Construction and Building Materials 142 (2017) 248–255

Contents lists available at ScienceDirect

Construction and Building Materials

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

Influence of recycled coarse aggregate derived from construction and demolition waste (CDW) on abrasion resistance of pavement concrete

Rakesh Kumar

Rigid Pavements Division, CSIR-Central Road Research Institute, Delhi Mathura Road, New Delhi 110 025, India

HIGHLIGHTS

- 4.75–10 mm and 10–20 mm size RCA were used to replace NCA of similar size range.
- Abrasion resistance of concrete made with RCA was investigated.
- RCA reduces abrasion resistance of paving concrete but not beyond acceptable limit.
- RCA can be used in paving concrete mixes.

ARTICLE INFO

Article history:
Received 9 December 2016
Received in revised form 23 February 2017
Accepted 9 March 2017
Available online 17 March 2017

Keywords:
Concrete
Recycled concrete aggregate
Compressive strength
Abrasion
CDW

ABSTRACT

Coarse aggregate has notable influence on concrete properties. The sustainability in concrete is generally achieved through reduced mining of natural resources required for the manufacturing of its basic constituents, by recycling of suitable industrial by-products or post-consumer materials including construction and demolition waste (CDW). CDW is composed of several materials depending on its locality of the origin. Recycled concrete aggregate (RCA) is obtained by crushing the concretized components of CDW. RCA is inhomogeneous with respect to its dynamic properties unlike natural coarse aggregate (NCA). A pavement concrete has to possess a proper strength and adequate abrasion resistance to resist surface wearing due to a moving traffic. This study presents the influence of using RCA as a replacement of NCA in paving concrete. Two series of concrete mixes, at two different water-cement ratios, that is, 0.44 and 0.38, were used in this study. The study exhibited that RCA reduces the abrasion resistance significantly yet it could be effectively used in pavement concrete.

1. Introduction

The global demand for construction quality aggregates is expected to be more than 51 billion metric tons by 2019 [1]. The mining, processing, and transport operations for such a large quantity of aggregates consume a huge amount of energy and adversely affect the ecology of the areas and riverbeds [2]. Ever increasing demand for quality aggregates has resulted in a faster rate of depletion of natural resources such as rocks, river, as well as land quarried sand, in many parts of the world endangering sustainable developments. Though the demand for aggregates is entirely based upon region to region, depending upon economic growth; generally, the availability of good aggregates is getting scarce everywhere. In concrete, the sustainability is generally achieved through a reduced mining of natural resources for the manufacturing of its basic constituents, by recycling of suitable industrial by-products or post-consumer materials including construction and demolition waste (CDW). Such usage requires that the durability of the concrete is not compromised but enhanced. The scarcity of availability of aggregates followed by rapid growth in infrastructural development calls for finding suitable alternative sources for it. Among all the alternate sources for aggregates, the recycling of construction and demolition waste (CDW) has grown in popularity because it is generally available everywhere [3]. Further, across several measures, use of RCA has a lower environmental impact than NCA [2]. CDW is generated whenever a building, road, bridge, industrial structure or a manufacturing facility is constructed, repaired or rehabilitated or demolished. A majority of RCA material comes from building renovations and demolition. Such demolition activities pollute the environment by releasing dust particles. CDW is typically composed of wood, plaster, concrete, asphaltic cement, roofing materials, glass, plastics, metal, insulating materials, carpeting, and other similar material depending on its locality of the origin. The construction and demolition is a continuous process, which seemingly will continue forever. The world needs to address a judicious management of the solid waste

E-mail address: rakesh_crri@hotmail.com

http://dx.doi.org/10.1016/j.conbuildmat.2017.03.077
0950-0618/

that it generates from construction and demolition processes. Table 1 shows CDW generated and recycled in few countries across the world.

Attempts to utilize CDW, in order to produce concrete aggregates have been made since the World War II [5] and possibly even before. However, it is important to note that the RCA derived from CDW is inhomogeneous unlike NCA derived from a rock. Recycled aggregate contains other deleterious materials, which make it difficult for complete replacement of a good quality natural aggregate for concrete; and, therefore, restricting its many applications such as in reinforced concrete structural elements. Several studies [6–16] have shown that the fresh and hardened state properties of concrete made with RCA widely depend upon the quality of the parent concrete from CDW. The maximum nominal size of recycled aggregate influences the amount of mortar attached to the recycled aggregate. The finer the aggregate, more mortar content is attached to it [7–10]. Due to this reason, specific broad conclusions are difficult to make for the use of RCA. A general conclusion for the reference purposes about the properties of concrete made with recycled aggregate with respect to natural aggregate with same water-to-cement (W/C) ratio is shown in Table 2. However, it is important to note that the quality of the concrete made with recycled aggregate depends entirely upon the quality of recycled aggregate; the proportion at which it has replaced natural aggregate, the amount of cement paste adhered to it, and other similar factors. Due to a wide variation in the available literature, it is apparent that numerous experimental data are generated for the in-house needs, using local RCA, in order to draw any specific conclusion for a given project activity. A lower density, higher water absorption, higher porosity and a lower specific gravity for the mortar content attached to the recycled aggregate in comparison with natural aggregate result in a decrease in compressive strength, modulus of elasticity, density, as well as durability factor of concrete. In a recent study Knaack and Kurama [25] have reported an insignificant influence on the rate of strength gain of RCA concrete compared to NCA concrete. An extensive study by Silva et al. [26] suggests that a performance based classification of RCA based on its physical properties for the use of RCA in concrete can minimize the variation in the properties of concrete containing it.

Concrete used in the construction of road surfaces, bridge decks, airfield runways, parking lots, and other similar applications is generally known as a pavement concrete or pavement-quality concrete. This concrete undergoes dynamic loading due to moving traffic and ambient environment. Therefore, this concrete has to possess a proper strength and durability properties relevant to its use in pavements. Deterioration of concrete surfaces occurs due to various forms of wear such as erosion, cavitations, and abrasion due to various exposures. Abrasion wear occurs due to rubbing, scraping, skidding, or sliding of objects on the concrete surface. This form of surface wear is observed in pavements, floors, or other surfaces on which friction forces are applied due to relative motion between the surface and the moving traffic. Concrete abrasion resistance is markedly influenced by a number of factors including concrete strength, aggregate properties, surface finishing, curing, and other similar factors. The characteristics of coarse aggregate have noticeable impact on the performance of the concrete pavements. Numerous studies [27–32] have indicated that the abrasion resistance of concrete is mainly dependent upon the concrete's compressive strength. The factors such as water to-cementitious materials ratio, type of aggregates and their properties, air entrainment, and other similar factors, which affect the concrete strength also influence the abrasion resistance. According to ACI Committee 201 [27], concrete subjected to abrasion should have a compressive strength at least 28 MPa. In general, a hardened cement paste possesses low resistance to abrasion. In order to develop a concrete for a high abrasion resistance, it is desirable to use a hard coarse aggregate, and paste having low porosity and high strength [28]. Sufficient information on the abrasion resistance of concrete containing RCA is not readily available. Therefore, this research project was undertaken to investigate the abrasion resistance of concrete incorporating RCA derived from the CDW generated in New Delhi, India. The paper presents the comparative properties of RCA against NCA. The influences of the replacement of NCA by RCA in size range 10–20 mm and 4.75 to 20 mm on strength and abrasion resistance of pavement concrete mixes are presented.

Table 1
CDW waste generated and recycled [4].

Country	Waste generated (Mt)	Percentage of recycling	Percentage of landfill
USA	180	56	44
Germany	59	17	83
UK	30	45	55
France	24	15	85
Italy	20	9	91
India	12	NA	NA

Table 2
Properties of concrete with RCA vis-a-vis NCA.

Property	RCA compared to NCA	References
Compressive strength	Decrease up to 25%	[6,10–12]
Splitting and flexural tensile strength	Decrease up to 10%	[6,7,11–14]
Modulus of elasticity	Decrease up to 45%	[6,8,9,12,13]
Drying shrinkage	Increase up to 50%	[15–18]
Creep	Increase up to 50%	[15,17,19]
Water absorption	Increased up to 50%	[13,17]
Freezing and thawing resistance	Decreased	[19,20]
Carbonation depth	Similar	[21,22]
Chloride penetration	Similar or slightly increased	[22–24]

2. Experimental study

The experimental study includes the evaluation of the suitability of the recycled concrete aggregates and comparison of their properties with natural coarse aggregates of similar size range, evaluation of sand, testing of cement, preparation and testing of concrete specimens for the study of influences of the replacement of NCA with RCA on concrete properties for pavement construction.

2.1. Materials

The materials used include; an ordinary portland cement (OPC), crushed quartzite natural and recycled aggregate in size range of 4.75 mm to 20 mm msa, land quarried sand for concrete, tap water, and polycarboxylate ether-based high range water reducing agent (HRWRA). The basic properties of the OPC used in the study are presented in Table 3. The gradation of fine aggregate (sand) is presented in Table 4. The water absorption, specific gravity, and bulk density of sand were 1.0%, 2.65, and 1600 kg/m^3, respectively. Potable water available at CSIR-CRRI laboratory was used for the mixing of the concrete mixes and for the curing of the concrete specimens. A high-range water reducing agent (HWRA) was used to get the desire workability for the concrete.

2.2. Recycled verses natural coarse aggregate

RCA in the size range of 4.75–10 mm and 10–20 mm was collected from a commercial recycling plant from time to assess the variation in its composition, as well as physical and mechanical