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Evaluation of laboratory performance of self-consolidating concrete with recycled tire rubber

Ruizhe Si, Jiaqing Wang, Shuaicheng Guo, Qingli Dai*, Song Han

Department of Civil and Environmental Engineering, Michigan Technological University, 1400 Townsend Dr., Houghton, MI 49931-1295, USA

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ABSTRACT

This study investigated the performance of early-aged and hardened self-consolidating concrete (SCC). Rubber-modified SCC mixtures were prepared with 15% as-received crumb rubber and 15% and 25% NaOH-treated crumb rubber based on volume of fine aggregates. The SCC sampled without rubber aggregates were cast as the control groups. The slump test, V-flannel flow test, and U-box test were conducted to evaluate the fresh properties of different types of rubber modified SCC. The fresh properties showed slightly reduced flowability with replaced rubber particles. The measured compressive and splitting tensile strength of rubber-modified SCC concrete were reduced in comparison with the control mixture. However, the surface-treated rubberized concrete had higher mechanical strength than as-received rubberized concrete due to better bonding at the interface. The measured ultrasonic transmission speed decreased with the increasing rubber content in concrete and these results also indicated the reduced dynamic modulus. The transport property evaluated from the electrical resistivity measurement indicated the decreased permeability with added rubber content. The durability performances (including alkali-silica reaction and drying shrinkage) of SCC mortar samples were generally improved with rubber-modified samples. Overall study showed that the rubber-modified SCC can maintain good workability and mechanical properties and enhance durability with reduced environmental impacts.

1. Introduction

With the rapid development of the worldwide automobile industry, tire production has increased enormously around the world in recent decades. Massive stockpiles of waste tire were generated every year. Solid waste management has become one of the serious problems we currently face. Since rubber is not biodegradable, the accumulation of waste tires can cause a serious environmental problems (Jain). Landfilling is one of the most common waste disposal methods (Yung et al., 2013). However, since 75% of waste tires is void space, huge dump sites and larger storage spaces are required to dispose of used tires (Adhikari et al., 2000). In addition, rainwater retained in the waste tires provide an ideal habitat for insects and pests (Dong et al., 2013). Meanwhile, the waste tire could become a fire hazard due to its flammability. Thus the accumulation of waste tires lead to negative effect on the environment and on human health (Oikonomou and Mavridou, 2009). The application of waste tire rubber in civil engineering projects provide an eco-friendly way to recycle the used tire rubber. The crumb rubber from waste tires could be used in cement concrete (Yung et al., 2013; Segre and Joekes, 2000; Rostami et al., 2000; Sukontasukkul, 2009; Hernandez-Olivares et al., 2002; Eldin and Senouci, 1993; Huang et al., 2013) or in asphalt concrete (Xiao et al., 2007; Mull et al., 2002; Tortum et al., 2005; Palit et al., 2004) as pavement construction (Yung et al., 2013). Many studies have been carried out to investigate the properties of concrete incorporating crumb rubber. The researchers suggested that cement concrete mixture containing crumb rubber can enhance toughness (Batayneh et al., 2008) and ductility (Kaloush et al., 1914), improve sound absorption (Sukontasukkul, 2009) and resistance to thermal changes (Kaloush et al., 1914), decrease unit weight (Siddique and Naik, 2004), and achieve better durability compared to plain concrete (Benazzouk et al., 2003; Paine et al., 2002; Afshinnia and Poursaee, 2015). However, the reduction of compressive and splitting tensile strength in rubberized concrete is inevitable due to the low stiffness of rubber and incompatibility between rubber and cement paste (Shu and Huang, 2014; Huang et al., 2011). Some researchers suggested that pretreatment of rubber particles with sodium hydroxide solution could reduce the loss of strength in rubberized concrete by enhancing the bonding strength between

* Corresponding author.
E-mail addresses: ruizhes@mtu.edu (R. Si), jiaqingw@mtu.edu (J. Wang), sguo3@mtu.edu (S. Guo), qingdai@mtu.edu (Q. Dai), songh@mtu.edu (S. Han).

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rubber particles and cement paste (Segre and Joekes, 2000; Siddique and Naik, 2004; Naik and Singh, 1991; Guo et al., 2017; Ma and Yue, 2013). However, the effectiveness of the NaOH surface treatment of rubber in improving the strength of rubberized concrete could be influenced by the size of the rubber aggregate. Li et al. (Li et al., 2004) found no detectable difference in strength in rubberized concrete with NaOH treated and untreated large size (about 20 mm) chip rubber aggregate.

Self-consolidating concrete (SCC) is a new type of concrete which has high flowability. The SCC can be self-compacted without segregation or bleeding (Su et al., 2001; Naik et al., 2012). Its rheological properties could reduce the disadvantage of ordinary cement concrete such as the noise caused by vibration in processing plants. Additionally, the construction time and the cost of labor could be reduced with the use of SCC (Han and Yao, 2004). Compared with ordinary cement concrete, there are some additional components in SCC such as fine filler and admixture (Bignozzi and Sandrolini, 2006). The proper admixture, i.e. superplasticizers and viscosity modifying admixture, and fine filler such as fly ash, limestone powder, and ground granulated blast furnace slag have the ability to adjust the flowability and enhance the stability of fresh SCC (Yung et al., 2013; Bignozzi and Sandrolini, 2006). These additional components enable the concrete to compact without vibrations. Furthermore, the fine filler (generally with an average size ranging between 10 and 30 μm) helps the mixture to form a densely-compacted microstructure. Thus the compressive strength of SCC could achieve a higher value than the ordinary cement concrete (Bignozzi and Sandrolini, 2006). Although, some properties were improved in SCC compared with that of ordinary cement concrete, SCC still appears to be brittle (Nehdi and Bassuoni, 2004).

The use of rubber particles in SCC could change the properties and join the new characteristics of SCC (Bignozzi and Sandrolini, 2006). The results of previous studies (Kaloush et al., 1914; Pierce and Blackwell, 2003; Yesilata et al., 2009; Najim and Hall, 2010) showed that the added rubber in SCC could reduce the bleeding of the fresh mixture, improve the thermal and acoustic insulation, and enhance the impact absorption of the concrete mixture. However, it was found that the workability of the cement concrete mixture could be reduced significantly with increased content of rubber aggregate due to the considerable fraction between rubber particles and other mixture components (Batayneh et al., 2008; Reda Taha et al., 2008). As SCC required high workability to achieve self-consolidation in field construction, the decrease in flowability caused by the added rubber aggregate needs to be minimized. Guo et al. (Guo et al., 2017) found that pretreated rubber aggregate with NaOH solution increased the slump of the fresh rubberized concrete.

The rubber modified SCC and normal concrete with NaOH treated rubber aggregate have been investigated in many studies, however, the surface modified rubber aggregate is seldom applied in the rubberized SCC mixtures. In order to improve the fresh properties and evaluate the performance of rubber modified SCC, NaOH-treated rubber aggregates were applied to replace portions of sand for SCC mixtures in this study. The fresh properties and hardened properties (mechanical, transport, acoustic, and durability) of rubber modified SCC mixtures have been tested and compared with the control mixture. The performances were thus evaluated for different modified SCC mixtures.

2. Materials preparation

2.1. Materials

In this study, Type I Portland cement, which complies with the requirement of ASTM C150 standard (ASTM C150 C150M-16e1, 2016), was used as binder. The gradation of coarse aggregate with the maximum aggregate size of 19 mm and sand (0–4 mm) was chosen by following the ASTM C33 standard (ASTM C33/C33M-16, 2016). The crumb rubber granules with the size between 1.44 mm and 2.83 mm were used for rubber-modified self-consolidating concrete or mortar preparation. Class-F Fly ash were used as fine fillers in the mixture. The polycarboxylate-based superplasticizer ADVA Cast 575 was used as high range water reducer (HRWR) in the experiment to adjust the flowability of the concrete or mortar mixture. Sodium hydroxide with the chemical purity about 95–98% was used for rubber aggregate surface treatment.

2.2. Rubber surface treatment with NaOH solution

The surface-treated rubber particles with alkali NaOH solution result in a weak basic condition around the rubber surface, which improve the hydration of the cement near the interface between rubber particles and cement paste (Guo et al., 2017; Si et al., 2017). In addition, the oxidized rubber surfaces contained carboxyl group (−COOH). With alkali treatment, the photon H^+ can be replaced with Na^+ to form high hydrophilic −COONa group on the surface of rubber particles (Guo et al., 2017). This will reduce contact angle and thus increase hydrophilic properties of rubber particles (Chou et al., 2007). With the improved hydrophilic properties of rubber particles, the water transfer rate on the rubber surface can be enhanced. Consequently, the workability of rubberized concrete with NaOH treated rubber aggregate could be potentially improved in comparison with the rubberized SCC containing as-received rubber. The surface bonding of NaOH treated rubber aggregate with cement paste in SCC is much less affected than normal concrete (Guo et al., 2017) due to high-flowability properties of the SCC mix.

The rubber aggregates were soaked in 1 N NaOH solution with stirring for about 20 min as the surface treatment. After that, the surface-treated rubber was washed with tap water several times to remove the residual NaOH and dried at room temperature.

2.3. Self-consolidating concrete sample preparation

One set of control SCC and three sets of rubber-modified SCC were prepared for fresh and hardened properties tests. Different rubber-modified SCC mixtures were prepared by using 15% as-received rubber, 15% NaOH-treated rubber, and 25% NaOH-treated rubber, based on the volume of sand. These four different types of concrete are named as: control SCC (C0), SCC with 15% as-received rubber (SCC-AS15), SCC with 15% NaOH-treated rubber (SCC-OH15), and SCC with 25% NaOH-treated rubber (SCC-OH25), respectively. The proportional design of these mixtures are presented in Table 1.

The concrete batches were prepared with a concrete mixer with a capacity of 6 ft^3. The fine aggregates (including rubber aggregate) and coarse aggregates were firstly mixed in a mixer drum for 1 min. Half of the mixing water was then added into the mixture and mixed for 30 s. After that, the binder, cement, and fly ash were added into mixer to mix for another minute. The HRWR was dispersed in the remaining water and then added into the mixer. Lastly, the concrete was mixed for 3 min, rested for 2 min, and mixed for another 2 min. Cylindrical concrete samples with the dimension of 4 by 8-in were prepared for the performance test.

2.4. Self-consolidating mortar sample preparation

Four types of self-consolidating mortar (SCM) were prepared for durability tests in this study. One control SCM mixture (M0) and three types of rubber-modified SCM were prepared. The rubber-