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Experimental Investigation on Durability Study of Portland Slag Concrete with Influence of High-Volume Recycled Aggregate

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Abstract The importance of environmental protection and conservation, as well as the utilization of sustainable materials, in modern construction, has more concern on the scarcity of natural aggregates. Because of this increasing interest in using recycled aggregates in construction, the use of recycled aggregates in concrete needs more concern about durability aspects rather than strength. Normally Recycled Aggregate concrete (RAC) contains more porosity and water absorption. More studies reveal that recycled aggregate concrete has less durability than conventional concrete. In this regard, current experimental investigation was carried out to determine the durability of RAC with the use of sustainable materials i.e., Portland slag cement was used instead of OPC. M-sand as an alternative for river sand, Natural coarse aggregate (NCA) was replaced with recycled aggregate by various percentages (30, 45 and 60 percent) and Nano silica. The cube strength of concrete was optimum at 45% replacement of recycled aggregates with natural coarse aggregates at all grades, the percentage of strength difference between 28 and 180 days compressive strength about 27%. Concrete durability properties (RCPT, Permeability, water absorption and Acid resistance) were tested at various replacement percentages for M20, M25, M30 and M35 grades. Chloride ion permeability was reduced about 56% at higher concrete grades (M30 & M35) due to Nano silica at 180 days. At 90 days, the acid effect on RAC strength loss was reduced by roughly 5%. Nano silica is added to higher grades to decrease the water demand and enhances the durability and strength properties.

Keywords Portland Slag Cement, M-Sand, Recycled Coarse Aggregate (RCA), Recycled Aggregate Concrete (RAC), Nano Silica (NS)

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1. Introduction

The influence of recycled aggregate on Mechanical and Durability Properties of concrete is noted that, in comparison to conventional concrete, the mechanical properties are subpar, while the durability properties were enhanced due to the replacement or addition of GGBs, fly ash, steel fibers, rice husk, etc. with RAC [1]. Durability studies were done on recycled aggregate concrete with OPC and OPC mixed with Pozzolanic materials, but resulted in RCA having lower strength and durability due to the residual material on the surface, which is unproductive to the well-built link between aggregate and cement paste, moreover it has high permeable and water absorption and low acid resistant [2]. This study was focused on the durability of high volume recycled aggregate concrete with Portland slag replaced by Nano silica at 1.5% by weight of cement for higher grades.

During this investigation, an effort has been made to ascertain how Nano materials affect the durability and strength of concrete. Most of the structures were deteriorated due to corrosion of reinforcement; normally this corrosion occurs due to the presence of Chlorides ions or carbonation. Corrosion of reinforcement affects the strength & durability of the structure. Chloride ions strip the steel reinforcing of its protective covering, making it susceptible to corrosion. Chloride attack makes for 40 to 45% of the causes of concrete structural collapse overall. Several methods evaluate the penetration of chloride into the concrete. RCPT is popular and regularly used due to its ease. By delivering a 60V dc potential across a cylindrical specimen for a duration of 6 hours, it is also a cost-effective and reliable test to evaluate the penetration of ions. The observed current vs. time is integrated to obtain the total charge passes in Columbus. The charge passed is classified into very low, low, high, moderate and negligible. RCPT may not be in a steady state, thus when Pozzolanic materials are used for making concrete, it evaluates more heat and the pore fluid pressure. Concrete resistivity and chloride diffusion coefficient are inversely correlated. Due to greater chloride penetration in permeable zones, soluble salts like chloride ions pass through concrete and cause corrosion. The second major factor for causing corrosion after chlorides is permeability. Permeable concrete shows lower resistivity against chemical attack. Various tests are commonly used for water penetration studies and several studies indicate that recycled aggregate concrete has high permeability. The permeability moulds were used to install cylinders that were 50mm in diameter and 100 mm in height (IS 3085:1965). The sides of the mould were then sealed with a sealant, the top plate was fixed, and the reservoir was filled with water to the height of the reservoir. A pressure pump was then used to apply the pressure. For 100 hours, a water pressure of 10 kg/cm^2 was applied, and the discharge water from the outlet has collected the presence of porous paste can change how the interfacial transition zones between the aggregates and the cement matrix [14, 15]. To comprehend these mechanisms, the microstructure of hardened RAC has been the subject of numerous studies [3]. The interfacial transition zone is located at the contact between the aggregate and cement paste. There is an increase in porosity from the aggregate surface to the cement paste in this region [4, 5]. The permeability depends on porosity, and the use of recycled enhances the permeability effect. If the replacement ratio increases with natural aggregates by more than 30%, thus the permeability increases [6]. With the addition of NS, the permeability of concrete was also reduced because there were no longer any microscopic pores in the cement mortar matrix and ITZ. Application of Nano silica to concrete is an effective technique to improve concrete characteristics [12]. Compared to other Nano particles that can be used in cementation systems, Nano silica has greater advantages. The cement hydration rate is increased by the Nano silica content, which serves as Pozzolanic material and the initial process that occurs in the formation of a crystal from a solution for the hydration products [7]. The fast reaction between NS and cement paste caused the creation of gels with high water-retention capacities [17, 18, 19] which decreased the mix workability. The use of NS in concrete was demonstrated to be favorable in raising compressive strength as well as decreasing porosity since the addition of NS resulted in a major consumption of portlandite (CH) in the Pozzolanic reaction, making concrete strong and dense [8]. Decalcification of the C-S-H gel results from exposure to an acidic solution and results in the formation of silica gel, which is rather weak [9]. Concrete contents begin to dissolve when an acidic solution seeps into the pores of the material. Pozzolanic materials could therefore be useful for increasing resistance to this kind of acid attack [10, 11].

2. Research Significance

To enhance the durability of RAC, Portland slag cement was used instead of OPC with Recycled aggregate concrete at higher replacement ratios. Very little research has been done on the longevity of employing slag in concrete projects made using recycled aggregate. The present study concentrated on the durability of the influence of high-volume recycled aggregate Portland slag concrete with and without Nano silica. Nano silica was used to increase the durability of higher grades of RAC. The early age strength of Portland slag cement is decreased by its high Pozzolanic characteristics; as a result, Nano silica was added as a filler element to increase the strength of RAC. The early hydration of C3S is often facilitated by NS due to its highly reactive surface. NS thickened cement paste and enhanced cement's hydration [20, 22]. Conducted tests on the impact of Nano silica on M30 and M35 grade concrete built using recycled aggregate and slag, as well as M20 and M25 grades without Nano silica. The addition of NS enhances the durability of RAC, thus RAC can be utilized for coastal projects at a cheaper cost than regular concrete, contrary to the presumption that it cannot be used for structures close to water. By using RCA in place of natural aggregates, it is possible to save up to 25%.

3. Material Properties

Portland slag cement (JSW) conforming to IS 455 (1989) was used [24]. Specific gravity - 2.9, Fineness of cement 2%. Standard consistency of 31% and having Initial setting time 55Min. Compressive Strength at 28 days is 42.80 N/mm^2.

M-Sand: M-Sand conforming to grading zone-II (IS: 383) was used. Specific gravity -2.67, Fineness modulus - 2.38. The water absorption of M-Sand is 2.20.

Aggregates: Crushed aggregate: Locally available coarse aggregates are taken for producing concrete conforming to the Grading zone of Zone-II of IS 383-1970, aggregate nominal maximum size 20 mm and 10 mm.

Recycled Aggregates: Conforming to IS 383-1970, aggregate nominal maximum size 20 mm and 10 mm. The properties of aggregates were mentioned in Table 1. Recycled aggregates are obtained from 15 years old RCC building (Non treated).

Table 1. Properties of Aggregates

S.No.	Properties	Crushed Aggregates	Recycled Aggregates
1	Size	20mm	20mm
2	Specific Gravity	2.74	2.82
3	Bulk density(kg/m^3)		
	Loose	1480	1367
	Compacted	1700	1560
4	Percentage of voids	37.72	39.50
5	Fineness modulus	6.62	5.80
6	Water absorption (%)	0.5	1.02
7	Abrasion value	30	32.5
8	Aggregate impact value (%)	17.92	20.57
9	Flakiness (%)	14	13
10	Elongation (%)	15	14

Nano Silica: Nano-SiO2 (XLP) type has large high chemical purity, big surface energy, strong surface adsorption, and good dispersion. It has PH 9.3-9.6, Specific gravity of 1.08-1.11. In the present study, NS was used as 1.5% by weight of cement.

4. Experimental Program

In this part, the experimental methodology is discussed step by step in Table 2. Mix proportions for all grades are mentioned in Table 3.

4.1. Cube Strength of Concrete

150mm × 150mm × 150mm cubes were cast and tested at 7, 28, 90 and 180 days with 30, 45 and 60 percent replacements as shown in Figure 1. The cube strength of concrete shows better results at 45 percent replacement of RCA with natural aggregates and the strength of RAC is lower than the conventional concrete at 60% replacement. The cube strength of concrete at various ages with all replacements is shown in Figure 2.

Figure 1. Testing of cubes

Table 2. Experimental Methodology.

Stage 1	Identification of material sources i.e. collection of demolished waste from buildings
Stage II	Evaluation of physical properties of identified resources (specific gravity, density and water absorption)
Stage III	Mix design and trails made for deciding cement and water content
Stage IV	The casing of specimens for grades at all replacements
Stage V	Evaluation of Mechanical properties for all grades at replacements
Stage VI	Durability studies on the prepared specimens and evaluated internal water absorption and acid attack

Table 3. Mix Proportions

		Cement (kg/m³)	NS (kg/m³)	FA (kg/m³)	CA (kg/m³)	RCA (kg/m³)	w/c
M20	M1RCA0%	300	--	700	1255	--	0.53
	M1RCA30%	305	--	696	872	374	0.53
	M1RCA45%	312	--	690	678	556	0.53
	M1RCA60%	320	--	684	489	734	0.53
M25	M2RCA0%	330	--	697	1249	---	0.46
	M2RCA30%	336	--	692	868	372	0.46
	M2RCA45%	340	--	689	679	556	0.46
	M2RCA60%	350	--	681	488	732	0.46
M30	M3RCA0%	381	5.8	676	1210	--	0.41
	M3RCA30%	384	5.9	671	842	360	0.41
	M3RCA45%	394	6	666	656	537	0.41
	M3RCA60%	403	6.2	659	472	708	0.41
M35	M4RCA0%	400	6	670	1200	--	0.39
	M4RCA30%	402	6.1	664	356	832	0.39
	M4RCA45%	406	6.2	661	651	533	0.39
	M4RCA60%	409	6.3	659	472	708	0.39

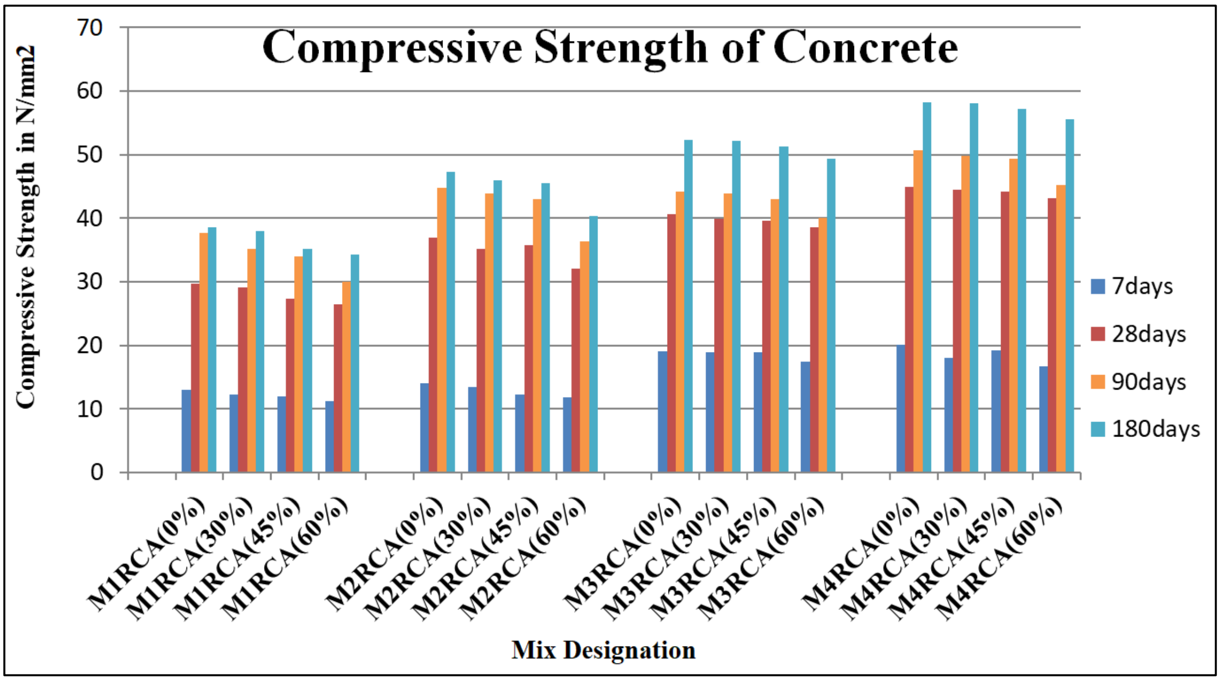

Figure 2. Cube Strength of Concrete

4.2. Rapid Chloride Permeability Test (RCPT)

100mm × 200mm sizes were cast, and each cylinder is cut into three parts of size (100mm × 50mm) by cutting machine to conduct RCPT test. 50mm × 100 mm slices were subjected to 60V DC voltage for 6hrs.0.3M NaOH solution is present in one reservoir while 3.0% NaCl solution is present in the other. Specimens were cast for all below mentioned grades and cured in water up to 28 days, and then specimens were removed from curing, placed in RCPT test apparatus and tested [25] at 28, 90 and 180 days. Nano silica was used for higher grades (M30 and M35) to study the influence of NS on slag-based RAC. By including Nano silica into the slag concretes, chloride ion penetration was decreased. RCPT values were shown in Table 4. Results were shown in Figure 3.

Table 4. RCPT Test Values

Grade of Concrete	Mix Designation	28 Days		90 Days		180 Days	
		T C passed	Chlo ion	T C passed	Chlo ion	T C passed	Chlo ion
M20	M1RCA (0%)	1325	Low	825	Very Low	725	Very Low
	M1RCA (30%)	1198	Low	764	Very Low	683	Very Low
	M1RCA (45%)	1024	Low	645	Very Low	576	Very Low
	M1RCA (60%)	1166	Low	672	Very Low	624	Very Low
M25	M2RCA (0%)	1285	Low	943	Very Low	678	Very Low
	M2RCA (30%)	1156	Low	743	Very Low	399	Very Low
	M2RCA (45%)	1102	Low	515	Very Low	341	Very Low
	M2RCA (60%)	1042	Low	623	Very Low	485	Very Low
M30	M3RCA (0%)	1060	Low	928	Very Low	650	Very Low
	M3RCA (30%)	1020	Low	850	Very Low	550	Very Low
	M3RCA (45%)	920	Low	632	Very Low	432	Very Low
	M3RCA (60%)	1205	Low	820	Very Low	520	Very Low
M35	M4RCA (0%)	1172	Low	984	Very Low	629	Very Low
	M4RCA (30%)	1033	Low	889	Very Low	598	Very Low
	M4RCA (45%)	1002	Low	740	Very Low	520	Very Low
	M4RCA (60%)	1156	Low	824	Very Low	625	Very Low

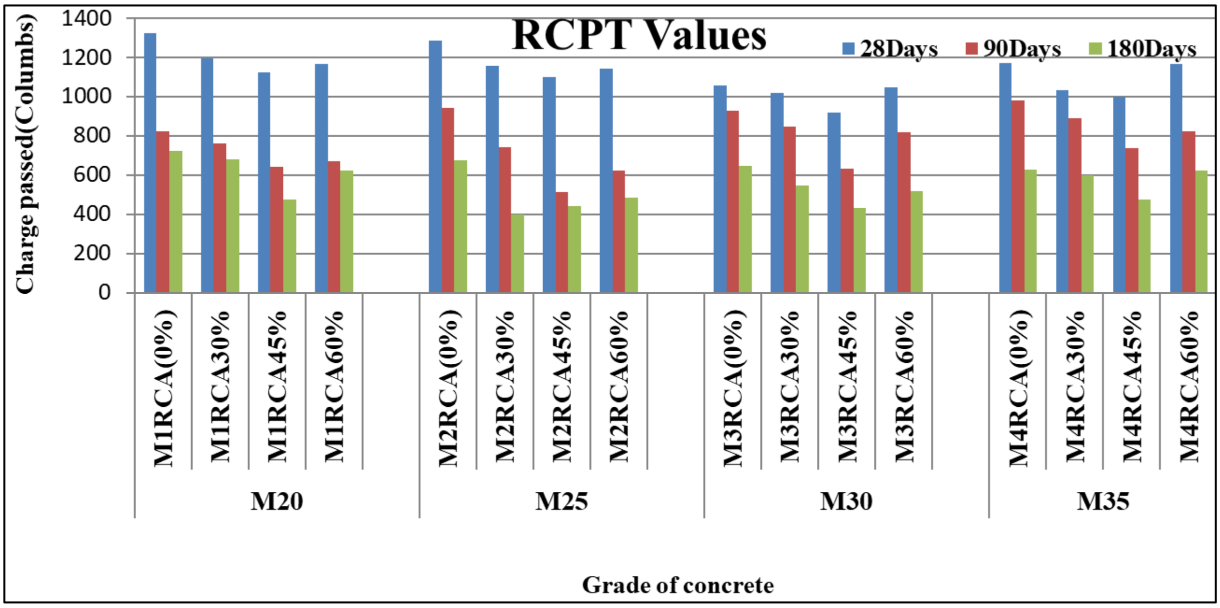

Figure 3. RCPT values

The following observations were observed regarding slag-based recycled aggregate concrete. Chloride ion Permeability of M20 grade was decreased by around 45% for a replacement of 0% after 180 days, and a similar trend was continued with a replacement of 30% and 45% with recycled aggregate, as well as a 60% replacement. At 180 days, the Chloride Ion Permeability of lower grades (M20 & M25) concrete has decreased roughly by 47% to 53%. At 180 days, the Chloride ion Permeability of higher grades M30 & M35 was reduced up to 56%, due to the addition of Nano silica at 30 and 45% replacements.

4.3. Permeability

Concrete deterioration caused by corrosion of the reinforcing steel and other deterioration processes may be primarily caused by the permeability of the concrete. 150 × 300mm size cylinders were cast and cured in water for about 28 days, then specimens were prepared for testing under permeability apparatus and measured the quantity of water by using measuring jar penetrating through the specimen. The percentage of permeability reduction was shown in Figure 4.

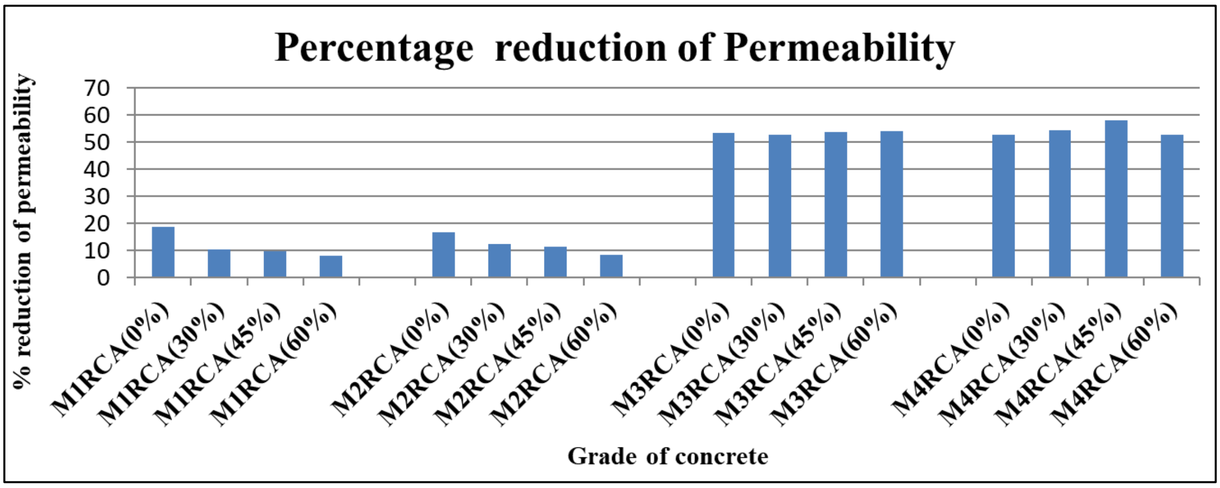

Figure 4. Percentage Reduction of Permeability

Concrete with 0% replacement at 28 days has higher permeability than recycled aggregate concrete. The permeability is low at 180 days at all replacements of recycled aggregate concrete. Permeability for M20at 180days was reduced by 25% than 28 days. Permeability for M25 at 180 days was reduced by 26% than 28 days. For higher grades the Permeability at 180 days was reduced by 28% than 28 days with NS.

4.4. Water Absorption

Test for Water Absorption after 28 days of curing, tests for water absorption (SWA) were performed on a 150mm cube specimen. Prior to drying, the specimens were weighed. Specimens have been dried at a temperature of roughly 105 ℃ in a hot air oven. The drying process was carefully watched. The dried samples were submerged in water after being cooled to room temperature. The surface dried with a clean cloth, and it was weighed. Once the weight was more or less consistent, this operation was discontinued. Water Absorption was evaluated as the difference between the measured water saturated mass and oven dried mass represented [26] in Figure 5 as a percentage of oven-dried mass. Water absorption results are reported in Figure 6.

Figure 5. Water Absorption Testing

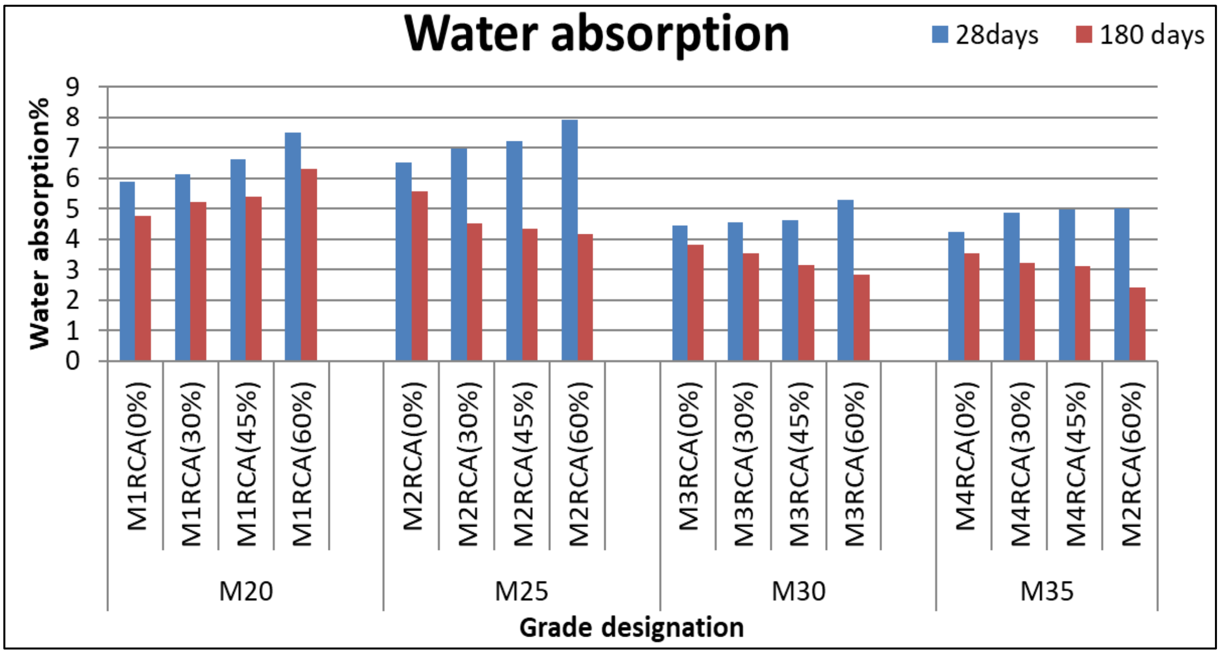

Figure 6. Water Absorption

4.5. Acid Attack

In the present study, resistance to the acid attack of recycled aggregate concrete mixes was studied by immersing concrete cubes of size 100mm × 100mm × 100mm with 1% and 3% in a diluted Sulphuric acid (H_2SO_4) solution and maintaining constant pH throughout the curing period. After soaking cubes, in the aforementioned solutions for about 28, 56 and 90 days, the changes in mass, shape and strength were measured. According to ASTM C 267 - 01, three factors indicated that —Acid Mass Loss Factor (AMLF) from Figures 7 & 8, Acid Strength Loss Factor (ASLF) from Figures 9 to 12 and Acid Attacking Factor (AAF) Figure 13 were reported as a result of the research. Acid Durability Loss Factor (ADLF) is the product of the above three factors; results were reported in Figure 14.

4.5.1. Mass Loss Factor

Figures 7 and 8 show the Mass loss factor for all grades at 1% H_2SO_4 and 3% H_2SO_4 at 14, 28, 56 and 90 days. The mass loss factor is higher being increased with acid percentage and age.

4.5.2. Strength Loss Factor

The following Figures from 9 to 12 show the Strength loss factor for all grades at 1% H_2SO_4 and 3% H_2SO_4 at 28, 56 and 90 days. The strength loss factor is higher with increasing the percentage replacement of recycled aggregate with conventional concrete. The following Figures from 9 to 12 show the percentage of strength loss factor is increasing with the age of concrete.

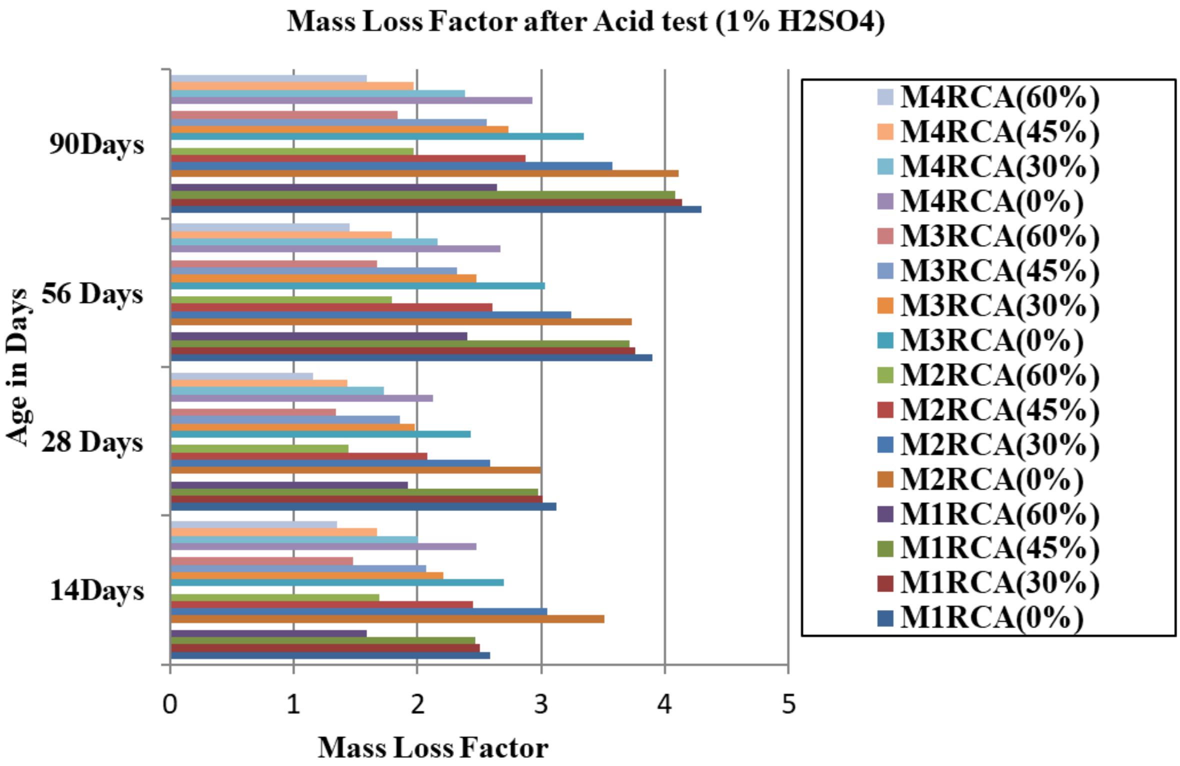

Figure 7. Mass loss factor after Acid test (1%H_2SO_4)

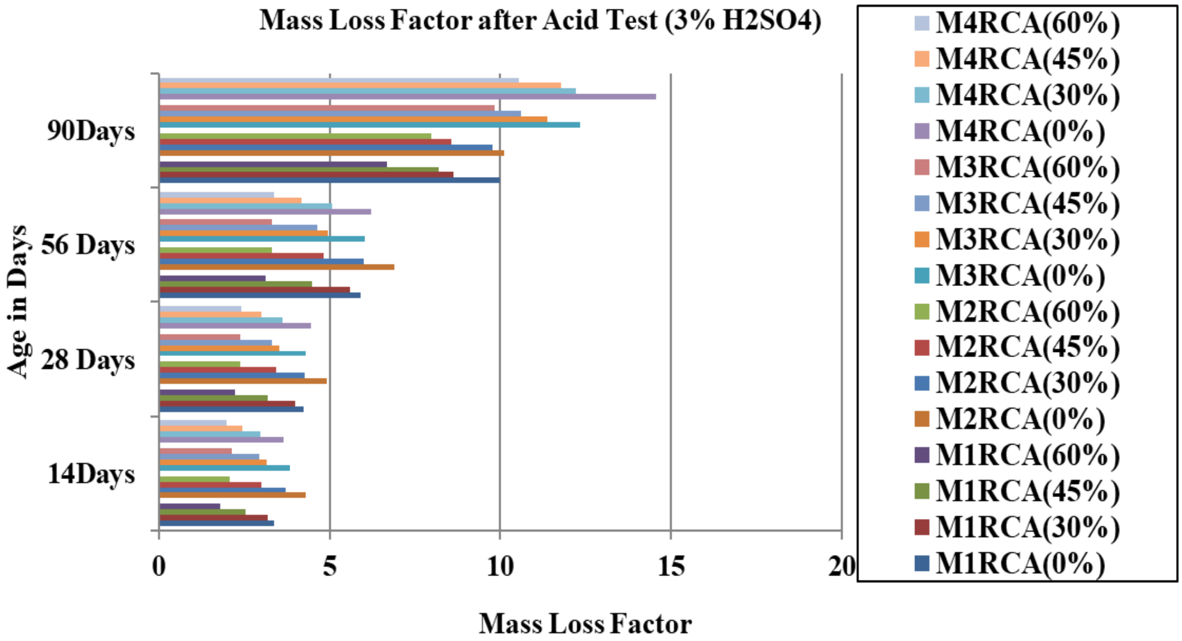

Figure 8. Mass loss factor after Acid test (3%H_2SO_4)

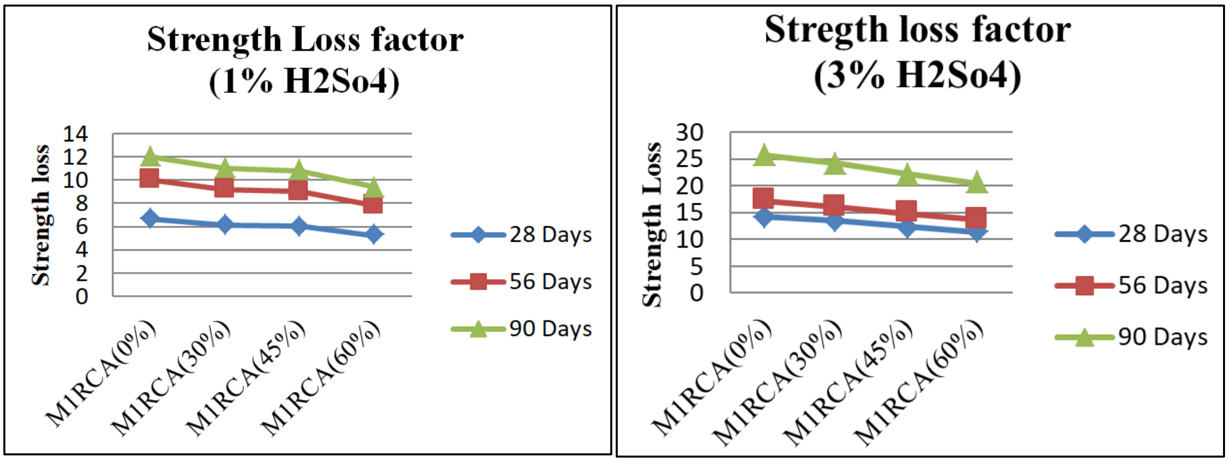

Figure 9. Percentage of strength loss factor for M20 Grade (RCA 0%, 30%, 45% & 60%)

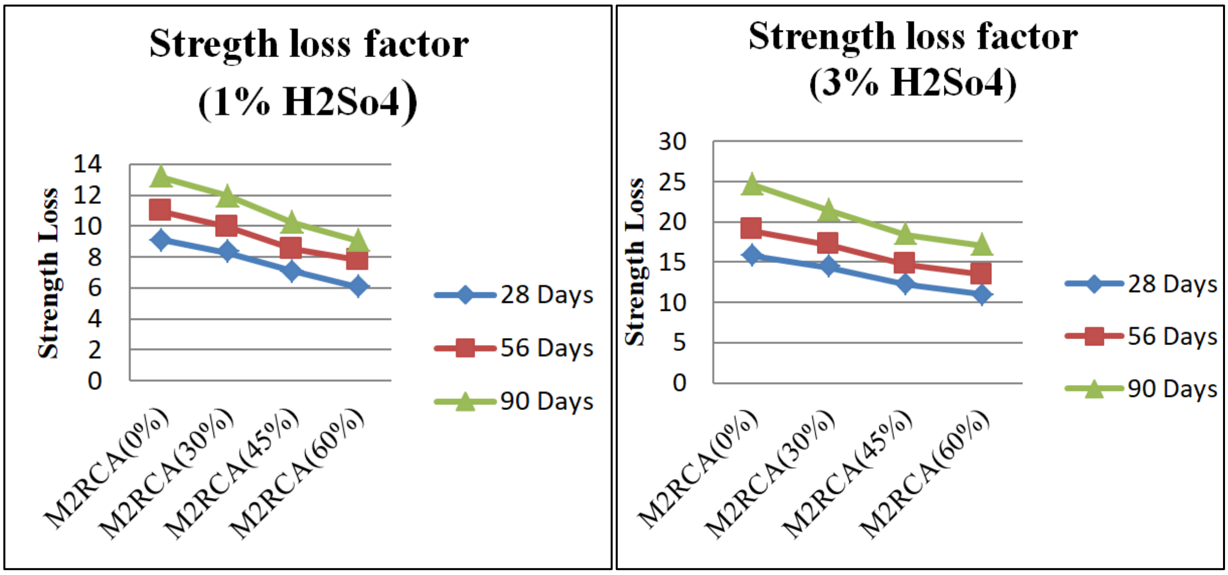

Figure 10. Percentage of strength loss factor for M25 Grade (RCA 0%, 30%, 45% & 60%)

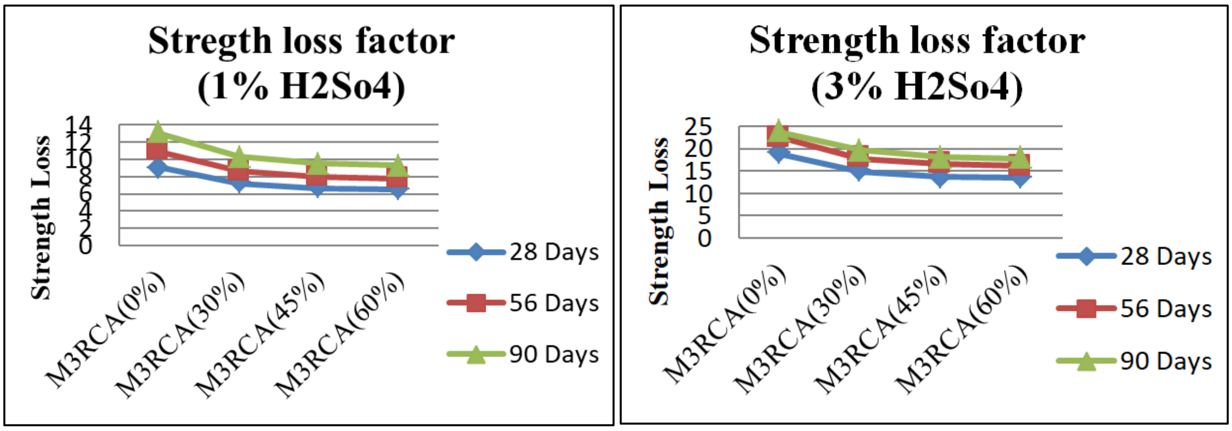

Figure 11. Percentage of strength loss for M30 Grade (RCA 0%, 30%, 45% & 60%)

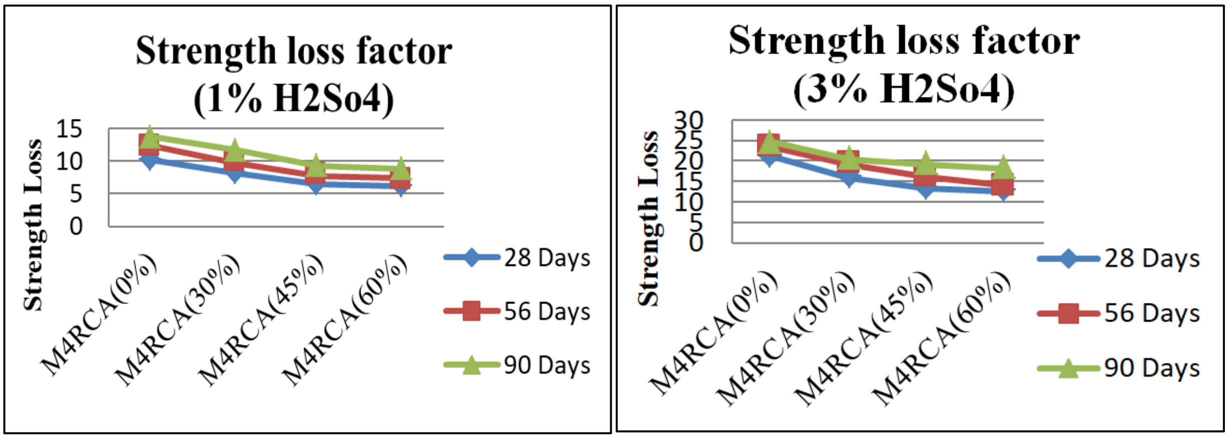

Figure 12. Percentage of strength loss factor for M35 Grade (RCA 0%, 30%, 45% & 60%)

4.5.3. Acid Attack Factor

The change in diagonal length after immersion in the acid solution for 90 days was tabulated in Table 5 and shown in Figure 13.

Table 5. Acid Attack Factor for All grades

Mix Id	**90 Days 1%H_2SO_4**	**90 Days 3%H_2SO_4**
M1 0%	2.2	2.65
M1 30%	1.73	2.22
M1 45%	1.60	1.80
M1 60%	1.42	1.76
M2 0%	2.66	3.27
M2 30%	2.17	2.35
M2 45%	1.94	2.10
M2 60%	1.68	1.90
M3 0%	2.28	2.48
M3 30%	1.60	1.94
M3 45%	1.48	1.67
M3 60%	1.49	1.58
M4 0%	2.50	2.93
M4 30%	1.82	2.24
M4 45%	1.67	2.16
M4 60%	1.56	1.82

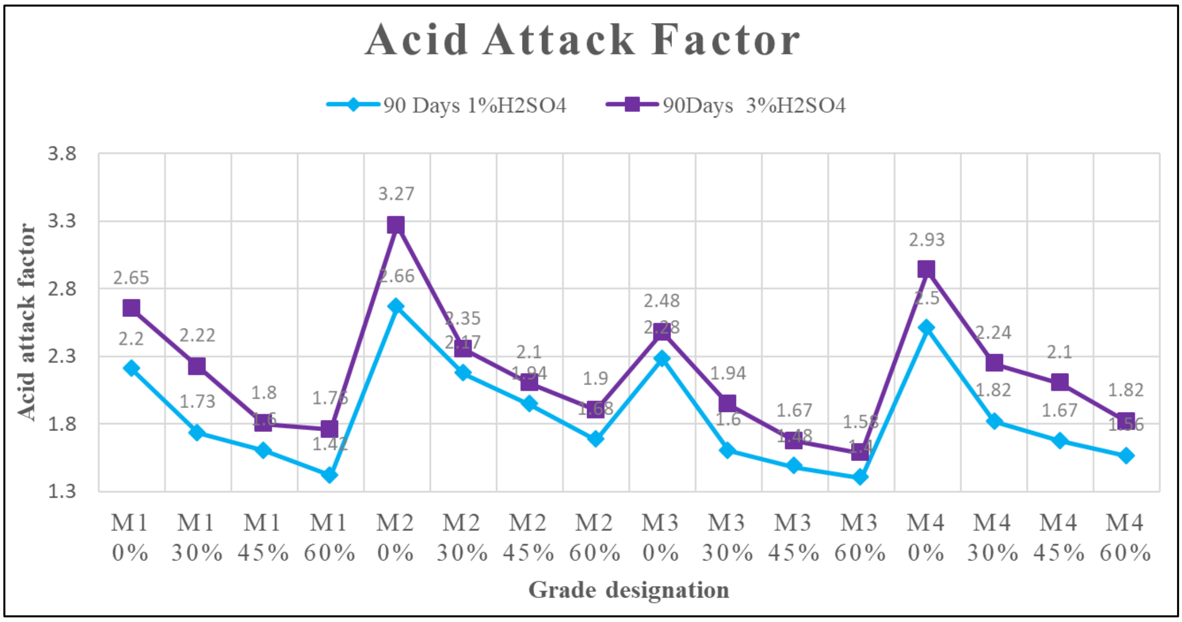

Figure 13. Acid attack at 90days

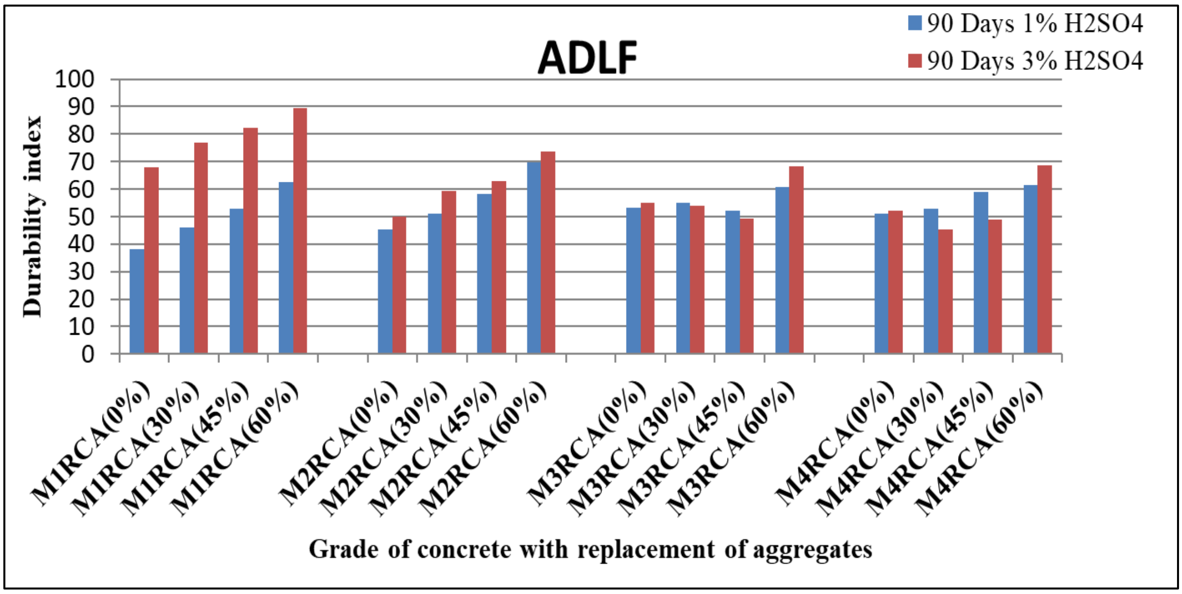

Figure 14. Durability Index at 90days

The above Figure 14 shows the variation of ADLF (Durability index) in concrete mixtures with and without recycled aggregate for 90 days of acid immersion. RAC with Nano silica was more durable than conventional concrete. The ADLF value clearly shows that slag-based concrete is more durable than ordinary concrete. The ADLF value reduces at 45% replacement of RCA and also ADLF was reduced at higher grades.

5. Discussion and Results

It was found that the cube strength of concrete at 30% and 45% replacement with RCA values were slightly different than conventional but at 60% replacement strength was reduced than conventional concrete for M20 and M25 grades. By this study M20 and M25 without Nano silica proved that 45% replacement with recycled aggregates was optimum. RAC concrete has low workability, due to the presence of mortar on aggregates it requires more water for making concrete, in this regard Nano silica was used at 1.5% by weight of cement for higher grades i.e., M30 and M35 for better workability. M sand was denser in microstructure, it had a narrow inter-transition zone than river sand with slag, due to this densification of pore structure in concrete was increased and resistivity towards chlorides was improved [21]. Due to the addition of Nano silica, chloride ion penetration was reduced by 18% lower in M 30 and M 35 grades than M20 and M25 grades. It was found that the performance of 60% replacement of recycled aggregate concrete with Nano silica was the same as conventional concrete. Water absorption increases with percentage replacement increases with more recycled aggregate being used in place of conventional concrete, the strength loss factor increases under acids.

6. Conclusions

1. By substituting 45% of recycled aggregate with natural coarse aggregate, the compressive strength of concrete was increased at all ages. The strength of RAC at 60% replacement is lower than conventional concrete at all ages. It is concluded that the optimum percentage of recycled aggregate replacement in concrete is 45% for all grades.M20 and M25cube strength of recycled aggregate at180 days was improved by nearly 28% at all replacements. At 30% replacement with natural coarse aggregate was higher than conventional concrete.
2. The cube strength at 45% replacement was higher than conventional concrete. The strength of RAC at 60% was lower than conventional concrete.M30 and M35 cube strength of recycled aggregate at 180 days was improved by nearly 30% at all replacements. By incorporating NS cube strength of slag cement-based concrete is more at 180 days.
3. Permeability was reduced up to 50% by adding Nano silica. M20 and M25 grade's percentage of permeability was reduced from15 to 20% only. At higher grades percentage of permeability was reduced up to 50%.
4. From 15% to 30%, the percentage of water absorptions was decreased. With an increase in replacement percentage, water absorption rises.
5. At various replacement levels, chloride ion penetration at 180 days was "Very Low" for all grades.
6. The ADLF value unequivocally demonstrates that concrete made of slag is more durable than regular concrete. At 45% replacement of RCA, the ADLF value decreases, and it likewise decreased at higher grades.

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