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Properties of self compacting concrete using recycled coarse aggregate

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Abstract

This paper presents the influence of different amounts of recycled coarse aggregate (RCA) obtained from a demolished Town Club building of Banki, N.A.C of Cuttack region, about 25 years old on the properties of self compacting concrete (SCC) and compared the results with normal vibrated concrete (NVC) containing 100% natural coarse aggregate (NCA). Important properties such as physical and mechanical properties of natural and recycled aggregates are carried out. NCA is partially replaced with RCA by an amount 10%, 20%, 30% and 40%. The effect of RCA on the properties of SCC in green state (e.g. Slump flow test, V-Funnel test and L-Box Test) and properties of concrete in hardened state (e.g. compressive strength, flexural strength, and Split tensile Strength) are studied. The mix design was carried out for M25 grade of concrete. The experimental results indicate that the compressive strength, flexural strength and split tensile strength of the SCC with 100% natural aggregate is less than the normal vibrated concrete (NVC) with 100% natural aggregate and the strength of SCC decreases with an increase in recycled aggregate (RA) replacement ratios. The present study recommends SCC marginally achieves required compressive strength up to 30% replacement of RCA.

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Keywords: Compressive strength, Flexural strength, Recycled coarse aggregates (RCA), Split tensile strength, Self compacting concrete (SCC)

Nomenclature

NCA	natural coarse aggregate
NVC	normal vibrated concrete
RA	recycled aggregate
RCA	recycled coarse aggregate
SCC	self compacting concrete

1. Introduction

SCC is a kind of concrete with excellent deformability and segregation resistance, was first developed at Japan in 1980. It is able to flow under its own weight and can completely fill the formwork even within congested reinforcement. SCC has favorable characteristics such as high fluidity, good segregation resistance and the distinctive self compactibility without any need for vibration during the placing process and so noiseless construction. The unique characteristics of SCC are a rapid rate of concrete placement with very less time. SCC offers a very high level of homogeneity; minimize the concrete

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void spaces and have uniform concrete strength and also provides the superior level of finishing and durability of structure. SCC also achieves same engineering properties and durability as traditional vibrated concrete. The use of SCC has gained a wider acceptance in recent years.

Recycled aggregates (RA) are produced from the re-processing of mineral waste materials, with the largest source being the construction and demolition waste. In general, the quality of RA is inferior to those of natural aggregates. The density of the RA is lower than natural aggregates and RA have a greater water absorption value compared to natural aggregates. As a result proper mix design is required for obtaining the desired qualities for concrete made with RA. Experimental studies on properties of RA with SCC have been contributed by the several researchers. The brief literature reviews of some of the latest studies are as follows: [1] studied the fresh and hardened properties of SCC using recycled concrete aggregates as both coarse and fine aggregates states. Three series of SCC mixtures were prepared with 100% coarse recycled aggregates, and different levels of fine recycled aggregates were used to replace river sand. The cement content was kept constant for all concrete mixtures. [2] studied on the potential usage of RCA obtained from crushed concrete for making of SCC, and additionally emphasizing its ecological value. In their experiment, three types of concrete mixtures were made, where the percentage of substitution of coarse aggregate by recycled aggregate was 0%, 50% and 100%. In the process of mixing, equal consistence of all concrete mixtures was achieved. [3] determined the influence of different curing conditions on the mechanical performance of concrete made with coarse recycled aggregate from crushed concrete. The properties analyzed include compressive strength, split tensile strength, modulus of elasticity and abrasion resistance. [4] studied the benefits of limestone powder, basalt powder and marble powder as partial replacement of Portland cement and used directly in the production of SCC. The water to binder ratio was maintained at 0.33 for all mixture. [5] studied on the effect of coarse aggregate gradation on the properties of SCC. Four SCC mixtures with A/B (size 5-10 mm coarse aggregate weight/size 10-20 mm coarse aggregate weight) ratio 4/6, 5/5, 6/4 and 7/3 were prepared; the bulk density of aggregates with various A/B ratios was investigated. The effectiveness of various types of coarse aggregates on fresh and hardened properties of SCC was investigated [6]. Five different coarse aggregate types such as basalt, marble, dolomite, limestone and sand stone were used to produce SCC containing fly ash. The water to binder ratio was maintained at 0.33 for all mixture. The objective of this paper is to study the effect of utilizing recycled coarse aggregate as partial replacement for natural coarse aggregate on the properties of SCC in fresh and hardened state.

1.1. Experimental study

The materials used in the present study are cement, sand, NCA and RCA. All these materials are tested in the laboratory to establish their physical and mechanical properties as per the specification of Indian Standards. Various properties of the materials like crushing value, impact value, and abrasion value of aggregates have been tested. Concrete Mix Design was carried out for M25 grade concrete as per the design guidelines of IS 10262-1982 [7] and SP-23 [8]. The fresh and hardened properties of SCC such as compressive strength, flexural strength and split tensile strength using RCA were studied.

1.2. Materials used and properties

The cement used for the present work is Portland Pozzolana Cement (PPC). The Physical properties of PPC obtained from experimentally and the value specified by IS 1489 (Part1):1991 [9] are presented in Table 1.

Table 1. Physical properties of Portland Pozzolana Cement

Characteristics	Value obtained experimentally	Value specified by IS 1489 (Part 1):1991
Normal consistency, Percent	33.50	NA
Fineness (m^2/Kg)	381	300
Initial setting time, minutes	28	30 (min)
Final setting time, minutes	450	600 (max)
Specific gravity	3.10	3.00
3 days compressive strength, MPa	16.40	16.00
7 days compressive strength, MPa	25.60	22.00
28 days compressive strength, MPa	38.20	33.00

The sand is brought from the river Kuakhai (Trisulia) which is about 35 km from the Institute. Sand is used as fine aggregate which is passing through IS 4.75 mm sieve. NCA consists of rock fragments that are used in their natural state or are used after mechanical processing such as crushing, washing and sizing. The size of aggregate used in this study was between 10 mm to 20 mm. The source of NCA is crushed stone. It is brought from Tapang granite quarry in the district of Khurda. RCA used in this study are brought from Banki N.A.C., which is about 52 kms from the Institute. The source of aggregate was a 25 years old town club building whose roof slab was demolished. The aggregates were separated by crushing the demolished debris manually and were then cleaned. The size of aggregate was kept between 10 mm to 20 mm which were used for casting. The debris are manually broken down. The properties of fine and coarse aggregates obtained experimentally as per IS: 383-1970 [10] is presented in Table 2.

Table 2. Properties of aggregates

Characteristics	Value obtained experimentally as per IS: 383-1970		
	Fine aggregate	Coarse aggregate	Recycled aggregate
Specific gravity	2.69	2.83	2.42
Fineness modulus	3.214 (Zone 1)	7.840	6.80
Water absorption (%)	0.14	0.34	1.25
Bulk density (kg/m^3)	1598	1424	1377
Abrasion value (%)	-	27.08	26.65
Impact value (%)	-	26.41	24.45
Crushing value (%)	-	31.78	37.14

Admixture mainly affects the flow behavior of the self-compacting concrete. A commercially available admixture a polycarboxylates based powerful super plasticizer Viscocrete-R-550 (L) (liquid form); product of Sika India Limited an ISO 9001 company is used for SCC. The properties of Viscocrete-R-550(L) are: Specific gravity at 27°C is 1.08, pH is 7.25 and bluish brown colour.

1.3. Mixing and testing of samples

Control mixture of NVC for M25 grade concrete (without RA) was designed as per standard specifications IS: 10262-1982 [7] (1:1.44:3.22), W/C=0.47 to achieve target strength 33.745 MPa. For mix proportion of SCC, first the quantities of fine aggregates were increased and coarse aggregate was decreased by 20%, and 30% and trial mixes were prepared to satisfy the EFNARC's guideline. But in both cases it could not be achieved. Finally mix design was prepared with increase in fine aggregate content by 35% and making adjustment of super plasticizer (@ 0.6% of cement in kg) and viscosity modifying agent (@ 0.34% of water in kg). The other five SCC mixtures were prepared by replacing natural coarse aggregate 0%, 10%, 20%, 30% and 40% with RCA by mass. The concrete mix identification was designated according to their replacement ratio as given in Table 3.

Table 3 Mix proportions with identification based on replacement ratio

Mix Identification	Concrete Mix Proportion
NCARR 0	M-25 Normal Vibrated Concrete with 100% NCA
SCARR 0	M-25 Self Compacting Concrete with 100% NCA
SCARR0.10	M-25 Self Compacting Concrete with 90% NCA + 10% RCA
SCARR0.20	M-25 Self Compacting Concrete with 80% NCA + 20% RCA
SCARR0.30	M-25 Self Compacting Concrete with 70% NCA + 30% RCA
SCARR0.40	M-25 Self Compacting Concrete with 60% NCA + 40% RCA

The fresh concrete test is conducted for NVC and SCC to know the workability of concrete. Slump test and compaction factor test was conducted for vibrated concrete. Fresh SCC test was conducted as per EFNARC 2005 [11] guidelines. Slump flow, T_{500}, V-funnel and L-Box tests were conducted for all mix proportion of SCC. The results were satisfied with the EFNARC 2005 guidelines. The hardened concrete specimens were tested after 7, 28, and 90 days of curing. The test specimens were cast in steel mould without compaction and demoulded after 24 hours. The specimen such as cubes and cylinders for compressive strength, prism for flexural strength and cylinder for split tensile strength was cured till the day of testing under water at normal temperature and humidity conditions. The compressive strength, flexural strength and split tensile strength of the concrete specimens were measured after 7, 28 and 90 days.

2. **Experimental results and discussions**

The hardened concrete properties such as compressive strength, flexural strength and split tensile strength were tested in the laboratory. The results are presented along with their graphical plots and discussions. Also, a comparative study of SCC using RCA and NCA is also presented.

2.1. Compressive strength

The compressive strength is measured using both cube and cylindrical specimens. The size of the cube specimen is 150 mm × 150 mm × 150 mm and size of the cylindrical specimen is 100 mm diameter and 200 mm height. Nine concrete cubes and nine concrete cylinders were casted for each concrete mix proportions. The compressive strength of three cubes and three cylinders are measured after 7, 28 and 90 days. Fig.1 shows the graphical plot between compressive strength and curing time of the concrete cube specimen. The compressive strength of NVC with 100% NCA was found to be highest at 7 days, 28 days and 90 days as compared with SCC with 100% NCA. The plot reveals that compressive strength in 7 days test in case of SCC with RCA replacement ratio 0.1, 0.2 and 0.3 are closer. But in 28 days test the SCC marginally achieves required compressive strength up to 0.30 replacement ratio. In 90 days test all kind of concrete with replacement ratio up to 0.40 achieves characteristic compressive strength. As percentage of RCA increases, the compressive strength of SCC decreases. Fig. 2 shows the graphical plot between compressive strength and curing time of the concrete cylinder specimen. It is seen that the compressive strength of NVC having 100% NCA has the highest compressive strength. The compressive strength of SCC decreases with increase in RCA replacement ratio in 7 days, 28 days and 90 days tests. The compressive strength increases with increase in curing time. The rate of increment of compressive strength is more up to 28 days in both cubes and cylinders for all types of SCC; thereafter the increment of compressive strength is comparatively less. Fig. 3 shows the relation between compressive strength of concrete cubes and RCA replacement ratio for 7 days, 28 days and 90 days. It may be observed that the 28 days and 90 days compressive strength of NVC with 100% NCA are very closure. Whereas in SCC with 100% NCA the 28 days compressive strength is relatively less as compared with the 90 days compressive strength. It indicates that as curing time increases, the compressive strength of SCC is also increases. It is also observed in all other mixes of SCC with up to 30% replacement of RCA. Fig. 4 shows the relation between compressive strength of concrete cylinders and RCA replacement ratio for 7 days, 28 days and 90 days. The same trend is also observed in the cylinder testing as observed in the cube. It may be concluded that 30% mixing of RCA in SCC gives the desirable characteristic strength.

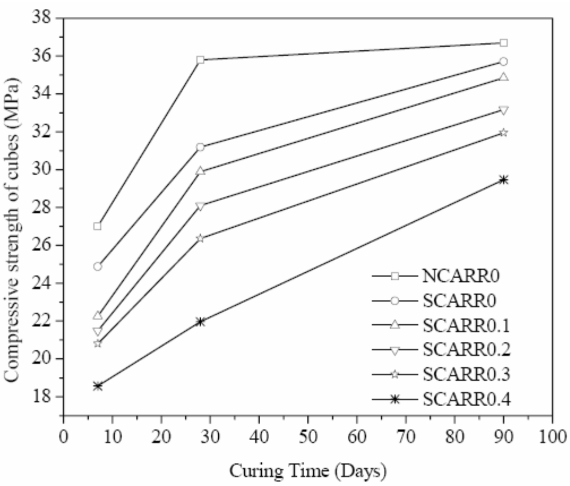

Fig. 1. Compressive strength of cube versus curing time

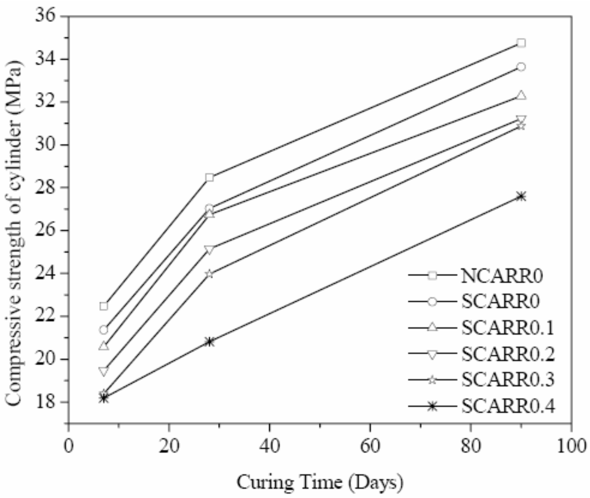

Fig. 2. Compressive strength of cylinder versus curing time

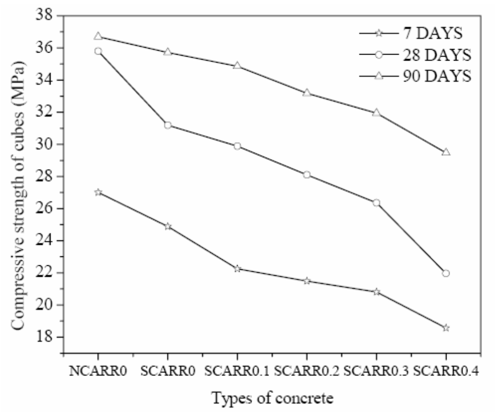

Fig. 3. Compressive strength of cube for types of concrete mix

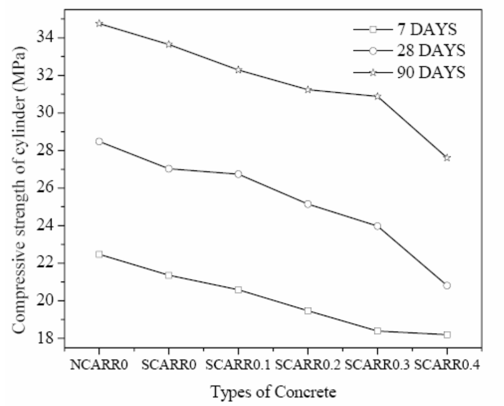

Fig. 4. Compressive strength of cylinder for types of concrete mix

2.2. Flexural strength

The flexural strength of concrete is conducted on prism of size 100 mm × 100 mm × 500 mm. Nine concrete prisms were casted for each concrete mix proportions for 7, 28 and 90 days. The flexural strength of three prisms each is measured after 7, 28 and 90 days. Fig. 5 shows the relation between flexural strength of concrete and age in days for both NVC as well as SCC at different replacement ratio of RCA. It is observed that the flexural strength of NVC with 100% NCA gives higher value as compared with SCC with 100% NCA. The difference of flexural strength is also more in 90 days as compared with 28 days strength. As replacement of RCA increases, flexural strength of SCC decreases. Fig. 6 shows the relation between flexural strength of concrete and RCA replacement ratio at 7, 28 and 90 days. It is observed that NVC with 100% NCA has the highest flexural strength and more than the theoretical value at 28 days and 90 days. The theoretical flexural strength was calculated using the equation $f_{cr} = 0.7\sqrt{f_{ck}}$. Where f_{cr} is flexural strength of concrete in MPa and f_{ck} is the characteristics compressive strength of concrete at 28 days in MPa. The flexural strength of SCC decreases with increase in RCA. The 28 days flexural strength of SCC obtained from experimental is less than the theoretical flexural strength in all the replacement ratio of RCA (for all types of mix).

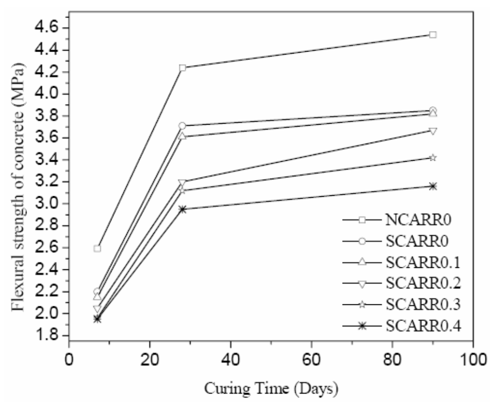

Fig. 5. Flexural strength of prism in different curing time

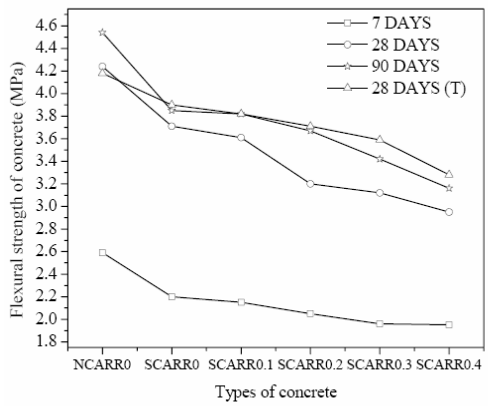

Fig. 6. Flexural strength of prism for types of concrete mix

2.3. Split tensile strength

The Split tensile strength is conducted on cylinder of 200 mm × 100 mm size. Nine concrete cylinders were casted for each concrete mix proportions for 7, 28 and 90 days. The split tensile strength of three cylinders (one set) is measured after curing period of 7, 28 and 90 days. Fig. 7 shows the relation between split tensile strength of concrete and age in days i.e. 7, 28 and 90 days of casting. It is observed that NVC with 100% NCA has the highest split tensile strength than SCC with 100% NCA. In case of SCC the split tensile strength of concrete decreases with increase in percentage of RCA. Fig. 8 shows the relation between split tensile strength of concrete and RCA replacement ratio i.e. types of concrete mix. In case of SCC, the split tensile strength uniformly decreases with increase in percentage of RCA in case of 7 days, 28 days and 90 days.

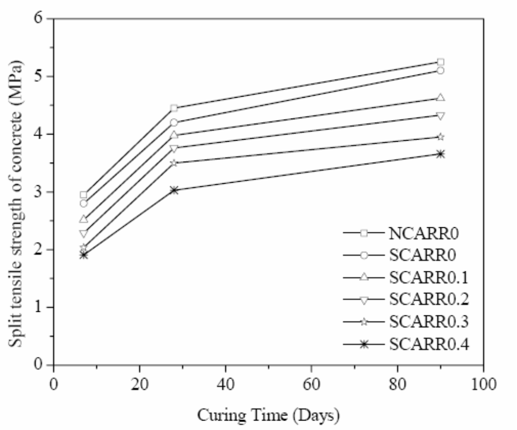

Fig. 7. Split tensile strength of cylinder for different curing time

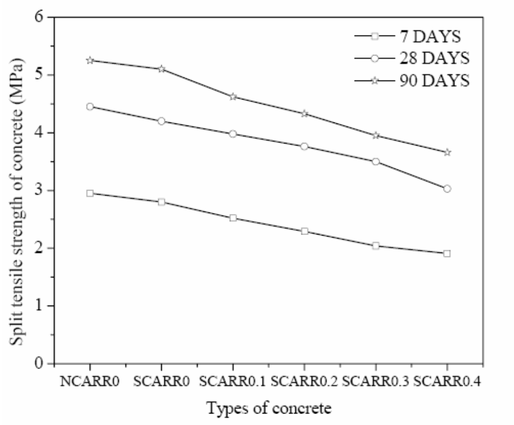

Fig. 8. Split tensile strength of cylinder for types of concrete mix

3. Concluding remarks

- The test results indicate that the compressive strength, flexural strength and split tensile strength of SCC is less than the NVC.
- The compressive strength, flexural strength and split tensile strength of SCC decreases with increase in the amount of RCA.
- The test result indicates that in 28 days test SCC marginally achieves required compressive strength up to 0.30 replacement ratio.
- It is observed that NVC with 100% NCA has the highest flexural strength and more than the theoretical value at 28 days and 90 days.
- The 28 days flexural strength of SCC obtained from experimental investigation is less than the theoretical flexural strength in all the replacement ratio of RCA.
- RCA show higher water absorption compared with conventional NCA due to old mortar attached with original concrete and has relatively lower specific gravity.

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