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Study of Properties of Concrete using GGBS and Recycled Concrete Aggregates

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***Abstract*— Concrete is playing a significant role in the growth of infrastructural and industrial segments for many decades. But concrete is not an environmentally-friendly material due to its destructive resource consuming nature. The basis of this research is to investigate the effects of using recycled materials in varying amounts on the fresh and hardened properties of concrete. The recycled materials used in this study are Ground granulated blast furnace slag (GGBS) and recycled concrete aggregates. GGBS was used as partial cement replacement and recycled aggregates as replacement for fine and coarse aggregate. The basic properties of natural and recycled aggregate were determined. The mix design was done to obtain a concrete mix (control mix) of grade M40. Mixes were prepared by replacing 40, 50 and 60% of natural aggregates with recycled aggregates. Then its fresh and mechanical properties were determined along with control mix. From test results concrete with 50% replacement of aggregate with recycled aggregates shows adequate strength compared to control mix. Mixes were prepared by replacing 40, 50 and 60% of cement with GGBS together with 50% replacement of recycled aggregates. From test results concrete with 40% and 50% replacement of cement with GGBS together with 50% replacement of recycled aggregates shows adequate strength compared to control mix.**

Keywords – Fine aggregate; Recycled Aggregates; Ground Granulated Blast Furnace Slag.

I. INTRODUCTION

Concrete which is the most versatile material for construction, is playing a significant role in the growth of infrastructural and industrial segments. Presently annual worldwide concrete production is about 12 billion tones. Aggregates have been readily available at economic prices and of qualities to suit all purposes. But now a days the cost of aggregates have risen fastly over the past few years. Production of cement emits CO2 in a harmful manner. About 7% of the world's CO2 emission is attributed to Portland cement industry. Also large amount of natural resources like lime stone, clay etc… is required for its production. That is concrete is not an environmentally-friendly material due to its destructive resource consuming nature. It will, however, remain the major construction material being used worldwide.

Using recycled concrete from old demolished structure as a replacement to aggregates is a good practice to conserve natural aggregates. Another practical solutions to conserve natural resources is to use supplementary cementitious material such as fly ash, slag, silica fume etc… as a replacement to cement thereby the microstructure, mechanical and durability characteristics of concrete can be improved. In this study a sustainable concrete is proposed which consists of substantial amount of supplementary cementitious material as a replacement to cement and recycled aggregate instead of natural aggregates. Ground granulated blast furnace slag is used as the supplementary cementitious material. A demolished stair case which is of about 23 years old is recycled and used in the place of coarse and fine aggregate. The mix proportion is to be done to obtain a M40 grade concrete. Mixes with different contents of Recycled aggregates (40%, 50% and 60%) as replacement to natural aggregates is examined and GGBS (40%, 50% and 60%) as replacement to cement is examined. The conventional mix and other mixes are to be tested for the fresh, mechanical and durability properties. The results are then compared with the conventional mix.

The main objective of this project is to find how effectively supplementary cementitious material (GGBS) and Recycled coarse and fine aggregate can be combined together and the optimum percentage of replacement of recycled concrete aggregates to natural aggregates and GGBS to cement. The strength and durability properties of concrete are also to be studied for various replacement percentages of GGBS and Recycled aggregate.

A. Recycled Concrete Aggregates

Construction and demolitions are processes that go hand in hand. The demolished building rubble in India generally goes to waste in landfills. After few years construction and demolition waste will be more than half of the national total waste in most countries of the world. Recycling of these concrete waste materials from demolished building can provide a solution to this problem. Landfills are becoming increasingly difficult to find, are too remote from the demolition site, or are too costly to maintain. At the same time sources of supply of suitable aggregate for making concrete are continuously being exhausted. The recycling of demolished building demolition waste materials into new buildings can provide a solution to these problems. Recycling is the act of processing the used material for use in creating new product. In order to reduce the usage of natural aggregate, recycled aggregate can be used as the replacement materials. Recycled aggregate are comprised of crushed, graded inorganic particles processed from the materials that have been used in the constructions.

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Fig.1 Recycled concrete aggregate

B. Ground Granulated Blast Furnace Slag (GGBS)

Ground granulated blast furnace slag, limestone powder, fly ash and silica fume are successfully used in concrete as a cement replacement which are cement saving, energy saving and cost saving and moreover cause environmental and socio-economic benefits. Blast furnace slag is a nonmetallic by-product produced in the process of iron making (pig iron) in a blast furnace and 300kg of Blast furnace slag is generated when 1 ton of pig iron produced. Blast furnace slag is mildly alkaline and exhibits a pH in solution in the range of 8 to 10 and does not present a corrosion risk to steel in pilings or to steel embedded in concrete made with blast furnace slag cement or aggregates.

GGBS is used to make durable concrete structures in combination with ordinary Portland cement. GGBS concrete has slightly slower strength development at early ages. At 7 days GGBS concretes will have 50 to 60% of its characteristic strength compared. At 28 days GGBS concrete may fully develope its characteristic strength and will continue to develop strength past 90 days. It is good practice to make 56 day cubes when using GGBS concrete at 50% and above should there be any concern over later strength development.

Fig.2 Ground granulated blast furnace slag

II. METHODOLOGY

A. Literature Review

[1] Basil Johny et al studied the properties of sustainable concrete using slag and recycled concrete aggregates. GGBS was replaced for 40%, 50% and 60% of cement and optimum percentage was found out. For the mixes prepared by replacing 50% cement with slag and 50% coarse aggregate, it satisfies the strength criteria required for an M30 mix.

[2] M L Berndt studied the properties of sustainable concrete containing fly ash, slag and recycled concrete aggregates by replacing cement by a percentage of fly ash or slag and natural aggregates by recycled concrete aggregates. The mixes containing 50% slag gave best overall performance

[3] Md Shakir Ahmed et al studied the strength of concrete with percentage replacement in natural coarse aggregate (NCA) with recycled concrete aggregates (RCA) for M20 mix concrete. The strength of concrete decreases as the percentage of RCA increases.

[4] S Arivalagan used GGBFS at various replacement levels and evaluated its efficiencies for M35 mix at different ages. M35 mix concrete is considered to perform the test by-weight basis by replacing 20%, 30% and 40% of cement by GGBS. It was observed that GGBS-based concretes have achieved an increase in strength for 20% replacement of cement at the age of 28 days.

B. Procurement Of The Materials

- Cement – Ordinary Portland cement
- Ground Granulated Blast Furnace Slag (GGBS)
- Natural Fine and Coarse Aggregate
- Recycled Fine and Coarse Aggregate
- Water
- Super plasticizer

C. Determination Of Material Properties

- Cement – Specific Gravity, Standard consistency, initial setting time, Final setting time
- GGBS - Specific Gravity, physical properties and chemical properties
- Fine Aggregates – Sieve analysis, Specific gravity, water content and water absorption, , Bulk density and Percentage voids
- Coarse Aggregates – Sieve analysis, Specific gravity, water absorption, Bulk density and Percentage voids
- Recycled Fine Aggregate – Sieve analysis, Specific gravity, water content and water absorption, , Bulk density and Percentage voids
- Recycled Coarse Aggregates – Sieve analysis, Specific gravity, water absorption, Bulk density and Percentage voids
- Super Plasticizer – Master Glenium SKY 8233
- Water

D. Mix Proportioning (M40)

Mix design can be defined as the process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required strength, durability and workability as possible. The mix proportioning is to be carried out to achieve specified characteristics at specified age, workability of fresh concrete and durability requirements. The mix design is carried out as per IS 10262:2000. The grade of concrete adopted for the study is M40.

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E. Mix Preparation And Specimen Preparation

- Preparation of control mix (M40)
- Preparation of mix with partial replacement of RCA for coarse aggregate (CA) (40%, 50% and 60%)
- Preparation of concrete with partial replacement of RFA for fine aggregate (FA) (40%, 50% and 60%)
- Find the optimum percentage of coarse and fine aggregate from above mixes
- Preparation of concrete with the optimum percentage of RCA for CA and the optimum percentage of RFA for FA together with GGBS as partial replacement for cement (40%, 50% and 60%)

Specimens:

Cubes of size 150x150x150mm, beams of Size 100x100x500mm and cylinders of size 300x150mm are to be casted for testing compressive strength, flexural strength and splitting tensile strength of corresponding mixes. Age of the specimens for compressive strength is 3, 7 and 28 days and for flexural and splitting tensile strength is 7 and 28 days.

F. Tests

a) Fresh properties
   i. Slump Test
   ii. Compaction factor test
b) Mechanical properties
   i. Compressive strength
   ii. Flexural strength
   iii. Splitting tensile strength

III. MATERIAL TESTING

A. Cement

Ordinary Portland cement of 53 grade was used for the study. Supplier was Dalmia cements. The various tests to determine properties as specific gravity, standard consistency, initial and final setting time was carried out. The properties of cement used is tabulated below.

TABLE 1 PROPERTIES OF CEMENT

Sl. No.	Name of Test	Result
1	Specific gravity	3.125
2	Standard consistency	35%
3	Initial setting time	240 minutes
4	Fineness of cement	5%

B. Fine Aggregate

Manufactured sand which was free from deleterious material was used as fine aggregate.

TABLE 2 PROPERTIES OF FINE AGGREGATE

Sl. No.	Name of Test	Result
1	Specific gravity	2.69
2	Water absorption	1.5%
3	Bulk density	1.323 kg/l
4	Percentage voids	54.44%

C. Coarse Aggregate

20mm size coarse aggregate which was free from deleterious materials was used for the study.

TABLE 3 PROPERTIES OF COARSE AGGREGATE

Sl.No.	Name of Tests	Result
1	Specific gravity	2.67
2	Water Absorption	0.8 %
3	Bulk Density	1.40 kg/l
4	Percentage voids	50.4 %

D. Recycled Fine Aggregate (RFA)

Recycled fine aggregate obtained by the demolishing of a reinforced cement concrete staircase having age 25 years are used. The following properties of RFA are determined in the laboratory.

TABLE 4 PROPERTIES OF RECYCLED FINE AGGREGATE

Sl. No.	Name of Tests	Result
1	Specific gravity	2.2
2	Water Absorption	3.6 %
3	Bulk Density	1.36 kg/l
4	Percentage voids	42.04 %

E. Recycled Coarse Aggregate

Recycled coarse aggregate obtained by the demolishing of a reinforced cement concrete staircase having age 25 years are used.

TABLE 5 PROPERTIES OF RECYCLED COARSE AGGREGATE

Sl.No.	Name of Tests	Result
1	Specific gravity	2.22
2	Water Absorption	2.7 %
3	Bulk Density	1.35 kg/l
4	Percentage voids	42.93 %

F. Ground Granulated Blast Furnace Slag

Ground granulated blast furnace slag was supplied by JSW cements. The specific gravity of GGBS was determined using Le Chatelier's flask. All the other physical and chemical properties were provided by the supplier.

TABLE 6 PROPERTIES OF GGBS

Sl.No.	Name of Tests	Result
1	Specific gravity	2.93

IV. MIX PROPORTIONING

Mix proportioning is the process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required strength, durability and workability as economically as possible. The mix design is carried as per IS 10262:2009. The concrete grade selected for this study is M40. The quantity of materials required for $1m^3$ of concrete is tabulated below.

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TABLE 7 MATERIAL QUANTITY FOR CM

Mix grade	M40
Mix designation	CM
w/c	0.38
Cement (kg/m^3)	414.74
Fine aggregate (kg/m^3)	801
Coarse aggregate (kg/m^3)	1095.65
Water (kg/m^3)	178.4
Super plasticizer (kg/m^3)	1.24

V. TESTS ON CONCRETE

A. Fresh Properties

i) Slump test

ii) Compacting factor test

B. Mechanical Properties

i) Compressive strength

ii) Flexural Strength

iii) Splitting tensile strength

Cubes, beams and cylinders were cast to test the compressive strength, flexural strength and splitting tensile strength of concrete. Cubes were tested at 3day, 7 day and 28 days after curing. Beams and cylinders were tested at 7 and 28 day after curing.

VI. TEST RESULTS

A. Conventional mix (CM)

Conventional mixes for M40 grade were prepared as per the mix proportion. The fresh properties and mechanical properties of CM were determined.

a) Slump test

The conventional mix shows a slump of 110 mm.

b) Compacting factor test

The conventional mix shows a compacting factor 0.91.

c) Compressive strength

TABLE 8 COMPRESSIVE STRENGTH FOR CONTROL MIX

Age in days	3	7	28
Compressive strength (N/mm^2)	28.9	39.99	50.22

d) Flexural strength

TABLE 9 FLEXURAL STRENGTH FOR CONTROL MIX

Age in days	7	28
Flexural strength (N/mm^2)	7.5	10.5

e) Splitting tensile strength

TABLE 10 SPLITTING TENSILE STRENGTH FOR CONTROL MIX

Age in days	7	28
Splitting tensile strength (N/mm^2)	2.26	2.83

B. Replacement of coarse aggregate with recycled coarse aggregate

Mixes were prepared by replacing 40, 50 and 60% coarse aggregate with recycled coarse aggregate (40 RCA, 50 RCA and 60 RCA). The following tests were determined for these mixes.

a) Slump test

The values of slump for 40 RCA, 50 RCA and 60 RCA are 120 mm, 110 mm and 110mm respectively.

b) Compacting factor test

MIX	**CM**	**40 RCA**	**50 RCA**	**60 RCA**
Compressive strength – 3 day(N/mm^2)	28.9	23.33	27.78	28.22
Compressive strength – 7 day (N/mm^2)	39.99	32.66	37.78	32
Compressive strength – 28 day (N/mm^2)	50.22	42.89	49.33	41.33

The values of compacting factor for 40 RCA, 50 RCA and 60 RCA are 0.89, 0.92 and 0.90 respectively.

c) Compressive strength

TABLE 11 COMPRESSIVE STRENGTH FOR RCA MIXES

d) Flexural strength

TABLE 12 FLEXURAL STRENGTH FOR RCA MIXES

MIX	**CM**	**40 RCA**	**50 RCA**	**60 RCA**
Flexural strength – 7 day (N/mm^2)	7.5	7.375	8	7
Flexural strength – 28 day (N/mm^2)	10.5	9.625	10.25	9.25

e) Splitting tensile strength

TABLE 13 SPLITTING TENSILE STRENGTH FOR RCA MIXES

MIX	CM	40 RCA	50 RCA	60 RCA
Splitting tensile strength – 7 day (N/mm^2)	2.26	1.93	2.59	2.46
Splitting tensile strength – 28 day (N/mm^2)	2.83	2.55	3.03	2.55

From the tables 11, 12 and 13 for compressive strength, flexural strength and splitting tensile strength of RCA mixes, 50 RCA shows a better result. So for further studies 50 RCA is adopted.

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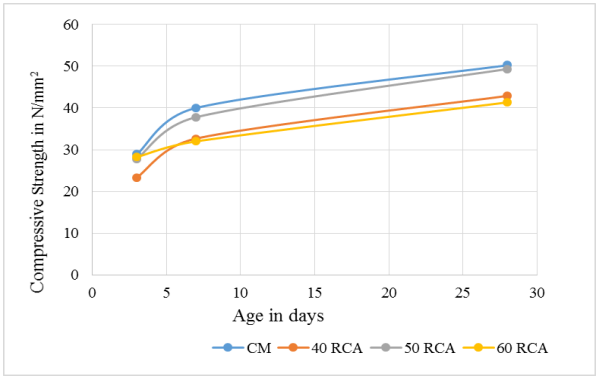

Fig.3 Development of compressive strength with age for CM and RCA mixes

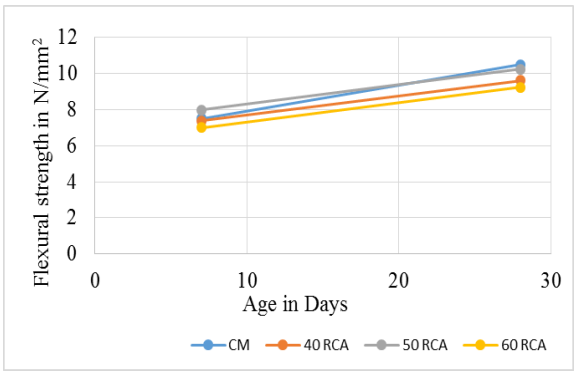

Fig.4 Development of flexural strength with age for CM and RCA mixes

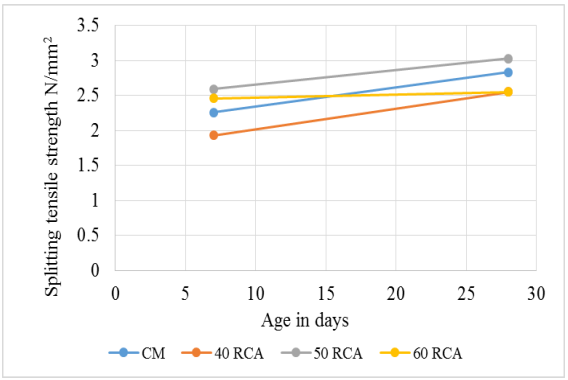

Fig.5 Development of splitting tensile strength with age for CM and RCA mixes

C. Replacement of fine aggregate with recycled fine aggregate

Mixes were prepared by replacing 40, 50 and 60% fine aggregate with recycled fine aggregate (40 RFA, 50 RFA and 60 RFA). The following tests were determined for these mixes.

a) Slump test

The values of slump for 40 RFA, 50 RFA and 60 RFA are 100 mm, 120 mm and 110mm respectively.

b) Compacting factor test

The values of compacting factor for 40 RCA, 50 RCA and 60 RCA are 0.91, 0.91 and 0.90 respectively.

c) Compressive strength

TABLE 14 COMPRESSIVE STRENGTH FOR RFA MIXES

MIX	CM	40 RFA	50 RFA	60 RFA
Compressive strength – 3 day (N/mm²)	28.9	31.11	28.22	27.33
Compressive strength – 7 day (N/mm²)	39.99	40.44	40.22	36
Compressive strength – 28 day (N/mm²)	50.22	49.77	53.48	45.38

d) Flexural strength

TABLE 15 FLEXURAL STRENGTH FOR RFA MIXES

MIX	CM	40 RFA	50 RFA	60 RFA
Flexural strength – 7 day (N/mm²)	7.5	9.875	9.75	8.75
Flexural strength – 28 day (N/mm²)	10.5	10	10.63	9.625

e) Splitting tensile strength

TABLE 16 SPLITTING TENSILE STRENGTH FOR RFA MIXES

MIX	CM	40 RFA	50 RFA	60 RFA
Splitting tensile strength – 7 day (N/mm²)	2.26	2.50	2.50	2.42
Splitting tensile strength – 28 day (N/mm²)	2.83	2.62	2.86	2.74

From the tables 14, 15 and 16 for compressive strength, flexural strength and splitting tensile strength of RFA mixes, 50 RFA shows a better result. So for further studies 50 RFA is adopted. The increase in strength may be due to the presence of unhydrated cement in recycled fine aggregate.

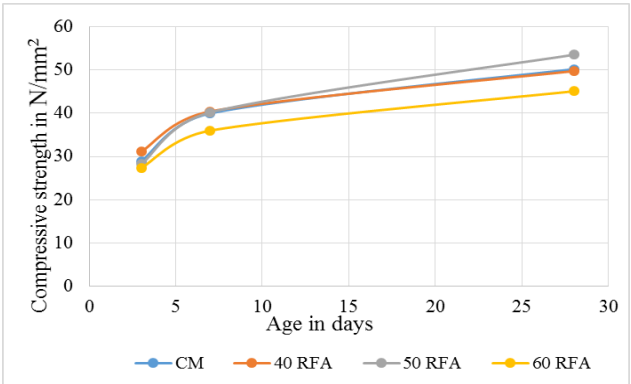

Fig.6 Development of compressive strength with age for CM and RFA mixes

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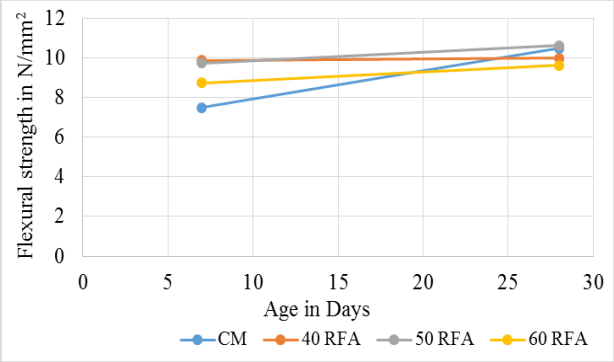

Fig.7 Development of flexural strength with age for CM and RFA mixes

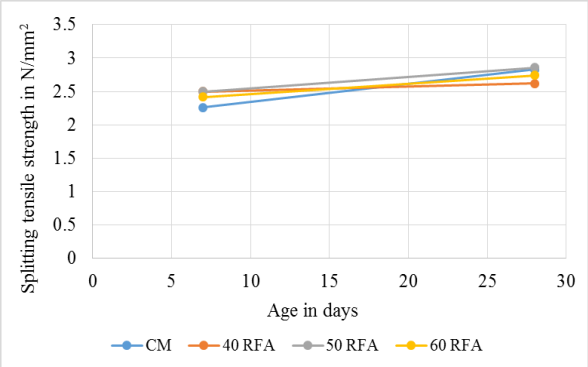

Fig.8 Development of splitting tensile strength with age for CM and RFA mixes

D. Replacement of cement with GGBS, coarse aggregate with recycled coarse aggregate and fine aggregate with recycled fine aggregate

Mixes were prepared by replacing 40, 50 and 60% cement with GGBS together with 50% recycled coarse aggregate and 50% recycled fine aggregate. The following tests were determined for these mixes.

a) Slump test

The values of slump for all these mixes are 110 mm.

b) Compacting factor test

The values of compacting factor for the mixes are 0.91, 0.91 and 0.90 respectively.

c) Compressive strength

TABLE 17 COMPRESSIVE STRENGTH FOR GGBS MIXES

MIX	CM	40 GGBS+ 50 RCA+ 50 RFA	50GGBS+ 50 RCA+ 50 RFA	60GGBS+ 50 RCA+ 50 RFA
Compressive strength – 3 day (N/mm^2)	28.9	24.88	23.55	22.44
Compressive strength – 7 day (N/mm^2)	39.99	33.55	32.22	30.22
Compressive strength – 28 day (N/mm^2)	50.22	49.55	48.44	44.2

d) Flexural strength

TABLE 18 FLEXURAL STRENGTH FOR GGBS MIXES

MIX	**CM**	**40GGBS+ 50RCA+ 50 RFA**	**50GGBS+ 50RCA+ 50 RFA**	**60GGBS+ 50RCA+ 50 RFA**
Flexural strength – 7 day (N/mm^2)	7.5	6.25	6.25	5
Flexural strength – 28 day (N/mm^2)	10.5	8.5	8	6.25

e) Splitting tensile strength

TABLE 19 SPLITTING TENSILE STRENGTH FOR GGBS MIXES

MIX	**CM**	**40GGBS +50RCA +50 RFA**	**50GGBS +50RCA +50 RFA**	**60GGBS+ 50RCA+ 50 RFA**
Splitting tensile strength – 7 day (N/mm^2)	2.26	2.19	2.07	1.98
Splitting tensile strength – 28 day (N/mm^2)	2.83	2.8	2.57	2.2

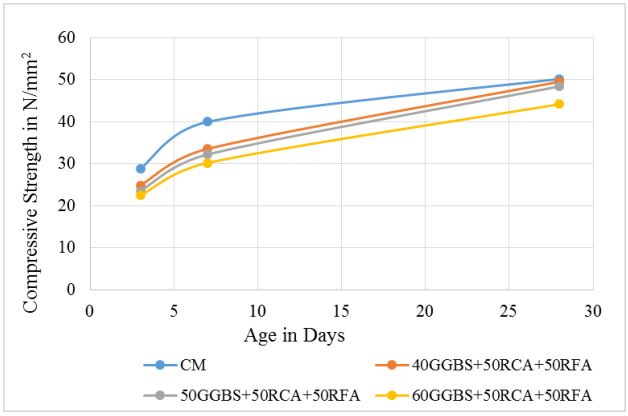

Fig.9 Development of compressive strength with age for CM and GGBS mixes

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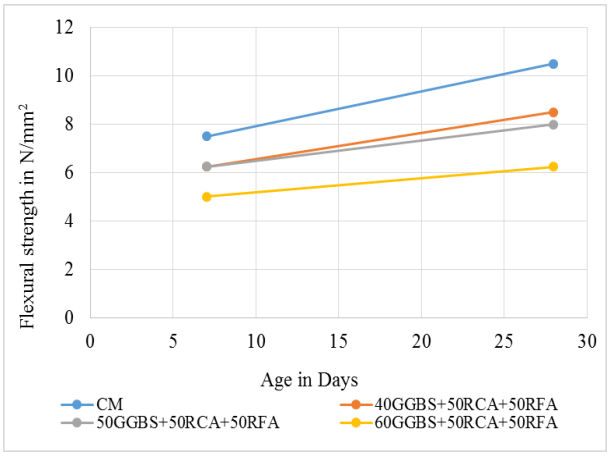

Fig.10 Development of flexural strength with age for CM and GGBS mixes

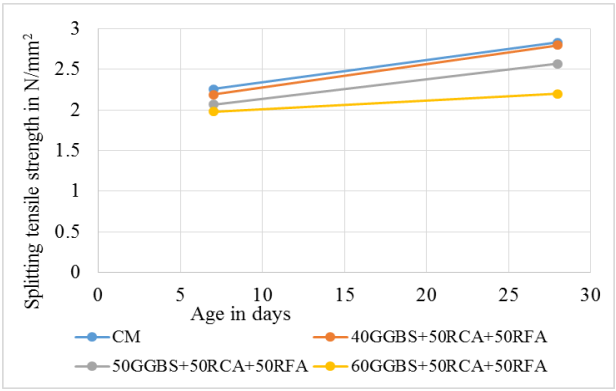

Fig.11 Development of splitting tensile strength with age for CM and GGBS mixes

For all the GGBS mixes the value of compressive strength, flexural strength and splitting tensile strength are less compared to CM for all ages. But when 40% and 50% cement are replaced with GGBS, the compressive strength achieves the target strength for M40 grade concrete. The reduction in compressive strength may be due to the later strength development of the mixes due the addition of supplementary cementitious material (GGBS).

VII. CONCLUSIONS

- Slump test and compaction factor test were conducted to find out the workability of concrete. All the mixes used for the study shows adequate workability.
- When mixes were made by replacing 40, 50 and 60% coarse aggregate and fine aggregate with recycled coarse aggregate and recycled fine aggregate, 50 RCA and 50 RFA mix shows good results in terms compressive strength, flexural and splitting tensile strength.
- When mixes were prepared by replacing 40, 50 and 60% cement with GGBS together with 50 RFA and 50 RCA, 40% and 50% replacement of cement with GGBS shows a better result in terms of compressive strength. Even though the values are lesser than that of CM, it meet the requirement of M40 grade concrete.

From the study conducted, it shows that replacement of coarse aggregate, fine aggregate and cement gives a satisfactory strength.

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