RASĀYAN *J. Chem.*
Vol. 18 | No. 3 |1557-1563| July-September | 2025
ISSN: 0974-1496 | e-ISSN: 0976-0083 | CODEN: RJCABP
http://www.rasayanjournal.com
http://www.rasayanjournal.co.in

CORROSION BEHAVIOUR OF $C_5H_{11}NO_2S$ ON STEEL REBAR IN CONCRETE FOR THE SALINE/MARINE SIMULATED ENVIRONMENT

Joshua Olusegun Okeniyi[1,2,✉] and Christopher Chintua Enweremadu[2]
[1]Department of Mechanical Engineering, Covenant University, Ota-112233, Nigeria
[2]Department of Mechanical, Bioresources and Biomedical Engineering, University of South Africa, Pretoria-0003, South Africa
✉ Corresponding author: joshua.okeniyi@covenantuniversity.edu.ng

ABSTRACT
In this study, the corrosion behaviour of $C_5H_{11}NO_2S$ (methionine) in steel reinforced concrete immersed in 3.5% NaCl in a simulated saline or marine environment is investigated. $C_5H_{11}NO_2S$ mixture was used as an admixture component in the reinforcement material samples subjected to medium and continuous electrochemical corrosion tests. These test results were analysed by analysing the goodness of fit of the Normal, Gumbel, and Weibull probability distributions using standard significance tests according to ASTM G16-13. The obtained results showed that there was no significant difference in the mean values of duplicates of concretes with the same $C_5H_{11}NO_2S$ mixture according to Student's *t*-test. In addition, Kolmogorov-Smirnov test data showed that the corrosion rate data were distributed according to the Weibull probability distribution function. According to these observations, the best inhibition activity against steel reinforcement corrosion in concrete immersed in 3.5% NaCl was shown by the 0.417% $C_5H_{11}NO_2S$ mixture, η = 97.60% ± 1.56%. This study clearly demonstrates the applicability of the organic chemical approach as a corrosion inhibitor of steel reinforcement in concrete in saline/marine environments.
Keywords: Reinforcing-Steel Corrosion, Steel-Reinforced Concrete, $C_5H_{11}NO_2S$ Corrosion-Inhibitor, Saline/Marine Simulating-Environment, Statistical Distribution and Decision Analyses, Inhibition Efficiency Modelling
RASĀYAN *J. Chem.*, Vol. 18, No.3, 2025

INTRODUCTION
Chloride-induced corrosion of steel reinforcement in concrete jeopardizes the durability and structural integrity of reinforced concrete.[1] The corrosion development occurs due to the ingress of chloride ions from saline products artificially produced in snow-cold cities via deicing salts usage or marine ambience naturally occurring at coastal cities.[1-2] Chloride ions from these sources reach the steel rebar (reinforcement) in concrete, posing a risk to both the steel bars and the concrete materials. This is because in the presence of oxygen and water, chloride ions catalyze the rusting reaction of the iron in the steel bar, while chloride ions are not consumed but rather retain the capability of further reactions.[3] The steel corroded in this wise usually expands within the pores of the concrete, creating hoop stresses that cause cracking, spalling, and delamination of the reinforcement material, which in turn leads to a decrease in the load-carrying capacity of the load-bearing material.[4] If left undetected, it can cause unprecedented but significant damage to existing built infrastructure, as well as economic and social impacts.[4-5] Thus, preventive corrosion protection requires the maintenance, renewal, and repair of structures damaged by corrosion, which is a huge cost in the billions of dollars and represents a large part of the budgets of many countries.[6-7] Addressing these problems would foster attainment of Sustainable Development Goals (SDGs) via durability improvements (SDG-9) for resilient infrastructure (SDG11) that would lower climate action of carbon emissions (SDG13) from frequent construction materials' repairs/replacements. Many methods were proposed for curbing the corrosion of steel reinforcement in concrete caused by the chloride permeation process. These include the use of surface treatments, waterproofing membranes or fibre-based polymers on the concrete and/or metal to prevent the ingress of corrosive chemicals, the application of cathodic protection to the steel reinforcement, the electrochemical realkalinization of the concrete, and the use of corrosion-inhibiting chemicals.[8-10] Among these methods, corrosion inhibitors are preferred because they are simple, economical, energy-saving, low-maintenance, and therefore of widespread interest, and are still

http://doi.org/10.31788/RJC.2025.1839177

very effective in reducing reinforcement corrosion.[8,11-12] Among the few known substances that can inhibit corrosion of metals, environmentally friendly organic chemicals are preferred because they are non-toxic and harmless to organisms and surrounding ecosystems.[12-13] In addition, organic materials containing N, S, and O show good adsorption properties for steel reinforcement when used as corrosion inhibitors in concrete reinforced with steel bars due to the relationship between their lone pair (π) electrons.[12,14] $C_5H_{11}NO_2S$ (Methionine) is an organic chemical containing N, S, O heteroatoms, and is non-toxic and non-hazardous to living organs and, in effect, to the environment, especially from being a product that has been a useful component in animal feeds.[15-17] This present study was motivated by the consideration that $C_5H_{11}NO_2S$ has shown effective anticorrosion performance on copper and its alloys, as well as on iron and its alloys in different corrosive environments.[18-19] One such study is relevant to the present discussion, where methionine ($C_5H_{11}NO_2S$) was used to prevent corrosion of stainless steel, including high-quality steel (Armco Iron) in sulfuric acid and hydrochloric acid environments, respectively.[19-20] Additionally, one of the authors of this article was involved in a study showing that $C_5H_{11}NO_2S$ was effective in inhibiting steel reinforcement corrosion in physically cast concrete within 0.5 M H_2SO_4 (for industrial/microbiological environment simulation).[21] However, there is a paucity of research works on the effectiveness of $C_5H_{11}NO_2S$ for inhibiting steel corrosion in concretes designed for areas with high chloride ion concentrations. Therefore, this study aimed to evaluate the corrosion resistance of steel embedment in reinforced concrete admixed with $C_5H_{11}NO_2S$ (methionine) and immersed in 3.5% NaCl medium (used to simulate artificial saline or natural marine environment). This proposition of $C_5H_{11}NO_2S$ as a non-toxic anticorrosion agent for the marine environment would potentially support responsible infrastructural material production (SDG-12) for fostering ocean health (SDG-14).

EXPERIMENTAL

Materials and Methods

$C_5H_{11}NO_2S$ (L-Methionine), portrayed in Fig.-1, used in this case, was provided by Oxford Laboratory Reagent® (Thana, India). The $C_5H_{11}NO_2S$ was used as an additive (i.e., admixture) during the casting of concrete having steel rebar embedded for reinforcing the concrete. Addition of L-methionine to the concrete samples was carried out at different concentrations ranging from 0.000% (weight percentage of cement used in the mix) in the blank samples, incremented at 0.083%, to 0.417% $C_5H_{11}NO_2S$ in concrete samples. Each of the $C_5H_{11}NO_2S$ mixture concentrations was also used for a duplicate batch of concrete having steel reinforcement. The second batch of concrete samples having a similar $C_5H_{11}NO_2S$ concentration is depicted hereafter as "_Dup". The mixing of the $C_5H_{11}NO_2S$ additive in concrete was carried out according to ASTM C192/192M–19 prescriptions for water-soluble powder.[22]

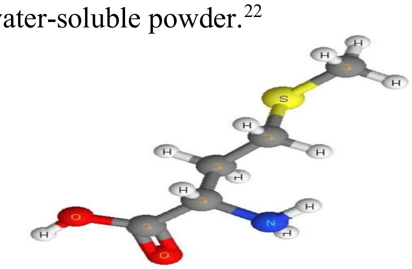

Fig.-1: 3-D Optimized Structure of $C_2H_{11}NO_2S$

General Procedure

The details of the casting and curing processes of the steel rebar reinforced concrete materials in this study were based on procedures reported elsewhere.[23] Additionally, the surface treatment of each steel rebar specimen was performed in the same manner and complied with the requirements of ASTM G109-23.[23-24] Each of the concrete specimens was placed longitudinally inside a plastic vessel containing 3.5% NaCl test solution to simulate the saline or marine service environment.[25]

Detection Method

In this study, the electrochemical corrosion investigation method was used to measure corrosion rates every 7 days for 10 weeks, using an LPR data logger model MS1500L (manufactured by Metal Samples®, Munford, AL, USA).[23] A total of 11 cases were included in the study, and statistical analysis was performed in this study.

Analytical Discussion

The respective equations of statistical probability distributions, of the Normal, the Gumbel, and the Weibull models, used for the present case as per ASTM G16-13(2024), are as follows:[26]

$$f(x) = \frac{1}{\sigma(2\pi)^{1/2}} \exp\left[-\frac{(x-\mu)^2}{2\sigma^2}\right]; \quad (1)$$

$$f(x) = \frac{1}{k} \exp\left[-\left(\frac{x-\lambda}{k}\right)\right] \exp\left\{-\exp\left[-\frac{(x-\lambda)}{k}\right]\right\}; \quad (2)$$

$$f(x) = \frac{k}{c}\left(\frac{x}{c}\right)^{k-1} \cdot \exp\left\{-\left(\frac{x}{c}\right)^{k}\right\}. \quad (3)$$

where x is corrosion data, μ is mean, σ Is the standard deviation, k is the shape parameter, λ Is the location parameter, and c is the scale parameter. Parameter estimation for each was performed using the maximum likelihood estimation technique as detailed in the published study.[13] The goodness of fit of each distribution model was investigated using the Kolmogorov-Smirnov goodness of fit (GoF) test statistic.[27] As an additional step in the significance test, Student's *t*-test statistics were used to investigate differences in the data from the duplicated specimens with similar $C_5H_{11}NO_2S$ concentration. For this significance of the variance test, the assumptions of equal variance (homoscedasticity) and unequal variance (heteroscedasticity) were used.[26] In all significance tests in this study, a significance level of $\alpha = 0.05$ was used.

RESULTS AND DISCUSSION

Probability Distribution Modelling

The plots in Fig.-2 show the Normal, Gambel, and Weibull distribution models of the analysed corrosion rate results from the concrete specimens having steel rebar as reinforcement. It can be seen from the figure that the reported results generally show that the normal distribution model of the corrosion rate is consistent with the Gumbel model, while the experimental data show that the Weibull model modelled values of results that was the highest among the three distributions, especially, for the blank specimens and some other cases. However, all of our distribution models show that the use of $C_5H_{11}NO_2S$ mixed into the reinforced concrete in NaCl leads to a decrease in corrosion rates compared to the measured data from the control samples. However, the discrepancies in the modelled results elicit the need to determine the probability distribution model that best describes the corrosion measurement data. This requires the rendering of the results to the nonparametric model of the Kolmogorov-Smirnov GoF statistics. It is also noticeable in Fig.-2 that although many replicates with similar $C_5H_{11}NO_2S$ concentrations show similarities in corrosion rate patterns while some other replicates show differences in model corrosion rates.

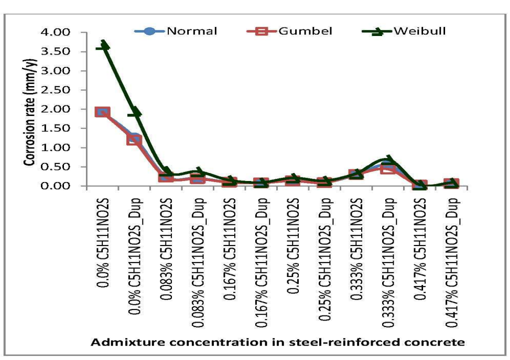

Fig.-2: Results of Analysis of Corrosion Rate Data with Normal Distribution, Gumbel Distribution, and Weibull Distribution

To investigate the difference in corrosion rates between samples with similar $C_5H_{11}NO_2S$ composition in reinforced concrete, the Student's *t*-test statistics would be used to determine whether the differences are due to chance alone or are significant.

Goodness-of-Fit Analyses

Figure-3 depicts the results from the Kolmogorov-Smirnov GoF Smirnov GoF test for the distribution that is scattered like the corrosion data among the Normal, Gumbel, and Weibull distributions. The figure also includes line plots with α = 0.05 to aid in the determination of the distribution scattering, like the dataset directly from the Figure.

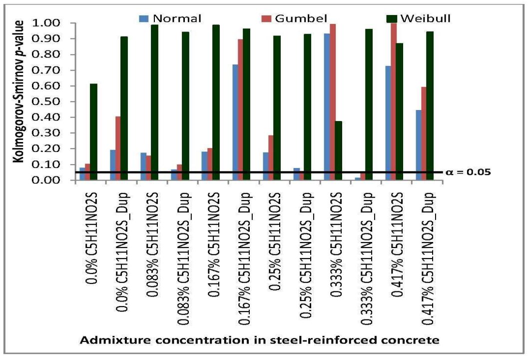

Fig.-3: Results from Rendering the Corrosion Rate Data to the Kolmogorov-Smirnov GoF Compatibility Testing to the Normal, the Gumbel, and the Weibull Probability Distributions

The plots of Kolmogorov-Smirnov *p*-values in Fig.-3 showed that, with only one exception, the tested corrosion data distributed like the Normal as well as like the Gumbel distributions, especially by their Kolmogorov-Smirnov *p*-values > 0.05. The exception to the distortion of corrosion rate data from the Normal and Gumbel distribution models is the corrosion data obtained from the 0.333% $C_5H_{11}NO_2S$_Dup mix of reinforced concrete sample, where the Normality *p*-value is 0.0152 and the Gumbel *p*-value is 0.0427. Both *p*-values are less than 0.05, which means that the corrosion data from the 0.333% $C_5H_{11}NO_2S$_Dup specimen elicited deviation from the Normal distribution and from the Gumbel distribution fittings. However, unlike these models, the corrosion data of all the concrete specimens in this study come from the Weibull distribution without any exception. The *p*-value of the Kolmogorov-Smirnov GoF testing applied to the corrosion data was found to be greater than 0.05 as per the Weibull model for those data. These results support the use of Weibull distribution models to explain the effects of $C_5H_{11}NO_2S$ mixtures on the corrosion performance of embedded steel bars in the reinforced concrete immersed in NaCl for this study.

Significance of the Differences in Corrosion Data Measurements

The results regarding the significance of the difference in the corrosion rate data of the additional (duplicate) concrete specimens of similar $C_5H_{11}NO_2S$ concentrations via the Student's *t*-test are plotted in Fig.-4, and for the homoscedasticity and heteroscedasticity assumption models.

The Fig.-4 also includes the α = 0.05 line plot for the direct identification of the significance of differences from the between-duplicate of corrosion rate data within the figure. Hence, it could be seen that all the *p*-values obtained for the specimens were greater than 0.05 significance level. These results conclude that the differences in corrosion rate measured between replicate concrete specimens containing similar $C_5H_{11}NO_2S$ concentrations are due to chance only and are not significant.

Modelling Corrosion Inhibition Behaviour

For detailing the effectiveness of anticorrosion behaviour by the $C_5H_{11}NO_2S$ admixtures, corrosion inhibition efficiency, η, modelling for the study employs the formula based on the Weibull mean corrosion rate (CR):[26]

$$\eta = \frac{CR_{blank} - CR_{admixed}}{CR_{blank}} \times 100 \quad (4)$$

Figure-5 shows the results of the corrosion inhibition efficiency evaluation using Equation (4) and then averaging for each replicate of reinforced concrete with similar $C_5H_{11}NO_2S$ concentrations. The figure portrays the corrosion according to the increasing inhibition performance of the $C_5H_{11}NO_2S$ concentrations on the steel bars in concrete. The extent of the degree of corrosion inhibition behaviour of $C_5H_{11}NO_2S$ mixture in Fig.-5 indicates that the model results for the blank sample (i.e., 0.000% $C_5H_{11}NO_2S$ mixture) depict a high variance between the blank duplicates.

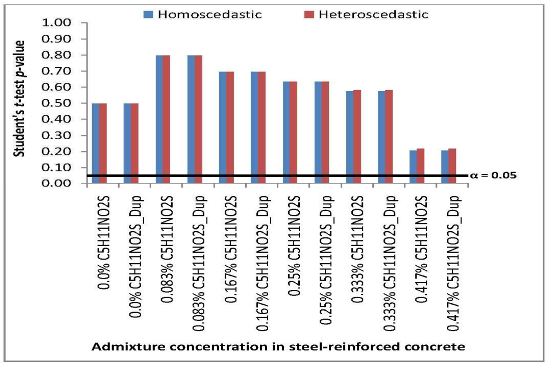

Fig.-4: Results from Subjecting the Corrosion Data from Duplicated Reinforced Concrete Specimens to the Student's *T*-Test Statistics

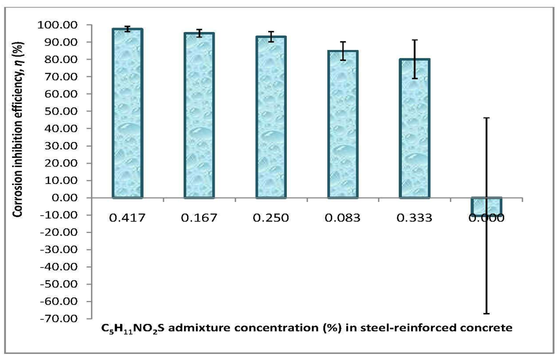

Fig.-5: Efficiencies of Corrosion Inhibition Performance by $C_5H_{11}NO_2S$ Admixture at different Concentrations on Steel Bars in Concrete

The form of variability in the encountered values for the prevailing corrosion conditions exemplified in this study has been indicated to be characteristic of the corrosion tests in corrosion standards.[26] Such features as may be present in corrosion tests form the basis of recommended testing methods that include the use of statistical analyses to identify and accurately describe the corrosion conditions present in a test model. Figure-5 also shows an undulating trend of increasing corrosion inhibition efficiency with the concentration of the $C_5H_{11}NO_2S$ admixtures. For instance, it could be noted that the 0.333% $C_5H_{11}NO_2S$ admixture exhibited the least corrosion inhibition effectiveness performance, η = 80.13±11.15%. However, this range of effectiveness by the 0.333% $C_5H_{11}NO_2S$ admixture exhibited variability that surpassed the higher range value of η = 84.87±5.38% obtained from the 0.083 $C_5H_{11}NO_2S$ admixture as well as the lower range value of η = 93.13±2.97% from the 0.25% $C_5H_{11}NO_2S$ admixture. This is just as the 0.167% $C_5H_{11}NO_2S$ admixture, having η = 95.13±2.23% exhibited a lower range of value that was surpassed by the higher range of value that could be obtained from the η = 93.13±2.97% by the 0.25% $C_5H_{11}NO_2S$ admixture. Although the effect of $C_5H_{11}NO_2S$ concentration on corrosion inhibition fluctuates, 0.417% $C_5H_{11}NO_2S$ mixture (the highest concentration of $C_5H_{11}NO_2S$ mixture used in this report) still showed the best corrosion inhibition efficiency, η = 97.60%±1.56%. All the $C_5H_{11}NO_2S$ concentrations used in this study were found to inhibit the corrosion of steel bars in concrete specimens immersed in 3.5% NaCl used to simulate saline or natural marine media, and this would support the attainment of the SDGs 9,11-14 previously identified for the study. It is noteworthy that the corrosion inhibition efficiency (from two of the $C_5H_{11}NO_2S$ mixtures) has two values falling in the range 75% < η < 90%, and which means "very good" efficiency model according to the classification of Coffey *et al*.[28] The rest of our corrosion inhibition obtained (from the rest of our $C_5H_{11}NO_2S$ admixed concretes in this study) exceeds η = 90%, which means "excellent" efficiency model according to the efficiency classification from that cited report.[28] The results from the study depict a high corrosion inhibition effect by the $C_5H_{11}NO_2S$ admixture on reinforced concrete steel bars in artificially created saline or naturally occurring marine environments, and show the organic chemical as a safe and environmentally friendly method for the corrosion protection of steel bars in the medium.

CONCLUSION

This paper has investigated the corrosion protection behaviour of $C_5H_{11}NO_2S$ (methionine) on steel bars in concrete in a simulated saline/marine environment. We draw the following conclusions from this study: Although almost all of the corrosion rate data in the study are distributed according to the Normal distribution and the Gumbel model, the Weibull distribution best fitted the corrosion rate by encompassing all the data from the studied concrete specimens by the $\alpha = 0.05$ test criteria of the Kolmogorov-Smirnov GoF statistics; The test results showed that these differences encountered between specimens having similar $C_5H_{11}NO_2S$ concentration were not significant by the statistics of the Student's *t*-test at the $\alpha = 0.05$, but were due to the chance of stochastic variability typical of corrosion tests; All concentrations of $C_5H_{11}NO_2S$ admixtures utilised in the studied specimens of concrete reinforced with steel rebar inhibited the corrosion of the steel in the simulated saline or marine test system of 3.5% NaCl employed for the study; The 0.417% $C_5H_{11}NO_2S$ admixture, which is the highest admixture employed for the studied concrete specimens reinforced with steel bars, also portrayed the optimal inhibition effectiveness performance at $\eta = 97.60\pm1.56\%$, on the steel bar corrosion in the concrete to be used in the simulated saline or marine environment; The effectiveness of $C_5H_{11}NO_2S$ in the mixture obtained in this study indicates a sustainable corrosion protection approach for concrete structures reinforced with steel bars and to be used in infrastructures meant for a saline/marine environment. That $C_5H_{11}NO_2S$ is non-toxic and harmless to the surrounding ecosystem makes the application of findings from this study support the attainment of SGDs 9, 11-14.

ACKNOWLEDGMENTS

The Authors thank the University of South Africa, Pretoria, South Africa, for the publication funding support for this research project via the Deal No R025T8P0L1.

CONFLICT OF INTERESTS

The authors have declared no conflicts of interest.

AUTHOR CONTRIBUTIONS

The present work is related to *SDG-9: Industry, Innovation, and Infrastructure*. All the authors contributed significantly to this manuscript, participated in reviewing/editing and approved the final draft for publication. The research profile of the authors can be verified from their ORCID ids, given below:

Joshua Olusegun Okeniyi https://orcid.org/0000-0002-7444-3977
Christopher Chintua Enweremadu https://orcid.org/0000-0002-5455-2500

REFERENCES

1. C. Chiu, F. Tu and C. Fan, *Natural Hazards,* **75(1)**, 581(2015), https://doi.org/10.1007/s11069-014-1349-3
2. Q.C. Truong, Q.T. Nguyen, C.P. Soueidy and E. Bastidas-Arteaga, *IOP Conference Series. Materials Science and Engineering,* **1289(1),** 012024(2023), https://doi.org/10.1088/1757-899X/1289/1/012024
3. J. Wei, J.H. Dong and W. Ke, *International Journal of Electrochemical Science*, **8(2),** 2536(2013), https://doi.org/10.1016/s1452-3981(23)14330-6
4. A. Chauhan and U.K. Sharma, *Engineering Fracture Mechanics*, **248,** 107719(2021), https://doi.org/10.1016/j.engfracmech.2021.107719
5. J. Shen, J. Liu, Y. Xu, K. Jia, F. Wu, W. Chen and D. Zhu, *KSCE Journal of Civil Engineering*, **25(9),** 3376(2021), https://doi.org/10.1007/s12205-021-0001-1
6. Q. Xu, B. Liu, D. Lin, M. Yao and X. Pang, *Materials,* **17(13)**, 3296(2024), https://doi.org/10.3390/ma17133296

7. G.K. Glass and N.R. Buenfeld, *Progress in Structural Engineering and Materials*, ***2*(4),** 448(2000), https://doi.org/10.1002/pse.54
8. N. Pandey, L. Gupta, M. Gautam, J. Bhattarai, and N.P. Bhattarai, In *E3S Web of Conferences*, **559**, 02008 (2024), https://doi.org/10.1051/e3sconf/202455902008
9. J.K. Das and B. Pradhan, *Journal of Building Engineering,* **50,** 104192(2022), https://doi.org/10.1016/j.jobe.2022.104192
10. B.K. Mussey, L.N.W. Damoah, D.S. Konadu and R.N.A. Akoto, 2022, in: *Sustainable Education and Development–Making Cities and Human Settlements Inclusive, Safe, Resilient, and Sustainable: Proceedings of the Applied Research Conference in Africa (ARCA)*, 2021, Springer International Publishing, pp.479-492, https://doi.org/10.1007/978-3-030-90973-4_40
11. K. Subbiah, H.S. Lee, M.R. Al-Hadeethi, T. Park and H. Lgaz, *Chemical Engineering Journal*, **458,** 141347(2023), https://doi.org/10.1016/j.cej.2023.141347
12. Y. Tong, J. Ye, Q. Wang, H. Zhang, H. Yu and A.O. Seibou, *Journal of Asian Architecture and Building Engineering*, **22(2)**, 415(2023), https://doi.org/10.1080/13467581.2022.2046004
13. A. Zomorodian and A. Behnood, *Buildings*, **13(5),** 1170(2023), https://doi.org/10.3390/buildings13051170
14. S. Mohammadkhah, A. Dehghani and B. Ramezanzadeh, *Scientific Reports*, **13(1),** 11130(2023), https://doi.org/10.1038/s41598-023-38130-2
15. G. Liu, V.S.R. Choppa, M.K. Sharma, H. Ko, J. Choi, and W.K. Kim, *Journal of Animal Science and Biotechnology*, **15(1),** 84(2024), https://doi.org/10.1186/s40104-024-00784-1
16. P.J. Garlick, *American Journal of Clinical Nutrition*, **136,** 1722S(2006), https://doi.org/10.1093/ajcn/136.6.1722S
17. S. Toue, R. Kodama, M. Amao, Y. Kawamata, T. Kimura and R. Sakai, *American Journal of Clinical Nutrition*, **136,** 1716S(2006), https://doi.org/10.1093/ajcn/136.6.1716S
18. B. El Ibrahimi, A. Jmiai, L. Bazzi and S. El Issami, *Arabian Journal of Chemistry*, **13(1),** 740(2020), https://doi.org/10.1016/j.arabjc.2017.06.018
19. G.L. Mendonça, S.N. Costa, V.N. Freire, P.N. Casciano, A.N. Correia and P. de Lima-Neto, *Corrosion Science*, **115,** 41(2017), https://doi.org/10.1016/j.corsci.2016.11.012
20. A.K. Aouniti, K.F. Khaled and B. Hammouti, *International Journal of Electrochemical Science*, **8,** 5925(2013), https://doi.org/10.1016/s1452-3981(23)14731-6
21. J.O. Okeniyi, A.O. Abioye, Z.C. Adikpewun, A.A. Otesanya, M.D. Eleshin, O.O. Gabriel and O. Adeoye, 2017, in: M.A. Meyers, H.A. Calderon Benavides, S.P. Brühl, H.A. Colorado, E. Dalgaard, C.N. Elias, R.B. Figueiredo, O. Garcia-Rincon, M. Kawasaki, T.G. Langdon, R.V. Mangalaraja, M.C. Gomez Marroquin, A. da Cunha Rocha, J.M. Schoenung, A. Costa e Silva, M. Wells and W. Yang (Eds.), *Proceedings of the 3rd Pan American Materials Congress,* 2017, Springer, Cham, pp.191-203, https://doi.org/10.1007/978-3-319-52132-9_19
22. ASTM C192/C192M-19, *Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory*, ASTM International (2019), https://doi.org/10.1520/C0192_C0192M-19
23. J.O. Okeniyi, I.J. Ambrose, S.O. Okpala, O.M. Omoniyi, I.O. Oladele, C.A. Loto and P.A.I. Popoola, *Sadhana*, **39,** 731 (2014), https://doi.org/10.1007/s12046-014-0287-5
24. ASTM G109-23, *Standard Test Method for Determining Effects of Chemical Admixtures on Corrosion of Embedded Steel Reinforcement in Concrete Exposed to Chloride Environments*, ASTM International (2023), https://doi.org/10.1520/G0109-23
25. R. Zhang, A. Castel and R. François, *European Journal of Environmental and Civil Engineering*, **16,** 402(2012), https://doi.org/10.1080/19648189.2012.667688
26. ASTM G16-13(2024), *Standard Guide for Applying Statistics to Analysis of Corrosion Data*, ASTM International (2024), https://doi.org/10.1520/G0016-13R24
27. J.O. Okeniyi and E.T. Okeniyi, *Journal of Statistical Computation and Simulation*, **82,** 1727(2012), https://doi.org/10.1080/00949655.2011.597882
28. R. Coffey, S. Dorai-Raj, V. O'Flaherty, M. Cormican and E. Cummins, *Human and Ecological Risk Assessment: An International Journal*, **19,** 232(2013), https://doi.org/10.1080/10807039.2012.702015

[RJC-9177/2024]