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Research Article

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Effect of Hydrochloric acid (HCl) on the Compressive Strength of Concrete at Early Ages

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Abstract This study investigates the effect of HCl on the strength of concrete at early ages. Concrete specimens of grade 20 were immersed in 5% and 10% HCl solutions after 24 hours of casting. The compressive strengths of the specimen's at1, 2,3,7,14,21 and 28 days of curing in the HCl solutions were determined. Compressive strength of the control specimens cured in water was also tested for comparison.

The results indicated that the compressive strength of the concrete specimens immersed in 5% HCl solutions increased up to 21 days. However, the compressive strength of concrete samples exposed to 5% and 10% HCl solutions decreased significantly at 28 days. Therefore, normal strength concrete at early age should not be used where the concentration of HCl is 5% or more.

Keywords Compressive strength, curing age, hydration

1. Introduction

Concrete is the most widely used construction material and second most consumed material after water [1]. Its popularity is as a result of numerous advantages such as availability, applicability and low cost [2]. For long, concrete has been considered to be a durable material requiring little or no maintenance except when it was subjected to aggressive environment with acid [3].

Concrete being very alkaline in nature is extremely susceptible to acid attack. The decomposition of concrete depends on the porosity of the cement paste, concentration of the acid, the solubility of the acid to calcium salt and on the fluid transport through the concrete. Aggressive acids such as Hydrochloric acid (HCl), acetic acid, Nitric acid and H_2SO_4 produce calcium salts that are very soluble.

Hydrochloric acid decomposes the calcium hydroxide of the cement into calcium chloride which is readily soluble in water. HCl damages concrete through dissolution process, soluble salts are formed and the concrete will be leached because of them. The color of the external surface of the sample was yellow whereas the color of their inner surface was brown. This was due to differences in the amount of Fe $(OH)_3$ [4]. These soluble salts can easily be transported to the outer parts of concrete. In this situation, continuous reactions increase the porosity of cement paste and increased pore volume and speed up the rate of reaction [5].

The chemicals formed as the products of reaction between hydrochloric acid and hydrated cement phases were some soluble salts, mostly with calcium, which were subsequently leached out, and some insoluble salts along with amorphous hydrogels which remain in the corroded layer. Chandra [6] proposed that besides dissolution, the interaction between hydrogels may also result in the formation of some Fe-Si, Al-Si, Ca-Al-Si complexes which appeared to be stable in *pH* range above 3.5. In addition Chandra [6] also mixed pure C_3A synthesized in laboratory with hydrochloric acid. Indications were received for the formation of Friedel's salt, $C_3A{\cdot}CaCl_2{\cdot}10H_2O$, by the action of $CaCl_2$, formed due to the reaction of hydrochloric acid with $Ca(OH)_2$, and C_3A phase. He concluded that attack by hydrochloric acid was a physico-chemical process of deterioration.

Work by Sadiq *et al.*, [7] revealed that the grade of concrete did not seem to have appreciable influence on the resistance of concrete to chemical aggression, but mostly depends on the type and concentration of the aggressive medium. The effects of these aggressive media were not only influenced by the type and concentration of the media, but also, by exposure periods and age of concrete before exposure. There are two ages of concrete exposure. It ranges from early to long term exposure.

Damage incurred at the early age facilitates the ingress of water and aggressive chemicals making the concrete more susceptible to both physical and chemical attacks, thus accelerating the deterioration. Concrete, at its early ages (less than 28 days), [1, 8-10] concrete can be attacked by chemicals at early age in maintenance work involving buildings that being used or stored chemicals or new project in which due to time constraint, the concrete is exposed to service environment at early age. In this paper, the effect of HCl solution on the compressive strength of concrete at early ages has been investigated.

2. Methodology

2.1. Materials

The materials used for this study were: ordinary Portland cement (OPC), river sand as fine aggregate and crushed granite of 20mm maximum size as coarse aggregate, HCl and water. The properties of the aggregates are shown in Table 1.

Table 1: Properties of aggregates

Properties	Granite	Sand
Specific gravity(ssd)	2.9	2.6
Absorption capacity (%)	1.5	3
Moisture content (%)	0.5	0.7
Fineness modulus	7.6	4.4
Loose bulk density(dry) kg/m^3	1411	1549
Compacted bulk density (dry) kg/m^3	1510	1689

2.2. Preparation of the Specimen and Testing Methods

Concrete specimens of grade 20 were produced in accordance with the B S 1881:108 [11]. After mixing, the specimens were cast in 100 x100 x100mm moulds and then compacted manually in two layers to achieve adequate consolidation. The specimens were demoulded and then immersed in HCl solutions of 5 and 10% concentrations. For comparison, control specimens were also immersed in water until testing ages. At ages of 1, 2, 3, 7, 14, 21 and 28 days, the compressive strengths of the specimens immersed in solutions and water were determined in accordance with the BS 1881, part 116 [12] with the aid of compression testing machine. The average of compressive strength of three specimens was reported at each curing age.

3. Results and Discussion

3.1. Residual Strength of Concrete Exposed to HCl

Residual compressive strength result of concrete exposed to HCl at 5 and 10% concentrations for 1 to 28 days exposure is shown in figure 1. For 1 to 21 days of exposure at 5% concentration, the range of strength increments were 8.11%, 11.32%, 13.60%, 11.49%, and 3.12% for 1, 2, 3,7,14 and 21 days exposure respectively. The higher strength could be mainly due to the formation of calcium chloride which accelerate the rate of hydration as observed by Susilorin *et al.*, [13]. But for 28 days exposure, the concrete lost about 10.19% of its original strength. Furthermore, a loss of strength was recorded for 10% concentration at the exposure periods. The concrete lost about 21.42% for 1 day, about 8.49% at 7 days and 25.99% at 28 days exposure. The lost in strength from the original strength could be due to the formation of large amount of calcium chloride due to high concentration of HCl.

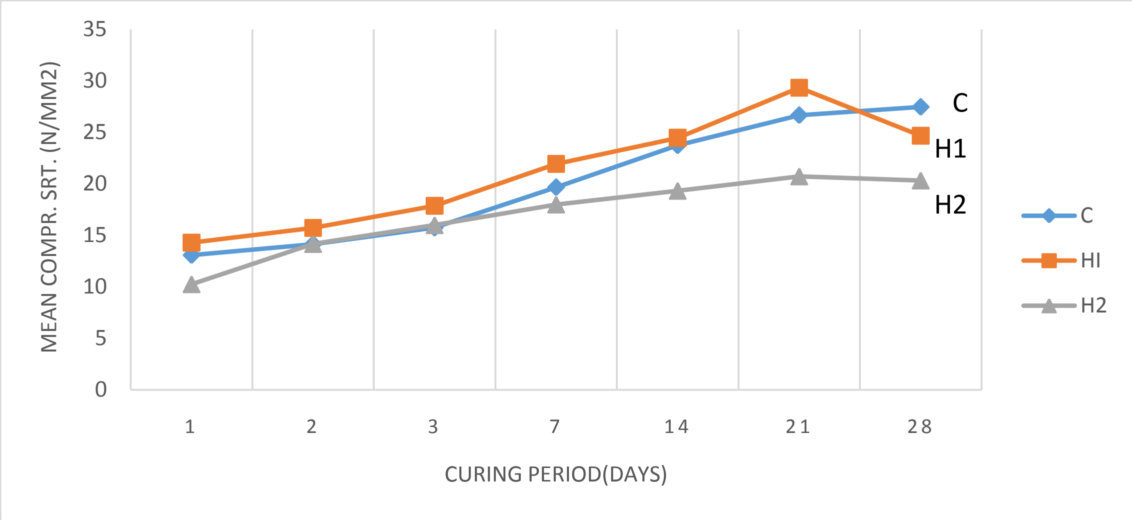

Figure 1: Relationship between residual strength of concrete and curing period in HC

4. Conclusion

Compressive strength of concrete specimens exposed to 5% HCl solution at early age increased up to 21 and for 10% HCl a loss of strength was recorded at all the exposure periods. However, the compressive strength decreases significantly at 28 days exposure in both 5% and 10% HCl. Therefore, normal strength concrete should not be used where the concentration of aggressive media of HCl is 5% or more.

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