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Research Article

Experimental Investigation on Durability Performance of Recycled Aggregate Concrete with Mineral Admixtures

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ABSTRACT

The adhesion of cement mortar and the negative influence of the previous interfacial transition zone (ITZ) on reinforced RAC were the main contributors to the durability of reinforcement. For various replacement amounts of recycled concrete aggregate (RCA), the influence of the inclusion of a mineral additive on the durability performance of RAC was investigated. 25% of ground granulated blast furnace slag (GGBS) and 10% of silica fume (SF) have been used as mineral admixtures. In this work, an experimental investigation was conducted to determine the effects of SF and GGBS combination on RAC with 0%, 25%, 50%, 75%, and 100% RCA. Durability characteristics, water absorption, sorptivity, sulphate attack, acid attack, and thermal resistance were taken. The homogeneity of RAC was also examined using an ultrasonic pulse velocity (UPV) test. The strength is gradually increased by the addition of GGBS, which forms a secondary C-S-H gel and has a lower heat of hydration. The mineral admixture lowers the amount of calcium hydroxide and delays the development of ettringite. Therefore, the addition of a mineral admixture increases resistance to an acidic and sulphate environment.

Keywords: Recycled Aggregate Concrete, Mineral Admixtures, Durability

Introduction

Concrete is extensively utilised in construction due to its abundant supply, high strength, affordability, and long-lasting nature. Given the ongoing rise in building waste, it is crucial to engage in the recycling of waste concrete. Recycled Coarse Aggregate (RCA) is obtained from the debris of building and demolition activities and is employed as a substitute for natural material in concrete production. Therefore, the use of long-lasting concrete made from recycled aggregate is crucial for the development of sustainable infrastructure. The incorporation of extra cementitious elements enhances the workability, strength, and long-term performance of concrete. Using industrial by-products as a mineral additive in concrete lowers the amount of cement used, increases homogeneity, and decreases porosity and microcracks. It results in a decrease in the generation of CO2 during the manufacturing of cement.[1] Experimental research on the durability of RAC with 65% GGBS and 30% fly ash was conducted by K.Y. ANN et al. They found that the Pozzolanic concentration increases RAC compressive strength. GGBS-equipped RACs have greater corrosion thresholds. Control concrete had a chloride threshold of 0.21-0.42, 30% fly ash RAC of 0.41-0.73, and 65% GGBS RAC of 0.20-0.43%. Pozzolanic content in concrete raises the threshold for chloride and the resistance to chloride ion penetration.[2] Shi-Cong Kou et.al conducted a comparative analysis between natural aggregate concrete and recycled aggregate concrete while considering various mineral admixtures. The researchers discovered that incorporating 10% of SF and 15% of MK enhances both the immediate and prolonged durability of recycled aggregate concrete. The addition of Silica Fume (SF) and Metakaolin (MK) to Recycled Aggregate Concrete (RAC) results in an increase in the ultrasonic pulse velocity. According to their report, incorporating 35% fly ash and 55% GGBS enhances the extended durability of recycled aggregate concrete.[3]

The mechanical strength of recycled aggregate concrete is improved by the addition of steel fibres and SCM.[4] Experimental research on the impact of the Interfacial Transition Zone (IZT) on strength development was conducted by Mahmoud Nili et al.[5] They concluded that the Concrete IZT has a dynamic nature and is dependent on the development of the cement paste and aggregate. Certain silica fume (SF)-GGBS combinations could improve the strength characteristics of natural aggregate concrete when compared to MS and GGBS alone. Pozzolans strengthen the microstructure and reduce bulk porosity because SF firmly acts as a filler, which significantly increases strength. Unhydrated microparticles in relatively large aggregates are particularly affected by self-desiccation at prolonged curing ages.[6] The performance of concrete composed entirely of recycled aggregate was studied by Valeria Corinaldesi et al. in relation to mineral additions. The results demonstrated that the addition of fly ash was highly efficient in decreasing the depths of carbonation and the infiltration of chloride ions in concrete. Valeria Corinaldesi et.al conducted an experimental study to examine the impact of mineral additions on the effectiveness of 100% recycled aggregate concrete. The results clearly showed that the addition of fly ash had a highly effective impact on reducing the depths of carbonation and chloride ion penetration in concrete. Applying it can be beneficial in prolonging the lifespan of RAC constructions due to its ability to delay the onset of reinforcement corrosion.[7] Bo yo et al. proposed determining the chloride diffusion coefficient using concrete material data such as water binder ratio, fly ash, and slag. The fast chloride migration method reveals that the chloride diffusion coefficient increases with the water-to-binder ratio and decreases with slag content. Because the binder amount affects concrete density, pore structure, and interfacial transition zone.[8] Recycled aggregate concrete was strengthened by pre-treated RCA. Due to old adhering mortar, RAC caused the weakest ITZ in concrete and raised w/c ratio and porosity. Pre-treating RCA with silica fume slurry makes RAC more chloride-resistant.[9]

In this investigation, crushed or demolished material is substituted for traditional virgin aggregates in the production of concrete using recycled aggregate. The production of concrete can considerably reduce its carbon footprint and energy consumption by incorporating recycled materials. The influence of the addition of a mineral additive on the durability performance of recycled concrete aggregate (RCA) was investigated for varying replacement amounts of Recycled Concrete Aggregate (RCA). As a mineral admixture, 10% Silica Fume (SF) and 25% Ground Granulated Blast Furnace Slag (GGBS) have been employed. The effects of SF and GGBS combination on the durability of RAC with 0%, 25%, 50%, 75%, and 100% RCA were investigated experimentally. Here, the durability properties, water absorption, sorptivity, sulphate attack, acid attack, and thermal resistance were all evaluated using all ten mix proportions.

Experimental program

Materials

Cement, Silica fume, GGBS

In this study, Portland pozzolana cement has been used. Silica fume (SF) and ground granulated blast furnace slag (GGBS) have been used as mineral admixtures. Table 1 provides the specific physical characteristics of cement, SF, and GGBS. As per IS 4031 part 11, a Le Chatelier flask with a volume of 250 ml was utilised to measure the specific gravity of cement.

Table 1.Physical properties

Consistency of cement	29%
Initial setting time	45 min
Fineness of cement	4%
Specific gravity of cement	2.91
Specific gravity of silica fume	2.23
Specific gravity of GGBS	2.9

Aggregate

M-sand was used as fine aggregate. It has a specific gravity of 2.56 and a fineness modulus of 3.54. It is classified as Zone II. Figure 1 shows how the fine aggregate's particles are spread out in terms of size. The 20 mm crushed stone serves as the natural coarse aggregate (NA), while crushed cement concrete derived from construction detritus is utilised as the RCA. Table 2 contains the specifications for both natural and recycled coarse aggregates.

Table 2.Coarse Aggregate Properties

Property	Natural aggregate (NA)	Recycled aggregate (RCA)
Specific gravity	2.68	2.6
Fineness modulus	7.2	6.9

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Impact value (%)	25.3	37.22
Water absorption (%)	0.6	2

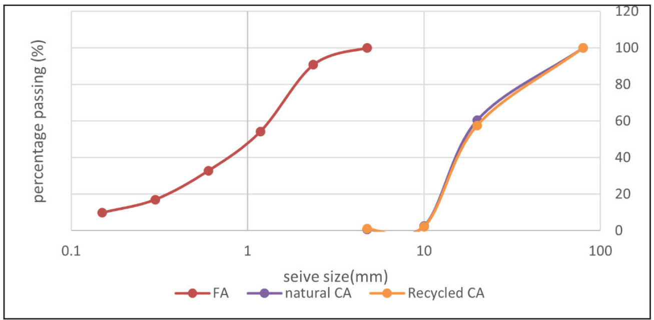

Figure 1.Distribution of Particle size

Mix Design

A typical mix composition of M25, by IS: 10262-2009, was formulated. The w/c ratio for the concrete was always kept at 0.50, without the inclusion of any chemical admixture. The concrete mix design is presented in Table 3. The composition ratios used for moulding the specimens are listed in Table 4.

Table 3.Mix design

Grade	M25
cement	394.3
water	197.16
Fine aggregate	673.79
Coarse aggregate(20mm)	1058.08
W/C ratio	0.5

Table 4.Mix proportions

S. No.	Mixes	Recycled Coarse Aggregate Replacement (%)	GGBS (%)	Silica Fume (%)
1	$R_0G_0S_0$	0%	0%	0%
2	$R_0G_{25}S_{10}$		25%	10%
3	$R_{25}G_0S_0$	25%	0%	0%
4	$R_{25}G_{25}S_{10}$		25%	10%
5	$R_{50}G_0S_0$	50%	0%	0%
6	$R_{50}G_{25}S_{10}$		25%	10%
7	$R_{75}G_0S_0$	75%	0%	0%
8	$R_{75}G_{25}S_{10}$		25%	10%
9	$R_{100}G_0S_0$	100%	0%	0%
10	$R_{100}G_{25}S_{10}$		25%	10%

Preparation and Evaluation of Specimens

Compressive Strength

The utilisation of Portland pozzolana cement has been employed in this investigation. SF and GGBS have been employed as mineral admixtures. The specimens were prepared for various RCA content (R0, R25, R50, R75, R100) and added with mineral admixtures of 10 % of SF and 25 % of GGBS. The slump value and weight of hardened concrete were observed for each specimen and average values were given in Table 5. The compressive strength of standard-sized concrete cubes measuring 150 x 150 x 150 mm was evaluated 28 days after curing. Table 5 contains the mean test results for three specimens.

Ultrasonic Pulse Velocity

Pulse velocity is the ratio between distance and time taken to pass through that distance. In this work, the direct method is used to determine the velocity at 14 days and 28 days. Table 6 gives the pulse velocity of RAC added with SF and GGBS and without SF and GGBS.

Sorptivity

The sorptivity test is the durability test which is used to measure the rate of absorption of water. Test specimen having the size of 100 mm diameter and 50 mm thickness is used. Specimens are placed in a furnace at 50± 2°C for 3 days. This is known as sample conditioning which allows the penetration of water inside the concrete at a relatively uniform level. The initial weight of all specimens is noted. Side surface sealed specimens are placed on the support which is placed at the bottom of the pan as shown in Figure 2. The 3 to 5mm of water level is maintained in the pan. At 5, 15 and 30 min after that every 1hr up to 6hr the mass of the specimen is noted.

Figure 2.Surface-sealed samples placed in water

Sulphate Resistance Test

As per ASTM C1012 standards, specimens of 150 mm concrete cubes were subjected to a sulphate attack test. Following a curing period of 28 days, the dry weights of the specimens were measured. The specimens were submerged in a solution containing 5% Na2SO4 by weight of water for a period of 90 days, to analyze sulphate attack. Following that, the specimens were subjected to compression strength testing.

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Acid Resistance Test

The acid attack test was conducted on 150 mm blocks of concrete. After 28 days of curing, specimens were removed, and their initial dry weight was noted. During the acid attack test, samples are submerged in a 5 % HCl solution. Following 90 days of exposure to acid, specimens were evaluated for compression strength and colour changes were recorded.

Test Result and Discussion

Compressive Strength

The control concrete is concrete produced without RCA content and mineral admixtures give 27.8 MPa as compressive strength. The compressive strength of RAC decreases with RCA content. Figure 3 gives the compressive strength of RAC added with mineral admixtures and without mineral admixture. RAC with 25% RCA added with mineral admixtures gets strength nearer to control concrete and RAC with 100% RCA added with silica fume gives compressive strength of 13.5% more than the similar mix without mineral admixture. Increase in strength with the addition of silica fume because the macro pores in RAC get reduced due to the addition of silica fume and GGBS.

Ultrasonic Pulse Velocity

From Table 6 it was observed that pulse velocity gets increased due to the addition of silica fume and GGBS. With the result, the pulse velocity increases with silica fume and GGBS. This is because the silica fume and GGBS reduces the pore in the RAC. The distance travelled by the pulse is increased due to the reduction of pores in the concrete. Hence, the ultrasonic pulse velocity is increased.

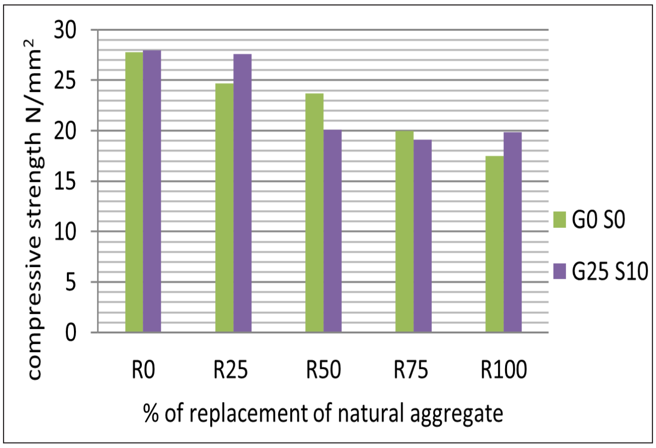

Figure 3.Compressive strength of RAC with and without mineral admixtures

Table 5.Compressive strength of RAC

Mix	Weight (Kg)	Slump value	Compressive strength(N/mm2)	% loss of compressive strength due to sulphate attack	% loss of compressive strength due to acid attack	Compressive Strength (N/mm^2) after exposure to 600 ° C
$R_0G_0S_0$	8.84	103 mm	27.8	1.06	1.79	26
$R_0G_{25}S_{10}$	8.616	100 mm	24.5	1.4	2.44	25.8
$R_{25}G_0S_0$	8.366	100 mm	24.7	5.2	4.04	29.3
$R_{25}G_{25}S_{10}$	8.69	70mm (Shear slump)	24.6	11.2	6.50	25.2
$R5_0G_0S_0$	8.35	60 mm (Shear slump)	23.7	14.7	15.18	23.5
$R5_0G_{25}S_{10}$	8.196	5 mm True slump	20.1	1.5	9.45	24.6

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$R_{75}G_0S_0$	8.303	5 mm True slump	20.0	4.0	10.5	28.4
$R_{75}G_{25}S_{10}$	8.01	5 mm True slump	19.11	5.8	4.76	23.7
$R_{100}G_0S_0$	8.293	5 mm True slump	17.48	8.6	1.02	26
R100 G25 S10	8.153	5 mm True slump	19.85	3.2	13.85	19.5

Table 6.Pulse velocity of RAC in Km/sec

Mix	Without mineral admixture		With mineral admixture	
	14 days	28 days	14 days	28 days
R_0	5.03	5.08	4.8	4.92
R_{25}	4.6	4.6	4.62	4.7
R_{50}	4.68	4.65	4.35	4.4
R_{75}	4.5	4.49	4.5	4.48
R_{100}	4.42	4.52	4.2	4.6

Sulphate Resistance

An analysis was conducted on the impact of sulphate ions on the compressive strength of RAC specimens. Figure 6 illustrates the percentage decrease in compressive strength of different RAC samples following exposure to sulphate. The results indicate that after 90 days of exposure, the compressive strength of 100% RAC without mineral admixtures decreases by 8.6% and the compressive strength of RAC with mineral admixtures decreases by 3.2% demonstrating the significance of sulphate attack on the RAC. Furthermore, the RAC specimen with 50% recycled aggregate, with mineral admixture showed the least effect when compared to those without mineral admixtures by the sulphate ions. Mineral admixtures often enhance the effectiveness of RAC in resisting sulphate exposure. The reason for this is that the mineral admixtures decrease the amount of calcium hydroxide, hence reducing the development of gypsum and delaying the creation of ettringite.

Sorptivity

The graph was plotted between absorption (I=change in mass (grammes)) and exposed area (mm^2). The density of water]) and the square root of time in sec (Öt) as depicted in Figure 4. The slope of the line represents the initial rate of absorption. The sorptivity rating increases proportionally with the percentage of natural aggregate replaced. The use of silica fume and GGBS decreases the rate of absorption of water, as shown in Figure 5.

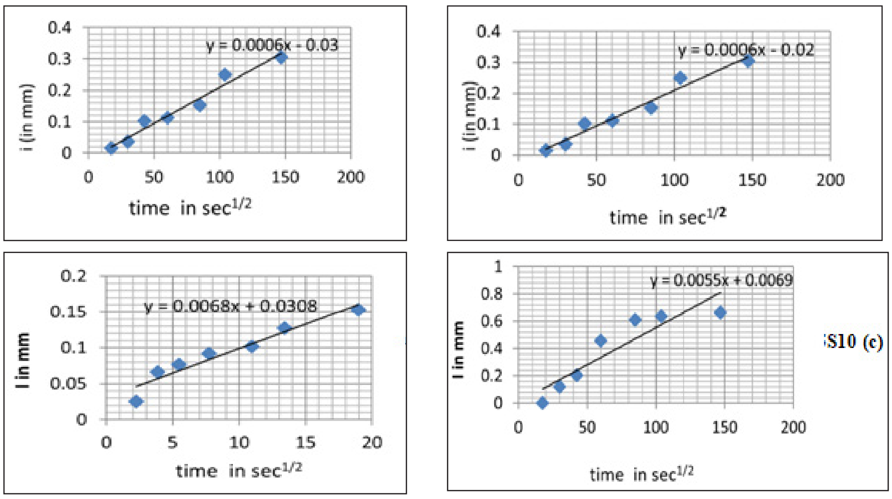

Figure 4.Graph plotted between absorption and the square root of time for (a) R0G0S0 (b)R0G25S10 (c) R100G0S0 (d)R100G25S10

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After being exposed to acid, the concrete experienced a reduction in weight and compressive strength, as seen in Figure 6. The weight loss in the concrete was larger when the R100 mix was used. In the case of compressive strength, if natural aggregate is replaced by recycled aggregate at a rate more than 25%, compressive strength is reduced by 12% to 15%; however, this reduction in compressive strength is less than 9% when silica fume and GGBS are present in the RAC.

Thermal Resistance

In general, the presence of porous matter in concrete increases its resistance to heat. At 600 °C, the concrete containing recycled aggregate and silica fume and GGBS undergoes more distinct shape changes. The low permeability of recycled aggregate concretecauses more stress inside the specimen. After being exposed to 600 °C, the colour of the concrete transforms to black. Table 5 displays the percentage of RAC's compressive strength that was lost when exposed to high temperatures. In the case of the R50 mixture, compression strength is reduced by 24%. In general, in concrete with more than 75% of recycled aggregate, the mineral admixture additions improve the performance of RAC against exposure to high temperatures.

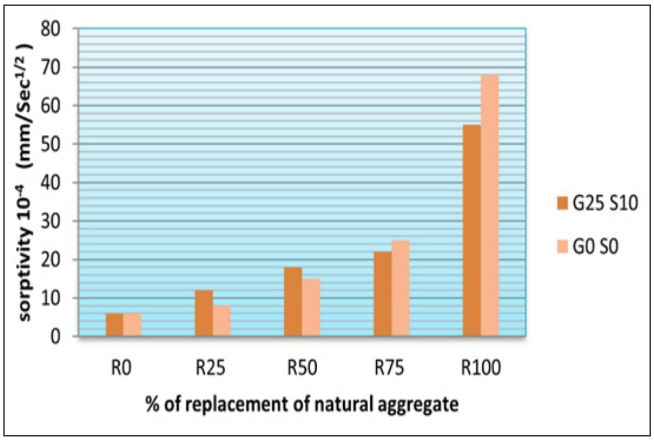

Figure 5.Sorptivity values of RAC

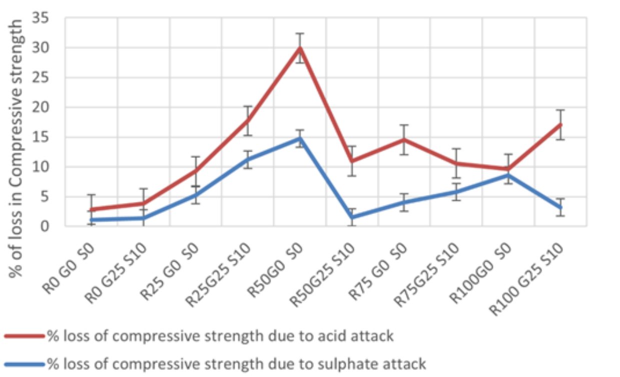

Figure 6.Caption:% loss of compressive strength due to acid and sulphate attack

Conclusion

- Based on the experimental data, the following conclusion is reached.
- The addition of 25% RCA to the RAC, along with SF and GGBS, resulted in compressive strength comparable to that of the control mix. The incorporation of mineral admixture decreases the porosity of concrete and generates a robust C-S-H gel matrix.
- The velocity of the pulse exhibited a positive correlation with time. This phenomenon arises due to the incorporation of GGBS, which generates an additional C-S-H gel and exhibits a reduced heat of hydration. As porosity diminishes, strength increases progressively.
- The water absorption rate is found to be higher with an increase in the proportion of RCA. Notably, the addition of both SF and GGBS in R100 resulted in a more significant decrease in the water absorption rate. The addition of mineral admixture up to 50% RCA improved the performance of RAC in terms of water absorption.
- The addition of mineral admixturesprovides more resistance against sulphate attack. Because mineral admixture reduces the calcium hydroxide content, it reduces the gypsum and delays ettringite formation.
- Temperature rises in concrete produce pore pressure. Changes in pore pressure result in the spalling of concrete.

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