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Structural analysis of FRP reinforced polymer concrete material

J. Tomás San-José [a,b,*], Iñigo Vegas [a], Find Meyer [c]

[a] LABEIN, c/Geldo – Parque Tecnológico de Bizkaia, Edif. 700, 48160 Derio, Vizcaya, Spain
[b] UPV-EHU Basque Country University, ESI de Bilbao, Alda. Urquijo s/n, 48013 Bilbao, Spain
[c] Carl Bro a|s, DK-5230 Odense M, Denmark

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Abstract

The paper deals with a study of precast elements made of polyester polymer concrete (PPC) reinforced with glass fibre rebars (GFRP). The paper describes the properties of the materials, which were tested on a microscopic scale using different experimental techniques such as porosimetry, scanning electron microscopy and petrography. Likewise, characterisation in a macro-scale was carried out to define the mechanical properties of the material (modulus of elasticity, stress–strain curve, ultimate strength and bond). Based on the latter properties, a relatively simple method is presented to estimate the ultimate bearing capacity of beams under bending load. The calculation method has been verified by testing beams and full-scale elements.

Keywords: Bearing capacity; GFRP; Polymer concrete

1. Introduction

The PPC studied in the present paper is a construction material comprising three phases: inorganic (aggregates), organic (thermosetting polyester resin) and inert (air porosity due to fabrication process). Most of its current applications in Europe relate to precast building elements and some structural components in civil works such as slabs and façade panels.

Service conditions often dictate specific material requirements that may be met by PPC when several composite properties are simultaneously considered. However, since the material cost of PPC tends to be high, optimization of its properties is necessary in order to keep the costs as low as possible while still meeting specific material requirements. Nowadays, important research activities [1] are being developed in the cost reduction topic of the polymer concrete, by acting in controlling the material structure to obtain specific material properties in every application.

The aim of this paper is to establish several basic properties of PPC based on isophthalic and orthophthalic resins and a relative simple guide to calculate the ultimate bending capacity of orthophthalic PPC reinforced with metallic and non-metallic Fibre Reinforced Polymer (FRP) bars. This research is part of an European project [2] investigating the development of new reinforcing materials for highly durability precast concretes. The work presented in this paper has been undertaken at LABEIN (Spain) and CARLBRO (Denmark).

2. PPC material aspects

Polymer concrete is produced by mixing well graded inorganic aggregates with a resin binder. The most common binder used is unsaturated polyester because of its good properties and relatively low cost. Polymer concrete is strong and durable, presents low permeability,

* Corresponding author.
E-mail address: tomas@labein.es (J.T. San-José).

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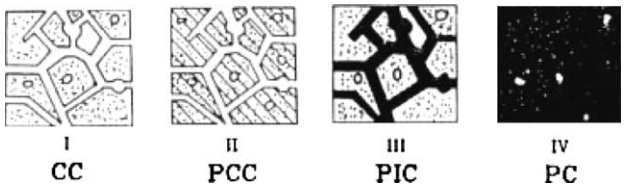

Fig. 1. Scheme of pore structure of hardened paste in different concretes.

and cures rapidly. A disadvantage of polymer concrete is the high cost of the resin binder (the cost of the filler is comparatively negligible).

The intention of the study here presented is to establish a general framework for the most important properties of the PPC. A macro and micro study scale level has developed with regard to present specific performances of this material in comparison with traditional cement-concrete (CC) by using two different PPC types, not comparable between them because of their different dosage and mixing procedures.

The two selected PPCs in this paper comprised the majority of the PPCs used in construction because of their similar: resin contents, dosages and casting procedures that the majority of the precast PPCs applied in construction sector nowadays. Within the field of polymers technology, in association with concrete, three kinds of materials can be distinguished (Fig. 1):

- Polymer Cement Concrete (PCC). A concrete modified with resins or polymers can be said to be a system where the binder matrix consists of cement and polymer, either the latter acting as a modifier of the former or as co-matrix. The addition of the polymer always takes place while mixing.
- Polymer Impregnated Concrete (PIC). The CC is impregnated by a polymer by means of introducing a monomer or a prepolymer within the pore networks of the concrete once it has been hardened and after "in situ" polymerization has taken place, which results in closing the opened porosity from CC.
- Polymer concrete (PC) uses the resin as the only binder.

2.1. PPC components and its dosage

In practice, PPC can be regarded as a triphasic system consisting of a dispersed phase, the aggregate, a continuous one formed of the polymer and a certain degree of porosity imposed by the manufacturing process. The properties of each of the concrete-polymer composites will be given by the properties of each one of the components as a function of their volumetric percentage and by interphase and superficial phenomena.

It is desirable to get the mix proportion for polymer concrete by repeated experiments because it does not depend merely on the object of usage, type of binder, shape and grading of aggregate, and the standard method as in the case of the cement concrete is not established. Normally, it is used as binder a polymer resin that is cured at environmental temperature. The most commonly used are epoxy, unsaturated polyester and methacrylate resins, despite the fact that there are other resins less widely used, such as polyurethane, furanic resins, phenolic and vynilester. The characteristics of the material will mainly rely on these two components properties and these can be controlled in order to obtain a "custom made" material. The main problems arises from the viscoelastic properties of the polymer, which result in creep and sensitivity to temperature.

The manufacturing process of structural polymer concrete elements requires well equipped plants so as to achieve continuous manufacturing, thus benefiting from a short curing period. After 3 h the strength can be in the range of 90% and the hardening period finishes after 24 h. PPC has commonly used aggregates from siliceous, ophitic, limestone or from basaltic rocks. Optimum polyester resin and filler contents have been defined depending on the best mechanical properties. The dosage study and mixing procedure has been performed studying the influence of the percentage of resin and fillers on two PC aspects: strengths (compression and bending) and superficial aspect (aesthetic and durability requirements), as presented in a previous publication of authors [3].

The dosage of the PPCs here analysed is based in quartz aggregates such as is presented in Table 1. Both type U and type G have been made of polyester resin but with two different thermosetting resin types; namely, isophthalic and orthophthalic. The PPC type U (isophthalic PPC) and G (orthophthalic PPC) have been obtained in different industrial plants. Due to this aspect, the casting process has produced two different materials, not only from a chemical point of view but also from a different internal structure.

Therefore, it seems very interesting to analyse the internal structure of the PPC (distribution of aggregates and air in the resin matrix), in relation to the macroscopic response based on the fundamental mechanical

Table 1
Polyester polymer concrete components dosage

Components	Orthophthalic PPC (%)	Isophthalic PPC (%)
Polyester resin content	12.3	10.7
TiO_2 colour additive	–	2.5[a]
Carbonate filler	–	22.3
Chalk	7	–
Quartz powder	6.7	–
Quartz fine sand	24.7	51.8
Quartz sand	–	15.2
Quartz gravel	49.3	–

[a] With regards to resin content.