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Mechanical Properties of Recycled Coarse Aggregate Concrete with Mineral Admixture

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Abstract

The most abundantly used construction material in the world is concrete. The basic materials used in the production of concrete are mined extensively, which has created a lot of pressure on the environment, leading to depleting these materials' natural sources. This creates a situation where alternate materials are being looked at, producing concrete that creates a minimum impact on the environment. This paper discusses M25 grade concrete's mechanical properties made with recycled coarse aggregate using mineral admixtures such as fly ash, GGBS, and combination. By utilizing the recycled coarse aggregate and mineral admixtures, the demand on the environment is reduced to a greater extent. This shows the direction towards making the concrete more sustainable and greener. M25 grade concrete's mechanical properties such as compressive strength, split tensile strength, and flexural strength are discussed. The results are compared with that of the normal concrete produced with natural aggregates.

Keywords: *Fly ash, GGBS, Recycled coarse aggregate, Compressive strength, flexural strength, Split tensile strength.*

I. INTRODUCTION

The most utilized construction materials in the world are concrete. The basic materials used in concrete production are cement, water, fine aggregates, and coarse aggregates. Aggregates form about 70-80% of concrete.

Natural aggregates have to be mined from nature, which creates a lot of environmental pollution. This also has a greater impact on the environment. As aggregates are finite resources, there is a necessity to look at alternative materials to replace the concrete's natural aggregates. Considering the present situation in the emerging cities, the main issue is the disposal of construction and demolition (C&D) waste produced by the construction industry. This C & D waste can be processed into aggregates and used in the production of concrete. This process will create lesser demand on the finite aggregate sources while utilizing the waste generated back into the construction. This will lead to a reduction of around 20 30% of the overall cost of concrete production compared to concrete produced using natural aggregate. In the present work, an attempt is made to study the mechanical behavior of M 25 grade concrete produced using fly ash, GGBS, and recycled coarse aggregate.

II. LITERATURE REVIEW

Several research scholars have studied the utilization of recycled aggregate in concrete over the past few decades. Several attempts are also being made to study the effect of using mineral admixtures in concrete. M.L Berndt [1] studied the properties of recycled aggregate concrete containing fly ash and slag. The results indicated that the replacement of 50% of cement slag showed better performance. Ozkan Sengul et al. [2] studied the properties of concrete containing ground fly ash and slag. Ordinary Portland cement was replaced up to 50% by fly ash and slag and a combination of fly ash and slag. The tests concluded that the compressive strength was lower at a higher water binder ratio than normal concrete. At lower water to binder ratio, the strength is comparable with normal concrete. The addition of fly ash and slag improves the durability characteristics of the concrete.

Patrick L Maier et al. [3] studied the use of GGBFS, recycled concrete aggregate, and crushed waste glass in concrete. The study showed that the GGBFS could be used up to 50% and recycled aggregate in concrete. Recycled aggregate replacement up to 50% enhanced the properties of concrete. Weerachart Tangchirapat et al. [4] studied fly ash's influence on slump loss and strength of concrete containing 100% recycled aggregates. Both the fine and coarse aggregates were replaced by recycled aggregates. Fly ash replacement of up to 35% gave a desirable compressive strength of the recycled aggregate concrete. The incorporation of fly ash did not significantly impact the splitting tensile strength and modulus of elasticity of concrete containing recycled aggregates. Ahmed [5] studied the properties of concrete containing recycled coarse aggregate and fly ash. The replacement of natural aggregate by recycled coarse aggregate was 25% to 100%. In addition to this, ordinary Portland cement was partially replaced by fly ash. From the study, it was found that fly ash improves the long term strength of recycled aggregate concrete. The workability of the recycled aggregate concrete decreased with the increase in the content of recycled aggregate concrete. Ilker Bekir Topcu [6] studied the properties of concrete produced with waste concrete aggregate. In this study, it was found that the water absorption of the concrete containing recycled aggregate was more compared to concrete containing natural aggregate. It is also reported that concrete workability decreases with the increase in the percentage of recycled aggregates. Shi-Cong-Kou et al. [7] studied the properties of natural and recycled aggregates concrete using different mineral admixtures. The results indicate that the addition of mineral admixtures improves the performance of the recycled aggregate concrete.

Rattapon Somna et al. [8] studied recycled aggregate concrete properties with fly ash by varying the water to binder ratio in the concrete. Fly ash was used as a partial replacement for ordinary portland cement up to 50%. Natural aggregates were fully replaced by the crushed limestone. From the results, for recycled aggregate concrete, the percentage of fly ash replacement should not exceed 35% for lower water to binder ratio and 20% for higher water to binder ratio. It was also shown that the ground fly ash improved the compressive strength of concrete, also reduced the water permeability coefficient. Khaldoun Rahal [9] studied the mechanical properties of concrete containing coarse aggregate. The results showed that for a similar slump, the cube and cylinder compressive strength and the indirect shear strength of recycled aggregate concrete were about 90% of the natural aggregate concrete with a similar mix proportion. Results also indicated that, as in natural aggregate concrete, the strength of concrete could be increased by lowering the water to cement ratio if admixtures are used to provide adequate workability. A.K.Mullick [10] has provided a list of options available for binder systems and aggregates to make concrete greener and sustainable.

III. EXPERIMENTAL INVESTIGATION

A. Materials used in the present study

Ordinary Portland cement (53 grade) confirming to IS 12269-1987 is used. Low calcium class F fly ash obtained from BTPS, Ballari which is in accordance to IS 3812-1981 is used, Ground granulated blast furnace slag (GGBS) was obtained from JSW Ballari, which was in accordance to IS 12089-1987 is used. Table 1 provides the chemical and physical properties of Cement, Fly ash, and GGBS. SEM micrographs illustrate the morphology of these materials. SEM images revealed that the cement particles are angular and non-spherical in shape, as shown in figure 1. The X-ray diffracts gram for cement is shown in figure 2. Figure 3 shows the SEM micrograph of fly ash particles, and figure 4 shows the X-ray diffract gram. The fly ash particles show spherical and smooth, and hollow spheres called cenospheres (microspheres) and plerospheres. Figure 5 shows the SEM micrograph of GGBS particles, and figure 6 shows the X-ray diffract gram. GGBS particles are elongated, long, and flaky in shape.

Table 1Physical, chemical properties of cement, fly ash, and GGBS.

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2o	LOI	Specific Gravity	Specific surface (m^2/Kg)
Cement	16.34	6.95	5.38	60.84	2.32	1.99	2.73	1.50	---	3.12	297
Fly ash	62.63	23.35	3.93	2.04	0.46	0.53	1.35	---	0.39	2.1	311
GGBS	33.77	13.24	0.65	33.77	10.13	0.23	--	--	0.19	2.9	436

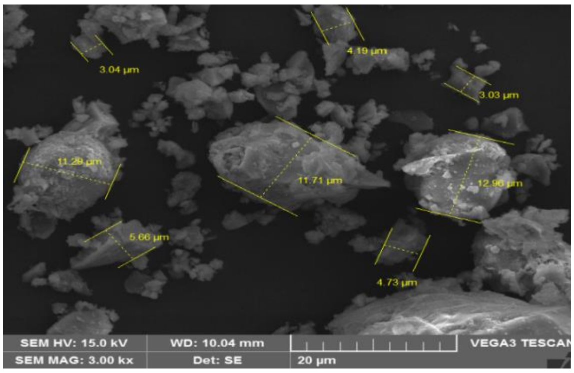

Fig 1: SEM Image of cement

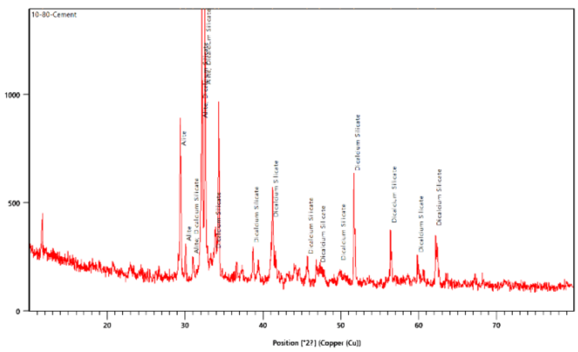

Fig: 2 XRD Image of cement

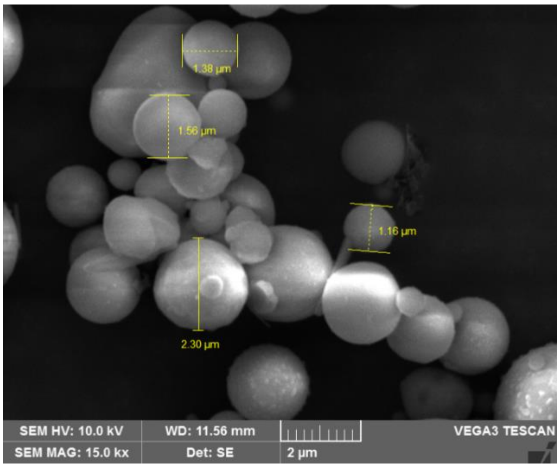

Fig 3: SEM Image of flyash

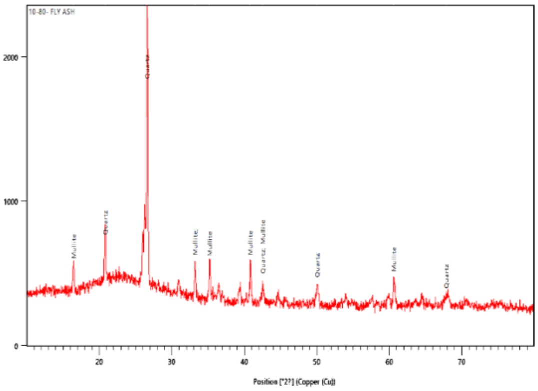

Fig 4: XRD Image of flyash

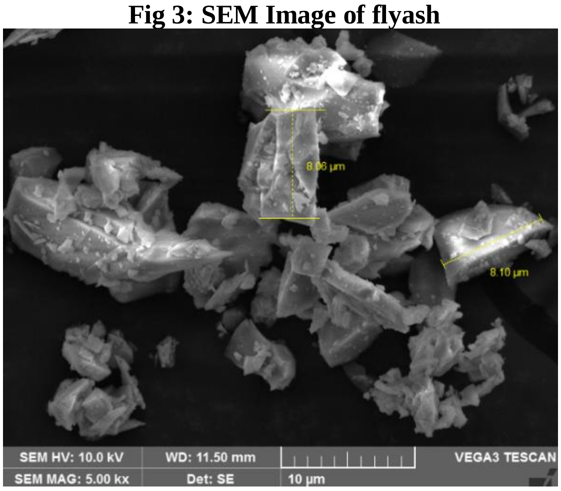

Fig 5: SEM Image of GGBS

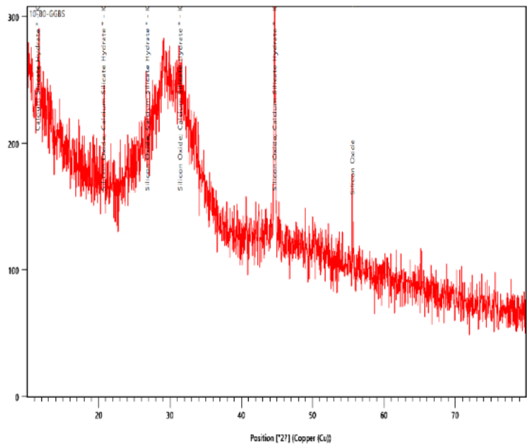

Fig 6:XRD Image of GGBS

B. Fine aggregates

The manufactured sand confirming to zone II according to the IS code is used in the present study. The physical and Mechanical properties of manufactured sand are provided in table 2.

Table 2: Physical and mechanical properties of fine aggregate

Type of Aggregate	Specific gravity	Water Absorption	Fineness Modulus
M-sand	2.58	0.92	3.57

C. Coarse aggregates

Locally available crushed rock aggregate is used as natural coarse aggregate (NCA) in the present study. Recycled coarse aggregates (RCA) was obtained from demolishing old concrete. The recycled concrete aggregate was processed into coarse aggregate to replace natural coarse aggregate for the present study. The recycled coarse aggregate was procured from M/S Rock crystals, Bengaluru. The properties of natural coarse aggregate and recycled coarse aggregate used in the present study are shown in table 3. The grain size distribution of natural coarse aggregate and recycled coarse aggregate used in the present study is given in fig 7.

Table 3: Physical properties of Natural coarse aggregate (NCA) and recycled coarse aggregate (RCA)

Type of Aggregate	NCA	RCA
Specific gravity	2.58	2.29
Water absorption	0.92	11.5
Fineness modulus	3.57	3.47
Elongation index	4.5	9.2
Flakiness index	0.35	2
Los Angeles abrasion loss For CA (%)	22.5	32.8

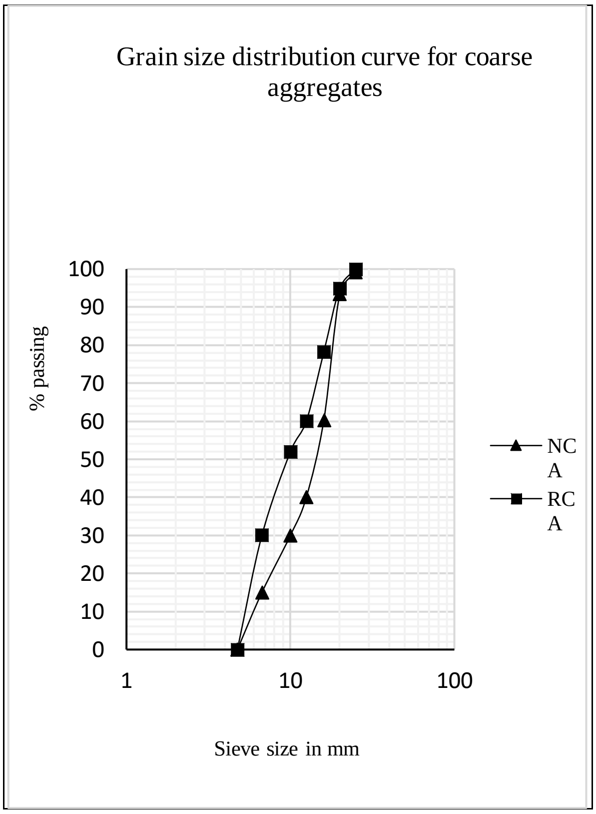

Fig 7: Grainsize distribution curve for NCA and RCA

D. Superplasticizer

The superplasticizer used in the present study is Master Glenium 8233. It is a high-performance superplasticizer based on polycarboxilic ether from BASF. The dosage of superplasticizer was arrived based on the required slump of the concrete. The slump of the fresh concrete was maintained around 100 mm.

E. Concrete Mix proportions

M 25 grade concrete is used for the present study. Two water-cement ratios, 0.40 and 0.45, are chosen for the present study. These ratios are designated as M1 and M2 series, respectively. For each water to cement ratio, twelve different proportions of concrete were cast. Hence a total of twenty-four proportions were casted for the present study. OPC was replaced by 20% fly ash and designated as F20, 30% GGBS designated as G30, and a combination of 20% fly ash and 30% GGBS designated as F20G30. Natural coarse aggregate was replaced with 50% and 100% recycled coarse aggregate and designated as RC50 and RC100 series. The mix proportions for the M1RC series are given in table 4, and the M2RC series is given in table 5.

Table 4: Mix Design details: M1RC series

Designation	Cement Kg/m³	Water Kg/m³	W/B ratio	Fly ash Kg/m³	GGBS Kg/m³	Fine Aggregate Kg/m³	Coarse aggregate Kg/m³	Recycled coarse aggregate Kg/m³	Super plasticizer %	Slump mm
M1NC	394.32	157.72	0.40	NA	NA	796.50	1165.33	NA	0.3	100
M1F20	315.45	157.72	0.40	78.86	NA	785.71	1149.53	NA	0.3	98
M1G30	241.52	138.01	0.40	NA	103.51	834.42	1220.80	NA	0.3	99
M1F20G30	197.16	157.72	0.40	78.86	118.23	783.5	1146.4	NA	0.4	99
M1RC50	394.32	157.72	0.40	NA	NA	795.48	581.92	581.92	0.5	98
M1F20RC50	315.46	157.72	0.40	78.86	NA	785.30	574.47	574.47	0.4	101
M1G30RC50	276.03	157.72	0.40	NA	118.23	793.90	580.75	580.75	0.45	99
M1F20G30RC50	197.16	157.72	0.40	78.86	118.23	783.91	573.45	573.45	0.4	99
M1RC100	394.32	157.72	0.40	NA	NA	795.30	581.77	581.77	0.55	99
M1F20RC100	315.46	157.72	0.40	78.86	NA	784.69	574.02	574.02	0.4	95
M1G30RC100	276.03	157.72	0.40	NA	118.30	794.30	581.05	581.05	0.45	95
M1F20G30RC100	197.16	157.72	0.40	78.86	118.30	783.70	573.30	573.30	0.45	97

The slump values were determined for all the mix proportions of concrete. The slump values for the M1RC series are given in table 4, and the M2RC series is given in table 5. M1RC 50 series concrete required a lesser dosage of superplasticizer compared to M1RC100 series for the same values of the slump. A similar observation was made in the M2 series. M2RC 50 series concrete required a lesser dosage of superplasticizer compared to M2RC100 series.

Concrete containing fly ash required a lesser dosage of superplasticizer compared to concrete containing GGBS. This is due to the ball bearing effect of fly ash particles in the composition. The increase in the dosage of superplasticizer for concrete containing GGBS is due to the particles' elongated shape, which increases the surface area of the particles, as shown in figure 5.

Table 5: Mix Design details: M2RC Series

Designation	Cement Kg/m^3	Water Kg/m^3	W/B ratio	Fly ash Kg/m^3	GGBS Kg/m^3	Fine Aggregate Kg/m^3	Coarse aggregate Kg/m^3	Recycled coarse aggregate Kg/m^3	Super plasticizer %	Slump mm
M2NC	350.50	157.72	0.45	NA	NA	830.48	1170.68	NA	0.2	98
M2F20	280.40	157.72	0.45	70.10	NA	820.30	1156.33	NA	0.3	99
M2G30	245.35	157.72	0.45	NA	105.15	828.11	1167.34	NA	0.4	101
M2F20G30	175.25	157.72	0.45	70.10	105.15	818.67	1154.04	NA	0.35	103
M2RC50	350.50	157.72	0.45	NA	NA	829.56	584.69	584.69	0.45	99
M2F20RC50	280.40	157.72	0.45	70.10	NA	819.93	577.91	577.91	0.4	98
M2G30RC50	245.35	157.72	0.45	NA	105.15	827.93	583.54	583.54	0.45	98
M2F20G30RC50	175.25	157.72	0.45	70.10	105.15	818.67	577.02	577.02	0.35	99
M2RC100	350.50	157.72	0.45	NA	NA	829.00	584.30	584.30	0.6	99
M2F20RC100	280.41	157.72	0.45	70.10	NA	819.75	577.77	577.77	0.4	96
M2G30RC100	245.35	157.72	0.45	NA	105.15	828.11	583.67	583.67	0.45	99
M2F20G30RC100	175.25	157.72	0.45	70.10	105.15	818.48	576.88	576.88	0.45	99

The mechanical properties of M1RC series concrete are given in table 6. Figures 8 and 9 give the compressive strength for the M1RC series at 7, 28, 56, and 90 days of curing. Figures 10 and 11 give the split tensile strength for the M1RC series at 28 and 56 days of curing. Figures 12 and 13 give the flexural strength for the M1RC series at 28 and 56 days of curing.

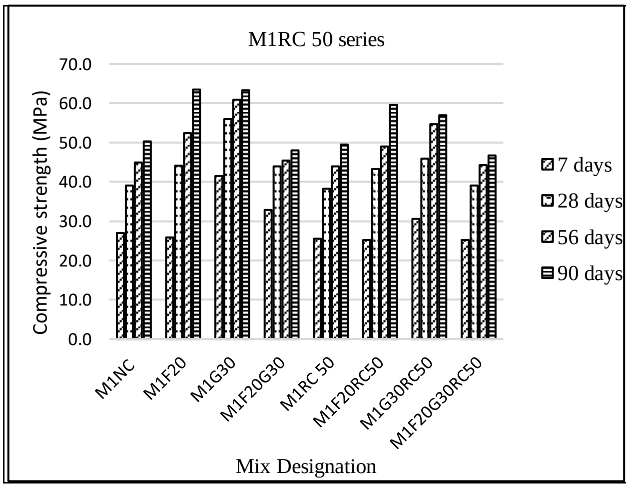

Figure 8: Compressive strength of M1RC 50 series.

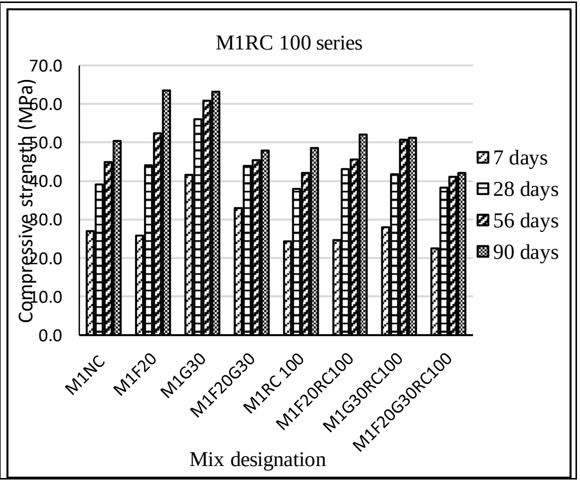

Figure 9: Compressive strength of M1RC 100 series.

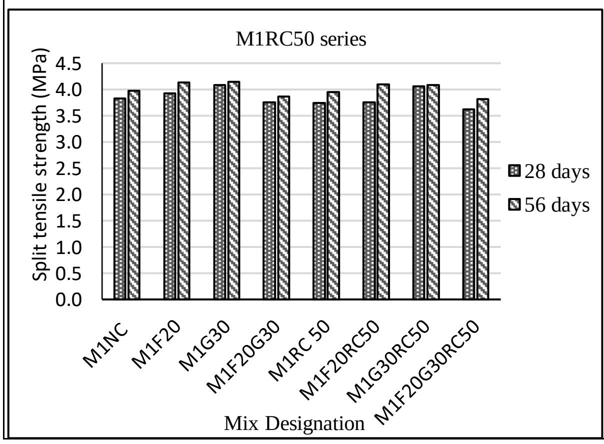

Figure 10: Split tensile strength of M1RC50 series.

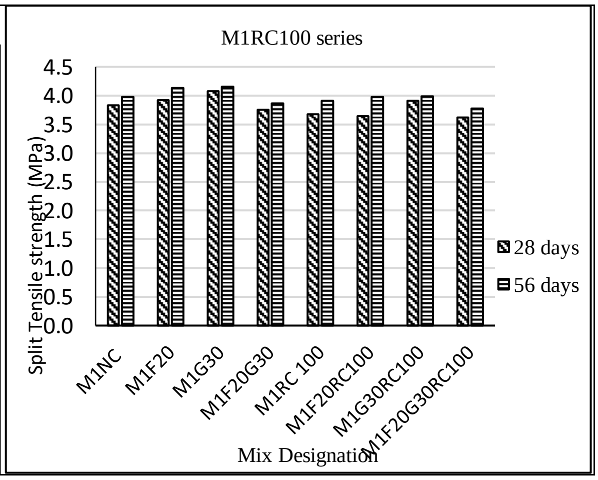

Figure11: Split tensile strength of M1RC100 series.

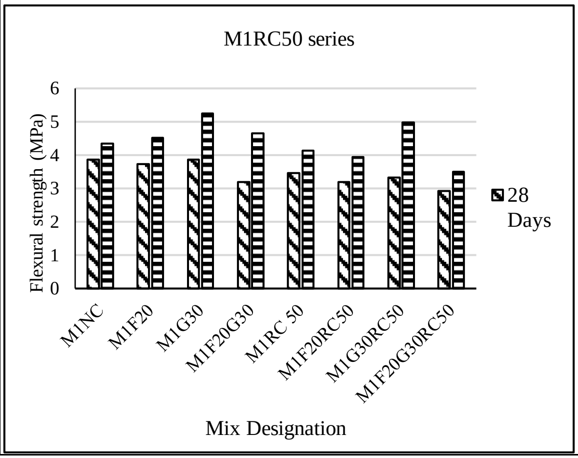

Figure 12: Flexural strength of M1RC50 series.

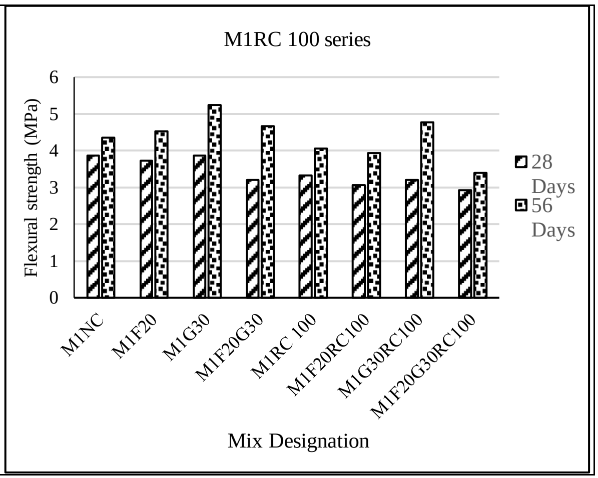

Figure13: Flexural strength of M1RC100 series.

The mechanical properties of M2RC series concrete are given in table 7. Figures 14 and 15 give the compressive strength for the M2RC series at 7, 28, 56, and 90 days of curing. Figures 16 and 17 give the split tensile strength for the M2RC series at 28 and 56 days of curing. Figures 18 and 19 give the flexural strength for the M2RC series at 28 and 56 days of curing.

Table 7: Mechanical properties: M2RC Series

Mix Designation	Compressive Strength (MPa)				Split Tensile strength (MPa)		Flexural Strength (MPa)	
	7 Days	28 Days	56 Days	90 Days	28 Days	56 Days	28 Days	56 Days
M2NC	24.8	35.64	40.67	42.22	3.52	3.85	3.47	4.40
M2F20	25.23	36.83	52	52.44	3.56	4.08	3.33	3.96
M2G30	34.34	47.26	53.11	60.44	3.85	4.09	3.60	4.72
M2F20G30	23.51	38.52	45.11	47.7	3.42	3.79	3.07	4.30
M2RC50	23.19	32.81	38.22	41.26	3.41	3.76	3.33	3.93
M2F20RC50	23.84	35.26	45.78	49.04	3.48	3.99	3.07	3.74
M2G30RC50	27.5	37.78	38.87	43.85	3.82	4.01	3.2	4.26
M2F20G30RC50	23.1	33.48	37.63	46.67	3.38	3.62	2.8	3.48
M2RC100	22.44	30.67	35.63	39.26	3.35	3.65	3.2	3.81
M2F20RC100	20.93	35.11	42.01	48.3	3.43	3.88	2.93	3.62
M2G30RC100	22.77	36.74	37.48	41.53	3.75	3.91	3.07	4.10
M2F20G30RC100	21.78	32.07	33.73	40.15	3.31	3.55	2.67	3.32

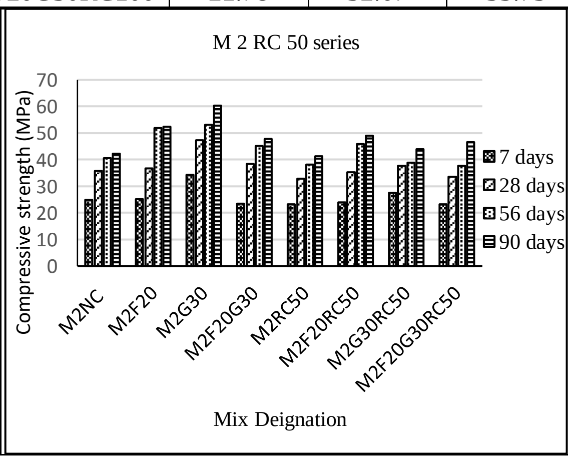

Figure 14: Compressive strength of M2RC 50 series.

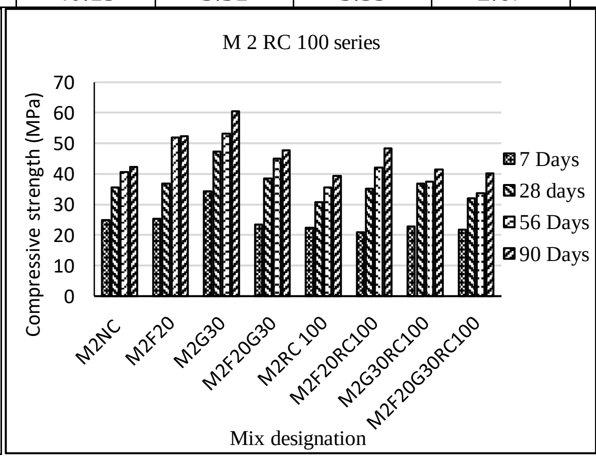

Figure 15: Compressive strength of M2RC 100 series.

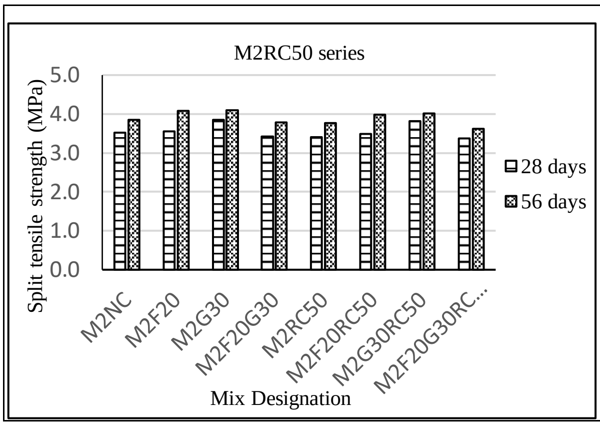

Figure 16: Split tensile strength of M2RC50 series.

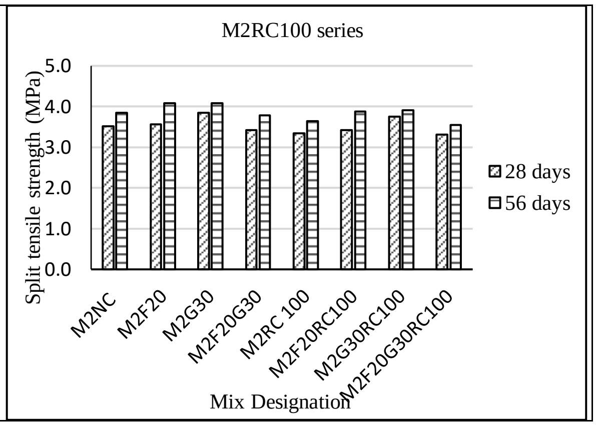

Figure 17: Split tensile strength of M2RC100 series.

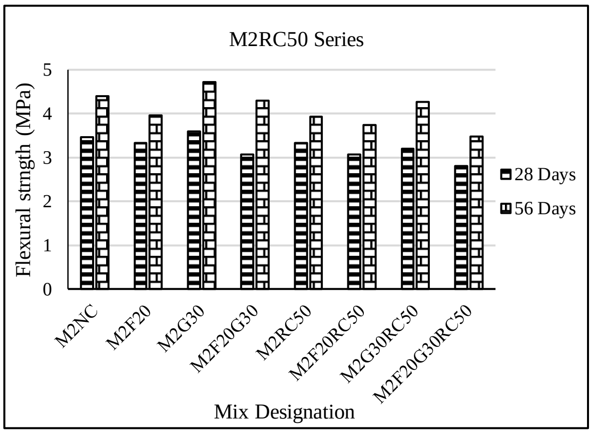

Figure 18: Flexural strength of M2RC50 series.

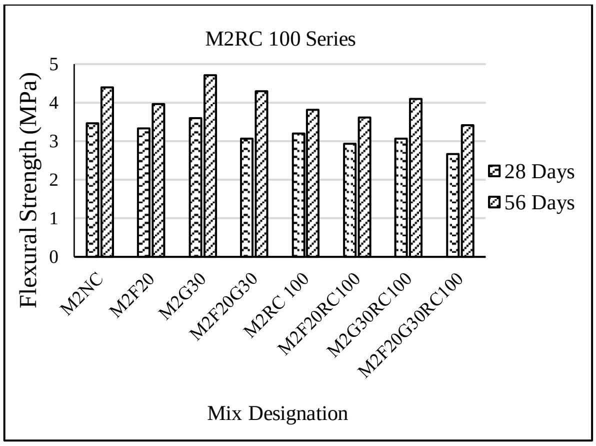

Figure 19: Flexural strength of M2RC100 series.

F. Mechanical properties.

1. Compressive strength.

The compressive strength of concrete was determined according to IS 516:2013 for the cube specimen of 150mm. The compression load was applied using a compression testing machine of 2000 KN capacity at the rate of 13.74 N/mm^2/min. The compressive strength of concrete for both the M1RC series and M2RC series is determined at 7, 28, 56, 90 days.

M1RC50 series has shown a decrease in strength of 1.8% after 90 days of curing, and the M1RC100 series has shown a decrease in strength of 3.5% after 90 days of curing compared to the M1NC series. M1F20RC50 series has shown a decrease in strength of 6.3% after 90 days of curing, and M1F20RC100 series has shown a decrease in strength of 18% after 90 days of curing compared to the M1F20 series. M1G30RC50 series has shown a decrease in strength of 9% after 90 days of curing, and M1G30RC100 series has shown a decrease in strength of 19% after 90 days of curing compared to the M1G30 series. M1F20G30RC50 series has shown a decrease in strength of 3% after 90 days of curing, and M1F20RC100 series has shown a decrease in strength of 12% after 90 days of curing compared to the M1F20G30 series. The 90 days compressive strength of concrete containing a combination of fly ash and GGBS is relatively lesser when compared to all other mixes in both M1RC 50 series and M1RC 100 series. This strength is comparable to concrete containing normal aggregate.

M2RC50 series has shown a decrease in strength of 2.25% after 90 days of curing, and the M2RC100 series has shown a decrease in strength of 7% after 90 days of curing compared to the M2NC series. M2F20RC50 series has shown a decrease in strength of 6.5% after 90 days of curing, and M2F20RC100 series has shown a decrease in strength of 8% after 90 days of curing compared to the M2F20 series. M2G30RC50 series has shown a decrease in strength of 27% after 90 days of curing, and M2G30RC100 series has shown a decrease in strength of 31% after 90 days of curing compared to the M2G30 series. M2F20G30RC50 series has shown a decrease in strength of 2% after 90 days of curing, and M2F20RC100 series has shown a decrease in strength of 15.5% after 90 days of curing to M2F20G30 series. These results indicate that the concrete containing recycled coarse aggregate has lesser strength than concrete containing natural aggregates.

The concrete containing GGBS has shown a higher initial strength compared to all other proportions. The rate of gain of strength is relatively lesser after 7 days. Concrete containing fly ash has shown comparatively lower initial strength, but the increase of strength after 7 days is comparatively higher. This may be due to the pozzolanic action of the flyash. The 90 days compressive strength of concrete containing a combination of fly ash and GGBS is relatively lesser than all other mixes in both M2RC 50 series and M2RC 100 series. This strength is comparable to concrete containing normal aggregate.

2. Split tensile strength

The split tensile strength of concrete was determined according to IS 5816: 2008. The load was applied using a compression testing machine of 2000 KN capacity. The load was increased continuously at a rate of 1.5 N/mm^2/min. The split tensile strength of concrete for both the M1RC and M2RC series is determined at 28 and 56 days.

M1RC50 series has shown a decrease in strength of 0.75% after 56 days of curing, and the M1RC100 series has shown a decrease in strength of 1.76% after 56 days of curing compared to the M1NC series. M1F20RC50 series has shown a decrease in strength of 0.72% after 56 days of curing, and M1F20RC100 series has shown a decrease in strength of 3.65% after 56 days of curing to the M1F20 series. M1G30RC50 series has shown a decrease in strength of 1.45% after 56 days of curing, and M1G30RC100 series has shown a decrease in strength of 3.85% after 56 days of curing to the M1G30 series. M1F20G30RC50 series has shown a decrease in strength of 1.30% after 56 days of curing, and M1F20RC100 series has shown a decrease in strength of 2.32% after 56 days of curing compared to M1F20G30 series. The 56 days split tensile strength of concrete containing fly ash and GGBS is relatively lesser compared to all other mixes in both M1RC 50 series and M1RC 100 series. This strength is comparable to concrete containing normal aggregate.

M2RC50 series has shown a decrease in strength of 2.30% after56 days of curing, and the M2RC100 series has shown a decrease in strength of 5.20% after 56 days of curing compared to the M2NC series. M2F20RC50 series has shown a decrease in strength of 2.21% after 56 days of curing, and M2F20RC100 series has shown a decrease in strength of 4.90% after 56 days of curing to M2F20 series. M2G30RC50 series has shown a decrease in strength of 1.96% after 56 days of curing, and M2G30RC100 series has shown a decrease in strength of 4.40% after 56 days of curing compared to the M2G30 series. M2F20G30RC50 series has shown a decrease in strength of 4.49% after 56 days of curing, and M2F20RC100 series has shown a decrease in strength of 6.33% after 56 days of curing compared to M2F20G30 series. These results indicate that the concrete containing recycled coarse aggregate has lesser split tensile strength than concrete containing natural aggregates. The 56 days split tensile strength of concrete containing fly ash and GGBS is relatively lesser compared to all other mixes in both M2RC 50 series and M2RC 100 series. This strength is comparable to concrete containing normal aggregate.

3. Flexural strength

The flexural strength of concrete for both the M1RC and M2RC series is determined at 28 and 56 days.

M1RC50 series has shown a decrease in strength of 5% after 56 days of curing, and the M1RC100 series has shown a decrease in strength of 6.67% after 56 days of curing compared to the M1NC series. M1F20RC50 series has shown a decrease in strength of 12.61% after 56 days of curing, and M1F20RC100 series has shown a decrease in strength of 12.83% after 56 days of curing compared to the M1F20 series. M1G30RC50 series has shown a decrease in strength of 5.14% after 56 days of curing, and M1G30RC100 series has shown a decrease in strength of 8.96% after 56 days of curing compared to the M1G30 series. M1F20G30RC50 series has shown a decrease in strength of 24.9% after 56 days of curing, and M1F20RC100 series has shown a decrease in strength of 27.0% after 56 days of curing compared to M1F20G30 series. The 56 days split tensile strength of concrete containing fly ash and GGBS is relatively lesser compared to all other mixes in both M1RC 50 series and M1RC 100 series. This strength is comparable to concrete containing normal aggregate.

M2RC50 series has shown a decrease in strength of 10.70% after 56 days of curing, and the M2RC100 series has shown a decrease in strength of 13.41% after 56 days of curing compared to the M2NC series. M2F20RC50 series has shown a decrease in strength of 5.55% after 56 days of curing, and M2F20RC100 series has shown a decrease in strength of 8.60% after 56 days of curing to the M2F20 series. M2G30RC50 series has shown a decrease in strength of 9.75% after 56 days of curing, and M2G30RC100 series has shown a decrease in strength of 13.14% after 56 days of curing compared to the M2G30 series. M2F20G30RC50 series has shown a decrease in strength of 19.0% after 56 days of curing, and M2F20RC100 series has shown a decrease in strength of 22.80% after 56 days of curing compared to M2F20G30 series. These results indicate that the concrete containing recycled coarse aggregate has lesser split tensile strength than concrete containing natural aggregates. The 56 days flexural strength of concrete containing fly ash and GGBS is relatively lesser compared to all other mixes in both M2RC 50 series and M2RC 100 series. This strength is comparable to concrete containing normal aggregate.

IV. CONCLUSION

From the result of the present investigation, the following conclusions are drawn.

- The use of mineral admixtures in concrete containing recycled coarse aggregate improves the performance of recycled aggregate concrete.
- The use of GGBS in recycled aggregate concrete will provide a higher early strength for the concrete.
- The use of fly ash in recycled aggregate concrete will provide better long term strength for the concrete.
- The strength of recycled aggregate concrete is relatively lesser compared to the strength of natural aggregate concrete.
- Recycled aggregate concrete with 50% replacement (RC 50 series) of the natural aggregates has shown better results compared to 100 % (RC 100 series) replacement

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