Journal of Cleaner Production 116 (2016) 217–222

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Zones of weakness of rubberized concrete behavior using the UPV

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A R T I C L E I N F O

Article history:
Received 15 October 2015
Received in revised form
27 December 2015
Accepted 28 December 2015
Available online 6 January 2016

Keywords:
UPV
Crumb rubber
Optimum percentage
Weakness zones
Rubberized concrete

A B S T R A C T

Many studies have addressed the recycling of rubber tires as a replacement material for fine or coarse aggregates used in concrete mixes. This research has focused on detecting the optimal amount of crumb tires as a partial substitute for fine aggregates in concrete mixes without radically affecting its main properties. Moreover, the performance of rubberized concrete with crumb rubber partially substituted for fine aggregates in various percentages (from 0% up to 100%) by volume has been studied under axial compression. The nondestructive, Ultrasonic Pulse Velocity (UPV) testing method has been implemented for this purpose. This approach has not been used for this purpose in the literature so far. The test results indicated three zones of weaknesses in rubberized concrete. However, Zone A demonstrated that even though the compressive strength is reduced it remains within accepted limits. Therefore the optimal rubber percentage was found to be 25% which is the boundary of zone A.

1. Introduction

Natural aggregates are definitely essential and valuable resources for the economic and social development of mankind, but they must be produced and used according to the sustainable development principles (Blengini and Garbarino, 2010; Marie and Quiasrawi, 2012). Consequently, utilization of concrete that uses scrap tires as a partial replacement of the natural aggregates has been emphasized and investigated within a large number of research studies (Bravo and De Brito, 2012; Ho et al., 2012; Richardson et al., 2012; Khaloo et al., 2008; Batayneh et al., 2008; Eldin and Senouci, 1992). Some studies have been conducted to examine the effect of recycled rubber on the properties of the fresh and hardened concrete and therefore the possibility of applying rubberized concrete in various civil engineering projects. The use of rubber particles in lightweight aggregate concrete may provide further opportunity to recycle waste tires (Lv et al., 2015).

The durability performance of rubberized concrete also studied. It was found that the rubberized concrete is highly resistant to the aggressive environment and can be implemented in the areas where there are chances of acid attack (Thomas et al., 2016).

Such applications may reduce the consumption of natural aggregates and minimize the accumulation of non-decaying scrap tire material. Other studies have concentrated on the ability of enhancing some long term properties of concrete mixes such as resistance to water absorption and carbonation (Thomas and Gupta, 2015).

In general, most of the studies found a reduction in the mechanical properties when rubber content increases. Almost all investigators reported significant reduction of 10–80% in compressive and tensile strength of rubberized concrete with increasing rubber content (Batayneh et al., 2008). The strength reduction is related to the rubber content and the low bond strength between the cement base matrix and the tire rubber particles (Ozbay et al., 2011). Other researches indicated advantages to rubberized concrete as crumb rubber delays the crack initiation time while reducing the crack length and width (Onuaguluchi and Panesar, 2014). When resistance to the cracking due to imposed deformation is a priority, use of rubber aggregates is a good consideration as a solution to improve durability in order to minimize maintenance expenses and to recycle used rubber tires and preserve the environment (Ho et al., 2012). The recycled tire rubber after chemical treatment proved to be an excellent aggregate to use in the concrete (Pelisser et al., 2011).

The main objective of this study is to predict the performance of rubberized concrete using nondestructive ultrasonic pulse velocity (UPV) test and to justify the optimal amount of crumb rubber that can be used in concrete as partial replacement for fine aggregates without significantly affecting its main engineering properties. A very limited number of studies have been published on the evaluation of the performance of rubberized concrete using nondestructive tests (Mohammed et al., 2011).

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http://dx.doi.org/10.1016/j.jclepro.2015.12.096
0959-6526/

Eldin and Senouci (1992) reported that only the percentage by volume of rubber in the mix has a significant effect on strength while the size and shape was found insignificant. As a result, this study is limited to the use of crumb rubber as replacement for fine aggregates.

The present investigation originates from an existing research paper by Batayneh et al. (2008) with objectives to widely explore the effect of crumb rubber on concrete performance using UPV.

The methodology developed for this investigation aims to:

- Detect a practical optimum percentage of rubber replacement for fine aggregates without affecting seriously the mechanical properties of concrete using UPV.
- Understand the performance of rubberized concrete with differing percentages of rubber under compression loading using the UPV test.

Qasrawi and Marie (2003) studied the use of UPV to anticipate failure in concrete under compression which will be adopted in this study to monitor in-depth the performance of rubberized concrete under compression. The performance of concrete is assessed by measuring the time for an ultrasonic pulse to travel through a specified length. The pulse velocity is calculated by dividing the length by the time taken by the pulse to propagate through that length. The velocity is an indication about quality, uniformity and strength of the concrete tested.

2. Experimental program

2.1. Materials

The waste tire particles used in this study were crumb rubber, which was obtained from a local industrial unit in Jordan. The crumb rubber has been reported to have a nominal size between 4.75 mm (No. 4 sieve) and 0.075 mm (No. 200 sieve) as defined by Siddique and Naik (2004). The scrap tires originated from a scrap yard of tires from different types of vehicles. Fig. 1 shows the sieve analysis results for both the crumb rubber particles and the fine aggregates (sand) used. The figure indicates that the gradation of the crumb rubber particles and the sand used fall between the minimum and maximum limits of the fine aggregates gradation limits specified by BS882:1992 (Neville, 1995). The crumb rubber particle size varied from 4.75 to 0.15 mm Fig. 1 (a and b) shows an image of the crumb rubber and the sand particles respectively. The crumb rubber was used in the concrete mixes to partially substitute fine aggregates in various percentages ranging from 0%, up to 100% by volume.

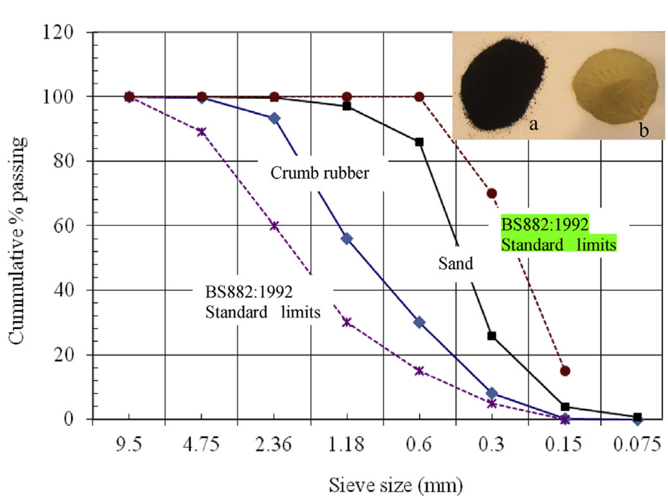

Fig. 1. Sieve analysis of crumb rubber and sand within BS882:1992 limits a. Crumb rubber particles b. sand particles.

The raw materials used for preparing the concrete mixtures consist of Ordinary Portland Cement (Type I) which is a general purpose cement with fairly high C3S content for good early strength development which conforms to ASTM C 150-92 specifications, natural silica sand which is used as fine aggregates, and crushed limestone coarse aggregates. All the materials used were supplied from natural local resources in Jordan. The physical and mechanical properties of the coarse aggregate used in this study are listed in Table 1. The absorption of the used crumb rubber is about 2.3% of its dry weight. This absorption capacity is relatively low when compared to local sand absorption of 3.55%. So this has been accounted for when proportioning the mixtures.

2.2. Specimen preparation and testing

In order to prepare the recycled crumb rubber concrete specimens, fine aggregates were replaced by waste materials of crumb rubber in several percentages. Mixes with 0% rubber were designed to target a compressive strength of 25 MPa at an age of 28 days. It is considered as a control mix for comparing the performance of the natural aggregates concrete with the rubberized concrete specimens. Percentages range from 10% to 100% as volumetric ratio of crumb rubber to natural sand are prepared in separate concrete mixes. For each mix, 6 cubes of 100 × 100 × 100 mm, were prepared. All the results taken are the average of the 6 cubes results. All specimens were fabricated and then cured in the laboratory in a water bath under a temperature of 23 °C ± 2 °C for 28 days in accordance with ASTM/C192M-06 standard practice (ASTM, 2006). The casting and curing temperature has a significant effect on fresh and hardened concrete properties (Burg, 1996). Therefore, it is kept constant for all mixes and tests. The workability of all mixes were tested at the casting time of the specimens using the slump test according to ASTM C143. Mix proportions and fresh properties are presented in Table 2. The compressive strength of the concrete was determined by testing the prepared concrete cubes of size 100 × 100 × 100 mm at the age of 28 days. As the rate of loading used during compressive strength determination affects the results (Mali et al., 2015), all the compressive strength tests were performed at room temperature of 20 °C with a constant rate of loading of 0.5 MPa/s.

A digital camera of 3× optical zoom and 2048×1536 pixel resolution have been used to visualize the crumb rubber particle distribution within each different hardened rubberized concrete mix as shown in Fig. 2. The visual inspection indicates that the distribution of aggregates, cement and crumb rubber particles seems to be homogeneous.

2.3. UPV measurement

The UPV measurements were conducted according to ASTM C597 using the direct method with the transducers firmly coupled

Table 1
Physical and mechanical properties of coarse aggregates.

Property	Crushed limestone coarse aggregates
Specific gravity (SSD)	2.57
Water absorption	1.67
Prodded bulk density (kg/m^3)	1502
LA abrasion (%)	25

SSD: surface saturated dry.
LA: los Angeles.