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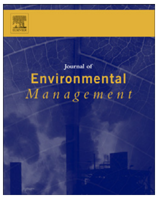

Research article

Effect of crumb rubber on the mechanical properties of crushed recycled pavement materials

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A R T I C L E I N F O

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A B S T R A C T

The low-carbon footprint of using recycled construction and demolition (C&D) aggregates in civil engineering infrastructure applications has been considered to be a significant solution for the replacement of conventional pavement aggregates. Investigations regarding the use of crumb rubber in the base and subbase layers of pavement have been well documented. However, information on the effects of crumb rubber and its size within C&D aggregates as the base/subbase layers is still very limited. In this study, crumb rubber with particle sizes ranging from 400 to 600 μm (fine) to 10–15 mm (coarse), 20 mm recycled crushed concrete (RCC), and 20 mm crushed rock (CR) were used. The crumb rubber was added to the two groups of C&D aggregates at 0.5, 1 and 2% by weight percentages of the aggregates. The effect of crumb rubber on the mechanical properties (such as California bearing ratio, unconfined compressive strength, aggregate crushing value, dynamic lightweight cone penetrometer, Clegg impact value, Los Angeles abrasion values, and resilient modulus) of the C&D aggregates was then examined. Based on the experimental test results, it was found that crumb rubber can be recycled as a waste material for the base and subbase layers in the pavement.

1. Introduction

Approximately 8.7 million tons of recycled crushed concrete (RCC) are stockpiled in Australia annually (Arulrajah et al., 2013). Construction and demolition (C&D) materials along with industrial and commercial wastes constitute more than 80% of the waste materials received for reprocessing in the state of Victoria, Australia (Sustainability Victoria, 2010). Also, CR is a material composed of graded coarse and fine aggregates produced by the crushing, scalping, and screening of a raw rock feed source, newer basalt surface spalls (NBSS) and/or crushed concrete (VicRoads, 2016). Therefore, reusing the recycled materials can reduce the carbon emissions by up to 65%, as well as result in significant cost savings through density benefits (Disfani et al., 2014). Industries have been trying to decrease the consumption of virgin materials through the use of low-carbon replacement resources and the reuse of construction and demolition materials in response to the challenges of environmental sustainability (Du et al., 2013; Mohammadinia et al., 2016).

Construction and demolition materials manufactured by processing construction and demolition wastes have been widely considered to be a potential substitute for natural aggregates (NA) to reduce the negative impacts of such wastes on the environment (Jian-he et al., 2015). Recycled crushed concrete (RCC) and crushed rock (CR) have been studied in different applications, such as permeable pavements (Turatsinze et al., 2005), pavement bases/subbases (Kou et al., 2011; Chummuneerat et al., 2014; Naito et al., 2014; Pettinari and Simone, 2015; Arulrajah et al., 2016; Arshad and Farooq Ahmed, 2017; Sas et al., 2017), pipe backfilling (Benazzouk et al., 2007), and in light duty pavements (Son et al., 2011). Although cement stabilization is one of the most practical solutions to improve the strength properties of C&D materials, the environmental cost of using cement is significant and requires mitigation (Arulrajah et al., 2016). It has been reported that the production of chemical binders, such as cement, releases high amounts of CO_2 emissions around the world amounting to 10% of global CO_2 emissions (Rahgozar et al., 2018). Therefore, the inclusion of alternative wastes, such as crumb rubber, broken glass, steel fibre, fly ash, geopolymers and electric arc furnace dust, has been extensively researched in recent years to decrease the CO_2 emissions (Ali et al., 2011; Guo et al., 2014; Feng et al., 2015; Ganjian et al., 2015; Jian-he et al., 2015; Arulrajah et al., 2016; Mardani-Aghabaglou

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et al., 2016; Baghabra Al-Amoudi et al., 2016; Baghabra Al-Amoudi et al., 2017).

About 500,000 tons of tyres are replaced in Australia every year. Also, recently, the treatment of scrap tyre rubber has become an environmental problem around the world since scrap tyres are very stable and nearly impossible to degrade in landfill treatment (Rahgozar and Saberian, 2016; Saberian et al., 2017b). The inclusion of such high-strain-capacity materials can be useful for improving the impact resistance, toughness, and fatigue performance of the base and subbase of roads (Pettinari et al., 2013). However, the inclusion of the rubber particles has shown both drawbacks and potential benefits. Although the addition of crumb rubber may decrease the compressive and tensile strength, structural applications may still be feasible if appropriate percentages of rubber aggregates are considered. Crumb rubber provides good water resistance with low absorption, low shrinkage, acid resistance, high impact resistance, and excellent thermal and sound insulation. Moreover, the inclusion of tyre in aggregates enables large deformations without full disintegration and easily absorbs significant plastic energy (Saberian and Rahgozar, 2016; Yadav and Tiwari, 2017). Feng et al. (2015) studied the mechanical properties, damage characteristics, and fatigue properties of rubber-modified recycled aggregate concrete. It was observed that by increasing the rubber content, the flexural strength, compressive strength, and elasticity modulus of the rubber-modified recycled aggregate concrete decreased. However, by increasing the rubber content, the peak strain, peak deflection, and ultimate strain increased. Also, the ultimate strain of rubber-modified recycled aggregate concrete was 3.45 times more than that of the control RCC when the rubber content reached 20% of the sand. Guo et al. (2014) investigated the fracture behaviour of steel fibre-crumb rubber-reinforced recycled aggregate concrete. Based on the results, it was concluded that by increasing the rubber content, the fracture toughness and fracture energy first increased and then decreased. The experimental study of Li et al. (2016) showed that while the compressive strength, flexural strength, and the density of RCC decreased with the inclusion of scrap rubber, the dynamic increase factor and toughness index increased with an increase in the rubber content.

Although several studies have been conducted to evaluate the effects of crumb rubber on the properties of the pavement base and subbase layers for road applications, very limited studies have been conducted to examine the effects of crumb rubber and its size on the properties of recycled crushed concrete (RCC) and crushed rock (CR). The aim of this research is to experimentally study the effects of crumb rubber on RCC and CR for base and subbase applications.

2. Materials and testing methods

2.1. Materials

Class 2 20 mm CR and 20 mm RCC were obtained from a local recycling facility in Melbourne, Australia. C&D aggregates are alkaline by nature since the pH value ranges from 10 to 12. The geotechnical properties of the CR and RCC are summarized in Table 1. The crumb rubber, produced by shredding worn tyres with two different sizes ranging from 400 to 600 μm (fine) and 10–15 mm (coarse), and a melting temperature of 170 °C, was collected from a local tyre recycling plant in Melbourne, Australia. Fig. 1 Shows the particle size distribution curves of the CR and RCC.

2.2. Sample preparations and mix designs

The virgin CR and RCC materials were mixed at the optimum moisture contents of 8 and 12%, respectively. The aggregates were then allowed to cure (i.e., to allow for the even water absorption of the aggregates) in a sealed container for at least 2 h (AS 1289.5.1.1). After curing, different percentages of the fine and coarse rubbers were added to the CR and RCC (i.e. replaced by dry weight of the aggregates) at 0, 0.5, 1, and 2% (by dry weight of each aggregate). In order to achieve a uniform distribution of crumb rubber, a Hobart Commercial Mixer was used to mix crumb rubber with aggregate for at least 5 min. Two replicate specimens were prepared for each mixture. A total of 196 specimens were prepared for the CBR, UCS, Clegg impact hammer, aggregate crushing value, Los Angeles, dynamic lightweight cone penetrometer, and resilient modulus tests.

Table 1
Physical properties of CR and RCC.

Geotechnical properties	CR	RCC
Fine content (%)	9	7
Sand content (%)	32	32
Gravel content (%)	63	63
Coefficient of uniformity (C_u)	66.67	42.86
Coefficient of curvature (C_c)	3.13	2.01
Loose density (natural) (t/m^3)	1.65	1.60
Maximum dry density (t/m^3)	2.24	2.01
Optimum moisture content (%)	8	12
Liquid limit (%)	30	35
Plasticity index	0–6	6
Flakiness index (%)	35	35
Colour	Grey	Grey

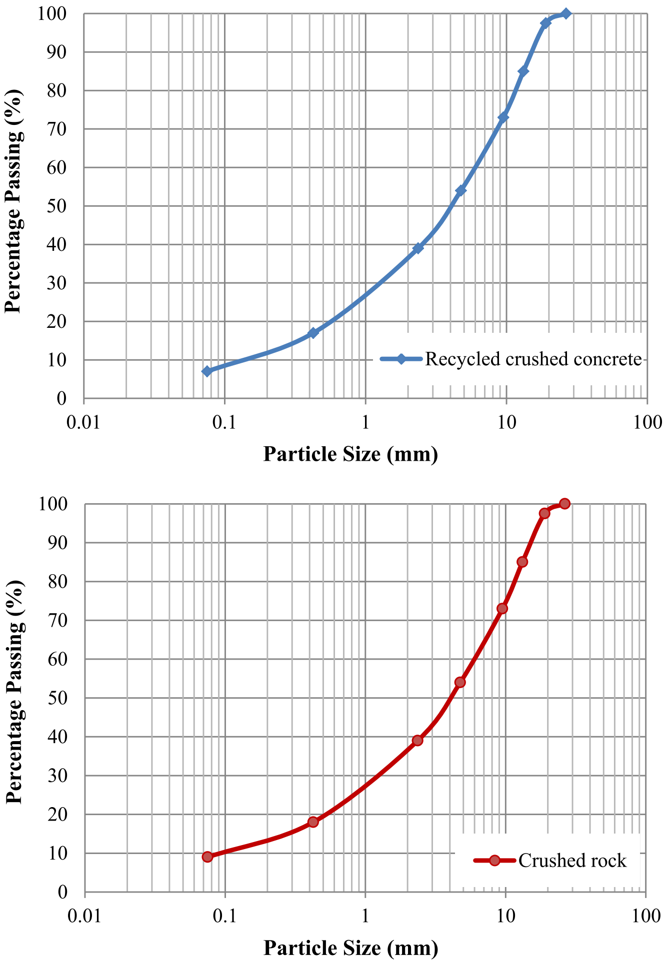

Fig. 1. Particle size distribution curves of the CR and RCC.