STRENGTH EVALUATION OF CONCRETE IN CHEMICALLY AGGRESSIVE ENVIRONMENT

BY

O. M. Sadiq, A. J. Akpan
Department of Civil Engineering
Ahmadu Bello University, Zaria

and

A. O. Musa
Department of Civil Engineering,
Bayero University, Kano

ABSTRACT

This paper reports on investigation into the corrosive effect of Hydrochloric acid (HCl), Nitric acid (HNO3and Sulphuric acid (H2So4) on concrete. Concrete cubes of three grades - 30, 40, 50 were cast and cured in a moist environment for 28 days. They thereafter immersed in the three distinct acid media (HCl, HNo3 and H2So4) of varied concentrations. The ages of curing in the aggessive media were 28, 56 and 84 days. Results show a gradual reduction in the compresive strength of the concrete for all cases. We also discovered that the degree of loss in compressive strength depends not only on the duration of immersion period, but specifically on the type of acid and its concentration. Sulphuric acid showed a greater degree of aggressiveness on concrete than either the Hydrochloric or Nitric acids.

1.0 INTRODUCTION

Many factors exist that influence the quality of concrete. They include the type of cement, the type and nature of aggregates and the quality of water; the batching, mixing, compaction and curing procedures adopted. Others include the presence of deleterious materials such as the presence of organic matters in the aggregates and the presence of aggressive chemicals in areas where the concrete is serving.

Chemical aggression has been known to produce devastating effects on concrete [2,3]. Two major sources of chemical aggression can readily be identified: i) the natural sources such as sea-water and soils rich in sulphates, nitrates, chlorides and carbonates;
ii) the artificial sources such as chemical manufacturing industries, sales and usage of industrial chemicals and catchment areas for effluents from rearing units.

Chloride, Nitrates and Sulphates [and many other salts] when present in the environment of the concrete could be individually and severally responsible for the reduction in the compressive strength of the concrete as a result of their adverse effects on the quality of the concrete {3,8,9}.

Mohan and Rai (6) have observed that the overall resistance of concrete against crystalization pressure and crack formation depends on the availability of water and environmental factors. This observation was supported by Biczak (5) who observed that the deteriorating action does not ensue, unless the destructive agent has access to concrete in the form of a wet gas, a fluid in dissolved form, but first of all in an ionised condition.

The action of sulphuric acid has been described to be of two types (4): Together with calcium hydroxide of cement it forms the poorly soluble gypsum. Gypsum thus produced tends initially to seal the pores and to offer certain degree of protection. In the case of continuous exposure to sulphuric acid, concrete is destroyed by the expansion of gypsum.

Hydrochloric acid on the other hand, decomposes the calcium hydroxide of cement into calcium chloride which being readily soluble in water, is either washed from concrete or crystallizes. Therefore, weak solutions are already detrimental. Hydrochloric acid is extremely corrosive to clinker minerals as well, so

that effective protection must be provided for concrete against hydrochloric acid attack.

Nitric acid occurs in chemical plants producing explosives, artificial manure and similar products. Although, Nitric acid is not as strong an acid as sulphuric acid, its effect on concrete even at moderate expousre is very destructive, since it transforms the calcium hydroxide of concrete into the highly soluble calcium Nitrate. The extreme destructive power of Nitric acid is demonstrated by the fact that even highly diluted solutions may result in extensive deterioration [1,4,10].

Although the main aggressive agent on concrete is the acid formed from the reaction of salts with water, many researchers have concentrated their efforts on the investigation of the chemical effects on concrete using the salts of nitrates, chlorides and sulphates (3). The percentage of the salts used did not really give a clear percentage of the attacking agent and the acid formed, since the formation of the acid from the salt depends on many other environmental factors. In this paper, we endeavour to investigate the effects of chemical attacks on concrete by direct use of the acids and also to bring into play the use of sufficiently varying concentrations as well using more realistic subjection periods.

2.0 EXPERIMENTAL PROCEDURE

2.1 Specimen Preparation

The three grades of concrete, 30, 40 and 50, used in this investigation were determined through the process of a normal mix design for concrete. Concrete materials were batched by weight and mixing was done using a laboratory mixer. The specimens were cast in 150mm cube moulds. Compaction was achieved mechanically to a standard density of 2435kg/m^2 that was used during the mix design. The concrete cubes were cured in a moist environment for 28 days.

At the end of 28 days of curing in a most environment, six concrete cubes were randomly selected from each of the grades of concrete and crushed using a standard compressive strength testing machine. The average crushing load of the six cubes from each of the grades was taken as the 28 day compressive strength [Tables 1 - 3].

2.2 Preparation of aggressive Media

Acid/water proportions required for the various percentages of concentrations of the acids was determined by calculations. Based on the results of the calculations, the acids and water were mixed volumetrically to achieve the desired percentages of concentrations of the acids. 5%, 10%, and 20% concentrations of Hydrochloric acid, Nitric acid and sulphuric acid were thus prepared.

2.3 Testing Procedure

Three different durations of immersion periods of 28 days, 56 days and 84 days were taken. At the end of the immersion periods, three concrete cubes for each of the grades were removed from each of the four distinct concentrations of the three acids. They were thoroughly rinsed in clean tap water and air-dried in the laboratory for 48 - 72 hours. They were then tested in a compressive strength testing machine and the average crushing load for each of the three cubes of each of the grades of concrete was taken as the retained or new compressive strength of the cubes immersed in any particular concentration of any of the acids of the immersion period under consideration.

At every stage of testing, three control cubes of zero percent concentration (i.e. immersed in water) were tested for each of the grades of concrete. The average compressive strength for the three cubes for each of the grades was taken to represent the new compressive strength of that grade of concrete.

3.0 OBSERVATIONS

Exothermic reactions were observed on mixing the acid with water. The heat production in the case of sulphuric acid was noticed to be higher than that of Hydrochloric acid or Nitric acid. Immediately the concrete cubes were introduced into the mixture, a vigorous reaction in hydrochloric acid and Nitric acid involving effervescence and boiling effects were produced. This vigorous reaction was not noticed in the case of sulphuric acid at the introduction of concrete cube specimens. What could, however, be noticed immediately was the instant extrusion of cement paste-like particles considered to be hydration products. The vigorous reaction in HCl and HNo_3 died down gradually. The mixture and the concrete cubes were turned green and brown in the cases of HCl and HNo_3 respectively. The intensity of the colours increased with age. In the case of $H_2 So_4$ the extrusion of the hydration products continued. The mixture remained colourless while the concrete cubes were turned white.

In the cases of HCl and HNo_3 the concrete cubes remained intact on the surfaces but felt very soft to the touch and the mortar surround could easily be removed with the slightest rubbing force. This was

not so in the case of H_2So_4, where the mortar surround was completely removed and deposited at the bottom of the plastic bowls, as white gelatinous precipitation, leaving the free sides of the concrete cubes exposed of coarse aggregates. Some of the extruded particles through the top of the cubes also settled there in the form of white gelatinous substance

The rate at which the volume of the mixture involving sulphuric acid decreases was faster than that of Nitric or hydrochloric acids. It follows therefore that the rate at which the mixture involving sulphuric acid permeates into the concrete is faster than that of HCl or HNo_3. The mixture involving hydrochlloric acid was observed to be covered with greenish foam and a greenish grease-like deposit on top of the cubes. That of Nitric acid was observed to be covered with a brownish foam and a brownish grease-like substance deposited on top of the cubes. The mixture, in the case of sulphuric acid was clear of foam.

4.0 RESULTS, ANALYSIS DISCUSSIONS

Figs. 1, 2 and 3 show the graphs of the compressive strength of the concrete at various concentrations of the three acids. We present the cases for the grades 30, 40 and 50 respectively at 56 days, 84 days and 28 days of immersion periods. Figs 4, 5 and 6 on the other hand, are the graphs of the compressive strength of the concrete at various immersion periods. Analyses of the graphs shows that the strength of concrete for all the grades, decreased with increase in percentage concentration of the acids. Strength was also found to decrease with increase in immersion periods. Before the test, there was no clear distinction as regards which is more aggessive between hydrochloric acid and nitric acid. But it is very clear from the graphs that sulphuric acid is most aggressive of the three acids.

Table I presents the results of the experiment for the grade 30 concrete in hydrochloric acid at various acid concentrations and duration of immersion, while tables 2 and 3 are the experimental results respectively for the grade 40 concrete in nitric acid and grade 50 concrete in sulphuric acid. From the tables, it can be observed that concrete cubes immersed in water increased steadily in compressive strength from 35.35N/mm^2 at the end of 84 days of immersion for grade 30 concrete, and from 50.18N/mm^2 to 62.18N/mm^2 at the end of 84 days of immersion for grade 50 concrete, while concrete cubes immersed in the acid decreased steadily in compressive strength. The decrease in compressive strength is observed to be accompanied with increase in concentrations of the acids and the duration of immersion periods. Analyses jof the tables shows that concentrations of 5% and above of sulphuric acid reduced the compressive strength of concrete grades 30, 40 and 50 to an unsafe value within 28 days of immersion. For the three concrete grades and at any equivalent immersion period, it takes 10% or more concentration by volume of either the nitric acid or hydrochloric acid to reduce the compreessive strength to an unsafe value. However, in less than 56 days of immersion, 5% concentration of either nitric acid or hydrochloric acid is enough to cause a significant damage to concrete. Sulphuric acid is thus shown to be more aggressive than either the nitric acid or the hyudrochloric acid.

5.0 CONCLUSIONS

The following conclusions can be made from the present experimental investigvation:

1. Investigation into the corrosive effects of hydrochloric, nitric and sulphuric acids has been conducted and reported.
2. Gradual reduction in compressive strength of concrete was observed.
3. The degree of reduction in compressive strength of concrete was found to depend on the type of acid, its concentration and the duration of the concrete in the aggressive medium.
4. Sulphuric acid is found to be more aggres sive than either Hydrochloric or Nitric acids, given the same concentration and immersion period.
5. Sulphuric acid attack on concrete can be recognised by a whitish colouration on the concrete surface and complete exposure of the coarse aggregate as a result of the re moval of cement mortar content Nitric acid attack can be visually observed by a soft con crete surface and a characteristic brownish colouration, while attack due to Hydrochloric acid can be recognised by characteristic greenish colouration.
6. The grade of concrete did not seem to have had appreciable influence on the resistance of the concrete to chemical aggression. This agrees with the conclusion of some previous researchers.

6.0 BIBLIOGRAPHY

1 Adekoya, A. D. (1990): "Corrosion in con

struction industry; corrosion in mining, iron, steel, water-treatment and power generating industries". Nigeria Corrosion Association, pp. 48 - 56

2. Beeby, A. W. 91978) "Concrete in the oceans, cracking and corrosion". Technical report No. 1 Cement and concrete association, pp. 1 - 75.

3. Fookes, P. G.; West, R., Mettam, J. D. and Berry, J. G. "Concrete deterioration and corrosion of steel in marine environments". Cement and Concrete Association, pp. 99 - 116.

4. George, R. B. and Beverly, P. Phipps (1979): "Corrosion Chemistry" - American Chemical Society Symposium Series, N89, Washington D.C.

5. Imre Biczak (1967): "Concret corrosion and concrete protection". Chemical Publishing Co. Inc. New York, N.Y.

6. Mohan an Rai (1980): "Deterioration of concrete in fertilizer factories". Durability of Building materials and components. ASTM ST/P 691, American Society for testing and materials, pp. 385 - 396.

7. Poole, A. B. (1983): "Alkalis in concrete: A matter of education for Engineers and Research Scientists". 6th Intern. Conference Alkalis in concrete, research and practice, G. M. Idorn and Rostan edition.

8. Simm, J. D. and Fookes, P. G (1989): "Improving reinforced concrete durability in the Middle East during the period 1960 - 1985". Analytical Review, Proceedings. Institution of Civil Engineers. Part 1, 86, pp. 333 - 358.

9. Soroka, I. and Setter, N. (1980): "Effect of mineral fillers on sulphate resistance of Portland Cement mortars". Durability of Building materials and components, ASTM ATP 691, P.J. Sereda and G. G. Litran eds., pp. 326 - 335. 691. P. J. Sereda amd G. G. Litran eds., pp. 326 - 335.

10. Structural Engineering Group 9366 and 9403 Discussion. Proc. Institute of Civil Engineering, Part 1, Feb. 1990, N. 86.

Table 1: Grade 30 concrete in Hyrochloric Acid [HCl]
Original Strength = 35.35 N/mm^2.

Immersion Period [days]	Acid Concentration [%]	New Strength [N/mm^2]	Percentage Change in Strength [%]
28	0	44.15	+3.69
	5	30.67	-27.97
	10	26.67	-37.36
	15	23.37	-47.46
	20	18.37	-56.86
56	0	46.67	+9.61
	5	27.56	-35.27
	10	24.15	-43.28
	15	19.85	-53.38
	20	17.33	-59.30
84	0	51.70	+21.42
	5	25.04	-41.91
	10	21.33	-49.91
	15	17.33	-59.30
	20	14.08	-66.93

Table 2: Grade 40 Concrete in Nitric Acid [HNO_3]
Original Strength = 42.58 N/mm^2

Immersion Period [days]	Acid Concentration [%]	New Strength [N/mm^2]	Percentage Change in Strength [%]
28	0	44.15	+3.69
	5	30.67	-27.97
	10	26.67	-37.36
	15	23.67	-47.46
	20	18.37	-56.86
56	0	46.67	+9.61
	5	27.56	-35.27
	10	24.15	-43.28
	15	19.85	53.38
	20	17.33	-59.30
84	0	51.70	+21.42
	5	25.04	-41.19
	10	21.33	-49.91
	15	17.33	-59.30
	20	14.08	-66.93

Table 3: Grade 50 Concrete in Sulphuric Acid [H_2So_4]
Original strength = 50.18 N/mm^2

Immersion Period [days]	Acid Concentration [%]	New Strength [N/mm^2]	Percentage Change in Strength [%]
28	0	53.85	+7.31
	5	31.40	-37.43
	10	29.04	-42.13
	15	27.00	-46.19
	20	24.15	-51.87
56	0	59.25	+18.07
	5	28.30	-43.60
	10	26.22	-47.75
	15	23.55	-53.07
	20	19.85	-60.44
84	0	62.81	+25.17
	5	24.59	-51.00
	10	19.85	-60.44
	15	14.82	-70.47
	20	12.15	-75.79

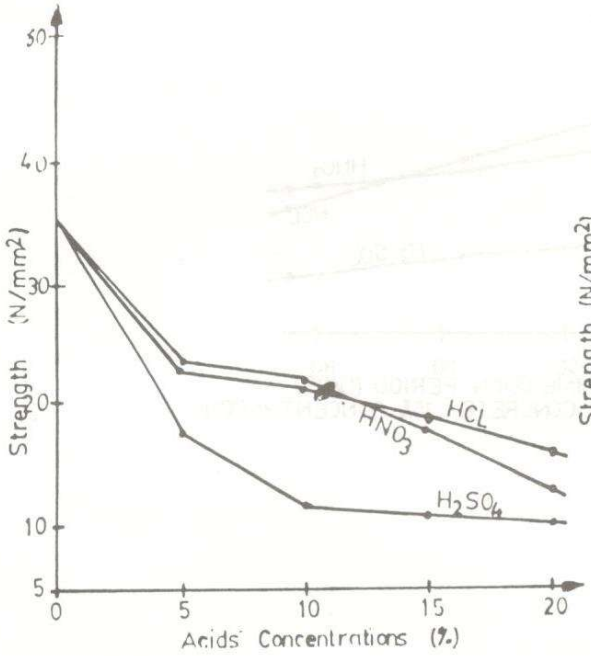


FIG 1 GRADE 30 CONCRETE AT 56 DAYS OF IMMERSION

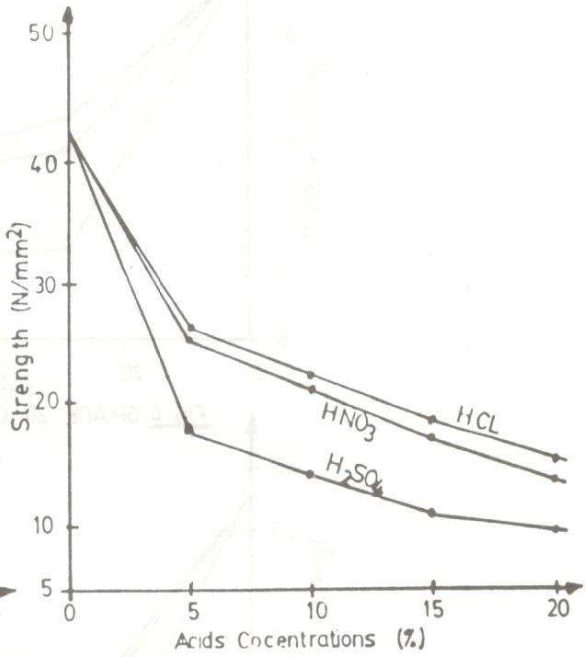


FIG 2 GRADE 40 CONCRETE AT 84 DAYS IMMERSION.

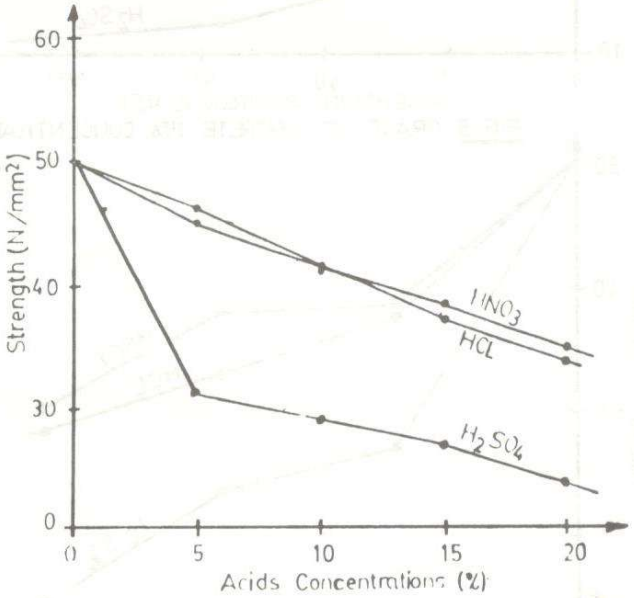


FIG 3 GRADF 50 CONCRETE AT 28 DAYS OF IMMERSION

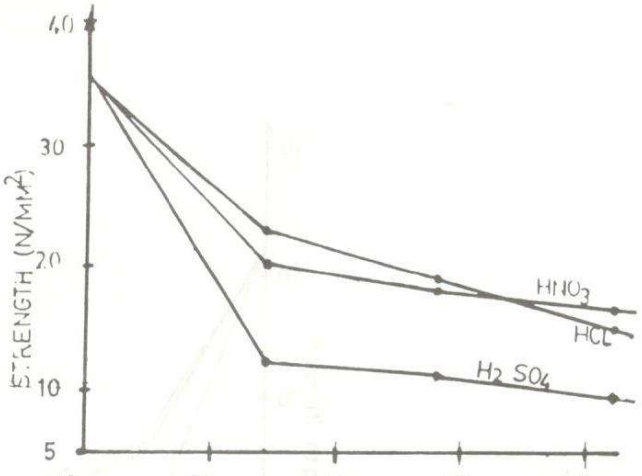


FIG 4 GRADE 30 CONCRETE 15% CONCENTRATION

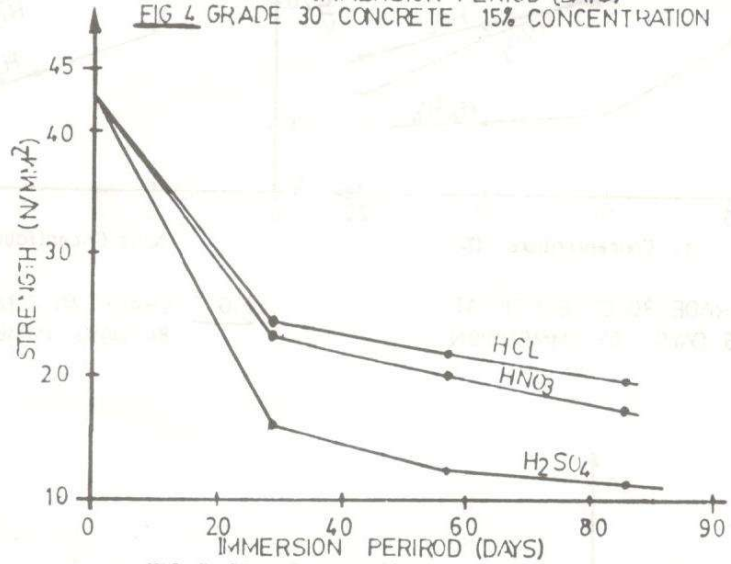


FIG 5 GRADE 40 CONCRETE 15% CONCENTRATION

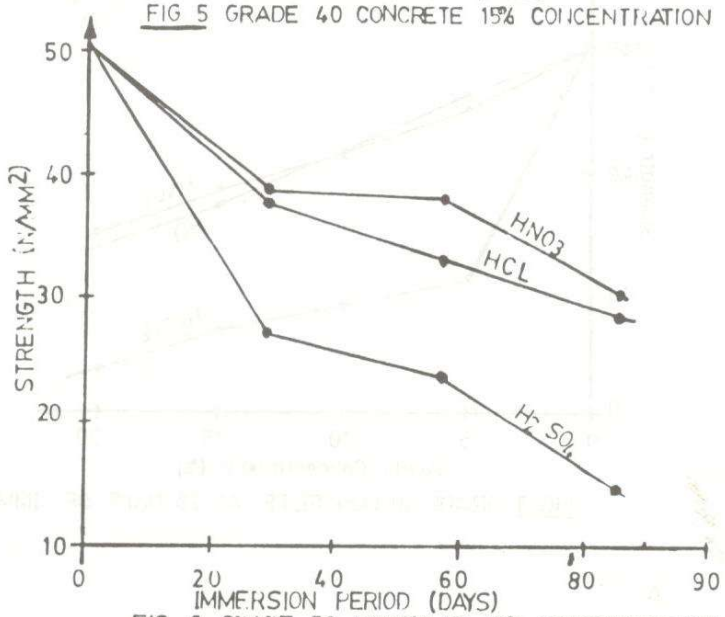


FIG 6 GRADE 50 CONCRETE 15% CONCENTRATION