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Evaluation of recycled concrete aggregates for their suitability in construction activities: An experimental study

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ABSTRACT

Construction and demolition waste disposal is a major challenge in developing nations due to its ever increasing quantities. In this study, the recycling potential of waste concrete as aggregates in construction activities was studied. The metal leaching from the recycled concrete aggregates (RCA) collected from the demolition site of a 50 year old building, was evaluated by performing three different leaching tests (compliance, availability and Toxic Characteristic Leaching Procedure). The metal leaching was found mostly within the permissible limit except for Hg. Several tests were performed to determine the physical and mechanical properties of the fine and coarse aggregates produced from recycled concrete. The properties of recycled aggregates were found to be satisfactory for their utilization in road construction activities. The suitability of using recycled fine and coarse aggregates with Portland pozzolanic cement to make a sustainable and environmental friendly concrete mix design was also analyzed. No significant difference was observed in the compressive strength of various concrete mixes prepared by natural and recycled aggregates. However, only the tensile strength of the mix prepared with 25% recycled fine aggregates was comparable to that of the control concrete. For other mixes, the tensile strength of the concrete was found to drop significantly. In summary, RCA should be considered seriously as a building material for road construction, mass concrete works, lightly reinforced sections, etc. The present work will be useful for the waste managers and policy makers particularly in developing nations where proper guidelines are still lacking.

1. Introduction

In developing nations, the demand for raw materials is continuously increasing for infrastructure development. At the same time, the demolishing and renovation activities for old buildings are also carried out in parallel which are resulting in the generation of concrete debris. Presently, the majority of demolition waste is disposed with municipal solid waste (MSW) in India since it is classified as non-hazardous as per MSW (Management and Handling Rules), 2000 (Ministry of Environment and Forests (MoEF), 2000a). Only gypsum board waste is categorized as hazardous waste in schedule III (Part B) of the Hazardous Waste (Management and Handling) rules, 2000 (MoEF, 2000b) and needs to be separately disposed. However, the presence of other harmful and toxic inorganic and organic contaminants in demolition waste may have adverse impact on the surrounding. Landfilling of waste requires significant land area and is therefore placed at the bottom of waste hierarchy pyramid. In developed nations, the recycled concrete aggregates (RCA) are suggested as a replacement to the natural aggregates (NA) in road and building construction activities (Hansen, 1992; Rodrigues et al., 2013; Medina et al., 2014). Some of these countries have specific codes dealing with the handling and use of RCA in such activities. However, the use of RCA in construction activities in many developing countries is still limited largely due to insufficient knowledge database, policies and specifications. The composition and characteristics of the RCA will depend on the construction materials used and demolishing operation. Therefore, the present study was planned to make the information available on RCA produced after the demolition activity at an old multi-storey building in India and to determine their impact on the quality of concrete.

It has been reported that the concrete made with recycled coarse aggregates (RC) has similar properties to that produced from NA (Silva et al., 2014). On the other hand, the use of recycled fine aggregates (RF) in concrete production needs caution because of its higher water absorption tendency compared to NA, which

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can adversely impact the properties of concrete (Evangelista and De Brito, 2007; Rodrigues et al., 2013).

While the physical and mechanical properties of RCA need to be determined for assessing its suitability in various construction projects, the metal leaching behavior of RCA should also be studied since the presence of mobilized heavy metals can have adverse impact on the surrounding environment. Galvín et al. (2013) tested seven recycled aggregate samples for potential release of heavy metals (such as Cr, Ni, Cu, Zn, As, Se, Mo, Sb, Ba, Hg, Pb and Cd) and anions (Cl^-, F^- and SO_4^{2-}). In the analysis of five samples, the heavy metal leaching exceeded the maximum limit (specified by European Union (EU) landfill directive), thus disqualifying the material to be accepted in an inert waste landfill. Butera et al. (2014) collected RCA samples from eleven different recycling facilities in Denmark and studied the leaching of heavy metals by performing the CEN 12457-1 compliance test (a single stage batch test at L/S = 2 L/kg over 24 h). For most of the samples, Se leaching was above the permissible limit and for few samples, Cr and Sb also exceeded the prescribed limits. Most of the previous studies were performed with ordinary Portland cement (OPC) and RCA mixture (Katz, 2003; Galvín et al., 2014; Medina et al., 2014; Silva et al., 2014) whereas studies examining properties of concrete produced from Portland pozzolana cement (PPC) and RCA are scarcely available in the literature. PPC is commonly used for concrete production in India (Madras Consultancy Group, 2014) and therefore, the nature of concrete prepared using PPC and RCA need to be studied.

In this research study, the waste collected from a demolition site was characterized and the RCA was sieved to separate out RC and RF fractions which were then subjected to various physical, mechanical and leaching tests. Their properties were checked against the prescribed standards for aggregates to use in road construction activities. The properties of the concrete prepared with waste derived aggregates were also analyzed.

2. Materials and methods

2.1. Materials

Waste sample was collected from the demolition of a 50 year old three storey library building. Prior to the demolition, all reusable materials (such as roofing material, doors, windows, glass panes, and switch boards) were separated out. In addition, the gypsum boards were also removed and stored separately. Subsequently, the building was demolished in three phases and the segregated concrete waste was stored onsite in six piles. The composition of demolition waste was determined after weighing the manually segregated components (Table 1). It can be observed that around 31% of the total demolished material comprised of concrete waste, while soil, bricks and flooring material constituted the majority of the remaining portion. The present study focused on the evaluation of recycling potential of concrete fraction only.

For the experimental study, around 1000 kg of the source separated unwashed concrete waste was collected randomly from the piles. Out of 1000 kg, around 60 kg of the waste was taken for metal leaching tests and divided into three parts to conduct the analysis in triplicate. The concrete samples were crushed and the material passing through 300 μm sieve was only used for metal leaching tests. Another 350 kg of the concrete waste was crushed and graded in the following sizes: (i) 0–4.5 mm, (ii) 4.5–10 mm and (iii) 10–20 mm. The simplified procedure adopted for waste sampling is illustrated in Fig. 1.

PPC 33 grade cement supplied by local vendor was used for concrete preparation in laboratory. The chemical composition of PPC and concrete waste samples were determined using X-ray fluorescence (XRF) technique (PANalytical, The Spectris Technology, The Netherlands). Crushed gravel and granite stones were used as natural coarse (NC) and fine (NF) aggregates, respectively.

Table 1
Composition of the waste generated from a demolition site.

Type	Composition (% by weight)
Concrete and masonry	31.3
Soil	21.6
Bricks	20.1
Tiles	15.6
Mosaic flooring	10.4
Wood	0.50
Gypsum board	0.40
Steel	0.10
Miscellaneous (plastic sheets, glass pieces, earth pipes, old rusted pipes)	<0.10
Total	100

For improving the workability and reducing the water cement ratio, POLYTANCRETE NGT superplasticizer, which is a polymeric liquid admixture was used for concrete production. The superplasticizer confirms the requirement of ASTMC 494 Type F and Indian Standards (IS) 9103.

2.2. Aggregate testing

The mechanical and physical properties of natural as well as waste derived aggregates were determined in accordance with Indian standard (IS 2386, 1963) for aggregates to be used in concrete works.

Particle size distribution test for fine aggregates was conducted to determine the fineness modulus (FM) and grade of the crushed aggregates. Based on the results, these were classified as per Unified Soil Classification Systems (USCS). Other basic properties like specific gravity and water absorption capacity of the aggregates were also determined by standard procedures laid in IS 2386 (1963). The aggregate impact and crushing value tests were performed to examine the resistance of RCA to impact loading and gradually applied compressive load, respectively. These tests are carried out to assess the potential of aggregates for their use in road construction activities. The resistance of aggregates to abrasive and attrition forces was determined by Los Angeles abrasion test. The purpose of this test is to determine the capability of the aggregates to withstand the abrasive effect of traffic. Using sodium sulfate based soundness test, the ability of the waste derived aggregates to resist weathering action was predicted. Shape test was also performed to determine the flakiness and elongation indices of the aggregates.

2.3. Leaching study

Three different leaching tests were conducted to predict the fate of heavy metals in the waste sample: compliance test, availability test and Toxicity Characteristic Leaching Procedure (TCLP).

The compliance test was performed as per EN 12457-3 standard and the results were compared with the prescribed limits for inert waste landfills mentioned in EU landfill directive. The test was performed using 175 g of oven dried crushed sample (size < 300 μm) and deionized water in a 2 L beaker. In the first stage of leaching, liquid to solid (L/S) ratio of 2 L/kg was used while the mixture was stirred for 6 h. Subsequently, the L/S ratio was increased to 10 by adding more de-ionized water and the stirring was extended for an additional 18 h (Galvín et al., 2013). The final solution after each stage was filtered using 0.45 μm membrane filter paper and samples were acidified with 0.1 N HNO_3 before analyzing for heavy