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Study of Effect of Chemicals (Acid) Attack on Strength and Durability of Hardened Concrete

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Abstract - *In recent century, the use of concrete has increased tremendously in all types of construction varying from industrial, residential, water storage, infrastructure and so on.. This material is generally highly durable and can be made to possess superior mechanical properties, such as high compressive and flexural strengths. When it comes to resistance to different types of chemicals, the durability of concrete is quite influenced by its manufacturing process (curing methods, finishing, etc.) and the materials that are used. It is well known that concrete deteriorates when exposed to chemical attack under acidic environments. Concrete structures may be subjected to acidic environments under variety of conditions such as acid spills, acid rains, drainage sewers, chemical factories, hot springs, industrial effluents, etc. In above cases, the acid that affects concrete may be different. Also, the duration of attack may range from few seconds to years.*

In the present study, an attempt is made to study the effect on acid exposure on strength of concrete through experimentation. Concrete cubes of single mix will be prepared and exposed to different concentration of Hydrochloric, Sulfuric and Nitric acid for 30 and 60 days. A total of 87 cubes of size 150mm x 150mm x 150mm are cast with M20 grade of concrete as per mix design mentioned above. Following which the cubes are immersed (cured) in water for 28 days. Next, the cubes are immersed in and sprayed with 5% and 10% concentrated acids like Hydrochloric acid, Sulphuric acid and Nitric acid for 30 days and 60 days. The cured cubes are then tested under compressive testing machine to determine their compressive strength.

Key Words: Hydrochloric acid, Nitric acid, Sulphuric acid, Compressive strength.

1. INTRODUCTION

In recent century, the use of concrete has increased tremendously in all types of construction varying from industrial, residential, water storage, and infrastructure and so on. It is interesting to note that the word 'concrete' comes from the Latin word 'concretus' which means compact or condensed. This material is generally highly durable and can be made to possess superior mechanical properties, such as high compressive and flexural strengths. It is typically made out of Portland cement, supplementary cementitious material, water, aggregates, and depending on its application and the requirements of a specific project, different types of chemical and mineral additives may be used in its production.

When it comes to resistance to different types of chemicals, the durability of concrete is quite influenced by its manufacturing process (curing methods, finishing, etc.) and the materials that are used. It is well known that concrete deteriorates when exposed to chemical attack under acidic environments (Fig.1). Concrete structures may be subjected to acidic environments under variety of conditions such as acid spills, acid rains, drainage sewers, chemical factories, hot springs, industrial effluents, etc. In above cases, the acid that affects concrete may be different. Also, the duration of attack may range from few seconds to years.

Fig -1: Deterioration of Concrete Structure

The spectrum of aggressive acidic media is wide. Acidic attack usually originates from industrial processes, but it can even be due to urban activity. Even natural exposure conditions may cause acid attacks. Free acids in natural waters are rare. Exceptions are carbonic waters and sulfurous and sulfuric acids in peat waters. Soils may contain huminous acids. Several organic and inorganic acids may occur in shallow regions of sea-water as a consequence of bacteriological activity. Significant quantities of free acids in plants and factories may be found. In these cases, the concentration of acid, which comes in contact with concrete structures, may reach to high values.

In actual environment, the acid exposed on concrete is not a pure acid but a diluted or type of mixed acid as in Fig-2. Concrete is susceptible to acid because of its alkaline nature. The components of the cement paste break during contact with acids. Acids such as nitric acid, hydrochloric acid and acetic acid are very aggressive as their calcium salts are readily soluble and removed from attack front. The effect of acid is mainly during the transformation of concrete from fresh state to hardened state.

Fig -2: Flow of Mixed Acid on Concrete

1.1 Objectives

The following objectives are proposed to meet the goal,

1) An extensive literature survey pertaining to chemical attack of materials specifically acids on concrete.
2) Determination of effect of acids on compressive strength of concrete through experimentation.
3) To study the effect of acid attack on concrete by varying following things:-

- Duration of attack.
- Concentration of acids.
- Type of acid.
- Method of attack.

1.2 Need for Study of Acid attack on Concrete Structures

The above mentioned study becomes necessary in following cases

- Acid spills in Battery Storage factories on concrete floors.
- Sulfuric acid attacks in Sewer pipes.
- Industrial effluents flowing through concrete channels.
- Paint manufacturing industries.
- Chemical Laboratories.
- Food Processing Industries.
- Fertilizer manufacturing and Storage plants.
- Leather Tanning Industries, etc.

2. LITERATURE REVIEW

The literature survey is oriented around the study of effect of acid attack on performance of concrete, strength of concrete and durability of concrete.

K. Kawai et al [1], In this paper, Author has proposed a prediction method for the deterioration of concrete due to sulfuric acid. Concrete cylinder specimens were immersed in various concentrations of sulfuric acid. Also, sulfuric acid was circulated over the surface of concrete. It was found that the rate of concrete deterioration caused by sulfuric acid depended on pH value of acid solutions. Also, time of exposure of concrete to acid plays a crucial role in rate of deterioration. Paper also monitors depth of erosion.

Emmanuel K Etal [2], The authors have carried out an experimental study in which four different concrete mixes are subjected to same acid attack with different periods of immersion. The deterioration of concrete is studied using Scanning Electron Microscope. The authors concluded that the increase in volume and the decrease in density of concrete due to sulfuric acid- cement paste reaction would be larger the higher the acidity of the acid solution.

Shintaro Miyamoto et al [3] ,In this study, the authors have tried to establish a relation between deterioration of hardened concrete and sulfuric acid molar fraction and molar fraction of mixed acids. The tests were carried out on cylindrical specimens which were placed in clean acid free plastic containers with enough acid solution to immerse the exposed surfaces completely. The test duration was limited to 120 mins and the surfaces of the test pieces were scrubbed every 20, 40, 60 and 120 mins during the test. The tests confirmed that the deterioration rate depends on amount of dissolution of potlandite.

Beulah M., Prahallada M [4]. The authors carried out an experimental investigation to study the effect of replacement of cement by 20% Metakaolin on high performance concrete with hydrochloric acid attack. Concrete cubes and concrete cylinders were immersed in various concentrations of Hydrochloric acid. The compressive strength of cubes and cylinders decreases with increase in concentration of acid. Also, the study revealed that formation of compound Jennite may be responsible for decrease in strength of concrete.

3. EXPERIMENTATION & RESULTS

Concrete cube specimens of size 150 mm x 150 mm x 150 mm will be casted using materials and mix design stated above. A total of 87 cubes will be cast and will be cured in potable water for 28 days. After 28 days, the hardened concrete cubes will be immersed – completely and partially in different concentration of three specific acid solutions. Water cured specimens for 28 days will be taken out and allowed to dry under shade and then the same concrete specimens will

be kept immersed in 5% and 10% concentrated acid solutions for 30 and 60 days for observation. The details of experimentation are as follows:-

Table -1: Details of Experimentation

CASE 1 : Complete Immersion In Solution					
Curing Period	Type of Acid	% Acid	No of Cubes	% Acid	No of cubes
30 days	HCl	5 %	3	10%	3
	HNO_3		3		3
	H_2SO_4		3		3
60 days	HCl	5 %	3	10%	3
	HNO_3		3		3
	H_2SO_4		3		3

CASE 2 : Spraying of Solution on Cubes					
Curing Period	Type of Acid	% Acid	No of Cubes	% Acid	No of cubes
30 days	HCl	5 %	3	10%	3
	HNO_3		3		3
	H_2SO_4		3		3
60 days	HCl	5 %	3	10%	3
	HNO_3		3		3
	H_2SO_4		3		3

3.1 Observations

After removal of cubes from acid solutions, a slight change in the color of cubes is observed which can be noticed in the following images. Also the density of concrete is affected which can be confirmed from reduction in weight of the cubes.

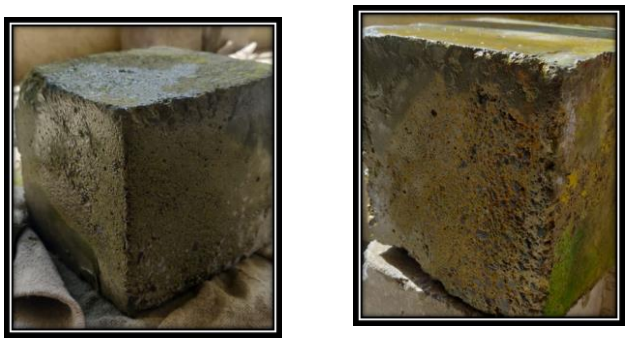
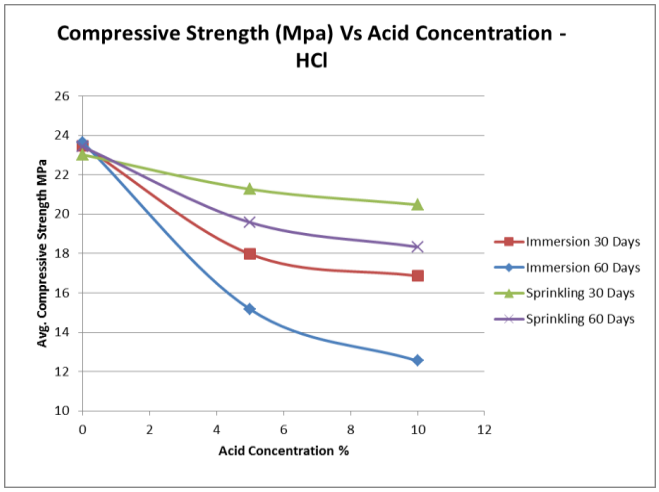


Fig -3: Cube immersed in 5% HCl (at left) for 30 days and Cube immersed in 10% HCl (at right) for 60 days.

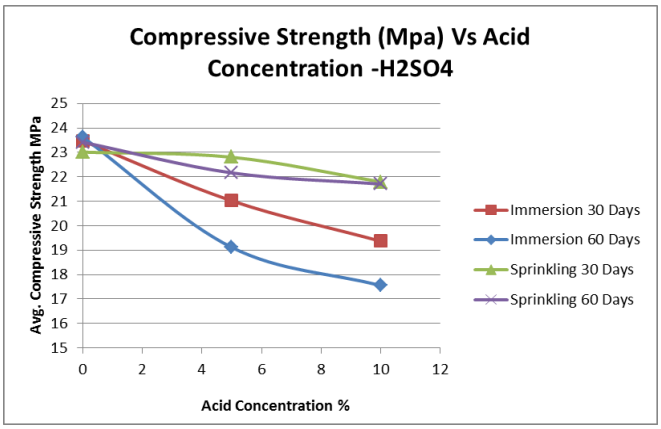
Fig -4: Cube immersed in 5% Nitric acid for 60 days.



Graph –1: Compressive Strength Vs Acid Concentration for HCl Acid

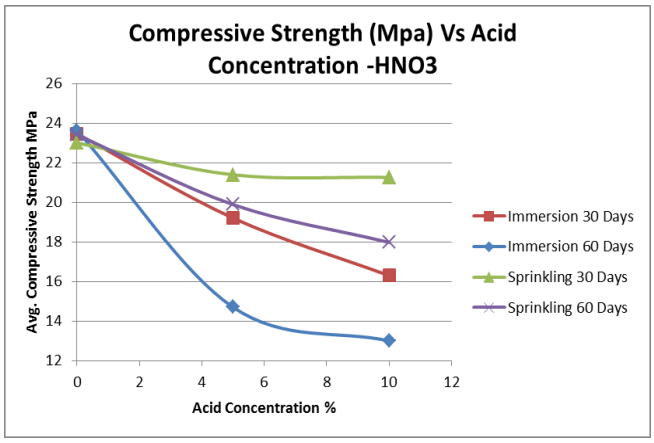
Lowest cube compressive strength is exhibited by the cubes immersed in 10 % concentration for 60 days which is around

12 MPa while sprinkling 5 % acid on the cube shows maximum cube compressive strength. Sprinkling acid on cubes have much less effecton compressive strength as compared to complete immersion of cubes in acidic environment.



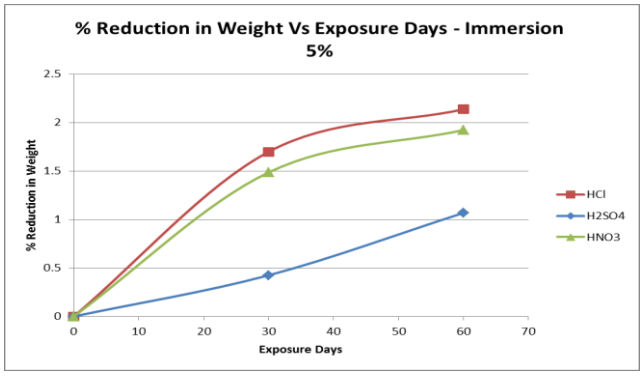
Graph –2: Compressive Strength Vs Acid Concentration for H_2SO_4 Acid

Incase of Sulphuric acid sprinkling on cubes has little or no effect on compressive strength. Lowest cube compressive strength is exhibited by the cubes immersed in 10 % concentration for 60 days which is around 18 MPa.



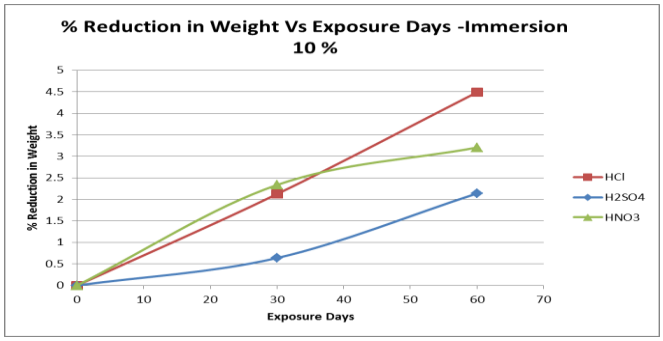
Graph –3: Compressive Strength Vs Acid Concentration for HNO_3 Acid

Curing cubes in 10 % Nitric acid by complete immersion for 60 days causes maximum effect on the compressive strength reducing it to 13 MPa. Sprinkling Nitric acid on cubes also has considerable effect unlike Hydrochloric and Sulphuric acid. Also as the exposure period increases, the effect on compressive strength also increases which is common observation for all the three types of acid.



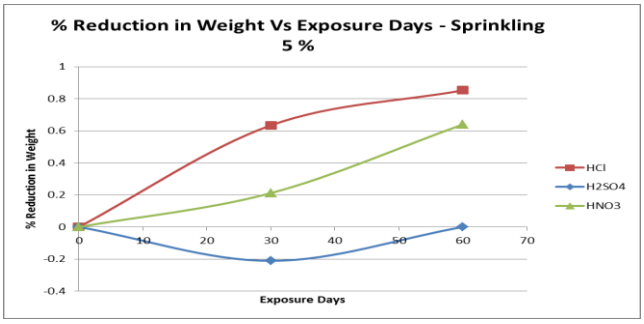
Graph –4: % Reduction in Weight Vs Exposure Time when cubes are immersed in 5% Acid

The above graph represent the % reduction in weight (mass) of concrete cubes for 5 % concentration of different acids when subjected to complete immersion for 30 days and 60 days. At higher exposure period of 60 days, maximum reduction of around 2.1% is observed when concrete cubes are immersed in Hydrochloric acid, also at lower exposure period of 30 days, maximum reduction of 1.7% is observed for Hydrochloric acid. As compared to HCl and HNO_3, Sulphuric acid has lower effect on weight of cubes.



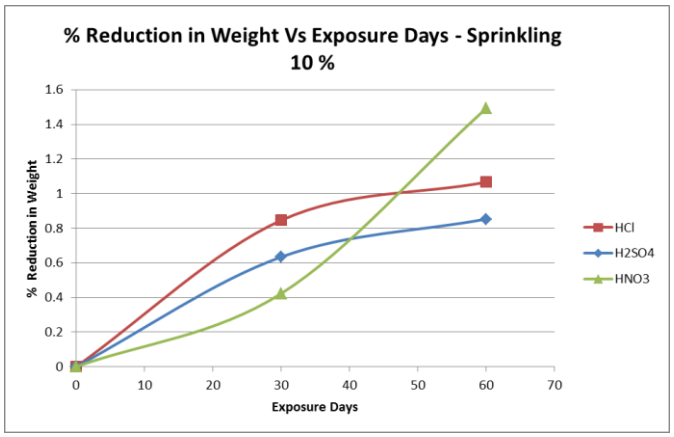
Graph – 5: % Reduction in Weight Vs Exposure Time when cubes are immersed in 10% Acid

At higher exposure period, mass reduction for HCl is more, whereas mass reduction is higheest for Nitric acid at lower exposure period.



Graph – 6: % Reduction in Weight Vs Exposure Time when cubes are sprinkled with 5% Acid

The above graph represent the % reduction in weight (mass) of concrete cubes for 5 % concentration of different acids when subjected to sprinkling for 30 days and 60 days. At higher exposure period of 60 days, maximum reduction of around 0.8 % is observed when concrete cubes are sprinkled with Hydrochloric acid, also at lower exposure period of 30 days, maximum reduction of 0.6 % is observed for Hydrochloric acid. Incase of Sulphuric acid, a reverse trend is observed where weight is increased at 30 days exposure period which is unusual.



Graph –7: % Reduction in Weight Vs Exposure Time when cubes are sprinkled with 10% Acid

The above graph represent the % reduction in weight (mass) of concrete cubes for 10 % concentration of different acids when subjected to sprinkling for 30 days and 60 days. At higher exposure period of 60 days, maximum reduction of around 1.5 % is observed when concrete cubes are sprinkled with Nitric acid, however at lower exposure period of 30 days, maximum reduction of 0.8 % is observed for Hydrochloric acid.

4. CONCLUSIONS

The extensive study on compressive strength and mass on cubes when subjected to different concentrations of various acids by different methods of exposure for different periods lead us to following conclusions:

1. Acidic curing environment has a negative effect on the compressive strength and density of the concrete.
2. Immersion of cubes leads to drastic reduction in compressive strength as compared to sprinkling for any type of acid. The reduction in compressive strength due to complete immersion is almost double than that for sprinkling of any particular acid (Hydrochloric or Sulphuric or Nitric acid) for particular exposure period (30 days or 60 days).
3. As the exposure period increases, the effect on strength and reduction in mass of the cubes also increases. This is applicable for both the methods of attacks – complete immersion and sprinkling, also for all the types of acids.
4. The rate of reduction of compressive strength and mass of the cubes is immense for lower concentration of acid (5%) which decreases as the concentration is raised from 5% to10%. Evidently, the compressive strength is lower at higher concentration of acid irrespective of the type of acid and method of attack.
5. The effect of Hydrochloric and Nitric acid on concrete is very much high as compared to Sulphuric acid. Complete immersion of the cubes in 10% HCl for 60 days causes maximum reduction in compressive strength to around 47%, which is 45% for Nitric acid and only 25% for Sulphuric acid.
6. In case of concrete structures which have to perform in acidic environment, particular attention should be given to the design, a higher factor of safety almost double for strength should be used and if feasible, special admixtures to mitigate the effect of acidic environment should be recommended.

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