J. Inst. Eng. India Ser. A (June 2022) 103(2):349–358
https://doi.org/10.1007/s40030-021-00608-y

ORIGINAL CONTRIBUTION

An Investigation of Mechanical and Durability Properties of Carbonated Recycled Aggregate Concrete

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Received: 26 February 2021 / Accepted: 11 December 2021 / Published online: 11 February 2022

Abstract Although the recycled aggregate concrete (RAC) is promoted globally, its use in structural applications is restricted because of its inferior durability owing to the porous and weak residual mortar adhered to recycled aggregate particles. The accelerated carbonation treatment has a potential to modify the pore structure of recycled aggregates. In this regard, the present study has been carried out to understand the effect of accelerated carbonation treatment on the properties of RAC. Mechanical, durability and nondestructive properties of natural aggregate concrete (NAC), RAC and carbonated recycled aggregate concrete (CRAC) were investigated and the results were compared to each other. A total of three mixes with 100% NAC, 100% RAC and 100% CRAC were studied. The results of this investigation reveal that all the properties of RAC were appreciably inferior to that of NAC. However, the accelerated carbonation treatment of recycled aggregates and their subsequent use in concrete enhanced all the aforementioned properties significantly.

Keywords Recycled aggregate · Carbonation · Durability properties · Permeability · Water absorption

Introduction

Concrete has widely been used for construction purposes for more than a century due to its satisfactory mechanical and durability properties and because of its versatility, easy availability and cost effectiveness. The rapid urbanization and industrialization have led to the increased demand of concrete. It is estimated that one cubic meter per capita of concrete is produced globally every year [1]. Due to increasing economy and development of infrastructure, large quantity of construction and demolition wastes (C&DW) is produced every year and the available landfill sites for dumping this waste are dwindling with time [2, 3]. The environmental issues that hinder the use of concrete in construction are that they utilize the naturally available raw materials and produce about 50% of total waste. In addition, the cement used for concrete production generates around 8% of global carbon dioxide emissions [4, 5]. For sustainability and environment protection, it is necessary to recycle and reuse the waste generated from construction industry and reduce the emission of gases responsible for global warming through sustainable technologies [6, 7]. The waste concrete when subjected to crushing process produces 65–80% coarse and fine aggregates and 20–35% adhered mortar [8]. It has been observed that there are numerous shortcomings of using recycled aggregates directly in concrete production and their applications are limited to road sub-base, embankments, non-structural components, etc. The adhered mortar on the recycled aggregates is highly porous which leads to high permeability and water absorption and has less density and resistance to fragmentation [9]. The untreated recycled aggregates when mixed with concrete make it harsh and affect both the mechanical and durability properties of recycled aggregate concrete (RAC). Numerous experimental studies are present in the literature wherein the properties of RAC have been studied and it is well documented that RAC exhibits significantly inferior properties relative to NAC [7, 10–15].

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In order to improve the properties of recycled coarse aggregates (RCAs) and use them for structural applications, the weak adhered mortar on RCAs needs to be beneficiated. Various methods have been presented by researchers for enhancing the properties of recycled aggregates. Methods like mechanical grinding [16], pre-soaking in acid [17], ultrasonic cleaning [18], heat and rubbing [19] remove the adhered mortar and enhance the various properties of RCAs while as methods like self-healing [20], immersion in colloidal nano-silica solution [21], two-stage mixing approach [22] and chemical treatment densify the adhered mortar. However, the beneficiation of adhered mortar by accelerated carbonation has proved to be very effective as it not only refines the recycled aggregate properties but also reduces the carbon dioxide emission into the atmosphere and prevents global warming. This method is cost-effective and more environment friendly than the other methods of treatment. During the process of carbonation, carbon dioxide reacts with moisture present in the atmosphere and leads to the formation of carbonic acid. The carbonic acid consumes calcium hydroxide present inside the cement mortar and forms calcium carbonate crystals. Carbon dioxide also reacts with silicate–hydrate gel of adhered mortar and forms calcium carbonate [23–25]. This process can be represented in the form of following reactions.

$$Ca\,(OH)_2 + HCO_3 \rightarrow CaCO_3 + H_2O$$

$$C-S-H + CO_2 \rightarrow CaCO_3 + Silica + H_2O.$$

Calcium carbonate being finer in nature fills the pores and micro-cracks which results in enhancement of both mechanical and durability properties of RAC. The process of carbonation can take place under atmospheric conditions with a carbon dioxide concentration of 0.03–0.06% but this may take up to 100 years for its completion [26–28]. To overcome this problem, the technique of accelerated carbonation has been developed. The existing literature on recycled aggregates has shown that the accelerated carbonation treatment augments the density and crushing values while also leading to a decrease in water absorption and permeability values of recycled aggregates.

Research Significance

Limited studies are documented wherein the effect of accelerated carbonation treatment of recycled aggregates on fresh, hardened and durability properties of RAC is studied. The primary aim of carrying out this investigation stems from the aforementioned concern. Mechanical, durability and nondestructive properties of NAC, RAC and carbonated recycled aggregate concrete (CRAC) were investigated and the results were compared with each other. It is reckoned that the accelerated carbonation treatment of recycled aggregates will significantly enhance the hardened and durability properties of RAC. As such, this research is expected to be of significant use to various stakeholders who expect to use RAC for various structural applications.

Materials and Experimental Program

Materials

43-grade cement satisfying the guidelines laid down in IS 8112 [29] was used as a binder in the present study. It was ensured that the cement is fresh and free from any protuberances. Tests were conducted in order to determine its physical properties and the results are presented in Table 1. The coarse aggregates used were inactive granular materials having diameter more than 4.75 mm, with 20 mm maximum nominal size. The aggregates were washed in order to remove any impurities before conducting the tests for determining their physical properties. Fine aggregates consisted of crushed stone particles passing through 4.75 mm sieve. Table 2 shows the properties of aggregates.

Table 1 Physical properties of cement used

Property	Units	Values Obtained	Limiting values
Blaine's fineness	m^2 /kg	350	≥ 225
Specific gravity	–	3.15	3.15
Consistency	%	29	30
Setting time			
Initial	Minutes	108	≥ 30
Final		224	≤ 600
Compressive strength			
3 days	MPa	26.3	≥ 23
7 days		35.8	≥ 33
28 days			≥ 43

Table 2 Physical properties of the aggregates

Physical property	NCA	RCA	CRCA	Fine aggregates (FA)
Maximum size (mm)	20	20	20	4.75
Relative density	2.74	2.30	2.60	2.65
Water absorption (%)	0.64	12.92	6.38	1.6
Impact value (%)	11.0	25.57	15.05	–
Crushing value (%)	18.85	29.40	23.78	–
Residual mortar (%)	–	41.70	–	–

Aggregates (coarse and fine) conformed to the grading requirements of IS 383 [30].

The coarse RCAs were generated by crushing tested PC samples of normal, medium and high strength, by using a jaw crusher available in the concrete laboratory. Both NCA and RCA were used in two sizes, 4.75–10 mm and 10–20 mm as 33.3% and 66.6% of total coarse aggregate, respectively, and were complying with the grading requirements of IS 383 [30]. Figure 1 shows the typical aggregate samples. The impact and crushing values of the aggregates were determined as per the procedure given in IS: 2386 [31]. The properties of aggregates, both coarse and fine, are presented in Table 2. Residual mortar attached to the RCA samples was determined as per the test procedure proposed by Nagataki et al. [32].

Accelerated Carbonation Treatment

An airtight steel-cubical carbonation chamber, connected to a CO_2 cylinder, was used for preparing the carbonated recycled aggregates (CRAs). Prior to carbonation process, the RCAs were pre-conditioned for a period of 24 h at a relative humidity of 50–70% in a chamber by maintaining a temperature of 25 ± 1 °C. This was done to lessen the water saturation of aggregates and accelerate the carbonation reactions. The aggregate samples were then transferred to the carbonation chamber and cured for a period of 48 h at 99% concentration of CO_2 gas at a pressure level of 2.76 bar. The required pressure was maintained with the help of pressure gauges. A desiccant in the form of silica gel was positioned at the bottom of the chamber to soak up the water evaporated from the RCAs. The physical properties of CRAs were determined and are reported in Table 2.

Concrete Mix Design

For all the concretes, mix design was carried out using the procedure outlined in 10262 [33] and the mix proportions are reported in Table 3. The control concrete consisting of NCAs was designed for the target cube compressive strength of 30 MPa. For comparison of test results, the equivalent mix proportions for RACs and CRACs were designed by direct weight replacement method which because of its simplicity has been used in the literature [34, 35] for design of RAC mix proportions and in situations wherein the materials having different specific gravities are replaced with each other. In this method, the weight of all the ingredients is kept constant except for the material (coarse aggregate in the present case) which is to be replaced. In the present investigation, since the specific gravity of NCAs (2.74) is higher than that of the RCAs (2.30) and CRCAs (2.60), the amounts of the RCAs and CRACs are decreased in accordance with their specific gravities so as to produce the same volumetric yield. This is because similar weights of different coarse aggregates (NCAs, RCAs and CRCAs) occupy different volumes depending upon the specific gravity. Since RCA particles have relatively high water absorption capacities, care was taken to ensure that RCAs are used in the saturated surface dry condition. Glenium 51, a commercially available superplasticizer, was used as a water reducing agent in NAC, RAC and CRAC mixes, and its amount was decided with the help of trial mixes so that each mix was given an initial slump of 100 ± 10 mm in fresh state. For each concrete mix cubes (150 mm), cylinders (200 × 100 mm dia.) and prisms (700 × 150 mm × 150 mm) were cast by mixing the ingredients in a standard drum type concrete mixer having a capacity of 300 L. Casting of all the samples was done at room temperature. The samples were cast in two layers to ensure proper compaction and removal of air voids. After 24 h of casting, the concrete samples were demolded, shifted to a water tank and cured for a period of 28 and 56 days.

Test Methods

Nondestructive Properties

Ultrasonic pulse velocity (UPV) tests were carried as per IS: 13,311 (Part I) [36]. Tests were performed on 150 mm cubes after 28 and 56 days of curing. In UPV test, the speed of an ultrasonic wave passing through the cube is

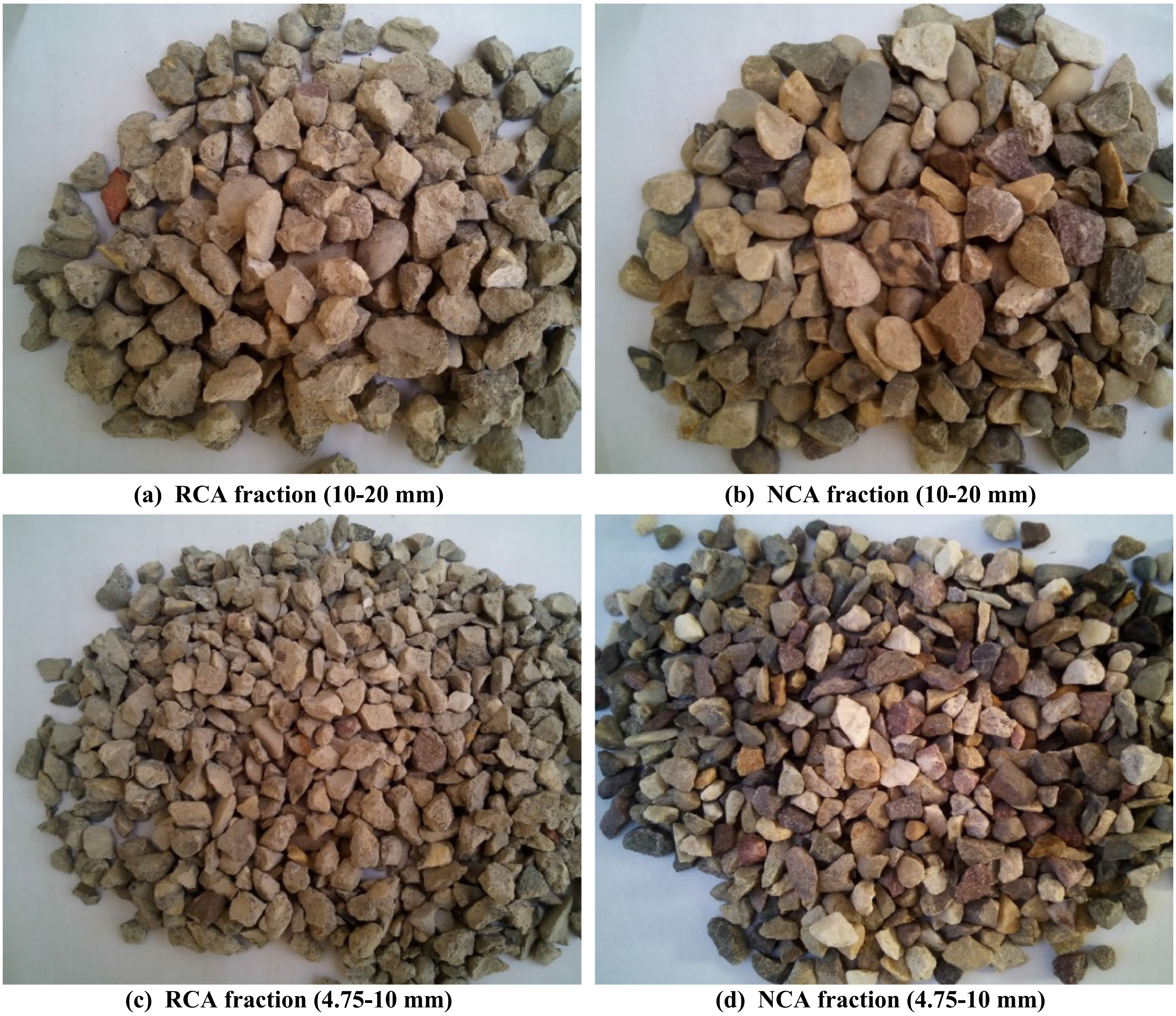

Fig. 1 Typical aggregate samples

Table 3 Concrete mix proportions

Mix	Ingredients (kg/m^3)									
	Cement	NCA		RCA		CRA		FA	Water	Superplasticizer
		10 mm	20 mm	10 mm	20 mm	10 mm	20 mm			
NAC	400	398.0	795.0	–	–	–	–	622	172	7.0
RAC	400	–	–	334.01	667.34	–	–	622	172	8.5
CRAC	400	–	–	–	–	377.66	754.34	622	172	8.0

utilized to assess the quality and strength of concrete. The ultrasonic pulse waves generated by an electro-acoustical transducer connected to one face of cube were passed through concrete and received by another transducer connected to the opposite face. Three replicate cubes were tested for each concrete type and an average of 9 readings was reported as the UPV value.

Rebound hammer (RH) tests were carried as per IS: 13,311 (Part II) [36] to find out the compressive strength of concrete. The RH calculates the rebound of a spring-controlled mass impacting against the surface of concrete. The rebound values are related to hardness of concrete and are used to ascertain the compressive strength. The RH test was performed on concrete cubes fixed under the platens of compression testing machine. The same set of cubes was consequently tested for compression. For each concrete mix, RH test was performed on three cubes and an average of 9 readings were taken for each cube.

Mechanical Properties

For determination of compressive strength, cubes of 150 mm size were tested in a 5000 kN compression testing machine as per the guidelines of IS 516. The compression test was performed under load-control mode at a rate of 5000 N/s. Three replicate specimens were tested for each mix at the age of 28 and 56 days and the average of the measured peak loads was reported as the compressive strength.

Cylinders having a diameter of 100 mm and 150 mm long were tested for splitting tensile strength as per the recommendations of IS 5816. The splitting tensile strength test was performed under load-control mode at the rate of 600 N/s up to failure. For each concrete type, i.e., NCA, RCA and CRCA, three replicate specimens were tested at curing ages of 28 and 56 days.

Testing for flexural strength was done in accordance with JCI-S-001–2003 on concrete prisms. Three-point bending test was conducted on a 100 kN capacity flexural testing machine on three replicate prisms of each concrete mix at curing ages of 28 and 56 days.

Durability Properties

The durability properties were evaluated in terms of Rapid chloride ion permeability (RCPT), water absorption, water permeability and sorptivity tests after 28 and 56 days of curing on six replicate specimens of each concrete mix.

Water permeability test was performed on 150 mm cubes as per BS EN-12390-8 [37]. It is considered to be a genuine indicator of the permeability of concrete. The setup used could accommodate three specimens at a time. The cubes are carefully fitted in the penetration test cells by means of screws and a sustained water pressure of 5 bar is applied for 72 h. The arrangement for maintaining the water pressure consists of a storage tank which is coupled to a pneumatic air compressor by means of a valve. After 72 h, water pressure is discharged following which the specimens are split vertically in a compression testing machine in order to determine the water penetration depth.

RCPT was done to evaluate the electrical conductivity of concrete and performed as per ASTM C1202-12 [38] on 50-mm-thick cylindrical specimens having a dia. of 100 mm. After sealing the lateral surface of the cylindrical specimens by a waterproof adhesive, the top and bottom surfaces of the samples were exposed to 3% NaCl and 0.3 mol/L NaOH solution. Across the ends of concrete specimen, a voltage of 60 V (DC) was maintained for 6 h and the charge passed was recorded at every 60-min interval.

Water absorption test was executed on 150 mm cubes as per ASTM C642-97 [39]. The test procedure consists of drying the concrete cubes to a constant weight and recording the dried weight after which the samples are immersed in water for 72 h and weighed again. The increase in weight as a percentage of original weight is expressed as water absorption.

The sorptivity test was conducted as per ASTM C 1585-4 [40] on 50-mm-thick cylindrical specimens having a dia. of 100 mm. Prior to testing, the circumferential surfaces of the cylindrical specimens were sealed with a waterproof adhesive and top surface was wrapped by a plastic sheet. The bottom face is exposed to a solution of water and calcium hydroxide in order to measure the rate of water uptake into the concrete sample by capillary rise.

Results and Discussion

Ultrasonic Pulse Velocity

Figure 2 shows the UPV values for all the three concrete mixes investigated. A perusal of Fig. 2 shows that the UPV values of NAC are higher than RAC corresponding to both the curing ages, i.e., 28 and 56 days. The decrease in UPV values for RAC may be accorded to the inferior quality of RCAs due to presence of micro-cracks in the interfacial transition zone (ITZ). Moreover, the low density and high water absorption of RCAs are also reckoned to affect the transmission of ultrasonic waves. It can be discerned from Fig. 2 that for all the concrete mixes, the UPV values are

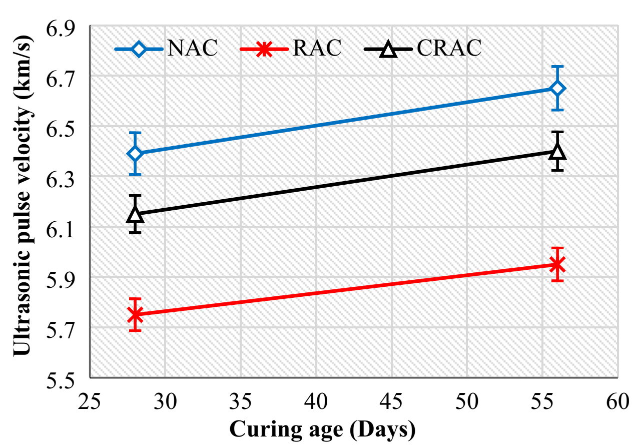

Fig. 2 UPV test results

more than 4.5 km/s and as per IS: 13311 [36], qualitatively the concretes can be classified as excellent. It can also be observed that UPV values of CRAC show a significant enhancement in comparison with the RAC after 28 and 56 days of curing ages, respectively. This behavior is ascribed to the lower pore spaces in CRAC due to the presence of calcium carbonate which results in better transmission of UPV waves.

Rebound Hammer and Experimental Compressive Strength

The 28- and 56-day compressive strengths of RAC are lower than that of NAC, illustrated for instance, by the values obtained after curing ages of 28 and 56 days, where the RH and experimental compressive strengths of RAC are lower in comparison with NAC. This decrease in compressive strength is attributed to the relatively porous and weak adhered mortar attached to RCA particles [41]. This weakens the ITZ which subsequently reduces the compressive strength. Moreover, the high water absorption capacity of RCAs has a negative effect on the hydration process and hence a reduction in compressive strength is witnessed. It can be perused from Fig. 3 that the compressive strength of RAC improved by using CRAs. For instance, compared to RAC, after 28 days of curing, CRAC exhibited an increase of 11.0% in experimental compressive strength and a decrease of 5.9% when compared to NAC. This behavior is ascribed to the high density of CRAs wherein the pores get filled with calcium carbonate which improves the ITZ. The CRAs also have lower water absorption capacity relative to RCAs thereby rendering sufficient water available for completion of hydration process which leads to an enhancement in compressive strength. The experimentally observed results of compressive strength are in concurrence to those of Wu et al. [42] and Xuan et al. [43]. As per the microstructural studies conducted by Luo et al. [44], the carbonation of RCAs leads to strengthening of the residual mortar and the old ITZ which in turn strengthens the CRCAs thereby enhancing the properties of resulting concrete.

Figure 3 presents a comparison of experimental and RH compressive strengths after curing ages of 28 and 56 days. The RH compressive strength is lower than the experimentally obtained values at both the curing ages. This may be due to the reason that manufacturer's curve for converting the rebound hammer number into compressive strength is generally on the conservative side. It is noteworthy that the difference between RH and experimentally observed values of compressive strength reduces with age of curing, e.g., for NAC the difference is 13.12% after 28 days and 3.33% after 56 days of curing. This is ascribed to the fact that hardness of concrete increases with age and RH values are directly related to hardness of the surface. The results are in concurrence to those of Sanchez et al. [45] and Jain et al. [46].

Split tensile Strength and Flexural Strength

Figure 4 shows a comparison of split tensile strength for all the concrete mixtures. It can be discerned from Fig. 4 that the tensile strength of RAC is lower in comparison with NAC after 28 and 56 days of curing. The decrease in strength is accorded to the inferior quality of RCAs and presence of micro-cracks at multiple interfaces in RCAs. At both curing ages (28 and 56 days), the CRAC exhibited an enhancement in split tensile strength in comparison with RAC. This is believed to occur due to the presence of calcium carbonate in the pores of RCAs which improves the ITZ in CRAC and consequently aids a proliferation in the tensile strength [1].

Figure 5 presents the flexural strength results of the concrete samples investigated in this study. Flexural

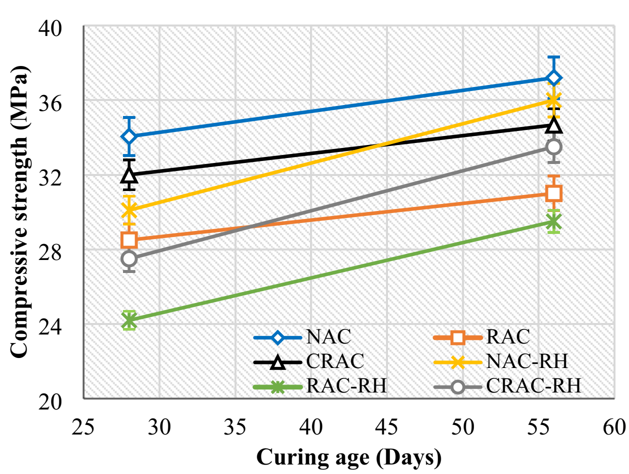

Fig. 3 Comparison of RH and experimental compressive strengths

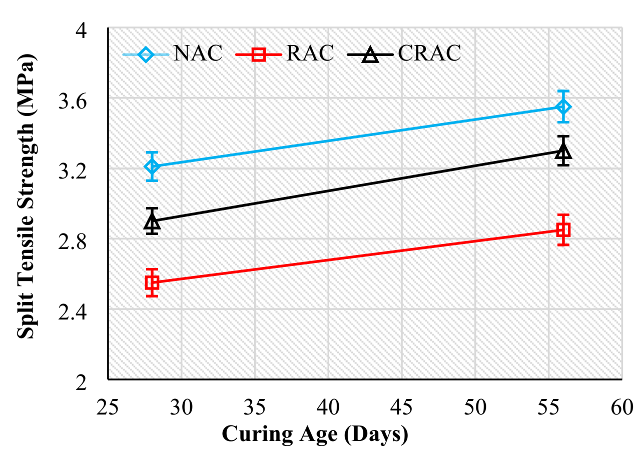

Fig. 4 Split tensile strength test results

strength of RAC exhibited a decrease at both curing ages, in comparison with NAC. CRAC demonstrated enhanced flexural strengths in comparison with RAC at both the curing ages. Similar observations were made by Ozbakkaloglu et al. [1] who reported that an increase in the amount of RCAs in concrete weakens the ITZ which in turn lowers both the tensile and flexural strengths. Xuan et al. [47] also reported an improvement in the flexural strength of 100% CRAC by 28.7% in comparison with 100% RAC. According to Xuan et al. [47] who measured the micro-hardness of cement paste in CRACs and found that micro-hardness on the ITZ of the CRACs was higher in comparison to RCAs. This enhanced micro-hardness led to improved ITZ which in turn improved the flexural and split tensile strength. This is reckoned to occur due to lower absorption of CRACs relative RCAs which leads to a comparatively lower w/c ratios around CRACs and hence, enhanced ITZ.

Chloride Ion Permeability

Chloride ion permeability is dependent upon the size and the volume of capillary voids in concrete. The presence of micro-cracks also has a bearing on resistance to chloride ion penetration. The RCPT results for all the concrete mixes are presented in Fig. 6. Total charge passed for a duration of 6 h was measured after 28 and 56 days of curing. The RCPT values reduced with the age of curing, e.g., relative to NAC, the chloride ion permeability of RAC was higher by 28% at 28 days of curing. This increase in chloride ion permeability can be accorded to the porosity of RCA particles thereby easing the way for chloride ions to pass through them. It is comprehended from Fig. 6 that utilization of CRAs in concrete improves the resistivity to penetration of chloride ions to a large extent. At both the curing ages (28 and 56 days), the chloride ion permeability

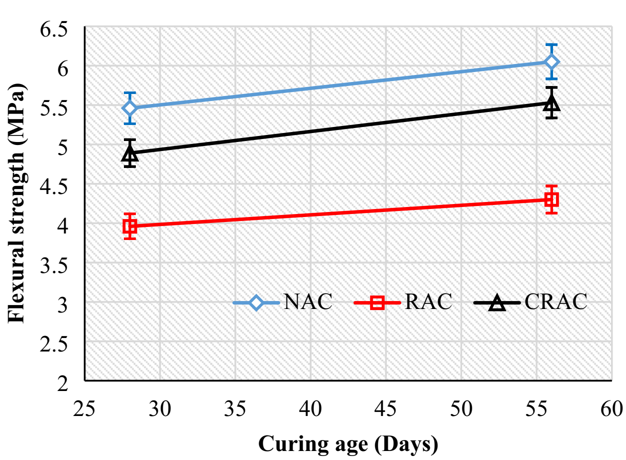

Fig. 5 Flexural strength test results

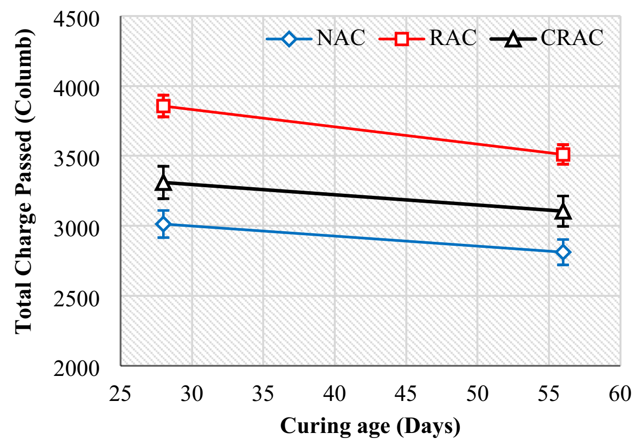

Fig. 6 Chloride ion permeability in terms of total charge passed in Coulombs

of CRAC decreased in comparison with RAC. The presence of calcium carbonate in the pore spaces of CRAs is believed to densify the RCAs, hence improving the chloride ion permeability [48]. Xuan et al. [43] observed that the resistance to chloride ion penetration improved appreciably by using carbonated RCA particles in the concrete mixes and an increase of 36.4% in chloride ion resistivity was reported at 56 days of curing for concrete made with 100% CRAs in comparison with 100% RAC. Zhan et al. [48] also reported similar observations with regard to chloride ion permeability by accelerated carbonation treatment of the aggregates.

Water Absorption

Figure 7 shows the water absorption of all the RAC mixes studied. At curing ages of 28 and 56 days, the water absorption values of RAC were higher than NAC. The high water absorption values in case of RAC may be ascribed to the porous residual mortar attached to RCAs. The water absorption values of concrete decreased significantly by using the CRAs. For example, at 28 days of curing, the water absorption of the CRAC showed a decrease of 21.12%, in comparison with the RAC, but exhibited an enhancement by 48.9%, relative to the NAC. This can be ascribed to the formation of calcium carbonate due to accelerated carbonation which fills the pores thereby resulting in a densified microstructure. Similar findings were reported by Xuan et al. [43] who observed that water absorption values decreased by using CRAs in concrete. They reported a 9.4% decrease in water absorption by using 100% CRAs. Zhan et al. [48] also observed that the transport properties of concrete are appreciably enhanced by the accelerated carbonation procedure of RCAs.

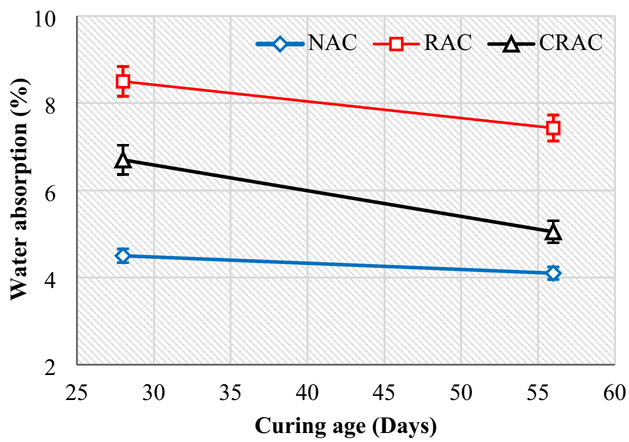

Fig. 7 Water absorption test results

Water Permeability

Water permeability is expressed in terms of observed penetration depth of water and provides a qualitative hint of durability of concrete. According to Hadegaard and Hansen [49], concrete is considered to be watertight provided that the observed penetration depth of water is less than 50 mm. In addition, if the value of penetration depth is less than 50 mm, it is considered as medium penetration [50]. For all the mixes, the observed penetration depths are reported in Fig. 8. A perusal of Fig. 8 vindicates that according to [49], the NAC and CRAC can be considered as watertight. The penetration depths of water in RAC are significantly higher than the NAC. For both curing ages (28 and 56 days), an appreciable decrease in water penetration depths is observed by using CRAs in concrete. The aforementioned trends can also be accorded to reduced porosity of CRAC which in turn decreases the water penetration depths in CRAC. These results are in concurrence to those of Xuan et al. [43].

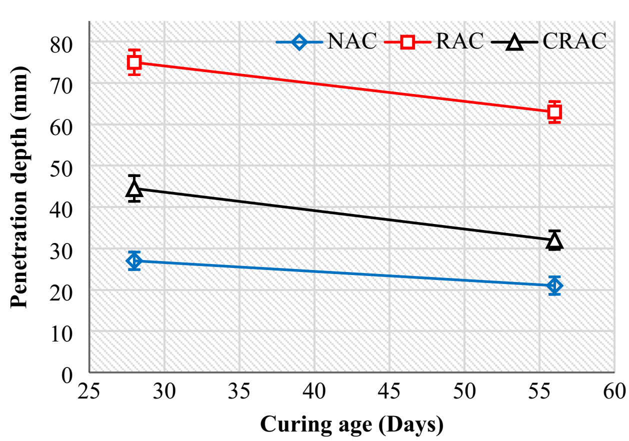

Fig. 8 Water penetration depth for all the mixes

Table 4 Test results for sorptivity after 28 days of testing

$\sqrt{\text{Time}}$ ($s^{1/2}$)	Absorption (mm)		
	CRAC	NAC	RAC
0	0	0	0
8	0.140	0.117	0.186
17	0.188	0.209	0.256
24	0.199	0.233	0.280
35	0.210	0.256	0.326
42	0.237	0.303	0.373
60	0.328	0.303	0.420
85	0.350	0.324	0.44
104	0.398	0.396	0.490
120	0.444	0.443	0.560
134	0.473	0.420	0.583
147	0.517	0.466	0.606
304	0.630	0.560	0.770
440	0.700	0.630	0.816
518	0.818	0.724	0.910
657	0.864	0.748	0.956
726	0.958	0.77	0.980
789	0.957	0.792	1.004
831	0.980	0.825	1.005

Sorptivity

The rate of water absorption or sorptivity of all the concrete mixtures was calculated only at 28-day curing age. For all the concrete mixes, Table 4 presents the rate of water uptake against the square root of the time elapsed. It can be discerned from Table 4 that the sorptivity of RAC was the highest, followed by CRAC and NAC. The sorptivity values decrease when the RCAs subjected to acceleration carbonation treatment are incorporated in concrete. These results are in consonance with the water absorption and water permeability results.

The mechanical and durability properties of CRAC concrete showed an enhancement over RCA concrete. This can be attributed to the densified microstructure of CRACs as observed by Xuan et al. [43] who studied the surface morphologies of recycled aggregates (CRACs and RCAs) and observed that that the hydration products of cement get converted into crystals of calcium carbonate viz. calcite and aragonite which appear in the form of blocks or fibers. These crystals fill the pores of RCA particles thereby densifying the entire microstructure. This in turn helps in the improvement of the strength as well as durability properties due to the existence of power-law relation between porosity and permeability.

Conclusions

An experimental study to improve the mechanical and durability properties of recycled aggregate concrete through accelerated carbonation treatment is presented. The results of this study reveal that the accelerated carbonation procedure of recycled aggregates appreciably enhanced all the studied properties. The salient conclusions of this study are presented below.

1. The UPV values of CRAC were higher than RAC but lower than NAC at both curing ages of 28 and 56 days, respectively. However, this conclusion cannot be quantified at this stage and more tests need to be done before arriving at a generalized conclusion.
2. The compressive strength of CRAC enhanced significantly in comparison with RAC. Furthermore, the RH compressive strength was lower than the experimentally obtained values at both the curing ages. However, the difference between RH and experimentally observed values of compressive strength reduced with age of curing.
3. Both the flexural as well as split tensile strength of RAC were appreciably lower than NAC. However, at both curing ages (28 and 56 days), the use of CRAs in concrete enhanced the aforementioned properties significantly.
4. The residual mortar attached to the surface of RCAs has a detrimental effect on all the durability properties of RAC. In this study, all the durability properties viz., RCPT, water absorption, water permeability and sorptivity of RAC were inferior to that of NAC. However, the accelerated carbonation treatment of recycled aggregates and their subsequent use in concrete enhanced all the aforementioned properties significantly.

Funding This research did not receive funding from any organisation.

Declaration

Conflict of interest The author declares that there is no conflict of interest that might have a bearing on the publication of this paper.

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