Corrosion Rate and Noise Resistance Correlation from NaNO₂-Admixed Steel-Reinforced Concrete

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ABSTRACT
The lack of correlation from measurements of corrosion potential with corrosion rate in corrosion monitoring of steel-reinforced concrete has constituted concerns instigating demands for further experiments or additional monitoring techniques in corrosion studies. This paper studies correlation of corrosion rate from linear polarization resistance instrument and noise resistance from the ratio of standard deviations of corrosion potential to that of corrosion current measured from NaNO₂-admixed steel-reinforced concrete in 3.5% NaCl. Different concentrations of NaNO₂ were admixed in replicates of steel-reinforced concretes immersed in the saline/marine simulating test-solution and corrosion of the embedded steel-rebar were monitored using the three different, non-destructive, electrochemical methods. Measurements of corrosion test-data from these were subjected to the descriptive statistics of the Weibull distribution function, for which test-data compatibility was ascertained using the Kolmogorov-Smirnov goodness-of-fit statistics. The analysed results of the measured corrosion test-variables, exhibited good correlation between the corrosion rate, as the dependent variable and the function of the admixed NaNO₂ molar concentration and the noise resistance, as independent variables. Both experimental and prediction, from correlation fitting, models identified 0.1208 M NaNO₂, the optimal concentration employed in the study, with optimum effectiveness, of η>90%, at inhibiting steel-rebar corrosion in the corrosive solution of concrete test-immersion. These bear suggestions of the suitability of the analysed more easily measured corrosion potential and corrosion current for indicating the corrosion activity of steel-reinforcement in concrete designed for corrosive service-environments.

Key words: Reinforcing steel corrosion, corrosion test-data modelling, weibull distribution, goodness-of-fit test-statistics, correlation fitting analyses

INTRODUCTION
Reinforcing steel corrodes due to aggressive agents in the service-environment of steel reinforced concrete materials, widely used globally for building structures and infrastructures and thus militates against structural integrity of the concrete structures (Yohai et al., 2013; Hu et al., 2012). Among known aggressive agents causative of steel-reinforcement (steel-rebar) corrosion degradation, ingress of chloride ion from artificial de-icing salt and/or natural marine (sea water) constitutes dominant factor affecting steel-reinforced concrete durability (Romano et al., 2013; Yang et al., 2013). Among many methods identified in studies for mitigating concrete...
steel-reinforcement corrosion, the use of corrosion inhibitors has gained wide acceptability due to ease of applications, relative lower cost than other methods and effectiveness at inhibiting steel-rebar corrosion (Yohai et al., 2013; Etteyeb et al., 2007; Ormellese et al., 2006).

However, ascertaining effectiveness of inhibitors at mitigating steel-rebar corrosion in aggressive environment requires adequate monitoring of the metallic corrosion (Al-Mehthel et al., 2009). Among many methods for monitoring concrete steel-reinforcement corrosion, the use of electrochemical techniques has been identified with the greater success in literature due to its sharing the same electrochemical nature as the corrosion process (Romano et al., 2013). Another strong point supporting the electrochemical test-techniques of reinforcing steel corrosion in concrete includes the fact that they are also non-destructive methods. A well known, fast and easily applied electrochemical monitoring technique of the corrosion condition of concrete steel-rebar includes the open circuit (also known as the half-cell) potential (OCP or HCP) method (Okeniyi et al., 2012, 2014a; Omotosho et al., 2012, 2014; Gulikers, 2010; Burubai and Dagogo, 2007). According to Gulikers (2010) the measurement procedure of the OCP is simple and straightforward. Song and Saraswathy (2007) also described the OCP monitoring technique as the main method of detection of corrosion and the most typical routine inspection of reinforced concrete structures. Although, the principle involved in the OCP monitoring technique is the measurement of corrosion potential of the reinforcing steel in concrete relative to specified reference electrode, the procedure and interpretation of its test-results are described in the standard of the American Society for Testing and Materials, ASTM C876-91 R99 (ASTM., 2005a; Gulikers, 2010; Song and Saraswathy, 2007; Broomfield, 2002). However, this method suffers the setback that it can only provide information of corrosion probability but cannot indicate nor correlate with the quantitative rate of steel reinforcement corrosion in concrete (Gulikers, 2010; Song and Saraswathy, 2007).

The foregoing constitutes reasons for which Elsener et al. (2003), in the recommendation of RILEM on half-cell potential measurement, indicated that the evaluation of the effectiveness of inhibitors performance by using the half-cell (i.e. the open circuit) potential is difficult. For tackling these, Song and Saraswathy (2007) mandated complementing of open circuit potential measurements by other methods while Elsener et al. (2003) recommended more research for unambiguous evaluation of inhibitor effectiveness on steel-rebar corrosion.

These engender motivation of this research study towards investigation of a simple, fast and easily applied additional measurement for complementing open circuit potential and that will also foster the correlation of the OCP monitoring technique with corrosion rate. For this, the measurement of corrosion current by the Zero Resistance Ammeter (ZRA) relative to the same reference electrode employed for the OCP measurement was conceived based on the idealization of Daniel cell described in Broomfield (2002). The premise in this study was that the porous partition by the semi-permeable membrane of the requisite reference electrode would permit charge exchange, when the reference and working electrodes are joined across the ZRA, while being impervious to ion movement (Okeniyi et al., 2013a; Broomfield, 2002). This, according to McCarter and Vennesland (2004), is potent at constituting measurement model of the reinforcing steel dissolution activity in the aggressive system of corrosive test-solution.

In reported study submitted elsewhere (Okeniyi et al., 2013b), the measurement model of the corrosion potential from OCP and corrosion current from the ZRA has been employed along with inhibitor concentration for correlation with corrosion rate. However, it is of interest in this study to investigate how the ratio of the standard deviation of the corrosion potential by OCP to that of the corrosion current by ZRA would correlate with corrosion rate obtained from the Linear Polarisation Resistance (LPR) instrument. Such correlation, if it could be established would find
usefulness, especially, for quick detailing of inhibitor performance at inhibiting steel-rebar corrosion in chloride contaminated medium. In literature, deliberating on corrosion studies (Song and Saraswathy, 2007; Nunez-Jaquez et al., 2005; Eden, 2000; Kelly et al., 1996), the ratio of standard deviation of corrosion potential to that of the corrosion current has been identified as the noise resistance. However, in none of these was the descriptive statistics followed by the test-data of corrosion potential and/or corrosion current studied for detailing the measurement of dispersion, i.e. the standard deviation, being employed for the noise resistance evaluation. Such form of study, however, finds necessity from the consideration of ASTM G16-95 R04 (ASTM., 2005b) that prescribed that employing descriptive statistics for detailing test-data distributed in other manner could lead to grossly erroneous conclusion. Therefore, the objective of this study was to investigate correlation of corrosion rate and noise resistance test-data, obtained through requisite study of descriptive statistics followed by those data, for detailing NaNO₂ effectiveness on steel-reinforcement corrosion. The choice for NaNO₂ in the study, followed from its being well-known at inhibiting concrete steel-rebar corrosion (Okeniyi et al., 2013c; Mennucci et al., 2009; Soylev and Richardson, 2008) such that the procedures from this study could find applicability for detailing performance for other inhibiting substances that are yet not well-known.

MATERIALS AND METHODS
Steel reinforced concrete materials and NaNO₂ admixtures: Steel reinforced concretes blocks used for the experimental were cast in duplicated slabs (Haynie, 2005) of size 100×100×200 mm, using standard procedures from ASTM C192/192M-02 (ASTM., 2005c) as reported in Okeniyi et al. (2013a). In each of the slabs were embedded 150 mm out of the 190 mm length of Ø12 mm deformed steel reinforcement, which have the 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 duplicated steel-reinforced concretes totaled twelve specimens and the admixed NaNO₂ molar concentration (M) with respect to concrete mixing water for these samples were as presented in Table 1.

Experimental procedure of corrosion testing: Each specimen of steel reinforced concrete samples were partially immersed, longitudinally, in plastic bowls containing 3.5% NaCl test-solution for simulating saline/marine environments (Zhou et al., 2012; Mennucci et al., 2009). These test-medium were made up in each bowl to just below the reinforcing steel but without touching the rebar.

Electrochemical test-monitoring for which correlation were being sought require measurements from each of the steel-reinforced concretes that were taken at interval for 54-days experimental period which include:

Table 1: Molar concentration NaNO₂ admixture in specimens of steel reinforced concretes

| Admixture in concrete | Molar concentration NaNO₂ in NaCl |
|----------------------|---------------------------------|
| 0 M NaNO₂ (Blank) in NaCl |
| 0 M NaNO₂ (Blank) in NaCl (Dup) |
| 0.0242 M NaNO₂ in NaCl |
| 0.0242 M NaNO₂ in NaCl (Dup) |
| 0.0483 M NaNO₂ in NaCl |
| 0.0483 M NaNO₂ in NaCl (Dup) |
| 0.0725 M NaNO₂ in NaCl |
| 0.0725 M NaNO₂ in NaCl (Dup) |
| 0.0966 M NaNO₂ in NaCl |
| 0.0966 M NaNO₂ in NaCl (Dup) |
| 0.1208 M NaNO₂ in NaCl |
| 0.1208 M NaNO₂ in NaCl (Dup) |
• Corrosion potential (V in mV unit) through Open Circuit Potential (OCP) as per ASTM C876-91 R99 (ASTM., 2005a), versus Cu/CuSO₄ reference electrode (CSE) Model 8-A (from Tinker and Rasor®), using a high impedance digital multimeter (Okeniyi et al., 2014a)

• Corrosion current (I in µA unit) versus Cu/CuSO₄ reference electrode CSE, using ZRA instrument (McCarter and Vennesland, 2004; Broomfield, 2002) Model ZM3P (from Corrosion Service®)

• Corrosion Rate (CR) measurements through direct instrument conversion to mpy using the three-electrode LPR Data Logger (Sastri, 2011), Model MS1500L (from Metal Samples®)

**Data analysis**

**Fitting corrosion test-data to the Weibull distribution statistics:** Measured corrosion test-data were subjected to the statistical analysis of the Weibull distribution with probability and cumulative distribution functions (Roberge, 2000, 2003, 2005; Haynie, 2005) given by:

\[
f(x) = \left(\frac{k}{c}\right)x^{k-1}\exp\left[-\left(\frac{x}{c}\right)^{k}\right]
\]

\[
F(x) = 1 - \exp\left[-\left(\frac{x}{c}\right)^{k}\right]
\]

where, \(x\) denotes test-data of corrosion test-variable, \(k\) and \(c\) are the shape parameter and the scale parameter, respectively, of the Weibull distribution model. Estimations of \(k\) and \(c\) were obtained, for sample size \(n\), from the maximum likelihood equations (Okeniyi et al., 2014b; Kvam and Lu, 2006):

\[
\frac{n}{k} - n\ln(\hat{c}) + \sum_{i=1}^{n} \ln x_i - \sum_{i=1}^{n} \left(\frac{x_i}{\hat{c}}\right)^k \ln\left(\frac{x_i}{\hat{c}}\right) = 0
\]

\[
\hat{c} = \left[\frac{1}{n} \sum_{i=1}^{n} x_i^k\right]^{1/k} = 0
\]

The unbiased estimated values of \(k\) and \(c\), from these, were used to compute the respective Weibull mean, \(\mu\) and standard deviation, \(\sigma\), as (Okeniyi et al., 2014a; Ajayi et al., 2013):

\[
\mu = c\Gamma\left(1 + \frac{1}{k}\right)
\]

\[
\sigma = \sqrt{c^2\left[\Gamma\left(1 + \frac{2}{k}\right) - \left(\Gamma\left(1 + \frac{1}{k}\right)\right)^2\right]}
\]

where, \(\Gamma(\bullet)\) is the gamma function of \((\bullet)\).
**Goodness-of-fit test statistics:** As per recommendation of ASTM G16-95 R04 (ASTM., 2005b) and Roberge (2003), the compatibility of the test-data from the corrosion test-monitoring methods employed to the Weibull distribution were studied using the Kolmogorov-Smirnov (K-S) Goodness-of-Fit (GoF) test-statistics (Okeniyi and Okeniyi, 2012; Izquierdo et al., 2004). This employs measurement of the absolute difference between the empirical distribution function $F^*(x)$ and the theoretical distribution function $F(x)$, through the statistics:

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

(7)

The evaluated $D$-value from this equation finds usefulness for direct computation of the K-S p-value using the procedure that had been reported in Okeniyi and Okeniyi (2012).

**Evaluating test-data of noise resistance ($R_n$):** Distribution of the corrosion potential and the corrosion current like the Weibull pdf would satisfy the condition of ASTM G16-95 R04 (ASTM., 2005b) for using the Weibull pdf for describing these corrosion test-data. By this, the noise resistance test-data prevailing in each concrete samples would be obtained as the ratio of Weibull standard deviation of the corrosion potential (mV) to the Weibull standard deviation of corrosion current (mA), i.e. (Okeniyi et al., 2014b; Song and Saraswathy, 2007; Nunez-Jaquez et al., 2005; Eden, 2000; Kelly et al., 1996):

$$R_n = \frac{\sigma_{\text{V(Weibull)}}}{\sigma_{I(\text{Weibull})}}$$

(8)

**Performance evaluators for correlation fitting model:** The performance evaluators employed for the correlation fitting model between the corrosion rate (CR) and noise resistance ($R_n$) include the correlation coefficient ($r$) and the p-value from the one-way analysis of variance (ANOVA) modelling (Okeniyi et al., 2013a; Mandal and Jothiprakash, 2012; Izquierdo et al., 2004).

**Inhibition efficiency:** Inhibition efficiency model, $\eta$, was evaluated for the replicates of NaNO₂ admixed samples relative to the replicates of control samples, through the formula (Okeniyi et al., 2014c; Zhou et al., 2012):

$$\eta = \frac{\mu_{\text{ctrl}} - \mu_{\text{inh}}}{\mu_{\text{ctrl}}} \times 100$$

(9)

**RESULTS AND DISCUSSIONS**

**Statistical analysis of corrosion test-data:** The Weibull mean and standard deviation models for the corrosion potential and the corrosion current are shown in Fig. 1a-b, respectively. In the figure, the standard deviations are shown as error bars in the form ‘$\mu \pm \sigma$’. In addition, Fig. 1a includes the linear plots of corrosion risk interpretation according to ASTM C876-91 R99 (ASTM., 2005a).

It could be observed from Fig. 1a-b, that the plots of mean model of corrosion potential and corrosion current exhibited similar pattern of corrosion test-responses. However, the severe
probability of corrosion risk condition in the 0M NaNO₂ (blank) samples, as per the ASTM C876-91 R99 (ASTM., 2005a) interpretation in Fig. 1a, exhibited more pronounced prevalence in Fig. 1b compared to the other NaNO₂-Zad mixed steel-reinforced concretes. This showed that the blank samples in the study represent severe condition of corrosive test-system which finds agreement with the preferred practice prescribed by Roberge (2003) for reducing the time for effect to be observed.

The other statistical models that are based on the Weibull pdf are shown in Fig. 2. These include the plot of the Weibull mean models of corrosion rate on which the plot of the noise resistance was superimposed in Fig. 2a and the plot of the K-S goodness-of-fit testing of the compatibility of the measured corrosion test-data to the Weibull pdf in Fig. 2b. In agreement to the inference from Fig. 1, Fig. 2a shows that the corrosion rate model by the Weibull pdf for the 0M NaNO₂-admixed (blank) samples also portrayed prevalence of severe corrosion condition above that which obtains from the other NaNO₂-admixed samples. Also, notable from Fig. 2a was that the plots of the noise resistance that was also shown in the figure exhibited general trend of lower noise resistance attending higher corrosion rate. This finds agreement with the findings from Kelly et al. (1996), where noise resistance was observed as generally tracking the polarisation resistance, which is usually employed for computing corrosion rate. This bears suggestions of the existence of some sort of relation that could be correlated between the corrosion rate and the noise resistance response from the NaNO₂-admixed steel-reinforced concretes studied in this work.

Avoiding erroneous conclusion from the Weibull detailing of the corrosion test-results in the study however require that the measured test-data from the corrosion monitoring techniques were
distributed like the Weibull pdf (ASTM., 2005b; Roberge, 2003). This was ascertained by the K-S GoF test-results in Fig. 2b, where linear plots of significant level, α = 0.05, has been included for directly interpreting test-data scattering like the Weibull pdf. This figure shows that the K-S p-value is >0.05 for the measured test-data from the corrosion monitoring techniques that were employed for the NaNO₂-admixed steel-reinforced concrete specimens. This implies that each measured datasets of the corrosion monitoring techniques comes from the Weibull distribution, thus bearing supports for the use of the Weibull pdf as the descriptive statistics for detailing the corrosion condition in the concrete samples.

**Correlation fitting and analysis of corrosion test-results:** Several correlation fittings were employed and studied with fitting performances of correlation coefficient, r and analysis of variance (ANOVA) of the resultant relationship between the dependent and independent variables being studied. Thus, by using Corrosion Rate (CR) as independent variable this finds correlation fitting with the noise resistance (Rn) and the admixed NaNO₂ concentration in the steel-reinforced concretes (ζ) as dependent variable that assume the form:

\[
CR = 10^k \left\{ 1.62 e^{-\xi \left[ 1 - 0.016 (1/\ln R_n) \right] } + 22.31 \left[ (1/R_n) + 0.89 (1/\ln R_n) - 2.96 (1/\ln R_n)^2 \right] - 1.61 \right\}
\]

(10)
For this correlation fitting model, the correlation coefficient, $r = 89.61\%$. The results of the one-way analysis of variance modelling based on this correlation fitting are presented in Table 2. From the table, the ANOVA p-value = 0.04 which implies that it could not be rejected that there is significant relationship between the dependent variable (CR) and the independent variables ($R_n$) and ($\zeta$).

### Inhibition efficiency from the experimental and predicted models:

The inhibition efficiency modelling from the applications of Eq. 9 to the experimental and the predicted models of CR are presented in ranking order of admixed NaNO$_2$ effectiveness in Fig. 3. Both the experimental model, Fig. 3a and the predicted model from the correlation fitting, Fig. 3b, of NaNO$_2$ effectiveness ranking showed agreements in the inhibition efficiency estimated versus (vs) the blank sample and the inhibition efficiency estimated vs the blank duplicate sample.

Importantly worth noting from Fig. 3a includes the fact that the experimental model identified the 0.1208 M NaNO$_2$(Dup) with optimal effectiveness, $\eta_{\text{exp}}$ (vs blank) = 97.15% or $\eta_{\text{exp}}$ (vs blank$_{\text{Dup}}$) = 97.27%. However, despite the fact that the 0.1208 M NaNO$_2$(Dup) did not rank as the optimally effective admixture in the predicted model in Fig. 3b, the predicted model still find comparisons to the experimental model by identifying the 0.1208 M NaNO$_2$ as the most effective admixture. This other 0.1208 M NaNO$_2$ admixture exhibited $\eta_{\text{pred}}$ (vs blank) = 96.89% or $\eta_{\text{pred}}$ (vs blank$_{\text{Dup}}$) = 96.73% at inhibiting concrete steel-reinforcement corrosion. By these, the experimental and the predicted models identified the 0.1208 M NaNO$_2$ admixed concretes with inhibition efficiency $\eta > 90\%$ even as both models also identified the other NaNO$_2$ admixtures with highly positive effectiveness at inhibiting steel-rebar corrosion.

These results find agreements with literature (Mennucci et al., 2009; Vaysburd and Emmons, 2004), where NaNO$_2$ has been identified as effective inhibitor, although none of these investigated the correlation fitting agreements with the experimental models of the noise resistance with corrosion rate as was done in this study. These bear implications that the measurements of the corrosion potential that had been identified in studies (Song and Saraswathy, 2007; Elsener et al., 2003) as not correlating with corrosion rate could find corrosion rate correlation if combined with other measurements as had been suggested by those studies. Such other measurement could simply be that of the corrosion cell current, by ZRA, versus the same reference electrode that was employed for the OCP measurement. This form of correlation could have been made possible by the identification of such current as being proportional to the dissolution model of the steel-rebar (iron) in the corrosive medium by McCarter and Vennesland (2004). In that report also, McCarter and Vennesland (2004) identified the measurement of this form of galvanic current as technically simple to undertake compared to that of the corrosion rate by the polarisation resistance technique. By this, the kind of correlation fitting model, from this study, bearing significant relationship between the CR by LPR with the noise resistance could find usefulness and applications for studying inhibition effectiveness of novel admixtures that are not yet well known.
Inhibition efficiency models in ranking order performance by the admixed NaNO₂ concentrations in steel-reinforced concrete samples (a) By the experimental model and (b) By the prediction from the correlation fitting model.

**CONCLUSION**

Corrosion rate and noise resistance correlation from NaNO₂ admixed steel-reinforced concrete has been investigated in this study. From this the following conclusions can be drawn:

- The corrosion potential, corrosion current and corrosion rate test-data measurements from the NaNO₂-admixed concretes followed the Weibull probability distribution function at $\alpha = 0.05$ significant level, according to the Kolmogorov-Smirnov goodness-of-fit statistics, this supports the use of the Weibull pdf as the descriptive statistics for detailing the corrosion test-performance of the NaNO₂ admixtures.
- The corrosion rate from linear polarisation resistance instrument correlated with the noise resistance test-data obtained from the ratio of standard deviation of corrosion potential to that of corrosion cell current as well as the concentration of NaNO₂ admixture. This correlation fitting exhibited correlation coefficient, $r = 89.61\%$ and ANOVA p-value = 0.04 indicating that the relationship between the dependent variable (corrosion rate) and independent variables (noise resistance and concentration of NaNO₂ admixture) is significant.
Both experimental and correlation fitting models identified 0.1208 M NaNO₂ admixed steel-reinforced concretes with optimal efficiencies at inhibiting reinforcing steel corrosion. By the experimental model the 0.1208 M NaNO₂(Dup) exhibited \( \eta_{\text{exp}}(\text{vs blank}) = 97.15\% \) or \( \eta_{\text{exp}}(\text{vs blank(Dup)}) = 97.27\% \), while by the predicted model, from the correlation fitting, the 0.1208 M NaNO₂ exhibited \( \eta_{\text{pred}}(\text{vs blank}) = 96.89\% \) or \( \eta_{\text{pred}}(\text{vs blank(Dup)}) = 96.73\% \) at inhibiting reinforcing steel corrosion in the NaCl-immersed concretes.

The agreements between the experimental and the predicted models, of positive effectiveness of the admixed NaNO₂ concentrations at inhibiting steel-reinforcement corrosion in concrete samples immersed in the chloride contaminated solution, bear indication of the use of corrosion potential and corrosion cell current measurements for evaluating noise resistance as useful and more simpler measurements that is potent at exhibiting correlation with corrosion rate. These results suggest that the technically simple measurements of corrosion potential and corrosion cell current could find usefulness and applications for ascertaining effectiveness of novel and not yet well-known admixtures at inhibiting concrete steel-reinforcement corrosion in aggressive medium.

REFERENCES
ASTM., 2005a. Standard test method for half-cell potentials of uncoated reinforcing steel in concrete. ASTM C876-91 R99, ASTM International, Conshohocken, PA., USA.
ASTM., 2005b. Standard guide for applying statistics to analysis of corrosion data. ASTM G16-95 R04, ASTM International, Conshohocken, PA., USA.
ASTM., 2005c. Standard practice for making and curing concrete test specimens in the laboratory. ASTM C192/192M-02, ASTM International, West Conshohocken, PA., USA.
Ajayi, O.O., R.O. Fagbenle, J. Katende, S.A. Aasa and J.O. Okeniyi, 2013. Wind profile characteristics and turbine performance analysis in Kano, North-Western Nigeria. Int. J. Energy Environ. Eng., Vol. 4. 10.1186/2251-6832-4-27
Al-Mehtel, M., S. Al-Dulaijan, S.H. Al-Idi, M. Shameem, M.R. Ali and M. Maslehuddin, 2009. Performance of generic and proprietary corrosion inhibitors in chloride-contaminated silica fume cement concrete. Constr. Build. Mater., 23: 1768-1774.
Broomfield, J.P., 2002. Corrosion of Steel in Concrete: Understanding, Investigation and Repair. CRC Press/Taylor and Francis Group, Boca Raton, FL., USA., ISBN-13: 9780203475287, Pages: 264.
Burubai, W. and G. Dagogo, 2007. Comparative study of inhibitors on the corrosion of mild steel reinforcement in concrete. Agric. Eng. Int. CIGR Ejournal, 9: 1-10.
Eden, D.A., 2000. Electrochemical Noise. In: Uhlig’s Corrosion Handbook, Revie, R.W. (Ed.). 2nd Edn., John Wiley and Sons, New York, USA., ISBN-13: 9780471157779, pp: 1227-1238.
Elsener, B., C. Andrade, J. Gulikers, R. Polder and M. Raupach, 2003. Hall-cell potential measurements-potential mapping on reinforced concrete structures. Mater. Struct., 36: 461-471.
Etteyeb, N., L. Dhouibi, H. Takenouti, M.C. Alonso and E. Triki, 2007. Corrosion inhibition of carbon steel in alkaline chloride media by Na₃PO₄. Electrochimica Acta, 52: 7506-7512.
Gulikers, J., 2010. Statistical interpretation of results of potential mapping on reinforced concrete structures. Eur. J. Environ. Civil Eng., 14: 441-466.
Haynie, F.H., 2005. Statistical Treatment of Data, Data Interpretation and Reliability. In: Corrosion Tests and Standards: Application and Interpretation, Baboian, R. (Ed.). 2nd Edn., ASTM International, West Conshohocken, PA, pp: 83-88.
Hu, J., D.A. Koleva and K. van Breugel, 2012. Corrosion performance of reinforced mortar in the presence of polymeric nano-aggregates: Electrochemical behavior, surface analysis and properties of the steel/cement paste interface. J. Mater. Sci., 47: 4981-4995.

Izquierdo, D., C. Alonso, C. Andrade and M. Castellote, 2004. Potentiostatic determination of chloride threshold values for rebar depassivation: Experimental and statistical study. Electrochim. Acta, 49: 2731-2739.

Kelly, R.G., M.E. Inman and J.L. Hudson, 1996. Analysis of Electrochemical Noise for Type 410 Stainless Steel in Chloride Solutions. In: Electrochemical Noise Measurement for Corrosion Applications, Kearns, J.R., J.R. Scully, P.R. Roberge, D.L. Reichert and J.L. Dawson (Eds.). ASTM International, USA, ISBN-13: 9780803120327, pp: 101-113.

Kvam, P. and J.C. Lu, 2006. Statistical Reliability with Applications. In: Springer Handbook of Engineering Statistics, Pham, H. (Ed.). Chapter 2, Springer, London, UK, ISBN: 978-1-85233-806-0, pp: 49-61.

Mandal, T. and V. Jothiprakash, 2012. Short-term rainfall prediction using ANN and MT techniques. ISH J. Hydraul. Eng., 18: 20-26.

McCarter, W.J. and O. Vennesland, 2004. Sensor systems for use in reinforced concrete structures. Constr. Build. Mater., 18: 351-358.

Mennucci, M.M., E.P. Banczek, P.R.P. Rodrigues and I. Costa, 2009. Evaluation of benzotriazole as corrosion inhibitor for carbon steel in simulated pore solution. Cem. Concr. Compos., 31: 418-424.

Nunez-Jaquez, R.E., C. Gaona-Tiburcio, J. Uruchurtu-Chavarin, C.P. Barrios-Durstewitz, F. Almeraya-Calderon and A. Martinez-Villafane, 2005. Corrosion evaluation of modified reinforcement concrete by electrochemical noise techniques. Portugaliae Electrochimica Acta, 23: 111-121.

Okeniyi, J.O. and E.T. Okeniyi, 2012. Implementation of kolmogorov-smirnov p-value computation in visual basic®: Implication for Microsoft Excel® library function. J. Stat. Comput. Simul., 82: 1727-1741.

Okeniyi, J.O., O.A. Omotosho, O.O. Ajayi, O.O. James and C.A. Loto, 2012. Modelling the performance of sodium nitrate and aniline as inhibitors in the corrosion of steel-reinforced concrete. Asian J. Applied Sci., 5: 132-143.

Okeniyi, J.O., I.J. Ambrose, I.O. Oladele, C.A. Loto and P.A.I. Popoola, 2013a. Electrochemical performance of sodium dichromate partial replacement models by triethanolamine admixtures on steel-rebar corrosion in concretes. Int. J. Electrochem. Sci., 8: 10758-10771.

Okeniyi, J.O., I.O. Oladele, I.J. Ambrose, S.O. Okpala, O.M. Omoniyi, C.A. Loto and A.P.I. Popoola, 2013b. Analysis of inhibition of concrete steel-rebar corrosion by Na2Cr2O7 concentrations: Implications for conflicting reports on inhibitor effectiveness. J. Cent. South Univ., 20: 3697-3714.

Okeniyi, J.O., O.M. Omoniyi, S.O. Okpala, C.A. Loto and A.P.I. Popoola, 2013c. Effect of ethylenediaminetetraacetic disodium dihydrate and sodium nitrite admixtures on steel-rebar corrosion in concrete. Eur. J. Environ. Civil Eng., 17: 398-416.

Okeniyi, J.O., C.A. Loto and A.P.I. Popoola, 2014a. Rhizophora mangle L. effects on steel-reinforced concrete in 0.5 M H2SO4: Implications for corrosion-degradation of wind-energy structures in industrial environments. Energy Procedia, 50: 429-436.

Okeniyi, J.O., C.A. Loto and A.P.I. Popoola, 2014b. Electrochemical performance of Anthocephala djalonensis on steel-reinforcement corrosion in concrete immersed in saline/marine simulating-environment. Trans. Indian Inst. Met., 67: 959-969.
Okeniyi, J.O., O.A. Omotosho, O.O. Ajayi and C.A. Loto, 2014c. Effect of potassium-chromate and sodium-nitrite on concrete steel-rebar degradation in sulphate and saline media. Construct. Build. Mater., 50: 448-456.

Omotosho, O.A., J.O. Okeniyi, O.O. Ajayi and C.A. Loto, 2012. Effect of synergies of K₂Cr₂O₇, K₂CrO₄, NaNO₂ and aniline inhibitors on the corrosion potential response of steel reinforced concrete in saline medium. Int. J. Environ. Sci., 2: 2346-2359.

Omotosho, O.A., C.A. Loto, O.O. Ajayi, J.O. Okeniyi and A.P.I. Popoola, 2014. Investigating potassium chromate and aniline effect on concrete steel rebar degradation in saline and sulphate media. Int. J. Electrochem. Sci., 9: 2171-2185.

Ormellese, M., M. Berra, F. Bolzoni and T. Pastore, 2006. Corrosion inhibitors for chlorides induced corrosion in reinforced concrete structures. Cement Concrete Res., 36: 536-547.

Roberge, P.R., 2000. Handbook of Corrosion Engineering. McGraw-Hill Professional, New York, USA., ISBN-13: 9780070765160, Pages: 1072.

Roberge, P.R., 2003. Statistical Interpretation of Corrosion Test Results. In: ASM Handbook: Corrosion: Fundamentals, Testing and Protection, Cramer, S.D. and B.S. Covino (Eds.). 10th Edn., ASM International, USA., ISBN-13: 978-0871707055, pp: 425-429.

Roberge, P.R., 2005. Computer based Data Organization and Computer Applications. In: Corrosion Tests and Standards: Application and Interpretation, Baboian, R. (Ed.). 2nd Rev. Edn., ASTM International, USA., ISBN-13: 9780803120983, pp: 89-104.

Romano, P., P.S.D. Brito and L. Rodrigues, 2013. Monitoring of the degradation of concrete structures in environments containing chloride ions. Constr. Build. Mater., 47: 827-832.

Sastri, V.S., 2011. Green Corrosion Inhibitors: Theory and Practice. John Wiley and Sons, New York, USA., ISBN-13: 978-0470452103, Pages: 328.

Song, H.W. and V. Saraswathy, 2007. Corrosion monitoring of reinforced concrete structures-A review. Int. J. Electrochem. Sci., 2: 1-28.

Soylev, T.A. and M.G. Richardson, 2008. Corrosion inhibitors for steel in concrete: State-of-the-art report. Constr. Build. Mater., 22: 609-622.

Vaysburd, A.M. and P.H. Emmons, 2004. Corrosion inhibitors and other protective systems in concrete repair: Concepts or misconcepts. Cem. Concr. Compos., 26: 255-263.

Yang, Z., H. Fischer and R. Polder, 2013. Modified hydrotalcites as a new emerging class of smart additive of reinforced concrete for anticorrosion applications: A literature review. Mater. Corrosion, 64: 1066-1074.

Yohai, L., M. Vazquez and M.B. Valcarce, 2013. Phosphate ions as corrosion inhibitors for reinforcement steel in chloride-rich environments. Electrochimica Acta, 102: 88-96.

Zhou, X., H. Yang and F. Wang, 2012. Investigation on the inhibition behavior of a pentaerythritol glycoside for carbon steel in 3.5% NaCl saturated Ca(OH)_2 solution. Corrosion Sci., 54: 193-200.