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Mechanical Properties of Recycled Concrete Aggregate with Varying Percentage of Recycled Aggregates

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Abstract - *To Most of the concrete structures in India were constructed in late 80's which have reached at its end of life now these structures might have not been constructed with proper quality control. Waste generated after demolition of such structures should be handled in Socio-economic terms. Recycling of concrete waste generated will certainly reduce burden on environment. This paper reports the experimental study on fresh and harden properties of recycled aggregate concrete (RAC) in comparison with natural aggregate concrete (NAC). Four grades of concrete viz. with characteristic strength of 20, 30, 40 and 50 MPa were prepared. In each grade natural coarse aggregates (NCA) were replaced with 0, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 percent by recycled coarse aggregates (RCA). The workability of each mix was reported by performing slump cone and compaction factor test. Cube compressive strength split tensile strength and flexural strength of RAC were examined with respect to NAC. The results indicate decrease in workability and strength properties with increase in replacement ratio of NCA to RCA.*

***Key Words*: Demolition waste, Natural aggregate concrete (NAC), Recycled aggregate concrete (RAC), Workability, Compressive strength, Split tensile strength.**

1. INTRODUCTION

The generation of construction and demolition has been rapidly increasing at a greater pace day by day. There is a gigantic boom in construction industry which has caused demolition of existing structure, due to scarcity of available land or safety issues. The various sources that contribute for generation of demolishing waste may be disaster caused by natural calamities, war inflicted damage, waste generated during construction. This waste directly enters as landfill causing huge land pollution which results in barren land. This activity has proved detrimental environment impact, hence there is need of effective planning and methodology in order to manage, handle, dispose or reuse this generated waste. On the other hand, conventional concrete being widely used in construction industry causes, depletion of natural resources, high energy consumption and generation of waste has adverse impact on environment.

India being a growing economy, this has brought a momentum boost in construction activities which are progressing rapidly. The current investment in construction is around $70 billion annually, with an identified need for an additional $50 billion and an anticipated annual growth rate of 15 percent (Arif et al., 2009b) [2]. In future the anticipated infrastructural development will demand around $163 billion investment in next ten years (Syal et al., 2006) [34] with the escalating rate of construction activities carried out in India, there is need to evaluate the quantity of waste being generated and investigate the practices for handling it in view of approaching towards green construction (Arif et al., 2009a) [2]. India generates total solid waste of about 960 million tons, of which the waste from construction is 14.5 million tons (Pappu et al., 2007; TIFAC) [22]. This quantity is however misleading, as it only estimates the waste that is accounted and properly disposed for (Talyan et al., 2008) [36]; as there is general practice in India of dumping construction waste by the roadside, natural streams or on a vacant land without intimating and documenting it. On a conservative basis it is estimated that over 25-30 million tons of construction and demolishing waste is generated annually that cause adverse impact on environment.

This issue of demolishing waste has become a main concern to planners, engineers and environmentalists. In this context, recycling of this concrete rubble waste by converting it to recycled coarse aggregates will serve dual purpose, by preserving landfills and by reducing mining of natural materials for new construction activities. The use of RCA in construction industry will be advantageous in terms of economic values and environmental concerns. Globally many countries have taken efforts for recycling demolished waste. Singapore recycles about 98% of its C & D waste due to constrain for land in country, recycling rate in Korea is 36% with a target to achieve 45% by 2016, in Scotland 63% of C & D waste was recycled in 2000, 95% of concrete waste was used as roadbed and backfill in Japan during year 2000. The quality protocol to produce aggregates from inert waste was published in 2004 by the Northern Ireland Environment Agency in the United Kingdom, which helped to promote 28% of its C & D waste to be recycled. Denmark and Netherlands have imposed policy for reuse of demolished waste to minimize landfills (Centre for science and Environment) [6]. In India recently recycling of C & D waste have been started at Burari in New Delhi and we must be conscious of the potential of recycling and reuse of different waste generated. Hence in order to achieve sustainable growth a well-defined practice regarding C & D waste generation, handling, recycling and reuse is to be developed.

1.1 Construction and demolition waste

Waste materials and by-products are created from several sources. When structures are demolished, the resulting material is either dumped in landfill sites or recycled in new applications. Rejected concrete and concrete materials not satisfying code requirements or due to delayed casting. Therefore, construction and demolition waste can be considered a renewable material.

The preceding discussion leads one to conclude that there is a desperate need to maximize the use of recycled aggregates derived from construction and demolition waste in construction, particularly in new concrete. Hence, the performance of the recycled aggregate concrete needs to be improved to satisfy the requirements of the national standards

1.2 Recycled Coarse Aggregates

In this paper an effect of replacing NCA by 0,10, 20, 30, 40, 50, 60, 70, 80, 90 and 100% by RCA was examined for different grades of concrete M20, M30, M40 and M50. The effect of replacement ratios on workability and mechanical properties viz. compressive strength, split tensile strength and flexural strength were studied and the percentage variation in results with respect to control mix was documented. This research has concluded the optimum use of percentage replacement of NCA by RCA. The recycled aggregate for the present experimentation was derived from waste generated from demolished residential structure in Pune city (India).

2. OBJECTIVES AND RESEARCH SIGNIFICANCE

The sustainable application of RAC in view of reducing the negative impact caused by construction and demolition waste generated in considerable amount all over the world. The main objective of the research carried was to investigate fresh and hardened properties of concrete using recycled coarse aggregate. The main variables were replacement of NCA with varying percentage of recycled coarse aggregate obtained from demolished construction sites. The various mixes were used to study the performance of RAC with varying percentage of RCA. In view of testing the hypothesis, the replacement of natural aggregate with RCA partially or 100 % would not result in significant decrease in mechanical properties of concrete.

3. EXPERIMENTAL PROGRAM

3.1 Testing program

Various concrete mix trails having replacement of natural coarse aggregate by varying percentage of RCA obtained from C & D waste were carried out for different concrete mix. A total of two different types of mix having compressive strengths 20 MPa and 30 MPa were used. Each mix had 0, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 percentage of recycled coarse aggregate as a replacement to NCA.

Abrams slump cone and compaction factor test were used to identify the workability of fresh concrete prepared in two different mix with eleven variations in percentage of NCA replacement as per IS 1199(1959) [41] and IS 5515(1983) [42] respectively. To evaluate the mechanical properties of recycled aggregate concrete 66 cubes, 66 cylinders and 66 beams were casted for compressive strength, splitting tensile strength and flexural strength, respectively.

Standard Cubes of dimensions 150x150x150 mm confirming to IS10086 (1982) [43] were prepared and tested according to IS 516 (1959) [44] for determining 28 days compressive strength of concrete for two mix with varying percentage of NCA replacement with recycled aggregate. Three cubes each for identical mix along with different percentage of replacement of NCA i.e., 66 cubes were tested, and the average compressive strength was noted. Standard cylinders 150 x 300mm length confirming to IS 10086 [43] were prepared and tested at a curing age of 28 days as per IS 5816 (1999) [45]. For determining 28 days split tensile strength of concrete for two mixes with varying percentage of NCA replacement three cubes each for identical mix along with different percentage of replacement of NCA i.e., 66 cylinders were tested, and the average split tensile strength was recorded. To determine the flexure strength of RAC, 66 beams of standard size (150 x150 x700 mm) were casted and tested at a curing age of 28 days according to IS 516 (1959) [44]. The beam specimens were tested under two-point loading 200mm apart to ensure pure flexure between points of loading using universal testing machine.

3.2 Material constituents

Fine coarse aggregate obtained from Bhima river basin having average particle size varying from 0.075mm to 2.36mm was used for all the mixes. The fineness modulus was 3.0, the specific gravity 2.65 and the water absorption capacity of 2.0%. The sieve analysis results are represented in Table 1. The gradation curve for fine aggregates lies well within the limits specified by IS 383 -1970 [46] and is parallel to zone II as represented in Chart-1. The natural coarse aggregates were obtained from common source, derived by crushing Deccan trap parent rock which had ensured uniform properties. The NCA used for all mixes had average particle size varying from 12.5mm to 20mm, the specific gravity 2.91 and the water absorption capacity of 1.45 %. The gradation curve as represented in Chart 2 for NCA lies well within the limits as specified by IS 383 -1970 [46]. The sieve analysis results for NCA are as shown in Table 2.

The recycled coarse aggregates were obtained by crushing demolished residential building in local area. The recycled coarse aggregates used for mixes had average particle size varying from 10mm to 20mm, the specific gravity 2.71 and the water absorption capacity of 3.54 %. The gradation curve as represented in Chart-3 for RCA lies well within the limits as specified by IS 383 -1970 [46]. The sieve analysis results for RCA are as shown in Table 3. Tests on respective NCA, recycled coarse aggregates and natural fine aggregates samples were performed regularly as per IS2386 (Part III) – 1963[48].

Sieve Sizes (mm)	Weight Retained (gms)	Weight Retained %	Cumulative Weight Retained %	Cumulative Passing %
10	0	0	0	100
4.75	53	5.3	5.3	94.7
2.36	128	12.8	18.1	81.9
1.18	273	27.3	45.4	54.6
0.600	256	25.6	71	29
0.300	212	21.2	92.2	7.8
0.150	60	6	98.2	1.8
0.075	0	0	98.2	1.8
Pan	18	1.8	100	0

Table 1: Sieve Analysis of Natural Sand

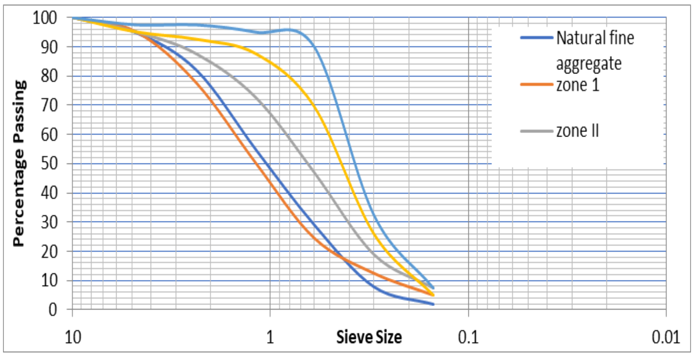

Chart -1: Gradation Curve For the natural fine aggregates.

Sieve Sizes mm	Weight Retained (gms)	Weight Retained %	Cumulative Weight Retained	Cumulative Passing %	IS Passing Limits %
40	0	0	0	100	100
25	0	0	0	100	-
20	225	11.26	11.26	88.7	85-100
16	547	27.38	38.64	61.4	-
12.5	630	31.53	70.17	29.8	-
10	510	25.53	95.7	4.3	0-20
4.75	86	4.3	100	0	0-05
Pass	0	0	100	0	-

Table 2: Sieve Analysis for Natural Coarse Aggregate

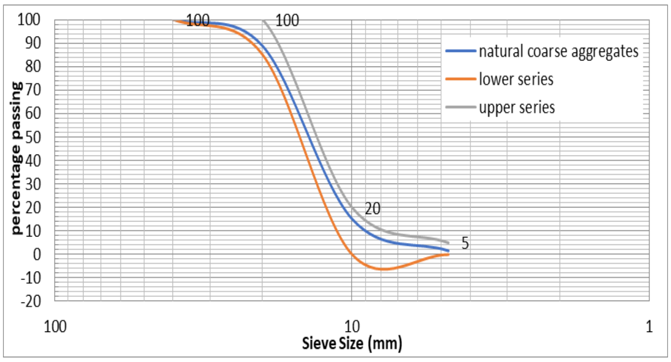

Chart -2: Gradation curve for the natural coarse aggregates

Sieve Sizes (mm)	Weight retained (gms)	Weight Retained %	Cumulative Weight Retained %	Cumulative Passing %	IS Passing Limits %
40	0	0	0	100	100
25	0	0	0	100	-
20	232	11.61	11.61	88.4	85-100
16	617	30.88	42.49	57.5	-
12.5	657	32.88	75.38	24.6	-
10	290	14.51	89.89	10.1	0-20
4.75	194	9.71	99.6	0.4	0-5
Pan	8	0.4	100	0	-

Table 3: Sieve Analysis for Recycled coarse Aggregate

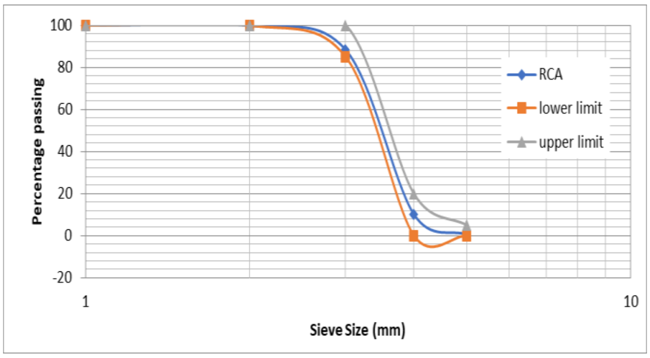

Chart-3: Gradation curve for the recycled coarse aggregates

Concrete Mix Proportion

As per guidelines of IS 10262:2009 [47] the concrete mix proportion for different concrete grades was designed. The designed concrete mix proportions were tested for different trails, to examine the homogeneity and cohesiveness of concrete mix and to select the percentage super plasticizer for different mixes. The concrete mix M_{20} and M_{30} were examined, with W/C ratio varying between 0.53 - 0.45. To achieve the desired workability, it was necessary to add chemical admixture (Aura mix 400) provided by FOSROC chemicals was used for mix of normal grade. NCA replacement with RCA by 0, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 percent by weight of NCA were observed at various W/C ratios. The mix proportions adopted for the concrete mixes are summarized in Table 4.

Mix	Grade	Targeted Compressive Strength MPA	Cement Kg/m³	Water Kg/m³	W/C Ratio	NFA Kg/m³	NCA Kg/m³
M_1	M_{20}	26.6	320	170	0.53	868	1165
M_2	M_{30}	38.25	390	175.5	0.45	798	1133

Table 4: Mix Proportion

In the present work, a rational approach was adopted for replacement of NCA with RCA during batching of concrete mix. The batching procedure adopted for control mix and for all mixes of RCA was similar. The water-cement ratio for RCA concrete mix was constant without changing the water content. This resulted in reduction in slump value as expected, in view of enhancing workability of concrete chemical admixture was added. The quantity of chemical admixture was decided to obtain expected slump for RCA mix. For normal grades of M_{20} and M_{30} mixes with NCA replacement above 40%. The chemical admixture added was, 0.9 and 1.1 percent of weight of cement for M_{20} and M_{30} mixes, respectively. As it is already proved that the addition of chemical admixture does not affect the mechanical properties of concrete and it only enhances the properties of fresh concrete (Neville 2002) [20]. This study was carried to identify the mechanical properties of RCA with constant W/C ratio for various mixes.

4. Hardened concrete properties

The results of compressive strength split tensile strength and flexural strength are summarized in Chart 4-6 for different mix and percentage replacement of NCA. The test results represent the average of three replicate tests conducted on sample specimen at curing age of 28 days.

4.1 Compressive Strength

From the cube strength of all mixes presented in Chart 4, it is observed that as the replacement of NCA with RCA increases, there was decrement in compressive strength of concrete as compared to control mix. There is insignificant reduction (3.8% to 8.2%) in compressive strength for 30% replacement of NCA. At a replacement of 40% of NCA it is observed that the compressive strength decreases considerably. With respect to 30% replacement the percentage decrease in compressive strength for 40% replacement were from 7.88 to 15.57 and 8.70 to 13.16 for M_{20} and M_{30} mixes, respectively. As replacement of NCA increases (40%-100%) there is enormous reduction in compressive strength, the average reduction in compressive strength is observed to be 18.48 % and 18.30% for M_{20} and M_{30} mixes, respectively. This reduction in compressive strength may be due to the porosity of RCA as the free water content available for hydration of cement will be partially absorbed by it. For control mix there is only one ITZ, while RAC have two ITZs, i.e., interface between adhered mortar and RCA (old ITZ) and interface between new mortar and adhered mortar (new ITZ). The performance of RAC is highly influenced by the adhesion mortar, with respect to strength and permeability (Otsuki et al 2003[21]; Ryu 2002 [30].

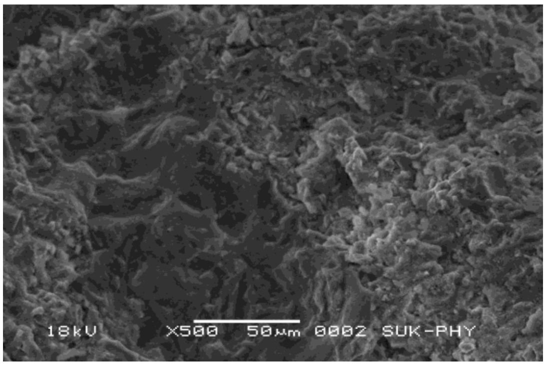

Fig -1: SEM image Showing ITZ for Cement content

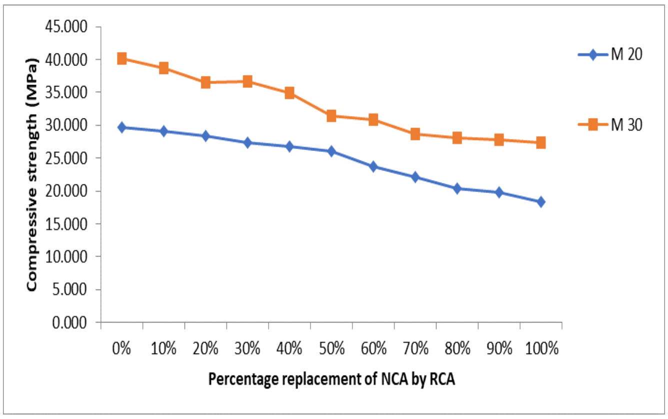

Chart-4: Effect of RCA content on compressive strength.

4.2 Split Tensile Strength

It is observed that as the percentage of NCA replacement with RCA increases, there is a decreasing trend in split tensile strength at the curing age of 28 days. Split tensile strength is governed by the number of micro cracks developed in the concrete due to shrinkage. In loaded specimen the energy is utilized in propagation of micro cracks and further development of cracks in the way of propagation, results development of split failure of the specimen. Fanlu Min et al. (2014) [9]. In case of RCA concrete, the formation of such micro cracks is more as compared to NCA concrete due to presence of adhered mortar, resulting in less energy requirement for development and crack propagation, hence decrease of split tensile strength is observed as the replacement is increasing.

The decreasing trend of tensile strength is presented in Chart 5. It is observed that there is marginal reduction (2.73% to 5.95%) in tensile strength for 20% replacement of NCA. As the replacement of NCA increases (30% -100%), there is significant reduction in tensile strength, the average reduction in tensile strength is observed to be 16% and 13% for M_{20} and M_{30} mixes, respectively. For 100% replacement of NCA there is severe reduction (24% - 32%) in tensile strength.

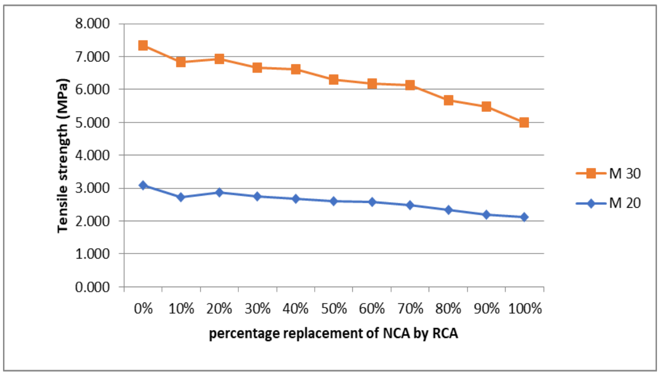

Chart-5: Effect of RCA content on tensile strength.

4.3 Flexural Strength

The flexural strength of all mixes is represented in Chart 6. The observations were that as the percentage of replacement of NCA is increased the flexural strength of RCA goes on decreasing compared to control mix. Due to presence of adhered mortar in RCA concrete, the brittleness of concrete increases resulting in reduction of elastic modulus as well as increase in post peak softening modulus. This leads towards lowering of flexural strength of RCA concrete with higher replacement levels Raghu Prasad B.K and et al (2010) [25]. Chart 6 shows graphical variation of flexural strength with respect to percentage increase in replacement of NCA. It is observed that there is subsidiary reduction (2.19% to 4.25%) in flexural strength for 20% replacement of NCA. As replacement of NCA increases (30%-100%) there is sustainable reduction in tensile strength, the average reduction in flexural strength is observed to be 17.82% and 14.21% for M_{20} and M_{30} mixes, respectively. For 100% replacement of NCA there is severe reduction (21% - 28%) in tensile strength.

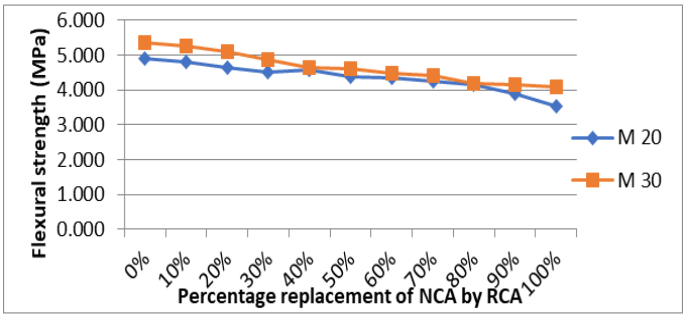

Chart-6: Effect of RCA content on flexure strength.

4.4 Statistical analysis for compressive strength

The mean, standard deviation, variance and coefficient of variance are as shown in the Table 5.

Mix	Mean	Standard Deviation	Variance	Coefficient of Variance
M20	24.17	4.0	16	16.55
M30	32.82	4.7	22.27	14.38

Table 5: Statistical analysis for compressive strength.

It is observed from standard deviation values that, the probability of characteristic strength achieved is 96% to 94%. It indicates that the experimental results are near to average strength for corresponding mixes. The normal distribution curve for different mixes is as shown in chart 7 which indicates that as the grade of concrete increases the results lie away from the mean strength. Further the correlation coefficient values for M20 and M30 grade has positive correlation of 0.96.

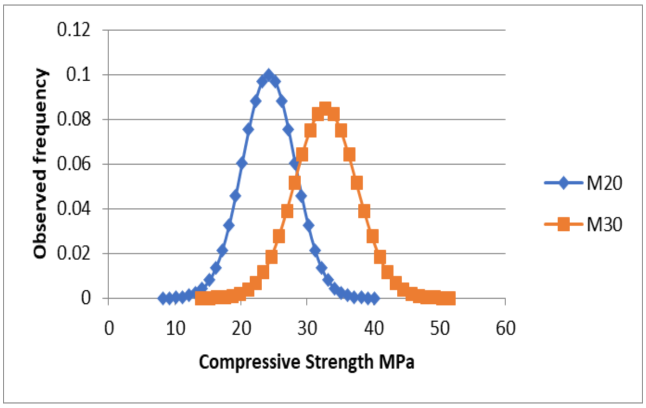

Chart-7: Normal distribution for mixes

5. CONCLUSIONS

Due to rapid urban development in India the amount of C & D waste generated is tremendous, which finds the necessity to utilize reuse demolished construction material. It may also help to reduce impact on environment and may help to conserve it. The experimental investigation leads following conclusions,

- The gradation of recycled aggregate used for the present work confirmed within the limits specified by IS 383-1970, whereas the specific gravity of RCA was found below the NCA.
- The workability of RAC is observed less as compared with NAC. This inference may be supported due to considerable water absorption of RCA than NAC.
- Performance of concrete mixes up to 30% replacement of NCA by RCA have shown insignificant adverse effect on compressive strength, therefore recycled aggregate derived from concrete rubble can be used to produce structural concrete.
- With replacement ratio over 30% caused rapid percentage reduction in compressive strength of all mixes. For 100% replacement enormous reduction in compressive strength were recorded.
- At the replacement level up to 20% split tensile and flexural strength of all mixes were closer to control mix. As percentage replacement increased the percentage reduction in the strength is highly significant.
- The partial substitution NCA by RCA may prove to be eco-friendly and works for effective utilization of waste. It can further eliminate dumping areas.
- Use of mineral admixtures as fly ash, silica fume, nano silica, colloidal nano silica may enhance interfacial zone between adhered and new mortar which may acts as micro filler, resulting in better performance of RAC.

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