Effective utilization of recycled concrete aggregate (RCA) in the structural applications

Thesis submitted in partial fulfillment
for the award of degree

Doctor of Philosophy

by

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Dedicated

To

Rudhransh (”Vishu”)

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DECLARATION

I, **Rahul Singh**, certify that the work embodied in this thesis is my own bonafide work and carried out by me under the supervision of **Prof. Rajesh kumar** from 21-July-2015 to 30-July-2022, at the Departement of Civil Engineering, Indian Institute of Technology (BHU), Varanasi. The matter embodied in this thesis has not been submitted for the award of any other degree/diploma. I declare that I have faithfully acknowledged and given credits to the research workers wherever their works have been cited in my work in this thesis. I further declare that I have not willfully copied any other's work, paragraphs, text, data, results, etc., reported in journals, books, magazines, reports, dissertations, thesis, etc., or available at websites and have not included them in this thesis and have not cited as my own work.

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Date: 01-08-2022 Rahul Singh

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Preface

As a result of the increasing rate of the urbanization, it is estimated that by 2050 the number of people living in cities will be approximately equal to the population of the whole world was in year 2000. Improved and large scale Infrastructural facilities have to be developed to accommodate the increasing urban population of the world. The requirement of growth of the construction industry putting direct pressure on natural resources, which are already depleting day by day. Development process not only uses the natural resources but also generate huge amount of waste. Apart from construction activities involved in infrastructural development, demolition activity is also a major part. Masonry and concrete of the demolished structure are treated as a waste due to their inertness. Hence, the waste generated during construction and demolition activities are termed as construction and demolition (C&D) waste. For sustainable development, the waste minimization and preservation of natural resources is the mostly required. Previous researches has established that demolition waste of buildings like concrete and masonry rubbles can be utilized as aggregate in the new concrete. When the waste recycled for aggregate contained concrete as well as other masonry produced aggregate is called recycled aggregate (RA). When only old concrete is recycled, it is called as recycled concrete aggregate (RCA). RCA can be subdivided in two major parts, coarse-RCA (C-RCA) and fine-RCA (F-RCA).

In this study RCA was used as aggregate (both coarse and fine) for the production of concrete. The use of RCA is one of the best solutions to mitigate the problem of ecological instability created by concrete waste. Literature shows that the RCA has less crushing strength, impact resistance, specific gravity, and more water absorption capacity than the natural aggregate (NA). About 25% to 30% RCA can be used in concrete production in place of NA without any harmful effect. When the replacement quantity is increased beyond 30%, the properties of concrete starts reducing in comparison to

NA-concrete. Two important approaches have been reported in literature to maximize the use of RCA into structural concrete: a) by minimizing the adhered mortar content; b) by strengthening the adhered mortar/strengthening of old inter-facial transition zone (ITZ). This study focuses on both approach for improving the properties RCA and hence RCA-concrete.

This present research is focused on the maximum utilization of RCA in place of NA for the production of new medium grade (M30 grade) concrete. Several methods were used to investigate the impact of both F-RCA and C-RCA, and their combination on the characteristics of concrete. The experimental investigation carried out in this study was divided majorly into three parts. In the first part, properties of RCA produced from the different types of concrete was analyzed. The objective was to observe the effect of parent concrete strength on produced aggregate by analysing the various physical and mechanical properties of F-RCA and C-RCA. Properties of RCA were lower than the properties of NA, and when the strength of old concrete increased the properties degrades further. The reduction in the aggregate properties is due the presence adhered mortar on it. Therefore, to improve the quality of C-RCA adhered mortar should be removed to the maximum extent.

In the second part, three types of mechanical/thermal treatment methods were studied for the removal of adhered mortar from C-RCA. The three methods are quenching and abrasion (QA), heating and abrasion (HA), simple dry abrasion (SDA). Four types of concrete samples were prepared by using 100% C-RCA obtained in the first part of study. RCA sampled for this part of study was classified as the aggregate obtained from high strength, low strength and mixed strength concrete waste. The objective was to analyze the effect of C-RCA type (based on the strength of old concrete) on the performance of concrete produced. Also, three RCA samples were treated with QA method while the fourth sample was treated with QA as well SDA method before mixing in concrete. This was done to observe the impact of treatment method type on the property of new concrete. Coupled effect of treatment application to remove adhered mortar and adopting a "re-modified two-stage mixing approach (R-TSMA)" to strengthen the adhered mortar, enhanced the bond strength between C-RCA and new mortar.

The third part of the study deals with the study on the effect of percentage replacement of C-NA and F-NA with C-RCA and F-RCA, respectively, on the properties of concrete. Replacement percentage of C-RCA as well as F-RCA used in this experiment was 30%, 60% and 100% (as a replacement of C-NA and F-NA by volume). Compared to C-RCA there has been significant resistance towards the use of F-RCA. In this experimental study both coarse as well as F-RCA were used, in order to investigate their compatibility with their substitutes NA. This study also proposes a technique based on experimental examination for the 100% use of C-RCA and F-RCA as a one-to-one substitute for C-NA natural sand (NS) in fresh concrete. The methods adopted in this study gives a promising result, concrete with 100% C-RCA performed equivalent to NA concrete. Upto 30% F-RCA can easily replace NS in the normal strength concrete, and upto 60% in the low strength concrete. The performance gap between conventional and recycled concrete was reduced with an increase in curing age. The recycled concrete containing three different combinations of F-RCA and C-RCA (0% and 100%, 30% and 0%, 30% and 100%) satisfied the target compressive strength criteria for M30 grade concrete as per IS 10262:2009. This study also shows that the density of RCA affected the concrete properties more than its water absorption. Also, the water permeability of recycled concrete (followed by its carbonation depth and compressive strength) was negatively influenced by incorporation of RCA.