Effect of Immersion Medium on the Compressive Strength of Steel-Reinforced Concretes

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***Abstract*—Frequent collapse of steel-reinforced concrete structures in recent times and the attendant safety risks of this to life and properties necessitates studying compressive strength of steel-reinforced concrete material in their service-environment. In the paper, effect of the ambient service-environments that were simulated as four different laboratory models of immersion test-media, on the mechanical property of compressive strength of steel-reinforced concrete specimens was investigated. These test-media include 0.5 M H_2SO_4, 3.5% NaCl, distilled water and ambient air for simulating different service-environments of steel-reinforced concretes. For the study, duplicated steel-reinforced concrete samples were subjected to compressive strength testing and analyses, as per ASTM C39/C39M-03 and ASTM C267-01, of 124 days post-concrete casting age, 96 of which the samples were immersed in their different test-medium. Results showed that out of the different media of concrete immersion, compressive strength was lowest in the steel-reinforced concrete specimens that were partially immersed in the 0.5 M H_2SO_4 test-medium, simulating industrial/microbial environments. In contrast, optimal compressive strength improvement was observed in the samples that were partially immersed in distilled water, for simulating atmospheric water, from rain. The results of compressive strength encountered in many of the samples studied, in their medium of test-immersion, bare implications on the need to fortify steel-reinforced concretes designed for the compressive strength reducing environments with compressive strength improving admixture for ensuring sustainable/structural durability of concrete structures.**

***Index Terms*—Steel-reinforced concrete material, compressive strength testing, compressive strength analyses, service-environments of construction material**

I. INTRODUCTION

Concrete is the most widely used and produced material globally [1-2], while steel-reinforced concrete is a material of choice for building structure and infrastructure due to its versatility, ease of manufacture and relatively lower cost [3-4]. However, incessant instances of building collapse are generating safety risks to life and properties both in the developed and the developing countries [5-7]. Collapse of building structures could be due to loss of load-bearing steel-reinforced member to blast [5], earthquake [6] or insidious deteriorating effects of the service-environment on the steel-reinforced concrete member [7-9]. For instance, while earthquake or seismic movement of the earth is not common in Africa, the continent which includes Nigeria, have its fair share of building collapse as the remaining part of the world. In the non-blast and the non-earthquake region, exposure of steel-reinforced concrete structures to certain environmental conditions, in the service-environment of the concrete, can lead to their deterioration and sometimes failure. In sub-Sahara Africa, environment that could prevail include:

- Microbial environment from sewage or underground that are potent with sulfate-reducing bacterial [8,10-11] e.g. *Dessulfubrio* and *Thiobacillus thiooxidans* [12], these produce sulphuric acid that deteriorates hydrated products of concrete into weak but volume expansive gypsum and ettringite;
- Industrial environment that could result in acid rain from the reaction of SO_2 pollutant from industries with atmospheric water for producing sulphuric acid that also deteriorate hydrated products of concrete [9,13-14];
- Chloride contaminated environments [8-9,12,15] such as saline, i.e. artificial de-icing salt area of temperate region, or marine, i.e. the natural coastal region, both of which induce chloride ingress into steel-reinforced concrete, that by corroding the reinforcing steel forms volume expansive rust that could lead to cracks, spalling and delamination of the concrete;
- Atmospheric water, from rain, in which carbon dioxide could dissolve, so that it could act as transportation medium of carbonation inducing environment [10,14];
- Atmospheric air, ambient to the concrete, through which carbon dioxide can diffuse into the steel-reinforced concrete and which can induce carbonation attack [14].

For specific example, it had been indicated in studies [7,17] that the coastal region of the city of Lagos exhibited the highest frequency of collapsed building structures in Nigeria and this had been attributed to the nearness of the region to water bodies containing chloride and sulphate ions. These substances are potent at attacking concrete infrastructure, destroying passive film on the reinforcing steel and eventual pitting and reducing the effective diameter of the reinforcing steel that protects the steel from corrosion degradation. The cracks resulting from these culminate in catastrophic failure due loss of structural integrity usually from the compressive strength of the concrete that had been reduced.

However, while studies have deliberated on the compressive strength effect of the sewage, i.e. microbial, environment on concrete, even as there had been numerous studies on the corrosion effect of the industrial/microbial, saline/marine and the carbonated environments on steel-reinforced concrete, there is paucity of study on the effect of different immersion media on steel-reinforced concrete. The objective of this study is therefore to investigate the effect of the medium of immersion on the compressive strength of steel-reinforced concrete.

II. MATERIALS AND METHOD

A. Experimental Materials

The steel-reinforced concrete samples were prepared according to standard procedures that had been described in literature [8,9,18] from potable water, natural river sand of 2.80 fineness modulus from Ogun River, South-West Nigeria, Ordinary Portland Cement (OPC) and granite passing 19 mm sieve [11]. The formulation employed for concrete mixing includes 300.0 kg/m^3 cement, 149.7 kg/m^3 water, 890.6 kg/m^3 sand and 1106.3 kg/m^3 of gravel. By these, the water/cement (w/c) ratio = 0.499 [3,10].

A total of ten steel-reinforced concrete samples, each of 100 mm × 100 mm × 200 mm, were employed for this experimental study, for constituting five steel-reinforced concrete duplicates. For these, the immersion mode in service-environment simulating-medium for the compressive strength testing includes:

i. Full immersion of two samples in water for 28 days after concrete casting for use as control specimens of compressive strength testing as prescribed in ASTM C39/39M-03 [19] and in ASTM C 267–01 [20] and in and according to standard practice in reported studies [11,21].
ii. Partial immersion of two samples, which had first been kept in curing room (of 25±2°C ambient temperature) for 28 days, in duplicated bowls containing 0.5 M H_2SO_4 medium for simulating both microbial (sewage) and industrial (acid rain) environments, for 96 days immersion period before compressive strength testing on the 124th post concrete casting day;
iii. Partial immersion of two samples, which had first been kept in the curing room for 28 days, in duplicated bowls containing 3.5% NaCl medium for simulating both saline (artificial de-icing salts) and marine (natural coastal) environments, for 96 days immersion period before compressive strength testing on the 124th post concrete casting day;
iv. Partial immersion of two samples, which had first been kept in the curing room for 28 days in duplicated bowls containing distilled water for simulating rainy environment in which atmospheric carbon dioxide could dissolve, for 96 days immersion period before compressive strength testing on the 124th post concrete casting day;
v. Leaving two samples, which had first been kept in the curing room for 28 days, in duplicated bowls containing no solution for simulating the environment of exposure to ambient, atmospheric, air, for 96 days immersion period before compressive strength testing on the 124th post concrete casting day;

B. Experimental Methods and Data Analyses

Compressive strength testing was done using Model YES 2000, hydraulically powered, Compression Testing Machine (Eccles Technical Engineering Ltd, England), see Fig. 1. From this, average change in compressive strength was evaluated for each duplicate versus the control of steel-reinforced concrete samples per medium of test-immersion using the relationship [9,11,20-21]:

$$CSCF_{(\%)} = \frac{f'_{c_{w,28}} - f'_{c_{\text{immersed sample, 96}}}}{f'_{c_{w,28}}} \times 100 \qquad (1)$$

Where:
$CSCF_{(\%)}$ is compressive strength change factor;
$f'_{c_{w,28}}$ is average compressive strength of sample totally immersed in water for 28 post concrete casting days;
$f'_{c_{\text{immersed sample, 96}}}$ is the average 124th day post concrete casting compressive strength of the experimental samples in their different medium of 96-day test-immersion.

Fig. 1. Compressive strength testing machine with steel-reinforced concrete specimen

III. RESULTS AND DISCUSSION

The results of the compressive strength analysis, by Equation (1) as per ASTM C267–01 [20], are presented in Fig. 2, in ranking order of the compressive strength change factor, $CSCF_{(\%)}$. By this ranking in the figure, negative value of $CSCF_{(\%)}$, indicated before the control sample in Fig. 2, represents steel-reinforced concrete sample that exhibited improvement, or increase, in compressive strength relative to the control sample, as per ASTM C267–01 [20]. Also, positive value of $CSCF_{(\%)}$, indicated after the control sample in Fig. 2, represents steel-reinforced concrete sample that exhibited reduction, or decrease, in compressive strength relative to the control sample, as per ASTM C267–01 [20].

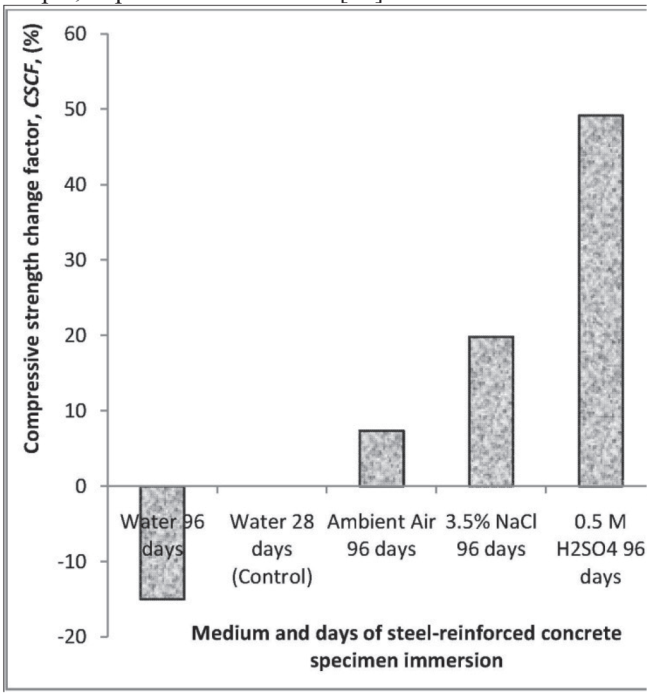

Fig. 2. Compressive strength analysis of steel-reinforced concrete samples plotted in ranking order of performance

Thus, it could be deduced from Fig. 2 that only the steel-reinforced concrete samples that were partially immersed in distilled water for 96 days, constituting 124 post concrete casting days, exhibited compressive strength improvement, $CSCF_{(\%)} = -15.00$, relative to the control samples, which were fully immersed in water for 28 (post concrete casting) days. The steel-reinforced concrete samples in ambient air, which are not actually immersed in liquid medium, exhibited compressive strength reduction versus control with $CSCF_{(\%)}$ of 7.36. This was followed in performance by the samples immersed in 3.5% NaCl, which also exhibited compressive strength reduction relative to the control samples. The highest reduction, representing the lowest numerical values, in compressive strength was encountered in the samples immersed in 0.5 M H_2SO_4 medium. For these samples, compressive strength analysis indicated $CSCF_{(\%)}$ value of 49.17, which interprets to compressive strength reduction relative to the control samples, as per ASTM C267-01 [20].

This high level of compressive strength reduction in the 0.5 M H_2SO_4-immersed concretes find agreements with the reports in Hewayde et al [11] where it had been indicated that sulphuric-acid attacks on concrete usually culminate in decline of the compressive strength of concrete. Recommendations from literature [9,11-13,15] have always include the need for using strength improvement admixture(s) to curb these form of reduction in the mechanical property of strength of this construction material. Use of such admixtures, if carefully selected, especially based on experimental studies, is also potent with the additional advantage of protecting the reinforcing steel in the concrete from corrosion attacks and degradation.

The findings in the study could be reasons the highest frequencies of collapsed building structure in Nigeria were exhibited in Lagos, Nigeria, which is both an industrial as well as a coastal region of Nigeria. The incessant building collapse in this region could therefore be due to the combined action of industrial pollutant, potent with acid rain, in the atmosphere of this city located in the global rain forest belt and in the natural marine coastal area of Nigeria that is potent with chloride ion contamination.

IV. CONCLUSION

In this paper, effect of immersion medium on the compressive strength of steel-reinforced concretes has been investigated. Conclusions that could be drawn from the study include:

- Steel-reinforced concretes partially immersed in distilled water, for simulating rainy environment, exhibited improvement in compressive strength, $CSCF_{(\%)} = -15.00$, relative to the control samples;
- Steel-reinforced concretes in ambient air, which though was not a liquid medium of immersion, still exhibited compressive strength reduction or decrease in compressive strength, at $CSCF_{(\%)}$ of 7.36, relative to the control samples;
- Steel-reinforced concretes in 3.5% NaCl medium, for simulating artificial saline or natural marine environments, exhibited compressive strength reduction at $CSCF_{(\%)}$ of 19.82, relative to the control samples;
- Steel-reinforced concretes in 0.5 M H_2SO_4 medium, for simulating industrial/microbial environments, not only exhibited compressive strength that interprets to the strength reduction range of ASTM C267-01, but which also represent the highest reduction, indicating the lowest values of compressive strength in the study, at $CSCF_{(\%)}$ value of 49.17, relative to the control samples.

It is therefore established in this study that steel-reinforced concretes immersed in acidic sulphate (i.e. industrial or microbial) service-environments are prone to deterioration that culminates in the highest reduction in their compressive strength, in comparison to the other environments in the study.

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