Construction and Building Materials 151 (2017) 534–545

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

The effects of porosity on mechanical behavior and water absorption of an environmentally friendly cement mortar with recycled rubber

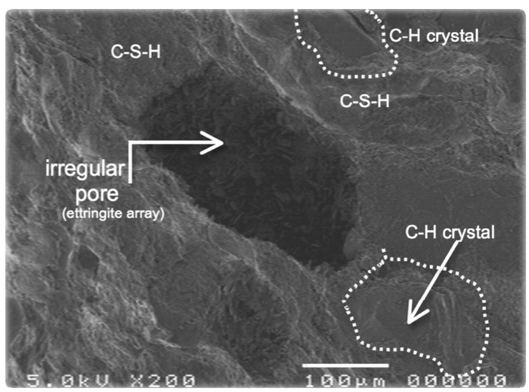
Andressa F. Angelin [a], Rosa C. Cecche Lintz [a], Luísa A. Gachet-Barbosa [a], Wislei R. Osório [a,b,*]

[a] School of Technology, University of Campinas–UNICAMP, Limeira, SP 13484-332, Brazil
[b] School of Applied Sciences/FCA, Research Group in Manufacturing of Advanced Materials (CPMMA/FCA), University of Campinas, UNICAMP, 1300, Pedro Zaccaria St., Jd. Sta Luiza, 13484-350 Limeira, SP, Brazil

HIGHLIGHTS

- Porosity affecting both water absorption and mechanical behavior.
- Rubberized cement with environmental-friendly application.
- Potential biodegradation and water treatment applications.
- Spheroidal and irregular porous morphologies are characterized.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 2 August 2016
Received in revised form 7 June 2017
Accepted 10 June 2017

Keywords:
Ceramic-matrix composites (CMCs)
Recycling
Mechanical properties
Porosity
Waste rubber
Molding compounds

ABSTRACT

The aim of this study is to analyze the effect of an environmentally friendly tire rubber content on mechanical and porosity a high-early strength (HES) cement mortar. These results were also associated with two distinctive porous morphologies (spheroidal and irregular). Specimens were produced using recycled tire waste rubber, which is constituted by a mixture between spheroid and fiber-like rubber particles. The use of a recycled rubber into a HES is scarce/absent in literature. A percentage of 30 wt% of the fine tire rubber replaces the natural sand as fine aggregate. The experimental results after 7 days show the compressive and tensile flexure strengths, water absorption and porosity. It is found that the rubber addition both the compressive and flexural strengths have considerably decreased. Both the control and rubberized mortars revealed irregular and spheroidal pores associated with gel/space ratio and air entrapped, respectively. An ettringite structure associated with gel/space ratio in a control mortar is observed. Distinctive engineering applications can be used for the rubberized mortar considering environmental, economical and lightweight aspects.

1. Introduction

Nowadays replacing with recycled materials evidences the tendency in the decrease the consumption of natural aggregate in civil construction by replacing with recycled materials. Consequently, the amount of the concrete waste that ends up in landfills is also

* Corresponding author at: School of Technology, University of Campinas–UNICAMP, Limeira, SP 13484-332, Brazil.
E-mail address: wislei.osorio@fca.unicamp.br (W.R. Osório).

http://dx.doi.org/10.1016/j.conbuildmat.2017.06.061
0950-0618/

decreased [1]. Several distinctive concretes and mortars have used the waste-recycled aggregates [2]. This induces to an environmentally friendly material in terms of energy consumption and efficiency. It seems that a biodegradation application can also be considered [2–6]. The lightweight concretes in civil construction using aerated and foam concretes have been investigated [7]. This characterizes a combination of load bearing capacity and thermal insulation [7]. It has recently been reported [8] that hydration (e.g. C-S-H gel formation) showed an important role in the engineering of the concrete and other cementitious composites [8]. This significantly affects the resulting physical and mechanical properties of both the cement mortars and concretes, which are intimately associated with the porosity and volume fraction of the intermixtures [8–10].

It has been reported that the waste tires have typically been applied in a non-critical structure, *e.g.* exterior wall materials, pedestrian blocks [11–14]. The lightweight effect for both the cement concrete and trench bedding materials can also be considered [11–14]. In a general way, it has widely been reported that independently of the size and morphology of the waste tire particles, both the compressive and tensile (flexural) strengths are decreased [12–16]. Some investigations have shown a slight increase in the compressive strength when coarse aggregates were replaced with 5% chipped rubber [16–20]. This seems to be associated with a better mixture grading. Additionally, the size of the rubber particles predominantly affects the compressive strength. In this sense, when coarse aggregate is replaced with the tire rubber particles, the decrease in the compressive strength is worth noted [20]. It is also worth noted that previous treatments on the waste tire rubber improve the adhesion with cement mortar [20–28].

It is known that rubber content in cementitious matrices induces to an increase in both the water absorption and porosity. This is intimately associated with the poor bonding between the rubber and the cement paste. These characteristics directly affect the mechanical strength and durability [29–32]. Thomas et al. [33] have observed that rubberized elements have lower density than a conventional. The density reduction is associated with the facility of the rubber tire particles to trap air throughout their rough and uneven surface and, also, because of their low density compared to conventional aggregate. This characteristic indicates their use in a production of lighter parts, and a rapid execution in civil constructions can be attained.

Kong et al. [24] have demonstrated that cement mortar strengths (compressive and flexural) and toughness behavior are intimately associated with a counterbalance among hydration kinetics, pore structure, composition and morphology of hydration products. A study with a 3% (in volume) rubberized-high strength concrete (HSC) [25–28] revealed that the deleterious effect has decreased ~10% the mechanical behavior when compared with the results of a HSC mortar. On the other hand, there are some investigations evidencing a slightly decrease in the tensile flexural strength when a fine (sand) aggregate replaces with fine tire particle [16,20].

Aiello and Leuzzi [20] have shown that the tensile strength has decreased (28%) when coarse aggregates (ranging between 50% or 75%) replace with shreds rubber tires. In this study five distinct rubber particle sizes were used, *i.e.* 20 mm, 16 mm, 12.5 mm, 10 mm and 8 mm. It is remarked that an interfacial bonding between rubber and cement mortar has an important role on the resulting mechanical behavior [34–40]. The mechanical behavior is improved when rubber particles associated with a treatment on rubber surface is applied [19].

The aim of this experimental investigation is focused on the effect of the recycled waste tire rubber constituted by a mixture between spheroid and fiber-like rubber particles on the experimental results of slump flow, water absorption, porosity level, and mechanical behavior of a cement mortar using a high-early strength (HES) Portland cement. Additionally, a 0.48 water-to cement ratio without gravel addition was used. It is noticeable that the HES is used instead an Ordinary Portland (O.P.) cement. Since potential applications for this proposed rubberized cement require rapid curing and no gravel content, the HES cement with rubber content was selected. Commonly, an O.P. cement with gravel content has a compressive strength of about 30 MPa. Besides, when the HES reference/control is considered, its resulting mechanical behavior after 7 days is similar or superior when previous studies are compared. Since a number of constructional applications require a maximum (~45 MPa) compressive strength in short-term period time (e.g. 7 days), the discussion in this study is limiting within 7 days. This is based on the fact that ~45 MPa for a reference cement mortar without gravel content is attained.

From the experimental results of the water absorption, workability and lightweight effect, the follow main novelty is attained: spheroidal and irregular porous morphologies are distinctively characterized. It is also found that the ettringite formation is predominantly formed inside of an typically irregular pore.

2. Experimental procedure

2.1. Materials and cement mortar preparation

It is remarkable that previous results were taken in account to organize this present study, which a 30% of rubber content was selected to replace with sand. Besides, it is worth noting that the aim is focused on the evaluate the effect of an environmentally friendly tire rubber mortar (without gravel addition) produced using a high-early strength (HES) cement upon the mechanical and porosity. This analysis is based on a unique rubber content correlating its corresponding experimental results with two distinctive porous morphologies constituted, *i.e.* spheroidal and irregular. A high early strength Portland cement according with Brazilian standard ABNT NBR 5733:1991 was selected. Triplicate experimentations (distinctive groups) of the cement mortars were produced. This HES was selected due to its corresponding chemical composition and compressive strength at 7 days are similar with that CEM-I 42.5 HES – high-early strength (NBN EN 197-1), type I (ASTM C150) and AS 3972 type HE. The cement has a density of 3.15 g cm^{-3} and their corresponding chemical and mineralogical compositions are shown in Table 1. Natural quartzitic sand was

Table 1
Chemical composition of the high early strength (HES) Portland cement used to elaborate the plain and rubberized cement mortars.

Chemical composition	%
CaO	63.33
SiO_2	19.19
Al_2O_3	5.15
Fe_2O_3	2.80
MgO	0.92
SO_3	2.82
K_2O	0.77
CO_2	2.78
C_3A	7.75
I.R.	0.48
L.O.I.	3.97
Mineralogical composition	
Clinker + Plaster	95
Slag	–
Pozzolanic	–
Limestone	5

Note: L.O.I. = Lost on ignition; I.R. = Insoluble residue.