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Behavior of Various Concrete Mixes with Inclusion of Recycled Coarse Aggregates Based on Durability Point of View

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Abstract*: *Cement concrete is the most extensively used construction material in the world with about six billion tons produced every year. It has emerged as the dominant construction material for the infrastructure needs of the 21st century. Aggregate is one of the main ingredients in producing concrete i.e. 75% of the concrete mass. The strength of the concrete produced is dependent on the properties of aggregates used, hence there is huge demand for this material. In order to reduce the use of natural aggregates from natural resources, the use of recycled aggregates in concretes is an interesting solution. It helps in reducing the cost of concrete manufacturing and also has numerous indirect benefits such as reduction in land-fill cost, energy saving, and protecting the environment from possible pollution effects. Durability and strength are two most important criteria for any concrete structures. One of the main causes of deterioration in concrete structures is its exposure to temperature variations mainly due to solar radiation and harmful chemicals that may be found in nature such as in industrial effluents. The most aggressive chemicals that affect the long term durability of concrete structures are the magnesium, sulphates and chlorides. These chemicals in presence of water increases the porosity of concrete and leads to loss of weight and strength. Hence this paper investigates the effect of thermal cycles and chemical attack on M20 & M25 grade cement concrete in partial replacement of natural aggregates with recycled aggregates with proportion of 10%, 20% and 30%. The effect of temperature variations were studied by analyzing loss in compressive strength after applying various thermal cycles on concrete cubes at 60° C and 90° C. The chemical resistance of the concretes was studied through chemical attack by immersing concrete cubes in 5% $MgSO_4$, H_2SO_4 and HCl solution and loss in strength and weight were measured at 7, 28, 60 and 90 days. The result shows possible use of RCA as 20% for both M20 & M25 grade concrete, and resistance to thermal cycles and chemical attack shows reduction in strength and weight with time.

Keywords: Compressive strength, thermal cycle, durability, NCA (Natural Coarse Aggregate), RCA (Recycled Coarse Aggregate).

I. INTRODUCTION

Cement concrete has clearly emerged as the dominant construction material for the infrastructure needs of the 21st century and construction of large number and variety of structures in the world today. It is the most extensively used construction material worldwide and is the second to water as the most heavily consumed substance with about six billion tons produced every year. Aggregate is one of the main ingredients in producing concrete as it consumes almost 75% of the concrete mass [2]. The strength of the concrete produced is mainly dependent on the properties of aggregates used.

The intensive use of aggregates in constructions is a very important environmental concern. In order to reduce the use of natural aggregates from natural resources and energy preservation, the use of recycled aggregates in concretes is an interesting solution [4]. Recycling this material is of particular interest because its use can considerably reduce the problem of waste storage, and simultaneously it helps in the preservation of natural aggregate resources. Again it helps in reducing the cost of concrete manufacturing and also cost saving due to reduction of transportation & crushing process of natural aggregates [3].

Durability and strength are two most important criteria for the use of concrete in structures. Any deficit of either durability or strength could make the structure flabby for the intended purpose [5]. If the structure is not durable, but it has sufficient strength, then the strength of structure reduces with the age due to deterioration of concrete and reinforcement due to surrounding environment. One of the main causes of deterioration in concrete structures is its exposure to temperature variation due to solar radiation and harmful chemicals that may be found in nature due to pollution from industries and vehicles. The most aggressive chemicals that affect the long term durability of concrete structures are magnesium, sulphates and chlorides. These chemicals in presence of water increases the porosity of concrete and leads to loss of stiffness and strength. Hence to objectives of this study are summarized as: (i) to find out the optimum percentage of replacement of NCA with RCA, (ii) to study the effect of thermal cycle on standard and optimum M20 mix, and (iii) to study the effect of chemical attack on standard and optimum M20 mix.

II. EXPERIMENTAL METHODOLOGY

A. General

This research is focused on use of RCA in M20 & M25 grade concrete with replacement of RCA with NCA by 10%, 20% and 30%, and examine the performance of concrete with prospective of durability in the terms of resistance against thermal cycles and resistance against chemical attack.

B. Compressive Strength Test

The compressive test was carried out using 200-ton of compression machine. The specimen cube size of 150 mm is used to determine the compressive strength, was placed between the platens and the load was applied at a standard rate of loading. The

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maximum load was noted. The test was repeated for three specimens and the average value of compressive strength has been calculated and recorded. The results of each mixes are provided in subsequent tables.

C. Thermal Cycles

Concrete surface temperature was measured during the hottest months of the year namely April and May in Bardoli. The measurement was carried out on the surface of roof slab of Civil Material Testing laboratory at Vidyabharti Trust Campus, Bardoli. A point which would be continuously exposed to sun radiation was selected. One copper constant thermocouple was fixed at this point and another was let in the air just adjacent to first one to measure the air temperature. Figure 1 gives the variation of concrete surface temperature and ambient air temperature, between 6.15 a.m. and 6.15 p.m. on a summer day. It can be observed that concrete surface temperature reaches around a maximum of 63° C when the ambient air temperature is around 32° C. At many places the ambient air temperature of 40° C to 47° C is common during summer. The concrete surface temperature at such places may reach between 80° C to 90° C. Hence, investigation of compressive strength of M20 & M25 grade concrete and various mixes by using RCA were subjected to thermal cycles at a temperature of 60° and 90° C.

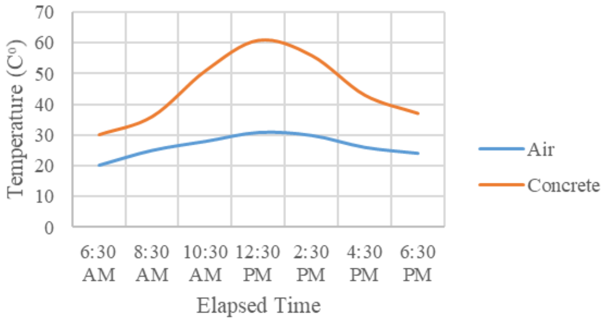

Fig. 1.Variation of concrete surface temperature and ambient air temperature.

D. Chemical Attack

To determine the resistance to chemical attack, the M20 & M25 grade concrete and trials by using RCA were immersed in water having 5% of Magnesium sulphate (MgSO4), Sulphuric acid (H2SO4), and Hydrochloric acid (HCL) by weight of water. The concrete cubes which were cured in MgSO4, H2SO4, and HCL were removed from the curing tank and allowed to dry for one day. The resistance of concrete to magnesium, sulphates and chloride attack was found by the % loss of compressive strength and weight, tested at 7, 28, 60 and 90 days. The results of each mixes are provided in subsequent tables.

III. MATERIALS USED

A. Cement

Ordinary Portland cement (OPC) of 53 grade was used throughout the work. Cement was tested at beginning and end of each phase of work to ensure no deterioration in quality of cement during the interim period. The necessary testing were conducted in accordance with relevant IS code of practice [8].

The details of the test result are presented in Table I.

Table- I: Test Results of OPC 53 Grade

No.	Tests	Results Obtained	Requirement as per IS:12269-1987
1	Consistency (%)	30	---
2	Specific surface area (m^2/kg)	264	> 225
2	Initial setting time (minutes)	130	> 30
3	Final setting time (minutes)	228	< 600
4	Compressive strength (N/mm^2) 3 days	31	> 27
	7 days	38	> 37
	28 days	54	> 53
5	Soundness (mm) Le-Chetelier Method	2.0	< 10

B. Natural Fine Aggregate

The fine aggregate as river sand available locally in Bardoli, Gujarat state has been used. The tests were carried out for coarse aggregate as per procedure laid down in the relevant IS code of practice [6] and the results are presented in Table II.

Table- II: Test results of Sieve Analysis and other tests of Fine Aggregate

No.	Tests	Results
1	IS Sieve size (% Passing) 10 mm	100
	4.75 mm	96.81
	2.36 mm	88.24
	1.18 mm	63.20
	600 micron	38.27
	300 micron	13.32
	150 micron	3.88
2	Fineness modulus	2.96
3	Specific gravity	2.69
4	Water absorption (%)	2.08
5	Silt content (% Passing on 75μ)	1.08
6	Bulk density (kg/m^3)	1714

C. Natural Coarse Aggregate (NCA)

The coarse aggregate as crushed basalt available in Chikhli, Gujarat was used. The tests were carried out for coarse aggregate as per procedure laid down in the relevant IS code of practice [7] and the results are presented in Table III.

D. Recycled Coarse Aggregate (RCA)

The recycled coarse aggregate as from construction waste was manufactured and used. The tests were carried out for coarse aggregate as per procedure laid down in the relevant IS code of practice [7] and the results are presented in Table III.

Table- III: Test results of Sieve Analysis and other properties of NCA and RCA

No.	Tests	Results	
		For NCA	For RCA
1	IS Sieve size 40 mm	100	100
	20 mm	95.95	49.49
	16 mm	53.23	18.67
	10 mm	24.99	0.54
	4.75 mm	1.55	0.41
2	Elongation Index (%)	20	22.84

3	Flakiness Index (%)	8	6.28
4	Impact Value (%)	13.89	12.70
5	Specific Gravity	2.832	2.606
6	Water Absorption (%)	1.163	2.076
7	Bulk Density kg/m^3	1321	1446

IV. DESIGN MIX PROPORTION

With the knowledge of properties of ingredients, necessary design of the mixes was carried out for M20 and M25 as per IS: 456-2019 [9]. Table IV provides the proportions of M20 & M25 grade of concrete respectively. In this standard mix proportion NCA were replaced by RCA in trial of 10%, 20% and 30% by weight as per IS: 10262-2019 [10].

Table- IV: Mix Proportion of M20 and M25

No.	Material	Proportion by Weight	
		M20	M25
1	Cement	330 kg	381 kg
2	Fine Aggregate (Natural)	693 kg	658.6 kg
3	Coarse Aggregate (10 mm down size)	386 kg	381 kg
4	Coarse Aggregate (20 mm down size)	901 kg	888 kg
5	Water	174.9 liter	171.4 liter

V. RESULTS AND DISCUSSION

This section represents the test results for various tests conducted on concrete under studies. The data represented here are the final calculated data obtained as an average of readings available by performing tests on three samples of the concrete cubes.

A. Exposure to Thermal Cycle

To investigate the behavior of concrete when exposed to thermal cycles, concrete cubes of various mixes were casted and cured for 28 days and then exposed to subsequent thermal cycles. One thermal cycle constitute of heating period of 8 hours and subsequent cooling (in air / room) temperature period of 16 hours [1]. The specimen after curing period where placed in a room for exposure to room temperature variations, whereas for exposure to 60° C and 90° C specimen were placed in electric ovens for 6 hours and allowed to cool for 16 hours at room temperature. This specimens were tested for compressive strength after exposure to such thermal cycles of 28, 60 and 90. Result obtained have been analyses to find out effect of thermal heat on strength of concrete. The results of M20 mix with different replacement of RCA with NCA are shown in Table 5 and that for M25 mix with different replacement of RCA with NCA are shown in Table V.

Table- V: Test results of compressive strength of M20 mix with different replacement of RCA with NCA at different temperature exposure and thermal cycles

Thermal Cycles		Compressive strength (N/mm^2)			
		M20	M20 + 10% RCA	M20 + 20% RCA	M20 + 30% RCA
28 Cycle	Room Temp.*	25.79	23.26	22.67	19.72
	60° C**	24.55	22.17	21.54	18.74
	90° C**	23.71	21.38	20.84	18.11
60 Cycle	Room Temp.*	26.53	24.12	23.45	20.28
	60° C**	24.42	22.25	21.56	18.68
	90° C**	23.62	21.52	20.88	18.13
90 Cycle	Room Temp.*	26.74	24.26	23.54	20.44
	60° C**	23.76	21.62	20.96	18.21
	90° C**	22.95	20.87	20.28	17.62

*Cured at 28 days, then kept into air

** Cured at 28 days, then exposed to temperature

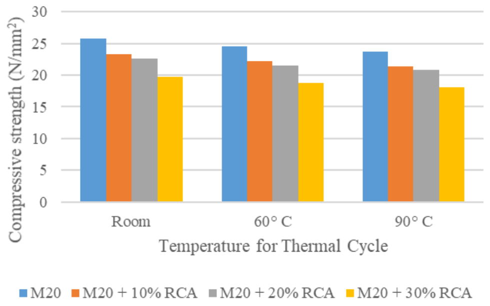

Fig. 2.Test results of compressive strength of M20 mix with different replacement of RCA with NCA at different temperature exposure and 28 thermal cycles.

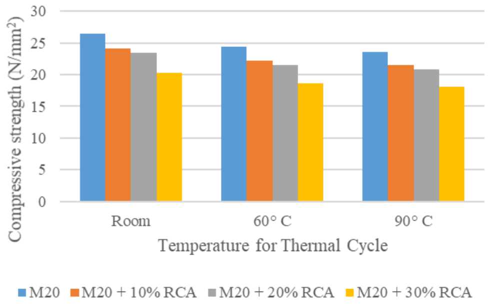

Fig. 3.Test results of compressive strength of M20 mix with different replacement of RCA with NCA at different temperature exposure and 60 thermal cycles.

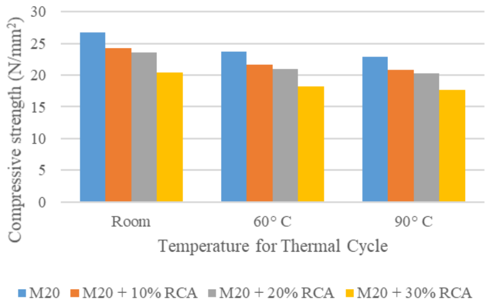

Fig. 4.Test results of compressive strength of M20 mix with different replacement of RCA with NCA at different temperature exposure and 90 thermal cycles.

From the above results it can be observed that the compressive strength of the M20 mixes with different replacement of RCA with NCA when exposed to the thermal cycles are decreasing with increase in numbers of thermal cycles i.e. from 28 cycles to 60 cycles to further 90 cycles as well as increase in temperature exposure from room temperature to 60° C and further up to 90° C. The minimum reduction in compressive strength is noted of 5.10% when exposed to 60 ° C temperature for 28 cycles whereas maximum reduction in compressive strength is noted of 14.32% when exposed to 90° C for 90 thermal cycles. But the result shows that the strength of M20 mix with 20% replacement of RCA with NCA is still acceptable after exposure to worst environmental thermal variation i.e. 90° C for maximum duration under investigation i.e. 90 thermal cycles.

Table- VI: Test results of compressive strength of M25 mix with different replacement of RCA with NCA at different temperature exposure and thermal cycles

Thermal Cycles		Compressive strength (N/mm^2)			
		M25	M25 + 10% RCA	M25 + 20% RCA	M25 + 30% RCA
28 Cycle	Room Temp.*	32.12	30.21	27.85	24.43
	60° C**	30.82	28.87	26.72	23.56
	90° C**	29.78	28.21	25.84	22.81
60 Cycle	Room Temp.*	32.96	30.94	28.56	25.12
	60° C**	30.68	28.79	26.57	23.38
	90° C**	29.61	27.84	25.62	22.87
90 Cycle	Room Temp.*	33.26	31.35	28.82	25.36
	60° C**	29.94	28.24	25.96	22.85
	90° C**	28.87	27.27	25.18	22.54

*Cured at 28 days, then kept into air

** Cured at 28 days, then exposed to temperature

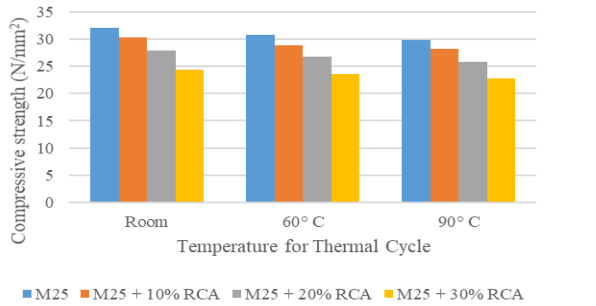

Fig. 5.Test results of compressive strength of M25 mix with different replacement of RCA with NCA at different temperature exposure and 28 thermal cycles.

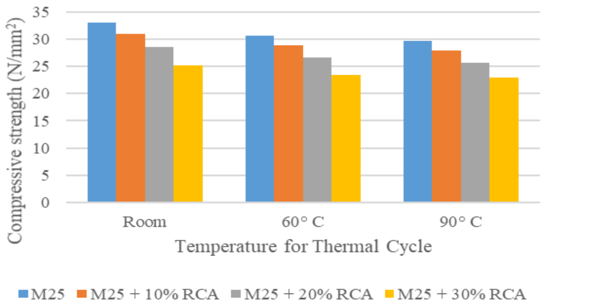

Fig. 6.Test results of compressive strength of M25 mix with different replacement of RCA with NCA at different temperature exposure and 60 thermal cycles.

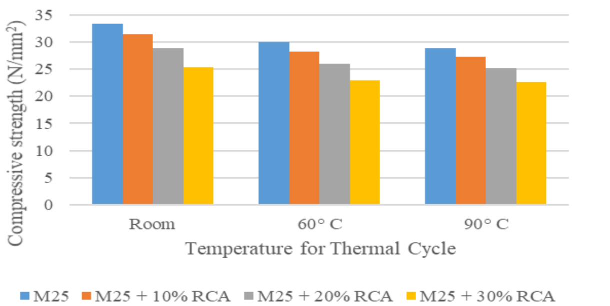

Fig. 7.Test results of compressive strength of M25 mix with different replacement of RCA with NCA at different temperature exposure and 90 thermal cycles.

From the above results it can be observed that the compressive strength of the M25 mixes with different replacement of RCA with NCA when exposed to the thermal cycles are decreasing with increase in numbers of thermal cycles i.e. from 28 cycles to 60 cycles to further 90 cycles as well as increase in temperature exposure from room temperature to 60° C and further up to 90° C. The minimum reduction in compressive strength is noted of 4.08% when exposed to 60 ° C temperature for 28 cycles whereas maximum reduction in compressive strength is noted of 12.87% when exposed to 90° C for 90 thermal cycles. But the result shows that the strength of M25 mix with 20% replacement of RCA with NCA is still acceptable after exposure to worst environmental thermal variation i.e. 90° C for maximum duration under investigation i.e. 90 thermal cycles.

B. Exposure to Chemical Environment

From the above results it can be clearly observed that, the maximum 20% of NCA can be replaced by RCA in both M20 & M25. Hence, here after the tests for examining the % loss of compressive strength and weight of concrete under exposure to chemical environment are performed for controlled mix and mixes with 20% replacement of RCA with NCA in both grade of concrete. Table 7, 8 and 9 represents the compressive strength of M20 & M25 mix with 20% replacement of RCA with NCA under exposure to $MgSO_4$, H_2SO_4 and HCl respectively and tested at 7, 28, 60 and 90 days.

Table- VII: Results of compressive strength due to various exposure with different duration for various mixes

Exposure Condition	Duration	Compressive Strength (N/mm^2)			
		M20	M20 with 20% RCA	M25	M25 with 20% RCA
Normal Water	7 days	17.67	14.2	21.77	18.33
	28 days	24.47	21.5	30.5	26.42
	60 days	26.42	23.68	32.53	28.27
	90 days	27.14	24.25	34.35	30.12
$MgSO_4$ solution	7 days	17.1	13.73	21.09	17.72
	28 days	23.19	20.31	28.91	25.02
	60 days	24.01	21.47	29.64	25.7
	90 days	23.85	21.26	30.26	26.48
H_2SO_4 solution	7 days	16.78	13.41	20.8	17.48
	28 days	22.84	20.05	28.6	24.69
	60 days	23.38	20.92	28.84	25.01
	90 days	22.52	20.09	28.6	25.04
HCl solution	7 days	17.3	13.84	21.31	17.88
	28 days	23.48	20.54	29.26	25.18
	60 days	24.82	22.15	30.55	26.46
	90 days	24.83	22.1	31.45	27.49

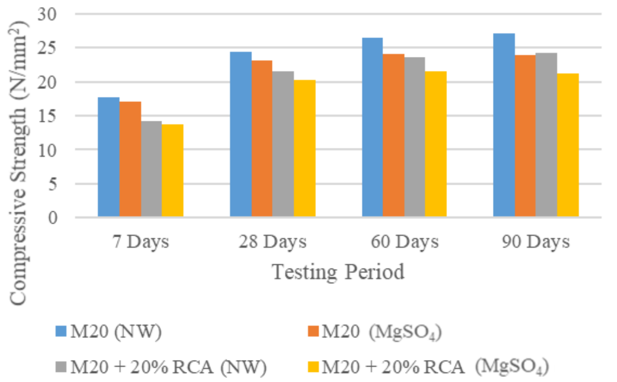

Fig. 8.Test results of Compressive Strength of M20 mix with 20% replacement of RCA with NCA under exposure of $MgSO_4$ for different duration.

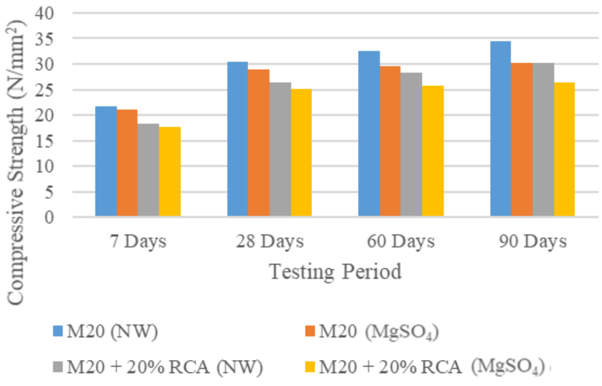

Fig. 9.Test results of Compressive Strength of M25 mix with 20% replacement of RCA with NCA under exposure of $MgSO_4$ for different duration.

From the above results it can be observed that compressive strength of M20 & M25 mix with 20% replacement of RCA with NCA under exposure to $MgSO_4$ is reducing with increase in duration of exposure. Also it can be noted that the minimum reduction in compressive strength is of 3.12% at 7 days and maximum reduction is of 12.34% at 90 days.

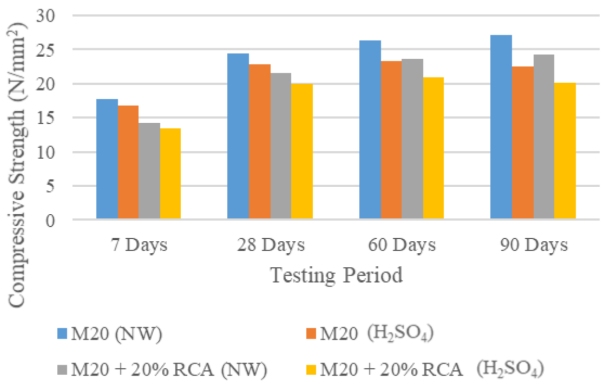

Fig. 10. Test results of Compressive Strength of M20 mix with 20% replacement of RCA with NCA under exposure of H_2SO_4 for different duration.

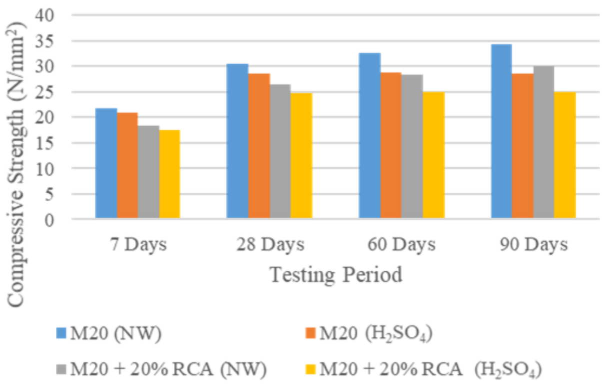

Fig. 11. Test results of Compressive Strength of M25 mix with 20% replacement of RCA with NCA under exposure of H_2SO_4 for different duration.

From the above results it can be observed that compressive strength of M20 & M25 mix with 20% replacement of RCA with NCA under exposure to H_2SO_4 is reducing with increase in duration of exposure. Also it can be noted that the minimum reduction in compressive strength is of 5.04% at 7 days and maximum reduction is of 17.15% at 90 days.

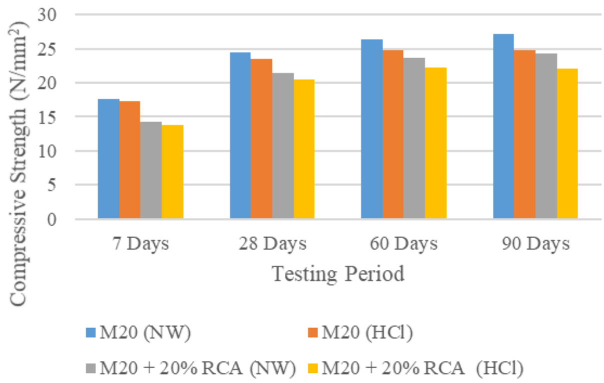

Fig. 12. Test results of Compressive Strength of M20 mix with 20% replacement of RCA with NCA under exposure of HCl for different duration.

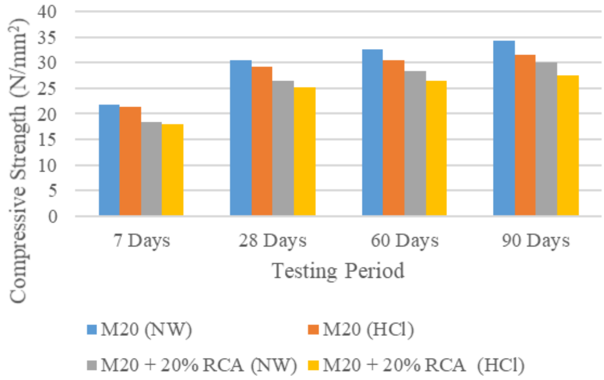

Fig. 13. Test results of Compressive Strength of M25 mix with 20% replacement of RCA with NCA under exposure of HCl for different duration.

From the above results it can be observed that compressive strength of M20 & M25 mix with 20% replacement of RCA with NCA under exposure to HCl is reducing with increase in duration of exposure.Also it can be noted that the minimum reduction in compressive strength is of 2.07% at 7 days and maximum reduction is of 8.86% at 90 days.

Table- VIII: Test results of weight loss due to various exposure with different duration for various mixes

Sr. No.	Duration	Weight of concrete cubes (kg)			
		Normal Water	$MgSO_4$	H_2SO_4	HCl
M20 Mix					
1	7 days	8.437	8.237	8.213	8.364
2	28 days	8.465	8.103	8.189	8.361
3	60 days	8.631	7.974	8.123	8.374
4	90 days	8.583	7.829	7.757	8.218
M20 + 20% RCA					
1	7 days	8.367	8.145	8.127	8.285
2	28 days	8.385	8.007	8.076	8.254
3	60 days	8.297	7.642	7.789	8.039
4	90 days	8.412	7.645	7.572	7.970
M25					
1	7 days	8.748	8.555	8.535	8.680
2	28 days	8.685	8.325	8.412	8.582

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3	60 days	8.816	8.210	8.354	8.609
4	90 days	8.788	8.133	8.000	8.475
M25 + 20% RCA					
1	7 days	8.692	8.493	8.443	8.615
2	28 days	8.614	8.220	8.285	8.472
3	60 days	8.645	8.042	8.116	8.397
4	90 days	8.597	7.939	7.719	8.237

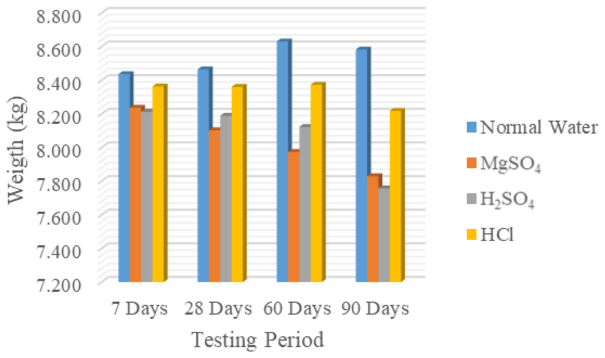

Fig. 14. Test results of weight loss due to various exposure with different duration for M20 mix.

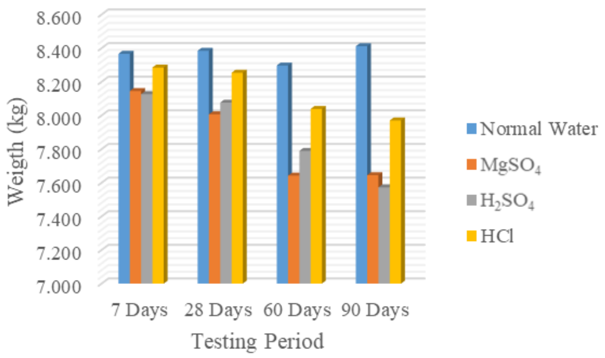

Fig. 15. Test results of weight loss due to various exposure with different duration for M20 with 20% replacement of RCA with NCA.

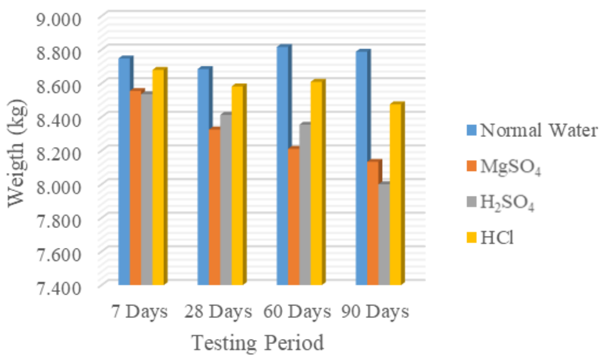

Fig. 16. Test results of weight loss due to various exposure with different duration for M25 mix.

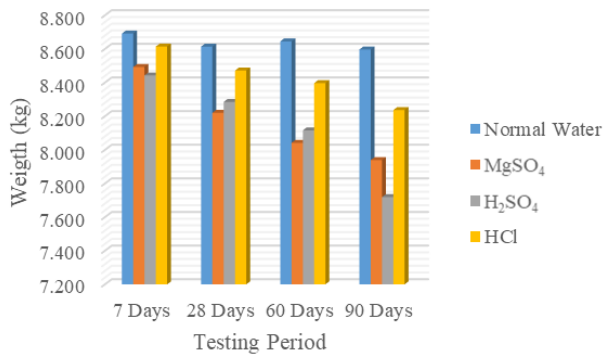

Fig. 17. Test results of weight loss due to various exposure with different duration for M25 with 20% replacement of RCA with NCA.

From the above results of weight loss in M20 and M25 with 20% replacement of RCA with NCA after exposure to MgSO4, H2SO4, and HCL solution at different duration, it can be observed that there is increasing trend of loss in weight to the concrete as duration of exposure increases. Also it can be noted that the loss in weight of concrete exposed to HCl solution is lower (i.e. from 0.87% at 7 days to 5.25% at 90 days) whereas somewhat severe when exposed to MgSO4 solution (i.e. 2.21% at 7 days to 9.12% at 90 days) and maximum for H2SO4 solution at early and later age (i.e. 2.43% at 7 days to 10.21% at 90 days).

VI. CONCLUSION

Based on above studies, following conclusions are drawn:

- Based on experimental work the replacement of RCA with NCA is 20% suggested.
- Reduction in compressive strength is observed when exposed to 60° C and 90° C for various numbers of cycles.
- The reduction in compressive strength is noted by 3.12% - 12.34% in concrete due to exposure to $MgSO_4$ for 7-90 days respectively.
- The reduction in compressive strength is noted by 5.04% - 17.15% in concrete due to exposure to H_2SO_4 for 7-90 days respectively.
- The reduction in compressive strength is noted by 2.07% - 8.86% in concrete due to exposure to HCl for 7-90 days respectively.
- The reduction in weight has been noted in concrete more severe with sequence of H_2SO_4 >$MgSO_4$ > HCl.

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