Efficient Replacement of Coarse Aggregate in Concrete by Recycled Coarse Aggregate

Mix design considering Residual Mortar Content

[1]Rahul P Nair,[2]JelittaRaju,[3]Anna Mathew, [4]Dona James, [5]Vilma Baby
[1,2,3,4]BTech students,[5] Assistant Professor
[1]Civil Engineering Department
[1]Muthoot Institute of Technology and Science, Varikoli,India

Abstract :The construction industry persists in a massive over production of primary aggregates. This has caused over-exploitation of natural resources and serious under-utilization of recycled aggregates. At present, the possibility of replacement of natural aggregates by recycled aggregates is not utilized sufficiently due to insecurities over the properties possessed by these. The research focuses on replacement of natural coarse aggregates in concrete with manually crushed recycled aggregates. Properties of recycled aggregates were studied and the average mortar content adhered to their surface was determined experimentally. Based on this, the mix design was altered, reducing the volume of virgin mortar content. Strength tests were conducted and the most efficient replacement percentages were determined for higher grades.

***IndexTerms* - Natural coarse aggregates, Manually crushed recycled coarse aggregates, Mortar content, Mix design, Most efficient replacement percentage**

I. INTRODUCTION

One of the major challenges the present society faces is the protection of environment. Some of the important elements in this regard include increased consumption of energy and natural raw materials, and improper disposal of waste materials. Natural resources are exploited on a large scale for the production of aggregates in construction, particularly coarse aggregates. Inert construction and demolition waste (especially crushed concrete) forms a possible source of alternative for natural aggregates. Over 60% of this type of material is now used as general fill for land reclamation, and rarely as aggregate.

Recycled concrete aggregate is generally produced by two-stage crushing of demolished concrete, followed by screening and removal of contaminants such as reinforcement, paper, wood, plastics etc. Concrete made with such recycled concrete aggregate is called recycled aggregate concrete (RAC). If exploited to the full extend, the use of RAC could lead to saving of a lot of natural resources, and would also cause large reduction in the quantity of waste produced. But the use of RAC is now limited due to insecurities over the properties possessed by these.

The study focuses on efficient replacement of coarse aggregate in concrete by RAC. Mixes were altered based on the mortar content adhered to the surface of RAC, so as to eliminate the negative effects due to comparatively weaker properties. The most efficient replacement percentage for different grades – M40, M50 and M60 was determined.

II. PROPERTIES OF RCA

Twenty four years old demolished building slabs (RCC) were manually crushed and sieved through standard IS sieves 20mm, 12.5mm, 10mm and 4.75mm for getting a nominal mix of 20mm, as per IS 383-1970. Initial studies include determination of material properties of RCA. Texture of RCA was found to be rougher than NCA (Natural Coarse Aggregate) due to the adhered mortar. Studies prove that fineness modulus of RCA was higher; owing to the fact that RCA is relatively coarser than natural aggregates. Physical properties such as specific gravity and density were found to be lower in RCA, due to the light and porous nature of attached mortar. The water absorption capacity is more for RCA than NCA as it is less dense and has more pores.

Fig 2.1: Manually crushed recycled aggregates

Table 2.1: Material Properties of RCA

Material	Specific Gravity	Water Absorption (%)	Fineness Modulus
NCA	2.73	0.29	2.39
RCA	2.53	4.406	3.27

III. RESIDUAL MORTAR CONTENT

RAC is viewed as a two-phase system, the first being the virgin aggregate phase and the latter, the residual mortar phase. Residual Mortar Content (RMC) refers to the mortar adhered to the surface of the recycled aggregates. This phase contains sand, cement and water. Generally, the properties of recycled aggregates are poor due to the presence of this layer, as it generates additional amount of mortar in the mixture when proportioned as in conventional concrete mixtures, resulting in the creation of multiple transition zones. Hence methods for removal of RMC from the aggregates are usually suggested for better performance. The possibility in making use of the presence of RMC in a wise manner so as to produce better results is still an unexplored area of research. This study focuses on the use of RAC in which RMC is kept intact and on its basis, the general mix design procedure is altered.

Two tests were carried out to determine the average residual mortar content (RMC) in the recycled aggregates collected:

Thermal treatment method: 500g sample saturated in water was placed in a muffle furnace at 500°C for 24 hours. These were then removed quickly and dropped into cold water (5-7°C). The mortar adhered to the aggregates became brittle and hence was easily removed. The remaining aggregates were sieved through IS sieve of 4.75 mm size and the weight of aggregates retaining was measured, after 24 hours of oven drying.

Freeze-Thaw method: 1000g of the RCA sample was heated at a temperature of 105°C for 24 hours. The aggregates were then immersed in 26% (by weight) sodium sulphate solution for the next 24 hours. The sample in the immersed state was then placed at a temperature of 80°C for 8 hours and 0°C for 16 hours overnight. The above freeze-thaw cycle was repeated for five consecutive days. After the last cycle, the solution was drained and the sample was washed in 4.75 mm IS sieve. The weight of oven dried aggregates was then noted.

For both tests RMC was calculated as per the following equation,

$$RMC\ (\%) = (W1-W2)/W1\times 100 \qquad \text{--- (1)}$$

Where, W1 = Initial weight of sample

W2 = Final weight of sample

Table 3.1: Residual Mortar Content

By Thermal Treatment Method	22.53%
By Freeze-Thaw method	20.46%
Average	**21.5%**

IV. CONCRETE MIX PROPORTIONS

Based on the quantity of residual mortar obtained, alterations were made in the mix design of concrete incorporating RCA. RMC varied with every mix and replacement percentage which was taken into consideration while carrying out mix design. The amount of fresh cement, sand and water was reduced depending on the residual mortar content. In this manner the effect of multiple transition zones created by RCA was reduced. The concrete mix proportions of the reference mixtures (Normal Aggregate Concrete - NAC) and the mixtures incorporating RCA are given in Table 4.1.

Table 4.1: Mix Proportion for NAC and RAC

Material	Quantity (kg/m^3)					
	M40		M50		M60	
	NAC	RAC	NAC	RAC	NAC	RAC
Cement	584.07	476.14	606.65	496.63	630.92	668.75
Fine aggregate	578.63	471.78	567.55	324.76	556.47	260.306
Coarse Aggregate	1134.59	1272.86	1122.78	953.43	1110.4	777.95
Water	157.7	128.56	157.7	129.1	157.7	133.74
Super Plasticizer	1.168	0.952	1.819	1.49	2.2	3.67

Concrete specimens were cast replacing different percentages of NCA by RCA. It was found while mixing that, additional water is required in RAC to get the same slump as that in conventional concrete due to higher porosity of RCA. Aggregates were soaked in water to a saturation level before mixing to reduce their absorption of water added for hydration process. This improved the internal water supply of the aggregates, had better workability and showed similar drying shrinkage with conventional concrete. Same degree of homogeneity as that in conventional concrete was obtained while using coarse recycled aggregates.

All specimens were cured under standard conditions for 28 days and tested in compression to find the optimum percentage of replacement. Flexural strength and split tensile strength of RAC specimens in optimum replacement percentage were found out to compare with those of NAC specimens.

V. RESULTS AND DISCUSSION

Various strength tests were conducted and the properties of RAC were compared to that of NAC. Their observations are summarized as shown below:

Table 5.1: Compressive strength at different percentages of replacement

% of replacement	Compressive strength (N/mm^2)		
	M40	M50	M60
0	56.72	67.64	71.57
20	54.65	65.42	70.32
40	53.10	62.37	70.25
50	51.33	60.95	69.43
60	**50.13**	60.18	69.28
65	46.67	**58.81**	69.07
70	40.74	56.71	**68.5**
75	35.24	55.11	65.62
Target	**48.25**	**58.25**	**68.25**

Table 5.1 displaysvalues of compressive strength obtained for different grades at varying percentages of replacement.It was found that compressive strength reduced with increased percentage of RCA. The target strength of the mix was attained for 0 to 65%, 0 to 70% and 0 to 75% replacement with RCA for M40, M50 and M60 grades respectively and the compressive strength values were comparable with those of NAC (Fig 5.1).

Thus the optimum replacement percentages were found to be 60, 65 and 70 for M40, M50 and M60 grades respectively.

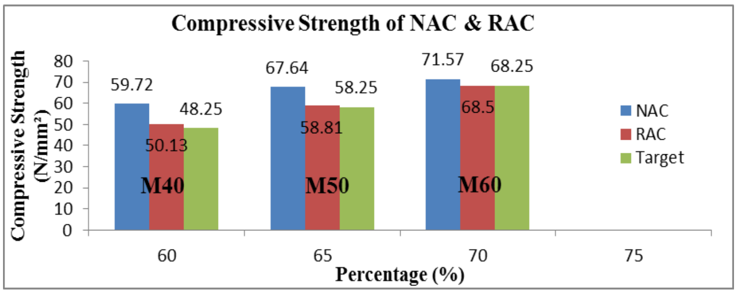

Fig 5.1:Compressive Strength Test Results of NAC & RAC

The decrease in compressive strength with increase in replacement by RCA is due to the presence of multiple transition zones created by the adhered mortar in RCA along with fresh mortar.

The optimum percentage of replacement is higher for higher grades. This can be attributed to the lesser effect of replacement as the relative aggregate content is lesser for higher grades.

Split tensile strength test of RAC gave satisfactory results that did not show significant decline with respect to NAC (Table 5.2, Fig 5.2). Flexural strength of RAC was also found to be comparable with that of NAC. The average flexural strength for all grades was found to be greater than the target value (Table 5.3, Fig 5.3).

Table 5.2: Split tensile Strength of concrete cylinder after 28 days

	M40	M50	M60
NAC	4.56	4.99	5.30
RAC	3.42	4.24	4.87
Target	4.42	4.94	5.42

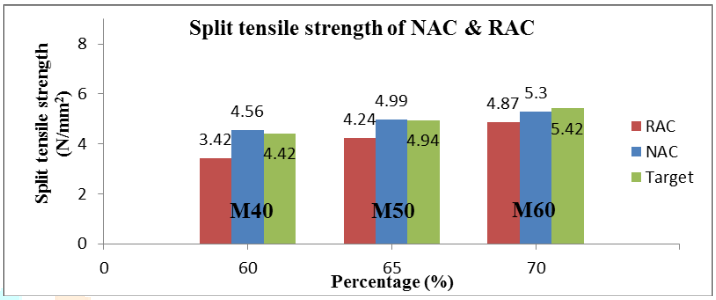

Fig 5.2: Split tensile strength results of NAC & RAC

Table 5.3: Flexural Strength of concrete beam after 28 days

	M40	M50	M60
NAC	5.47	5.87	7.46
RAC	4.73	5.26	6.1
Target	4.42	4.94	5.42

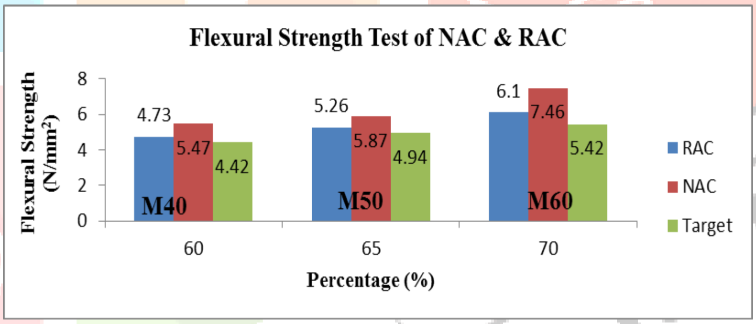

Fig 5.3: Flexural strength results of NAC & RAC

It is evident from the results that the properties of NCA and RCA are comparable. It is inferred that on modifying the mix proportion by considering the mortar attached to virgin aggregates, the properties of Recycled Aggregate Concrete can be measured at par with conventional concrete. Thus RCA proves to be an efficient, reliable and sustainable alternative for natural aggregates.

References

[1] C.Thomas, J.Setien, J.A.Polanco, P.Alaejos and M.Sanchez de Juan. 2012. Durability of recycled aggregate concrete. Construction and building materials, pp 1054-1065.

[2] Hardik Gandhi, Dr.Dharshana Bhatt and ChetnabenVyas. 2013. Study on Use of Recycled Coarse Aggregate In Concrete. National Conference on Recent Trend in Engineering & Technology.

[3] Praveen Mathew,Vilma Baby, Dipak Kumar Sahoo and Glory Joseph. 2013. Manually recycled coarse aggregate from concrete waste - a sustainable substitute for customary coarse aggregate', American Journal of Engineering Research (AJER). Vol.3 pp-34-38.

[4] Valeria Corinaldesi. 2011. Structural Concrete Prepared with Coarse Recycled Concrete Aggregate: From Investigation to Design. Advances in Civil Engineering, pp. 1-6.