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Polymer-cementitious composites containing recycled rubber particles

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HIGHLIGHTS

- Epoxy polymer contributes to cement hydration.
- Higher coarse rubber particle amount lead to reduced mechanical performance.
- Finer rubber combined with epoxy polymer achieves superior strength and stiffness.
- Epoxy polymer enhances the adhesion between cement and rubber aggregates.

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ABSTRACT

Waste from scrap tires is one of the most environmentally harmful waste since it leads to significant soil and air pollution. This work investigates the effect of recycled rubber particles incorporation into cementitious composites modified with epoxy polymer. A Design of Experiment (DoE) was conducted to identify the effect of epoxy polymer inclusion (35 and 50 wt%), rubber inclusion (10, 15 and 20 wt%) and rubber particle size (coarse and fine particles) factors on the bulk density, mechanical strength and stiffness of the composites. Third-order interaction effects were obtained, except for density which was affected by two second-order interactions. Larger epoxy polymer and rubber amounts decreased the bulk density of the composites. Epoxy polymer contributes to cement hydration, even without water content. Higher incorporation of coarse rubber particles leads to reduced mechanical performance. In general, lower amounts of epoxy polymer and finer rubber aggregates provide superior mechanical strength and modulus. The use of epoxy polymer also enhances the adhesion between cement and rubber aggregates. This rubber polymer-cementitious composite achieved promising results, being a feasible alternative to reuse end-of-life rubber tyres into structural applications.

1. Introduction

The significant increase of hazardous wastes disposal is a major concern in many countries due to their potential threats to public health or the environment. Scrap tyres pose a risk for the leaching of toxins into the groundwater when discarded to landfills. On average, 1 billion tyres reach their end-of-life period per year and it is estimated that 5 billion tyres will be discarded by 2030 [1]. Although some countries, such as EU countries, have strict regulations about destination of waste tyres, i.e. projecting a high recycling ratio of 96% [2], discarded tyres have been normally sent to landfills [1]. Tyre burning has been the main destination for scrap tyres [2], however, this method is unsafe for environment, since burning areas are subjected to temperature rise. In addition, poisoned smoke is released during the combustion process of scrap tyres. In general, heavy metal and other pollutant content are used to produce the rubber for tyres, making them unsuitable to be used as fuel [3].

In contrast, the use of recycled aggregates in construction industry has been proved to be an adequate solution to recycle solid wastes. One example is the carbon fibre powder waste (CPW), a recycled aggregate obtained from mechanical processing of carbon fibre laminates. It has been used as a sustainable high value aggregate in epoxy polymer matrix composites [4]. Higher compressive strength (∼118 MPa), flexural strength (∼4.48 MPa), and flexural modulus (∼4.14 GPa) of epoxy polymer were

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enhanced by adding CPW at 20 wt%. On the other hand, cementitious samples have presented divergent results with CPW reinforcement. Contreras et al. [5] have investigated the incorporation of heat treated and pristine CPW (1.5, 3.5 and 5.5 wt%) in cement-based composites. CPW in pristine created more voids due to its higher polymer content, leading to reduced compressive strength. The flexural strength was increased approximately 3 times with higher amount (5.5 wt%) of heat-treated CPW inclusions. The increase of the flexural strength was caused by the contribution of the well oriented fibres, when the fibre worked in traction.

Waste rubber particulates have been also studied as viable aggregates for concrete production. Their incorporation in cement-based materials has reduced carbon dioxide emissions, besides being economically viable [6] as an inexpensive resource with good energy absorption when deformed. Rubber particles contributed to obtain lightweight components, reducing product density at about 45% when coarse aggregates were used [7,8]. Past studies also reported that rubber aggregates provide reductions in compressive strength [6,8], flexural strength [8,9] and modulus of elasticity [10] of cementitious materials. This effect has been attributed to the weak rubber-cement adhesion, leading to a fast crack propagation around rubber particles. This effect has been also attributed to an undesired agglomeration of rubber particulates in one face of concrete samples, resulting in an inhomogeneous composition [7]. The substitution of up to 5% of conventional aggregates with rubber particles was considered acceptable in obtaining similar specific properties of mortars [11]. Apparent porosity increased at about 35% and water absorption was 4 times higher than conventional mortar when rubber particles were incorporated [8]. The higher energy absorption capacity of rubber particles was able to modify the normal brittle failure of ordinary concrete to pseudo-ductile [12]. Moreover, the workability of the cement mortar was not affected when rubber particles were incorporated up to 30 vol% [8].

The use of chemical treatments, such as silane coupling agent and NaOH solution, has contributed to increase overall rubber reinforced concrete strength by 15% [13]. Furthermore, the use of polymeric admixtures in cement products has led to increased mechanical properties due to stronger chemical bonding between cement hydrates and polymeric films [14]. Epoxy polymer is one of the main polymeric components used in concrete and mortar compositions. This polymer presents some advantages, such as high workability, ductile failure, increased flexural, compressive and tensile strength, reduced porosity and density of concrete samples [15]. The use of particulate reinforced epoxy-mortar has been identified as a promising material for restoration works to replace traditional mortars due to higher adhesion, ductility and mechanical properties [16]. In addition, epoxy polymers can provide positive effects over cement hydration and mortar strength. Anagnostopoulos, Sapidis and Papastergiadis [17] have found that epoxy polymer at 20 wt% retarded the hydration of Portland cement, leading to increments in compressive strength, tensile splitting strength and elastic modulus by 21%, 48%, and 162%, respectively.

Although several studies have been conducted to assess the mechanical performance of epoxy polymer modified concrete, scarce efforts have been carried out to understand the influence of sustainable aggregates in such products. A single study performed by Shu and Zhang [18] investigated the effect of epoxy polymer inclusions (40–60 wt%) into rubbered cementitious composites, achieving enhanced mechanical properties up to 3.7 times under compressive loads. The present work provides a better understanding with respect to the use of epoxy modified cement reinforced with rubber waste aggregates. This innovative composite intends to fulfil structural and durability requirements combining a recycled inexpensive component and epoxy polymer. A Design of Experiment (DoE) was conducted to assess statistically the influence of rubber particle size/amount, and epoxy incorporation on the mechanical, physical and morphological properties. The viability of such material can enhance sustainability of pre-cast building materials for secondary structural applications, i.e. external division walls, inexpensive housing, pavements, etc. besides reducing the cost of the final product.

2. Materials and methods

2.1. Materials

The triphasic material was composed by Portland cement, epoxy polymer and rubber particles. Thermosetting polymer, supplied by Huntsman (Brazil), was constituted of epoxy resin (Renlam M type) and hardener (HY956 type) mixed at 5:1 ratio, respectively. The cementitious phase consisted of ordinary Portland Cement (ASTM III) was sourced by Holcim (Brazil). The rubber particles were sourced by a local tyre remoulding company in Brazil. The particles were washed and classified by sieving process in particle size ranges of 10–20 US-Tyler (2–0.84 mm) and 50–100 US-Tyler (0.297–0.149 mm), as shown in Fig. 1.

2.2. Statistical analysis

The Design of Experiment (DoE) technique was conducted to evaluate the significance of each experimental factor over the investigated responses using a full factorial design. A full factorial design consists of investigating all combinations of experimental factors (k) and their respective levels (n), resulting in n^k experimental conditions [19]. The statistical software Minitab 17 was used to analyse the data.

Three experimental factors and their respective levels were evaluated: epoxy polymer inclusion (35 and 50 wt%), rubber particle inclusion (10, 15 and 20 wt%) and rubber particle size (10–20 and 50–100 US-Tyler). Holmes et al. [20] have recommended up to 20 wt% of rubber particles in cement-based materials to avoid significant reductions in mechanical properties. Epoxy polymer amount levels were determined using similar raw materials in preliminary investigations [21,22], which verify their effects on particle packing optimization and optimum system rheology. A full factorial design $2^2 3^1$ was conducted, leading to 12 experimental conditions as shown in Table 1. A reference condition (R1) made without rubber and polymer was prepared with a water-cement (w/c) ratio of 0.35. Two blend compositions (R2 and R3) were also produced by mixing epoxy polymer at different epoxy-cement ratios (see Table 2). Epoxy polymer in pristine condition (R4) was also evaluated. Reference conditions were evaluated to understand the interaction between cement and epoxy polymer in different compositions (R2 and R3) and to characterise the individual raw materials (R1 and R4). Responses such as bulk density, strength

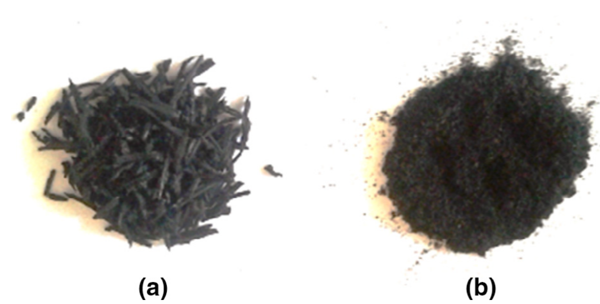

Fig. 1. Rubber particles: (a) 10–20 US-Tyler and (b) 50–100 US-Tyler.