Construction and Building Materials 121 (2016) 400–409

Contents lists available at ScienceDirect

Construction and Building Materials

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

Carbonation and electrical resistance of self compacting concrete made with recycled concrete aggregates and metakaolin

Navdeep Singh, S.P. Singh *

Department of Civil Engineering, Dr. B R Ambedkar National Institute of Technology, Jalandhar 144 011, India

ARTICLE INFO

Article history:
Received 6 March 2016
Received in revised form 30 May 2016
Accepted 2 June 2016

Keywords:
Self compacting concrete (SCC)
Recycled concrete aggregates (RCA)
Carbonation
Electrical resistivity

ABSTRACT

The paper presents the results of an investigation conducted to examine the carbonation and electrical resistance of self compacting concrete (SCC) made with coarse recycled concrete aggregates (RCA). Self compacting concrete mixes were prepared by systematically replacing coarse Natural Aggregates (NA) by RCA at 0, 25, 50, 75 and 100%. In order to study the carbonation resistance of SCC made with RCA, accelerated carbonation tests were conducted for an exposure period of 4, 8, 12 and 16 weeks. The four probe method was used for electrical resistivity tests. The results indicate that with the increase in RCA content as replacement of NA, decrease in the carbonation resistance of SCC has been observed. For example, at 28 days of curing and 16 weeks of exposure, the carbonation depth of SCC mix containing 100% RCA has been found to increase nearly by 58% compared to that of SCC mix made with 100% NA. Similarly, electrical resistivity of SCC made with 100% RCA has been found to decrease nearly by 48% compared to that of control concrete at 28 days of curing. The addition of 10% Metakaolin (MK) has been found to compensate the loss in the carbonation and electrical resistance on account of substitution of NA with RCA up to some extent.

1. Introduction

The problem of generation and disposal of construction and demolition (C&D) waste emerged in the last of couple of decades. For avoiding or escaping to the environment impact caused due to construction industry, it is necessary to recycle the C&D waste. Recycled aggregates are now considered as the materials for the future in construction industry. Many countries have already implemented their use in the field of infrastructure development. The USA and some countries in Europe and Asia have started using recycled concrete aggregates (RCA) as construction materials since past decade. These countries use an approximate amount of 900 million tonnes of C&D waste annually [1]. For example, the use of C&D waste by countries mainly Germany, UK, Netherlands, France and USA crossed the mark of 286 million tonnes in 2010 alone [2]. Centre for Science and Environment, New Delhi in 2014 has estimated the global annual generation for C&D waste has been reached about 1.3 billion tonnes. This amount has been expected near to be doubled in 2025 by a report submitted by World Bank. Up to 2013, the total generation of C&D waste in India has reached about 530 MT [3].

Recycled concrete aggregates are nowadays considered as a non-conventional material for construction industry. A serious environmental impact can be avoided by suitably using C&D waste and its use can definitely help in preserving natural stocks for future use [4–6].

In now days, C&D wastes are used in concrete industry as replacement of coarse Natural Aggregates (NA) either in conventional form of concrete which is generally called Normally Vibrated Concrete (NVC) or in another type of concrete called self compacting concrete (SCC) [7]. Self compacting concrete was first developed in Japan in late eighties [8,9]. Self compacting concrete has gained its popularity worldwide because it is dense, homogeneous and has better engineering and durability properties as compared to NVC. Due to the presence of the large amount of fine particles, the pore structure of SCC is somewhat different from that of NVC. The physical properties of RCA are different from those NA as RCA consists of two different materials. Experiments conducted on concrete made with RCA indicate that attached or adhered mortar is responsible for its poorer properties as it lowers the density, increases water absorption and also leads to higher abrasion values [10,11].

Previous studies confirmed that replacement of NA with RCA and NA with Recycled Aggregates (RA) (obtained from crushed bricks and tiles) degrades the overall performance of all types of

* Corresponding author.
E-mail address: spsingh@nitj.ac.in (S.P. Singh).

http://dx.doi.org/10.1016/j.conbuildmat.2016.06.009
0950-0618/

concretes. A significant drop in workability, compressive strength, tensile strength, flexural strength etc. has been observed for higher percentage replacements. For example, use of RCA in NVC decreases the compressive strength up to 10–30%. Likewise, significant drops in other mechanical properties have been witnessed on replacement of NA with RA [12–17]. The poor performance of concrete made with RCA can be compensated by adding cement additions thus encouraging its use in making SCC which is a better performer as compared to NVC [2].

Durability of concrete is a relative property since it simultaneously depends on the chemical and physical characteristic of concrete and environmental conditions. The atmosphere, water and the soil are the environments to which concrete is exposed. In these environments, concrete is subjected to chemical and physical attacks such as sulphate attack, acid attack, carbonation, alkali aggregate reaction, freezing thawing, abrasion, etc. The performance of concrete against all these attacks is termed as durability. Out of all, carbonation is one of the most important factors having fatal consequences at later ages if not estimated and controlled. Carbonation is a major risk for reinforced concrete structures because it lowers alkalinity of concrete to such an extent that iron may rust and spall the cover. Carbonation of concrete is a slow and continuous process, progressing from the outer surface to inward and it slows down with increasing diffusion depth [18]. Carbonation process decreases the alkalinity of concrete to such an extent (from pH value 12–13 to 8–9), that the thin surface passive layer of reinforced bars dissolves which results in promotion of corrosion. Hence it is an unwanted process in concrete chemistry. Carbonation is a major cause for deterioration of concrete structures and mainly depends on various parameters like temperature, relative humidity, water cement ratio, water binder ratio, curing regimes, addition of admixtures, porosity, type of concrete and aggregates, cover, super plasticizer, relative humidity, temperature and concentration of carbon dioxide. In the design of concrete structures, carbonation is one of the many important factors that determine the service life of structures [19–21].

Corrosion is an electro chemical process which involves the flow of electrons through concrete. Electrical resistivity is a non-destructive test and it provides a good estimation regarding corrosion probability of concrete. According to Polder and et al. Concrete resistivity is a geometry independent material property which describes the electrical resistance. It is the ratio of applied voltage and resulting current in a unit cell [22]. Electrical resistivity describes the ability of concrete to oppose the movement of currents (ions) through its medium. Hence, higher resistivity helps in inhibiting the chances of corrosion in concrete. If concrete electrical resistivity is increased, the rate of corrosion decreases. The corrosion rate of steel can be measured indirectly by measuring the electrical resistivity of concrete [23,24]. The resistivity of concrete also depends upon many factors which are similar to factors which affects carbonation [25].

A lot of research has been carried out to evaluate the carbonation resistance of NVC made with NA and RCA and SCC made with NA. As reported in studies on NVC containing NA, an increase in content of RCA increases the carbonation depth by 1.3–2.5 times than that of concrete made with NA [26–30]. Even an increase of 3 times in carbonation depth of concrete made with 100% RCA has been reported compared to that of NVC made with 100% NA [31]. The reported behaviour of variation in carbonation depths is completely dependent on the permeability conditions of adhered mortar of RCA [26,32,33]. In particular, a diminutive literature of SCC made with NA is available in which carbonation depths have been examined. Investigations have clearly demonstrated that SCC mixes are more durable than NVC mixes in association with carbonation coefficients. The obtained values of carbonation coefficients were quite small when compared to those of NVC mixes. For instance, the reduction in carbonation coefficients have been found to be 5.5% more in case of SCC than in NVC at same water to cement ratio (w/c) [19,34,35]. Based on the earlier studies, the presence of higher contents of calcium hydrates (CH) and calcium silicate hydrates (CSH) compounds with better microstructural properties are responsible for lowering the carbonation depths in SCC in comparison to NVC [36–38]. Also, sufficient work has been carried out to investigate the electrical resistivity of NVC and SCC containing NA wherein the electrical resistivity has been tested and probability of corrosion of steel is estimated. Test results from previous investigations revealed that addition of mineral admixtures improved the electrical resistivity of NVC and SCC made with NA at all the ages [39–41]. A growth of nearly 26% in resistivity values has been noticed after curing period of 28 days [42]. Similar results were obtained in the presence of fly ash (FA) in which resistivity values increased by 63% in comparison to control mix [43]. Presence of mineral admixtures has been found to change the micro structural behaviour and densify the pore structure, subsequently hindering the movement of ions through pores, resulting in higher resistivity values [44–47]. However, to the best of knowledge of the authors, no information on the carbonation resistance and electrical resistivity of SCC made with RCA is available in literature.

2. Research significance

It has been reported in the preceding section, wherein brief review literature on the subject has been presented, that there is no information available on the carbonation resistance and electrical resistivity of SCC made with RCA. Keeping in view the applications of SCC made with RCA, this investigation has been planned to evaluate the carbonation resistance and electrical resistivity as aforesaid, with incorporation of cement additions such as FA and metakaolin (MK). It is proposed to recommend most appropriate combination of materials in terms of RCA (replacement level) and cement additions (type and replacement level) for optimum performance in terms of carbonation and electrical resistance. The accelerated carbonation and electrical resistivity tests have been conducted on SCC mixes containing different replacement levels of NA with RCA. Fly ash and MK have been used in different proportions as partial replacement of Portland Cement (PC). In addition, the compressive strength tests on all the SCC mixes have also been conducted.

3. Experimental programme

3.1. Materials

Portland cement of grade 43 confirming IS 8112: 1989, natural sand, natural and recycled crushed gravel of maximum size 10 mm were used in the preparation of nine different SCC mixes. Coarse RCA were obtained by crushing the waste concrete specimens present in the Structures Testing Laboratory of the Department of Civil Engineering of the author's Institute. The aggregates were crushed manually and were reduced to required size i.e. 10 mm maximum. Larger size (>10 mm) of RCA made the production of SCC rather difficult as it required higher doses of superplasticizer (SP) to satisfy the workability criteria. The physical properties of all the ingredients used in this investigation are presented in Tables 1–4. Poly carboxylic ether based was used in order to achieve adequate workability and a viscosity modifying agent (VMA) was employed in order to attain bleed free mixes. In addition to this, FA and MK were incorporated in different proportions as cement based materials. The particle size distribution of PC, FA, MK, NA, RCA and Fine aggregates are presented in Fig. 1.