimental setup, where the strain gages and cables are visible. The transmission cables were connected to the Spider 8 and to the computer in order to obtain the data results in a continuous manner during the tests. The distance (L) between support points is 120 mm, being L/3 the distance where the loads are applied at the middle of the two semi-circles.

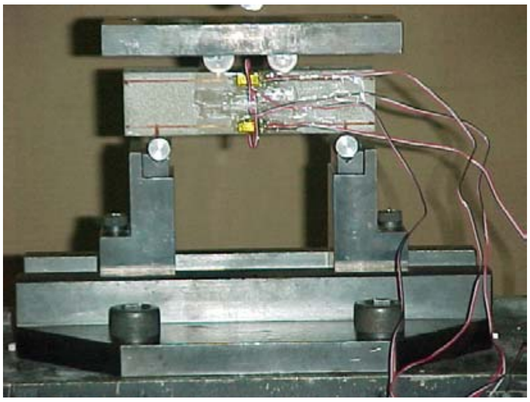

Figure 1. Experimental setup.

An Instron machine with a cell load capacity of 100kN and a load velocity of 1 mm/min was used, being the laboratory temperature around 20°C. In Fig. 2 it is illustrated the Spider 8, the laptop, the machine panel as well as the connection accessories and cables used in the tests performed.

Figure 2. Overall view of the acquisition system used.

3. Results and discussion

With the data obtained from the flexural tests it was possible to build the diagrams for load versus displacement and for the extension versus time, both in tension and compression. By observing Tab. 3 it can be concluded that the maximum flexural strength rupture is reached for composition of 18% resin. The same conclusion can be observed in Fig. 3 where the variation of the load rupture as function of resin percentage is shown.

Table 3. Average values of load rupture.

Specimens	*Rupture load [kN]*
R14	15,5
R16	18,3
R18	19,3
R20	18,8

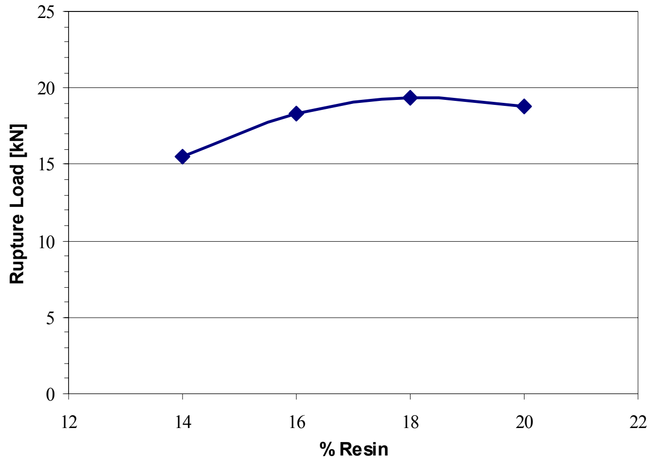

Figure 3. Rupture load as function of resin percentage.

In Fig. 4 the curves of load versus displacement for three specimens tested 18% of resin and hardener are illustrated, being the best results for the strength. For the same composition, Fig. 5 shows the deformation versus time curves corresponding to the specimen concrete R18-1.

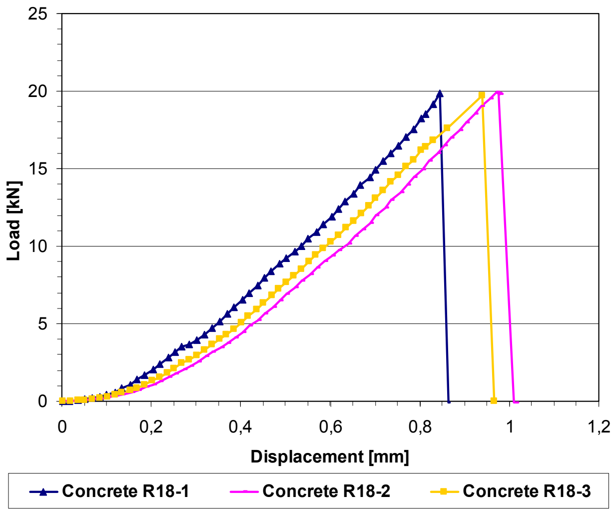

Figure 4. Load versus displacement for concrete specimens with 18% of resin.

Table 4 shows the mechanical properties of the concrete polymer, which represent the average results obtained from experimental tests.

Table 4. Main mechanical properties of the polymer concrete.

Mechanical properties	*%Resin in the concrete*			
	14	16	18	20
Flexure strength [MPa]	30,0	32,8	36,5	35,7
Poisson coefficient	0,28	0,33	0,35	0,34
Compression elasticity modulus [GPa]	9,8	10,4	12,0	11,2
Compression strength [MPa]	44,3	52,0	81,8	78,7
Traction strength [MPa]	5,6	7,0	10,9	10,6

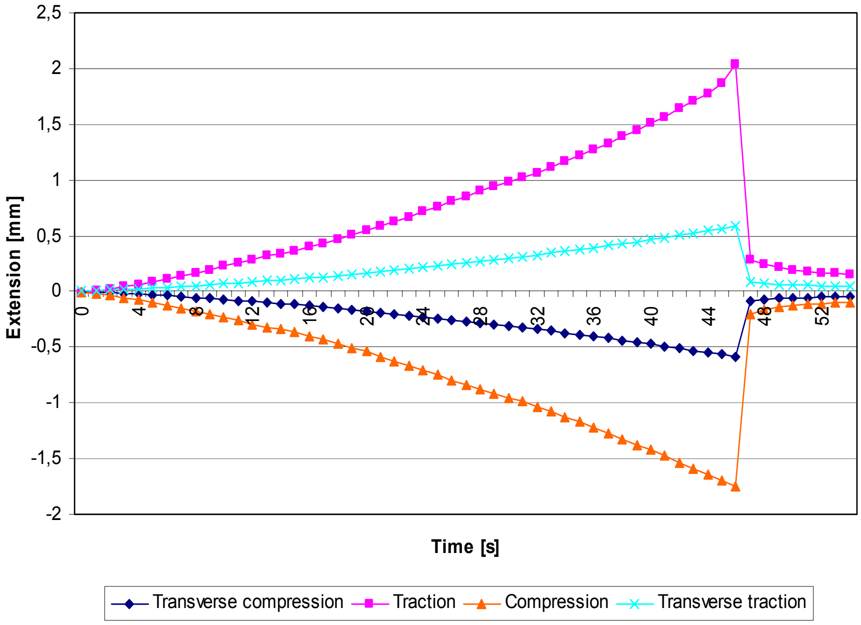

Figure 5. Extension versus time curves for the polymer concrete speciment R18-1.

Figure 6 shows the variation of the mechanical properties of the flexural strength as well as the tension and compression strength with resin percentage. The strength increases with the resin percentage up to 18%, verifying a lightly decrease above this value. The same conclusion can be drawn for elasticity modulus and Poisson coefficient.

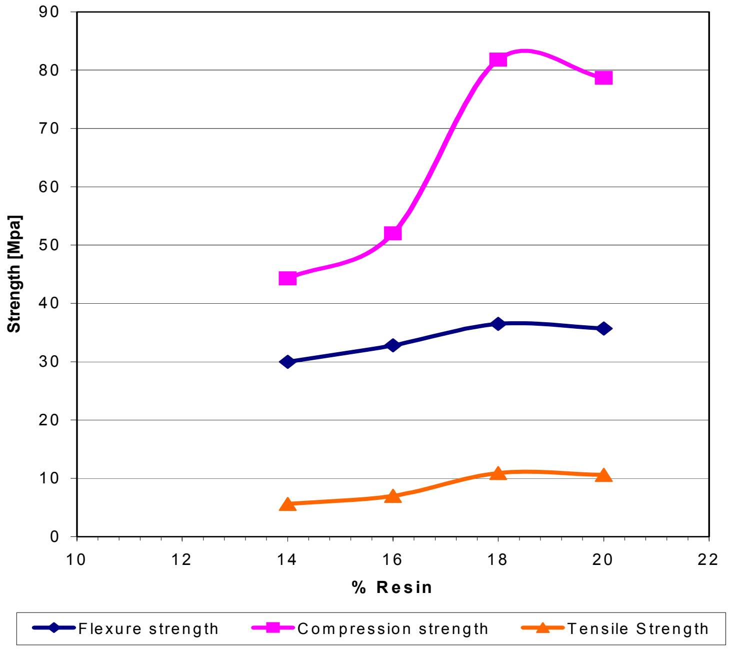

Figure 6. Main mechanical strengths of the polymer concrete.

Table 5 presents the mechanical properties obtained in the present work, as well as the results published in the best literature (Paul, 1988 and Tavares *et al*. 2001) for cement concrete and polymer concrete.

The properties of the cement concrete strength are affected by cure conditions, humidity, temperature, relations between water and cement, agglomerate characteristics, type of cement, its composition, among others.

By analysing Tab. 5 it can be observed that the polymer concrete flexural strength with 18% of resin is about 5 times greater than that for cement concrete. It can be said that among the concrete tested the one that presents best static flexural strength is the one with 18% of resin and hardener. The same observation can be concluded about the mechanical properties present in Tab. 4. In addition, then is a save of 2% of resin when compared with the specimens R20.

Table 5. Mechanical properties comparative table between cement concrete and polymer concrete.

Concrete types	*Compression strength* [MPa]	*Tensile strength* [MPa]	*Compression elastic modulus* [GPa]	*Flexural strength* [MPa]
Cement concrete (Portland)	5 to 60	0,6 to 4,2	------	1,1 to 7,2
Polymer concrete	82	10,9	12	36,5

4. Conclusions

From the work presented in this paper some conclusions can be drawn, namely:

(i) the specimens with best mechanical properties are those with 18% of resin, which corresponds to a new and optimized formulation;

(ii) the mechanical behaviour is essentially linear elastic with fragile rupture. This situation is likely due to the presence of the thermosetting resin and owing to the three-dimensional set resulting from the reaction from monomer and cure agent;

(iii) since the polymerization is well done, this behaviour is adequate to study and characterization of rupture linear elasticity tenacity;

(iv) the compression strength is about 5-6 times greater than traction strength, being necessary to reinforce the concrete in the traction zone;

(v) the values of the strength properties of cement concrete are much lesser than those of polymer concrete, independently of the method of integrity evaluation used to quantified the strength.

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6. Responsibility notice