Arunprasad Jaychandran[1], Murugan Ramaiyan[2],*
Christian Johnson Singaram [3],Anukarthika Balakrishnan[3]

[1]Research Scholar, Department of Civil and Structural Engineering, Annamalai University, Tamilnadu, India, [2]Department of Civil and Structural Engineering, Annamalai University, Tamilnadu-608002, India,[3]Department of Civil Engineering, Erode Sengunthar Engineering College,Perundurai, Tamilnadu, India.

Scientific paper
ISSN 0351-9465, E-ISSN 2466-2585
https://doi.org/10.62638/ZasMat1129

Zastita Materijala 65 (2)
350 - 359 (2024)

Non-destructive evaluation of subsurface corrosion on hot steel angle sections embedded in concrete and its repair by cement slurry and nitozinc coating

ABSTRACT

This research article presents a comprehensive investigation into the materials and corrosion resistance of angle components critical to infrastructure construction. The study focuses on two key angle materials: steel angles and Fiber-Reinforced Plastic (FRP) angles, selected based on project-specific requirements. The concrete mix design, incorporating crucial components like chemicals (Calcium Chloride, Sodium Hydroxide, Calcium Hydroxide), aggregates (M Sand and 20 mm Aggregate), and cement (Portland Pozzolana Cement - 43 grade), ensures that the structural integrity and performance meet desired standards. The research also involves advanced corrosion assessment techniques, including the Half-Cell Potential Test and the Applied Voltage Test (Holiday Test), which offer insights into material conductance, corrosion resistance, and protective coating integrity. Moreover, a Chemical Resistance Test examines the impact of various solutions on these materials, highlighting their suitability for diverse industrial applications. The results underscore the importance of tailored material selection, proactive corrosion management, and the critical role of protective coatings in ensuring infrastructure longevity and safety. This study contributes to the advancement of corrosion assessment methods, supporting the durability of critical infrastructure materials.

Keywords: *corrosion, coating, chemical resistance, durability, FRP, angle section*

1. INTRODUCTION

Corrosion monitoring activities play a vital role in assessing the integrity of steel components within concrete foundations [1]. Corrosion can lead to the deterioration of the concrete surrounding the reinforcement, necessitating timely inspections and repairs [2]. Several methods are employed for assessing and addressing this corrosion-related damage [3]. One such method is the Half-Cell Potential Method, which measures electro-potential and helps in evaluating the condition of the steel reinforcement within the concrete [4,5]. It provides insights into the likelihood of corrosion occurring [6]. The Ultrasonic Pulse Velocity Test measures the velocity of ultrasonic waves through the concrete [7-9].

*Corresponding author: Jaychandran Arunprasad
Email ID: arunprasadcivil@esec.ac.in
Paper received: 26. 11. 2023.
Paper corected: 26.02.2024.
Paper accepted: 09. 03. 2024.
Paper is available on the website: www.idk.org.rs/journal

This test is invaluable for determining the concrete's quality and detecting any voids or defects within it [10-12]. The Rebound Hammer Test assesses the concrete's surface hardness and, by extension, its structural integrity [13,14]. This test is particularly useful in cases where manual repair is considered, provided there is no calcium chloride present in the concrete [15,16]. Cathodic Protection is a crucial technique used to halt the rusting process of steel reinforcement within the concrete [17]. This method is instrumental in preventing further corrosion damage, and preserving the structural integrity of the concrete [18].

Additional methods, such as Parallel Seismic Time Testing, Impulse Response, Impact-Echo, Ultrasonic Tomography, Ground Penetrating Radar, and Impedance Tomography, employ various physical quantities, including acoustic wave pass-through time, vibration frequency, magnetic flux, and electric potential, to assess different aspects of concrete and reinforced concrete structures [19-21]. These methods are employed for evaluating the condition of concrete and its reinforcing steel in various structural elements, including foundation slabs, columns, beams, walls, and more [22].The experimentally proven coatings were applied in subsurface concrete models and the efficiency of the coatings, and admixtures in concrete were studied for durability [23]. Methodology for maintenance of subsurface corrosion of most susceptible to high rates of metal corrosion has been reviewed by*Petter*.Investigation on the application of protective coatings upon the reinforcements and addition of admixtures in the concrete have been carried out by S.Christian Johnson and G.Thirugnanam [24, 25].Protective methods like applying zinc-rich coatings such as epoxy coatings in the stub angle concrete interface to combat the crevice corrosion, have been suggested for field applications in aggressive environments [26]. Several non-destructive techniques like half-cell potential tests, applied voltage tests, and chemical resistance tests including experimental investigations in the laboratory have been elaborately carried out [27].

This paper aims to find the effectiveness of coating and prevent the corrosion of steel angles induced in concrete which can reduce the durability of concrete structures. It leads to the formation of cracks in concrete. Corrosion of the structure can be reduced by using additives and anticorrosive coatings such as zinc coatings on the angles. In this work, an attempt is made to apply epoxy coating on angles and to study the corrosion of angles up to the cracking of concrete in a short time, the corrosion rate is increased by impressing direct current, and the corrosion process is monitored continuously. The durability of concrete is calculated by performing chemical resistance and applied voltage tests. It is aimed to study the effectiveness of coating applied on angles and its durability.

2. MATERIALS AND MIX DESIGN

In this research, two types of angle materials were considered for the construction: steel angles and FRP (Fiber-Reinforced Plastic) angles, with dimensions of 300x50x50mm and 150x50x50mm [28-30]. The choice of these materials depends on various factors, including their intended use and the specific requirements of the project. To create the concrete mix, several essential components were utilized, including chemicals and aggregates [31]. The chemicals included 3M of Calcium Chloride, 3M of Sodium Hydroxide, and a saturated solution of Calcium Hydroxide. These chemicals play a crucial role in influencing the concrete's properties, such as setting time and durability [32]. In terms of aggregates, fine aggregate (M Sand) and coarse aggregate (20 mm Aggregate) were incorporated into the mix [33]. The selection of aggregates is vital in determining the concrete's strength and workability [34]. Lastly, the binding agent, cement, was chosen in the form of PPC (Portland Pozzolana Cement) - 43 grade. The specific grade of cement plays a significant role in determining the concrete's overall quality and performance [35]. The mix proportion employed for the study was based on a 1:1.5:3 ratio, which corresponds to M20-grade concrete [36]. This ratio was applied to ensure the concrete's desired properties [37]. The design mix ratio was then calculated by dividing the required weight of all materials by the weight of cement, resulting in the following proportions: Cement: Fine Aggregate: Coarse Aggregate: Water = 1: 1.85: 2.9: 0.5. This precisely defined mix ratio is critical for achieving the desired structural strength and performance characteristics of the concrete [38].

3. EXPERIMENTAL INVESTIGATIONS

3.1.Half-Cell Potential Test

This test method covers the estimation of the electrical half-cell potential of uncoated reinforcing steel in field and laboratory concrete, to determine the corrosion activity of the reinforcing steel [39]. This test method is limited by electrical circuitry. A concrete surface that has dried to the extent that it is a dielectric and surfaces that are coated with a dielectric material will not provide an acceptable electrical circuit [40]. The values stated in inch-pound units are to be regarded as the standard. For the Half-cell potential test, we cast 8 specimens for testing and the test is undertaken after 28 days of providing 2V while curing of specimens.As per ASTM C876 [32] limits below -350mV corrosion does not occur. From the -350mv to -200mV. Probability of occurrence of corrosion when potential head exceeds -200mV.The test setup is shown in Figure 1 and the ASTM standard value is presented in Table 1.

Figure 1. (a) Accelerated corrosion test setup

Slika 1. (a) Ubrzano podešavanje testa korozije

Figure 1. (b) HCP test on corroded specimen

Slika 1. (b) HCP test na korodiranom uzorku

Table 1. Potential Test Valve (ASTM Standard)

Tabela 1.Ventilzaispitivanjepotencijala (ASTM standard)

Corrosion	Potential (C-CSE)
> 95%	More Negative than -350mV
50%	-200 to -350mV
< 5%	More Positive than -200mV

3.2.Applied Voltage Test

Non-conductive plastic material is used in a metallic vessel. The specimens are suspended vertically in the vessel with at least 25 mm clearance from the bottom. Test specimens are separated by not less than 40 mm [41]. Test specimens shall be separated from any wall of the vessel by not less than 40 mm. The depth of the electrolyte is the test length of the specimen to be immersed, but the immersed area shall not be less than 23, 200 mm^2.AC power was used for powering the overlays. A VARIAC was used to regulate the applied voltage. A transformer was used to elevate the applied voltage to a maximum of 420 volts. The overlays were connected to the AC power in parallel. An amp-meter was used to record the electrical current going through each overlay. The total current going through both overlays was limited to the maximum capacity of the power source.

Epoxy coatings were applied on the angle for thevoltage test. Dimensions of 300mm x 50mm x 6mm angles are used in this test.The effect of electrical and electrochemical stresses on the bond of coating to steel and the integrity of the coating shall be assessed [42]. The test setup is shown in Figure 2. The tests were conducted as per IS 13620:1993. In this test, the coated angles were tested and readings were noted.

Figure 2.Applied Voltage Test – Setup

Slika 2. Test primenjenog napona – podešavanje

3.3.Chemical Resistance Test

The chemical resistance test, conducted in accordance with IS 13620:1993, is a vital evaluation of coating durability for reinforcing bars. In this test, the coated reinforcing bars are subjected to immersion in various solutions to assess their resistance to chemical corrosion [43]. Figure 3 depicts the test setup of the chemical resistance test. The solutions used include distilled water, a 3M aqueous solution of $CaCl_2$, a 3M aqueous solution of NaOH, and a solution saturated with $Ca(OH)_2$. This comprehensive evaluation ensures that the coating can withstand exposure to a range of potentially corrosive substances. It is important to note that this test is a physical inspection procedure, focusing on the coating's ability to withstand chemical exposure.

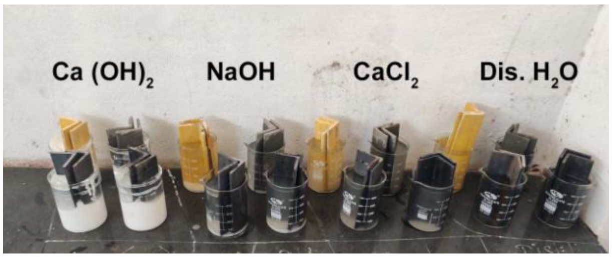

Figure 3. Chemical Resistance test setup

Slika 3. Podešavanjet esta hemijske otpornosti

Following the designated experimental period, the test examines the formation of any holidays, imperfections, or defects in the coating. After the completion of 45 days, the test setup is meticulously investigated to determine the coating's performance under these challenging conditions, providing valuable insights into its durability and suitability for various applications.

4. RESULT AND ANALYSIS

4.1.Half Cell Potential Test Results

In an investigation aimed at assessing the electrical conductance of various angle materials, a test was initiated after 28 days of the curing process. This test was extended for an additional 8 days post-curing, encompassing a 6-hour test period. The objective was to chart the current, measured in amperes, against time in seconds, creating a graph that depicted the variations in electrical properties over time. This graph was then subjected to smoothing to provide a clear representation of the data. Subsequently, the area under the smoothed curve was integrated to calculate the total charge passed during the 6-hour test period, expressed in ampere-seconds or coulombs. This measure of total charge passed served as a crucial indicator of the electrical conductance of the concrete during the testing phase.

The presented Table 2, and Figure 4 provide detailed data on the half-cell potential test readings for three types of angle specimens: Uncoated Angle, Nitozinc Coated Angle, and FRP (Fiber-Reinforced Plastic) Angle.

Uncoated Angle:The readings for the Uncoated Angle exhibited consistently negative potentials throughout the 6-hour test period, with values ranging from -159 to -218mV. These negative potential values suggest that the Uncoated Angle is susceptible to electrical conduction, and the increasing negative potential values signify the material's gradual degradation over time. This electrical conductance points to the angle's vulnerability to corrosion, making it an unfavorable choice for applications that require corrosion resistance.

Table2 Half-cell potential test readings

Tabela 2 Očitavanjatestapotencijalapolućelije

Specimens	**Half-cell potential test readings (mV)**			
	24	**48**	**72**	**96**
Uncoated Angle	-159	-165	-178	-194
	-168	-176	-189	-211
	-165	-179	-192	-218
Nitozinc Coated Angle	-142	-150	-162	-170
	-148	-152	-160	-180
	-134	-140	-164	-184
FRP Angle	0	0	0	0
	0	0	0	0
	0	0	0	0

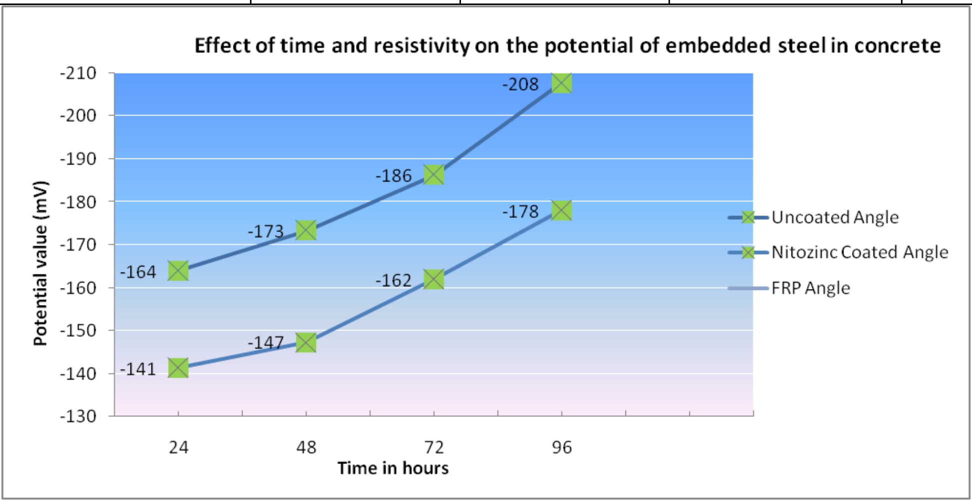

Figure 4.Effect of time and resistivity on the potential of embedded steel in concrete

Slika 4.Uticaj vremena I otpora na potencijal ugrađenog čelika u beton

Nitozinc Coated Angle:In contrast, the Nitozinc Coated Angle displayed positive potentials throughout the test, with values ranging from -142 to -184 mV. These consistent positive potentials signify the angle's ability to resist electrical conduction, indicating its corrosion resistance. The Nitozinc Coating effectively maintained its electrical integrity over the testing duration, highlighting its suitability for applications where corrosion resistance is of utmost importance.

FRP Angle:The FRP Angle consistently registered at zero amperes during the entire test period, signifying its complete lack of electrical conduction. This property underscores the angle's electrical non-conductivity, making it an ideal choice for applications where electrical insulation is a critical requirement.

The half-cell potential test results provide valuable insights into the electrical conductance and corrosion resistance of the tested angle materials. While the Uncoated Angle displayed negative potentials and susceptibility to corrosion, the Nitozinc Coated Angle demonstrated positive potentials and resistance to electrical conduction. The FRP Angle's consistent zero amperes confirmed its electrical non-conductivity. Nitozinc Coating is resistive against corrosion compared to Uncoated steel angles. FRP angle does not conduct any current.

4.2.Applied Voltage Test Results

The Applied Voltage test, often referred to as a holiday test, is a critical method used in the field of material inspection and quality control. It involves assessing the integrity of coatings or linings on various substrates, specifically looking for the presence of holidays. Holidays, in this context, refer to imperfections or discontinuities in the coating or lining film, such as pinholes, voids, cracks, inclusions, or contaminants. These defects, though often invisible to the naked eye, can compromise the protective properties of the coating and pose significant risks, especially in applications designed for critical services, such as immersion, chemical storage, or transportation.

The Applied Voltage test is an essential tool to ensure the reliability and safety of coated or lined materials, as a failure to detect these holidays could potentially lead to catastrophic events. The test is conducted after a specified experimental period during which the coated or lined materials are exposed to various conditions and stresses. At the end of this period, the formation of holidays is assessed through readings obtained from the test.

The test results, as summarized in Table 3, provide valuable insights into the condition of the coated or lined specimens, with specific observations for Nito Zinc Coated Angle, Uncoated Angle, and FRP (Fiber-Reinforced Plastic) Angle.

1. *Nito Zinc Coated Angle:Observation: Low holidays.*

The Nito Zinc Coated Angle, after undergoing the Applied Voltage test, demonstrated a low presence of holidays. This observation suggests that the Nito Zinc coating effectively protected the underlying substrate from the formation of imperfections or defects. The low holiday count signifies that the coating is of high quality, and the material is suitable for applications that require a high level of protection against corrosive or environmental factors.

2. Uncoated Angle:Observation: Severe Holidays.

In contrast, the Uncoated Angle exhibited severe holidays following the Applied Voltage test. This observation highlights the vulnerability of uncoated materials to imperfections or defects. The presence of severe holidays indicates that the material is at high risk of corrosion or other forms of degradation. It underscores the critical importance of applying protective coatings or linings to substrates, especially in environments where materials are subjected to harsh conditions.

3. FRP Angle:Observation: Very Low Holidays.

The FRP Angle displayed very low holidays, indicating that the fiber-reinforced plastic coating effectively protected the substrate from imperfections. FRP is known for its corrosion-resistant properties and durability, and these results validate its effectiveness in maintaining a high level of protection. This observation underscores the suitability of FRP in applications where corrosion resistance and material integrity are paramount.

The observations from this test demonstrate the significance of protective coatings and linings in preserving material integrity and preventing catastrophic failures. The ability to detect imperfections that are often invisible to the naked eye underscores the importance of 100% inspection of coated or lined surfaces. Whether applied to newly coated materials or those that have aged, the test equipment's portability makes it a versatile and practical choice for quality control and maintenance in various industrial settings.

4.3.Chemical Resistance Test

It is a physical inspection test. After the test experiment period,the informationonholidays wascalculated. After 45 days of completion, the test setup is investigated.In this comparative analysis of various chemical treatments, it can be observed the effects of different solutions on four different types of angle materials, namely NitoZinc Coated, Cement Slurry Coated, Uncoated, and FRP Angles. The experiment involved immersing these angles in four different solutions: Distilled Water, 3M $CaCl_2$, 3M NaOH, and $Ca(OH)_2$. The study was conducted over a specified period, and the results are summarized in the table below, indicating the number of angles that exhibited specific characteristics after exposure to each solution.In the case of NitoZinc Coated Angle, the weight changes after exposure to these solutions were as follows: 20% for Distilled Water, 19% for 3M $CaCl_2$, 19% for 3M NaOH, and 19% for $Ca(OH)_2$. For Cement Slurry Coated Angle, the weight changes were 17% for Distilled Water, 18% for 3M $CaCl_2$, 15% for 3M NaOH, and 15% for $Ca(OH)_2$. Uncoated Angle displayed weight changes of 10% for Distilled Water, 11% for 3M $CaCl_2$, 12% for 3M NaOH, and 12% for $Ca(OH)_2$. Lastly, the FRP Angle exhibited consistent weight changes of 20% for all the tested solutions. The graphical representation of test results is shown in Figure 5.

Distilled Water:

NitoZinc Coated Angle showed no significant weight change (20%). This indicates its excellent resistance to pure water, suggesting that the coating effectively protects the underlying material from corrosion in a water-rich environment. Cement Slurry Coated Angle exhibited a relatively small weight change (17%), implying good resistance to pure water, although slightly less effective than NitoZinc Coated Angle. The uncoated Angle experienced a moderate weight change (10%). While it's less susceptible to water than coated angles, this change suggests potential vulnerability to water-induced corrosion over time. FRP Angle demonstrated no significant weight change (20%), indicating its exceptional water resistance. This material is ideal for applications requiring high water resistance.

3M $CaCl_2$ Solution:

NitoZinc Coated Angle displayed a minor weight change (19%), signifying good resistance to chloride-rich solutions. Cement Slurry Coated Angle exhibited a slightly higher weight change (18%), indicating slightly reduced resistance to calcium chloride compared to NitoZinc Coated Angle. Uncoated Angles showed a moderate weight change (11%), suggesting moderate susceptibility to chloride-induced corrosion. FRP Angle experienced no significant weight change (20%), showcasing its excellent resistance to calcium chloride.

3M NaOH Solution:

NitoZinc Coated Angle demonstrated a slight weight change (19%), suggesting good resistance to alkaline conditions. Cement Slurry Coated Angle had a relatively higher weight change (15%), indicating it might be slightly more vulnerable to sodium hydroxide. The uncoated Angle showed a moderate weight change (12%), implying some vulnerability to strong alkali. FRP Angle displayed no significant weight change (20%), highlighting its strong resistance to alkaline solutions.

$Ca(OH)_2$ Solution:

NitoZinc Coated Angle showed minimal weight change (19%), emphasizing its resistance to highly alkaline environments. Cement Slurry Coated Angle exhibited a slightly higher weight change (15%), indicating it can withstand alkaline conditions. Uncoated Angle displayed a moderate weight change (12%), suggesting it might be moderately susceptible to strong alkalinity. FRP Angle showed no significant weight change (20%), underscoring its resistance to highly alkaline solutions.

These scientific observations reveal the chemical resistance and durability of the tested angle materials in different environmental conditions. NitoZinc Coated Angle and FRP Angle consistently exhibited strong resistance across various chemicals does not produce any holidaysmaking them suitable for applications demanding robust corrosion resistance. On the other hand, Uncoated Angle and Cement Slurry Coated Angle showed large number of holidays showing varying degrees of susceptibility to different chemicals and loss of weight, underlining the importance of protective coatings and material selection for specific industrial contexts.

Table 3.Test results of chemical resistance of samples

Tabela 3.Rezultati ispitivanja hemijske otpornosti uzoraka

Chemicals	Weight changes (%)			
	NitoZinc Coated Angle	Cement Slurry Coated Angle	Uncoated Angle	FRP Angle
Distilled Water	20	17	10	20
3M$CaCl_2$	19	18	11	20
3MNaOH	19	15	12	20
$Ca(OH)_2$	19	15	12	20

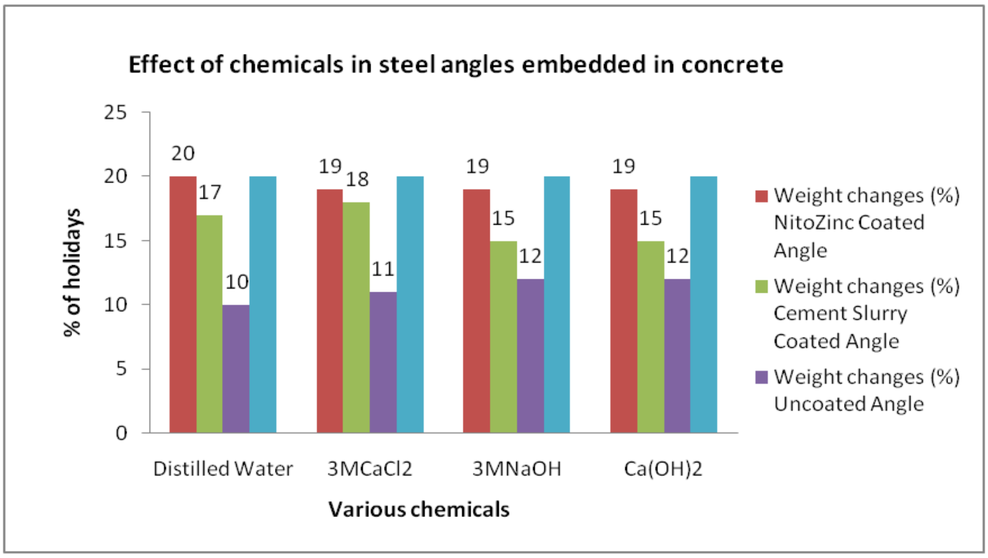

Figure 5.Effect of chemicals in steel angles embedded in concrete

Slika 5.Uticaj hemikalija na čelične uglove ugrađene u beton

5. CONCLUSION

The conducted investigations involving the Applied Voltage test and the Chemical Resistance test provide significant insights into the electrical conductance and chemical resistance properties of various angle materials. These findings hold substantial implications for material selection in applications where corrosion resistance and electrical integrity are critical.

1. The Uncoated Angle exhibited negative potentials -159 to -218 mV), indicating susceptibility to corrosion and electrical conduction, making it unsuitable for corrosion-sensitive applications. In contrast, the Nitozinc Coated Angle maintained positive potentials (142 to -184 mV), highlighting its corrosion resistance and electrical integrity, suitable for applications demanding protection. The FRP Angle consistently registered zero amperes, confirming its electrical non-conductivity, making it an ideal choice for applications requiring insulation.
2. The Uncoated Angle demonstrated a consistent negative potential, indicating its susceptibility to electrical conduction and corrosion. It is, therefore, an unfavorable choice for applications requiring corrosion resistance.The Nito Zinc Coated Angle consistently displayed a positive potential, signifying its ability to resist electrical conduction and maintain its corrosion resistance. This makes it a suitable choice for environments where protection against corrosion is paramount. The FRP Angle exhibited a consistent zero potential, highlighting its electrical non-conductivity and making it ideal for applications where electrical insulation is essential.
3. The experiments conducted with different chemical solutions showcased varying effects on the tested angle materials. Distilled Water had no significant impact on any of the angle types. 3M $CaCl_2$ produced minor changes in the NitoZinc Coated, Uncoated, and Cement Slurry Coated angles, while affecting 11 angles of the FRP category. 3M NaOH and $Ca(OH)_2$ had similar effects, leaving the NitoZinc Coated, Uncoated, and Cement Slurry Coated angles mostly unchanged, but causing alterations in all FRP angles.
4. These results are crucial in the context of material selection for applications demanding high corrosion resistance and electrical integrity. The Nito Zinc Coated Angle consistently demonstrated resistance to both electrical conduction and chemical-induced alterations, rendering it a preferred choice for critical services where protection against corrosion is paramount. The Uncoated Angle, with its susceptibility to corrosion, serves as a cautionary example of the importance of protective coatings in such applications. Lastly, the FRP Angle's electrical non-conductivity and varying chemical resistance make it a versatile material suitable for specific applications.
5. These tests provide essential data for informed decision-making in industries requiring materials capable of withstanding harsh conditions. The choice of materials should consider not only their inherent properties but also the environmental factors they will be exposed to, ensuring the longevity and safety of the

applications. The results reaffirm the significance of protective coatings and linings in preserving material integrity and preventing catastrophic failures, while also emphasizing the role of electrical conductance and resistance in specific industrial contexts.

Acknowledgments

The authors wish to acknowledge the Department of Civil Engineering, Annamalai University, and Erode Sengunthar Engineering College, Tamil Nadu for the facility and support extended for the research work.

6. REFERENCES

[1] R.Alfred, J.Mathew (2013) Electrical Indication of Concrete's Ability to Resist chloride Ion Penetration. International Journal of Advanced Scientific and Technical Research.,3(6), 51-59.

[2] A.Ahmad, A.Kumar(2013)Chloride ion migration/diffusion through concrete and test methods. International Journal of Advanced Scientific and Technical Research., 6(3), 151-180.

[3] B.P.Baltazar-García, B.Zamora, et al. (2024) Behavior of Potential of Half-Cell AISI 1018 and GS in Concrete Buried in Sand in the Presence of MgSO4. European Journal of Engineering and Technology Research., 9(1), 32-36. DOI:https://doi.org/10.24018/ejeng.2024.9.1.3123.

[4] N.Kumar, S.Prakash, S.Ghani, M.Gupta, S. Saharan (2024) Data-driven machine learning approaches for predicting permeability and corrosion risk in hybrid concrete incorporating blast furnace slag and fly ash. Asian Journal of Civil Engineering., 1-13. https://doi.org/10.1007/s42107-023-00977-8

[5] M.A.M.Ariffin, M.A.R.Bhutta, M.W.Hussin, M.Mohd Tahir, Nor Aziah, Sulfuric acid resistance of blended ash geopolymer concrete. https://doi.org/10.1016/j.conbuildmat.2013.01.018

[6] R.Mohanraj, K.Vidhya (2024) Evaluation of compressive strength of Euphorbia tortilis cactus infused M25 concrete by using ABAQUS under static load. Materials Letters., 356, 135600. https://doi.org/10.1016/j.matlet.2023.135600

[7] T.Bakharev, J.G.Sanjayan, Y.B.Cheng (2003) Resistance of alkali-activated slag concrete to acid attack, Cement and Concrete Research, 33, 1607 – 1611.https://doi.org/10.1016/S0008-8846(03)00125-X

[8] M.T.Bassuoni, M.L.Nehdi (2007) Resistance of self-consolidating concrete to sulfuric acid attack with consecutive pH reduction.Cement and Concrete Research., 37, 1070–1084.https://doi.org/10.1016/j.cemconres.2007.04.014

[9] R.Mohanraj, S.Senthilkumar, P.Padmapoorani (2022) Mechanical properties of RC beams With AFRP sheets under a sustained load. Materials and Technology., 56(4), 365–372. https://doi.org/10.17222/mit.2022.481

[10] C. Bilim, C.D.Atis, H. Tanyildizi, O. Karahan (2009) Predicting the compressive strength of ground granulated blast furnace slag concrete using artificial neural network.Advances in Engineering Software., 40, 334–340.https://doi.org/10.1016/j.advengsoft.2008.05.005

[11] M.Velumani, R.Mohanraj, R.Krishnasamy, K. Yuvaraj (2023)Durability Evaluation of Cactus-Infused M25 Grade Concrete as a Bio-Admixture. Periodica Polytechnica Civil Engineering., 67(4), 1066-1079 . https://doi.org/10.3311/PPci.22050

[12] Ch.Kennedy, Ph. Kpae, W. Oruene(2018) Comparative Half Cell Potential and Concrete Resistivity Corrosion Probability Assessment of Embedded Coated Steel Reinforcement in Concrete Accelerated Environment. International Journal of Scientific & Engineering Research., 9(5).141-159. DOI:10.14299/ijser.2018.05.06

[13] R. Krishnasamy, C. J.Singaram, S. Palanichamy, R. Mohanraj (2024) Testing and Evaluation of Buckling and Tensile Performance of Glass Fiber–Reinforced Polymer Angle Section with Different Joints/Connections. Journal of Testing and Evaluation., 52(1), 1-16. http://doi.org/10.1520/JTE20230010

[14] L.V.Dias, S.M.Soares J.A.Salvador Filho, F.G.S. Ferreira (2021)Evaluation of chloride migration in ultra-high performance concrete (UHPC) with glass powder.11(2), 61-75. https://doi.org/10.21041/ra.v11i2.512

[15] D.Mills, P.Lambert, Sh.Yang (2021) Electrochemical Noise Measurement to Assess Corrosion of Steel Reinforcement in Concrete. 14(18), 5392. https://doi.org/10.3390/ma14185392

[16] R.Mohanraj, S.Senthilkumar, Pr. Goel, R. Bharti (2023) A state-of-the-art review of Euphorbia Tortilis cactus as a bio-additive for sustainable construction materials. Materials Today: Proceedings. https://doi.org/10.1016/j.matpr. 2023.03.762

[17] S.Gunaselvi, P.Satheeshkumar, M.Jeganathan (2020) Surface Modification of Steel by Nickel Coating in Electrochemical Process. Journal of New Materials for Electrochemical Systems., 23(2), 112-122. DOI:https://doi.org/10.14447/jnmes.v23i2.a08

[18] K. Chansuriyasak, Ch. Wanichlamlart, P. Sancharoen, W. Kongprawechnon S. Tangtermsirikul (2010) Comparison between half-cell potential of reinforced concrete exposed to carbon dioxide and chloride environment. Songklanakarin J. Sci. Technol., 32 (5), 461-468.

[19] L.Maria Nicula,O.Corbu, M.Iliescu, A.V.Sandu, An. Hegyi (2021) Study on the Durability of Road Concrete with Blast Furnace Slag Affected by the Corrosion Initiated by Chloride. Hindawi Advances in Civil Engineering., p.1-16.https://doi.org/ 10.1155/2021/8851005

[20] R.Mohanraj, S.Senthilkumar, S. Shanmugasundaram, P.Padmapoorani (2022) Torsional performance of reinforced concrete beam with carbon fiber and aramid fiber laminates. Revista de la Construcción., 21(2), 329-337. https://doi.org/10.7764/RDLC.21.2.329

[21] L. Sadowski (2016) Methodology for Assessing the Probability of Corrosion in Concrete Structures on the Basis of Half-Cell Potential and Concrete Resistivity Measurements. The Scientific World Journal.http://dx.doi.org/10.1155/2013/714501

[22] S.C.Johnson, G.S.Thirugnanam (2010) Experimental study on corrosion of transmission line tower foundation and its rehabilitation. International Journal of Civil & Structural Engineering., 1(1), 27-34.

[23] P. Claisse, J. L. Marriaga (2012) The effect of other ions on chloride migration in concrete. 3rd International Conference on the Durability of Concrete Structures.,p.17-19.

[24] R. Siddique, J. Klaus (2009) Influence of metakaolin on the properties of mortar and concrete. Applied Clay Science., 43(3-4), 392–400.https://doi.org/10.1016/j.clay.2008.11.007

[25] P.Padmapoorani, S.Senthilkumar, R.Mohanraj (2023) Machine Learning Techniques for Structural Health Monitoring of Concrete Structures: A Systematic Review. Iranian Journal of Science and Technology, Transactions of Civil Engineering, 47(4). https://doi.org/10.1007/s40996-023-01054-5

[26] R. Rodrigues, St. Gaboreau, J. Gance, I. Ignastiadis St. Betelu(2020)Numerical Insights into Its Physical Aspect and Its Ability to Locate Highly Corroding Areas in Macrocell Corrosion of Steel in Concrete. Corros. Mater. Degrad., 1, 373–407.https://doi.org/10.3390/cmd1030018

[27] R.Paul Borg, E.Gatt, St.Sammut(2017) Chloride Ion Detection in Concrete through Galvanic Voltage and Resistivity. Jordan Journal of Civil Engineering., 11(4), 638-645.

[28] V.L.Satish (2020) Half Cell Potential Studies for Durability Studies of Concrete Structures in Coastal Environment., NDE2020.e12608.

[29] R.Mohanraj, S.Senthilkumar, P.Loganathan, R. Krishnasamy (2023) Confinement effectiveness of 2900psi concrete using the extract of Euphorbia tortilis cactus as a natural additive. Matéria (Rio de Janeiro)., 28(1). https://doi.org/10.1590/1517-7076-RMAT-2022-0233

[30] S.Irico, L.De Meyst, D.Qvaeschning, M.Cruz Alonso, Kristina Villar, and Nele De Belie (2020)Severe Sulfuric Acid Attack on Self-Compacting Concrete with Granulometrically Optimized Blast-Furnace Slag-Comparison of Different Test Methods. Materials., 13, 1431. https://doi.org/10.3390/ma13061431

[31] W.Yourey,Y.Fu, N.Li, V.Battaglia, W.Tong (2021) Design Considerations for Fast Charging Lithium Ion Cells for NMC/MCMB Electrode Pairs. Batteries., 7(1), 4 https://doi.org/10.3390/batteries7010004

[32] ASTM C 876-91(2008) Standard test method for half-cell potentials of uncoated reinforcing steel in concrete.

[33] K.Ravikumar, S.Palanichamy, C.J.Singaram, M. Rajendran (2023) Crushing performance of pultruded GFRP angle section with various connections and joints on lattice towers. Matéria (Rio de Janeiro)., 28, e20230003. https://doi.org/10.1590/1517-7076-RMAT-2023-0003

[34] P.Loganathan, R.Mohanraj, S.Senthilkumar, K. Yuvaraj (2022) Mechanical performance of ETC RC beam with U-framed AFRP laminates under a static load condition. Revista de la Construcción., 21(3), 678- 691. https://doi.org/10.7764/RDLC.21.3.678

[35] G.Palanisamy, V.Kumarasamy (2023) Rehabilitation of damaged RC exterior beam-column joint using various configurations of CFRP laminates subjected to cyclic excitations. Matéria (Rio de Janeiro)., 28(2), e20230110. doi: http://dx.doi.org/10.1590/1517-7076-rmat-2023-0110.

[36] A.A.Rajesh, S.Senthilkumar, S.Samson (2023) Optimal proportional combinations of rubber crumbs and steel slag for enhanced concrete split tensile strength. Matéria (Rio de Janeiro)., 28(4), e20230206. doi: http://dx.doi.org/10.1590/1517-7076-rmat-2023-0206.

[37] P.Prasanthni, B.Priya, G.Dineshkumar, G.N. gobinath (2023) Mechanical properties of coal ash concrete in the presence of graphene oxide. International Journal of Coal Preparation and Utilization. In press. doi: http://dx.doi.org/10.1080/19392699.2023.2284991

[38] A.R.Krishnaraja, S.Kandasamy (2018) Flexural performance of hybrid engineered cementitious composite layered reinforced concrete beams. Periodica PolytechnicaCivil Engineering., 62(4), 921-929. doi: http://dx.doi.org/10.3311/PPci.11748.

[39] S.C.Johnson, G.S.Thirugnanam (2015) Structural integrity assessment of transmission line tower foundations: a comprehensive approach. CIGRE India Journal, 4(2), 42-49.

[40] R.Krishnasamy, S.C.Johnson (2020) Experimental investigations on glass fibre reinforced polymer composite pultruded sections and transmission line towers modules. Water and Energy International., 62(10), 33-37.doi.org/10.1007/976-3-030-31680-8

[41] K.Gurunaathan, S.C.Johnson, G.S.Thirugnanam (2017) Anticipated and actual performance of composite girder with pre-stressed concrete beam and RCC top flange. Structural Engineering and Mechanics International Journal., 61(1), 117-124.

[42] A.R.Krishnaraja, S.Anandakumar, M.Jegan, et al. (2019) Study on impact of fiber hybridization in material properties of engineered cementitious composites. Matéria (Rio de Janeiro)., 24(2), e12347. doi: http://dx.doi.org/10.1590/s1517-707620190002.0662.

[43] A.A.Rajesh, S.Senthilkumar, K.Sargunan (2023) Interpolation and extrapolation of flexural strength of rubber crumbs and coal ash with graphene oxide concrete. Matéria (Rio de Janeiro). 28(4), e20230179. doi: http://dx.doi.org/10.1590/1517-7076-rmat-2023-0179.

IZVOD

NEDESTRUKTIVNA PROCENA PODZEMNE KOROZIJE NA UGAONIM PROFILIMA OD VRUĆEG ČELIKA UGRAĐENIH U BETON I NJIHOVA SANACIJA CEMENTNOM SUSPENZIJOM I NITOCINK PREMAZOM

Ovaj istraživački članak predstavlja sveobuhvatno istraživanje materijala i otpornosti na koroziju ugaonih komponenti kritičnih za izgradnju infrastrukture. Studija se fokusira na dva ključna ugaona materijala: čelične uglove i uglove od plastike ojačane vlaknima (FRP), odabrane na osnovu zahteva specifičnih za projekat. Dizajn betonske mešavine, koji uključuje ključne komponente kao što su hemikalije (kalcijum hlorid, natrijum hidroksid, kalcijum hidroksid), agregati (M pesak i 20 mm agregat) i cement (Portland Pozzolana cement - 43 stepen), osigurava da se strukturalni integritet i performanse ispune željeni standardi. Istraživanje, takođe, uključuje napredne tehnike procene korozije, uključujući test potencijala polućelije i test primenjenog napona (Holidai Test), koji nude uvid u provodljivost materijala, otpornost na koroziju i integritet zaštitnog premaza. Štaviše, test hemijske otpornosti ispituje uticaj različitih rešenja na ove materijale, naglašavajući njihovu pogodnost za različite industrijske primene. Rezultati naglašavaju važnost odabira materijala po meri, proaktivnog upravljanja korozijom i kritične uloge zaštitnih premaza u obezbeđivanju dugovečnosti i bezbednosti infrastrukture. Ova studija doprinosi unapređenju metoda procene korozije, podržavajući trajnost kritičnih infrastrukturnih materijala.
Ključne reči: *korozija, premaz, hemijska otpornost, trajnost, FRP, ugaoni presek*

Naučni rad
Rad primljen: 26.11.2023.
Rad korigovan: 26.02.2024.
Rad prihvaćen: 09.03.2024.
Rad je dostupan na sajtu: www.idk.org.rs/casopis