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Evaluating the performance of self compacting concretes made with recycled coarse and fine aggregates using non destructive testing techniques

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HIGHLIGHTS

- Performance of SCC made with different replacement levels of Recycled Concrete Aggregates (RCA) with the use of Non Destructive Testing (NDT) techniques has been studied.
- Non-destructive tests such as Electrical Resistivity, UPV and Rebound Hammer were conducted on various SCC mixes made with different replacement levels of Coarse Recycled Concrete Aggregates (CrRCA) and Fine Recycled Concrete Aggregates (FnRCA).
- It has been observed that the SCC mixes containing low and intermediate percentage of RCA (CrRCA and FnRCA) as replacement of NA do not have any adverse effect on the overall performance.

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ABSTRACT

The paper presents the results of an investigation conducted to evaluate the performance of Self Compacting Concrete (SCC) made with different replacement levels of Recycled Concrete Aggregates (RCA) with the use of Non Destructive Testing (NDT) techniques. Non-destructive tests such as Electrical Resistivity, Ultrasonic Pulse Velocity (UPV) and Rebound Hammer were conducted on the various SCC mixes made with different replacement levels of Coarse Recycled Concrete Aggregates (CrRCA) and Fine Recycled Concrete Aggregates (FnRCA) at different periods of curing. Compressive strength tests on all the SCC mixes were also conducted for reference. The results show that increase in the content of RCA as replacement of Natural Aggregates (NA), decreases the electrical resistivity, UPV and rebound numbers for all SCC mixes. The linear regression coefficients depict excellent relationship between electrical resistivity, UPV and rebound numbers with compressive strength at all curing ages. It has been observed that the SCC mixes containing low and intermediate percentage of RCA as replacement of NA do not report any negative effect on the overall performance of SCC. Using waste materials (RCA) in new concrete certainly reduces its cost, encourages the concrete industry and correspondingly leads to the effective management of Construction & Demolition (C&D) wastes.

1. Introduction

The current demand of the construction industry is to produce such type of concretes which not only withstand the extreme environments but also conserve the natural resources. The introduction of Self Compacting Concrete (SCC) in the construction industry has already brought the revolution and has resolved few of the critical issues up to some extent due to its immense advantages [1,2]. On the other hand, the initial production cost of SCC in contrast to Normally Vibrated Concrete (NVC) has also proved to be a major challenge in the present concrete industry. It has been reported that the cost of ingredients used for making SCC is considerably higher than those for NVC [3]. The overall cost can be reduced by using alternate materials in the form of filler materials as partial replacement of cement or by replacing Natural Aggregates (NA) with Recycled Concrete Aggregates (RCA). To achieve environmental sustainability and practical applicability of SCC in construction industry, incorporation of Construction and Demolition (C&D) wastes as RCA seems to be the most feasible solution.

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Recycled Concrete Aggregates are obtained after the processing of inorganic materials which are used previously in civil engineering construction. After processing, RCA can be classified into two categories i.e. Coarse Recycled Concrete Aggregates (CrRCA) and Fine Recycled Concrete Aggregates (FnRCA). Recycled Concrete Aggregates can be differentiated from NA on the basis of their physical characteristics mainly. The concrete made with RCA behaves differently than that of concrete made with NA. The use of RCA in construction industry was initiated in the last decade but its implementation has been restrained in only few categories due to its poor physical and mechanical properties [4,5].

The quality of any concrete can be estimated quite satisfactorily with several Non-Destructive Tests (NDTs'). Various non-destructive testing techniques have been used in laboratory as well as in situ for the assessment of various characteristics of concretes. Most of the NDTs' have gained worldwide recognition due to their ease and the simplicity in estimating the overall quality of concrete for the past few decades. Electrical resistivity is an easy measure for accessing the transport properties in durable concrete structures. The probability of corrosion is inhibited with higher resistivity values in concrete due to uneasy movement of ions. There are various methods with which the electrical resistance can be evaluated in concrete but the technique based upon 'four probes' (also known as Weener Array Four Probe method) has been most widely used due to its high accuracy and low contact resistance losses [6]. The electrical resistivity has found to be increased with increase in curing time and with incorporation of various cement additions [7,8] whereas; it decreases with change in nature of aggregates in different types of concretes [9,10]. The observed change in the resistivity has been noticed due to the poor physical and mechanical behaviour of RCA. Ultrasonic Pulse Velocity (UPV) test has been found to be beneficial in estimating the overall performance of concrete. It provides information regarding elastic modulus, strength, uniformity, layer thickness, cracking, honeycombing, deterioration of concrete etc. In addition to the above, the test also offers an idea of the presence of voids, honeycombing or other discontinuities in concrete [11–13]. The rebound hammer test is another popular NDT which is used to evaluate the performance of concrete. According to ASTM 805-02 'This test method is applicable to assess the in-place uniformity of concrete, to delineate regions in a structure of poor quality or deteriorated concrete, and to estimate in-place strength development'. According to the available literature, a good correlation between compressive strength and UPV values has been obtained in NVC mixes made with NA and RCA and for SCC mixes made with NA. A similar behaviour has been obtained for compressive strength and rebound numbers at different curing periods [13–15].

2. Objectives

Based on the literature, it has been observed that a lot of research has been carried out to evaluate the performance of NVC made with NA and NVC made with RCA using NDTs'. Also, a chunk of literature is available on the SCC made with NA in which the overall performance has been judged with various NDTs'. To the best knowledge of the authors, a very few or no information is available on the assessment of SCC made with different replacement levels of Coarse Natural Aggregates (CNA) with CrRCA and Fine Natural Aggregates (FNA) with FnRCA with the use of the aforementioned NDT techniques (Electrical resistivity, UPV and Rebound Hammer). Therefore the current investigation has been planned; evaluate the performance of SCC made with RCA (CrRCA and FnRCA), viz. a viz. SCC made with NA (CNA and FNA) at different replacement levels of NA with RCA and to recommend the most appropriate combination of materials in terms of RCA for optimum/equivalent performance of SCC made with RCA viz. a viz. SCC made with NA. The emphasis here in this investigation is to achieve a most sustainable SCC that can be used in civil engineering construction which comprises alternative materials in the form of both CrRCA and FnRCA.

3. Experimental programme

3.1. Materials and mix proportions

Portland cement (PC) of 43 Grade complying the requirements of Indian Standard: 8112-1989 has been used in the current investigation. The chemical composition and physical properties of PC are listed in Tables 1 and 2 respectively. Coarse Natural Aggregates conforming to relevant Indian Standard 2386 (1963); Indian Standard 383(1970) were used for preparation of SCC mixes. The maximum nominal size of the crushed stone coarse aggregates was kept around 10 mm throughout the investigation. Coarse Recycled Concrete Aggregates were obtained manually by crushing the waste concrete specimens present in the Structures Testing Laboratory of the of the authors institute. The gradation of the CrRCA has been kept similar to that of CNA during the investigation. Natural river sand procured from Pathankot quarry, Punjab (India) was used as FNA. Fine Recycled Concrete Aggregates were obtained after straining the residue left from the recycled crushed gravel. Likewise, the gradation of FNA and FnRCA was kept almost identical. Fly Ash (FA) was obtained from Ropar Thermal Power Plant, Punjab, India.

The chemical composition of FA as provided by its supplier matches to 'Class F' type according to Indian Standard: 1727 (1967) and ASTM C-618 (1991). The particle size distribution curves for CNA, FNA, PC and FA are presented in Fig. 1. The physical properties of aggregates (CNA, CrRCA, FNA and FnRCA) are pre-

Table 1
Chemical composition of PC.

S No	Test parameter	Test value (%)	Recommended value (%)
1	Ratio of lime to silica, alumina and iron oxide	0.90	1.02 (max), 0.66 (min)
2	Ratio of alumina to iron oxide	1.58	0.66 (min)
3	Insoluble residue	1.1	2 (max)
4	Magnesia	2.6	6 (max)
5	Total sulphur content	1.3	2.5 (max)
6	Total loss of ignition	1.2	5 (max)
7	Total alkali	0.49	0.6 (max)
8	Chloride content	0.08	0.1 (max)
9	Calcium oxide: 61.3%, Magnesium oxide: 2.6%, Silica: 20.1%, Aluminium oxide: 6.80, Ferrous oxide: 4.30, Silicon trioxide: 1.3%		

Table 2
Physical properties of PC.

Characteristic	Units	Result obtained	Permissible range specified (IS: 8112-1989)
Specific gravity	–	3.15	3.10–3.15
Fineness	cm^2/gm	2340	2250 (minimum)
Soundness	Mm	3	10 (maximum)
Normal consistency	%	34	30–35
Setting time	minutes	65	30 (minimum)
		410	600 (maximum)
Compressive Strength	MPa	23	23.00 (minimum)
		35.5	33.00 (minimum)
		45.1	43.00 (minimum)