FLEXURAL BEHAVIOR OF REINFORCED RECYCLED CONCRETE BEAMS: A REVIEW

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Abstract

Concrete is the most commonly used construction material which has been used in all type of civil engineering construction work. The concrete industry at present globally consumes 8 to 12 billion tones of natural aggregate annually. The huge consumption of natural aggregates at domestic and commercial construction will inevitably degraded the environment. Thus there is an urgent need to restrict the use of natural aggregates. Thus solution lies to use the recycled concrete aggregates into construction work. The aim of this study is to investigate the flexural behaviour of Recycled Aggregate Concrete. Many researches have been done in European countries and also of some Asian countries to investigate the mechanical properties of Recycled Concrete Aggregate, however approximately only 14% research has been done to study the structural behaviour of Recycled Concrete Aggregate. This study gains importance in view of the wide potential for demolished concrete to serve as a source of quality aggregate feed stock in a variety of structural and non-structural applications. This review study presents the impact of Recycled Concrete Aggregate, with different replacement ratios, on flexural strength. The review study yielded the following findings in regards to concrete structural properties:(1)Beams with RCA did experience greater mid span deflections under a service load and smaller cracking moments, (2) The flexural strength of the beams made with the Recycled Aggregate Concrete is lower than that of the concrete beams with natural aggregate; however the values are greater than the theoretical values (3) Also addition of some fibres in RCA, there is an improvement of almost all the structural properties of Concrete.

Keywords: *Recycled concrete aggregate, recycled aggregate, replacement ratio.*

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1. INTRODUCTION

Concrete is the most vitally construction material which has been used in all type construction work. Around 10 billion tons of concrete is consumed per year, which means a ton of concrete is consumed per person every year. The concrete industry at present globally consumes 8 to 12 billion tones of natural aggregate annually. The demand of natural aggregates will increase in future due to rapid construction of buildings, bridges and roadways as of year 2020. The huge consumption of natural aggregates at domestic and commercial construction will inevitably degraded the environment. Thus there is an urgent need to restrict the use of natural aggregates.

Further development of infrastructural facilities is accompanied by construction, remodeling and demolition of structures and highways. The waste generated mainly consists of inert and non biodegradable materials such as concrete, plaster, wood, metal, broken tiles, bricks; masonry etc. fig.1.1 shows the typical composition of Construction and Demolished waste (C&D waste hereafter). The concrete constitutes more than 65 percent of the total C&D waste.

The total quantum of C&D waste generated in India is estimated to 11.4 to 14.69 million tons per annum (*TIFAC, 2000*). These wastes are heavy, having high density, very often occupy considerable storage space either on road sides or communal waste bin. In most part of the world, on travelling a few kilometers by road, it is not uncommon to see huge piles of such waste, which is heavy as well, stacked on roads especially in large projects, resulting in traffic congestion.

To overcome both the aspects i.e. to meet the increasing demand of concrete and management of demolished concrete waste, sustainable solution exists in recycling waste concrete for use as aggregate in new concrete, or recycled concrete aggregates (RCA, fig. 1.2)

Thus the use of Recycled Aggregate Concrete on a large scale may help to reduce the effects of the construction on these factors by reusing C & D waste and preventing more NA from being harvested.Fig.1.1- Composition of construction & demolished waste in India (*S K Bhattacharya et al. 2013*).

2. RECYCLED CONCRETE AGGREGATES

The recycled concrete aggregates can be defined as crushed concrete composed of aggregate fragments coated with cement paste or cement mortar from the demolition of the old structures or pavements that has been processed to produce aggregates suitable for use in new concrete. The processing, as with many natural aggregates, generally involves crushing, grading and washing. This removes contaminant materials. The resulting coarse aggregate is then suitable for use in concrete.

Due to the low quality/strength of Recycled concrete aggregates the application of concrete waste was limited to the sub-base in road construction, bank protection, noise – barriers and embankments.

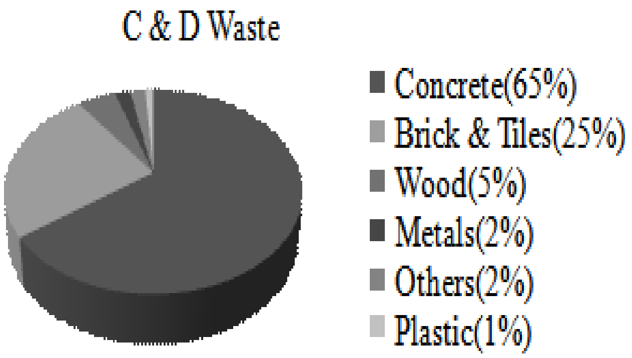

Fig.1.1- Composition of construction & demolished waste in India (*SK Bhattacharya et al. 2013*).

When demolished concrete is crushed, a certain amount of mortar and cement paste from the original concrete remains attached to aggregate particles in recycled aggregate. This attached mortar is the main reason for the lower quality of RCA compared to natural aggregate (*M. Etxeberria et al. 2007).*

Therefore in-order to find the scope of Recycled concrete aggregate as construction material researchers was interested to find the physical and mechanical properties of recycled concrete aggregates. Based on available experimental evidence the important properties of recycled concrete aggregate (RCA) and concrete made with recycled aggregate (RAC) are briefly presented-

- Increased water absorption.
- Decreased bulk density.
- Decreased specific gravity.
- Increased abrasion loss.
- Increased crushability.
- Increased quantity of dust particles.

M. Heeralal et al (2009) was investigated the properties of aggregates obtained from the construction and demolished waste, the result obtained is presented in table 1.1.

3. FLEXURAL PERFORMANCE OF RAC

Due to the fact that appropriate structural design guides for recycled concrete material have not been established, only approximately 14% of all concrete waste is made into aggregate and recycled. To promote the use of recycled concrete aggregates (RCAs), flexural tests of reinforced high-strength and normal-strength concrete beams were tested. This paper presents data from other researchers' studies that were examined in evaluating the flexural strength of reinforced concrete beams with RCA.

While several studies have been taken out worldwide in-order to find out the material properties of Recycled concrete aggregate, structural behaviour of reinforced concrete beam with RCA has been relatively limited

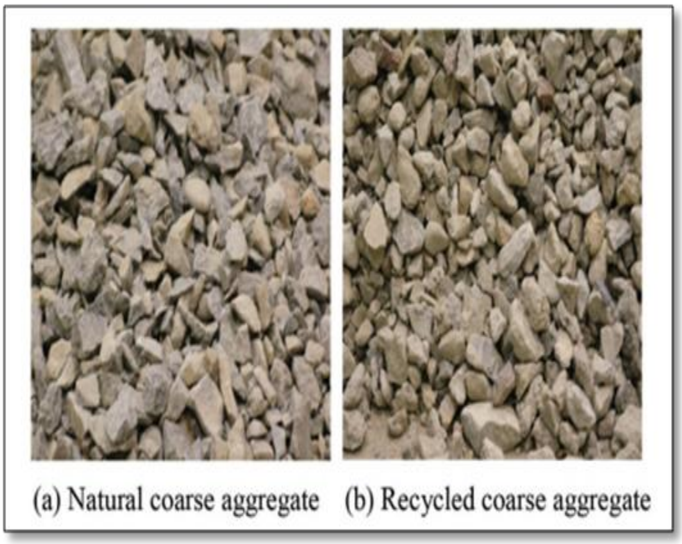

Fig.-1.2: Recycled Coarse Aggregate (*Thomas H.K. Kang 2014*).

It has been found that the flexural strength of reinforced concrete beam with RCA decreases with the increase in replacement ratio (*G.Murali and V.R. Ramkumar 2012*). Results shows that the reduction in flexural strength with replacement ratio is not linear but it shows that upto 30% replacement ratio the flexural strength is slightly lower or comparable to the flexural strength of the normal concrete (*Thomas H.K. Kang et al. 2014*).

Ryoichi Sato et al. 2007 found that there are many factors which are directly affecting the flexural strength of RAC beams. These factors are W/C of original concrete used for producing recycled concrete aggregate, curing condition, W/C of recycled concrete and tension reinforcement ratio. *Ravande kishore (2007)* carried out flexural tests on a total of 8 reinforced concrete beams with RCA. The flexural specimens consist of our types of M25 grade beam specimens and four types of M30 grade beam specimens (RAC and NAC). The beams were simple-supported, and a monotonic static load was applied to test the beam specimens under two point loading. Based on the test results, the author concluded that the ultimate load and ultimate moment carrying capacity of RAC beam specimens are lower than that of the beam specimens with the natural aggregates; however the values are greater than the theoretical values. Table 1.3 shows the test result obtain by author.

Silica fume is one of the cement replacement materials, when it is mixed in the RAC with some fibres it shows an improvement in the flexural strength. When in RAC mix consists 60% of Recycled fine aggregate and 40% natural sand and 15% of silica fume and 0.15% polypropylene fibre the ultimate load at beam testing are found 39.6kN which was 33.33% higher the conventional and other concrete beams (*M. Kaarthik, and K.Subrmanian 2014*).

Similarly when "Equivalent Mortar Volume method" had been used for the RAC mix design the results shows that the flexural performance of the RAC is comparable or even superior to the natural concrete (*Gholamreza Fathifazal et al. 2009*).

Table- 1.1: Properties of Natural & Recycled Aggregate Concretes (*M. Heeralal et al.2009*).

Properties	100% Natural Aggregate	25% Recycled Aggregate	50% Recycled Aggregate	75% Recycled Aggregate	100% Recycled Aggregate
Bulk Density	1.46	1.44	1.39	1.35	1.28
% of Voids	44.26	44.95	45.21	46.18	48.26
Void Ratio	0.79	0.82	0.825	0.85	0.93
Specific Gravity	2.78	2.72	2.68	2.61	2.55
Fineness modulus	7.1	7.12	7.135	7.142	7.15
Water absorption	1.00	2.10	3.52	4.85	5.68
Flakiness Index	3.56	3.82	4.06	4.31	4.6
Elongation Index	7.13	7.43	7.75	8.05	8.4
Agg. Impact value	32.20	33.15	33.68	34.15	34.48
Agg. Crushing value	22.77	23.00	24.21	27.08	28.16
IAPST	18.10	18.72	19.29	19.79	20.41
Angularity Number	10.31	11.35	12.09	13.30	13.99

Table- 1.2: Measured concrete properties (*Thomas H.-K. Kang et al.2014*).

Concrete	f_c' MPa	f_{ct} MPa	f_r MPa	E_c MPa
H0-Series	64.5	4.2	13.0	3.77×10^4
H15-Series	59.4	3.5	11.9	3.62×10^4
H30-Series	48.8	3.4	10.8	3.28×10^4
N0-Series	38.6	3.3	10.2	2.92×10^4
N15-Series	32.7	3.0	9.7	2.92×10^4
N30-Series	31.7	2.7	9.0	2.65×10^4
N50-Series	29.0	2.7	8.9	2.53×10^4

Note: f_c' is measured compressive strength of concrete; f_{ct} is measured splitting strength of concrete; f_r is measured modulus of rupture of concrete; E_c is modulus of elasticity of concrete calculated using measured f'_c according to ACI 318-11.

Table- 1.3: Ultimate load and ultimate moment of various types of beam specimens (*Ravande kishore 2007*).

Beam notation	Ultimate Load, (kN)	Percentage reduction of of load over NAC, %	Exp. Ultimate Moment, kN-m	Percentage reduction of of moment over NAC, %	Theo. Ultimate moment, kN-m	Percentage increase over theoretical moment, %
M25 NU	125	5.60	27.10	5.50	18.20	48.9
M25 RU	118		25.60			40.6
M25 NB	137	2.90	29.70	3.03	20.20	47.0
M25 RB	133		28.80			42.6
M30 NU	142	7.00	30.80	7.14	20.70	48.8
M30 RU	132		28.60			38.2
M30 NB	146	2.70	31.60	2.53	24.30	30.0
M30RB	142		30.80			26.7

N-natural, R-recycled, U-under reinforced, B-balanced.

3.1 Midspan Deflection:

Based on service load deflection, RCA reinforced concrete beams perform less well than conventional concrete beams. However, the change in aggregate does not have enough influence on deflection to discourage RCA use in concrete beams.

In order to understand the flexural behavior of the RAC beam the beam was tested for service load and the results were compared with the load-deflection of the natural concrete while the W/C ratio for the mixes was kept same and same moment is applied the result revealed that the RAC beams with 100% replacement ratio having 13 % higher service deflection (*Ivan S. Ignjatovic´ et al. 2013*). Although the results shows that RAC has large mid span deflection, compared to natural concrete, the deflection of RAC beams was in the permissible limits that was recommended by ACI 318 (*Gholamreza Fathifazal et al. 2009*).

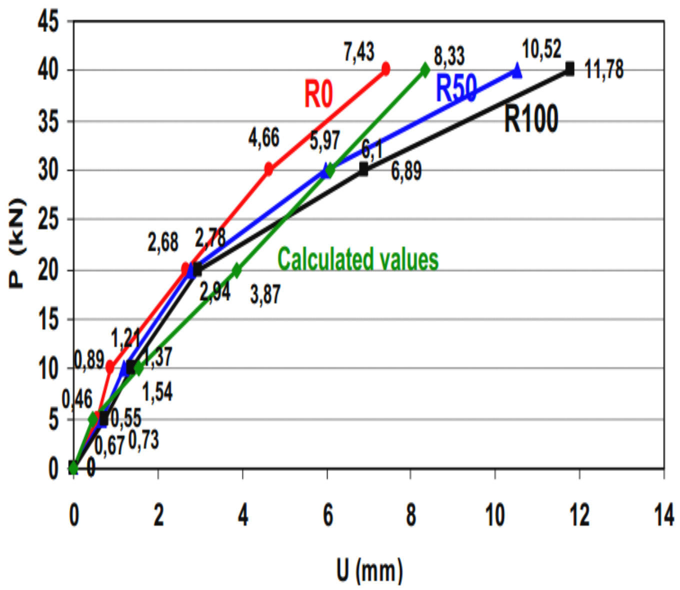

Fig.- 1.4: Calculated and measured values of deflection (Vlastimir Radonjanin et al. *2009*).

To reduce the mid span deflection of the RAC steel fibres were added to the RAC and results shows that the steel fibres improved tremendously with respect to ductility and energy absorption of RAC beams (*M. Heeralal et al. 2009*). When the load-deflection curve is studied in two parts first part upto the elastic limit i.e. linear behavior the deflection value is same irrespective of the type and quality of the aggregate. And second part is post elastic area in which increase in replacement ratio causes increase in deflection value, and this increment is R0 beam is 4% for the ―R50 beam and 10% for the ―R100 beam for the service load level. The main reason for such behavior of the tested beams is a lower modulus of elasticity of concrete types R100 and R50 in comparison to referent concrete R0 (*Vlastimir Radonjanin et al. 2009*).

3.2 Crack Width and Spacing:

When the beam specimens were testing for flexural behavior of RAC cracks was developed. The crack spacing of RAC, consists recycled coarse aggregates and virgin fine aggregate was 0.57-1.3 times than that of natural concrete. And crack spacing of RAC, consists Recycled Coarse and Recycled Fine Aggregate, was 1.1-1.7 times than that of natural concrete (*Masaru Sogo et al. 2014*). The main controlling factor of crack width is compression steel but the crack width of the RAC beams are wider than that of the normal concrete irrespective of the presence of compression steel or not (*Gholamreza Fathifazal et al. 2009*). When the RAC beam specimens, with 100% replacement ratio, were prepared with the same W/C ratio as the natural concrete it was found that RCA has 10 % lower cracking load, which means less crack spacing and wider crack width (*Ivan S. Ignjatovic´ et al. 2013*).

In order to prevent the lower cracking load of RCA beams silica fume has been used and result found that the notable splitting cracks along the tension reinforcement observed in recycled concrete beams of the first phase were mitigated by the addition of silica fume (*González-Fonteboa Belén et al. 2009*)

4. CONCLUSION

1) Recycled Aggregate Concrete is sustainable solution to reduced environmental impact by reducing the amount that must be disposed and it reduces the demand for natural aggregates.
2) Recycled Aggregate Concrete can successfully apply to use as Structural concrete.
3) Adhered mortar of the parent concrete is the weakest point of strength consideration of Recycled Aggregate Concrete.
4) Flexural Strength of Recycled Aggregate Concrete is lower than that of virgin concrete.
5) Many researchers shown by their study that flexural strength of Recycled Aggregate Concrete can be increased by using fibres, or admixtures or adopting new method of mix design eg. Equivalent Mortar Method.
6) Beams made with the Recycled Aggregate Concrete shows wider cracks at lower spacing.
7) Mid span deflection of Recycled Aggregate Concrete beams is larger than that of normal concrete. However it is within the permissible limit according to the concern codes.

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