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Modelling Total-corrosion Behaviour of Reinforcing-steel in 3.5% NaCl-immersed Concrete with *Cymbopogon citratus* leaf-extract admixture

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Modelling Total-corrosion Behaviour of Reinforcing-steel in 3.5% NaCl-immersed Concrete with *Cymbopogon citratus* leaf-extract admixture

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Abstract-
In this paper, the total-corrosion behaviour of reinforcing-steel embedment in concrete samples, having *Cymbopon citratus* (*C. citratus*) leaf-extract admixture, and which were immersed in 3.5% NaCl (a saline/marine simulating environment) is investigated. Electrochemical data of macrocell current measurements were obtained, as an easy to undertake corrosion monitoring technique, from the steel-reinforced concrete specimens, that had been admixed with different concentrations of the *C. citratus* leaf-extract, before being immersed in the corrosive test-medium.The obtained data were then rendered to prescribed specification from ASTM G109 for the modelling of the total-corrosion prevailing in the reinforcing-steel within the concrete test-samples. Results obtained showed that *C. citratus* leaf-extract admixture in the concrete samples led to reduction in the total-corrosion of the reinforcing-steel, and, especially, in agreements with previous works where other types of electrochemical monitoring techniques had been employed.

Key words: Reinforcing-steel; *Cymbopogon citratus*; macrocell current; total-corrosion; concrete; saline/marine simulating environment

1. Introduction

Curbing the menace of corrosion attacks on building and infrastructural construction materials, among which steel-reinforced concrete is known to be of most widely employed, have attracted many control techniques [1-5]. However, ascertaining effectiveness of applied techniques require monitoring procedure that must be representative of the corrosion condition that is prevailing within the corrosion test-system. For steel-reinforcement corrosion in concrete, non-destructive testing (NDT) of electrochemical monitoring techniques are normally employed [6-9]. This is majorly due to the applicability of the methods to laboratory experiments and to real-time field testing, and with the additional considerations that the techniques exhibit acceptable relationship with requisite technical and financial scope of routine test-applications [10-15]. The combination of technical and financial scope acceptability portend needs for easy-to-undertake monitoring approach that has been found to exhibit the potential of having good correlations with other corrosion monitoring methods, especially, when requisitely modelled. For this, the macrocell current measuring technique applied to steel-reinforcement corrosion monitoring has been observed in previous research to have exhibited good correlation with other quantitative measurements of corrosion testing [11-12,16]. However, further research on other corrosion control materials are required both for testing effectiveness of the material on corrosion control or otherwise and for reinforcing suitability of the macrocell current method for representing corrosion condition in steel-reinforced concretes.

Leaf-extract obtained from *Cymbopogon citratus* (*C. citratus*) had been used for inhibiting the corrosion of reinforcing-steelin concrete immersed in NaCl medium, in a previous study that had been reported elsewhere, with performance comparison with $NaNO_2$[17]. However, total-corrosion effect by the *C. citratus* leaf-extract, on reinforcing-steel, was not analyzed in that study, which rather employed statistical probability distribution for detailing performance and corrosion rate for ranking anticorrosion effects. Whereas, while total-corrosion effect of this plant-extract had been studied on reinforcing-steel in 0.5 M H_2SO_4-immersed concrete [18], for amicrobial/industrial simulating medium, no study has been done on the total-corrosion behaviour of this construction material in the NaCl medium. This paper, therefore, investigates the total-corrosion behaviour of reinforcing-steel in concrete with *C. citratus* leaf-extract admixture, and which were immersed in 3.5% NaCl, for a saline/marine simulating-environment.

2. Experimental

Leaf-extract from *Cymbopogon citratus* (*C. citratus*) was obtained as had been detailed in reported studies [17-18]. Also, utilized for this work is reinforcing-steel of diameter 12 mm by 190 mm length, from which 150 mm was embedded in steel-reinforced concrete that was freshly cast to be of size 100 mm by 100 mm by 200 mm. Before use for reinforcing concretes, the steel specimens were subjected to surface preparation recommended in ASTM G109–07(2013) [19]. During casting, *C. citratus* concentrations varying from 0.00 g/L for the control sample up to 6.67 g/L, in increments of 1.67 g/L, was admixed in the water used for mixing the concrete, as prescribed in ASTM C192/192M-19 [20]. The steel-reinforced concrete specimens were, after casting, kept in curing room for a 28-day period, before being immersed in the 3.5% NaCl testing medium for corrosion monitoring experiment of the reinforcing-steel. Total-corrosion model employs macrocell current measurements via a zero resistance ammeter (ZRA). These macrocell current monitoring approach applies the dictates of ASTM G109–07(2013) [19] in a two-electrode system of the $Cu/CuSO_4$ (CSE) utilised as the reference electrode, just as the reinforcing-steel served as the working electrode [21-25]. For the present case, the macrocell current were measured every five days for 40 days before they were then taken every week for the next seven weeks, which thus total an 89-day experimental period of n = 16 data-points. Total-corrosion, *TC*, modelling then follows the use of the measured macrocell current, *i*, in the formula detailed from [19]:

$$TC_m = TC_{p-1} + \left[\left(t_p - t_{p-1} \right) \times \left(i_p + i_{p-1} \right) \big/ 2 \right];\ p = 2,\ 3,\ \ldots,\ n$$

* MERGEFORMAT (1)

Where: t is the time difference (s) of the previously measured macrocell current (A), i_{p-1}, at time t_{p-1}, from the measured macrocell current (A), i_p, at the present time t_p.

3. Result and discussions

In Figure 1, the measured macrocell current is plotted for each of the steel-reinforced concrete specimens in the 3.5% NaCl test-solutionof immersion. From the figure, it could be observed that the macrocell current were highly spiked in the control specimen of the steel-reinforced concretes. This shows that the reinforcing-steel within that sample exhibited corrosion activity that were generally higher than what obtained in the other samples containing *C. citratus* leaf-extract admixture, especially, from the 15th day of the experiment. Other inference that could be drawn from the plots in the figure include the consideration that the low concentrations of *C. citratus* leaf-extract tend to exhibit lower corrosion activity in their test-systems, in comparisons with test-systems having high *C. citratus* leaf-extract concentrations.

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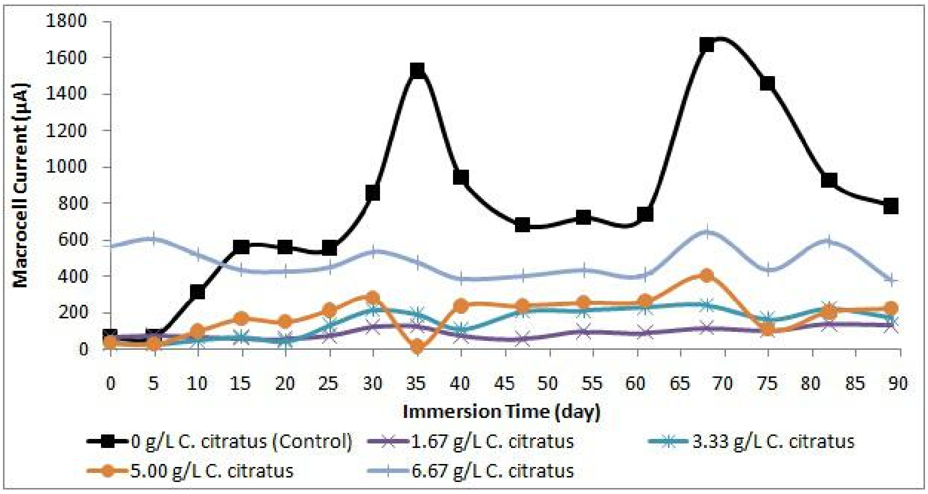

Figure 1: Plots of measured macrocell current obtained from the NaCl-immersed steel-reinforced concrete samples with varying concentrations of *C. citratus* leaf-extract admixtures

In Figure 2, the total-corrosion resulting from the measured data of macrocell current modelling are plotted. The plots in the figure still showed, generally, higher trends of total-corrosion models in the control sample, than the samples having *C. citratus* leaf-extract admixture. However, it took up to the 35th day of the experiment before the total-corrosion in the control sample surpassed that of all the other steel-reinforced samples with *C. citratus*. This disparity in timely representation of corrosion prevalence could follow from the quantitative nature of macrocell current monitoring approach, for the galvanic current of the macrocell is known to depict the reduction process,caused by the corrosion activity, at the cathode. Nevertheless, the plots in Figure 2 highlight better the confirmation that the low concentrations of *C. citratus* are required for effective reduction of corrosion effect on reinforcing steel in concrete immersed in the 3.5% NaCl test-environment. This was deducted from the consideration that the 1.67 g/L *C. citratus* was modelled with the lowest prevalence of corrosion activity from the plots of total-corrosion models in Figure 2. The performance of *C. citratus* concentrations in that figure indicated that the modelled total-corrosion showed higher slopes of increasing trends as the concentration of *C. citratus* admixture increases. The only exception to this is that of the control sample, which exhibited the highest slope of total-corrosion trend in the study.

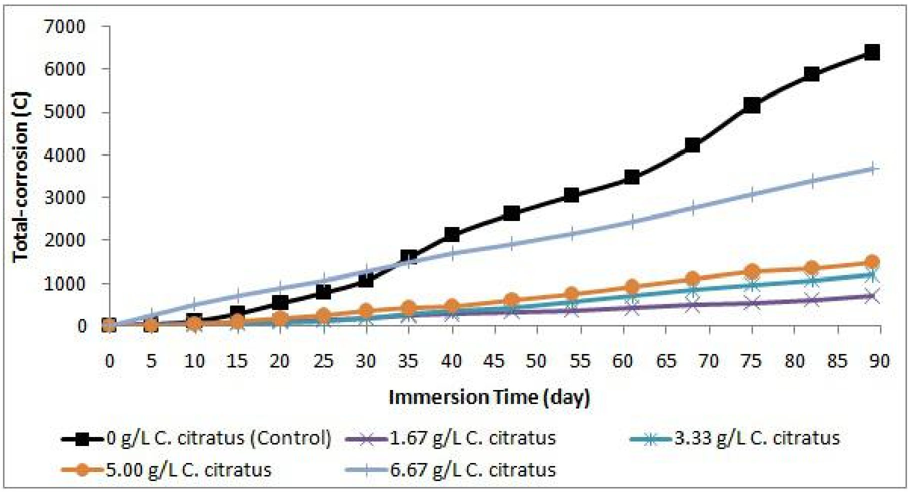

Figure 2: Plots of total-corrosion model of corrosion activity from the NaCl-immersed steel-reinforced concrete samples with varying concentrations of *C. citratus* leaf-extract admixtures

The findings of high reduction of corrosion activity in the presence of low concentrations of *C. citratus* exhibited agreements with report from other research work reported elsewhere [17]. This is still despite the consideration that in that cited work, corrosion rate reckonings, via linear polarization resistance (LPR), was the variable for detailing *C. citratus* performance in a study that does not involve total-corrosion modelling. This finds concordance with the findings from other works on steel-reinforced concrete that had the 0.5 M H_2SO_4 as the medium of test-immersion, andwherein corrosion rate by LPR in [26] and total-corrosion model in [18] both indicated needs for higher *C. citratus* concentration for effective corrosion reductions. Thus, while studies have depicted that macorcell current constitute qualitative measurements that may not indicate self-corrosion [25,27] findings from this and other studies on *C. citratus* performance are indicating agreements between qualitative detailing of corrosion activity with that from macrocell current data that are rendered to total-corrosion modelling. These agreements being observed from total-corrosion models of macrocell current measurement and quantitative measurements of corrosion rate could, therefore, make the macrocell current a simpler, as well as faster, to-undertake corrosion monitoring approach. However, further studies are being recommended for adequately situating the forms of correlation that might exist, or otherwise, between the total-corrosion models (from macrocell current measurements) and the quantitative measurements of corrosion rate.

4. Conclusion

In this paper, the total-corrosion behaviour of reinforcing-steel embedment in 3.5% NaCl-immersed concrete samples, having different *C. citratus* leaf-extract concentrations, and has been investigated. The results from the study indicated that the C. *citratus* leaf-extract showed reductions of corrosion activity by the reinforcing steel in the concrete samples having the plant extract, in comparisons to the control sample. Findings in the study also showed that the low concentrations of *C. citratus* exhibited better reduction in the trends of the total-corrosion models. That the results from this study, in which total-corrosion modelling from macrocell current measurement was employed, exhibited agreements with findings from the literature wherein other quantitative corrosion monitoring measurements had been used, therefore, supports the use of total-corrosion models from macrocell current as a simple-to-undertake technique for detailing corrosion activity in corrosive test-system.

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