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Investigation on mechanical, durability and time-dependent properties of standard grade recycled aggregate concrete with pozzolanic material

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Sustainable development is the development that meets the needs of the present without compromise the availability for future generations to meet their own needs. Sustainability goals concentrate on the global challenges, including poverty, inequality, environmental degradation and climate change. Sustainable Construction is the utilization of materials and products in buildings and construction that will require less use of natural resources and boost the reusability of such materials and products for the same or similar purpose, thus reducing waste as well. In this research paper, experimental investigation were carried out to study the strength and durability properties of standard grade recycled aggregate concrete (RAC), namely M40 with constantly replacing 30% cement by fly ash throughout each sample, keeping all the materials quality and composition same and only replacing the different percentage of natural aggregate (NA) by recycled aggregate (RA) to study the properties of RAC. Concrete prepared by natural aggregate concrete (NAC), recycled aggregate concrete made with 25% replacement of NA by RA (R25),50% replacement of NA by RA (R50), 75% replacement of NA by RA (R75) & 100% replacement of NA by RA (R100) were tested. The present work results show that the replacement of RA by NA up to 100 percent does not affect the strength and durability of concrete significantly.

Keywords: Recycled aggregate, Recycled aggregate concrete, Strength of concrete, Durability of concrete, Creep and shrinkage

1 Introduction

The use of RA in concrete opens a whole new range of possibilities in the reuse of materials in the building industry. The utilisation of RA is an excellent solution to the problem of the excess of waste material, provided that the required final product quality, strength and durability is reached[1]. The studies on the use of RA have been going on since 50 years. In fact, none of the results showed that RA is unsuitable for structural use[2, 3]. However, some hypothetical problems associated to durability aspects resulted in RAC, that's the reason, it is being employed mostly for road construction and for base filler. It is not the best economic valorisation of this resource and it is consider by many researchers to be a down-cycling process that depreciates the capacities of the material[4]. But the production of structural concrete with RA, however, offers great potential and recycles the materials viably and effectively.Using RA instead of NA has positive influences in terms of the environment and economics[5].

Hence utilization of the demolished concrete debris as recycled aggregate, conserves natural aggregates, reduces the impact on landfills, decreases energy consumption and can provide cost savings, results in significant economical and environmental benefits without compromising the strength and durability[6].

About 30% of the total municipal solid waste generated in the country comprises of Construction and Demolition (C&D) waste. Before 2016, responsibilities for C&D waste management were included under the Solid Waste Management Rules. In 2016, the Ministry of Environment, Forest and Climate Change (MoEFCC) notified the C&D Waste Management Rules, 2016 to regulate the handling and management of C&D waste generated in India, thus bringing special emphasis on this issue[7]. C&D waste accounts for about 20 percent of the industrial waste generated and for about 80 percent of illegal dumping. It is most likely to increase the wastes from building debris many folds, in future, as the buildings built in the boom after 1965 face refurbishment[4]. In order to short out the environment issue regarding the dumping that much demolition waste and to fulfil the future need it is necessary to recycle the concrete for structural use as well.

It is estimated that the concrete demand of India is 2.4 billion annually. Crushed aggregate contribute about 60% of the concrete for M40. This implies that about 1.4 billion tonne per year of stone as crushed

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aggregate is required to meet the concrete demand[8]. About 90 billion tons of concrete is consume in the world. About 55 Billion tons of aggregate is utilize by the world[9]. This puts huge pressure on the natural sources of good aggregates, which causes the reserves to considerably decline around the world. Also the extraction of the fast rate of natural resource create soil degradation, water shortages, biodiversity loss, damage to ecosystem functions and global warming exacerbation[9]. So in order to have healthy ecosystem and environment it is need of hour to reduce the depletion rate of natural resource. At the same time, for fulfilling the need of present with future availability we need to look for alternative of natural resource. It is possible only by recycling the demolished concrete waste for producing the RA. It leads to economical and sustainable construction and development of society and therefore fulfilling every requirement of all the people of society[10]. In this way we can save large area of land from being barren due to huge deposit of this non biodegradable demolition waste by recycling the concrete waste[11].

The principal binder of concrete is cement, which is manufactured 329 million tons annually in India in the year 2020. The manufacturing of cement is a major contributor to greenhouse gas emissions. So, concrete industry significantly impact the ecology of our planet[12]. How to develop concrete technology in a sustainable way becomes an urgent issue in the world. Green house gases are main factor to global climate change. Pozzolans are a broad class of siliceous or siliceous and aluminous materials which, themselves, possess little or no cementitious value but, in the finely divided form and in the presence of water, react chemically with calcium hydroxide at normal temperature to form compounds having cementitious properties[13]. Pozzolana are naturally occurring pozzolans of volcanic origin. Artificial pozzolans can be produced, for example by thermal activation of kaolin-clays to obtain metakaolin, or can be obtain as waste or by-products from burning pulverized coal in thermal power plants. Fly ash is a fine powder when it mixed with lime and water; it forms a compound similar to Portland cement[14]. Fly ash can be used as a partial replacement of cement or as an admixture to the concrete mix[15]. The utilization of fly ash as a component of blended cement can save a significant amount of energy and cost in cement manufacturing, apart from reducing the consumption of cement the utilization of fly ash in construction solve the problem of dumping of huge waste obtain from thermal power plant, thereby save the land area and environment as well[16].

In developing countries like India, the generation of C&D waste is 150 million tonnes annually and these figures are likely to double fold in the next 10 years[6]. But the official recycling capacity is a meagre 6,500 tonnes per day — just about one percent. as many as 53 cities were expected to set up recycling facilities to recover material from C&D waste by 2017 - but only 13 cities have done that by November,2020. This is deplorable when the demand for primary building material, including minerals, sand, stone, iron ore, timber and aluminium, is rising at an unprecedented rate. On the other hand, the recycle of construction waste is highly essential from the view point of Life Cycle Assessment (LCA) and effective recycling of the construction resources and to resolve the dumping issue of large amount of demolish waste. Experimental results on fresh and hardened concrete is carried out in this paper, which is prepared as NAC, R25, R50, R75 & R100 with 30% replacement of cement by fly ash constantly throughout the investigation.

Durability of concrete is the capacity of a construction material to resist chemical attacks, actions due to weathering or abrasion or other processes of deterioration[17]. When exposed to cyclic freeze-thaw (F-T), concrete possesses the ability to deteriorate as the cycle increases[18]. Weather is considered cold if the temperature of three successive days falls below 40°F (5°C) (ACI CT-13). This is a concern for the low temperature regions of the world, which go through many cycles of F-T a year, as continuous deterioration increases surface scaling in concrete that ultimately leads to the total collapse of structures[19]. There have been concerning questions regarding the F-T durability of recycled aggregate concrete because of the varying difference in the quality and composition of crushed concrete. Many researchers concluded that the resistance of concrete containing RAC increases the F-T resistance, which could be due to the reduction of frost susceptibility of porous aggregates particles.

The use of fly ash improved the strength and durability of RAC, especially at later ages[20]. The properties of concrete with RA were similar to the properties of NAC. Similarly, the durability and mechanical properties of the mixture with 100% RA coarse aggregate and 30% fly ash were better than that of a similar mixture prepared without fly ash. The durability and mechanical properties of RAC with fly ash discussed in this paper are quite encouraging to promote its use in structural concrete. For a concrete to be used structurally it should have a characteristic strength more than 25N/mm^2. Concrete of lesser strength are termed non-structural concrete.

The present work is carried out to conserve the natural resource, resolve the environmental issue, reduce construction and save the landfill area.

2 Materials and methods

2.1 Cement

Ordinary Portland cement (OPC) of 53 grade, confirming to IS: 12269-1987[21] was used in the work. The specific gravity of cement was 3.15.

2.2 Fine aggregate

Fine aggregate from river source from nearby area was used. The specific gravity was 2.63, the fineness modulus was 2.88 and the sand was confirming to Zone-II as per IS-383-2016[22].

2.3 Coarse aggregate-natural and recycled

The coarse aggregate used in the investigation was from two sources viz; natural (crushed granite) source and recycled aggregate (crushed building demolished waste and crushed concrete pavements by machine) of size 10mm & 20mm. The specific gravity of natural aggregate was 2.85, while the fineness modulus was 7.086. And the specific gravity of RA was 2.74, while the fineness modulus was 7.476.

2.4 Fly Ash

The fly ash used in the present experimental workwas low calcium fly ash confirming to IS 2386[23](part 1) with specific gravity 2.0

2.5 Chemical Admixture

A super plasticizer named FAIRFLO-333 of company named FAIRMATE CHEMICAL PVT. LTD. has been used in this present work.

2.6 Water

Water is an important constituent of concrete as it participate in chemical reaction with cement, so it helps to form the workability, strength and durability. Quality and quantity of water is necessary to be looked in to very carefully. Potable water was used in preparation of M40 grade concrete.

2.7 Mixing, casting, and curing

All the concrete mixtures were prepared in a laboratory pan mixer in accordance with IS 456-2000[24] and IS10262-2019[25]. The triple mixing method was adopted for RAC, the advantage of which was to allow less water near the interfacial transition zone (ITZ). The method essentially involves the following sequence: 1) mixing CA and FA for 15 seconds; 2) adding half of water and mixing for15seconds; 3) adding fly ash admixture for 15seconds; and 4) adding cement and remaining half of water along with super plasticizer and mixing for 60 seconds. The mix design for reference and all other percentage replacement of NCA by RCA, are shown in Table 1. The oiled molds were filled with concrete in layers and vibrated on a table vibrator. The cast specimens were remoulded after 24 hours and water-cured until the date of testing. The specimens were tested immediately after removal from water on the day of testing.

3 Results and Discussion

The compressive, split tensile, flexural strengths, elastic modulus; durability; and long-term properties of the NAC, R25,R50, R75, and R100 mixtures were determined as per relevant Indian and international standard practices, as given in Table 2. A standard loading rate of 140 kg/cm^2/min (0.33 ksi/s), 1.2 N/mm^2/min (0.0029 ksi/s), 180 kg/min (6.62 lb/s) was adopted as recommended in IS 516-1959[26].

Table 1 — Mix proportions of concrete ingredient

Ingredient		NA	R25	R50	R75	R100
Cement, kg/m^3		290	290	290	290	290
Water, kg/m^3		186	186	186	186	186
Water-cementitious materials ratio		0.45	0.45	0.45	0.45	0.45
Fly ash, kg/m^3		123	123	123	123	123
Fine aggregate, kg/m^3 (SSD condition)		798	798	798	798	798
NA 20 mm	Coarse aggregate, kg/m^3 (SSD condition)	557	413	273	135	—
NA 10 mm		557	414	273	135	—
RCA		—	275	546	808	1070
Total		1114	1102	1092	1078	1070
Super plasticizer		0.6	0.6	0.6	0.6	0.6

Table 2 — Details of tests conducted

S. No	Property	Age at test, days	Specimen size, mm (in.)	Test method
1	Compressive strength	14,7, 28, 56	Cube—150 x150 x 150(5.91 x 5.91 x5.91)	IS 516-1959[26]
2	Split tensile strength	7, 28, 56	Cylinder—Φ 150 x 300 (Φ 5.91 x11.81)	IS 5816[27]
3	Flexural strength	56	Prism—100 x 100 x500 (3.94 x 3.94 x 19.69)	IS 516-1959[26]
4	*Elastic modulus*	28, 56	Cube—150 x 150 x 150 (5.91 x 5.91 x 5.91)	—
5	Resistivity	28	Prism—100 x 100 x500 (3.94 x 3.94 x 19.69)	Wenner's Probe
6	Rapid chloride penetration	56	Disc—Φ 95 x 50(Φ 3.74 x 1.97)	ASTM C1202[28]
7	Drying shrinkage	14,28,56,91	Prism—100 x100 x 500 (3.94 x 3.94 x 19.69)	ASTM C512[29]
8	Creep	up to 90 days	Prism—100 x 100 x500 (3.94 x 3.94 x 19.69)	ASTM C512[29]

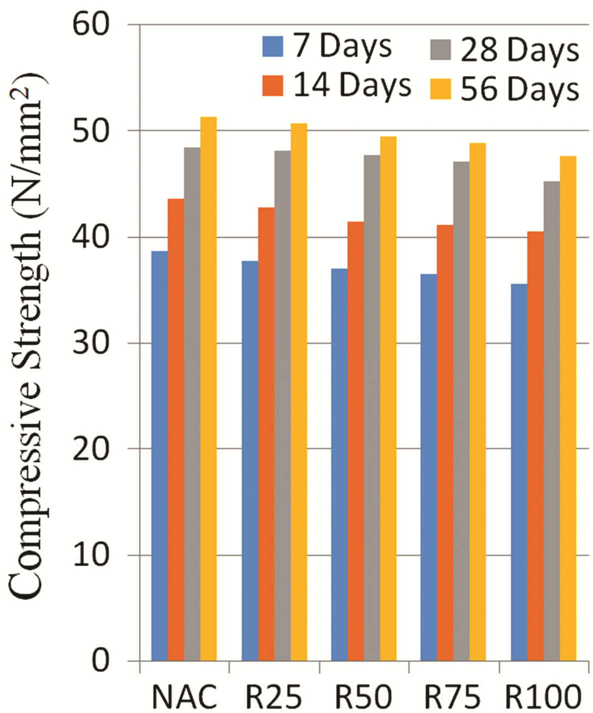

Fig. 1 — Compressive strength of NAC, and RAC.

3.1 Compressive Strength

The test results presented in Fig. 1 indicate that the compressive strength of R100 mixture is similar to that of NAC at different ages. Similarly, the strength of R25, R50 and R75 mixtures were observed to be comparable to that of NAC. It was therefore concluded that the replacement of NA with RA did not have any adverse effect on the strength of the concrete, and hence the use RA in concrete event 100% replacement can be considered.

3.2 Split tensile strength

Figure 2 presents the split tensile strength test results from which it can be observed that the strength of RAC with different proportions of RCA as well as that of NAC has increased with age. Compared to NAC & R100 mixtures, a lower split tensile strength was observed for R50 and R75 concrete mixtures. The higher split tensile strength of R100 could be because of the rough surface texture of the adhered mortar in RCA which provides better bonding and interlocking between the cement mortar and the RCA as compared to the NA[30].

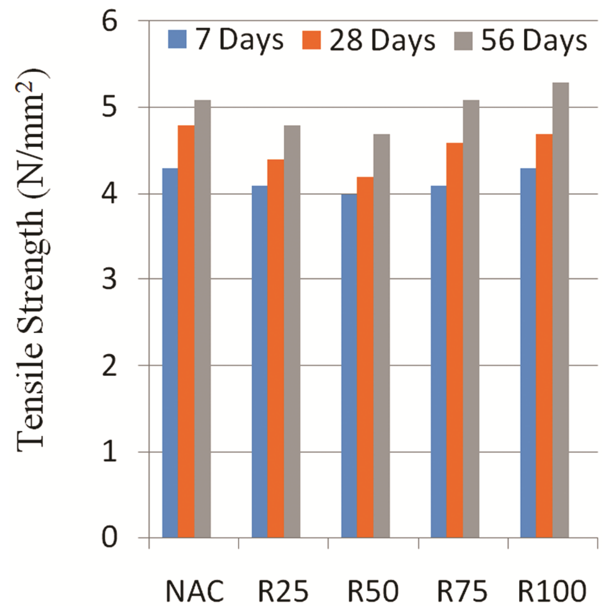

Fig. 2 — Tensile strength of NAC, and RAC.

3.3 Flexural strength

The flexural strength of the NAC, and RAC mixtures at 56 days are presented in Fig. 3. The results indicate that R100 mixture had the highest flexural strength, while that of NAC have compare to R25,R50 and R75 were the lowest. The higher flexural strength of R100 mixture could be due to the similar reasons as those attributed for its higher split tensile strength.

3.4 Elastic modulus

The elastic modulus of NAC was found to be higher than the respective values of RAC mixtures. Fig. 4 indicates that the elastic modulus of RAC decreased with increase in percentage of RCA. It is a well-known phenomenon that the elastic modulus of concrete increases with increase in compressive strength[31]. However, the behavior of RAC, in this respect, appears to be in contradiction to said phenomena, as observed by the test results of the current study as well as of others[31,32], the elastic modulus of RAC decreased with an increase in percentage of RA.R100 mixture with maximum compressive strength exhibits the lowest elastic modulus. This may be due to micro cracks and fissures which could have formed in the aggregates during the manufacturing process of RCA, leading to higher deformation during loading[32].

It is recognized that the aggregates' porosity and density affects the dimensional stability and elastic modulus of concrete and compressive strength also. Thus, deformation of adhered mortar that is generally porous in nature and hence undergoes crushing, during the initial stages of load application, results in higher strain and lower elastic modulus[33]. The crushed adhered mortar might be resisting further deformation due to the applied load and therefore exhibiting a higher compressive strength. The effect of quantity of adhered mortar and the extent of modification of the same by the cementitious admixture on the elastic modulus of RAC needs further study

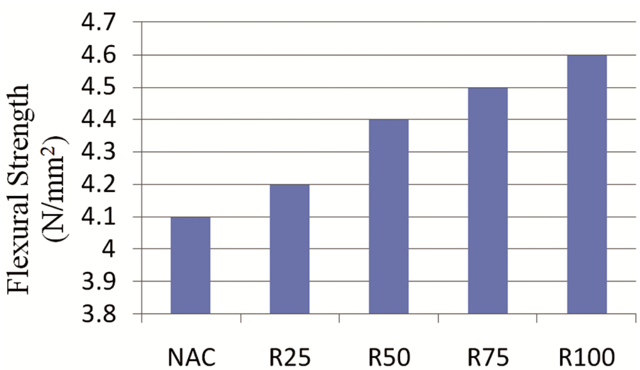

Fig. 3 — Flexural strength of NAC, and RAC at 56 days .

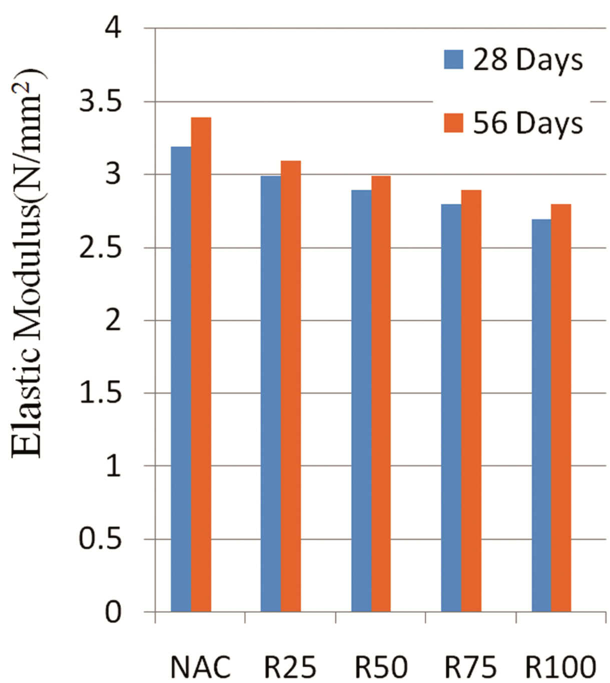

Fig. 4 — Elastic Modulus of NAC, and RAC at 28, and 56 days.

The modulus of elasticity of concrete decreases with increasing recycled aggregate content as a consequence of lower modulus of elasticity of recycled aggregate compared to natural aggregate[34]. The modulus of elasticity of concrete depends on the elastic moduli and volume proportions of aggregate materials. An aggregate of higher elastic modulus increases the elastic modulus of concrete[35]. Hence the lower modulus of elasticity of RA than NA, the modulus of elasticity of RCA is lower than that of NCA.

3.5 Concrete resistivity

The resistivity of saturated concrete specimen was determined at the age of 56 days using Wenner's probes. The variation of concrete resistivity in the concrete mixtures is presented in Table 3.

It is seen from Table 3 that the resistivity of R25, R50, R75, and R100 mixtures is greater than that of NAC mixture. It is noted that the higher resistivity of RAC is helpful in delaying the Initiation of reinforcement corrosion and so RAC performs superior than NAC in this aspect. The criteria for assessing the concrete resistivity with respect to corrosion of reinforcing steel are also presented in Table 3.The use of certain percentage of fly ash improved the resistivity of RCA concrete and decreased the penetrability of chloride ions. Work done by other researcher[16,34] also revealed, that after

Table 3 — Resistivity of RAC and corrosion susceptibility at 28 days

Mixture designation	Resistivity, (KΩ cm)	Chloride ion permeability based on surface resistivity	Likely corrosion rate based on surface resistivity	Corrosion risk based on surface resistivity
NAC	17.55	Moderate	Moderate	Moderate
R25	34.68	Low	Moderate	Low
R50	24.33	Low	Moderate	Low
R75	23.61	Low	Moderate	Low
R100	22.58	Low	Moderate	Low

56 days of curing RCA shows measurably higher resistance to chloride ion penetration compared to that of NAC. It could be due the porosity of recycled aggregate grains, to a certain extent, have a some advantage over natural aggregate, because the present pores can absorb water from the cement paste[12], so that the interfacial transition zone of greater compactness is formed and hence with the increase percentage of RA concrete resistivity also increases. Also strong bond formation in RAC than NAC, due to rough surface of RA, which provide favourable condition for the cementitious materials in adhesion and cohesion among the concrete ingredients[18].

3.6 Rapid chloride permeability test

The rapid chloride permeability test (RCPT) was conducted on disc specimens of diameter 95 mm (3.74 in.) and thickness 50 mm (1.97 in.) accordance to ASTM C1202. The test results of RCPT are presented in Fig. 5.

Fig. 5 indicate that the chloride ion permeability, of RAC mixtures is lower than that of the NAC mixture. The chloride ion permeability was increased with increase in percentage of RCA. The chloride ion permeability is higher by 7.14%, 16.66%, 25.39 % and 27.7% when the percentage of RCA was 25% 50%, 75%, and 100%, respectively, when compared to NAC mixture. It is well-known that fly ash alters the pore structure of the concrete mixtures through formation of more calcium-silicate-hydrate (C-S-H) products which fill the voids in the concrete[29]. The increased quantity of C-S-H product would block the ingress path and the alumina present in the fly ash forms C_3A and absorbs more chloride ions to form Friedel's salt ($C_3A.CaCl_2.10H_2O$). Hence, the pore size refinement of RAC with fly ash could have contributed to enhanced resistance to chloride permeability[22]. The RCPT test results suggests that all mixtures used in the present study, can be classified under the "low" permeability class—that is, chloride permeability between 1000 to 2000 Coulombs, as per ASTM C1202[29].

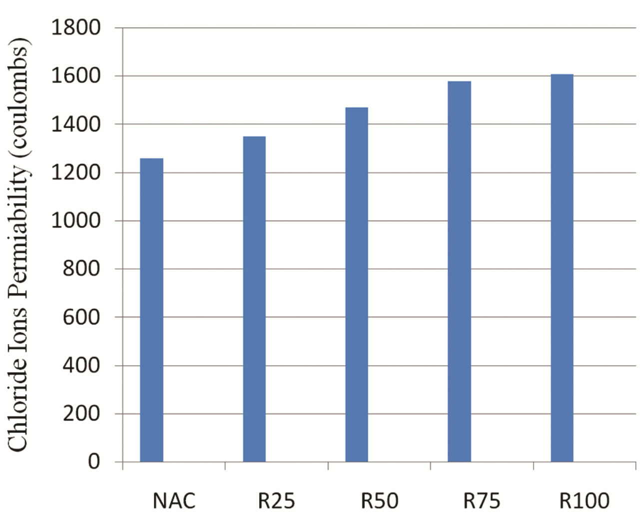

Fig. 5 — Chloride permeability at 56 days.

Chloride ions penetration of concrete increases as the percentage of RA in concrete increases, it is due to the adhere old mortar presence in RA which increases the porosity and decrease the specific gravity of RA than NA[36]. These minute porous hole of RA increases the chloride permeability of RAC than NAC, and hence as the percentage of RA increases in the concrete the chloride permeability also increases. Also, the charge passed for RAC was greater than for NAC. The high level of charge passage in RAC, which increase as the percentage of RA increases may be attributed to the porosity of RCA, which could substantially enhance the ionic mobility and hence increases the chloride permeability[37].

3.7 Drying shrinkage

The drying shrinkage of NAC and R100 mixtures was evaluated as per ASTM 512[29] using 500 x 100 x 100 mm prism specimens with embedded vibrating wire strain gauges. The gauge length of the strain gauge was 150 mm. The test for drying shrinkage is done after 14,28,56 and 91days of water curing. The initial reading of the strain gauge was noted just after removing the concrete prisms from the curing tank. The specimens were then placed in a temperature-controlled chamber which was maintained at 22 ± 2°C and the strain gauge readings were measured at regular intervals using a vibrating wire strain gauge read-out unit. The difference between the two consecutive strain gauge readings gave the drying shrinkage strain.

Figure 6 shows the specimen during the test. The results, presented in Fig. 7, indicate that the drying shrinkage strain of NAC, R50 and R100 mixtures at 91 days were 356.6με, 435.9 με and 490.6 με, respectively. Thus, the drying shrinkage of R100 mixture is 37% higher than that of the NAC at 91 days. The higher shrinkage of the R100 specimens can be due to higher volume of mortar in the mixture that includes both new mortar and residual mortar, and higher-porosity RCA, which can hold higher water content. From the Fig. 7, it is observed that the estimated shrinkage of R100 at 91 days is 1.20 times that of the NAC. But, the shrinkage strain of R100 specimens is lower than the calculated shrinkage strain at 56 days, but the same has been increased at later ages and at 91 days, the observed shrinkage strain of R100 sample is 1.16 times the estimated shrinkage strain. It was also observed that shrinkage strain gradually reduced for NAC after 28 days of drying.

Fig. 6 — Drying shrinkage test setup.

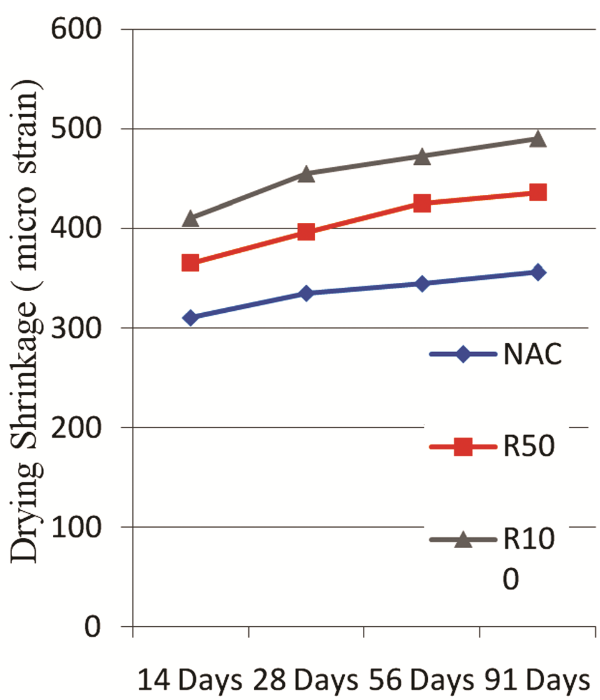

Fig. 7 — Variation of drying shrinkage with time.

3.8 Creep

The short-term creep study of the NAC, R50 and R100 mixtures was performed on similar type of specimens as those used for drying shrinkage and following the procedure as given in ASTM C512[29] is followed. The exposure conditions of creep specimen were same as those for drying shrinkage specimen. The 28-day water-cured concretes pecimens were mounted, without delay after removal from water, on a loading frame, as shown in Fig. 8.

All the specimens were loaded at 35% of their respective compressive strengths at the time of loading. The strain gauge readings just before and immediately after the application of load were measured and the respective strains were calculated.

The difference in the strains gave the elastic strain of the concrete mixtures and was found to be 134 με, 180 με, and 212 με for NAC, R50 and R100 respectively.The strain gauge readings were measured at regular intervals during the period of study. The difference between the initial reading just before loading and the strain gauge readings calculated at a given age gave total deformation of the specimen at that age, the results are presented in Fig. 9.

Fig. 8 — Creep test setup.

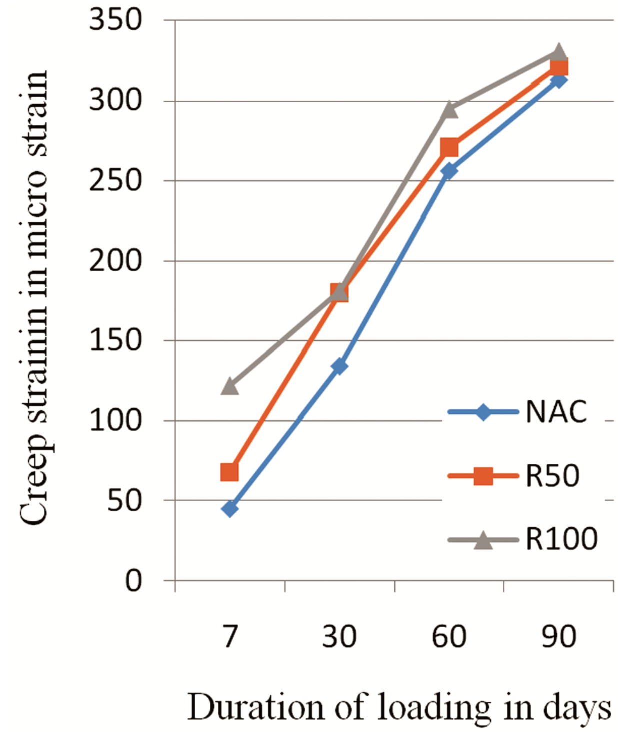

Fig. 9 — Variatizon of basic creep with time.

From Fig. 9, it is seen that NAC, R50 and R100 specimens exhibited a basic creep strain of 312.9με, 331.3 με and 330.5 με, respectively, at 90 days.

Also, the basic creep strain of the R100 sample was 1.35 times the creep strain of that of NAC specimen at 30 days, and 1.15 times at 60 days and 1.06 times at 90 days after loading. Thus, it can be seen that the basic creep of the R100 sample is only slightly lower than NAC at 90 days.

4 Conclusion

From the present study, the following conclusions are drawn.

- Use of recycled aggregate even up to 100 percent does not affect the mechanical properties of concrete as per the findings of the test results.
- Consumption of natural resource is significantly minimized. This in turn directly reduces the fast rate of depletion of natural recourse and their consequence effects on ecological balance and environment.
- Due to use of RA in construction, cost of transportation of dumping the C&D waste and new natural aggregate from mining site to town/ city is reduced, these make the construction economical.
- Reuse of C&D solve the dumping issue of huge waste in a wise full way.
- The RAC exhibited low specific gravity and increased water absorption in comparison to NA due to the presence of adhered mortar.
- The modified mixture proportioning method adopted in this study yielded satisfactory slump and compaction factor value.
- The mechanical properties such as compressive, split tensile, and flexural strengths of RAC with fly ash was comparable to that of NAC, whereas the elastic modulus of RAC was lower than that of NAC.
- The resistivity was higher and chloride permeability was lower for RAC when compared to NAC. It shows that the RAC mixtures with fly ash are more durable than NAC mixtures.
- The drying shrinkage of R100 was found to be 40% higher than that of the NAC.
- Creep of R100 was observed to be higher than NAC in the initial ages but the same was found to be converging with that of NAC at later ages.
- It was observed that RAC, with properties comparable to that of NAC, can be produced using fly ash.
- The use of fly ash in RAC mixtures can also promote increased consumption of fly ash in countries such as India which are exploring various methods for effective use of the same.
- Use of fly ash as partial replacement of cement further save the natural recourse. It save the environment from being polluted, as during the production of cement create heavy pollution and favors sustainable development.
- Use of fly ash in construction solve the problem of dumping the waste generated from thermal power plant.

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