Construction and Building Materials 48 (2013) 116–123

Contents lists available at SciVerse ScienceDirect

Construction and Building Materials

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

Rubber modified concrete improved by chemically active coating and silane coupling agent

Qiao Dong [1], Baoshan Huang *, Xiang Shu [1]

Department of Civil and Environmental Engineering, The University of Tennessee, Knoxville, TN 37996, United States

HIGHLIGHTS

- Coupling agent surface treatment.
- Chemical coating around rubber particle.
- Chemical bonding between rubber particles and cement hydration products.
- Improved compressive and tensile strength, chloride ions resistance and energy absorption of rubber modified cement concrete.

ARTICLE INFO

Article history:
Received 27 February 2013
Received in revised form 16 June 2013
Accepted 18 June 2013
Available online 23 July 2013

Keywords:
Rubber modified concrete
Coupling agent
Compressive strength
Fracture energy
Split tensile strength
Chloride ion resistance
Energy absorption

ABSTRACT

In the study, a new approach was employed to improve the performance of rubber modified cement concrete by developing a cementitious coating layer around rubber particles with silane coupling agent. To validate the effectiveness of the approach, coated and uncoated rubber modified concrete were evaluated through laboratory experiments. The compressive strength, split tensile strength, chloride ion resistance, and energy absorption capability were characterized through laboratory tests for concrete containing different contents of crumb rubber. The results show that the compressive and split tensile strength of the concrete incorporating coated rubber improved by 10–20%, compared to concrete with uncoated rubber. Although concrete with uncoated rubber exhibited lower chloride ion resistance than control concrete without rubber, concrete with coated rubber could maintain chloride ion resistance similar to that of control concrete. The energy absorption capability of concrete was also improved through the cementitious layer developed using silane coupling agent.

1. Introduction

The United States generates approximately 270 million waste tires (approximately 3.6 million tons) per year, representing 1.2% by weight of all municipal solid waste [1,2]. Since the majority of scrap tires today have either been used as fuel for generating energy (46%) or dumped at waste grounds (36%), more and more environmental awareness has led people to seek alternative usage of scrap tires. About 21% of these waste tires have been recycled into civil engineering applications, such as used as modifiers or additive in asphalt paving mixtures and Portland cement concrete (PCC) mixtures [3]. Main current applications of PCC with waste tires have been on secondary or non-critical structures including exterior wall [4] and pedestrian blocks [5], or as lightweight aggregate in flowable fill for both PCC and trench bedding materials [6,7]. Potential uses of rubber modified PCC have also been reported for highway sound walls, residential drive ways, garage floors and foundation pads for machinery and in railway stations where vibration damping is required [8].

Recycling waste tire rubber has a great environmental benefit by reducing harmful environmental pollution of disposing tires to landfill sites. Waste tires are not desired at landfills because they require huge dump sites due to their 75% void space. They may cause catastrophic fires and become habitat for insects because of retained rainwater [8–10]. Tires can trap methane gases and cause them to become buoyant to the surface which can damage landfill liners that have been installed to keep landfill contaminants from polluting ground water [9]. In addition to reduce dump pollution, when use crumb rubber in concrete to improve its freeze–thaw resistance, the benefit includes reducing the usage of chemical air-entraining agents as a means of freeze–thaw protection [11]. For the influence of waste rubber on environment, investigations of laboratory leachate derived from crumb rubber, and soil samples collected from the field showed no deleterious effects to the environment [10,12].

* Corresponding author. Tel.: +1 (865)974 7713; fax: +1 (865)974 2669.
E-mail addresses: qdong2@utk.edu (Q. Dong), bhuang@utk.edu (B. Huang), xshu@utk.edu (X. Shu).
[1] Tel./fax: +1 (865)974 2608.

0950-0618/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.conbuildmat.2013.06.072

In addition to reduce environmental pollution, the benefit of recycling waste rubber in concrete includes improved properties of concrete, such as improved freeze–thaw resistance, sound and heat insulation, and energy absorption [8,11–14]. Research has suggested that rubber modified PCC can effectively increase the ductility and prevent brittle failures [15,16]. It was reported that adding crumb rubber reduces the strength and abrasion resistance of concrete but the energy absorption is significantly improved [17]. Potential applications of the ductile rubber modified PCC could be structural components subjected to impact and dynamic load (such as bridge approach slabs and airport runways). However, the significant reduction of strength caused by addition of rubber has prohibited these applications. Another benefit of rubber modified PCC is light weight. Rubber has much lower specific gravity than typical or conventional aggregates, so the replacement of aggregates with rubber consequently reduces the overall specific gravity of the rubber modified PCC [1]. Most researchers reported improved freeze and thaw resistance of rubber modified PCC [18,19]. However, some researchers indicated that a higher percentage of rubber content compromises the freeze–thaw durability of rubber modified PCC [20].

One method to improve the performance of rubber modified concrete is to treat the surface of rubber particles. Natural rubber does not form a strong bond with cement mortar. Chemical treatment of rubber particles alters the surface properties of rubber particles and will potentially improve the bond between rubber particles and cement mortar. Segre and Joekes [21] used NaOH to treat the waste tire chips before incorporating them into cement concrete. Li et al. [22] employed cement paste pre-coating of rubber particles. Rostami et al. [23] simply washed rubber chips with water before applying them to cement concrete. Tantala et al. [24] applied acidic and plasma etching to increase the surface area of rubber particles. Guneyisi et al. [25] added silica fume to improve the strength of concrete containing waste crumb rubber. All of the surface treatments have reported varying degrees of success.

However, none of the surface treatments so far have shown conclusive evidence of an effective method to improve the strength of concrete containing rubber particles/chips (especially at more than 10 volume percent). Generally, addition of 15% rubber chips into coarse aggregate will result in 45% reduction in compressive strength and 25% reduction in splitting tensile strength [2,26,27]. Lack of "strong" chemical bond between rubber and surrounding cement mortar is an important reason for the significant loss of strength. In order to overcome the existing technical barriers that limit the performance of rubber modified concrete, attempts have been made to approach this problem by developing a strong bond around rubber particles to prevent the failure initiating at the interface between rubber particles and cement mortar. Instead of increasing the surface friction, a chemical bond should be established at the interface.

This study employed a new approach to improve the performance of rubber modified cement concrete through developing a cementitious coating around rubber particles with silane coupling agent [28]. Laboratory experiments were conducted to verify the feasibility of the approach.

2. Materials

2.1. Rubber preparation

Two waste tire rubber particles were used in the study. One was original crumb rubber (uncoated) and the other one was coated with a coupling agent. The rubber particle size ranged from 0.425 mm to 4.75 mm and around 80% weight of rubber particles were composed of 2–4.75 mm particles. Table 1 shows the gradation of rubber particles. Silane surface treatment was used to develop chemical bonding between rubber particles and cement matrix. For the concrete incorporating crumb rubber, failures usually occur on interfaces of rubber particles and untreated rubber particles do not break during testing, which may be attributed to the weak interaction between rubber particle and cement matrix. In this study, cement was used as a coating material to attach on the rubber by chemical bond developed with silane coupling agent. The rubber particles coated with cement were cured in oven around 110 °C to make the chemical bond fully developed as illustrated in Fig. 1. Microscope pictures taken from previous studies had shown the improved interface treated by the silane coupling agents [29,30].

Table 1
Gradation of rubber particles.

Sieve size (mm)	Passing percent (%)
4.75	87.6
2.36	12.4
1.15	0.9
0.6	0

The procedures by Cao and Chung [31] and Xu and Chung [32] were followed in this study to create the surface coating. Surface treatment for rubber particles using silane involves (i) making an ethyl alcohol aqueous solution at a selected concentration, (ii) adding silane to the solution and stirring for 10 min by using a magnetic stirrer in a flask, (iii) adding rubber particles to the solution made in (ii) and stirring for 20 min, (iv) heating to 80 °C and refluxing for 30 min while stirring and then cooling to room temperature, (v) rinsing with alcohol by filtration, and (iv) drying at 110 °C for 12 h. As shown in Fig. 2, the silane coupling agent is a 1:1 by weight mixture of Z-6020 ($H_2NCH_2CH_2NHCH_2CH_2CH_2\ Si(OCH_3)_3$) and Z-6040 ($OCH_2CH_2CH_2OCH_2CH_2CH_2Si(OCH_3)_3$) from Dow Corning Corp. The amine group in Z-6020 serves as a catalyst for the curing of the epoxy and consequently allows the Z-6020 molecule to attach to the epoxy end of Z-6040 molecule. The trimethylsiloxy ends of the Z-6020 and Z-6040 molecules then connect to the –OH functional group on the surface of the cement paste.

2.2. Preparation of concrete

Commercially available Type I Portland cement conforming to ASTM C150 was used in this study. The coarse aggregate selected in this study was No. 57 limestone. Its saturated dry density was 2560 kg/m^3 and absorption was 0.4%. The fine aggregate used in this laboratory study was natural sand with a fineness modulus of 4.08 and a saturated dry density and absorption of 2500 kg/m^3 and 1.3%, respectively. To investigate the influence of different rubber content on the concrete properties, five rubber contents were included to prepare the concrete mixtures, as shown in Table 2. The "0%" concrete mixture contained no rubber was used as the control concrete. In the "15%U" concrete mixture, 15% of the aggregate by volume was replaced with uncoated waste rubber, whereas in the "15%C" concrete, 15% of the aggregate by volume replaced with coated waste rubber. The cement content of coated rubber concrete was determined by subtracting the amount of cement in the coating from the total cement content. Concrete specimens were prepared using a mechanical mixer and applying standard rodding for compaction. The specimens were cured in a standard moisture curing chamber until the days of testing except for the chloride ions resistance test.

3. Laboratory tests

Compressive strength test, split tensile strength test, chloride ion resistance test and low velocity impact test were conducted to evaluate the influence of coated rubber on the mechanical properties, durability and energy absorption capability of concrete.

3.1. Compressive strength test

Cylindrical specimens, 101.6 mm (4 in.) in diameter and 203.2 mm (8 in.) in height, were fabricated for compressive strength testing, in accordance with the ASTM C39 and AASHTO T22. The compressive test was conducted on three specimens at 7 and 28 days using an Instron loading frame.

3.2. Split tensile strength test

An MTS machine was used to test the split tensile strength of concrete according to ASTM D 3967. 101.6 mm (∅) × 50 mm (H) pills were cut from 101.6 mm (∅) × 203.2 mm (H) cylinders for testing. Three specimens were tested for each concrete mixture at 7, 28 and 60 days.