METHODS OF ASTM G16 AND CONFLICTS IN CORROSION TEST DATA: CASE STUDY OF NANO$_2$ EFFECTIVENESS ON STEEL-REBAR CORROSION

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ABSTRACT

In this paper, applications of the methods of ASTM G16 for addressing inherent conflicts in laboratory measurements of corrosion test data were studied, using the inhibiting effect of NaNO$_2$ on the corrosion of concrete steel-rebar for the case study. For this, electrochemical monitoring techniques were employed for studying effectiveness of different concentrations of NaNO$_2$ admixture in replicated concrete samples immersed in NaCl and in H$_2$SO$_4$ media for an experimental period of sixty-eight days. The corrosion test data from this experimental setup were subjected to the probability density fittings of the Normal and the Weibull functions as well as to significance testing methods of ASTM G16-99 R04 specifications. Results identified 10g (0.1208M) NaNO$_2$ admixture with optimal inhibition efficiency model, $\eta = 88.38\pm4.62\%$, in the saline/marine simulating environment and the 8 g (0.0966M) NaNO$_2$ admixture with optimum effectiveness, $\eta = 13.51\pm83.48\%$, in the acidic environment. The techniques of ASTM G16 adequately identified and addressed conflicting effectiveness from the test data of NaNO$_2$ admixtures in the studied test environments.

Keywords: Steel-rebar, corrosion inhibition, normal and weibull pdf's, statistical tests.

INTRODUCTION

Corrosion of concrete steel-rebar affects durability of reinforced concrete structures and infrastructures which is generating safety and socio-economic concerns globally (Dong *et al*., 2012; Tang *et al*., 2012; Ormellese *et al*., 2009). Environmental agents of corrosion such as carbonation, chloride ingress and acidic sulphate attack renders steel-rebar in concrete susceptible to corrosion damage by reducing concrete alkalinity and initiating destruction of protective passive layer from cement hydration (Tang *et al*., 2012; Tommaselli *et al*., 2009). Methods proposed in studies for mitigating steel-rebar corrosion had include practices for improving concrete durability and measures of preventing concrete steel rebar corrosion (Dong *et al*., 2012; Shi *et al*., 2012). For these, use of corrosion inhibitor had been identified as an easy and economical method for preventing reinforcing steel corrosion and prolonging service life of reinforced concrete structures (Ormellese *et al*., 2009; Tommaselli *et al*., 2009).

In spite of the ease and cost effectiveness advantages of corrosion inhibitors for mitigating rebar corrosion, its responsible application requires satisfying the critical demand of its presence in suitable concentration for it to be effective in the corrosive environment (Söylev and Richardson, 2008). This dependency of inhibitor

effectiveness its suitable concentration in the corrosive system has lead to prevalence of contradictory effectiveness reports in literature (Feng *et al*., 2011; Ormellese *et al*., 2009; Söylev and Richardson, 2008; Jamil *et al*., 2003). Even, well known inhibitors and commercialised ones were not spared from these (Królikowski and Kuziak, 2011; Ormellese *et al*., 2006; Jamil *et al*., 2003). While some studies reported effective corrosion inhibitions, others had requested need for further research. Reasons identified by Ormellese *et al*. (2009) for these include lack of standard procedure for evaluating effectiveness and non-availability of reliable test data.

The standard of the American Society of Testing and Materials, ASTM, designation G16 had recognised that corrosion test data could be characterised by inherent scatter that would make interpretation difficult for investigators. These scatter, according to the standard, usually originate from variety of factors which instigate stochastic deviations of measured values from the expected values of the prevailing condition. Without a standard procedure for addressing these randomised deviations, in corrosion test data, interpretations of such data could be contradictory. However, ASTM G16 had proposed statistical evaluation procedures that could be used, as the rational approach, for tackling difficulties arising from unaccounted factors which induce

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randomised scatter in corrosion test data.

In spite of these, there is paucity of study where ASTM G16 methods had been employed for analysing corrosion test data for the study of corrosion inhibition of concrete steel-rebar. While Castrellon-Uribe *et al.* (2008) and Cuevas-Arteaga (2008) had employed ASTM G16 for analysing electrochemical noise test data from the corrosion of stainless steel and of high temperature HK-40m alloy, respectively, none of these involve corrosion inhibition. No study has used the procedures of this standard for investigating $NaNO_2$ effect on reinforcing steel corrosion. This study therefore examines the applications of ASTM G16-99 R04 methods for studying corrosion inhibition of sodium nitrite ($NaNO_2$) admixture in steel reinforced concrete. The interests in the work include employing inhibiting properties of $NaNO_2$ admixture on rebar corrosion to study how procedures of ASTM G16 could be employed for addressing or identifying conflicts in corrosion test results of steel reinforcement in concrete.

MATERIALS AND METHODS

Materials
Steel reinforced concretes and inhibitor admixtures
Ø12mm deformed steel reinforcement was obtained from Federated Steel Rolling Mills, Ota, Ogun State, Nigeria, for use in this study. This rebar, having 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, was cut into 190mm rods for each specimen.

Twenty-eight reinforced concrete block samples used for the experiment were produced as replicated "_R" blocks (Haynie, 2005), each of size 100mm × 100mm × 200mm. Embedded in each block was 150mm length of the steel rebar which was symmetrically placed across the width of the block leaving 40mm steel protrusion for electrochemical connections. This protrusion was painted with glossy paint for each block. The formulation used for the reinforced concrete specimens was $300.0kg/m^3$ of cement, $149.7kg/m^3$ of water, $890.6kg/m^3$ of sand, and $1106.3kg/m^3$ of granite stones. The water/cement (w/c) ratio was 0.499. The concentration of $NaNO_2$ admixed in each of these reinforced concrete samples are shown in Table 1, in which the aggressive solution of their immersion were also indicated.

Experimental Procedures
Corrosion test setup and electrochemical test measurements
Steel reinforced concrete samples were partially immersed, longitudinally, in plastic bowls containing solution of corrosive test environments. Each of the first replicated set of fourteen samples was partially immersed in 3.5% NaCl solution and the second replicated set in $0.5M$ H_2SO_4 solution. In each bowl, the test solution was made up to just below the reinforcing steel rebar but was not touching it.

Non-destructive electrochemical measurements (Song and Saraswathy, 2007; Broomfield, 1997) were taken from the experimental setup, first, in five days interval for forty days and thereafter in seven days interval for the following four weeks. This totals sixty-eight days experimental period. The electrochemical test methods employed include:

i. Half-cell potential (HCP) according to ASTM C876-91 R99, versus $Cu/CuSO_4$ electrode (CSE), using a high impedance digital multimeter;
ii. Corrosion cell current (CCC) in the concrete-test solution system, versus CSE, using zero resistance ammeter (McCarter and Vennesland, 2004; Broomfield, 1997);

Table 1. Concentrations of $NaNO_2$ admixed in sample of steel reinforced concretes.

S.No	Admixture in concrete	S.No	Admixture in concrete	S.No	Admixture in concrete	S.No	Admixture in concrete
1.	0 g $NaNO_2$ (Control in NaCl)	2.	0 g $NaNO_2$ (Control in H_2SO_4)	3.	0 g $NaNO_2$ (Control in NaCl_R)	4.	0 g $NaNO_2$ (Control in H_2SO_4_R)
5.	2 g (0.0242M) $NaNO_2$ in NaCl	6.	2 g (0.0242M) $NaNO_2$ in H_2SO_4	7.	2 g (0.0242M) $NaNO_2$ in NaCl_R	8.	2 g (0.0242M) $NaNO_2$ in H_2SO_4_R
9.	4 g (0.0483M) $NaNO_2$ in NaCl	10.	4 g (0.0483M) $NaNO_2$ in H_2SO_4	11.	4 g (0.0483M) $NaNO_2$ in NaCl_R	12.	4 g (0.0483M) $NaNO_2$ in H_2SO_4_R
13.	6 g (0.0725M) $NaNO_2$ in NaCl	14.	6 g (0.0725M) $NaNO_2$ in H_2SO_4	15.	6 g (0.0725M) $NaNO_2$ in NaCl_R	16.	6 g (0.0725M) $NaNO_2$ in H_2SO_4_R
17.	8 g (0.0966M) $NaNO_2$ in NaCl	18.	8 g (0.0966M) $NaNO_2$ in H_2SO_4	19.	8 g (0.0966M) $NaNO_2$ in NaCl_R	20.	8 g (0.0966M) $NaNO_2$ in H_2SO_4_R
21.	10 g (0.1208M) $NaNO_2$ in NaCl	22.	10 g (0.1208M) $NaNO_2$ in H_2SO_4	23.	10 g (0.1208M) $NaNO_2$ in NaCl_R	24.	10 g (0.1208M) $NaNO_2$ in H_2SO_4_R
25.	16 g (0.1932M) $NaNO_2$ in NaCl	26.	16 g (0.1932M) $NaNO_2$ in H_2SO_4	27.	16 g (0.1932M) $NaNO_2$ in NaCl_R	28.	16 g (0.1932M) $NaNO_2$ in H_2SO_4_R

iii. Corrosion rate (CR) measurements through direct instrument conversion to mpy using the three-electrode LPR Data Logger, Model MS1500L (Sastri, 2011).

For ensuring good electrical contact for these measurements, a water retentive conducting sponge was employed for the point of contact of the measuring probes and the reinforced concrete (Song and Saraswathy, 2007). This sponge was wetted before measurements using solution containing drinkable tap water, iso-propyl alcohol and detergent (ASTM C876-91 R99).

Data Analysis
Probability distribution modelling
Each measured variable of electrochemical test data, x, were subjected to the statistical analysis of the Normal and the Weibull probability density functions, pdf's (Okeniyi *et al.*, 2013; Roberge, 2008; Roberge, 2005). These have respective cumulative density function given by:

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

$$F(x) = 1 - \exp\left\{ -\left(\frac{x}{c} \right)^k \right\} \quad (2)$$

Where μ and σ are the mean and standard deviation of the Normal model, k and c are the shape parameter and the scale parameter of the Weibull model. Estimations of k and c were obtained, for sample size n, from the maximum likelihood equations (Kvam and Lu, 2006):

$$\frac{n}{\hat{k}} - n \ln(\hat{c}) + \sum_{i=1}^{n} \ln x_i - \sum_{i=1}^{n} \left(\frac{x_i}{\hat{c}} \right)^{\hat{k}} \ln\left(\frac{x_i}{\hat{c}} \right) = 0 \quad (3)$$

$$\hat{c} - \left\{ \frac{1}{n} \sum_{i=1}^{n} x_i^{\hat{k}} \right\}^{\frac{1}{\hat{k}}} = 0 \quad (4)$$

These estimates were used to compute the Weibull mean model, μ_W, as (Omotosho et al, 2010)

$$\mu_W = c\Gamma\left(1 + \frac{1}{k} \right) \quad (5)$$

Where $\Gamma(\cdot)$ is the gamma function of $(\cdot)$.

Goodness-of-fit and significance of difference tests
As prescribed by ASTM G16-95 R04, compatibility of each variable of electrochemical data to the Normal and the Weibull distribution functions were verified using the Kolmogorov–Smirnov (K-S) goodness-of-fit (GoF) test statistics at $\alpha = 0.05$ significant level (Okeniyi *et al.*, 2013; Okeniyi and Okeniyi, 2012; Omotosho *et al.*, 2010; Roberge, 2005). This test measures the absolute difference between empirical distribution function $F^*(x)$ and theoretical distribution function $F(x)$, for n data points, through the statistics (Okeniyi and Okeniyi, 2012)

$$D_n = D(x_1,...,x_n) = \sup_{-\infty < x < \infty} \left| F^*(x) - F(x) \right| \quad (6)$$

Also from ASTM G16-95 R04, differences of central tendency evaluations for the replicated samples of each $NaNO_2$ admixtures, 0g to 16g, were studied for significance using student's t-test statistics. These include the t-test with equal variance (EV) and that with unequal

Table 2. Mean of corrosion test data by the Normal and the Weibull pdf models for samples in NaCl medium.

S. No.	Admixture concentration in concrete	Normal distribution			Weibull distribution		
		HCP (-mV CSE) ($\mu_{N\text{-}HCP}$)	CCC (-µA) ($\mu_{N\text{-}CCC}$)	CR (mm/y) ($\mu_{N\text{-}CR}$)	HCP (-mV CSE) ($\mu_{W\text{-}HCP}$)	CCC (-µA) ($\mu_{W\text{-}CCC}$)	CR (mm/y) ($\mu_{W\text{-}CR}$)
1.	0g NaNO$_2$ (Ctrl) in NaCl	597.31	647.00	2.354	590.38	658.82	5.278
2.	0g NaNO$_2$ (Ctrl) in NaCl_R	567.62	710.88	2.360	560.34	718.46	5.415
3.	2g NaNO$_2$ in NaCl	523.23	200.81	1.149	518.66	201.13	1.564
4.	2g NaNO$_2$ in NaCl_R	483.72	187.96	1.345	482.84	192.75	1.821
5.	4g NaNO$_2$ in NaCl	512.54	224.85	0.743	508.98	225.71	0.876
6.	4g NaNO$_2$ in NaCl_R	510.51	230.54	1.348	508.04	232.89	1.925
7.	6g NaNO$_2$ in NaCl	444.77	165.65	0.383	443.94	165.56	0.511
8.	6g NaNO$_2$ in NaCl_R	535.38	290.54	0.796	527.07	290.96	1.013
9.	8g NaNO$_2$ in NaCl	447.64	186.66	0.729	446.99	190.39	1.038
10.	8g NaNO$_2$ in NaCl_R	469.44	199.95	0.846	465.12	205.76	1.360
11.	10g NaNO$_2$ in NaCl	356.85	111.82	0.576	355.26	111.86	0.835
12.	10g NaNO$_2$ in NaCl_R	484.03	146.08	0.311	483.90	146.37	0.407
13.	16g NaNO$_2$ in NaCl	496.26	255.88	0.916	489.50	254.56	1.199
14.	16g NaNO$_2$ in NaCl_R	368.31	175.61	0.606	368.23	175.95	0.827

variance (UV) assumptions. Significance of differences of variability was investigated using one-way (factorial) analysis of variance, ANOVA. These methods test whether differences encountered in replicated samples (the *t*-test) or in concrete samples with different admixtures (the factorial ANOVA) were significant or due to chance or experimental complexities/error.

Inhibition efficiency

Inhibition efficiency model, η, was evaluated for the replicates of $NaNO_2$ admixed samples relative to the replicates of control samples, through the formula (Obot *et al*., 2010):

$$\eta = \frac{\mu_{ctrl} - \mu_{inh}}{\mu_{ctrl}} \times 100 \qquad (7)$$

RESULTS AND DISCUSSION

Corrosion test data modelling and analyses

Results of corrosion test data by the Normal and the Weibull distribution models are presented, for samples immersed in NaCl in table 2 and samples in H_2SO_4 in Table 3. From the pdf models, the Weibull mean were underestimated, compared to the Normal mean, for the HCP of all samples and the CCC of two other samples (6g and 16g) in NaCl, for the HCP of a replicate of 2g as well as the CR of a replicate of 4g sample in H_2SO_4 medium. Apart from these, the Weibull mean for the test variables

Table 3. Mean of corrosion test data by the Normal and the Weibull pdf models for samples in H_2SO_4 medium.

S. No.	Admixture concentration in concrete	Normal distribution			Weibull distribution		
		HCP (-mV CSE) ($\mu_{N\text{-HCP}}$)	CCC (-μA) ($\mu_{N\text{-CCC}}$)	CR (mm/y) ($\mu_{N\text{-CR}}$)	HCP (-mV CSE) ($\mu_{W\text{-HCP}}$)	CCC (-μA) ($\mu_{W\text{-CCC}}$)	CR (mm/y) ($\mu_{W\text{-CR}}$)
1.	0g $NaNO_2$ (Ctrl) in H_2SO_4	257.41	77.65	0.270	265.37	83.19	0.316
2.	0g $NaNO_2$ (Ctrl) in H_2SO_4_R	451.59	146.49	0.181	472.17	146.53	0.198
3.	2g $NaNO_2$ in H_2SO_4	333.08	56.94	0.145	334.27	57.41	0.163
4.	2g $NaNO_2$ in H_2SO_4_R	72.64	6.05	0.641	71.49	6.25	0.838
5.	4g $NaNO_2$ in H_2SO_4	132.87	23.97	0.216	142.33	24.35	0.226
6.	4g $NaNO_2$ in H_2SO_4_R	70.49	12.80	0.460	71.31	13.03	0.434
7.	6g $NaNO_2$ in H_2SO_4	192.36	44.39	0.423	192.47	44.96	0.571
8.	6g $NaNO_2$ in H_2SO_4_R	109.82	20.13	0.470	110.99	20.44	0.634
9.	8g $NaNO_2$ in H_2SO_4	102.33	15.01	0.044	104.44	15.07	0.046
10.	8g $NaNO_2$ in H_2SO_4_R	119.56	16.74	0.272	120.59	16.90	0.375
11.	10g $NaNO_2$ in H_2SO_4	424.62	104.75	0.804	440.99	107.38	1.018
12.	10g $NaNO_2$ in H_2SO_4_R	261.31	44.95	0.617	277.57	45.81	0.795
13.	16g $NaNO_2$ in H_2SO_4	136.82	37.37	0.111	175.99	37.41	0.115
14.	16g $NaNO_2$ in H_2SO_4_R	208.44	54.97	0.487	209.21	55.41	0.525

Table 4. ANOVA of corrosion test data of concrete samples.

Test Data	Source of variations	Deg of Free dom	Samples in NaCl medium				Samples in H_2SO_4 medium			
			SS	MS	*F*	*p*-value	SS	MS	*F*	*p*-value
HCP	Treatments	13	757509.07	58269.93	2.6610	**0.0021**	2650592.16	203891.70	14.8553	**0.0000**
	Residuals	168	3678883.21	21898.11			2305834.63	13725.21		
	Totals	181	4436392.29				4956426.79			
CCC	Treatments	13	5513494.09	424114.93	9.5242	**0.0000**	266171.70	20474.75	12.2663	**0.0000**
	Residuals	168	7481092.64	44530.31			280423.73	1669.19		
	Totals	181	12994586.73				546595.43			
CR	Treatments	13	69.32	5.33	1.8023	**0.0462**	8.58	0.66	0.8080	**0.6512**
	Residuals	168	497.02	2.96			137.22	0.82		
	Totals	181	566.33				145.79			

of the remaining samples in both media were overestimated compare to their Normal mean. For the CR (mm/y) of the control samples in NaCl medium the Weibull mean overestimations, ($\mu_W = 5.278$; $\mu_{W(rep)} = 5.415$), more than doubled the Normal mean modelled for these samples, ($\mu_N = 2.354$; $\mu_{N(rep)} = 2.360$). However, other overestimations by the Weibull were in moderate proportions compare to their Normal values.

Kolmogorov-Smirnov goodness-of-fit test results
The graphical representation of the K-S GoF *p*-values was as shown in figure 1, for samples in NaCl, figure 1(a) and in H$_2$SO$_4$, figure 1(b). These also include the significant level $\alpha = 0.05$ for identifying test data which follow/did not follow the pdf models. From the figure, it could be observed that all data of the test variables of the studied samples in both test media, scattered like the Weibull pdf. While all the HCP and the CCC test data also followed the Normal pdf, in both test media, eleven, out of the twenty-eight test samples being investigated, had the test

data of CR not following the Normal pdf, according to the K-S GoF test statistics. In spite of the CR overestimations of Weibull mean for the replicated control samples in NaCl medium, compared to the Normal, the CR test data of these samples followed the Weibull pdf even with higher K-S *p*-values (0.169, 0.176$_{(rep)}$) than that from the Normal (0.063, 0.074$_{(rep)}$).

The Kolmogorov-Smirnov GoF tests results were in agreements for many of the replicated samples studied. However, discrepancies in results still abound that could lead to conflicting interpretations of results even between replicates of concrete samples, with the same NaNO$_2$ admixtures that agreed in following/not following, the pdf models employed. Addressing these conflicts require needs of testing if these differences, encountered within replicates of samples, were significant or not through the use of the student's *t*-test statistics.
Significance of difference testing between replicates
Significance test results, obtained through the student's *t*-
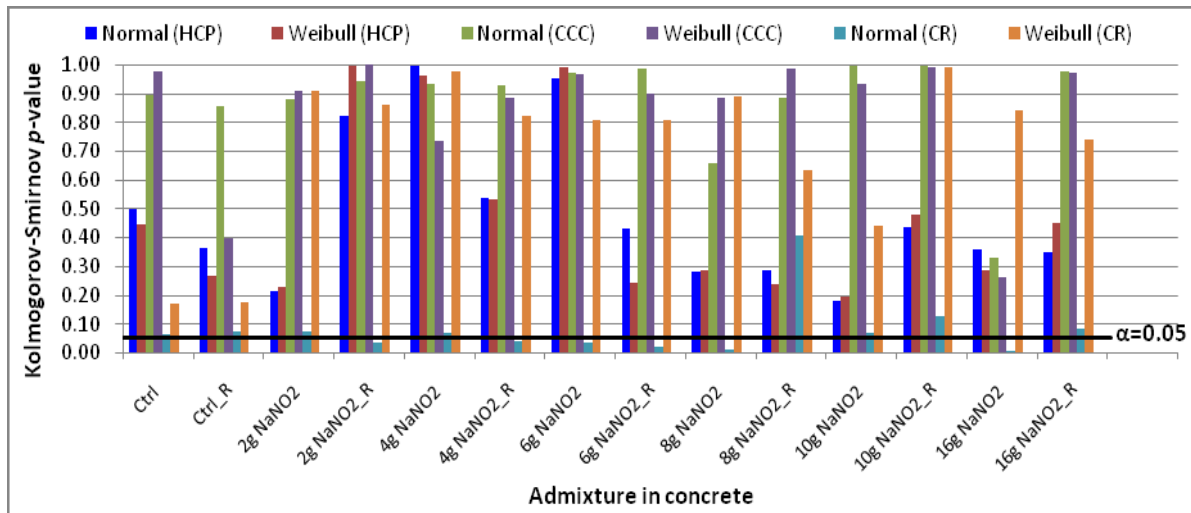
(a)
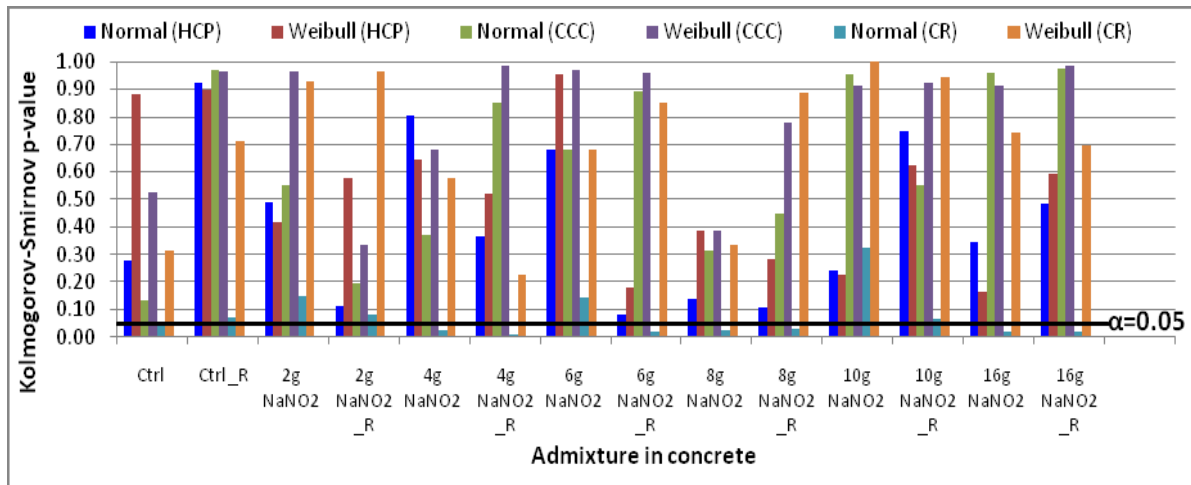
(b)

Fig. 1. Results of K-S goodness of fit tests for concrete specimens in (a) NaCl medium (b) H$_2$SO$_4$ medium.

test statistics, of test data differences between replicated concrete samples are presented in figure 2, for each replicated NaNO$_2$ admixed concretes in the NaCl, figure 2(a), and H$_2$SO$_4$ media, figure 2(b). These also include the significant level α = 0.05 for directly identifying significant difference.

Figure 2(a) showed that the differences encountered in the corrosion test data of the replicated samples of the control, the 2g NaNO$_2$, the 4g NaNO$_2$ and the 8g NaNO$_2$ in NaCl medium were not significant. In the H$_2$SO$_4$, figure 2(b), medium, only the replicated samples with 8g NaNO$_2$ admixture exhibited differences that were not significant, according to the student's *t*-test. The CCC data of the replicated samples with 6g NaNO$_2$ and the HCP data of the 10g NaNO$_2$ replicates as well as replicates of 16g NaNO$_2$ had differences that were significant, in the NaCl medium. All concrete samples

immersed in H$_2$SO$_4$ had HCP and CCC test data of their replicates exhibiting differences that were significant except all the corrosion test data of samples with 8g NaNO$_2$ and the CCC data of the 6g NaNO$_2$ samples. All these were invariant for the *t*-test with equal variance and the *t*-test with unequal variance assumptions.

The corrosion rate (CR) test data for all replicated samples in this study had differences between the replicates of their samples that were due to chance but that were not significant, in their respective test environments, figure 2(a) and figure 2(b). All these constitute statistical bases for differences between replicate samples with same admixture concentration and from this the differences among samples with different admixture concentrations could be investigated using ANOVA, according to specifications of ASTM G16.
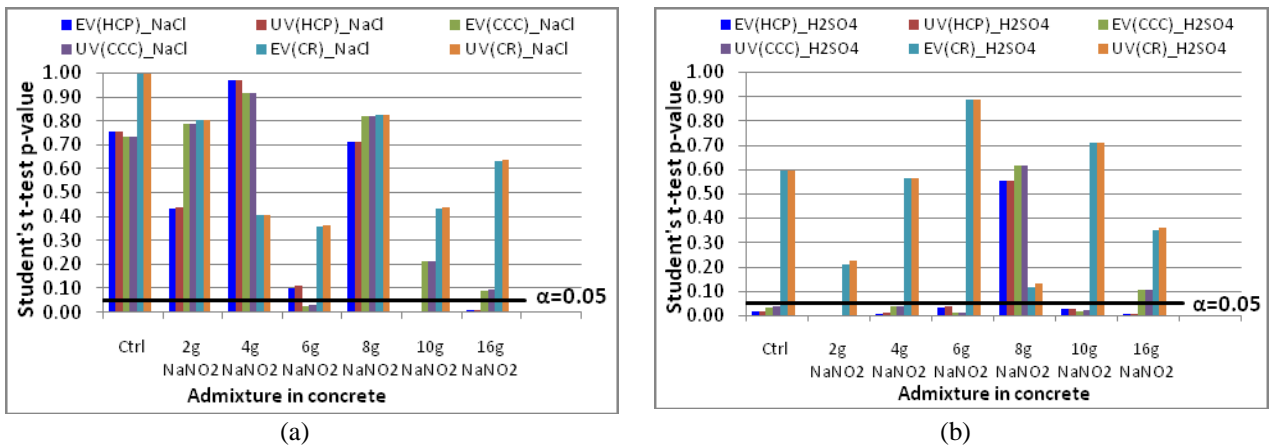

Fig. 2. Results of student's *t*-test statistics for replicated concrete samples in (a) NaCl medium (b) H$_2$SO$_4$ medium.
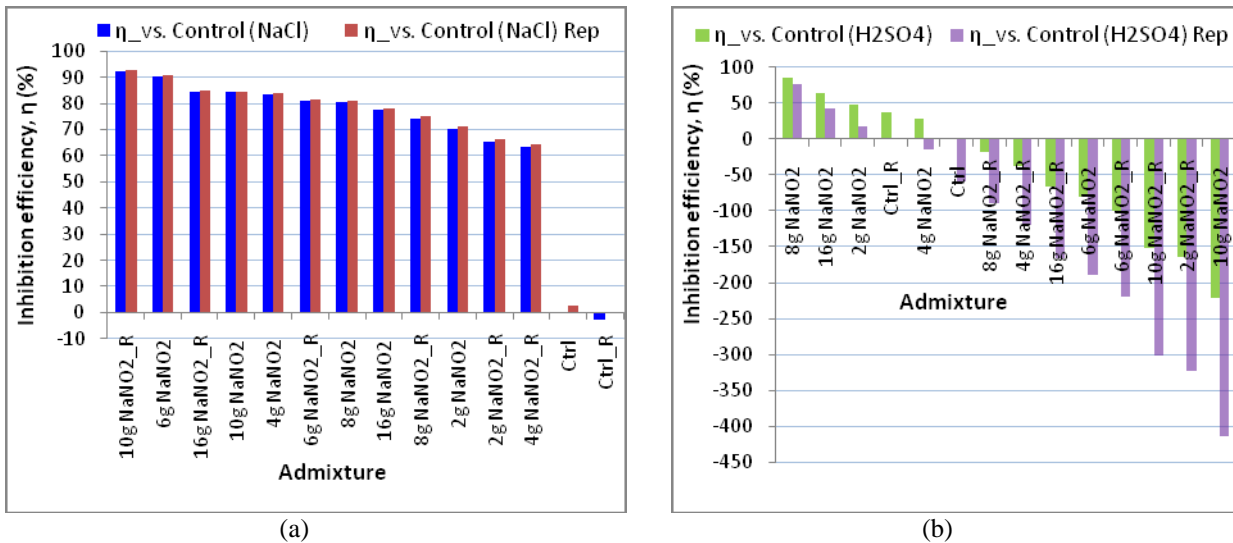

Fig. 3. Ranking of inhibition efficiency for modelling inhibitor admixture effectiveness vs. each replicate of control samples: (a) replicates in NaCl medium; (b) replicates in H$_2$SO$_4$ medium.
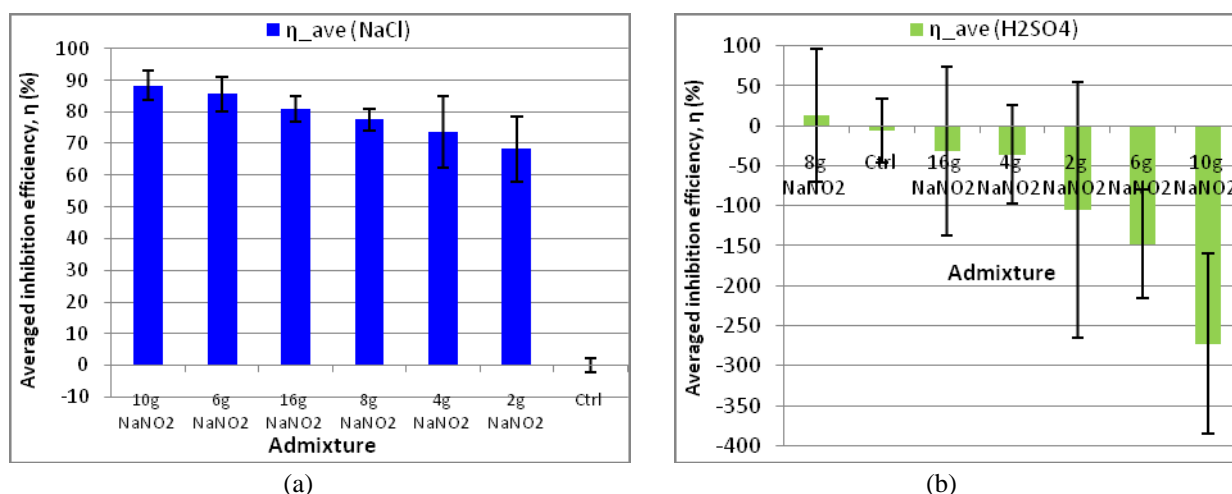
(a)   (b)

Fig. 4. Ranking of averaged inhibition efficiency for NaNO$_2$ admixtures (a) NaCl medium; (b) H$_2$SO$_4$ medium.

Analysis of variance among different admixture concentrations

The one-way factorial ANOVA results for the variables of corrosion test data of concrete samples, in their test media, are presented in table 4. From this table, it could be deduced that differences were significant in HCP test data (NaCl: $p = 0.0021$, H$_2$SO$_4$: $p < 0.0001$) and in CCC test data (NaCl medium: $p < 0.0001$, H$_2$SO$_4$ medium: $p < 0.0001$) of samples with different NaNO$_2$ admixtures. However, the CR test data exhibited differences that were significant, $p = 0.0462$, for samples in NaCl medium only, while modelled CR test data were not significantly different, $p = 0.6512$, among concrete samples in H$_2$SO$_4$ medium.

Inhibition effectiveness modelling for NaNO$_2$ admixtures

The CR test data followed the Weibull pdf for all samples, figure 1. Therefore the Weibull mean of CR data ($\mu_{W\text{-}CR}$) was employed for modelling inhibition efficiency, η. These are presented in figure 3, in ranking order of effectiveness for samples in NaCl, figure 3(a), and in H$_2$SO$_4$, figure 3(b). Figure 3(a) showed that the 10g NaNO2_R (replicate concrete) sample had optimum inhibition efficiency, $\eta = 92.29\%$ relative to the control and $\eta_{(rep)} = 92.49\%$ relative to the control replicate, in NaCl medium. Also, inhibition by the other NaNO$_2$ admixtures were strong such that the least effective admixture in the medium, the 4g NaNO$_2$ sample, still had $\eta = 63.53\%$, $\eta_{(rep)} = 64.56\%$.

In the H$_2$SO$_4$ medium, the 8g NaNO$_2$ sample lead the effectiveness ranking, figure 3(b) with $\eta = 85.56\%$, $\eta_{(rep)} = 76.92\%$, however, its replicate sample, 8g NaNO$_2$ (Rep), exhibited negative inhibition efficiency of $\eta = -18.69\%$, $\eta_{(rep)} = -89.73\%$. Also, the other two admixtures with positive inhibition effectiveness, the 16g NaNO$_2$ and the 2g NaNO$_2$ samples, had their replicate samples with much

higher negative inhibition efficiencies in the acidic test environment. These results bear implications of the identification of conflicting effectiveness. These seemed to have been presaged by the lack of significant difference, from the ANOVA modelling, among the CR test data of samples with different admixture concentrations in the acidic medium.

The student's *t*-test application on CR test data upheld that the differences between the replicate samples studied were not significant. Thus, it is of interest to moderate their differences through averaging model of inhibition efficiency for each replicated samples (Obot *et al.*, 2010; Haynie, 2005). Results of these are shown for samples in NaCl, figure 4(a) and in H$_2$SO$_4$, figure 4(b). In figure 4(a), the averaged model of inhibition efficiency showed that the 10g NaNO$_2$ admixture retailed optimal inhibition effectiveness, $\eta = 88.38\pm4.62\%$, in the NaCl medium, while the 2g NaNO$_2$ now ranked as the least effective admixture behind the 4g NaNO$_2$ admixture.

The averaged inhibition effectiveness model re-affirmed that most NaNO$_2$ admixtures studied aggravated steel-rebar corrosion in H$_2$SO$_4$ medium, figure 4(b). In this medium, only 8g NaNO$_2$ admixture had resultant positive effectiveness of $\eta = 13.51\pm83.48\%$ that was even characterised with variability which ranged highly into the negative inhibition region. All the other NaNO$_2$ admixtures in the medium exhibited negative efficiency whereby that of the 10g NaNO$_2$ admixture was as low as $\eta = -272.63\pm112.93\%$. By this, sodium nitrite, an oxidising agent, tends to accelerate corrosion in the H$_2$SO$_4$ medium as expressed by Davis (2000). Further studies are needed on corrosion inhibiting admixture for concrete steel-rebar in acidic medium.

CONCLUSION

Techniques of ASTM G16-95 R04 identified prevalent corrosion inhibition of concrete steel-rebar by $NaNO_2$ admixtures in NaCl medium while the methods also identified and addressed conflicting inhibition effect by the admixture on concrete steel-rebar in H_2SO_4 medium.

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