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Investigation of the mechanical properties and carbonation of construction and demolition materials together with rubber

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ABSTRACT

One of the ways to improve the strength properties of construction and demolition (C&D) wastes is to adopt the accelerated carbonation technique. The main objective of this study was to evaluate the effects of the eco-friendly carbonation approach on the mechanical properties of C&D aggregates together with crumb rubber. Crumb rubber with particle sizes ranging from 400 to 600 μm was added to the 20 mm recycled concrete aggregate (RCA) and crushed rock (CR) at 0.5, 1, and 2% by weight percentage of the aggregates. Then, the unconfined compression strength (UCS) and resilient modulus (M_r) tests were conducted on the carbonated RCA and CR samples together with crumb rubber, and the results were compared with those of the uncarbonated specimens. The results showed that the carbonation process led to a significant increase in the UCS values. However, carbonation resulted in a decrease in the deformability of the specimens compared with the uncarbonated specimens. Moreover, carbonation resulted in a significant increase in the M_r values compared with those of the uncarbonated values. Also, the carbonation process had a more substantial effect on the M_r values of the CR than of the RCA.

1. Introduction

Recently, the landfilling and soaring production of solid wastes have exacerbated CO_2 emissions, and, consequently, increased pollution worldwide. When screening for landfill sites the hierarchy of aspects to be considered could be summarized as community need, landfill type, groundwater, alternative potential uses for the site, buffer distances, geology, flora and fauna, infrastructure, surface water, and land ownership (EPA Victoria, 2015). Therefore, due to the lack of suitable land for the landfilling of solid wastes, the traditional approach is uneconomical and unsustainable. In addition, the construction industry is keen to use recycled solid wastes instead of virgin and natural materials (Azam et al., 2014; Choudhary et al., 2014; Arulrajah et al., 2017; Saberian et al., 2018a). Every year, approximately 9 million tons of RCA are replaced in Australia (Arulrajah et al., 2013). Also, the CR is produced by the crushing, scalping, and screening of crushed concrete newer basalt surface spalls (NBSS) and/or raw rock feed source (VicRoads, 2016). Moreover, approximately 0.5 million tons of rubber tyres are replaced in Australia annually. However, as scrap tyres are very tough and difficult to degrade in landfills, recently, the treatment of scrap tyre rubber has become an environmental problem. Therefore, incorporating the waste-stream materials, such as scrap tyres, RCA, and CR, into civil engineering projects will dramatically reduce the carbon footprint of the projects as well as reduce the demand for virgin quarry materials. Reusing the wastes can also provide cost reductions and a quantifiable positive environmental life-cycle impact by the reduction of cement production and waste debris in landfills (Kardos and Durham, 2015; Saberian and Rahgozar, 2016; Saberian et al., 2017b, 2018b; Rahgozar et al., 2018). In addition, although the inclusion of rubber to concrete and C&D aggregates decreases the compressive and strength properties, it will provide good water and acid resistances, low shrinkage, high impact resistance, outstanding thermal and sound insulations, and good fatigue and toughness performance (Rahgozar and Saberian, 2016; Siddique and Naik, 2004).

Fig. 1 shows a view of circular economy of the C&D wastes. Large amounts of C&D wastes are generated in Australia, which include concrete, bricks, and asphalt etc. Of this total waste stream, 66% of them are recycled and the remaining are disposed to landfills. Although the rate of recycling is considered high, Australian State Governments are committed to achieving more than 70% of recycling rate. The Victoria Government launched the Towards Zero Waste Strategy in 2005 and had set the target at 80% for recovery of

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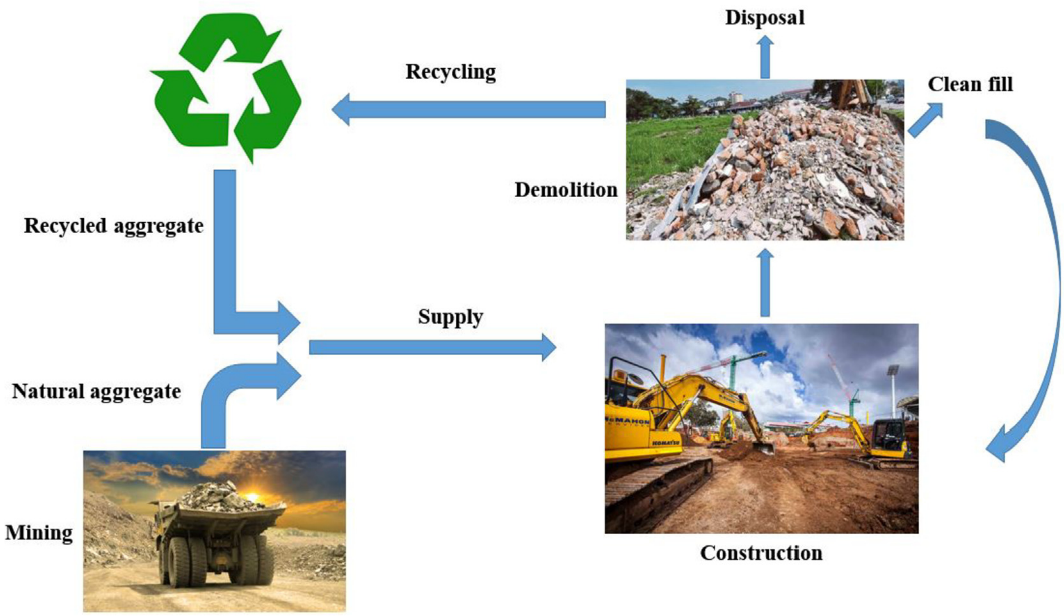

Fig. 1. A circular economy view of the C&D wastes.

materials from C&D (Akhtar and Sarmah, 2018). New Zealand and Australia are promising to adopt, reuse, and recycle waste materials by imposing landfill levy on disposal of waste. Previously, disposal cost rates ranged from $42 to $102 (31–76 USD) per tonne, and this has now increased at $10 (7.5 USD) per year until 2016 upon the revision of cost increment (Australian Government, 2012).

A few technologies have been developed for improving the mechanical properties of RCA to extend its application. Otsuki et al. (2003) and Tam et al. (2005) used a two-stage mixing method and reported that the mixing approach could improve the properties of RCA since the RCA would be coated with mortar with a lower water-binder ratio in the premixing process. Such an approach leads to a stronger interfacial transition zone (ITZ). Kou and Poon (2010) concluded that the addition of polyvinyl alcohol (PVA) solution could increase the strength and durability of RCA. Elhakam et al. (2012) proposed a self-healing method by immersing the RCA in water for up to 30 days. This would result in improving the properties of RCA since the unhydrated cement particles would react with water again. Since the carbonation process can improve the mechanical properties of RCA, it has been recently reported that the properties of RCA can be improved when using carbonated RCA. Due to the sequestration of CO_2 by the RCA, this process is environmentally friendly and also low cost (Monkman and Shao, 2010; Zhan et al., 2014; Zhang et al., 2015; Xuan et al., 2016).

The aim of this research was to evaluate the effects of the eco-friendly carbonation approach on the mechanical properties of construction and demolition aggregates (i.e., RCA and CR) together with crumb rubber. In this regard, the unconfined compression strength and M_r tests were undertaken on the carbonated RCA and CR aggregates together with crumb rubber. The results were compared with those of the uncarbonated specimens.

2. Materials and methods

2.1. Materials

Materials used in the present study were Class 2 CR and RCA with nominal sizes of 20 mm, which are widely used for road base, landscaping, building, civil construction and infrastructure projects in Melbourne, Australia (Arulrajah et al., 2017; Li et al., 2018; Mohammadinia et al., 2016; Saberian et al., 2018a). The properties of CR and RCA are summarized in Table 1. The corresponding particle size distribution curves are presented in Fig. 2. Also, the used crumb rubber with a size of 400–600 μm was collected from a local tyre recycling plant in Melbourne, Australia.

Table 2 provides the chemical composition of the RCA and CR which were obtained by X-ray fluorescence (XRF) spectroscopy. The total amount of the major components (i.e. SiO_2, Fe_2O_3, and Al_2O_3) for RCA and CR were 72.32% and 66.79%, respectively.

2.2. Mix design and sample preparation

To make the specimens, the optimum moisture contents of 8 and 12% were first added to the 24-h-oven-dried CR and RCA, respectively. Then, each sample was allowed to cure in an air-tight sealed container for at least 2 h to an even water absorption by the aggregates (AS 1289.5.2.1, 2017). Then, different percentages of the crumb rubber were added to the aggregates at 0, 0.5, 1, and 2% (by dry weight percentage of each aggregate). For mixing the samples with water and rubber, each blend was mixed by Hobart Commercial Mixer for at least 5 min.

For the UCS test, the mould had an effective internal height and

Table 1
Properties of the used aggregates.

Properties	RCA	CR
Fine content (%) (less than 0.075 mm)	7	8
Sand content (%) (ranging from 0.075 mm to 4.75 mm)	31	32
Gravel content (%) (ranging from 4.75 mm to 76.2 mm)	62	60
Loose bulk density (natural) (Mg/m^3)	1.60	1.65
Compacted bulk density (Mg/m^3)	2.65	2.76
Maximum dry density (Mg/m^3)	2.01	2.24
Coefficient of uniformity (C_u)	42.86	66.67
Coefficient of curvature (C_c)	2.01	3.13
Optimum moisture content (%)	12	8
Liquid limit (%)	35	30
Plasticity index	6	6
Flakiness index (%)	35	35
pH	11.6	9.8