Electrochemical Performance of Sodium Dichromate Partial Replacement Models by Triethanolamine Admixtures on Steel-Rebar Corrosion in Concretes

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This paper studies electrochemical performance of partial replacement models of sodium dichromate ($Na_2Cr_2O_7$) inhibitor by triethanolamine ($C_6H_{15}NO_3$) admixtures on the corrosion of steel-rebar embedded in concrete immersed in corrosive environments. For these, 3.5% NaCl and 0.5M H_2SO_4 media were employed for respectively simulating saline/marine and industrial/microbial corrosive test-environments. Test-results of electrochemical monitoring techniques were subjected to statistical modelling of probability distribution fittings, goodness-of-fit tests and analyses for detailing admixture performance in steel-reinforced concretes. Results from these identified 6 g $Na_2Cr_2O_7$ + 2 g $C_6H_{15}NO_3$ and the 2 g $Na_2Cr_2O_7$ + 6 g $C_6H_{15}NO_3$ partial $Na_2Cr_2O_7$ replacement admixtures with excellent inhibition efficiencies, $\eta = 91.7\%$ and $\eta = 90.0\%$, respectively in the NaCl-immersed concretes. Also, the 2 g $Na_2Cr_2O_7$ + 6 g $C_6H_{15}NO_3$ exhibited inhibition efficiency $\eta = 52.5\%$ that lagged behind $\eta = 72.0\%$ of 8 g $Na_2Cr_2O_7$ but which both represent good efficiency criteria in the H_2SO_4-immersed concretes.

1. INTRODUCTION

Corrosion degradation of reinforcing steel in concrete is a major deterioration mechanism affecting durability of reinforced concrete building and infrastructure [1-4]. Usually, steel-reinforced

concrete is structurally reliable, especially, due to its inherent capability to protect the steel reinforcement embedded in it. By this, it had remained the most commonly used construction material globally. However, steel rebar in concrete corrodes when the stable, passive film of oxide layer from the hydration of cement pastes, which protects the steel in the concrete pore structure, is broken down by aggressive agents in the service environment of the reinforced concrete structure. These aggressive agents include carbonation from the atmosphere, chloride ingress from artificial saline (de-icing salts applications) or natural marine environments and sulphate attack from acid rain in industrial or microbial activities in sewage environments [4,5-6]. Out of the many methods that had been proposed for tackling steel-rebar corrosion problems, the use of corrosion inhibitor admixtures had been recognised as a simple, economical and effective approach for mitigating steel rebar corrosion in concrete [6-7].

Dichromates are well known and highly effective corrosion inhibiting substance but they suffer the setback of the toxicity of the chromate components [8-12]. These chromate components are highly hazardous to the environmental ecosystems [12-14]. However, the fact that chromate compounds are high performance corrosion inhibitors is making the search for their replacement difficult [12,15-16]. Partial replacement admixture, in order to be suitable for such partial dichromate replacement model, would have to exhibit the property of inhibition effectiveness comparable to that by dichromate compound while it must also be non hazardous to the environment.

Triethanolamine ($C_6H_{15}NO_3$) is a compound with the structure shown in Figure 1, and unlike the dichromates, this is not very toxic compound. Also, triethanolamine had been employed for mitigating chloride induced corrosion of reinforcing steel in simulated alkaline pore solution [17]. However, no experiment has been carried out for studying partial replacement model of toxic sodium dichromate inhibitor by triethanolamine admixture in concrete slabs immersed in corrosive environments. Thus, this paper studies performance of partial replacement models of sodium dichromate ($Na_2Cr_2O_7$) inhibitor by triethanolamine ($C_6H_{15}NO_3$) admixtures on the corrosion of steel-rebar in concrete slabs in sodium chloride (NaCl) and in sulphuric acid (H_2SO_4) media.

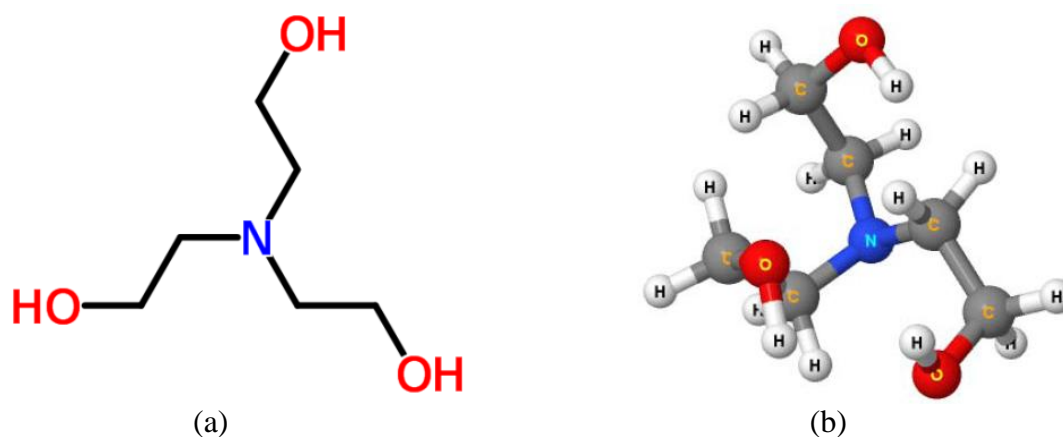
          (a)   (b)

Figure 1. Structure of triethanolamine (a) molecule (b) ball and stick model.

Because this study entailed experimental measurements, heed became necessary to the specifications of ASTM standard [18] which identified susceptibility of measured corrosion test-results to deviations from prevalent conditions of corrosive activities in the test-systems. This, therefore, necessitates use of statistical analyses [19] for aiding interpretations of test-results and detailing admixture performance. Statistical modelling tools prescribed in [18] for this were employed in the study and these include comparative probability distribution fitting models, goodness-of-fit studies and numerical correlation analyses [20-23].

2. MATERIALS AND METHODS

2.1. Reinforcing steel and reinforced concrete block specimens

The Ø12mm reinforcing steel used in the study was obtained from Federated Steel Rolling Mills, Ota, Ogun State, Nigeria. The deformed rebar has composition in % of: 0.27 C, 0.40 Si, 0.78 Mn, 0.04 P, 0.04 S, 0.14 Cr, 0.11 Ni, 0.02 Mo, 0.24 Cu, 0.01 Co, 0.01 Nb, 0.01 Sn and the balance Fe. The steel rebar were cut into 190mm specimens. Each of these were grinded with grades of abrasive papers, pickled in H_2SO_4 according to standard procedure [24], rinsed and cleaned in ultrasonic cleaner, degreased with acetone, dried with warm air stream and kept in desiccator prior to being used for the experiment [25-28].

Reinforced concrete block samples used for the electrochemical monitoring experiment were produced as replicated blocks [19], each of size 100 mm × 100 mm × 200 mm ≡ 2×10^3 m^3 volume per concrete block specimen. 150 mm length of the rod of steel-rebar was then embedded in each of these blocks, by symmetrically placing them (the rods) across the width of each of the blocks and with the remaining length protruding for electrochemical connections. Each of these blocks was made of drinkable water and a mixture of Portland cement, clean natural river sand and granite stones, of maximum size ≤ 19 mm [1,29]. These were employed in reinforced concrete specimen formulation of 300.0 kg/m^3 cement, 890.6 kg/m^3 sand, 1106.3 kg/m^3 granite stones and 149.7 kg/m^3 water. From this, the water/cement (w/c) ratio employed equals 0.499 [24,30]. The concrete blocks were mixed and cast in accordance with standard procedure [31]. The protruded rebar from the concrete was painted with glossy paint.

2.2. Inhibitor admixture

Analytical reagent grade of sodium dichromate ($Na_2Cr_2O_7$) and triethanolamine ($C_6H_{15}NO_3$) were used in the experiment. These were weighed for the concrete block specimens (see Table 1) using analytical weighing balance (Adam Equipment®, 250g × 0.0001g) and were thoroughly mixed with some water before being made up to the required water volume for each concrete batch [31]. From Table 1, the duplicates of blank specimen in each media were with neither $Na_2Cr_2O_7$ nor $C_6H_{15}NO_3$ admixtures. Also, the sodium dichromate replacement models were initiated from 8 g $Na_2Cr_2O_7$ duplicate samples. After these, increments of 2 g $C_6H_{15}NO_3$ admixtures were consistently used for

partially replacing the $Na_2Cr_2O_7$ inhibitor until the 8 g $C_6H_{15}NO_3$ ($\equiv$ 0 g $Na_2Cr_2O_7$) was attained. These, by the duplicated sample model for each of the admixtures, constitute twenty-four concrete specimen samples for the experimental study.

Table 1. Partial sodium dichromate replacement models by triethanolamine admixtures in concrete samples

S/No	Admixed inhibitor by mass (concentration)	S/No	Admixed inhibitor by mass (concentration)
1.	0g admixture (Blank in NaCl)	2.	0g admixture (Blank in H_2SO_4)
3.	0g admixture (Blank in NaCl_Dup)	4.	0g admixture (Blank in H_2SO_4_Dup)
5.	8 g $Na_2Cr_2O_7$ in NaCl	6.	8 g $Na_2Cr_2O_7$ in H_2SO_4
7.	8 g $Na_2Cr_2O_7$ in NaCl_Dup	8.	8 g $Na_2Cr_2O_7$ in H_2SO_4_Dup
9.	6g $Na_2Cr_2O_7$ + 2g $C_6H_{15}NO_3$ in NaCl	10.	6g $Na_2Cr_2O_7$ + 2g $C_6H_{15}NO_3$ in H_2SO_4
11.	6g $Na_2Cr_2O_7$ + 2g $C_6H_{15}NO_3$ in NaCl_Dup	12.	6g $Na_2Cr_2O_7$ + 2g $C_6H_{15}NO_3$ in H_2SO_4_Dup
13.	4g $Na_2Cr_2O_7$ + 4g $C_6H_{15}NO_3$ in NaCl	14.	4g $Na_2Cr_2O_7$ + 4g $C_6H_{15}NO_3$ in H_2SO_4
15.	4g $Na_2Cr_2O_7$ + 4g $C_6H_{15}NO_3$ in NaCl_Dup	16.	4g $Na_2Cr_2O_7$ + 4g $C_6H_{15}NO_3$ in H_2SO_4_Dup
17.	2g $Na_2Cr_2O_7$ + 6g $C_6H_{15}NO_3$ in NaCl	18.	2g $Na_2Cr_2O_7$ + 6g $C_6H_{15}NO_3$ in H_2SO_4
19.	2g $Na_2Cr_2O_7$ + 6g $C_6H_{15}NO_3$ in NaCl_Dup	20.	2g $Na_2Cr_2O_7$ + 6g $C_6H_{15}NO_3$ in H_2SO_4_Dup
21.	8g $C_6H_{15}NO_3$ in NaCl	22.	8g $C_6H_{15}NO_3$ in H_2SO_4
23.	8g $C_6H_{15}NO_3$ in NaCl_Dup	24.	8g $C_6H_{15}NO_3$ in H_2SO_4_Dup

2.3. Experimental Procedures

2.3.1. Corrosion test setup

Steel reinforced concrete samples being studied were divided into two sets. Specimens in the first set were partially immersed, longitudinally, in plastic bowls containing 3.5% NaCl [8,32-33]. The specimens in the second set were partially immersed in bowls containing 0.5M H_2SO_4 [34-36]. By this, a replicated set of twelve samples were immersed in each of the corrosive test-solutions, which were made up, in each bowl, to just below the reinforcing steel protruding from the concrete, but without touching the rebar.

2.3.2. Electrochemical measurements

Electrochemical monitoring techniques were employed for measurements of corrosion test-variables [25,33,37-39] through ninety-six days experimental setup of concrete samples in five days interval for the first forty days and, thereafter, in seven days interval for eight weeks. These measured electrochemical test-variables include:

   i.   Half-cell potential (HCP) measurements: of the reinforcing steel versus Cu/CuSO$_4$ electrode (CSE), using a high impedance digital multimeter, according to standard procedure [1,40-41].

   ii.   Corrosion current (CC) measurements: versus CSE, using zero resistance ammeter Model ZM3P by Corrosion Service® [42-43].

   iii.   Corrosion rate (CR) measurements: through direct instrument conversion to mpy [44-45] using the three-electrode LPR Data Logger, Model MS1500L by Metal Samples® [46] and which was connected for measurement as described in literatures [2,25,38].

2.4 Data Analyses

2.4.1. Probability distributions and goodness-of-fit analyses

   Measurements of electrochemical test data from the corrosion test setup were subjected to the statistical analyses of the Normal and the Weibull probability distribution functions [25,41,47-50] as prescribed in [18]. These statistical modelling tools have respective cumulative distribution functions given by:

$$F_N(x) = \frac{1}{\sqrt{2\pi}\sigma} \int_{-\infty}^{x} \exp\left[-\left(\frac{x-\mu}{\sqrt{2}\sigma}\right)^2\right]dx \tag{1}$$

$$F_W(x) = 1 - \exp\left[-\left(\frac{x}{c}\right)^k\right] \tag{2}$$

   Where x is corrosion test data variable, μ and σ are the Normal mean and standard deviation, k and c are the Weibull shape and scale parameters, useful for estimating the Weibull mean, μ_W, through the equation:

$$\mu_W = c\Gamma\left(1+\frac{1}{k}\right) \tag{3}$$

   As specified in [18], compatibility of the electrochemical test data to the Normal and to the Weibull probability distribution functions were studied for each measured test-variable by the Kolmogorov−Smirnov (K-S) goodness-of-fit (GoF) tests [21-23,25,47,51]. This measures the absolute difference between empirical distribution function $F^*(x)$ and theoretical distribution function $F(x)$ through the statistics

$$D_n = D(x_1,...,x_n) = \sup_{-\infty < x < \infty} |F^*(x) - F(x)| \tag{4}$$

   The *D*-value estimation from Equation (4) was used for direct computation of the K-S *p*-value using procedures described in [51]. By this, criteria of significant level $\alpha = 0.05$ was set such that K-S *p*-value $< \alpha$ bear indication of the corrosion test-data not scattering like the applied fitting of probability distribution function (pdf). Alternatively, K-S *p*-value $\geq \alpha$ indicate that there is no reason to reject that the applied fitting of probability density function is suitable for describing the corrosion test-data of the modelled electrochemical test-variable.

2.4.2. Performance evaluation of correlation fitting models

It is of interest to study numerical correlation fittings of the modelled test variables of sodium dichromate partial replacement by triethanolamine admixtures [18,52-53]. These facilitate investigation of preference, for criteria of admixture performance prediction, between the correlation fitting models and the probabilistic models. This preference study of performance prediction entails application of different performance evaluators for testing fittings of the correlation models. Performance evaluators employed include the correlation coefficient, *r*, [18,22] and the Nash-Sutcliffe efficiency, *NSE*, [51,54] given, respectively, by:

$$r = \frac{\sum_{i=1}^{N}\left(P_m - \bar{P}_m\right)\left(C_p - \bar{C}_p\right)}{\sqrt{\sum_{i=1}^{N}\left(P_m - \bar{P}_m\right)^2} \times \sqrt{\sum_{i=1}^{N}\left(C_p - \bar{C}_p\right)^2}} \tag{5}$$

$$NSE = 1 - \frac{\sum_{i=1}^{N}\left(P_m - C_p\right)}{\sum_{i=1}^{N}\left(P_m - \bar{P}_m\right)} \tag{6}$$

Where P_m denotes probabilistic model of corrosion test-variable, C_p denotes correlation fitting prediction of corrosion test-variable, $\bar{P}_m$ denotes mean of the probabilistic model and $\bar{C}_p$ denotes mean of the correlation fitting prediction of corrosion test-variable. Also, *N* denotes number of test-variable data employed for the correlation fitting.

2.4.3. Inhibition efficiency modelling

Predicted values of corrosion rate from the statistical modelling applications find usefulness for ascertaining performance of the partial replacement of sodium dichromate inhibitor by triethanolamine admixtures through estimation of inhibition efficiency, *IE*(η), using the relationship [32,34-35,52]:

$$IE\left(\eta\right) = \frac{CR_{predicted,blank} - CR_{predicted,admixture}}{CR_{predicted,blank}} \times 100 \tag{7}$$

3. RESULTS AND DISCUSSIONS

3.1. Probability distribution modelling of variables of corrosion test data

The Normal and the Weibull distribution mean models of datasets of measured corrosion test-variables, i.e. half-cell potential, corrosion current and corrosion rate, are plotted in Figure 2 for the studied steel reinforced concrete samples immersed in NaCl and in H_2SO_4 media. From the plots, it could be observed that disparities abound between the Normal and the Weibull mean models of corrosion test-variables from the NaCl-immersed samples while the Normal and the Weibull mean models of samples in H_2SO_4 medium bear good agreements. These disparities in test-variable mean

models, encountered in a good number of the NaCl-immersed reinforced concrete samples, identified the Weibull distribution models as over-predicting mean values compared to the mean models from the Normal distribution function.
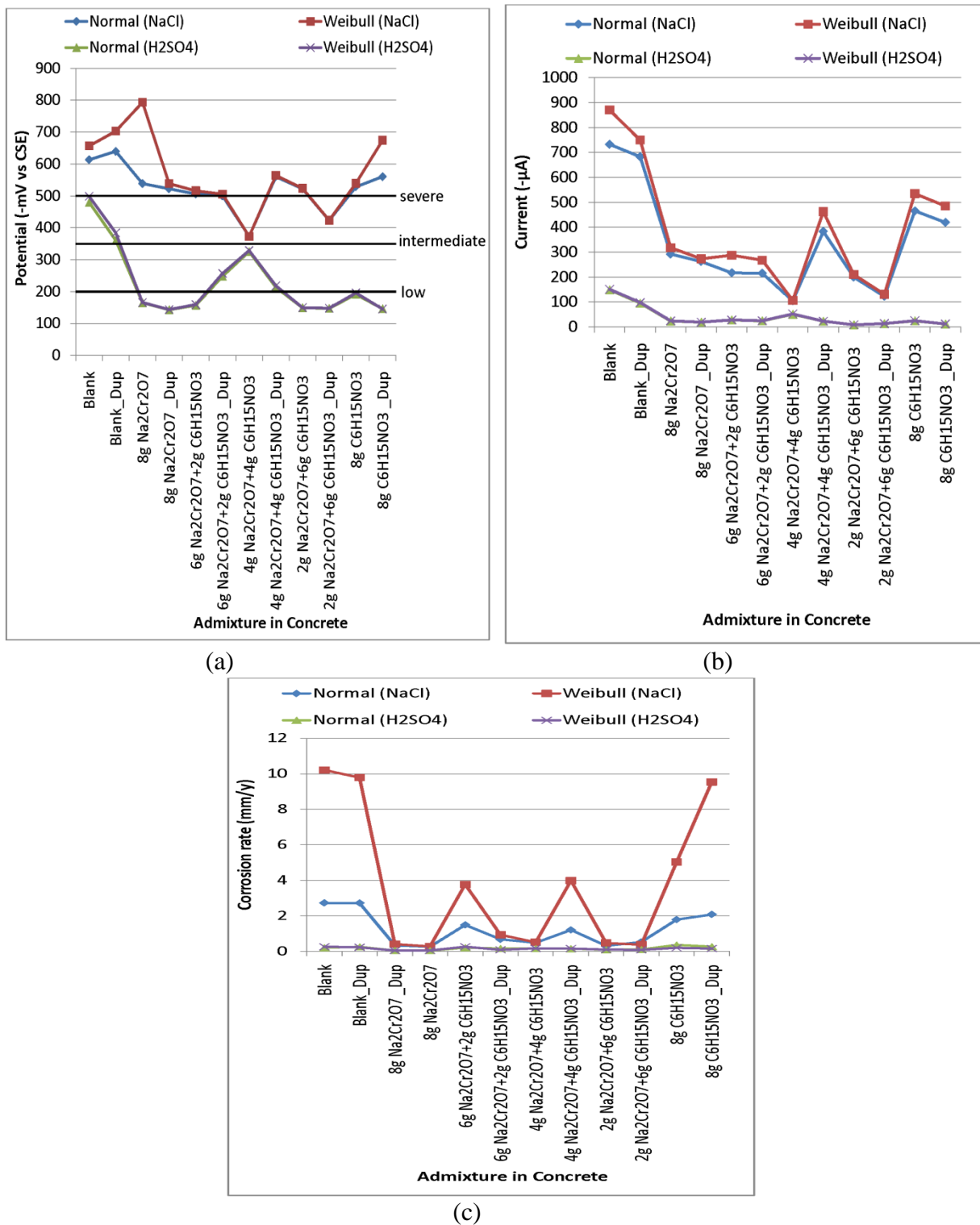

Figure 2. Plots of mean models of probability density fittings of corrosion test-variable data (a) half-cell potential with linear plots as per [40]; (b) corrosion current; (c) corrosion rate.

The foregoing engender question on which of the distribution functions fit the measured data of the test-variables better than the other, and for this the goodness-of-fit test statistics would be required. Also, from modelled results of the replicates of concrete samples with similar admixture and corrosive environments, it could be observed that, even though results of some duplicate samples find similarities, those of some others differ appreciably. This kind of difference also calls for application of statistical model of numerical correlation analysis for enacting trend of admixture performance on steel-rebar corrosion that were prevailing in both corrosive media [18].

In spite of the foregoing, interpretations of the modelled results of corrosion potential in Figure 2(a), as per [40] according to the linear plots in the figure, showed prevalent probability of severe corrosion risks in most of the samples immersed in NaCl medium. Concrete samples immersed in the H_2SO_4 medium exhibited probability of low (<10% risk of) corrosion except the blank samples in the medium which have both duplicate samples in the high (>90% risk of) corrosion probability range as per [40]. However, the experimental real-time mitigations of corrosion by the inhibitor admixed samples are more observable from the mean models of corrosion current, see Figure 2(b), and that of the corrosion rate, see Figure 2(c).

3.2. Goodness-of-fit test results

Results of the application of the Kolmogorov-Smirnov goodness-of-fit tests to the Normal and Weibull probability fittings of datasets of corrosion test-variables were presented in Figure 3 for the concrete samples in the NaCl and H_2SO_4 media. In the figure, the linear plot of significant level $\alpha = 0.05$ was also indicated for direct identification of datasets scattering or not scattering like the each of the probability fitting functions.

From Figure 3(a), it could be observed that three samples (all immersed in H_2SO_4 medium) have HCP datasets not following the Normal pdf, while two samples (one immersed in NaCl and the other in H_2SO_4 medium) have HCP datasets not following the Weibull pdf. However, the datasets of corrosion current from all the concrete samples studied, Figure 3(b), followed both the Normal and Weibull probability density fittings. Fourteen, out of the twenty-four, reinforced concrete samples (seven in each of the two corrosive media) have corrosion rate datasets that were not Normally distributed according to the Kolmogorov-Smirnov goodness-of-fit criteria, Figure 3(c). From this Figure 3(c), however, it could be noticed that the Kolmogorov-Smirnov goodness-of-fit test statistics certified the datasets of corrosion rate of concrete samples in both corrosive test-environments as scattering like the Weibull probability density function.

These considerations bear implications that the datasets of corrosion test-variables were fitted by the Weibull better than the Normal distribution function. This bear support for the use of the Weibull distribution fitting function for describing the prevalent condition of corrosive activities in the reinforced concrete samples studied, in their respective corrosion test-media.
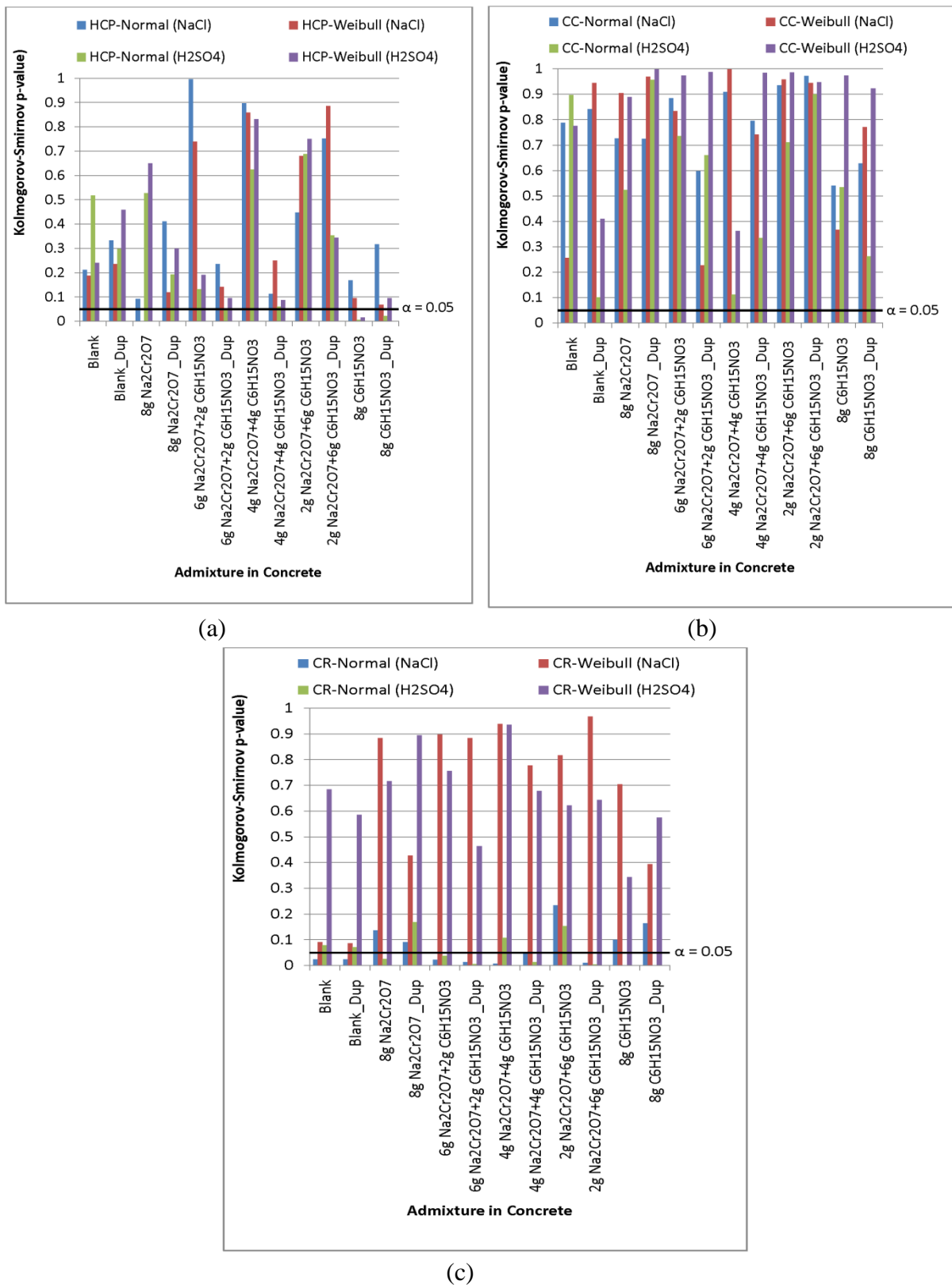
(a)

(b)

(c)

Figure 3. Kolmogorov-Smirnov goodness-of-fit test-results of the probability distribution fittings of datasets of corrosion test-variables (a) half-cell potential (b) corrosion current (c) corrosion rate.

3.3. Correlation statistics models of probabilistic results

Correlation statistics applications to the Weibull mean models of corrosion test-variables, as the probabilistic model for describing concrete steel-rebar corrosion, showed that the corrosion rate, *CR*, in the NaCl-immersed samples depends on other variables according to:

$$CR = 0.1285\sqrt{a \cdot b} + 61.7119\sqrt{I}\left(1 - 0.005787\sqrt{I}\right) - 189.6199\sqrt[3]{I} + 14.6334\sqrt{V}\left(1 - 0.01958\sqrt{V}\right) + 123.8967 \quad (8)$$

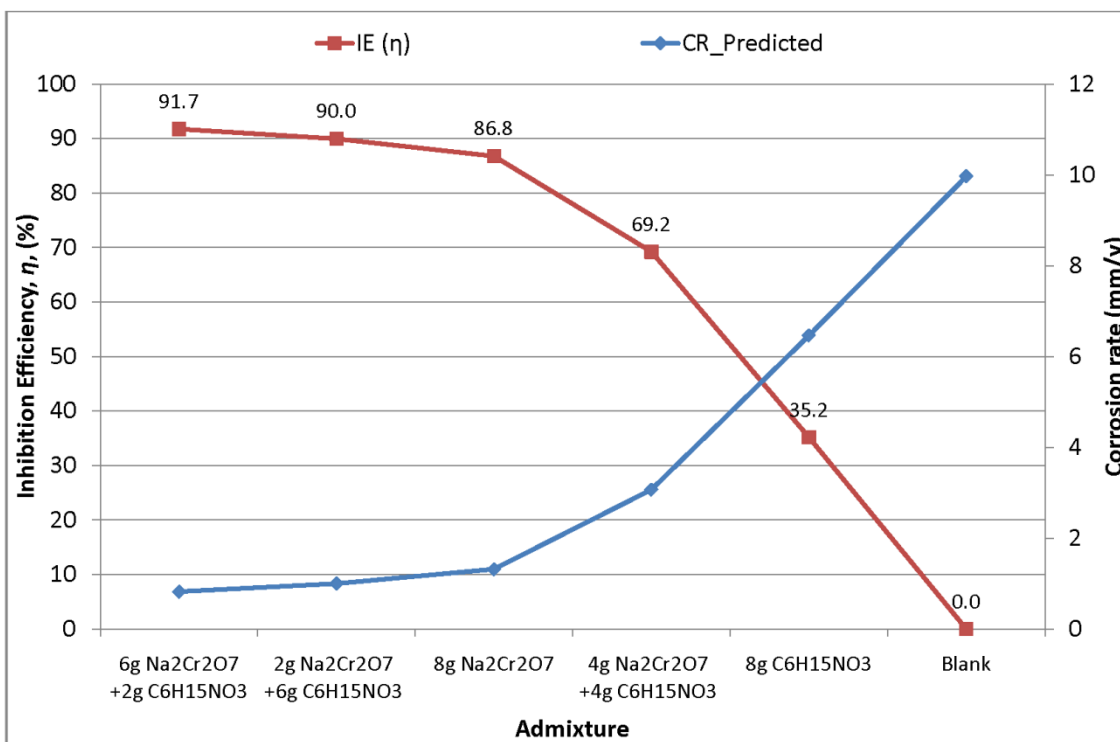For concrete samples in H$_2$SO$_4$ medium, the corrosion rate correlate with other variables as:

$$CR = 10^{-3}\left\{-5.0366 \times 10^{-2} \cdot \left[\exp\left(a + \sqrt[3]{b}\right)\right] + 1.0612I - 1.2370V + \ln\left(I^{135.4780} \cdot V^{39.0915}\right) - 222.1443\right\} \quad (9)$$

Where $a \equiv$ the mass of Na$_2$Cr$_2$O$_7$, $b \equiv$ the partial Na$_2$Cr$_2$O$_7$ replacing mass of C$_6$H$_{15}$NO$_3$, admixed in the reinforced concrete samples, $V \equiv$ the half-cell potential in –mV vs CSE, $I \equiv$ the corrosion current in $-\mu$A.
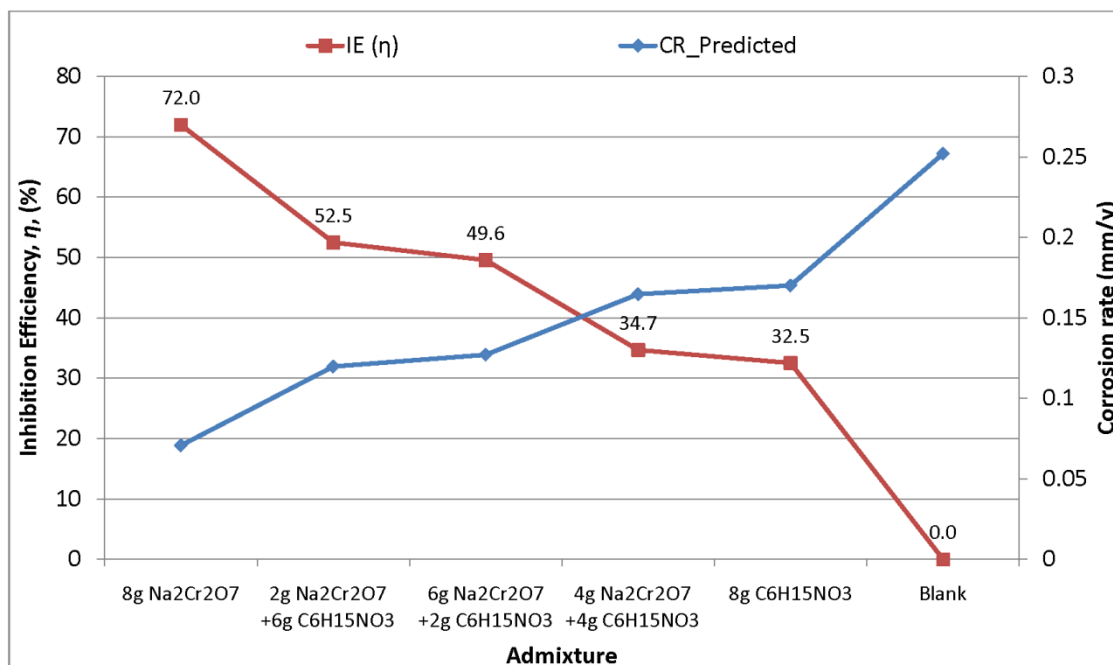
For the NaCl-immersed concrete samples, performance evaluation showed that the fitted correlation function for steel-rebar corrosion rate, Equation (8) were modelled at correlation coefficient, r = 93.25% and Nash-Sutcliffe Efficiency, *NSE* = 86.95%. These, according to literature [54], portend model prediction efficiency that could be classified as "excellent" (at r = 93.25%) or as "very good" (at *NSE* = 86.95%) correlation fitting of test-variables for the samples in NaCl medium. For samples in H$_2$SO$_4$ medium, the correlation fitting function for corrosion rate of steel-rebar, Equation (9), were modelled at r = 89.42%, classifiable as "very good", and *NSE* = 96.24%, indicating "excellent" model prediction efficiency as per the classifications in [54].

3.4. Inhibition efficiency result models of admixture performance

The efficient modelling of the corrosion rate test-results by the correlation analyses facilitates use of predictions from the numerical correlated models for modelling inhibition efficiency (η) and subsequent admixture performance. By these, Figure 4 presents plots of the averaged corrosion rate prediction, from the correlation fitting models, superimposed on the ranking of averaged inhibition efficiency of partial Na$_2$Cr$_2$O$_7$ replacement models by C$_6$H$_{15}$NO$_3$ admixtures in steel reinforced concretes. The ranking of admixture performance in concretes immersed in NaCl, Figure 4(a), identified the 6 g Na$_2$Cr$_2$O$_7$ + 2 g C$_6$H$_{15}$NO$_3$ as well as the 2 g Na$_2$Cr$_2$O$_7$ + 6 g C$_6$H$_{15}$NO$_3$ admixtures with considerably high effectiveness at inhibiting steel-rebar corrosion in the test-medium. In the highly corrosive chloride contaminated test-environment, as could be observed from the blank sample models, the respective inhibition efficiencies of these two partial replacement admixtures were η = 91.7% and η = 90.0%.

(a)

(b)

Figure 4. Performance ranking of partial $Na_2Cr_2O_7$ replacement models by $C_6H_{15}NO_3$ admixtures on inhibition of concrete steel-rebar corrosion (a) in NaCl (b) in H_2SO_4

These two effectiveness models, as could be noted from the figure, surpassed the inhibition efficiency of the 8 g $Na_2Cr_2O_7$ admixture whose η = 86.8%, a performance that actually reconfirmed effectiveness of the compound of chromate at inhibiting steel-rebar corrosion. Also notable was the fact that the 8 g $C_6H_{15}NO_3$ admixture exhibited least inhibition performance thus questioning

suitability of $C_6H_{15}NO_3$ for total replacement of $Na_2Cr_2O_7$ as inhibitor for mitigating steel-rebar corrosion in the chloride medium. The high inhibition efficiency by the 6 g $Na_2Cr_2O_7$ + 2 g $C_6H_{15}NO_3$ could be attributed to the high effectiveness of the also high dichromate component. However, the also high and comparable effectiveness of the 2 g $Na_2Cr_2O_7$ + 6 g $C_6H_{15}NO_3$ admixtures bear suggestions of the suitability of the 6 g $C_6H_{15}NO_3$ as a high enough partial replacement model of the 6 g $Na_2Cr_2O_7$ for mitigating steel-rebar corrosion in chloride media. Applying classification criteria in [54] to the efficiencies of these two partial replacement admixture showed that their ≥ 90% efficiencies are classifiable as "excellent", relative to the prevailing corrosion in the blank samples in their NaCl medium.

In the H_2SO_4 medium, Figure 4(b), the performance of 2 g $Na_2Cr_2O_7$ + 6 g $C_6H_{15}NO_3$ admixtures, inhibition efficiency $\eta = 52.5\%$, surpassed that of the other partial $Na_2Cr_2O_7$ replacement by $C_6H_{15}NO_3$ admixtures, though it lagged behind that of 8 g $Na_2Cr_2O_7$ with $\eta = 72.0\%$. It is however worth noting that the performances of these admixtures, which are within $50\% \leq \eta \leq 74\%$ in the H_2SO_4 medium, both translates to "good" efficiencies when interpreted by applications of efficiency classifications presented in [54].

4. CONCLUSIONS

Performance of partial replacement models of sodium dichromate ($Na_2Cr_2O_7$) inhibitor by triethanolamine ($C_6H_{15}NO_3$) admixtures on the corrosion of steel-rebar embedded in concrete immersed in NaCl and in H_2SO_4 media had been investigated in this paper. From these, conclusions that could be drawn include:

• Interpretations of the half-cell potential test-variable showed that the chloride contaminated environment of the NaCl medium exhibited higher prevalence of steel-rebar corrosion risks than the acidic environment of H_2SO_4 medium, in the reinforced concretes immersed in these corrosive media;

• Statistical probability density fittings applications to the measured datasets of corrosion test-variables showed that the Weibull distribution function described the datasets of corrosion test-variable better than the Normal distribution function, according to Kolmogorov-Smirnov goodness-of-fit test criteria;

• Numerical correlation analyses of corrosion test-variables indicated that the correlation fittings of samples in NaCl medium exhibited excellent (by correlation coefficient, $r = 93.25\%$) or very good (by Nash-Sutcliffe efficiency, $NSE = 86.95\%$) prediction efficiency, while the correlation fittings of samples in the H_2SO_4 medium exhibited "very good" (by correlation coefficient, $r = 89.42\%$) or "excellent" (by Nash-Sutcliffe efficiency, $NSE = 96.24\%$) prediction efficiency;

• Ranking of admixture performance prediction models identified with optimal effectiveness in the NaCl medium, the 6 g $Na_2Cr_2O_7$ + 2 g $C_6H_{15}NO_3$ and the 2 g $Na_2Cr_2O_7$ + 6 g $C_6H_{15}NO_3$ partial $Na_2Cr_2O_7$ replacement admixtures which have respective inhibition efficiencies, $\eta = 91.7\%$ and $\eta = 90.0\%$, that could be classified as "excellent" efficiencies at inhibiting steel-rebar corrosion in chloride medium, this bear suggestions of the 6 g $C_6H_{15}NO_3$ as a high enough partial replacement model of the highly effective 6 g $Na_2Cr_2O_7$ at mitigating steel-rebar corrosion in chloride contaminated medium;

- The rankings of admixture performance prediction models identified the 2 g $Na_2Cr_2O_7$ + 6 g $C_6H_{15}NO_3$ with inhibition efficiency η = 52.5% which lagged behind that of the optimal 8 g $Na_2Cr_2O_7$ with inhibition efficiency η = 72.0% but both of which could be classified within the same "good" efficiency criteria of steel-rebar corrosion inhibition in the acidic medium.

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