SELF COMPACTING CONCRETE (SCC) AS GREEN CONCRETE WITH RECYCLED CONCRETE AGGREGATES (RCA) – AN EXPERIMENTAL STUDY

Srinivas Vasam[1], K.Jagannadha Rao[2], M.V.Seshagiri Rao[3]

[1]*Research scholar, Dept. of Civil Engineering - JNTUH-Hyderabad, India*
[2]*Professor, Dept. of Civil Engg., Chitanya Bharathi Institute of Technology(CBIT), Hyderabad, India*
[3]*Professor, Dept. of Civil Engg., JNTUH CE Hyderabad, India*

Abstract

The construction industry has become one of the main sources of environmental pollution due to the emission of carbon monoxide and other pollutants during the production of construction materials and operation of construction equipment. Self-compacting concrete (SCC) provides a healthier working environment by avoiding noise pollution, emission of smoke and vibrations during construction. Also, the depleting sources of natural aggregate (NA) and disposal problem of demolished waste have prompted the researchers to take up studies& investigations on the use of Recycled Concrete Aggregate (RCA) in structural concrete. Thus, SCC with RCA has more significant environmental related advantages in comparison to the vibrated concrete. This paper presents experimental results of investigations carried out on SCC of grade M20 with RCA designed on the basis of modified NAN-SU mix design and the workability tests performed in this research were as per The European (EFNARC) Guidelines for Self Compacting Concrete (SCC) Specification to arrive at the SCC mix proportions. Workability and hardened state properties of Self-compacting concrete (SCC) with various percentages of RCA as partial replacement of natural aggregates (NA) (0%, 25%, 50% 75% & 100%) were studied. The results have indicated that the natural aggregate can be replaced completely with the RCA for low strength concrete with more or less 10% deviation in strength which can be compensated by proper designing of mix.

Keywords: *Sustainable materials, Recycled Concrete Aggregates (RCA), Natural Aggregates(NA), Self Compacting Concrete (SCC), Fresh Properties, Hardened state properties, Environmental,*

--***--

INTRODUCTION

The experimental investigations on the process of Recycling and Reuse of Construction and Demolition Wastes (CDW) have long been accepted to have the possibility to conserve natural resources and to decrease energy used in production. In some Countries it is a standard process of use for both construction and maintenance, particularly where there is a scarcity of construction aggregate. Reuse and recycling of Construction and Demolition Wastes (CDW) waste is one key component of a larger holistic practice is called sustainable or green building practice, and Researches on Construction Demolished Wastes (CDW) reveal that the behavior of structural concrete with recycled aggregate(RA) is comparable to that of the concrete with conventional natural aggregate. The reuse of such materials solves the disposal problem, apart from reducing the cost and economical production of construction materials.

SCC was introduced by Okamura H, Japanese researcher in the late 1980's, and it is developed in Japan to obtain better quality of concrete which is used for structural concrete as durable without depending on the vibrating & finishing equipments and to a lesser extent, on skilled Work men force [1]. Self Compacting Concrete is one of the difficult concretes to design due to the necessity of getting equilibrium between its different required properties which depend on different mechanisms. Furthermore, the mix proportion process and the resulting workability properties is complicated by the multiplication of the constituents available in the construction market; rounded or crushed aggregates with other different mineral natures, ordinary Portland (OPC) or blended cements, a variety of mineral admixtures, different types of Super plasticizer (SP), and sometimes other chemical admixtures like Viscosity Modifying Admixtures (VMA). Moreover, workability requirements of fresh self compaction concrete(SCC) with Recycled concrete aggregate (RCA) using a modified mixing procedure (Modified Nan-SU et al Mix design) was adopted to achieve better proportions of Concrete mix, workability and hardened properties of concrete for structural application approaches of construction industry.

In this context the process for self compaction concrete is obviously needed to deal with all its constituted materials and its workability properties thereof, particularly with its powder and paste requirements. One of the greatest challenges of the present time is to evolve strategies for the utilization of the large amounts of construction and demolition wastes which has increased considerably over the last few years in all countries. The use of RCA in concrete opens a whole new range of possibilities in the recycled and reuse of materials in the building construction industry. When structures made of concrete are demolished or renovated, concrete recycling and use of Recycled Concrete is an increasingly common method of utilizing the concrete rubble. The utilization of Recycled Concrete Aggregates (RCA) is a good solution to decrease the problems of excess waste material, provided that the desired quality of the product is reached. Recycling of demolished concrete is a very important issue for saving energy, natural resources and for environmental protection. One has to be cautious in the use of recycled concrete aggregate (RCA), since it exhibits different characteristics from natural aggregate and it can be used as part of proposed concrete mix of SCC along with natural aggregate. SCC needs to have sufficient paste when crushed angular natural aggregates or unfavorable characteristics of RCA are used for achieving good flow ability and also for better coating of the aggregates for enhanced strength.

Recycled concrete aggregates (RCA) are processed from the construction waste materials, with the largest source being the demolished construction waste In general; the quality of RCA is inferior to those of Natural Aggregates (NA). The density of the RCA is lower than natural aggregates and RCA have a greater water absorption value compared to natural aggregates. As a result proper mix design is required for SCC made with RCA for obtaining the desired qualities. Experimental studies on properties of RCA with SCC have been contributed by the several researchers.

S.C. Kou, et al [3] studied the fresh and hardened properties of SCC using RCA as both fine and coarse aggregate states. For investigation prepared with 100% recycled coarse aggregates Three SCC mixes , and different levels of recycled fine aggregates were used to replacement of river sand and natural Coarse aggregate. The cement content was kept constant for all SCC mixtures. W/B ratios of 0.35, 0.40 and 0.44 were used. The experimental results indicate that the properties of the SCCs with river sand and crushed fine recycled aggregates showed only slight differences. The feasibility of max. utilizing fine and coarse recycled aggregates with rejected fly ash and Class F fly ash for SCC.

Grdic, et al [4] Studied on the potential usage of RCA obtained from crushed concrete for production of SCC, and additionally emphasizing its ecological value. They concluded that RCA showed high water absorption compared with conventional Natural Aggregates due to old mortar attached with previous concrete and has relatively lower specific gravity

Venkataram Pai et al [6]: have experimentally aimed at producing SCC mixes of M25 grade by using the Modified Nan Su method, incorporating five mineral admixtures. They have concluded that in the modified Nan Su method of developing SCC, the quantity of the powder mainly depends on the specific gravity and consistency of the powder itself. The SCC mix containing GGBS exhibiting greater strength could be because of the high pozzolonic activity of GGBS.

Debashis Das, V.K Gupta et al. [8] have carried out experimental investigation on production of self compaction concrete (SCC) using Micro-silica and flyash from Dadari, Thermal Power Plant, Delhi. Vengala et al. [9] developed SCC using flyash from Silchar, Thermal Power Station, Karnataka. Naveen Kumar et al. [10] developed SCC using blend of flyash and metakaolin. Praveen Kumar et al. [11] used stone crusher dust partially replacing aggregates to obtain SCC.

EXPERIMENTAL STUDY

The materials used in the present study are cement, sand, NA 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 M20 grade concrete as per the design guidelines of Modified Nan-su mix Design [6]. Workability and Hardened properties of SCC with RCA such as comp strength, split tensile strength and flexural strength were studied.

MATERIALS USED, MIX PROPORTIONS AND PROPERTIES : For present experimental investigation following materials are used.

CEMENT:

In the present investigation Ordinary Portland Cement (OPC) - 53 Grade (Ultra Tech) cement is used. Care is taken that it is freshly produced and from a single producer. The cement thus produced was tested for physical properties in accordance with IS 4031[20] OPC cement having specific gravity of 2.92 was used for preparation of present concrete. The initial and final setting times were found as 60 minutes and 185 minutes respectively.

FINE & COARSE AGGREGATES

FINE AGGREGATE: it is natural and obtained from local market. The physical properties like specific gravity, gradation fineness modulus, bulk density are tested as per IS-2386.Fineness modulus of aggregate = 2.65 & Specific gravity = 2.64 and fine aggregate confirms to Zone III grading of IS.2386.

COARSE AGGREGATE: Locally available machine crushed well graded angular granite aggregates of maximum size 12 mm was used. Recycled aggregate from demolished waste was crushed and classified before use. The properties of natural coarse aggregate and natural coarse aggregate with 25%, 50%, 75% and 100% RCA are given in Table 1.

Table 1: Properties of Coarse aggregates propotions (Natural Aggregates & Recycled Concrete Aggregates)

Type of mix	Fineness Modulus	Specific Gravity	% of Water Absorption	Bulk Density	% voids
100%NCA (MIX-I)	6.36	2.81	1.25	1.49	44.03
25 % RCA(MIX-II)	6.52	2.73	2.20	1.45	45.60
50 % RCA (MIX-III)	6.70	2.65	3.64	1.40	47.20
75 % RCA (MIX-IV)	6.85	2.58	4.60	1.36	48.00
100 % RCA(MIX-V)	7.10	2.35	5.65	1.26	49.30

FLY ASH: In the present investigation, the fly ash used is obtained from Vijayawada Thermal Power Station in Andhra Pradesh. The specific surface area of fly ash is found to be 475 m^2/kg by Blaine's permeability Apparatus.

MICRO SILICA: In the present investigation, the Elkem micro silica grade 920D is used and the manufacturer of micro silica is M/s Elkem. The specific surface area of micro silica is found to be 19 m^2/gm.

GLENIUM B233: It is observed that with the use of large quantities of finer material (fine aggregate + fly ash + cement+micro silica) the concrete is stiff and requires more water for required workability. Hence in the present investigations an ultra high range water reducing admixture Glenium B 233 is used.

VISCOSITY MODIFYING AGENT (VMA): Glenium B233 stream 2 is used as VMA to enhance the viscosity of the mixture.

WATER: Potable Water available from local sources and it is free from deleterious materials was used for mix preparation and curing of all the mixes tried in this present investigation.

MIX DESIGN PROCEDURE: There is no Standard method mix design for SCC. Many Research &Academic institutions and ready-mixed (RMC), Precast and Construction Contracting Companies have been developed their own mix proportioning methods production of SCC. Different mix design methods available for getting the trial mixes of SCC are Japanese method, Sedran et al Method, Method proposed by Gomes, Ravindra Gettu et al. method, Nan-Su et al method and the method proposed by Jagadish Vengala. Step by step procedure of modified Nan Su Mix Design Method used in this investigation for designing the SCC with RCA mixes is given as below:

Mix Design of M20 grade SCC with RCA by Modified Nan Su Mix Design Method

Step-1: Coarse and Fine Aggregate Contents Calculation

For this required prop of coarse aggregates (CA) and fine aggregates (FA) can be calculated by knowing packing factor (PF).

$$(PF^{scc}) = \frac{\textit{Apparent desity of aggregate in SCC (Pd)}}{\text{Apparent desity of loose aggregate in SCC (Pl)}}$$

Calculation of Coarse Aggregates (CA) content

$$W_{ca} = PF \text{ X } W_{dc} \text{ X} \left(1 - \frac{S}{a}\right)$$

Calculation of Fine Aggregates (FA) content

$$W_{fa} = PF \text{ X } W_{df} \text{ X} \left(\frac{S}{a}\right)$$

Step-2: Determination of Cement Content

To achieve good flow ability and segregation resistance, the content of powder (binders) should not be too low. However larger qty of cement used will increase drying shrinkage of Self Compacting Concrete(SCC) . in General, HPC or SCC used to provides a compressive strength of 20 psi (0.14 MPa) / one kg cement in Taiwan. Since the qty of cement is not enough for normal grades to gain the required strength, correction factors are introduced. Therefore cement content to be used is $C = C.F \left(\frac{f_c^{\prime}}{20}\right)$

Step 3: Calculation of Mixing Water Content Required by Cement: It can then be obtained by $W_{WC} = C \text{ X } \left(\frac{W}{C}\right)$

Step 4:Calculation of Filler Contents : The volume of filler paste can be calculated as follows

$$V_{pf} = 1 - \left(\frac{C}{1000\ G_C}\right) - \left(\frac{W_{fa}}{1000\ G_{fa}}\right) - \left(\frac{W_{ca}}{1000\ G_{ca}}\right) - \left(\frac{W_{wc}}{1000\ G_w}\right) - V_a$$

W_{ca}= coarse aggregates in SCC (kg/m^3)content ; W_{fa}: fine aggregates in SCC (kg/m^3)content ; W_{dc}: bulk density of coarse aggregates in air (kg/m^3); W_{df}: bulk density of fine aggregates in air (kg/m^3); PF: is the ratio of mass of aggregates of tightly packed state in SCC (Packing factor), so that of loosely packed state in air; S/a: is the volume ratio of fine aggregates to total aggregates (50% - 57%).

Step 5 : Amount of filler required is $W_f = V_{pf} \text{ X } 1000 \text{ X } \left(\frac{G_f}{1+W/F}\right)$

Step 6: water content required for Mixing of filler paste is $W_{wf} = \left(\frac{W}{F}\right) W_f$

Step 7: Calculation of Water Content required for SCC Mix.

The water content required for SCC mix is the total amount of water needed for cement and filler(Fly Ash) in mixing. Therefore, it can be calculated as $W_W = W_{WC} + W_{Wf}$

Step 8: Calculation of Dosage for Super Plasticizer (SP):

the flow ability property will improve by adding required dosage of Super Plasticizer (SP), SCC ability and segregation resistance of fresh self compacting concrete to attain design requirement. Water content of Super Plasticizer (SP) can be regarded as part of the mixing water. If the dosage of Super Plasticizer (SP) used is n% of the amount of binders and its solid content is m% then the dosage can be obtained as follows (n%=1.8%)

Dosage of Super Plasticizer (SP) in SCC $W_{SP} = n\% \, (C + W_f)$

Step 9: Total water required for SCC Mix in SCC in kg/m^3 = W =(W_{wc}+W_{wf}+W_{wsp})

Step 10 : Adjustment of required water content for SCC mix

According to the present of moisture content in Aggregate at the ready mixed concrete (RMC) plant or Construction site works, actual quantity of water used for mixing should be adjusted.

Step 11: Trial mixes and Tests on Workability SCC properties

Trial Mixes were produced using the content of materials calculated as above and checked for fresh state properties before casting the cubes.

Step -12: Adjustment of Proportions SCC Mix

If the quality control(QC) results of tests fail to meet the required performance of the fresh Self Compacting Concrete, adjustments in the materials are made until all properties of Self Compacting Concrete(SCC) with RCA will satisfy the requirements in the Mix design specified,

Step 13: Estimated quantities of material per cubic meter of concrete:

Based on the above method of mix design, the mixture constituents of SCC were achieved for design strength of M20 are given in Table 2.

Table 2- Details of Mix Design & Quantities of Ingredients of Concrete
(Various Quantities of Ingredients of Standard Grade Self compacting Concrete with Recycled aggregate (M20 Grade) Concrete per cubic metre)

Mix Identification	MIX-1 (M20) – 0% R.A.	MIX-2 (M20) – 25% R.A.	MIX-3 (M20) – 50% R.A.	MIX-4 (M20) – 75% R.A.	MIX-5 (M20) – 100% R.A.
Cement (Kg)	350	350	350	350	350
Fly ash (kg)	100	100	100	100	100
CA - 12mm (NA) (Kg)	804	603	404	201	0
CA - 12mm (RA) (Kg)	0	201	400	603	804
River Sand (Kg)	940	940	940	940	940
Admixture (gms)	129	129	129	129	129
VMA (gms)	29	29	29	29	29
Water (lts)	186.04	189.25	196.02	198.00	200.10
(P(C+F) : FA: CA)	= (1 : 2.68 :2.29)	=(1 : 2.68 :2.29)	=(1 : 2.68 :2.29)	=(1 : 2.68 :2.29)	=(1 : 2.68 :2.29)
	W/P = 0.424	W/P = 0.424	W/P = 0.424	W/P = 0.424	W/P = 0.424

Test Details

For each SCC with RCA mix, cubes of size 150X150X150 mm were cast to Determine the Concrete Compressive Strength at the age of 7 and 28 days. For splitting Tensile and Flexural strength cylinders of 150 dia x 300mm and 100x100x500mm Prisms were cast and tested at 28 days. The specimens were demoulded after 24 hours of casting and were water curing at 27 ± 2^{o}C until the test age. The tests were conducted as per IS 516 and IS:5816-1999.

RESULTS & *DISCUSSIONS*

Workability:Slump and compaction factor values for different mixes were plotted in Figures 1 and 2. The workability of concrete decreased as RCA content as replacement of natural coarse aggregate increased. The low workability of RCA is due to the high water Absorption capacity of Recycled aggregate(RA) .

TABLE 2(c) : Workablity Test Results

MIX IDENTIFICATION		**WORKABLITY TEST RESULTS**					
Mix	**Mix Prop Trials**	**Flow Table (mm)**	**V - Funnel Test (Sec)**		**U- Box Test (mm)**	**L- Box Test (h2/h1)**	**Remarks**
			T_0	**T_5**			
Normal Range		**650-800**	**6-12**	**8-14**	**0-30**	**0.8-1.0**	
Property		**Filling Ability**	**viscocity**		**Passing Ability**	**Passing Ability**	
M20 Grade	**MIX-1 (M20) – 0% R.A.**	**690**	**8.2**	**11.5**	**28**	**0.96**	
	MIX-2 (M20) – 25% R.A.	682	8.6	10.8	26	0.92	
	MIX-3 (M20) – 50% R.A.	674	7.8	10.2	25	0.86	
	MIX-4 (M20) – 75% R.A.	663	7.3	9.8	23	0.84	
	MIX-5 (M20) – 100% R.A.	658	7.0	9.5	20	0.81	

Hardened Strength : The concrete mixes used in this investigation include M20 Grade SCC concrete with RCA 0% , 25 %, 50% , 75% & 100% respectively. The strength variation in the batches of concrete is shown below.

TABLE 2(d) : Hardened Concrete Test Results

Mix identification		**HARDENED CONCRETE TEST RESULTS**						
Mix	**Mix Prop Trials**	**Compression** (Result in MPa)		**Spilit Tensile** (Result in MPa)		**Flexural** (Result in MPa)		**Remarks**
		7 Days	**28 Days**	**7 Days**	**28 Days**	**7 Days**	**28 Days**	
Normal Range								
Low Strength of Self compacting Concrete with Recycled aggregarate	**MIX-1 (M20) – 0% R.A.**	21.2	37.6	2.8	3.8	3.2	4.1	
	MIX-2 (M20) – 25% R.A.	20.7	36.2	2.5	3.6	2.9	3.8	
	MIX-3(M20) – 50% R.A	20.4	34.6	2.3	3.3	2.7	3.6	
	MIX-4(M20) – 75% R.A	20.2	32.4	2.1	3.2	2.4	3.5	
	MIX-5(M20) – 100% R.A	18.7	29.2	2.0	2.7	2.3	3.4	

CHARECTERISTICS OF SCC IN HARDEND STATE

It is observed that the compressive strength of the SCC is decreasing with increased recycled aggregate. The compressive strength values of M20 SCC with 25% RCA are almost same as that of SCC with natural aggregate though there is a slight difference. There is a significant decrease in the 28 day compressive strength of SCC with RCA compared to that of SCC with natural aggregate. There is not much variation in the7 day compressive strengths of SCC with and without RCA. The variation in compressive, split tensile and flexural strengths, when recycled aggregates partially replaced by natural coarse aggregate by various percentages, are graphically shown.

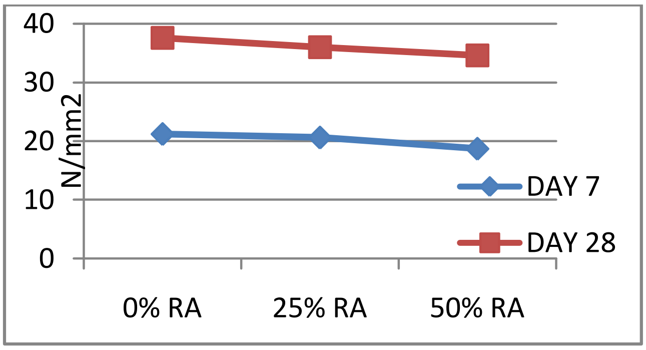

Figure-1 Variation of compressive strength with percentage RCA

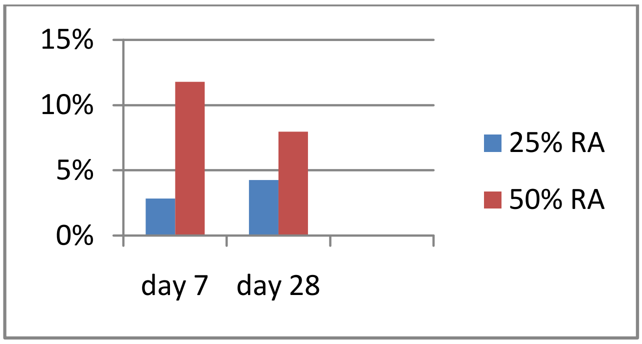

Figure-2 Percentage Decrease in compressive strength w.r.t conventional concrete

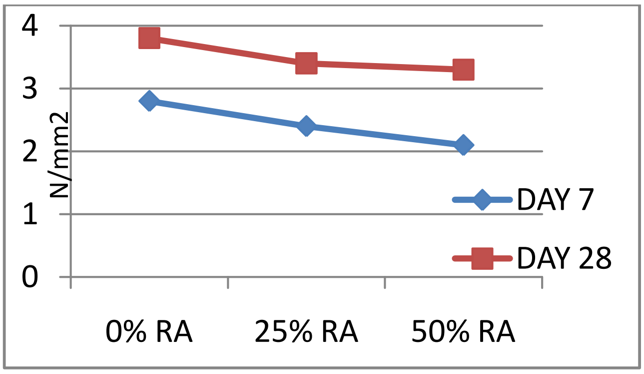

Figure-3 Variation of Split Tensile strength with percentage RCA

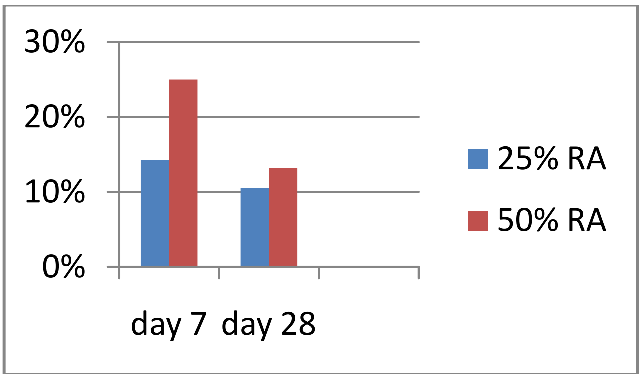

Figure- 4 Percentage decrease in Split Tensile strength w.r.t conventional concrete

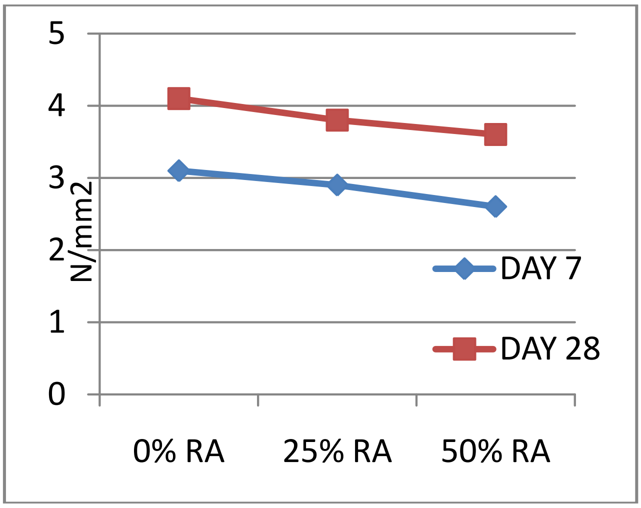

Figure-5 Variation of Flexural strengths with percentage of RCA

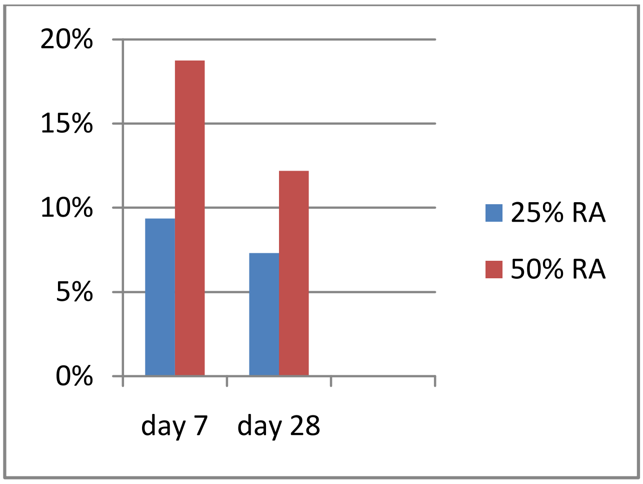

Figure-6 Percentage decrease in Flexural strengths w.r.t conventional concrete

CONCLUSIONS

Using RCA in SCC mixes reduces the utilization of natural aggregates apart from solving waste disposal problem, reduction of noise and air pollution and thus makes more environmental friendly concrete. The following conclusions are drawn based investigations :

- There is a marginal decrease (<10%) in 7 day and 28 day compressive strength of SCC with RCA compared to natural aggregate SCC for 25% 50% and 75% replacement of Natural Aggregate (NA)with Recycled Aggregate(RA).
- For the same M_{20} grade concrete the variation in 7 day and 28 day split tensile strength is from 11% to 25% as natural aggregate is partially replaced with RCA by 25% and 50%.
- The decrease in flexural strength was 9.37% and 18.75% for 25% and 50% replacement of natural aggregate with recycled aggregate respectively at 7 days curing and the corresponding decrease in flexural strength at 28days curing was 7.31% and 12.19% for 25% and 50% replacement respectively.

- Natural aggregate(NA) can be partially replaced by RCA upto 25% without compromising the strength of M_{20} grade concrete even in SCC also.

Acknowledgements: The authors thank the Management and Dr. P. Jannadha Rao of ACE Engineering College, Hyderabad for providing the facilities in carrying out the experiments.

REFERENCES

[1] Okamura H, et.al., (1995) Mix-design for self compacting concrete. Concrete JSCE 25:107–120.
[2] "The European Guidelines for Self Compacting Concrete Specification"(EFNARC), Specification and Guidelines for Self-Compacting Concrete, UK, ISBN 0953973344, http://www.efnarc.org/, 2002.
[3] Kou, S.C., Poon, C.S., (2009) Properties of Self Compacting Concrete (SCC) prepared with coarse and fine recycled concrete aggregates, Cement and Concrete Composites 31: pp.- 622-627.
[4] Grdic, Z.J., Troplicic-curcic, G.A., Despotovic, I.M., Ristic, N.S., 2010. Propertis of self-compacting concrete prepared with coarse recycled concrete aggregate. Construction and Building Materials 24, pp. 1129-1133.
[5] Nan Su, et.al., (2001) A simple mix design method for SCC. Cement and Concrete Research 31:pp- 1799–1807.
[6] B. H. Venkataram Pai, et.al., (2014) "Development of SCC with various mineral admixtures", American Journal of Civil Engineering, Vol. 2, No. 3, May 30, 2014.
[7] Text Book of "Concrete Technology by M.S.Shetty," pp.575-593.
[8] Debashis Das et.al., (2006): Effect of Maximum size and Volume of Coarse Aggregate on the properties of Self Compacting Concrete, ICJ(Journal): pp53-56.
[9] Jagdish Vengala et.al., (2003): Experimental Study for Obtaining Self Compacting Concrete(SCC), ICJ(Journal): pp 1261-1266.
[10] Naveen Kumar et.al., (2006): SCC with Flyash and Metakaolin, The Indian Concrete Journal, pp1261-1266.
[11] Praveen Kumar and S.K. Kaushik, "Self Compacting concrete with crusher dust, flyash and micro-silica", ICJ(Journal)Aug-05: pp.53-56.
[12] Hardik Updhayay et.al. (2011): Testing and Mix design Method of SCC, National Conference on Recent Trends in Engineering & Technology,at BVM EC College, Gujarat.
[13] HemantSood,et.al.,(2009): Incorporating European Standards for Testing Self Compacting Concrete(SCC) in Indian Conditions, International Journal of Recent Trends in Engineering(IJRTE),Vol. 1, No. 6. Nov 2009: pp 41-45.
[14] AAhmadi, et.al. (2007): Development of Mechanical properties of Self Compacting Concrete(SCC) Contain Rice Husk Ash, - International Journal of Civil, Architectural, Structural and Construction Engineering - Vol 10.
[15] Srinivas Vasam, K. Jagannadharao, "Use of SCC and RCA For Sustainable Construction - An Overview", IJRET, Volume: 02 Issue: 11 | Nov-2013

List of Indian Standards

1. IS:4031-1988 *Methods of Physical Tests for Hydraulic Cement (Part 1-6),* BIS- New Delhi.
2. IS:12269-1987 "Specification for 53 Grade Ordinary Portland Cement, (first revision)", BIS- New Delhi.
3. IS:516-1959 - (Reaffirmed 1999) *Methods of Tests for Strength of Concrete*, BIS- New Delhi.
4. IS:5816-1999 *Splitting Tensile Strength of Concrete-Method of Test*, BIS- New Delhi.
5. IS: 456-2000- Code of practice for plain and Reinforced concrete (3rdrevision)- BIS- New Delhi.