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Analysis on Corrosion of Reinforcement in Concrete Structures and Corrosion Control (Inhibitor) of Reinforced Concrete Structures

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***Abstract*— Structures made of reinforced concrete (RC) have the potential to be extremely durable and resistant to a number of environmental cases. A reinforcing bar is placed in the concrete construction to increase the tensile stress. Steel reinforcement corrosion is a primary deterioration process that impacts the long-term durability of reinforced concrete structures. This corrosion will increase the costs involved in addition to the structural issues. Thus, to increase the service life of a structure made of concrete, different methods have been developed to stop the corrosion of the steel reinforcement in the structure. The most effective is found to be a corrosion inhibitor. This paper provides an analysis of corrosion of reinforcement in concrete structures and corrosion control (Inhibitor) of reinforced concrete structures. The impact of corrosion inhibitors on various steel bar diameters placed in concrete beams is demonstrated by the study. Impressed current method is used for creating an accelerated corrosion. An experimental work is carried out using a mixed corrosion inhibitor Zinc Oxide and Sodium Nitrite with different diameter 9 mm and 18 mm of steel bar embedded in concrete. It was looked at the importance of zinc oxide and sodium nitrite, which are used to prevent steel bars from corrosion when they are embedded in concrete and submerged in a 4% solution of sodium chloride. The results from concrete beams cast both with and without corrosion inhibitors are compared.**

***Keywords*— Steel reinforcement, reinforced concrete, concrete structures, corrosion inhibitor, Zinc Oxide and Sodium Nitrite.**

I. INTRODUCTION

A frequent deterioration mechanism in reinforced concrete structures that impacts both the structural capacity and durability of the structure is corrosion of the reinforcement in the concrete [1].

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In order to prevent corrosion and ensure that reinforced concrete structures last for the intended period of time, a great deal of research has been done in recent years [2].

The reinforcing steel, also known as rebar, corrosion and corrosion products are created when oxygen and moisture from the surrounding environment seep into the concrete. Tensile stresses develop in the concrete and internal pressure is created around the rebar as a result of the corrosion products taking up more volume than the initial steel reinforcement, which has an impact on the structure's performance [3]. Concrete delamination, cracking, spalling, and a reduction in the cross-sectional area of the reinforcing steel are examples of damages caused by corrosion. It has the potential to result in dangerous results like structural failure, as well as aesthetic damages and a loss in the structure's load bearing capacity [4].

In addition to its structural effects, corrosion can have an impact on an economy of a country. Due to the requirement for maintenance and repairs, steel corrosion in structures results in significant losses for society [5]. A large number of concrete constructions have structural defects as a consequence of corrosion and require restoration and rehabilitation in order to operate and perform structurally properly. The price of corrosion is directly impacted by the cost of restoration and repair. Furthermore, the indirect cost of corrosion is almost ten times greater than the direct cost, accounting for factors such as lost productivity and traffic delays. Together, the direct and indirect costs of corrosion exceed the world's GDP by over three times. As a result, corrosion's effects can be described in terms of both structure and economics.

In order to extend the service life of reinforced concrete constructions that are susceptible to these types of conditions, certain method such as epoxy-coated reinforced steel, cathodic protection, corrosion inhibitor has been developed [6]. Theory of corrosion by electrochemistry It will function in two parts: a cathode and an anode. The metal will oxidize and produce some electrons in the anodic region. Three reactions involving the flow of electrons toward the cathode, namely electroplating, hydrogen liberation, and oxygen absorption, will take place [7]. The process will continue as the electron is spent, and the electron flow will cause some potential to be generated on the metal surface. This electron flow will cause the metal to corrode [8].

The impressed current method is used for creating an accelerated corrosion to the steel embedded in the concrete by constant supply of current from the power supply [9]. Then the specimen which is immersed in the 3% NaCl solution is taken. The steel that will be used as the anode is connected to the positive terminal of the power supply, whereas the counter electrode, which will operate as the cathode, is linked to the negative terminal [10]. With the support of sodium chloride (NaCl) solution, which will function as an electrolyte, after the steel is implanted in the concrete, the current will start to flow from the counter electrode [11].

The application of corrosion inhibitors is the most well-known technological development among these strategies for protecting reinforced concrete structures from corrosion [12]. According to definitions, a corrosion inhibitor is "a chemical compound that, when added to concrete in adequate amounts, can prevent corrosion embedded steel and has no adverse effect on properties of concrete" [13]. The corrosion rate in reinforced concrete is delayed and slowed down by corrosion inhibitors, which provide a protective film over the steel bar's surface. To postpone and reduce the rate at which corrosion in reinforced concrete develops, corrosion inhibitors are typically included into the concrete. Inhibitors can be put to the surface of the concrete for repair work or added directly to the concrete as an additive for new construction works. This paper presents an analysis of corrosion of reinforcement in concrete structures and a description of corrosion control (inhibitor) for reinforced concrete structures. The impact of corrosion inhibitors on various steel bar diameters placed in concrete beams is demonstrated in this research. An experimental work is carried out using a mixed corrosion inhibitor Zinc Oxide and Sodium Nitrite with different diameter 9 mm and 18 mm of steel bar embedded in concrete. Following is the arrangement of the remaining content in the document: In section II, the literature survey is included. Section III describes the preparation and analysis of the specimen composition; Section IV describes the experimental results; and Section V concludes the paper.

II. Literature Survey

S. M. Salman and W. D. Salman, et. al. [14] provides the results of experiments from the testing of four columns made of reinforced concrete it had been packed with carbon fiber-reinforced geopolymer adhesive. The jacket had one, two, or three layers, depending on the circumstances. According to the results, when compared to an unconfined RC column, the load enhancement ratio and deformation capacity were improved by 333% and 411%, respectively, by the confinement utilizing carbon fiber reinforced geopolymer adhesive.

Douier K. A., Hawileh R. A. and Abdalla J. A., et. al. [15] studies that carbon fiber reinforced polymer (CFRP) and galvanized steel mesh (GSM) sheets behave in flexure to reinforce reinforced concrete columns. Comparing the GSM strengthened specimen to the control specimen, the test results showed that the first had a 58% higher ultimate load-carrying capability. Furthermore, in comparison to the identical control specimen, the CFRP strengthened specimen's ultimate load-carrying capacity increased by 47%.

Qiao G., Guo B. and Ou J., et. al. [16], Using the finite element method (FEM), an impressed current cathodic protection (ICCP) system was modeled numerically in three dimensions. From there, the potential of the reinforced bars and concrete was determined. The paving design of the anode proposed in this study provides total protection for the reinforced bars when the impressed voltage is 2.5V, as per the protection potential condition. In addition, an ICCP system prototype involving a T-beam is constructed to confirm the numerical simulation's results. Qiao G., Liu T., Hong Y. and Ou J., et. al. [17] The solid-state and current-confining corrosion sensor is investigated in this work, this is the crucial hardware component of the corrosion monitoring system designed to strengthen concrete buildings using electrochemical theory. To optimize the sensor's geometric configuration and model the distribution of the electric field in concrete, the finite-element approach is utilized. The simulation results show that the improved corrosion sensor can accurately limits the electric field in a specific location.

W. Cheng, H. -H. Sun, K. H. Tan and Z. Fan, et. al. [18] introduces a method that employs a GPR array to increase sensitivity in detecting early-stage corrosion. Reconstructing images of the reinforcing bars during the corrosion process is carried out by the method using a linear multiple-input multiple-output (MIMO) GPR array. Compared to conventional SISO ground-penetrating radar (GPR) configurations, the MIMO array offers a broader perspective in sensing corrosion products surrounding the reinforcing bars, thereby improving sensitivity and robustness in detecting early-stage corrosion.

F. Mae Velasquez, S. J. C. Clemente and N. C. Concha, et. al. [19] Using the impressed current approach, it was examined how well deteriorated rebar connected to concrete filled with corrosion inhibitor. The primary factors of this investigation are the bond strength and corrosion development by reinforcement, non-coated (NC), and coated (C) with corrosion inhibitor. Conversely, a model generated from the SLRA for bond strength in relation to corrosion level revealed that the bond strength of reinforcement (C and NC) decreases by 1.2078 MPa and 0.5508 MPa, respectively. Since the P-value and Multiple R for C and NC are 0.0009, 0.7667, and 0.0371, 0.5415, respectively, it is determined that both models are significant.

A. A. Kuznetsov, A. V. Ponomarev and G. V. Volchanin, et. al. [20] examines the possibility of applying technical techniques for visual control to process images in order to perform the evaluation of reinforced concrete structures' corrosion. The program's result is the identification of regions with a certain quantitative concentration of corrosion products. When the suggested method, when combined with video endoscopic devices, it will be possible to automatically evaluate the corrosion status of reinforced concrete structures on challenging-to-reach surfaces.

Bouzaffour K., Lescop B., Talbot P., Gallée F. and Rioual S., et. al. [21] suggests a novel embedded sensor for concrete that can be used to detect steel corrosion. The interaction between a dipolar RFID tag's antenna and a layer of steel exposed to concrete's chloride serves as the basis for the autonomous UHF RFID (Ultra High Frequency Radio Frequency Identification) sensor. Metallic coatings of a few micrometers in thickness can be found by reducing the effect that seawater intrusion has on the antenna property. This gives the go-ahead to develop the suggested technique for tracking steel mass loss in concrete.

Martínez Ibernón A., Gasch I., Romero J. M. G. and Soto J., et. al. [22] shows that principal component analysis (PCA) and voltammetric stainless steel (SS) sensors work together to identify the elements of corrosion processes, such as carbonation or the existence of chlorides in the concrete. Techniques from electrochemistry were used. A PCA was then used to evaluate the data to develop the durability control model. The validation of the model confirms that it can detect the concrete state with accuracy. The service life of reinforced concrete structures (RCS) is sustainably extended with the support of this novel process.

A., James, Chiniforush, P., E., Bazarchi, A., Panjebashi Aghdam, M., Akbarnezhad, I., Martek, Hosseini, A., ans F, Ghodoosi, et. al. [23] examines the process of corrosion undertaken in concrete in coastal regions. It also describes how carbonation and chlorination get into reinforced concrete structures and how it affects the structure's service life. Measurements of carbonation, carbonation depth, carbonation-induced mass loss, and carbonation-induced corrosion potential are made. The procedures for testing, maintaining, repairing, and protecting reinforced concrete structures from corrosion structure is described.

H., Lopez-Calvo, P., H., Gomez-Barranco, Montes-García, V., Jimenez-Quero, T., Bremner, and M., Thomas, et. al. [24] examined the impact of crack width, high performance concrete's cover depth and concrete quality on steel corrosion. Disodium tetrapropenyl succinate, calcium nitrite, and 20% fly ash were used in the test, which was conducted on a concrete specimen with reinforcing covers measuring 25 and 45 mm. It was discovered that the use of inhibitors, irrespective of the extent of the crack or the cover of the reinforcement, effectively decreased the rate of corrosion in both cracked and uncracked concrete.

Elsener, B., and Angst, U., et. al. [25] explains the primary processes by which steel corrosion in concrete, with a particular emphasis on corrosion caused by chloride and field investigations utilizing corrosion inhibitors. Studies conducted in the lab and in the field have demonstrated that adding corrosion inhibitors in suitable dosages can significantly slow down the rate at which corrosion is induced by the introduction of chloride. More factors that affect corrosion performance are the water-to-cement ratio, curing, additional cementitious materials, and execution. Y., Choi, S., Yi, M., Kim, W., Jung, and E., Yang, et. al. [26] analyzed and contrasted the bond characteristics of corroded rebar at every stage of corrosion carried on by various corroding techniques. It was discovered that when corrosion levels were high (above 2%), more cracks were seen in the concrete, leading to a significant decrease in bond strength. The polarization resistance technique was found to be more successful in assessing the levels of corrosion because it did not negatively affect the features of the concrete or the concentration of chlorides contained in the concrete.

III. METHODOLOGY

In order to find out the property of material that are being used in the experiment; various test was performed. The values that are obtained from the test are used for mix design of M40, M50 and M60 grade concrete. It also helped in knowing whether the specific material or treatment is suitable for a particular application.

Materials Used: • Cement (Ordinary Portland cement 43 grade) • Sand • Coarse aggregate (angular, 20mm) • Steel reinforcement (8mm and 16mm) of grade Fe500 • Curing tank • Sodium chloride (NaCl) solution • Super plasticizer (third generation super plasticizer) • Mixed corrosion inhibitor (Zinc oxide and Sodium nitrite) • Power supply • Multimeter • Connection wires

Specimen Description: A rectangular mould of 500 x 100 x 100 mm was used to cast a total of 12 beams measuring 450 mm in length, 100 mm in thickness, and 100 mm in width. These beams were casted without inhibitors and with inhibitors, out of which four beams were casted for M40, four for M50 and other four for M60 with an effective cover of 50 mm. Each beam has steel bars embedded in it that had a diameter of 9 and 18 mm. The embedded reinforcing steel has a total length of 450 mm in which 400 mm was embedded in the concrete and the rest 50 mm were left unembedded. While M50 and M60 concrete utilized 1% PCE with 0.35 and 0.40 water cement ratios, respectively, superplasticizer was not used in the M40 concrete formation with a 0.40 water cement ratio, respectively, based superplasticizer. The beams were then allowed to cure for a total of 28 days to acquire the necessary strength.

Procedure and Test Set Up: The galvanostatic method, sometimes referred to as the impressed current method, is used to create an accelerated corrosion (increasing the rate of corrosion). To produce a significant amount of corrosion quickly, the reinforcement embedded in the concrete receives a steady current from a DC (direct current) source. By applying Faraday's law, one can determine the level of corrosion that occurs in the concrete following a continuous current supply.

The test set up was done using DC source, a working electrode (rebar), counter anode and an electrolyte (NaCl solution). The anode, or steel, is connected to the power supply's positive terminal, and the counter electrode is connected to the negative terminal, which operates as the cathode. With sodium chloride solution acting as an electrolyte as support, to achieve the necessary degree of corrosion over a short period of time, a constant current of 0.12 Ampere is delivered from the counter anode to the reinforcement put in concrete. After the curing, the samples are taken out from the tank and is left to dry at a room temperature. Concrete examples are immersed in a big barrel of sodium chloride solution, which is made by adding 4% NaCl by the weight of water such that the water does not touch the reinforcement and is just below the peak of concrete as shown in figure 3.15. Next, the connections are established to allow current to flow at a set voltage of 10 V. This connection is left undisturbed for 1 to 6 days for generation of corrosion. After 6 days the connection is removed and the sample is taken out for the testing of weight loss method.

The initial weight in the weight loss method is determined by measuring the reinforcement prior to its embedding in concrete. Then the reinforcement which is removed from the accelerated current method is measured and is taken as the final weight. Both the weight of reinforcement with and without inhibitor is measured. Faraday’s law is being used and length of the actual mass loss is determined.

IV. RESULT ANALYSIS

This chapter includes the results obtained after performing various tests on beam with different diameter (with and without inhibitor) placed in a water containing 4% NaCl and the rate of corrosion accelerated with the help of impressed current method. After inducing current in the beam for the generation of corrosion for 1 to 6 days, the beam is then left in the sun for surface dry. After 24 hours, in order to find the flexural strength of the beam, four-point loading is done. Flexural strength of beam casted without and with inhibitor is given in Table 1. Figure 1 shows the graphical representation of flexural strength of the beam using different Grade of concrete specimens having different diameters without inhibitor.

TABLE I. FLEXURAL STRENGTH WITH INHIBITOR AND WITHOUT INHIBITOR

S. No.	Grade of concrete	Diameter of bar (mm)	Flexural strength (N/mm2)	
			without inhibitor	with inhibitor
1	M40	9	14.21	15.22
		18	18.11	19.32
2	M50	9	15.34	16.05
		18	18.97	19.86
3	M60	9	16.51	17.55
		18	19.86	22.45

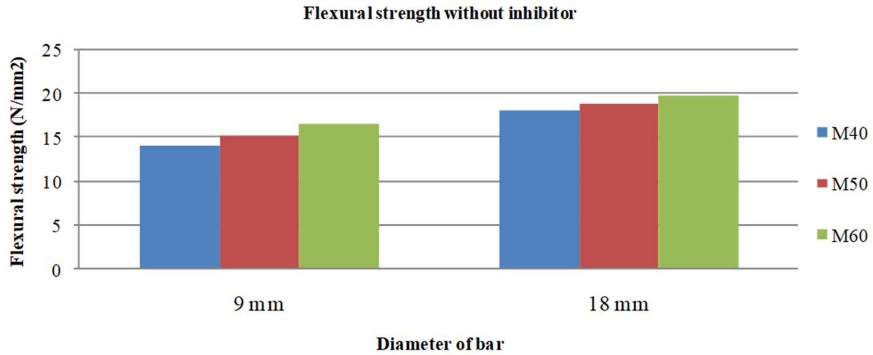

Figure 1. Flexural strength without inhibitor

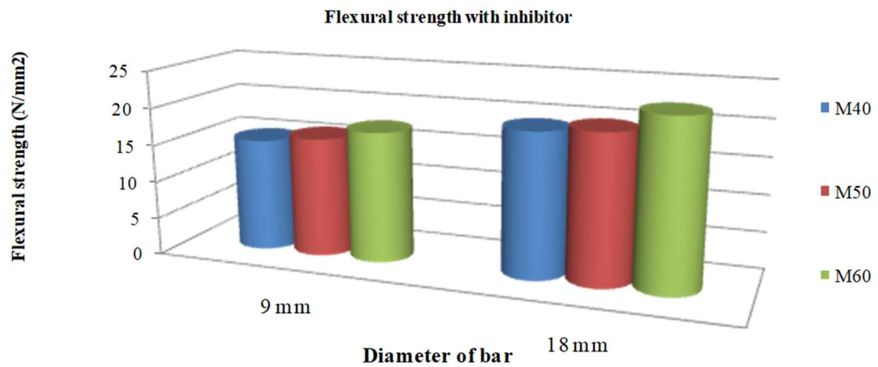

Figure 2. Flexural strength with inhibitor

The real mass loss of rust per unit surface area is given by equation 1, And Table 2 represents the actual mass loss value for without and with inhibitor.

$$M_{ac} = \frac{W_i - W_f}{\pi D L} \quad (1)$$

Where,

W_i=initial weight of the bar before corrosion (g)

M_{ac} =actual mass of rust per unit area of the bar (g/cm2)

D = diameter of the rebar (cm)

W_f = weight after corrosion (g) for a given duration of induced corrosion (T)

L= Length of the rebar sample (cm)

TABLE II. COMPARISON OF ACTUAL MASS LOSS FOR WITH INHIBITOR AND WITHOUT INHIBITOR

S. No.	Grade of concrete	Diameter of bar (mm)	M_{ac} (g/cm2)	
			without inhibitor	*with inhibitor*
1	M40	9	0.22	0.1
		18	0.091	0.08
2	M50	9	0.092	0.07
		18	0.07	0.06
3	M60	9	0.064	0.051
		18	0.058	0.032

From Figure 1 and Figure 2 it states that flexural strength of the beam is high for different Grade of concrete specimens with different diameters with inhibitor. Flexural strength of the beam is low for different Grade of concrete specimens without inhibitor.

Actual mass loss of the beam using different Grade of concrete specimens having different diameters without inhibitor is graphically represented in below Figure 3.

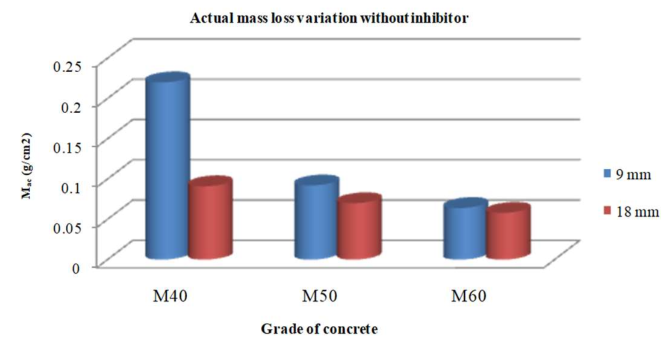

Figure 3. Actual mass loss variation for different diameter without the inhibitor

Various grades of concrete samples Figure 4 below shows the actual mass reduction with inhibitor for various diameters.

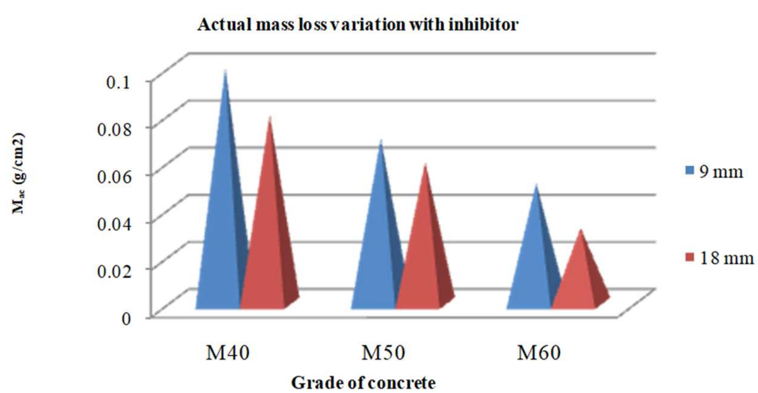

Figure 4. Actual mass loss variation for different diameter with the inhibitor

The Actual mass loss is low for different Grade of concrete specimens with different diameters with inhibitor. At the same time, Actual mass loss is high for different Grade of concrete specimens with different diameters without inhibitor. From overall analysis, it states that Corrosion Control (Inhibitor) based Reinforced Concrete Structures have higher flexural strength and minimal Actual mass loss.

V. CONCLUSION

In this paper, analysis on corrosion of reinforcement in concrete structures and corrosion control (Inhibitor) of reinforced concrete structures is described. In the development of infrastructure, reinforced concrete is one of the most often utilized construction materials. The corrosion of rebar is causing severe deterioration to reinforced concrete infrastructure world. This study examines the impact of corrosion inhibitors on various steel bar diameters placed in concrete beams. An experimental work is carried out using a mixed corrosion inhibitor Zinc Oxide and Sodium Nitrite with different diameter 9 mm and 18 mm of steel bar embedded in concrete. Impressed current method is used for creating an accelerated corrosion. The effect of applying inhibitors and increasing the rate of corrosion on a specimen made of reinforced concrete were seen through laboratory studies. When compared to reinforcement without inhibitor, the reinforced concrete coated with inhibitor demonstrated a stronger flexural strength. Higher flexural strength is achieved for large diameter of concrete specimens. The Actual mass loss is low for different Grade of concrete specimens with different diameters with inhibitor. From overall analysis, it states that Corrosion Control (Inhibitor) based Reinforced Concrete Structures have higher flexural strength and minimal Actual mass loss. Therefore corrosion inhibitor is the better technological advancement for corrosion protection of reinforced concrete structure.

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