A Study on Behaviour of Silica Fume base Recycled Aggregate Concrete

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Abstract—There is a dramatically increase in the Construction waste in the last decades which has increasing social and environmental concerns on the recycling. Due to large scale consumption of natural aggregates (NA) and the increased amount of construction & demolition waste (C&DW) going to landfill sites causes significant damage to the environment and causes serious problems. Recent technology has greatly improved the recycling process for waste concrete. The paper presents comparison of properties of natural and recycled aggregates and also the effect of mineral admixture (Silica Fume) on behaviour of Recycled Aggregate Concrete (RAC) of grade M 25. The experimental results of various tests carried on recycled aggregate concrete (RAC) prepared with different amount of recycled coarse aggregate (RCA) are presented herein. The compressive strength, flexural strength & split tensile strength along with modulus of elasticity is studied at the age of 28 days. The results show that there is minor effect on strength with 40% recycled aggregates in concrete and later the flexural strength, compressive strength and split tensile strength of the concrete goes on reducing as the recycled aggregate content increases. The paper focuses on the possibility of the use a normal structural concrete with a combination of recycled aggregate and Silica fume.

Keywords*—C & D waste, Fly Ash, Recycled Aggregates, Recycled aggregate concrete.*

I INTRODUCTION

Construction aggregates make up more than 80 percent of the total aggregate market. And as the consumption for the aggregate is increased there is necessity to find the alternative source of aggregate .Since problem of construction waste disposal has become a major problem in most of developing as well as developed countries in the world. This waste can be recycled and reused rather than dumping it on dumping sites, which increase in the cost of transportation and its disposal. 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. 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, at many places to obtain raw aggregate at many places mountains are being cut which causes depletion of the aggregate reserves. But then to the situation in India is not serious, yet there are some parts of country where crushed stone aggregates are not available within several kilometres of the radius. Also, there are several instances in India when the authorities have stopped the exploitation of coarse aggregates, which hampers the infrastructure development rate. 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. Researchers are going on to cut down the use of cement by replacing part of cement with mineral admixtures such as fly ash, silica fume, metak oline, *etc.*

Among several mineral admixtures, Silca fume, a by product of silicon metal. Taking severity of the situation into consideration, present experimental investigation is undertaken to utilize construction and demolition waste and fly ash in the concrete.

II WORLD SCENARIO

The first extensive and well documented reuse was just after Second World War [1]. In US the production of RAC is approximately 140 million tons. The disposal of this C & DW is a serious problem due to non-availability of dumping grounds in the vicinity and very high rates of waste generation. In such a way 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.

III INDIAN SCENARIO

In India there is need of large quantities of construction materials for creating all the facilities like infrastructure and real-estate. The planning Commission of India allocated approximately 50% of capital outlay in successive 10^{th}& 11^{th} five year plans for infrastructure development. Rapid infrastructural development of highways, airports *etc.* and growing demand for housing has lead to scarcity & 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.

IV EXPERIMENTAL PROGRAMME

A. Materials

The details of various materials used during the study are given below. 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. Silica fume, is used for cement replacement 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 Table 1 and Table 2.

B. 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%, & 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 Silica fume. 20% of total cement quantity is replaced with Silica fume.

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

As the study is intended for utilization of C & D waste in normal structural concrete only, the scope of work is limited to M25 grade of concrete and only 28 days of curing. The mixes are designed according to I.S. 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 Table 3and Table 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 I.S. 516.

C. 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 I.S. 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.

D. 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 I.S. 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.

E. 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 I.S. 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.

F. 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 obtained are presented in Table 9.

V. RESULTS

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

Ingredients	Mix Designation					
	MS0	MS20	MS40	MS60	MS80	MS100
Water	203	209	216	223	230	236
Cement	286	286	286	286	286	286
Siica fume	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					
	M0	M20	M40	M60	M80	M100
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

Sr. No.	% of recycled aggregate	Mixes without Silica fume	Mixes with Silica fume
1	0	M0	MS0
2	20	M20	MS20
3	40	M40	MS40
4	60	M60	MS60
5	80	M80	MS80
6	100	M100	MS100

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

Mix	Compressive strength	Mix	compressive strength
M0	34.25	MS0	36.22
M20	31.66	MS20	32.6
M40	29.62	MS40	29.79
M60	26.85	MS60	27.71
M80	20.88	MS80	21.99
M100	20.82	MS100	21.07

Table 7: Split Tensile Strength (in N/mm^2)

Mix	Split Tensile strength	Mix	Split Tensile strength
M0	2.37	MS0	2.314
M20	2.33	MS20	2.228
M40	2.15	MS40	2.368
M60	2.06	MS60	2.156
M80	2.05	MS80	2.373
M100	2.03	MS100	3.126

Table 8: Flexural Strength (in N/mm^2)

Mix	Flexural strength	Mix	Flexural strength
M0	3.75	MS0	6.5
M20	3.5	MS20	4.58
M40	3.12	MS40	3.9
M60	3.04	MS60	3.76
M80	3.06	MS80	3.58
M10	3.12	MS100	3.41

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

Mix	Modulus of Elasticity
MF0	23687
MF20	21852.5
MF40	20708.7
MF60	21400.2
MF80	19330
MF100	19244

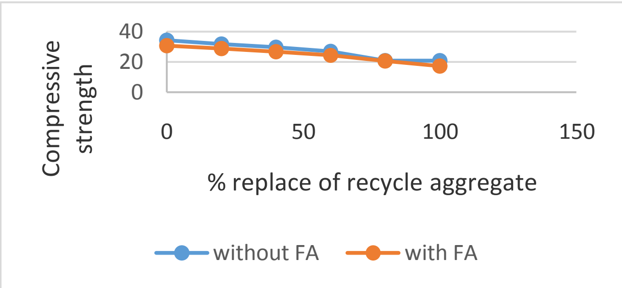

Figure 1: Comparison of compressive strength

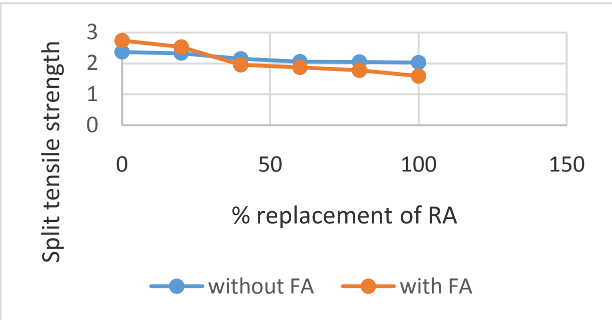

Figure 2: Comparison of split tensile strength

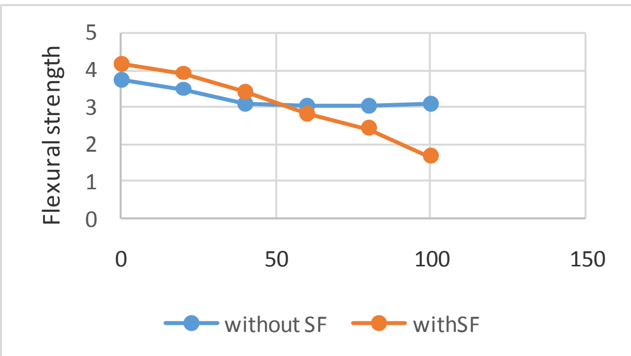

Figure. 3: Comparison of flexural strength

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,

$$Ec = 5000 \sqrt{fck}$$

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,

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

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,

f_{ck} is cube compressive strength of concrete,

$f_{ck'}$ is cylinder compressive strength of concrete.

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

Comparison of Modulus of Rupture:

sExperimental 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 Table 11 and Table 12

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

Mix	Experimental value	IS Code	ACI code	BS code	Euro code
MF0	23687	22361	23665	20004	23960
MF20	21852.5				
MF40	20708.7				
MF60	21400.2				
MF80	19330				
MF100	19244				

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 11: Modulus of Rupture (in N/mm^2) of RA Concrete

Mix	Experimental value	IS Code	ACI code	Euro code
M0	3.75	3.13	3.1	3.32
M20	3.5			
M40	3.12			
M60	3.04			
M80	3.06			
M100	3.12			

Table 12: Modulus of Rupture (in N/mm^2) of RA Concrete

Mix	Experimental value	IS Code	ACI code	Euro code
MF0	3.99	3.13	3.1	3.32
MF20	3.88			
MF40	3.61			
MF60	3.22			
MF80	2.86			
MF100	2.40			

VI DISCUSSIONS

A. 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 Silica fume, workability is observed to be increased.

B. 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 is due to the fact that there is 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.

C. Compressive strength :

The results of compressive strength tests for all mixes (Table 6) are shown in Fig. 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 Silica fume is observed to be about 5.3% more than the normal concrete without silica fume. This increase in strength of mixes might be due the addition of 20% Silica fume as a replacement to the cement. This increase can be beneficial as strength gain at early stages is more.

For every 20% replacement of natural aggregates with recycled aggregates, there is about 7.56% reduction in strength up to 60 % replacement. For 80% replacement the reduction in strength is about 19%. For 100% replacement there strength is same that for 80%. However, we can say there is only slight reduction in strength for 100% recycled aggregate concrete compared to 80% replacement.

All the specimens (with and without Silica fume) with less than or equal to 60% recycled aggregates are satisfying the design strength. From experimental results use of up to and about 60% recycled aggregates might give design strength of 25 MPa. In contrast, the mixes with 80% and 100% recycled aggregates are giving strength below design strength. However, the strength given by these mixes shows that the normal purpose structural concrete can be manufactured with 100% recycled aggregates even with 20% Silica fume as a replacement to cement.

D. Splitting Tensile Strength

The results of splitting tensile strength tests for all mixes (Table 7) are shown in Fig. 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, as in case of compressive strength. However, the degree of reduction is not greater.

It is observed that the 20% use of Silica fume as a replacement to cement causes 2.5% reduction in splitting tensile strength. However, specimens 40% recycled aggregates with Silica fume are observed to give more splitting tensile strength than specimens with no Silica fume.

E. Flexural Strength

The results of flexural strength tests for all mixes (Table 8) are shown in Fig. 3. It is observed that the flexural strength of concrete mixes go on reducing with increasing recycled 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 silica fume, but it is higher for specimens with silica fume.

Specimens for normal concrete with silica fume is 70%more than that of concrete without silica fume and 20%, 40% recycled aggregates with silica fume are observed to be 25% more strength than specimens with no silica fume. The experimental values of modulus of rupture are compared with the theoretical values of IS 456:2000, ACI: 318 and Euro code EC: 02. The theoretical value by Euro code is higher than IS code and ACI. The predicted values by IS code and ACI are almost same. It is observed that the modulus of rupture for specimens with no silica fume and up to 60% recycled aggregates is higher than the theoretical values given by all codes. As the replacement level increases beyond 60 percent, the experimental values go on reducing.

F. 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 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 20% are within the range of values given by Indian Standard code and American Concrete Institute. 40% replacement can be permissible with reference to BS code. As the replacement level increases above 40% the values goes on decreasing and becomes lower than the theoretical values given by all the codes.

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.

VII CONCLUSIONS

In the present experimental investigations the mechanical properties of recycled aggregate concrete with and without silica fume. 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% silica fume as substitution to cement. The combined effect of recycled aggregates and silica fume on the properties of concrete is explored in the present study.

- With increasing recycled aggregate content and in presence of silica fume the workability of mixes is observed to be increase.
- The results of strength tests show that with increasing recycled aggregate content compressive and tensile strength of concrete go on reducing. However, it is observed that replacement of natural aggregates up to 60% cause small reduction in strengths. All the specimens with up to 60% recycled aggregates with and without silica fume satisfy the design strength.
- 20 % silica fume in the mix, as a replacement to cement, increase 28 days compressive strength.
- 20 % silica fume in the mix, as a replacement to cement, results in increased tensile strength and modulus of rupture for specimens.
- Also, the modulus of elasticity values for specimens with silica fume and up to 60% recycled aggregates are observed to be satisfactory when compared with theoretical values given by various codes.
- A combination of silica fume and 100% recycled aggregates can be used for normal structural concrete with design strength 20 MPa.
- With some modifications in mix proportions and with use of chemical admixtures a study can be carried out to achieve higher grade concrete using same combination.

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