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Research Paper

A STUDY ON BEHAVIOR OF METAKAOLIN BASE RECYCLED AGGREGATE CONCRETE

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Construction waste has been dramatically increased in the last decade, social and environmental concerns on the recycling have consequently been increased. Recent technology has greatly improved the recycling process for waste concrete. This study presents comparison of properties of natural and recycled aggregates and also the effect of mineral admixture (Metakaolin) on behavior of Recycled Aggregate Concrete (RAC). This study presents the experimental results of recycled aggregate concrete (RAC) prepared with different amount of Recycled Coarse Aggregate (RCA). Six mixes of concrete with 0%, 20%, 40%, 60%, 80%, 100% replacement of natural aggregate with recycled aggregate (RCA) were cast respectively with target compressive strength 25 MPa. In addition to this partial replacement to the weight of cement is done with Metakaolin (20%) for all mixes. The compressive strength using cube specimen, flexural strength using beams specimen, split tensile strength using cylinder specimens were determined at the age of 28 days. The result show that there is minor effect on strength with 20% to 40% recycled aggregates in concrete and later the compressive strength, flexural strength and split tensile strength of the concrete goes on reducing as the recycled aggregate content increases. The study focuses on the possibility of the use of recycled aggregate as a structural material

Keywords: C & D waste, Metakaolin, Recycled Aggregates, Recycled aggregate concrete

INTRODUCTION

The problem of waste disposal has become a major problem in the developed countries as well as developing countries like India. This is due to the enormous increase in the quantity of disposable materials, the continuing storage of dumping sites, increase in the cost of transportation and its disposal. The large-scale depletion of Natural Aggregate (NA) and the increased amounts of construction and demolition waste going to landfill sites are causing significant damage to the environment and developing serious problems denting the public and the environmentalist's aspirations for a waste-free society. Therefore the concept of recycling the waste material and using it again in some form has gathered momentum. Also, recycling not only solves the problem of waste disposal but also reduces the cost and conserves the non-renewable natural sources.

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Demolition waste generated in many countries is no exception to the above problem. And hence, recycling technology is making considerable headway in the recycling of demolished concrete.

In India too, the same trend of depletion of the aggregate reserves. The situation in India is not serious, yet there are some parts of India where crushed stone aggregate are not available within several kilometers of the radius. However, the gravity situation in the future, demands serious rethinking on the part of the Indian community, especially when the volume of concrete construction is expected to increase manifold in coming decades.

Along with construction and demolition waste, excessive use of cement in concrete is a major cause of concern for environmentalists. Cement manufacturing industries are one of the major contributors of global warming through excessive CO_2 emission. Researches are going on to cut down the use of cement by replacing part of cement with mineral admixtures such as fly ash, silica fume, Metakaolin, etc.

WORLD SCENARIO

Reuse of C & DW in the construction is not new. The first extensive and well documented reuse was just after Second World War (Vivian *et al.,* 2007). Recycling the concrete waste was observed to be one of the best options to mitigate quantities of construction waste (Salomon *et al.,* 2004). The research in recycled aggregates concretes spans longer than last three decades. In developed countries, disposal of C & DW is a serious problem due to non availability of dumping grounds in the vicinity and very high rates of waste generation. The rate of waste generation in developed countries is so high that the conventional ways of recycling the waste, i.e., sub base filling, land reclamation, etc., are not sufficient to tackle the problem of waste disposal.

Going through the wide literature it was observed that, the basic barrier to use recycled aggregates is ever increasing demand of aggregates with growing rates of infrastructure development. Also, low specific gravity, low packing density, lower resistance to impact, crushing and abrasion are some problems associated with recycled aggregates. However, it is also observed that a normal structural concrete can be easily achieved with partial or full use of recycled aggregates.

INDIAN SCENARIO

In India there is severe shortage of infrastructural facilities like houses, roads, hospitals, etc., and there is need of large quantities of construction materials for creating all these facilities. The planning Commission of India allocated approximately 50% of capital outlay in successive 10th and 11th Five Year Plans for infrastructure development. Rapid infrastructural development of highways, airports, etc., and growing demand for housing has lead to scarcity and rise in cost of construction materials. Most of the waste materials produced by demolished structures are disposed by dumping them as land fill. Waste dumping on land is causing shortage of dumping place especially in urban areas. Unfortunately there is no any provision for the use of RA in concrete in the Indian standard codes for the specification of concrete. Lack of codified provision does not; however, indirectly or directly imply a prohibition on the use of RA. Therefore, it is necessary to start recycling and re-use of demolition concrete waste to save environment, energy and cost.

EXPERIMENTAL PROGRAM

Materials

The details of various materials used during the study are presented here.

The cement used is Ultratech Ordinary Portland Cement (OPC) of 53 Grade conforming to Bureau of Indian Standard Specifications (IS: 12269-1987) with a specific gravity of 3.15.

The locally available natural sand conforming to grading Zone II (IS: 383-1970) is used in recycled aggregate concrete.

The natural coarse aggregates obtained from the locally available quarries with maximum size of 20 mm and satisfying the grading requirements of BIS (IS: 383-1970) is used during this work.

The recycled coarse aggregates are obtained from the demolished building. The scrap concrete obtained from demolished building is transported to the nearby crusher and recycled aggregates of size less than 20 mm are obtained. The pieces greater than 20 mm are crushed again to the maximum size of 20 mm.

A cementitious material, Metakaolin, is used for cement replacement. Metacem 20 micron is used in the present experimental investigation.

Various physical properties of natural and recycled aggregates are determined prior to concrete mix design. The same properties are listed in Tables 1 and 2.

Table 1: Properties of Natural Aggregate

Test	Result
Aggregate crushing value	11.26
Aggregate impact value	11.11
Specific gravity	2.70
Water absorption	3.06%
Fineness modulus	3.09

Table 2: Properties of Recycled Aggregate

Test	Result
Aggregate crushing value	15.45
Aggregate impact value	15.16
Specific gravity	2.54
Water absorption	8.70%
Fineness modulus	2.62

Specimen Preparation

During present experimental investigation in all six proportions of concrete mixtures are prepared. One mix is prepared with natural aggregates and is a reference mix.

Remaining five mixes are prepared with 0%, 20%, 40%, 60%, 80% and 100% replacement of natural aggregates with recycled aggregate by weight. Only a part of natural aggregates, i.e., coarse aggregate is replaced by recycled aggregates. In all six mixes, cement is partly replaced with a processed Metakaolin (Metacem 20 micron). 20% of total cement quantity is replaced with Metakaolin (MK).

As the study is intended for utilization of C and D waste in normal structural concrete only, the scope of work is limited to M25 grade (f_{ck} = 25 MPa) of concrete and only 28 days of curing. The mixes are designed according to IS 10262-2009. The adopted water cement ratio is modified to cope up with water absorption property of coarse as well as natural aggregates. The mix proportions obtained for various mixes are as given in Tables 3 and 4.

The mixing of concrete ingredients is done using pan mixer in the laboratory. The test specimens prepared are: concrete cubes of size 150 mm × 150 mm × 150 mm for compressive strength test, beams of size 100 mm × 100 mm × 500 mm for flexural strength test, cylinders with 150 mm (diameter) and 300 mm (height) for split tensile strength test and modulus of elasticity. All specimens are prepared and cured according to IS 516.

Compressive Strength Test

Three cubes with size of 150 mm × 150 mm × 150 mm for each proportion are used for the determination of the compressive strength at 28 days of curing. The compressive strength test confirming to IS 516 is carried out. The average value of three cubes is taken as the compressive strength of respective mix. The results obtained from this test are presented in Table 6.

Table 3: Mix Proportion Details (Quantities in kg/m^3)

Ingredients	Mix Designation					
	MK0	MK20	MK40	MK60	MK80	MK100
Water	203	209	216	223	230	236
Cement	286	286	286	286	286	286
Metakaolin	71	71	71	71	71	71
Fine Aggregate (Sand)	800	800	800	800	800	800
Coarse Aggregates (Natural)	1100	880	660	440	220	0
Coarse Aggregates (Recycled)	0	220	440	660	880	1100

Table 4: Mix Proportion Details (Quantities in kg/m^3)

Ingredients	Mix Designation					
	MK0	MK20	MK40	MK60	MK80	MK100
Water	203	209	216	223	230	236
Cement	358	358	358	358	358	358
Fine Aggregate (Sand)	800	800	800	800	800	800
Coarse Aggregates (Natural)	1100	880	660	440	220	0
Coarse Aggregates (Recycled)	0	220	440	660	880	1100

Table 5: Mix Designation Details

S. No.	% of Recycled Aggregate	Mixes without Metakaolin	Mixes with Metakaolin
1.	0	M0	MMK0
2.	20	M20	MMK20
3.	40	M40	MMK40
4.	60	M60	MMK60
5.	80	M80	MMK80
6.	100	M100	MMK100

Table 6: Compressive Strength (in N/mm^2)

Mix	Compressive Strength	Mix	Compressive Strength
M0	34.25	MMK0	32.87
M20	31.66	MMK20	24.82
M40	29.62	MMK40	14.72
M60	26.85	MMK60	12.23
M80	20.88	MMK80	10.20
M100	20.82	MMK100	8.25

Splitting Tensile Test

Three cylinders with size of 150 mm (diameter) and 300 mm (height) are used for each proportion to determine the split tensile strength. The split tensile test confirming to IS 516 is carried out. The average value of three cylinders is taken as the split tensile strength of respective mix. The results obtained from this test are presented in Table 7.

Flexure test

Three beams with size of 100 mm × 100 mm × 500 mm for each proportion are used for the determination of the flexural strength at 28 days of curing. The load was applied using a flexure testing machine. The flexure test confirming to IS 516 is carried out. The average value of three beams is taken as the flexure strength of respective mix. The results obtained from this test are presented in Table 8.

Modulus of Elasticity

Modulus of elasticity test is carried out in accordance with IS: 516-1959. The modulus of elasticity is determined at a standard rate of loading on a universal testing machine using extensometers until the specimen fails. Three cylinders for each proportion are tested at the age of 28 days curing, and the average modulus of elasticity is determined. The results

Table 7: Split Tensile Strength (in N/mm²)

Mix	Split Tensile Strength	Mix	Split Tensile Strength
M0	2.37	MMK0	2.61
M20	2.33	MMK20	2.59
M40	2.15	MMK40	2.62
M60	2.06	MMK60	1.74
M80	2.05	MMK80	1.64
M100	2.03	MMK100	1.12

Table 8: Flexural Strength (in N/mm²)

Mix	Flexural Strength	Mix	Flexural Strength
M0	5.5	MMK0	5.08
M20	5.1	MMK20	4.88
M40	4.92	MMK40	4.83
M60	4.5	MMK60	3.92
M80	4.1	MMK80	3.83
M100	3.6	MMK100	3.67

Table 9: Modulus of Elasticity (in N/mm²)

Mix	Modulus of Elasticity
MMK0	28374.5866
MMK20	25172.07655
MMK40	21884.94997
MMK60	23073.22504
MMK80	21256.5608
MMK100	17578.86614

obtained are presented in Table 9.

RESULTS

The mix designations are as described in Table 5.

The results of various tests carried out are as given herein.

Comparison of Modulus of Elasticity

Experimental values of modulus of elasticity for various mixes are obtained and those are compared with theoretical values given by various codes.

Equations for Modulus of Elasticity

The Indian code of practice (IS 456) recommends the empirical relation between the static modulus of elasticity and cube compressive strength of concrete as,

5Ø8Ü5ØPÜ = 5000 "5ØSÜ5ØPÜ5ØXÜ

$EC = 500 \sqrt{fck}$

The ACI code (ACI-318) defines the relationship between elastic modulus of concrete and cylinder compressive strength as,

$EC = 57000 \sqrt{fck'}$

$EC = 4734 \sqrt{fck'}$

The Euro-code recommends the following equation for static modulus of elasticity of concrete from its cylinder compressive strength as,

$EC = 22000 (fck'/10)^{0.3}$

The British Code of practice (BS – 8110) recommends the following expression for static modulus of elasticity with cube compressive strength of concrete as,

$EC = 20000 + 0.2\ fck$

where,

E_c is the static modulus of elasticity at 28 days in MPa,

fck is cube compressive strength of concrete,

fck' is cylinder compressive strength of concrete.

The comparison of theoretical and experimental values is given in Table 10.

Comparison of Modulus of Rupture

Experimental values of modulus of rupture for various mixes are obtained and those are compared with theoretical values given by various codes. The comparison of theoretical and experimental values is given in Tables 11 and 12.

The Indian code of practice (IS 456) recommends the empirical relation between the static modulus of rupture and cube compressive strength of concrete as,

$f_r = 0.7 \sqrt{f_{ck}}$

The ACI Code (ACI -318), defines the flexural tensile or modulus of rupture of concrete as,

$f_r = 0.62 \sqrt{f_{ck'}}$

The Euro-code (EC-02) recommends the relationship between flexural tensile or modulus of rupture of concrete and cube compressive strength of concrete as,

$f_r = 0.3 f_{ck}^{0.67}$

Table 10: Modulus of Elasticity (in N/mm²) of RA Concrete

Mix	Experimental Value	IS Code	ACI Code	BS Code	Euro Code
MMK0	28374.5866	22361	23665	20004	28960
MMK20	25172.07655				
MMK40	21884.94997				
MMK60	23073.22504				
MMK80	21256.5608				
MMK100	17578.86614				

Table 11: Modulus of Rupture (in N/mm²) of RA Concrete

Mix	Experimental Value	IS Code	ACI Code	Euro code
M0	5.5	3.13	3.1	3.32
M20	5.1			
M40	4.92			
M60	4.5			
M80	4.1			
M100	3.6			
M60	4.5			
M80	4.1			
M100	3.6			

Table 12: Modulus of Rupture (in N/mm²) of RA Concrete

Mix	Experimental value	IS Code	ACI Code	Euro Code
MMK0	5.08	3.13	3.1	3.32
MMK20	4.88			
MMK40	4.83			
MMK60	3.92			
MMK80	3.83			
MMK100	3.67			

DISCUSSION

Physical and Mechanical Properties of Aggregates

The specific gravity and density of recycled aggregates is observed to be less compared to that of natural aggregates. This might be due the fact that there is a mortar adhered to the surface of recycled aggregates. The attached mortar is light and porous in nature resulting.

The water absorption for recycled aggregate is higher compared to that of natural aggregates. This is because the voids content is more in recycled aggregates and in addition to this cement particles are also adhered to the aggregate.

The mechanical properties of recycled coarse aggregates namely crushing strength, impact strength are relatively less compared to natural aggregates due to separation and crushing of light porous mortar adhered to recycled aggregates during testing.

Workability

The slump test is conducted for each mix to know the degree of workability. It reveals that the workability is low in case of recycled aggregate concrete compared to normal concrete. This may be due to high absorption capacity and rough surface texture of recycled coarse aggregates. Also, in presence of Metakaolin, workability is observed to be reduced. The slump can be increased by using plasticizers.

Compressive Strength

The results of compressive strength tests for all mixes (Table 6) are shown in Figure 1. In general, it is observed that the compressive strength of concrete mix goes on reducing with increasing recycled aggregate content of mix compared to concrete with natural aggregates. The compressive strength of normal concrete with Metakaolin is observed to be about 10% less than the normal concrete without fly ash. Almost same % of strength reduction is observed for all mixes with and without Metakaolin. This reduction in strength of mixes might be due the addition of 20% Metakaolin as a replacement to the cement. This reduction might diminish over a longer age of concrete as strength gain rate in Metakaolin concrete is less at early age.

The compressive strength of recycled aggregate concrete without Metakaolin is more than the recycled aggregate concrete with Metakaolin at all levels of replacement. For recycled aggregate concrete without Metakaolin the strength goes on reducing as the percentage of replacement increases up to 40% replacement level and on 100% replacement the strength remains almost constant as that of 40% replacement. On the other hand the compressive strength of the recycled aggregate concrete with Metakaolin continuously goes on reducing as the percentage of replacement increases.

Splitting Tensile Strength

The results of splitting tensile strength tests for all mixes (Table 7) are shown in Figure 2. In general, it is observed that the splitting tensile strength of concrete mixes go on reducing with increasing recycled aggregate content of mix compared to concrete with natural aggregates,

Figure 1: Comparison of Compressive Strength

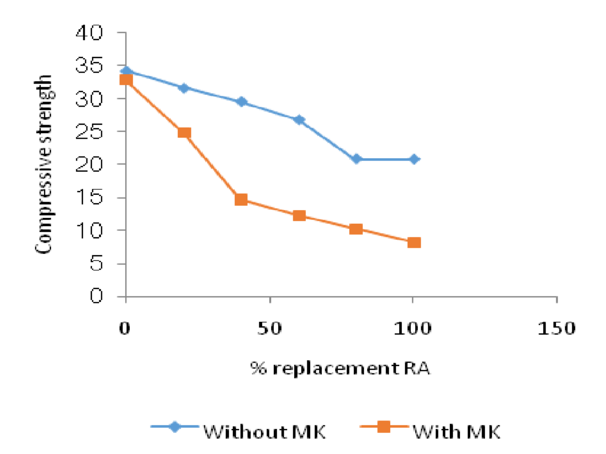
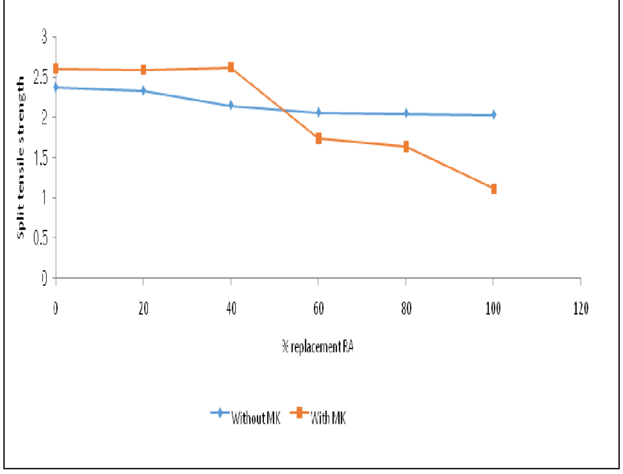


Figure 2:Comparison of Split Tensile Strength



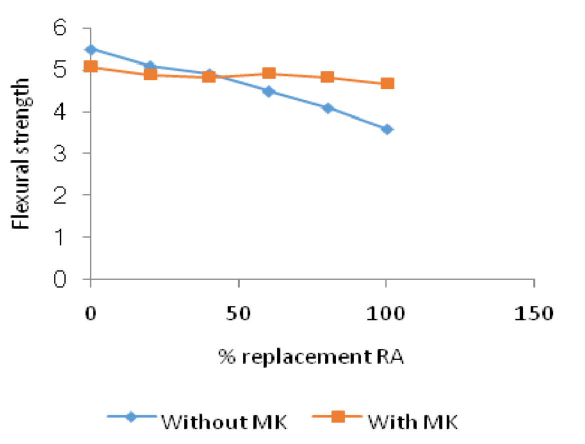
as in case of compressive strength. However, the degree of reduction is not greater.

It is observed that the 20% use of Metakaolin as a replacement to cement causes a reduction in splitting tensile strength. The degree of reduction goes on reducing with increasing recycled aggregate content. However, specimens for normal concrete with Metakaolin and 20% recycled aggregates with Metakaolin are observed the splitting tensile strength of recycled aggregate concrete without Metakaolin remains almost constant from 20% to 40% replacement level. On the other hand the Splitting tensile strength of recycled aggregate concrete with Metakaolin continuously goes on reducing as the percentage of replacement increases. The rate of strength reduction is fast up to 60% replacement then the reduction rate decreases.

Flexural Strength

The results of flexural strength tests for all mixes (Table 8) are shown in Figure 3. It is observed that the flexural strength of concrete mixes go on reducing with increasing recycled

Figure 3: Comparison of Flexural Strength



aggregate content of mix compared to concrete with natural aggregates, as in case of compressive strength. The degree of reduction is not greater for specimens with no Metakaolin, but it is higher for specimens with Metakaolin.

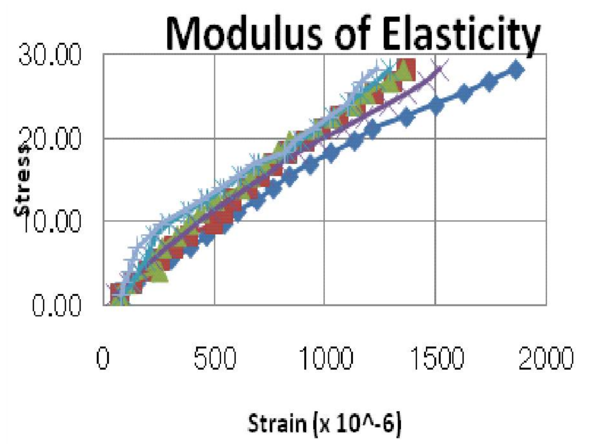
The Flexural strength of recycled aggregate concrete without Metakaolin goes on reducing up to 40% replacement level and is more than the recycled aggregate concrete with Metakaolin up to this level of replacement, further as the percentage of replacement increases the strength remains almost increase up to 100% replacement level. On the other hand the strength of recycled aggregate concrete with Metakaolin continuously goes on reducing as the percentage of replacement increases.

The experimental values of modulus of rupture are compared with the predicted values of IS 456:2000, ACI: 318 and Euro code EC: 02. The predicted value by Euro code is higher than IS code and ACI. The predicted values by IS code and ACI are almost same. The experimental values show that the values 100 percent replacement levels are higher than that of predicted values of all codes. As the replacement level increases 0 to 100%, the experimental values goes on increase of predicted values by codes because of to adding the admixture Metakaolin

Modulus of Elasticity

It is observed from the theoretical values given by various codes that the modulus of elasticity predicted by Euro-code (EC: 02) is higher than those predicted by Indian standard (IS 456: 2000), British standard (BS: 8110), American concrete institute (ACI: 318) and the

Figure 4: Comparison of Modulus of Elasticity



value by British standard (BS: 8110) is lower of all. The value predicted by IS code and ACI is almost same.

The experimental values obtained show that the modulus of elasticity goes on decreasing as the level of replacement of recycled aggregates goes on increasing. The experimental values of modulus of elasticity up to 60% are within the range of values given by Indian Standard code and American Concrete Institute. As the replacement level increases above 60% the values goes on decreasing and becomes lower than the theoretical values given by all the codes.

The degree of reduction of modulus of elasticity for specimens with Metakaolin is not more with replacement up to 60%. However, as the recycled aggregate content increases to 80%, 100% there sudden drop down in the modulus of elasticity value. This trend is similar to that observed in compressive strength, splitting tensile strength and flexural strength. Replacement of natural aggregates with recycled aggregates up to 60% is observed to give satisfactory strengths.

CONCLUSION

In the present experimental investigations the mechanical properties of recycled aggregate concrete with and without Metakaolin. Mechanical properties such as compressive strength, splitting tensile strength, flexural strength and modulus of elasticity are studied. The basic test variables are replacement ratios for natural aggregates (0%, 20%, 40%, 60%, 80%, and 100%) with recycled aggregates and use of 20% Metakaolin as substitution to cement. The combined effect of recycled aggregates and Metakaolin on the properties of concrete is explored in the present study.

- As mortar is attached to the surface of RCA it exhibits low specific gravity and high water absorption than conventional aggregate.
- The recycled aggregate prone to higher water absorption than the natural aggregate care must be taken to maintain the water cement ratio while designing for corresponding strength.
- After crushing the net quantity of the coarse aggregate from the recycling process is collecting to be 60% of the total quantity.
- About 40% of the finer particles are thrown as waste.
- Using Metakaolin 20% in concrete it is economical to the replace the recycled aggregate to the natural aggregate
- To replace recycled aggregate 20 to 40% to achieve minimum target strength as compare to conventional concrete.
- For the flexural test the strength of recycled aggregate concrete is nearly constant at 40% replacement increasing to the

replacement of 40% recycled aggregate the value goes on decreasing but the codal provision the value is sufficient to good use in concrete.

- The flexural strength of recycled aggregate concrete is satisfying the strength of the different codal provision.
- Recycled aggregate concrete can be used for normal structural purposes with 20% to 60% replacement of natural aggregates.
- The Modulus of Elasticity of concrete containing recycled aggregate with 20% Metakaolin at 28 days is at sufficient value up-to 80% replacement level and then it reduces.

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