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Epoxy resin and ground tyre rubber replacement for cement in concrete: Compressive behaviour and durability properties

M.A. Fernández-Ruiz [a,*], L.M. Gil-Martín [a], J.F. Carbonell-Márquez [b], E. Hernández-Montes [a]

[a] Department of Structural Mechanics, University of Granada (UGR), Campus Universitario de Fuentenueva s/n, 18072 Granada, Spain
[b] Departamento de Mecánica, Universidad de Córdoba, Campus de Rabanales, Edificio Leonardo da Vinci, E-14071 Córdoba, Spain

HIGHLIGHTS

- The introduction of polymers in concrete is gaining more traction in civil engineering.
- Concrete with ground tyre rubber presents a flatter post-peak branch in the stress-strain.
- Concrete mixtures with epoxy without hardener has shown the highest durability.

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ABSTRACT

In this research, the compressive behavior of concrete mixtures incorporating epoxy resin with and without hardener and ground rubber (tyre powder) as cement replacement was investigated. Various experimental mixes were produced varying the polymer/cement mass ratio. A general design criteria was adopted in the design of the mixtures in order to have a fair comparison between polymer-cement and traditional concretes. Concrete mixes were characterized through mechanical and durability tests. Mechanical tests included compressive and flexural strength. Durability was evaluated through the study of chloride ingress into the concrete matrix. Results indicate that the use of polymer-cement concrete modifies the post-peak slope of the stress-strain curve, showing a better ductility, having a special interest in earthquake engineering.

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1. Introduction

Ordinary cement concrete is the most widely used construction material in the world due to its low cost and its relatively good strength in compression. However, it presents some drawbacks: its unfriendliness to the environment [1], its porosity (allowing the ingress of deleterious substances such as chlorides and carbon dioxide [2]) which compromises its durability and its low tensile strength and strain ranges [3] which, due to its brittle behaviour, lead to low ductility. Current seismic design is based on the structural performance which forces us to find a balance between structural ductility and structural strength. Concrete with enhanced properties of ductility constitutes a feasible strategy in seismic design. In addition to this, the durability of Reinforced Concrete (RC) structures is becoming an important part of structural design [4]. In this context, the introduction of polymers in ordinary cement concrete is gaining more traction in the field of civil engineering.

Polymer-Modified Concrete (PMC) is made by the mixing ordinary cement concrete with polymer additives such as liquid resins, polymer powders, latexes, water-soluble polymers, etc. The incorporation of these polymers improves bond, strength, impermeability, chemical resistance and durability properties of concrete and mortars [5,6]. PMC has typically been used in repair works [7] and non-structural products (waterproofing and anticorrosive finishes) [8]. However, in modern concrete construction the use of PMC for structural applications is increasing day by day [9,10].

Polymer Cement Concrete (PCC) is a type of PMC in which a certain percentage of cement is replaced by polymer. One of the polymers suitable for admixing into mortars and PCC is epoxy resin [5,9]. In general, epoxy resin consists of a resin and a hardener which are mixed before use. Mechanical and durability properties of epoxy-modified concrete [9] and structural behaviour of RC members made with epoxy-modified concrete [11,12] have been studied in the literature. Furthermore, mechanical properties of

* Corresponding author.
E-mail addresses: malejandrofr@ugr.es (M.A. Fernández-Ruiz), mlgil@ugr.es (L.M. Gil-Martín), jcarbonell@uco.es (J.F. Carbonell-Márquez), emontes@ugr.es (E. Hernández-Montes).

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epoxy-modified mortars with and without hardener have also been considered in research [5]. However, little attention has been paid to the effect of partial substitution of cement by epoxy resin (with and without hardener) in concrete ductility and durability properties.

Ground Tyre Rubber (GTR) is another polymer suitable to be used in PCC [13]. The growth of the automobile industry in the last years has boosted tyre production, generating massive stockpiles of used tyres. These tyres are non-degradable in nature at ambient conditions and, for this reason, new applications for the reuse of scrap tyre rubber are needed. Numerous studies have investigated the introduction of tyre rubber in concrete to replace fractions of its mineral aggregates, the so-called Crumb Rubber Concrete (CRC) [14–16]. However, the works focusing on concrete mixes in which cement is partially replaced by tyre-rubber powder are limited [13].

In this work, the compressive and flexural behaviour of epoxy-modified concrete (with and without hardener) and concrete incorporating ground tyre rubber as partial cement replacement is studied in comparison with traditional concrete. Here, cement replacement is expressed in terms of polymer/cement mass ratio (*p/c*). Cement is partially replaced by epoxy (*p/c* of 10%, 15% and 20%, with and without hardener) and ground tyre powder (*p/c* 2.5%, 5% and 10%). The ability of each mixture to absorb energy during deformation is analysed through the measurement of its toughness (estimated as the area under the stress-strain curve). Chloride ingress into the concrete matrix is evaluated using an $AgNO_3$-based colorimetric test for each studied mixture, with the objective of improving the knowledge of its durability.

2. Materials and experimental methods

2.1. Materials used

The aggregates used in this work were siliceous crushed sand (0–4 mm) and gravel (4–16 mm). Grain size distributions for sand and gravel are shown in Fig. 1. The cement was Ordinary Portland cement CEM I 32.5 R with a relative density of 3 kg/dm^3.

Bisphenol A (epichlorhydrin)-type epoxy resin was used. In this work, the term "Component A" is used to refer to the resin itself and the term "Component B" to the hardener. Both components were stored at room temperature to avoid damage. The properties of components A and B are listed in Table 1. The epoxy resin was supplied by Sika [18].

The ground rubber is a commercial product whose use is widespread. In the sector of civil engineering it has been used in hot mix asphalt mixture with the aim of constructing sustainable flexible road pavement. Ground rubber used in this work was obtained from crumb tyre rubber by grinding it to powder by a mechanical trituration process. Grain size distributions for ground tyre powder used for replacement of cement are shown in Fig. 2. As can be seen from Fig. 2, the particles of ground rubber are generally between 63 µm and 0.6 mm. The apparent and relative densities of the ground tyre rubber are 0.4 kg/dm^3 and 0.5 kg/dm^3, respectively. More information about its chemical composition can be seen in [19]. In order to enhance the hydrophilicity of the rubber surface, rubber powder was surface-treated with NaOH saturated aqueous solution for 20 min as suggested in [20,21].

2.2. Mixture proportions and mixing procedure

Four types of mixtures have been studied: traditional concrete, hardener-free epoxy-modified concrete, epoxy-modified concrete with hardener and ground tyre rubber concrete. In order to have a fair comparison between the different kinds of PCC considered herein and traditional concrete, the following design criteria was adopted (as shown in [22]):

- The aggregate content (by weight and volume) of PCC mixes was the same as in the traditional concrete.
- The water/cement ratio (*w/c*) of PCC mixtures was the same as in traditional concrete.
- The volume ratio (water + polymer + cement) to aggregate in PCC mixtures was the same as in traditional mixture.

Details of all the mixture proportions considered in this work are given in Table 2. The first mixture corresponds to the ordinary cement concrete, shown as T (Traditional). The design compressive strength for the traditional concrete was 30 MPa. In the hardener-free epoxy-modified concrete mixtures, cement was replaced by epoxy resin without hardener with *p/c* 10%, 15% and 20%. These mixtures were shown as EA-*x* (only component A, where *x* is the *p/c* percentage). In the epoxy-modified concrete with hardener mixtures, cement was replaced by epoxy resin with hardener with *p/c* 10%, 15% and 20%. These mixtures were shown as EA+B-*x*

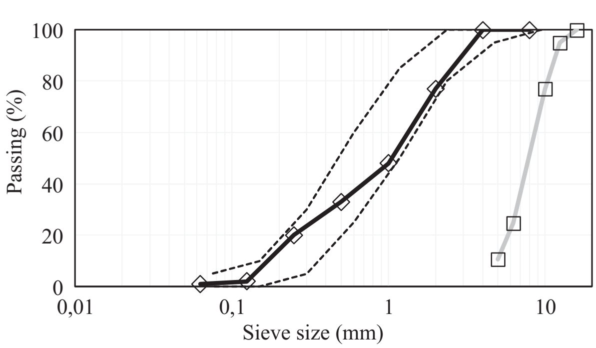

Fig. 1. Sand grading (black thick line) with higher and lower boundaries (dashed black lines) proposed in [17] and gravel grading (grey thick line).

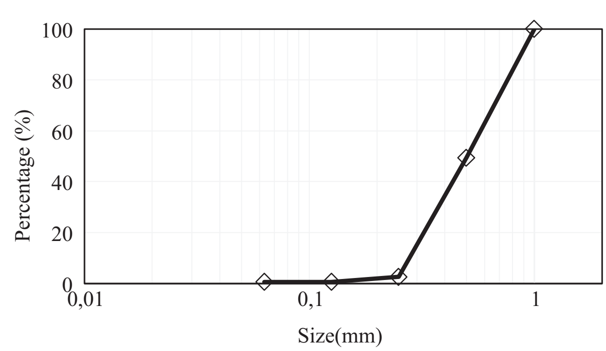

Fig. 2. Tyre rubber powder grading. Adapted from [19].

Table 1
Properties of epoxy resin (components A and B) obtained from data sheet of Sikafloor® 161.

Component	Solid content (% in weight)	Density (kg/l, 23°)	Kinematic viscosity (mm^2/s, 40°)	Flash point (°C)
A	~100%	1.6	20.5	ca. 89
B		1.03	ca. >20.5	>93.33

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