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Effect of Acidic Curing Environment on the Strength and Durability of Concrete

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Abstract

This paper investigates the effect of acidic curing environment on the strength and durability of concrete cured in water containing various percentages of Nitric acid. 60 number grade M20 concrete cubes of sizes 150mm x 150mm x 150mm, 18 number 150mm x 150 mm x 450mm concrete beams and 18 number 150mm x 300mm concrete cylinders are casted for compressive, flexural and tensile strength tests respectively, using a water cement ratio of 0.69 and mix ratio of 1:3:4, and cured in water containing 0, 5, 10, 15, and 20% of nitric acid by volume of water for 7, 14, 28 and 60 days. The result shows that the compressive strength of the cubes at all percentage concentration of the acid decreases with curing age. Also, the percentage decrease in strength increases with both percentage of acid and curing age. Thus the rate of deterioration is highest at 60 days curing in 20% acid concentration (47.8%). Tensile and Flexural strength tests at 28 days curing revealed that the strength decreased with increase in percentage concentration of acid, with a decrease of 22% at 20% concentration of acid in the case of flexural strength and 41% in the case of tensile strength. For a particular curing age, both the strength and mass of Concrete decrease with an increase in the concentration of acid. Also, for a particular concentration of acid, the strength and weight of concrete decrease with curing age. A near linear relationship exists between weight loss and loss in compressive strength. It can therefore be concluded that deterioration of concrete cured in acidic medium increases with concentration of acid and curing age. The durability decreases faster as the concrete ages. Thus, concrete structures cannot stand the test of time in acidic environment unless special cements are used.

Keywords: Acidic curing environment, Compressive Strength, Flexural Strength, Tensile Strength, Durability and Weight loss

1 Introduction

It is a known fact that the concrete is the most widely used construction material and that the curing environment has a profound effect on its strength development as well as its durability (Rao et al 2004). Concrete therefore should be cured in an environment that is devoid of factors that will negatively affect the rate of strength development. However, while this ideal situation can always be simulated in the laboratory, these ideal conditions are not always met in the real world situation. Concrete works could be in constant contact with chemicals (as can be seen in the case of acid rains, chemical factories or acidic soils, etc.) that negate the durability of structures in such environment. One of such substance that could affect the rate of strength gain in concrete is acid attacks. These can damage the foundation of structures and thus could lead to the failure of the entire structure (Tyagher, 2013).

Different researchers are in agreement on the fact that acids have a profound effect on the strength and other properties of concrete (Zivica and Bajza (2001), Asavapisit 2002, Maluk 2013, Turkel et al 2007). At the base of the acid attack, according to Tyagher (2013) is the attack on the calcium hydroxide (free lime) formed during the hydration of cement as represented by equation 1

$2HX + Ca(OH)_2 \rightarrow Ca_2X + 2H_2O$ -- (1)

The factors that affect the rate of concrete decomposition when subjected to acidic attacks include porosity of the cement paste, acidic concentration, solubility of the acid, fluid transport through the concrete, water movement over the surface of the concrete, concrete quality, types of cement and aggregate (Reddy et al. 2012, Kolapo and Opeyemi 2012, Mtallib 2002, Rao et al 2004). The Acids that have the greatest effect on concrete are H_2SO_4 and HNO_3. Though H_2SO_4 is a stronger acid, at brief exposure HNO_3 has a more detrimental effect as it transform $Ca(OH)_2$ to a highly soluble nitrate salt resulting in greater deterioration as shown by equation (2)

$2HNO_3 + Ca(OH)_2 \rightarrow Ca(NO_3)_2 + 2H_2O$ (Calcium Nitrate) ------------------------------------ (2)

As the concentration of acid increases, one would expect the attack to be more severe. Thus, though acid attack occurs at PH below 6.5, the attack is more severe at PH values below 5.5. This, according to Ali and Frantisek (2000), is because OPC is a highly alkaline material (PH above 12.5) and thus as the PH decreases the equilibrium of the cement matrix is disturbed and hydration compounds are easily altered by hydrolytic decomposition. Thus apart from portlandite that is decomposed by acidic solution as shown in equation 2, the products of hydration are also attacked as shown in equation (3)

$CH + HA \rightarrow CA + Si(OH)_4 + H_2O$ (Chemist notation) Or

$xCaO.ySiO_2.nH_2O + 2xHA \rightarrow xCaA_2 + ySi(OH)_4 + (x + n - 2y)H_2O$ -----------------------------(3)

This research work attempts to examine the rate of strength loss as well as durability of concrete when cured in acidic environment.

2. MATERIALS AND METHODOLOGY

2.1 Materials

The materials used in this research include fine aggregate, coarse aggregate, nitric acid, Ordinary Portland cement and water.

The fine and coarse aggregate was river sand and gravel respectively, obtained from River Benue in Makurdi Benue State.

The cement used was a 42.5 grade OPC manufacture by Dangote cement industries plc Gboko plant.

The acid used in this research was nitric acid and it was mixed in the curing water at 0, 5, 10, 15 and 20% concentrations.

The water used was obtained from the water treatment plant of the University of Agriculture makrdi.

2.2 Experimental Program

The experimental program for this research work is divided into two parts. In the first part, 60 number grade M20 concrete cubes of sizes 150mm x 150mm x 150mm, 18 number 150mm x 150 mm x 450mm concrete beams and 18 number 150mm x 300mm concrete cylinders for compressive, flexural and tensile strength tests respectively are casted using a water cement ratio of 0.69 and mix ratio of 1:3:4. The cubes, beams and cylinders were de-molded after 24 hours and cured for 7, 14, 28 and 60 days, the curing water having been mixed with 0, 5, 10, 15, and 20% of nitric acid by volume respectively. In the second part, for each percentage of acid 12 cubes, 3 cylinders and 3 beams were cured in the water. And for each of the curing conditions above, 3 cubes each were tested for compressive strength after 7, 14, 28 and 60 days and 3 beams and 3 cylinders were tested for tensile and flexural strength respectively after 28 days of curing. The mix design was as per ACI 211.1-1991 and grade M20 concrete was adopted.

3 RESULTS AND DISCUSSIONS

3.1 Preliminary test on OPC and Aggregates

The test carried out on OPC included setting times, specific gravity and standard consistency.

These tests were carried out in accordance with provisions of ASTM C403, ASTM C127 and ASTM C91 respectively. Also oxide composition test was carried out at the Geological research institute, Kaduna using XRD analysis. The results presented in Table 1. The result shows that the cement used met the specification of ACI E1 and BS12 for a class II Portland cement.

Preliminary test on fine and coarse aggregates included moisture content, specific gravity and particle size determination in accordance with the provisions n ASTM C70, ASTM C136 and C117 respectively. The results are presented in table 2.0 and Fig 1A and B respectively. Comparing with the provision of BS 822 shows that the gradation of the particle falls within the zone 2; which means that it is suitable for construction purposes.

3.2 Effect on Compressive Strength

The compressive strength of concrete cured in varying percentages of acid at 7, 14, 28 and 60 days as well as the percentage decrease in strength is presented in fig 2 and fig 3 for strength and percentage change in strength respectively. It can be observed from fig. 2 that the compressive strength of the cubes at all percentage concentration of the acid decreases with curing age from 7 days to 60 days. This is because as the concrete ages, the deteriorating effect of the acid increases, which agrees with Turkel et al 2007. Also it can be seen from table 3 and fig 3 that the percentage drop in strength increases with both percentage of acid and curing age. Thus the rate of deterioration is highest at 60 days curing in 20% acid concentration (47.8%) almost at 50%. This is because as the curing age increases more C-S-H and CH are liberated from the cement hydration providing more materials for the nitric acid to react with and hence causing further deterioration. This agrees with the results of experimental work by Reddy et al 2012 and the theory by Allahverdis and Skvara 2000 as well as the theory presented in equations ii and iii. Another reason for increase in percentage decrease in strength with curing age could be that, as the curing age increases, the concentration of the acid also increases due to the evaporation of the curing water, thus leaving more acid available to increase the rate of the deterioration reaction in line with Le Chaterlier"s principle.

3.3 Flexural and Tensile Strength

The result of flexural and tensile strength and percentage decrease in strength is shown in Fig 4 and 5 respectively. It can be seen from the curve that not only does acidic curing environment affect compressive strength but also the flexural strength as well as the tensile strengths. In both cases the strength decreased with increase in percentage concentration of acid, with a decrease of 22% from 0% to 20% in the case of flexural strength and 41% in the case of tensile strength.

3.4 Relationship between weight loss and compressive strength

The relationship between loss in weight and compressive strength is expressed in fig. 6. For a particular curing age, both the strength and mass decreases with an increase in the concentration of acid. Also, for a particular concentration of acid, the strength and weight of concrete decrease with curing age. Fig. 7 shows that a near linear relationship exist between weight loss and loss in compressive strength.

4.0 CONCLUSION

The following conclusions can be drawn from this research work:

1. Acidic curing environment have a negative effect on the compressive, flexural and tensile strengths as well as density of concrete cured in acidic water.
2. The decrease in strength of concrete increases with both curing age and percentage concentration of acid in the curing water
3. A near linear relationship exists between loss in weight and strength as the percentage of acid increases
4. The rate of deterioration of Concrete cured in acidic environment increases as the concrete ages, reaching about 50% after 60 days of curing
5. For Concrete structures that are to be set up in acidic environment, particular attention must be given to the design, a higher factor of safety for strength used and if possible, special cements used to mitigate the effect of the deterioration due to the acidic environment.

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Table 1: Properties of OPC.

	Oxide	% Oxide Composition	Code Specification
Chemical Properties of OPC	SiO_2	10.50	
	TiO_2	0.34	
	Al_2O_3	2.10	
	Fe_2O_3	4.95	
	SO_3	2.84	
	CaO	76.57	
	MgO	1.40	
	Na_2O	0.52	
	K_2O	0.33	
	MnO	0.23	
	Cr_2O_3	0.02	
	V_2O_5	0.041	
	BaO	0.16	
Physical Properties	Specific Gravity	2.85	2.30 - 2.90 (ACI E1 – 07)
	Initial Setting time	83 minutes	≥ 45 minutes (BS -12: 1996)
	Final setting time	258 minutes	≤ 10 hours (BS -12: 1996)
	Standard consistency	28%	26-30%
	Fineness	0.037	0.01-0.06 (BS -12: 1996)
	Soundness	2.5mm	≤10mm (BS -12: 1996)

Table 2: Properties of Aggregates

Material	Property	Value	Code Specification
Fine Aggregates	Specific Gravity	2.61	2.30 - 2.90 (ACI E1 – 07)
	Moisture Content	5.30%	0 – 10% (ACI E1 – 07)
Coarse Aggr.	Specific Gravity	2.66	2.60-2.70 (ACI E1 – 07)

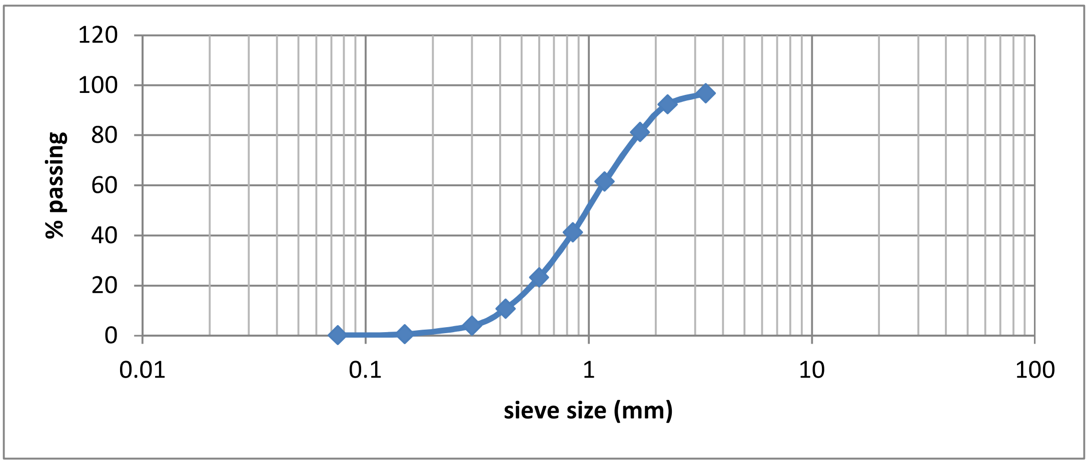

Fig 1A: Graph of Particle size determination for Fine Aggregates

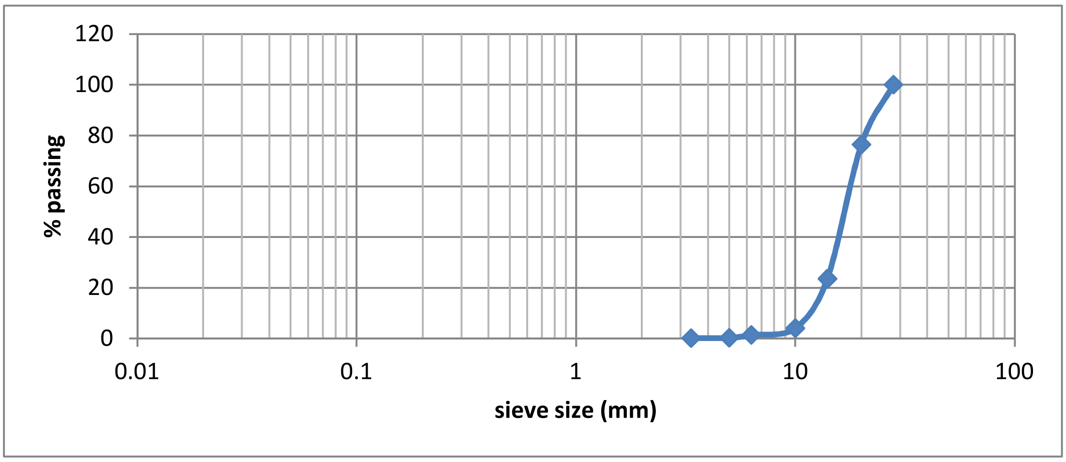

Fig 1B: Graph of Particle size determination for Coarse Aggregates

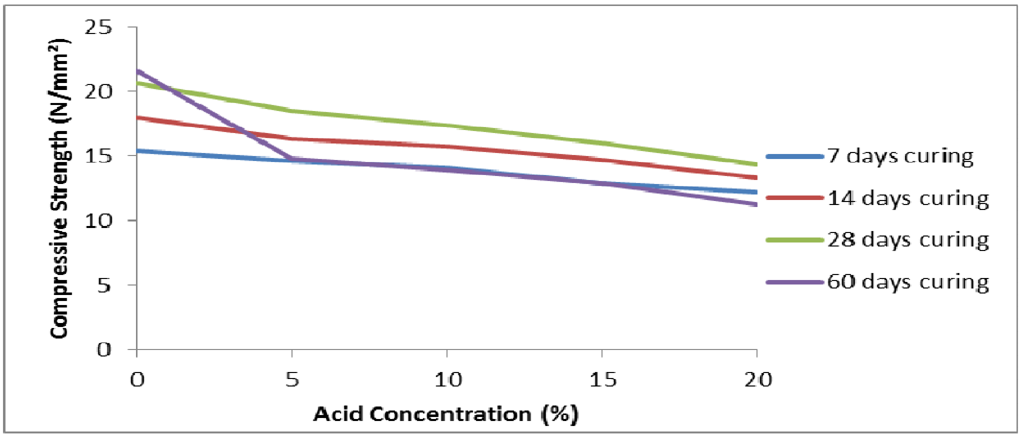

Fig 2: Compressive Strength at various curing ages

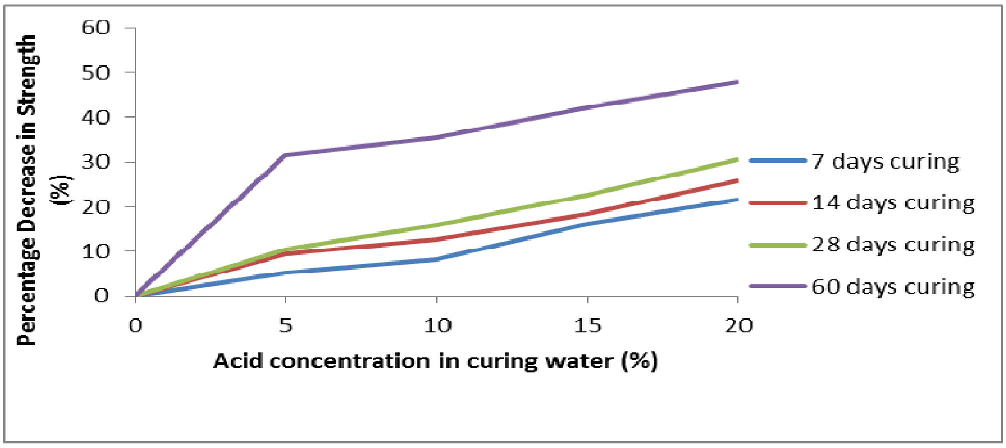

Fig. 3: Percentage decrease in compressive strength

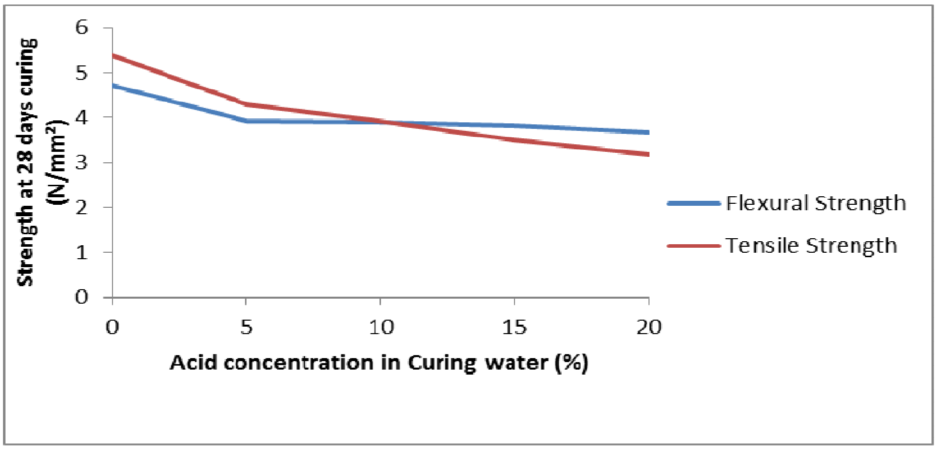

Fig. 4: Tensile & Flexural Strength at 28days curing

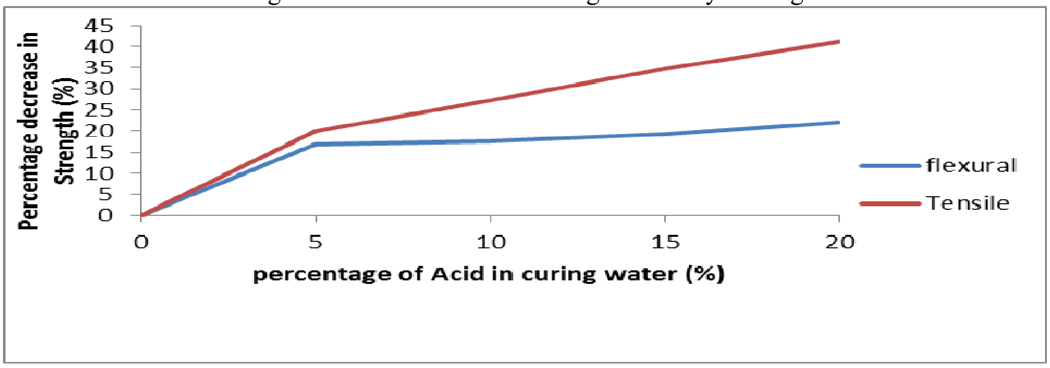

Fig. 5: Percentage decrease in Tensile & Flexural Strength

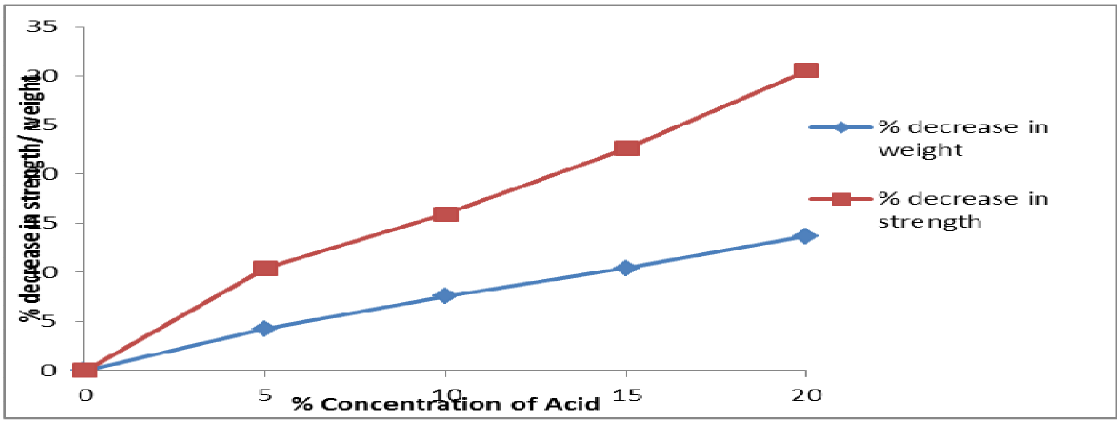

Fig. 6: Comparism of decrease in strength and weight

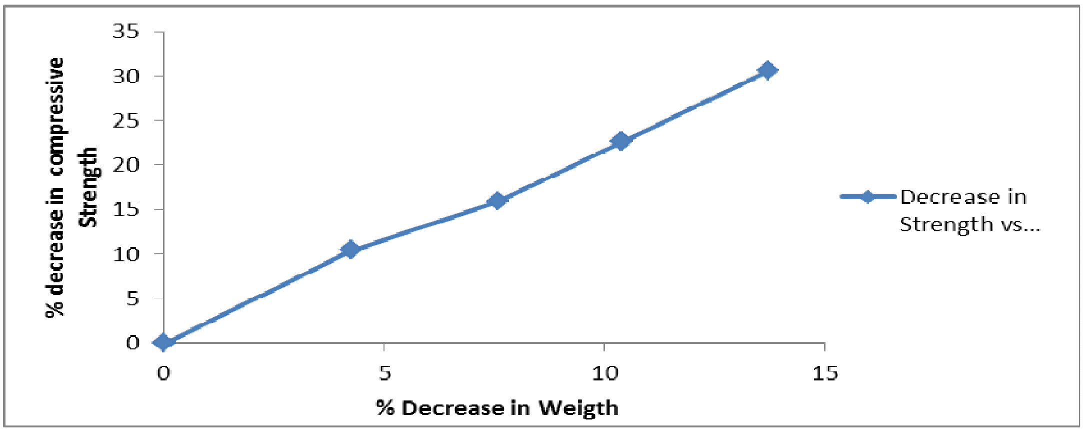

Fig. 7: Relationship between weight loss and loss in compressive strength.