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Chemical Resistance of Nano Silica Added Concrete

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Abstract: This study investigated the effects of nano silica on acid and sulphate resistance of concrete. The changes in mass and compressive strength of the concrete specimens for different immersion periods were determined. It was observed that, M 30 grade concrete produced with 0 %, 1 %, 2 %, 3 % nano silica have shown mass loss of 11.24 %, 9.01 %, 5.10 % and 3.59 % respectively at 56 days of immersion in acid solution. M 40 grade concrete produced with 0 %, 1 %, 2 %, 3 % nano silica have shown mass loss of 9.36 %, 8.71 %, 4.98 % and 3.56 % respectively at 56 days of immersion in acid solution. M 30 grade concrete produced with 0 %, 1 %, 2 %, 3 % nano silica have shown mass loss of 2 %, 1.55 %, 1.26 % and 0.91 % respectively at 56 days of immersion in sulphate solution. M 40 grade concrete produced with 0 %, 1 %, 2 %, 3 % nano silica have shown mass loss of 1.63 %, 0.82 %, 0.43 % and 0.29 % respectively at 56 days of immersion in sulphate solution. Similarly, the reduction in compressive strength after immersion in acid and sulphate solution was observed with the addition of nano silica. Among the two chemical environments, sulfuric acid was found to be most dangerous for all concrete mixes. Concrete mixes produced with nano silica showed superior durability.

***Keywords:** Nano silica, Chemical resistance, Acid attack, Sulphate attack, Concrete.*

I. INTRODUCTION

For quite some time, concrete has been utilized for the construction of structural members such as foundation, column, slabs, retaining walls, and many other infrastructure projects. Apart from these projects, concrete is extensively getting used in water and sewage treatment plants, cement plants, power stations, fertilizer plants and other chemical industries. In any case, the industrial environment can be especially forceful and dangerous to ordinary concrete in specific circumstances, which may unfavorably influence the performance of the plant. In spite of the fact that concrete is very strong precisely, it is exceptionally vulnerable to physical and chemical attacks, which cause retrogression of concrete bringing about a decrease in its quality, strength and durability.

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The common forms of chemical attacks on concrete are an acid attack, alkali attack, sulphate attack, chloride attack, carbonation. The rate of attack relies upon attacking chemical, its concentration, the composition of concrete and its permeability. One approach to avert this deterioration is to keep away from the infiltration of chemicals in the concrete by making the structure progressively impermeable. Thus, the resistance of concrete to all these chemical attacks is influenced by materials used for the production of concrete and its production, and placement procedures. Right now, the utilization of pozzolanic materials as partial replacement to cement is generally acknowledged for reducing the permeability of concrete.

Many researchers studied the effect of nano silica on different properties of cement composites. It was shown that the addition of nano silica in concrete results in more uniform and compact microstructure [1]. It also makes the interfacial transition zone between aggregate and the binding paste denser [1], [2]. Nano silica in cement composites acts as a filler to improve its microstructure, and also promotes pozzolanic reaction [3], [4]. Addition of nano silica particles into cement paste significantly reduces calcium leaching thereby forming denser C-S-H gel [5]. Nano silica incorporated concrete showed higher compressive strength as compared to normal concrete [6]–[9]. From the existing literature, it is clear that nano silica does have the potential to produce chemical resistant concrete. This study evaluates the effects of the introduction of nano silica on the resistance of concrete against acid attack and sulphate attack.

II. MATERIALS AND METHODS

Ordinary Portland Cement (OPC) 53 grade and colloidal nano silica were employed for the preparation of concrete. The particle size of nano silica particles varied from 5 to 40 nm showing that it was much finer than cement. Continuously graded aggregate with a maximum particle size of 20 mm was used. Sand confirming to the requirements of Zone I of IS 383: 2016 was used. The processed fly ash conforming to the requirements of IS 3812:2013 was used as cement replacement material. Polycarboxylate based superplasticizer was used as workability admixture. Concrete of M 30 and M 40 grade has been made with and without nano silica so as to analyze the chemical resistance of concrete. Initially, M 30 and M 40 grade concrete mixes were designed as per IS 10262:2009 with w/c ratio of 0.34 and 0.29 respectively. The final concrete mix was settled to get the required compressive strength by doing few changes in initially designed mixes as per the site conditions and mixing equipment. The mix proportions for the two mixes are given in Table 1.

Cylindrical specimens of 105 mm diameter and 210 mm long were cast by using plastic moulds which were stripped after 24 hrs. All concrete specimens were cured in water for 28 days.

After 56 days, cylindrical specimens were immersed in two different solutions to know their resistance to acid and sulphate attacks. To check the acid, and sulphate resistance of concrete, concentrated sulphuric acid, and magnesium sulphate with 5 % concentrations were used. The decision to test medium solutions and their concentration depended on pragmatic usage of concrete as a construction material in sewage treatment plants, processing and chemical industry, and mining. The cylindrical specimens were submerged in plastic tubs so that all sides were in contact with the test medium.

Table 1: Composition of M 30 and M 40 grade concrete with and without nano silica

Mix No	Cement kg/m^3	Fly ash kg/m^3	Nano silica kg/m^3	20 mm aggregate kg/m^3	10 mm aggregate kg/m^3	Sand kg/m^3	Super plasticizer kg/m^3	Water kg/m^3
M 30 NS 0	286	153	0	731	433	837	4.30	148
M 30 NS 1	283.14	153	7.15	731	433	837	4.30	148
M 30 NS 2	280.28	153	14.30	731	433	837	4.30	148
M 30 NS 3	277.42	153	21.45	731	433	837	4.30	148
M 40 NS 0	385	162	0	730	392	760	5.30	156
M 40 NS 1	381.15	162	9.625	730	392	760	5.30	156
M 40 NS 2	377.30	162	19.250	730	392	760	5.30	156
M 40 NS 3	373.45	162	28.875	730	392	760	5.30	156

It was ensured that the solution must be at least 25 mm above the top surface of specimens. Already, researchers have utilized the pH value of the concentrated solution as a marker to check the aggressiveness of solution. But it is not a true indicator of concentration and hence test medium was replaced with fresh material after every 7 days. The specimens were examined after 1, 7, 14, 28, and 56 days of immersion to know the rate of attack. At the end of each test period, specimens were taken out from the plastic tub and cleaned by rinses in running cold tap water. After cleaning, specimens were allowed to dry for ½ hr before weighing in the digital balance. Finally, all the specimens were tested to know the compressive strength following IS 516:1959. Visual assessment of cylindrical specimens was done by using the scale which is shown in Table 2 [10].

Table 2: Visual assessment scale used

Scale Value	Degree of Attack
0	No attack
1	Very slight attack
2	Slight attack
3	Moderate attack
4	Severe attack
5	Very severe attack
6	Partial disintegration

III. RESULTS AND DISCUSSION

Visual assessment of cylindrical specimens after 1, 7, 14, 28, 56 days of immersion to test medium was done. The visual assessment of different specimens after 56 days of immersion in acid and sulphate solution is shown in Table 3.

Table 3: Rating as per visual examination of specimens

Mix	5 % H_2SO_4	5 % $MgSO_4$	Mix	5 % H_2SO_4	5 % $MgSO_4$
30/C	4-5	1-2	40/C	4	0-1
30/1	4-5	1-2	40/1	4	0-1
30/2	4-5	1-2	40/2	4	0-1
30/3	4-5	1-2	40/3	4	0-1

Visual examination of cylindrical specimens of M 30 and M 40 grade concrete exposed to sulphuric acid solution showed severe to very severe deterioration. Visual examination of cylindrical specimens of M 30 and M 40 grade concrete exposed to magnesium sulphate solution showed very slightly to slight deterioration. Figure 1 and Figure 2 shows the photographs of the M 30 and M 40 grade concrete specimens after 56 days of immersion in acid solution.

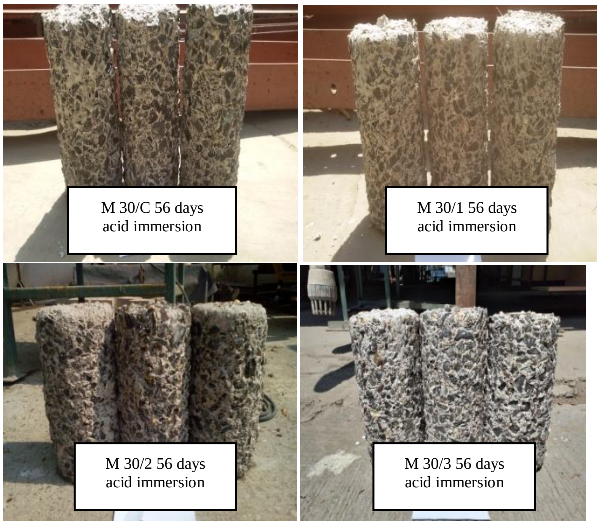

Figure 1: M 30 grade concrete specimens after 56 days in an acid immersion

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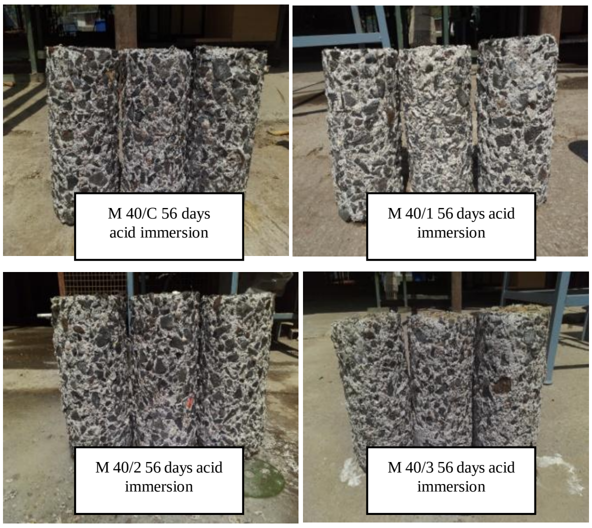

Figure 2: M 40 grade concrete specimens after 56 days in an acid immersion

Figure 3 and Figure 4 shows the average % drop in compressive strength of M 30 and M 40 grade concrete samples exposed to the sulphuric acid solution at different immersion periods.

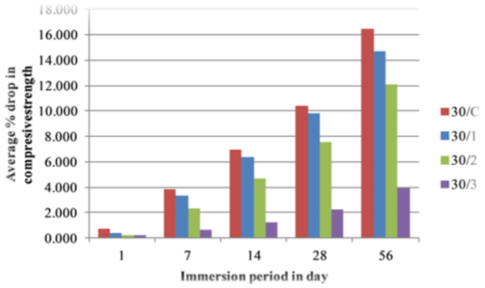

Figure 3: Average % drop in compressive strength for M 30 and grade concrete with immersion in acid solution at different period

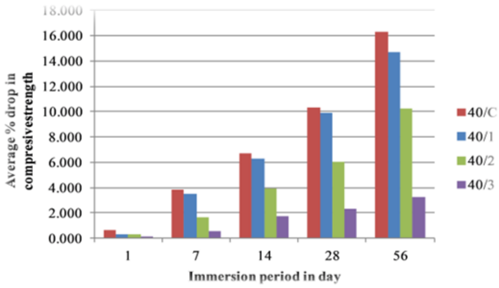

Figure 4: Average % drop in compressive strength for M 40 and grade concrete with immersion in acid solution at different period

After 56 days of immersion period, control sample concrete (concrete without nano silica) showed the maximum compressive strength loss percentage and concrete with 3 % nano silica showed minimum compressive strength loss percentage. At this age, % compressive strength loss in M 40 grade concrete is less as compared to % compressive strength loss in M 30 grade concrete produced with and without nano silica. For M 30 grade concrete produced with 0 %, 1 %, 2 %, and 3 % of nano silica, % loss in compressive strength at 56 days of acid exposure was found to be 16.44 %, 14.70 %, 12.11 % and 3.92 % respectively as compared to 56 days curing compressive strength. For M 40 grade concrete produced with 0 %, 1 %, 2 %, and 3 % of nano silica, % loss in compressive strength at 56 days of acid exposure was found to be 16.26 %, 14.70 %, 10.26 % and 3.26 % respectively as compared to 56 days curing compressive strength. An almost similar trend was noticed for M 40 grade concrete. It is important to note that for M 30 and M 40 grade concrete produced with and without nano silica, % loss in compressive strength continuously increases with acid solution exposure period. From the above discussions, it can be inferred that as nano silica content increases in concrete, % loss in compressive strength reduce and hence such a concrete shows excellent resistance to acid attack.

With increasing exposure duration to the acid solution, persistent weight decrease was seen for M 30 and M 40 grade concrete samples produced with and without nano silica. Figure 5 and Figure 6 shows the average % mass loss for concrete specimens immersed in an acid solution for 56 days.

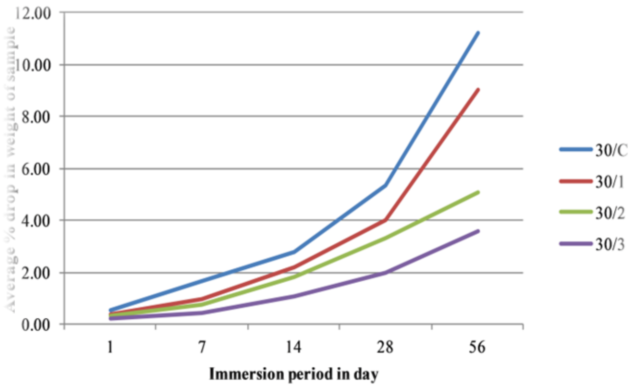

Figure 5: Average % drop in weight for M 30 grade concrete immersed in acid solution.

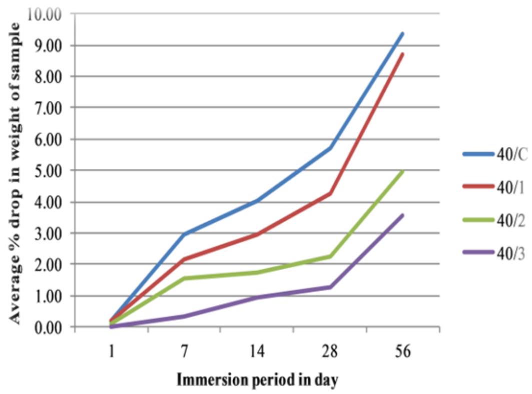

Figure 6: Average % drop in weight for M 40 grade concrete immersed in an acid solution.

M 30 grade concrete produced with 0 %, 1 %, 2 %, 3 % nano silica have shown mass loss of 11.24 %, 9.01 %, 5.10 % and 3.59 % respectively at 56 days of immersion in acid solution. M 40 grade concrete produced with 0 %, 1 %, 2 %, 3 % nano silica have shown mass loss of 9.36 %, 8.71 %, 4.98 % and 3.56 % respectively at 56 days of immersion in acid solution. At 56 days of immersion, M 30 and M 40 grade concrete produced without nano silica have shown highest mass loss (11.24 % and 9.36 % respectively) as compared to M 30 and M 40 grade concrete produced with 3 % of nano silica (3.59 % and 3.56 % respectively).

Concrete is an alkaline material and when it is attacked by sulphuric acid, the $Ca(OH)_2$ reacts with it and form ettringite. This formation slowly increases the volume of solid-phase causing gradual disintegration of concrete. The same has been seen as indicated by the mass loss of concrete. Acid resistance of concrete increased when nano silica % increased in concrete.

Figure 7 and Figure 8 shows the average % drop in compressive strength of M 30 and M 40 grade concrete samples exposed to the sulphate solution at different immersion periods. After 56 days of immersion period, control sample concrete (concrete without nano silica) showed the maximum compressive strength loss percentage and concrete with 3 % nano silica showed minimum compressive strength loss percentage. At this age, % compressive strength loss in M 40 grade concrete is less as compared to % compressive strength loss in M 30 grade concrete produced with and without nano silica.

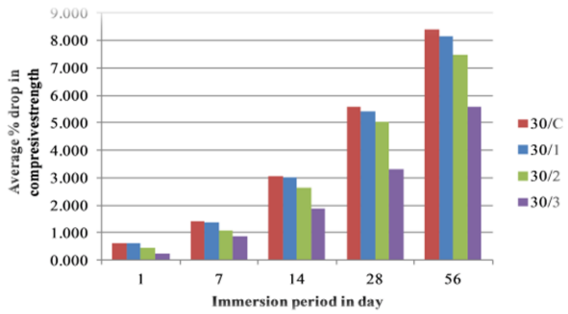

Figure 7: Average % drop in compressive strength for M 30 grade concrete with immersion in sulphate solution at a different period.

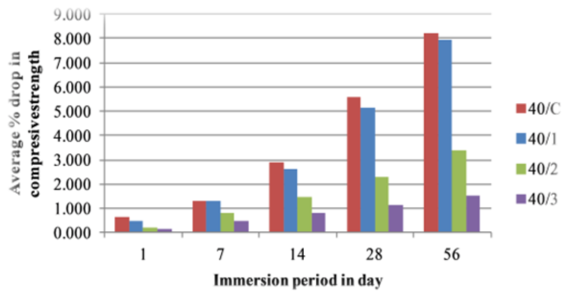

Figure 8: Average % drop in compressive strength for M 40 grade concrete with immersion in sulphate solution at a different period.

For M 30 grade concrete produced with 0 %, 1 %, 2 %, and 3 % of nano silica, % loss in compressive strength at 56 days of sulphate solution exposure was found to be 8.38 %, 8.14 %, 7.46 % and 5.59 % respectively as compared to 56 days curing compressive strength. For M 40 grade concrete produced with 0 %, 1 %, 2 %, and 3 % of nano silica, % loss in compressive strength at 56 days of acid exposure was found to be 8.23 %, 7.96 %, 3.40 % and 1.54 % respectively as compared to 56 days curing compressive strength. Here also, for M 30 and M 40 grade concrete produced with and without nano silica, % loss in compressive strength continuously increases with acid solution exposure period. From the above discussions, it can be inferred that as nano silica content increases in concrete, % loss in compressive strength reduce and hence such a concrete shows excellent resistance to sulphate attack.

Figure 9 and Figure 10 shows the average % mass loss for concrete specimens immersed in sulphate solution for 56 days. M 30 grade concrete produced with 0 %, 1 %, 2 %, 3 % nano silica have shown mass loss of 2 %, 1.55 %, 1.26 % and 0.91 % respectively at 56 days of immersion in sulphate solution. M 40 grade concrete produced with 0 %, 1 %, 2 %, 3 % nano silica have shown mass loss of 1.63 %, 0.82 %, 0.43 % and 0.29 % respectively at 56 days of immersion in sulphate solution.

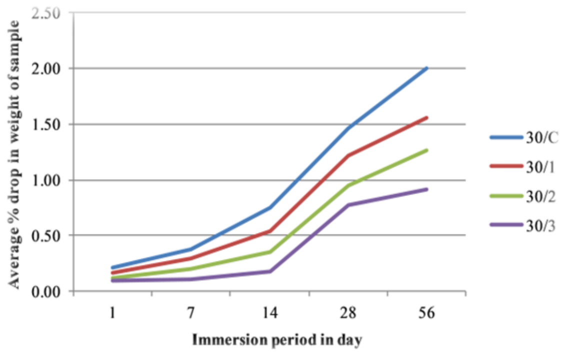

Figure 9: Average % drop in weight for M 30 grade concrete immersed in sulphate solution.

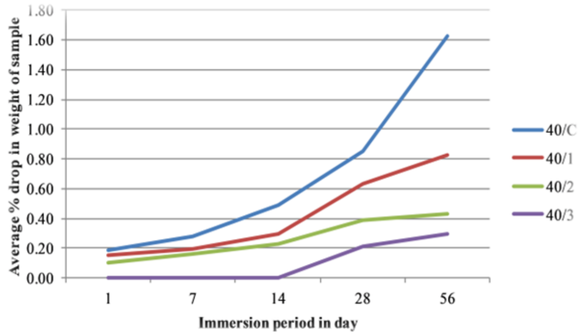

Figure 10: Average % drop in weight for M 40 grade concrete immersed in a sulphate solution.

IV. CONCLUSION

Based on the experimental study carried out to access the effect of acid and sulphate attack on concrete produced with and without nano silica, the following conclusions can be drawn

1) Both the control mix and nano silica added concrete was susceptible to sulphuric acid and magnesium sulphate attack. Visual inspection of the concrete specimens shows that the level of deterioration is different in different mixes.
2) For M 30 and M 40 grade concrete, control sample (concrete without nano silica) was more susceptible to sulphuric acid and magnesium sulphate attack and has shown maximum mass loss than nano silica added concrete mixes. The presence of nano silica in concrete lowers the detrimental effect of sulphuric acid and magnesium sulphate.

3) With the attack of sulphuric acid and magnesium sulphate, the compressive strength loss was minimum for M 30 and M 40 grade concrete mix in which cement was replaced with nano silica. The mass loss was minimum in the mix containing 3 % of nano silica as a replacement to cement.
4) Thus, nano silica added concrete is assessed to be structurally durable and can be used for construction projects located in acidic and sulphate environments.

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