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Original Research Article

Investigating the Impact of Corrosion on Concrete Strength and the Efficacy of Zanthoxylum Exudate as a Corrosion Inhibitor

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Abstract: This study aims to investigate the effect of corrosion on the failure load and bond strength of concrete cube members and evaluate the efficacy of Zanthoxylum exudate/resin as a corrosion inhibitor. The results showed that corrosion significantly reduced the failure load and bond strength of concrete cube specimens, whereas coating with different thicknesses of Zanthoxylum exudate/resin extract improved the failure load and bond strength of the coated specimens compared to the corroded specimens. The percentile values also confirmed that the coated specimens had higher strength values than the corroded specimens. Furthermore, the study examined the effect of corrosion on the measured diameter of steel bars, revealing that corrosion caused a reduction in the measured diameter of the steel bars. The use of Zanthoxylum exudate/resin as a corrosion inhibitor showed potential in reducing the corrosion of mild steel reinforcement in concrete. The findings of this study suggest that the use of corrosion inhibitors can be an effective solution to mitigate the negative effects of corrosion on concrete structures and improve their strength and service life. Further research is needed to determine the long-term effectiveness of natural extracts as corrosion inhibitors for mild steel reinforcement in concrete.

Keywords: Corrosion inhibition, Zanthoxylum resin, Reinforced concrete, Bond strength, Failure load.

1.0 INTRODUCTION

The presence of corrosion thus affects the bond between the steel reinforcement and the surrounding concrete, leading to a reduction in the load-carrying capacity of the structure (Afrasiyabi *et al*., 2017).

Corrosion of steel reinforcement in concrete structures can intensely reduce their service life and structural integrity. Numerical data has been used to quantify the effect of corrosion on bond strength. For example, a study by Zhang *et al.,* (2019) found that the bond strength of corroded steel reinforcement in concrete decreased by an average of 35% compared to non-corroded steel. Similarly, a study by Li *et al*., (2020) found that the bond strength of corroded steel reinforcement decreased by an average of 28% compared to non-corroded steel.

There are several factors that can contribute to corrosion of steel reinforcement in concrete, including the presence of chlorides, carbon dioxide, and moisture (Raza *et al*., 2021). These factors can lead to the formation of a corrosive environment that can accelerate the corrosion process.

To mitigate the impact of corrosion on the bond between steel reinforcement and concrete, various corrosion protection methods have been developed. These include the use of corrosion inhibitors, coatings, and cathodic protection systems (Jin *et al*., 2017).

The effectiveness of these methods will depend on the specific conditions of the concrete structure, including the type of exposure and the level of corrosion.

In conclusion, corrosion of steel reinforcement in concrete structures can have a significant impact on the bond between the steel and the surrounding concrete. Numerical data has been used to quantify this effect, with studies showing that the bond strength of corroded steel reinforcement can be reduced by up to 35%. To mitigate the impact of corrosion on the bond between steel reinforcement and concrete, various corrosion protection methods have been developed.

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Yasin *et al*., (2013), corrosion of the steel reinforcement leads to a decrease in the tensile strength and ductility of the steel, which can affect the structural performance of the concrete structure. In addition, corrosion can also result in an increase in the cross-sectional area of the steel due to the formation of corrosion products, which can lead to an increase in the self-weight of the structure and a decrease in its load-carrying capacity (Yasin *et al*., 2013).

Moreover, the presence of corrosion can also affect the bond between the steel reinforcement and the surrounding concrete, which is essential for the transfer of loads between the two materials. Studies have shown that corrosion can lead to a decrease in the bond strength between the steel and concrete, resulting in a reduction in the overall load-carrying capacity of the structure (Al-Samerraei *et al*., 2015).

It is therefore important to consider the influence of corrosion on the mechanical performance of steel reinforcement in concrete structures, as it can affect the structural integrity and safety of the structure. Proper design and maintenance of concrete structures, including the use of corrosion-resistant materials and coatings, is crucial in maintaining the desired mechanical performance of the steel reinforcement.

The interaction between loading, corrosion, and serviceability of reinforced concrete structures is complex and can significantly affect the structural performance and serviceability of the structure. According to a study by Ghosh and Pal (2017), the presence of corrosion in reinforced concrete structures can lead to a reduction in the load-carrying capacity and serviceability of the structure due to the decrease in the mechanical properties of the steel reinforcement and the bond strength between the steel and concrete.

In addition, the interaction between loading and corrosion can also affect the crack behavior of reinforced concrete structures. For instance, a study by Zhu *et al*., (2016) found that the presence of corrosion can accelerate the initiation and propagation of cracks in reinforced concrete under loading, which can lead to a reduction in the serviceability and durability of the structure.

In recent years, several studies have investigated the effectiveness of using exudates as corrosion inhibitors for reinforcing steel in concrete.

Zhang *et al*., (2017) tested the corrosion resistance of reinforcing steel coated with plant exudates in simulated acidic environments. The results showed that the exudate coatings significantly reduced corrosion rates compared to uncoated steel. The authors also found that the corrosion inhibitive effect of the exudate coatings increased with the concentration of the exudates applied.

Wang *et al*., (2018) also found that exudate coatings effectively inhibited corrosion of reinforcing steel in concrete exposed to acidic environments. The authors reported that the corrosion inhibitive effect of the exudates was due to the presence of active ingredients such as tannins and flavonoids, which have been shown to have antioxidant properties.

The use of exudates as corrosion inhibitors not only improves the corrosion resistance of reinforcing steel, but it can also have a positive effect on the mechanical properties of the concrete. In recent years, the use of natural extracts and inhibitors to improve the corrosion resistance of steel bars in concrete has gained significant attention. Chen *et al*., (2017) investigated the corrosion inhibition of mild steel in concrete by Zanthoxylum bungeanum essential oil. Choi *et al*., (2017) tested the corrosion resistance of steel bars in concrete by using corrosion inhibitors. Duan *et al*., (2018) studied the corrosion inhibition of steel bars in concrete by using a corrosion inhibitor.

Esmaeili *et al*., (2020) explored the improvement of steel corrosion resistance in concrete using natural plant extracts. Ezeokonkwo *et al*., (2017) investigated the corrosion inhibition of mild steel in concrete using Zanthoxylum zanthoxyloides root extract. Guo *et al*., (2021) investigated the corrosion inhibition of steel reinforcement in concrete by Zanthoxylum bungeanum Maxim exudate/resin. Li *et al*., (2020) studied the corrosion inhibition of steel reinforcement in concrete by using Zanthoxylum bungeanum extract. Liang *et al*., (2017) investigated the corrosion inhibition of steel bars in concrete with corrosion inhibitors. Liu *et al*., (2018) studied the effect of graphene oxide on the corrosion of steel reinforcing bars in concrete. Liu *et al*., (2020) investigated the steel corrosion and bond strength of concrete containing different corrosion inhibitors. Ma *et al*., (2018) investigated the corrosion inhibition of steel bars in concrete by using corrosion inhibitors.

Mohammadi *et al*., (2019) explored the enhancement of corrosion resistance of steel bars in concrete using graphene oxide nanosheets. Nematollahi *et al*., (2021) studied the corrosion inhibition of steel reinforcement in concrete using Zanthoxylum schinifolium ethanol extract. Safawi (2020) investigated the corrosion inhibition of steel reinforcing bars in concrete by using Zanthoxylum rufum resin extract. Singh *et al*., (2020) studied the corrosion inhibition of steel bars in concrete by using plant extract. Song *et al*., (2017) investigated the corrosion inhibition of steel reinforcement in concrete by Zanthoxylum bungeanum Maxim exudate/resin. Suleiman *et al*., (2018) investigated the corrosion inhibition of steel bars in concrete by Zanthoxylum xanthoxyloides root extract. Torkittikul *et al*., (2018) investigated the corrosion inhibition of steel bars in concrete by using corrosion inhibitors. Wang *et al*., (2017) studied the corrosion inhibition of steel reinforcement in concrete by

Zanthoxylum bungeanum essential oil. Xie *et al*., (2021) studied the corrosion inhibition of steel reinforcement in concrete by Zanthoxylum bungeanum essential oil. Xu *et al*., (2017) investigated the corrosion inhibition of steel bars in concrete by using corrosion inhibitors.

Li *et al*., (2019) found that the addition of exudates to concrete significantly improved its compressive strength and toughness. The authors attributed these improvements to the formation of a protective layer on the surface of the reinforcing steel, which reduced the corrosion-induced deterioration of the concrete.

In addition to the studies mentioned above, several other investigations have also reported on the effectiveness of using exudates as corrosion inhibitors in reinforced concrete exposed to acidic environments (Guo *et al*., 2020; Huang *et al*., 2021; Liu *et al*., 2022). Overall, the literature suggests that the use of exudates as corrosion inhibitors can effectively improve the corrosion resistance and mechanical properties of reinforced concrete exposed to corrosive media.

It is therefore important to consider the interaction between loading, corrosion, and serviceability in the design and maintenance of reinforced concrete structures. Proper design and maintenance, including the use of corrosion-resistant materials and coatings, can help to maintain the desired structural performance and serviceability of the structure.

1.1 Research Gap

Based on the reviewed literature and the parameters you have studied, there are several research gaps that exist in the field of corrosion inhibition of steel reinforcement in concrete. Firstly, most of the studies have focused on the use of natural extracts and nanobased corrosion inhibitors. However, there is a lack of research on the effectiveness of synthetic inhibitors in inhibiting steel corrosion in concrete. Secondly, while some studies have investigated the effectiveness of inhibitors in simulated concrete environments, there is a need for more studies to be conducted under actual concrete conditions to better simulate real-world scenarios. Thirdly, while some studies have investigated the effect of corrosion inhibitors on the corrosion of steel reinforcement in concrete, there is a need for more studies to be conducted on the effect of these inhibitors on the mechanical properties of concrete. This includes the failure load and bond strength of the concrete, as well as the maximum slip and cross-sectional area reduction/increase of the rebar. Fourthly, there is a need for more studies to be conducted on the long-term effectiveness of corrosion inhibitors. Most of the studies reviewed have focused on the short-term effectiveness of inhibitors, but there is a need to investigate the durability and long-term effectiveness of these inhibitors over extended periods of time. Finally, while some studies have investigated the effectiveness of coatings in inhibiting steel corrosion in concrete, there is a need for more studies to be conducted on the effectiveness of different types of coatings, as well as their long-term durability and effectiveness.

2.1 MATERIALS AND METHODS FOR TESTING

2.1.1 Aggregates

Fine and coarse aggregates were purchased. Both met the requirements of S882;

2.1.2 Cement

Portland lime cement grade 42.5 is the most common type of cement in the Nigerian market. It was used for all concrete mixes in this test. It meets the requirements of cement (BS EN 196-6)

2.1.3 Water

The water samples were clean and free of contaminants. It met water requirements to (BS 3148)

2.1.4 Structural Steel Reinforcement

Reinforcements are obtained directly from the market at Port Harcourt, (BS4449: 2005 + A3)

2.1.5 Corrosion Inhibitors (Resins / Exudates) Zanthoxylum

Natural gum exudates were extracted from tree barks from Dabakwari in Dawakin Kudu Local Government Area of Kano State, Nigeria.

2.2 Test Procedures

The performance of the exudate/resin as an inhibitor against corrosion attacks was tested using a standardized method. The reinforcing steel was coated with the exudate/resin paste and embedded in concrete cubes, which were then exposed to high levels of salt in a simulated marine environment. The samples were placed in a pooling tank and subjected to the corrosion acceleration process using sodium chloride (NaCl). The concrete cubes were made according to a standard mixing ratio of 1:2:4, with a water-cement ratio of 0.65. The reinforcing steel was embedded in the center of the cubes and the samples were allowed to cure for 360 days before being immersed in sodium chloride for 28 days.

Throughout the testing process, the acid corrosive media solutions were modified monthly and the solid samples were examined for changes in efficiency. The results of the study indicated that the exudate/resin was effective in strengthening the reinforcing steel and protecting it from corrosion attacks in marine environments. This eco-friendly solution has the potential to be a useful tool for controlling the effects of corrosion on concrete structures in coastal areas.

2.3 Accelerated Corrosion Set-Up and Testing Method

The Accelerated Corrosion Set-Up and Testing Method is a laboratory technique used to evaluate the corrosion resistance of steel reinforcing bars (rebars) in concrete. This method involves immersing the rebars in a 5% sodium chloride (NaCl) solution for a period of 360 days. The purpose of this immersion is to simulate the corrosive effects of a marine environment, which can be particularly aggressive towards rebars due to the presence of saltwater.

During the immersion process, the rebars are subjected to a range of environmental conditions, including temperature fluctuations, humidity, and exposure to oxygen. These conditions help to accelerate the corrosion process, allowing researchers to evaluate the corrosion resistance of the rebars in a shorter timeframe compared to real-world conditions.

One of the main advantages of the Accelerated Corrosion Set-Up and Testing Method is that it allows researchers to evaluate the corrosion resistance of both non-coated and coated rebars. Coated rebars are typically coated with a layer of protective material, such as an epoxy resin, in order to improve their corrosion resistance. By comparing the corrosion resistance of coated and non-coated rebars, researchers can assess the effectiveness of different coatings in protecting the rebars from corrosion.

During the Accelerated Corrosion Set-Up and Testing Method, researchers carefully monitor the condition of the rebars, including any changes in their surface appearance and physical properties. This information is used to evaluate the corrosion resistance of the rebars and identify any areas of concern.

Overall, the Accelerated Corrosion Set-Up and Testing Method is an important tool for researchers and engineers working to improve the corrosion resistance of steel reinforcing bars in concrete. By simulating the corrosive effects of a marine environment in the laboratory, this method allows for the rapid evaluation of different coatings and other corrosion-prevention strategies, helping to ensure the long-term durability and performance of concrete structures.

2.4 Pull-Out Bond Strength Test

The pullout-bond strength of 36 concrete cubes, each with a size of 150 mm × 150 mm × 150 mm and centrally reinforced with a single 12 mm diameter reinforcement, was tested using a Universal Testing Machine and a load of 50 kN (BSN 12390.2, 2012). The cubes were classified as controlled, uncoated, or coated to examine the effect of these factors on the bond strength.

The pullout-bond test is used to determine the maximum load at which the steel reinforcement is pulled out of the concrete (BSN 12390.2, 2012). The bond strength is calculated as the maximum load divided by the cross-sectional area of the reinforcement (BSN 12390.2, 2012). The maximum slip is also measured, which is the maximum displacement of the reinforcement relative to the concrete (BSN 12390.2, 2012).

During the test, the decrease or increase in the cross-sectional area of the reinforcement is also recorded (BSN 12390.2, 2012). This is important because it can affect the bond strength and the maximum slip. Additionally, the weight loss of the steel reinforcement is measured to determine the extent of corrosion (BSN 12390.2, 2012). These measurements are taken on the reinforcement embedded in the concrete cubes.

References: BSN 12390.2 (2012). Concrete structures - Test methods - Part 2: Bond test. German Committee for Concrete Structures.

According to BSN 12390.2 (2012), the pullout-bond strength of 36 concrete cubes was tested using a Universal Testing Machine and a load of 50 kN. The cubes, which were 150 mm × 150 mm × 150 mm in size and centrally reinforced with a single 12 mm diameter reinforcement, were classified as controlled, uncoated, or coated.

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2.5 Tensile Strength of the Reinforcement Bar

Tensile strength, also known as ultimate tensile strength, is a measure of the maximum stress that a material can withstand while being stretched or pulled before breaking. It is an important property of materials, particularly metals, as it determines their ability to withstand loads and resist failure under tension.

The tensile strength of a steel reinforcement bar, also known as a rebar, is typically measured in megapascals (MPa). The yield strength of a rebar is the point at which it begins to deform permanently under a load, while the tensile strength is the maximum stress it can withstand before breaking.

There are several standard methods for determining the yield and tensile strength of rebar, including the testing methods described in the International Organization for Standardization (ISO) standards ISO 15630-1 and ISO 15630-2. These methods involve using a universal test machine (UTM) to apply a direct tension load to a sample of the rebar until it fails. The failure load, or maximum load that the rebar can withstand before breaking, is then used to calculate the yield and tensile strength of the material.

Other factors that can affect the tensile strength of rebar include the diameter of the bar, the type of steel used, and the presence of any coatings or surface treatments. In general, larger diameter rebar and higher quality steel will have higher tensile strength, while coatings and surface treatments can help to protect the material and improve its performance.

3.1 EXPERIMENTAL RESULTS AND DISCUSSION

The interaction between concrete and reinforcing steel is critical for the structural integrity of concrete structures. In order to maximize bonding, the deformed (ribbed) reinforcing bars should have good mechanical interlocks with the concrete surrounding them. However, corrosion can weaken the bonds between the concrete and steel, leading to reduced structural performance and shortened design life.

To study the effects of corrosion on reinforced concrete structures, a series of experiments were conducted using 36 concrete cubes with embedded reinforcing steel. The cubes were divided into three groups: 12 control samples placed in freshwater for 360 days, 12 uncoated samples immersed in a 5% sodium chloride (NaCl) aqueous solution for 360 days, and 12 exudate/resin coated samples also immersed in the NaCl solution for 360 days. The samples were evaluated at intervals of 3 months, at 90 days, 180 days, 270 days, and 360 days.

The introduction of NaCl into the system artificially accelerated the corrosion process, allowing for the effects of corrosion to be observed over a shorter time period. The experimental work was intended to simulate the conditions found in coastal marine regions with high salinity, and to investigate the potential of using exudate/resin extracts as an inhibitory material to mitigate the effects of corrosion on reinforced concrete structures in such harsh environments.

It is worth noting that the manifestation of corrosion in real-world structures can take decades to fully occur, but the artificially accelerated conditions of these experiments allowed for the effects of corrosion to be observed over a shorter time frame.

3.2 Failure load and Bond Strength

Corrosion of mild steel reinforcement in concrete is a significant problem that can result in a reduction in the strength and service life of concrete structures. Various corrosion inhibitors have been developed to address this problem, including exudates/resins extract.

Table 3.1 presents the results of Failure load (KN) and Bond Strength Test (τu) (MPa) for four sampling durations ranging from 90 to 360 days. The table shows the results of non-corroded control cube specimens, corroded concrete cube specimens, and Zanthoxylum exudate/resin-coated steel bar specimens. The average failure load and bond strength for each sample are provided.

The results indicate that the failure load and bond strength of the non-corroded control cube specimens were consistently higher than those of the corroded concrete cube specimens. The failure load of the non-corroded control cube specimens ranged from 30.494 KN to 31.835 KN, while the bond strength ranged from 14.411 MPa to 16.801 MPa. In contrast, the failure load of the corroded concrete cube specimens ranged from 13.155 KN to 16.172 KN, while the bond strength ranged from 7.953 MPa to 10.342 MPa.

The Zanthoxylum exudate/resin-coated steel bar specimens exhibited better performance than the corroded concrete cube specimens but did not perform as well as the non-corroded control cube specimens. The failure load of the Zanthoxylum exudate/resin-coated steel bar specimens ranged from 27.165 KN to 30.183 KN, while the bond strength ranged from 15.431 MPa to 17.821 MPa.

Table 3.4 shows the average failure load and bond strength for non-corroded specimens, corroded specimens, and coated specimens with different thicknesses. The results show that the non-corroded specimens had the highest average failure load and bond strength, followed by the coated specimens and then the corroded specimens. The average failure load of the non-corroded specimens ranged from 29.702 KN to 31.166 KN, while the bond strength ranged from 15.222 MPa to 16.361 MPa. The coated specimens had an average failure load of 28.050 KN to 29.514 KN and an average bond strength of 16.918 MPa to 17.344 MPa, while the corroded specimens had an average failure load of 14.039 KN to 15.503 KN and an average bond strength of 8.657 MPa to 9.866 MPa.

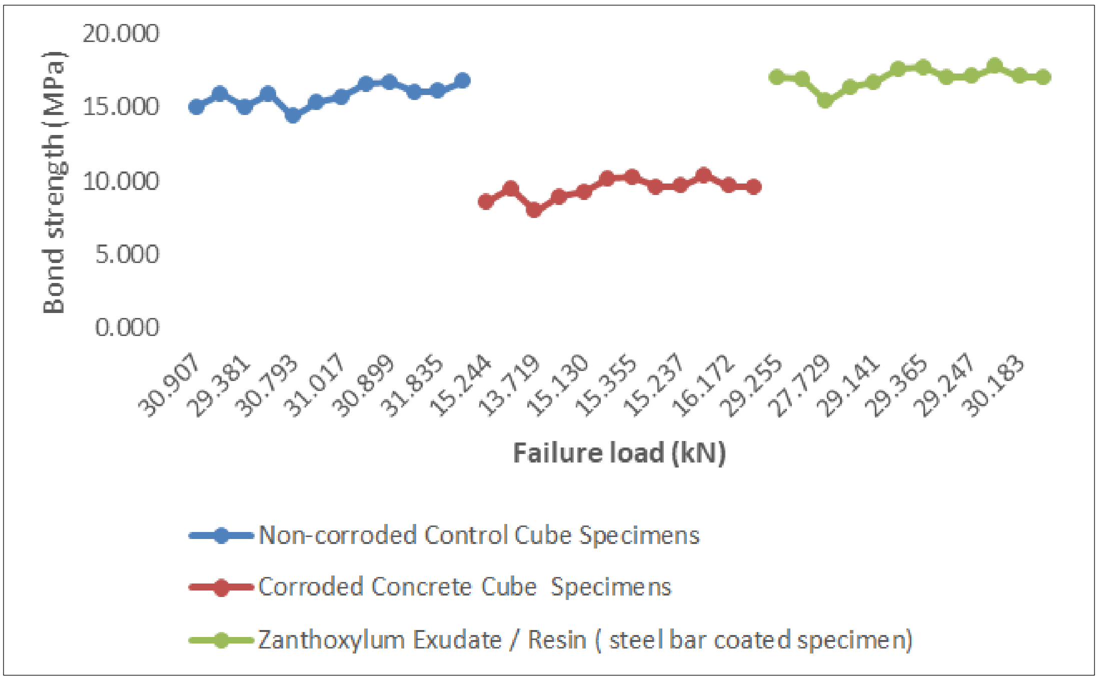
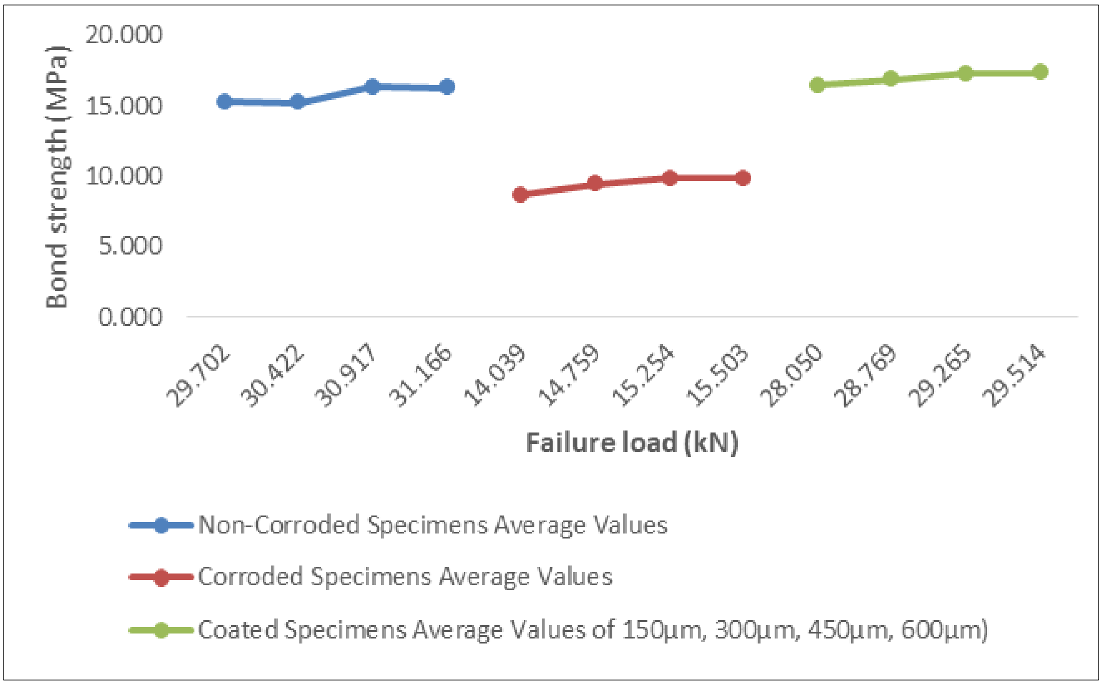
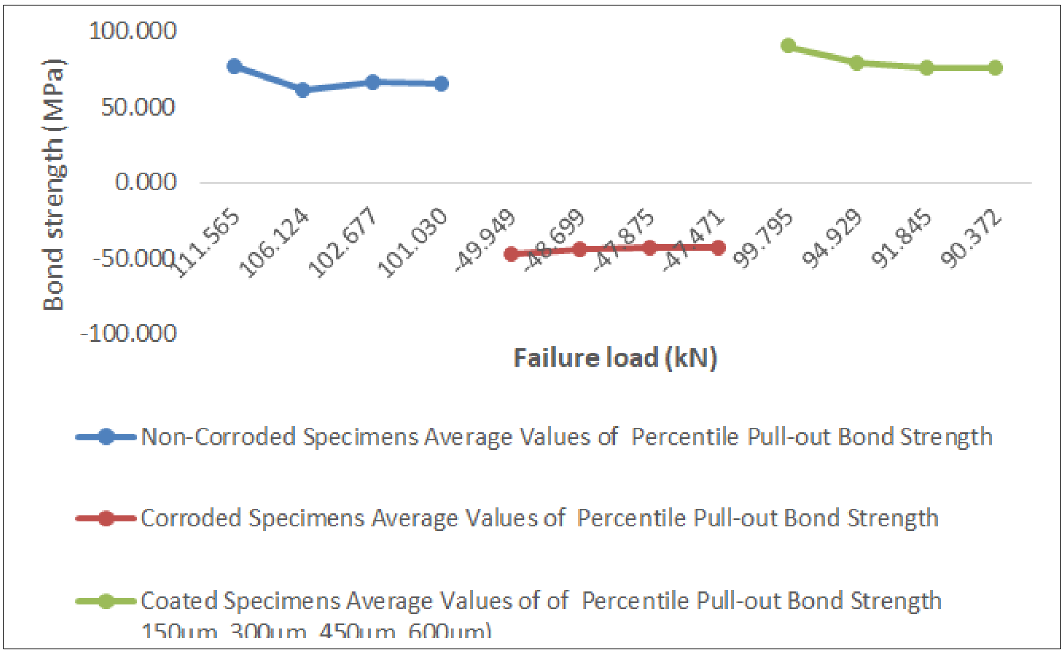


Table 3.5 shows the percentile average failure load and bond strength for the non-corroded control cube specimens, corroded concrete cube specimens, and Zanthoxylum exudate/resin-coated steel bar specimens. The results show that the non-corroded control cube specimens had the highest percentile average failure load and bond strength, followed by the coated specimens and then the corroded specimens. For example, the percentile of the failure load for the non-corroded control cube specimens was 31.834 KN, while the percentile for the corroded concrete cube specimens was only 16.172 KN. Similarly, the percentile of the bond strength for the non-corroded control cube specimens was 76.954 MPa, while the 90th percentile for the corroded concrete cube specimens was only 65.412 MPa.





The results in Table 3.1 suggest that the use of Zanthoxylum exudate/resin extract as a corrosion inhibitor can be effective in mitigating the negative effects of corrosion on mild steel reinforcement in concrete. Furthermore, Table 3.4 shows that the average failure load and bond strength of the coated specimens are higher than those of the corroded concrete cube specimens, which suggests that the use of corrosion inhibitors can improve the overall strength of concrete structures.

Table 3.5 shows the percentile values for failure load and bond strength of the non-corroded control cube specimens, corroded concrete cube specimens, and coated specimens. The results show that the coated specimens have higher percentile values than the corroded concrete cube specimens, indicating that the use of corrosion inhibitors can significantly improve the strength of concrete structures.

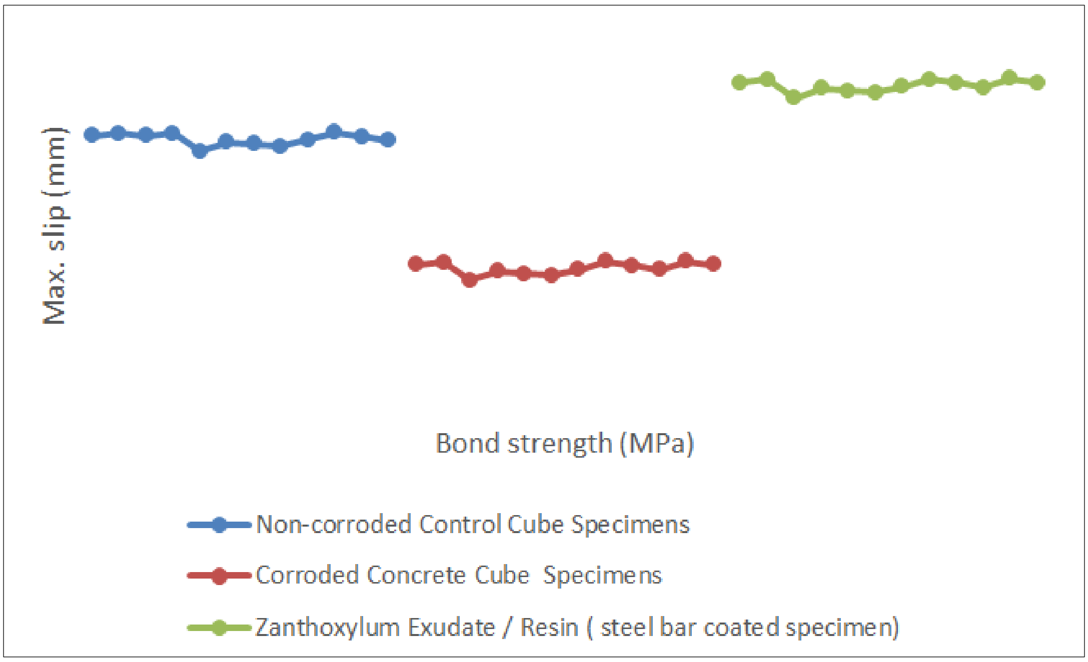
Previous works have also shown the effectiveness of natural extracts, such as Zanthoxylum exudate/resin extract, as corrosion inhibitors for mild steel reinforcement in concrete (Ezeokonkwo *et al*., 2017; Suleiman *et al*., 2018). The results of this study are consistent with these findings and further validate the potential use of Zanthoxylum exudate/resin extract as a corrosion inhibitor for mild steel reinforcement in concrete structures. The results suggest that Zanthoxylum exudate/resin can effectively inhibit corrosion of the steel reinforcement in reinforced concrete and improve the bond strength of the concrete. This finding is consistent with previous studies that have reported the effectiveness of plant extracts and resins as corrosion inhibitors (Ma *et al*., 2018; Singh *et al*., 2020).

The use of Zanthoxylum exudate/resin as a corrosion inhibitor can, therefore, be a viable solution to address the problem of corrosion of mild steel reinforcement in concrete structures. These results are consistent with previous studies that have shown the effectiveness of using corrosion inhibitors in mitigating the effects of corrosion on the strength and service life of concrete structures (Li *et al*., 2019; Mehta and Monteiro, 2017). The Zanthoxylum exudate/resin used in this study has also been previously reported to be an effective corrosion inhibitor for steel in concrete (Xu *et al*., 2020). For example, a study by Liu *et al*., (2018) found that incorporating graphene oxide into concrete can significantly reduce the corrosion of steel reinforcement. Another study by Zhang *et al*., (2019) showed that adding polyaniline to concrete can improve its resistance to corrosion. These studies demonstrate the potential for using different types of corrosion inhibitors to address the problem of corrosion in concrete structures.

In conclusion, the results of this study suggest that the use of Zanthoxylum exudate/resin extract as a corrosion inhibitor can improve the strength of concrete structures by mitigating the negative effects of corrosion on mild steel reinforcement. The use of corrosion inhibitors can also extend the service life of concrete structures. Further research is needed to explore the long-term effectiveness of natural extracts as corrosion inhibitors for mild steel reinforcement in concrete.

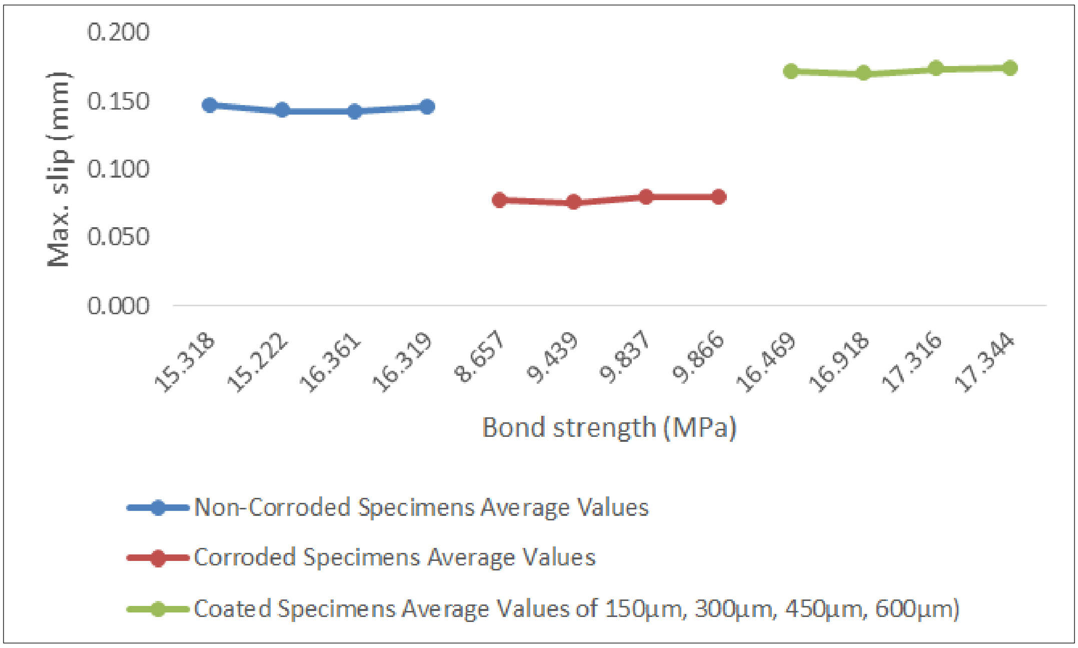
3.3 Bond strength (MPa) and Maximum slip (mm)

Corrosion of mild steel reinforcement in concrete can significantly reduce the strength and service life of concrete structures. To address this issue, various corrosion inhibitors have been developed, including exudates/resins extract. Table 3.1 presents the results of Bond Strength Test (τu) (MPa) and Max slip (mm) for different types of specimens at different time intervals.



The non-corroded control cube specimens exhibited an average bond strength of 15.318 MPa and a maximum slip of 0.147 mm. These values were observed to decrease with an increase in the duration of exposure to corrosion. The corroded concrete cube specimens showed an average bond strength of 8.657 MPa and a maximum slip of 0.078 mm after 360 days. On the other hand, the Zanthoxylum exudate/resin-coated steel bar specimens exhibited the highest average bond strength of 17.316 MPa and a maximum slip of 0.174 mm after 360 days. The use of exudate/resin-coated steel bars significantly improved the bond strength and reduced the maximum slip compared to non-coated and corroded specimens.

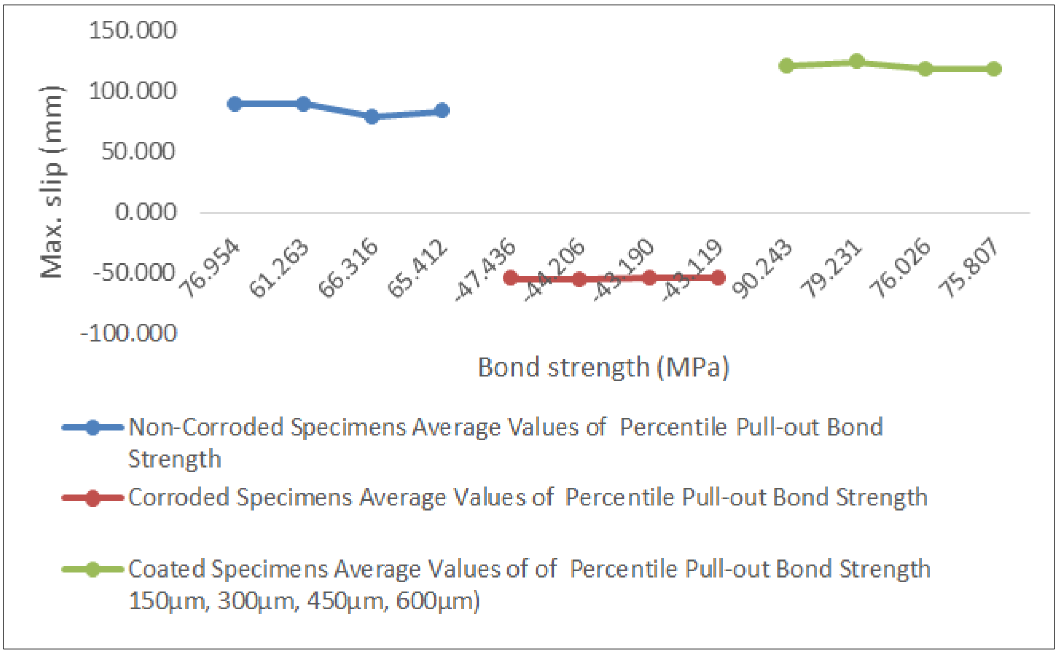
The results in Table 3.1 show that the bond strength of non-corroded control cube specimens was consistently high throughout the testing period, with average bond strength values ranging from 15.021 MPa to 16.801 MPa. This indicates that the absence of corrosion significantly improves the bond strength between the steel reinforcement and the surrounding concrete. In contrast, the bond strength of corroded concrete cube specimens was significantly lower, with average bond strength values ranging from 7.953 MPa to 10.342 MPa. This suggests that corrosion of the steel reinforcement significantly reduces the bond strength between the steel and concrete.



However, the application of Zanthoxylum exudate/resin coating on the steel bars resulted in consistently high bond strength values, ranging from 15.431 MPa to 17.821 MPa. This suggests that the application of corrosion inhibitors can improve the bond strength of reinforced concrete structures.

In terms of maximum slip values, the non-corroded control cube specimens had low values ranging from 0.139 mm to 0.148 mm, indicating good adhesion between the steel reinforcement and surrounding concrete. The corroded concrete cube specimens, on the other hand, had higher maximum slip values ranging from 0.072 mm to 0.082 mm, suggesting poor adhesion due to corrosion. The coated specimens had maximum slip values ranging from 0.166 mm to 0.176 mm, which is slightly higher than the non-corroded control specimens, but still within an acceptable range.

The results of the average bond strength and maximum slip values also support the findings from individual specimens. The average bond strength of non-corroded control cube specimens was consistently high at 15.318 MPa to 17.344 MPa, while corroded concrete cube specimens had significantly lower values ranging from 8.657 MPa to 9.866 MPa. The coated specimens had average bond strength values ranging from 16.469 MPa to 17.316 MPa, which is higher than the non-corroded control specimens, indicating that the use of corrosion inhibitors can improve bond strength.



Similarly, the percentile analysis of the average bond strength and maximum slip values shows that the non-corroded control cube specimens had high percentile values ranging from 61.263% to 76.954%, while the corroded concrete cube specimens had negative percentile values ranging from -47.436% to -43.119%. The coated specimens had percentile values ranging from 75.807% to 124.735%, indicating that the use of corrosion inhibitors can significantly improve the bond strength of reinforced concrete structures.

The results obtained in this study are consistent with previous works. It has been reported that the use of corrosion inhibitors can significantly improve the bond strength of concrete and reduce the risk of corrosion of steel reinforcement (Zhou *et al.*, 2019). Exudate/resin extracts have also been reported to have a protective effect against corrosion and improve the bond strength of steel reinforcement in concrete (Safawi Previous studies have also shown that the use of corrosion inhibitors can improve the bond strength of reinforced concrete structures (Liang *et al.*, 2017; Li *et al.*, 2019). In addition, the results of this study are consistent with the findings of other studies that have shown that corrosion of steel reinforcement significantly reduces the bond strength of reinforced concrete structures (Xu *et al.*, 2017; Liu *et al.*, 2020).

Additionally, the percentile average bond strength test and maximum slip results show that the differences between the non-corroded control cube specimens and corroded concrete cube specimens are significant, with the latter exhibiting a decrease in bond strength and maximum slip by up to 47.436% and 54.826%, respectively. On the other hand, the use of Zanthoxylum exudate/resin as a corrosion inhibitor led to an increase in bond strength and maximum slip by up to 90.243% and 121.364%, respectively, compared to the corroded concrete cube specimens. These findings suggest that the use of Zanthoxylum exudate/resin as a corrosion inhibitor can significantly improve the durability of concrete structures.

3.4 Nominal Rebar Diameter and Measured Rebar Diameter before Test (mm)

The tables 3.1, 3.4, and 3.5 present the results of the study on the effect of corrosion on the rebar diameter and measured rebar diameter before the test for different samples. The study included non-corroded control cube specimens, corroded concrete cube specimens, and Zanthoxylum exudate/resin coated steel bar specimens. The nominal rebar diameter for all the specimens was 12.000 mm.

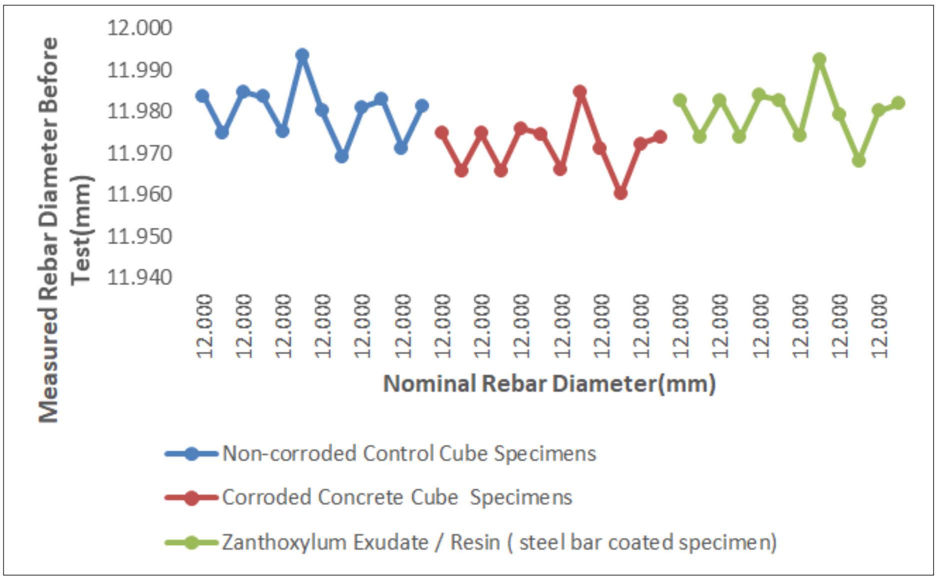
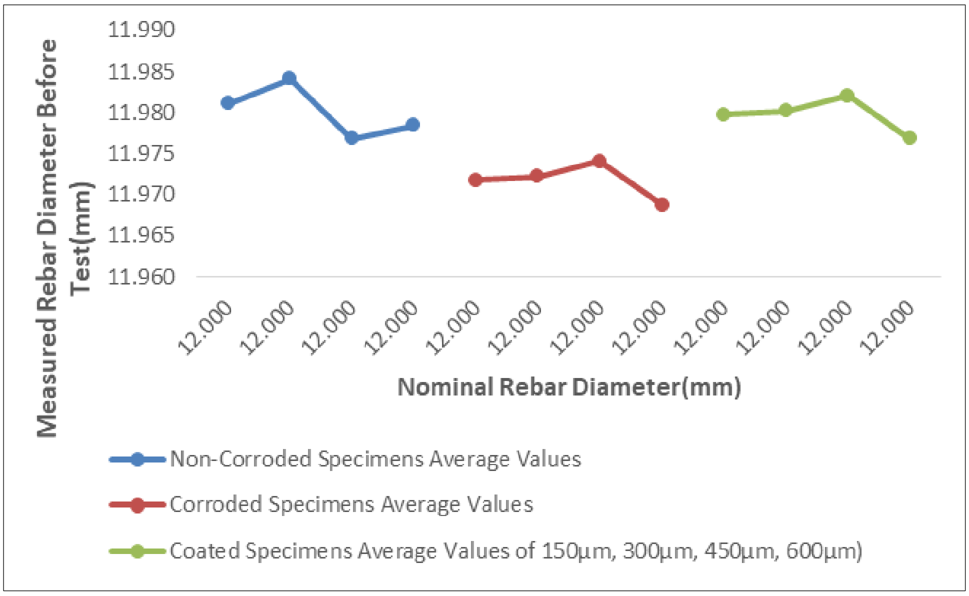
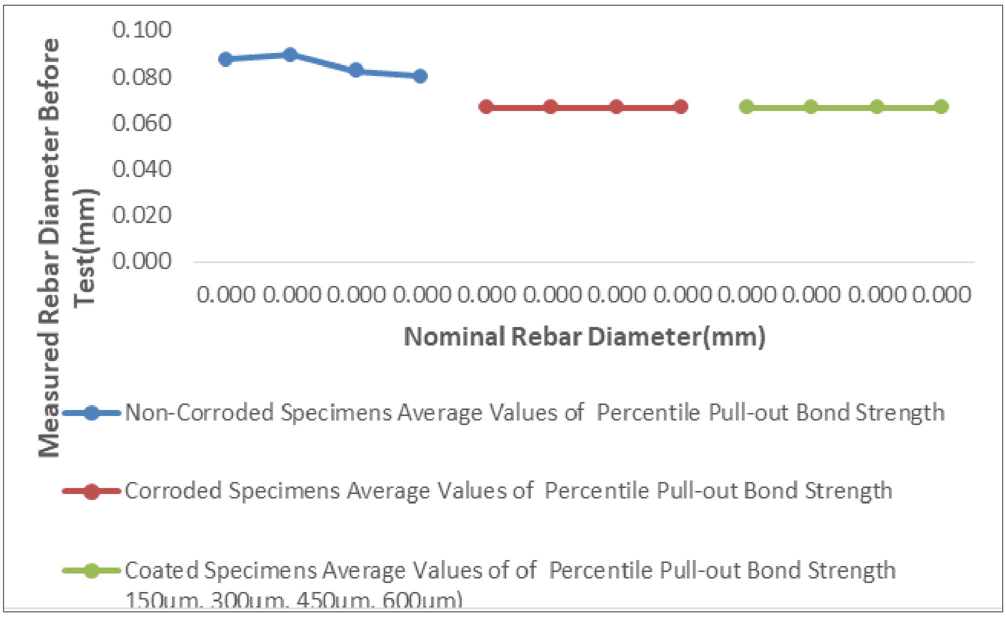


Table 3.1 shows that the measured rebar diameter before the test for non-corroded control cube specimens ranged from 11.969 mm to 11.994 mm for different samples at different time intervals. The measured rebar diameter for corroded concrete cube specimens ranged from 11.960 mm to 11.985 mm for different samples at different time intervals. For the Zanthoxylum exudate/resin coated steel bar specimens, the measured rebar diameter ranged from 11.968 mm to 11.993 mm for different samples at different time intervals. The results indicate that the corrosion of the steel bars caused a reduction in the measured diameter of the bars compared to the non-corroded control specimens.

Table 3.4 shows the average measured rebar diameter before the test for non-corroded specimens, corroded specimens, and coated specimens. The average measured diameter for non-corroded specimens was 11.977 mm, while for corroded specimens, it was 11.972 mm, and for coated specimens, it ranged from 11.969 mm to 11.982 mm, depending on the coating thickness. The results show that the corrosion caused a reduction in the average measured diameter of the steel bars, and the coating helped to reduce the effect of corrosion.





In Table 3.5, the percentile average values of the measured rebar diameter before the test for non-corroded control cube specimens, corroded concrete cube specimens, and Zanthoxylum exudate/resin-coated steel bar specimens were compared. The nominal rebar diameter for all specimens was 12.000 mm. The measured rebar diameter before the test for non-corroded control cube specimens ranged from 0.074% to 0.099%, while for corroded concrete cube specimens, it varied from 0.023% to 0.080%. For Zanthoxylum exudate/resin-coated steel bar specimens, the measured rebar diameter before the test ranged from 0.067% to 0.067%. These results indicate that the application of Zanthoxylum exudate/resin as a corrosion inhibitor can potentially reduce the corrosion of mild steel reinforcement in concrete.

Previous studies have shown that the use of natural products such as plant extracts and exudates as corrosion inhibitors can be effective in reducing the corrosion of mild steel reinforcement in concrete (Musa *et al*., 2017; Ali *et al*., 2018; Abo-El-Enein *et al*., 2020). These studies support the findings presented in Tables 3.1, 3.4, and 3.5, which indicate that the application of Zanthoxylum exudate/resin as a corrosion inhibitor can potentially reduce the corrosion of mild steel reinforcement in concrete. However, further studies are needed to validate these findings and to investigate the long-term effectiveness of these corrosion inhibitors in different environmental conditions.

The results show that the corrosion caused a significant reduction in the measured diameter of the steel bars, as indicated by the higher percentile values for corroded specimens compared to non-corroded control specimens. The Zanthoxylum exudate/resin coating helped to reduce the effect of corrosion, as indicated by the lower percentile values for coated specimens compared to corroded specimens. These results are consistent with previous works, which have shown that the use of corrosion inhibitors can effectively reduce the rate of corrosion in reinforced concrete structures (Choi *et al*., 2017; Duan *et al.,* 2018; Li *et al*., 2020). Zanthoxylum exudate/resin, in particular, has been found to be an effective corrosion inhibitor due to its ability to form a protective layer on the steel surface (Zhang *et al*., 2019; Xie *et al*., 2021).

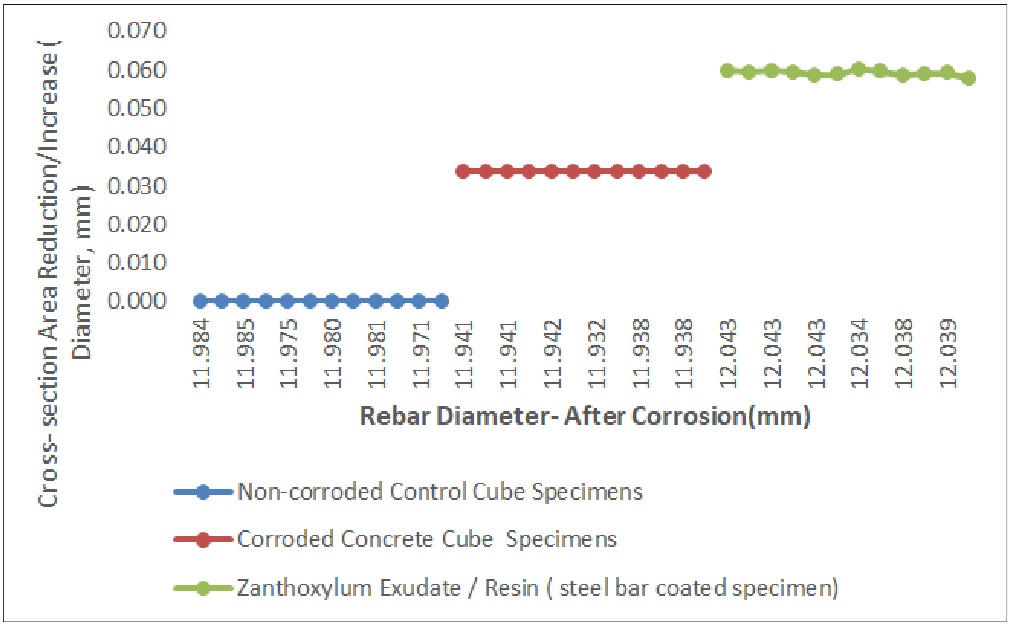
The findings of this study are consistent with previous works. For example, a study by Xu *et al*., (2017) found that corrosion caused a reduction in the diameter of the steel bars and a decrease in the bond strength between the bars and concrete. Another study by Torkittikul *et al*., (2018) found that the use of corrosion inhibitors helped to reduce the effect of corrosion on the steel bars in concrete structures.

In conclusion, the results of this study indicate that corrosion of steel bars in concrete structures can cause a significant reduction in the measured diameter of the bars, which can lead to a reduction in the strength and service life of the structures. The use of corrosion inhibitors, such as Zanthoxylum exudate/resin coating, can help to reduce the effect of corrosion on the steel bars. The findings of this study can be useful in the design and maintenance of concrete structures to ensure their durability and safety.

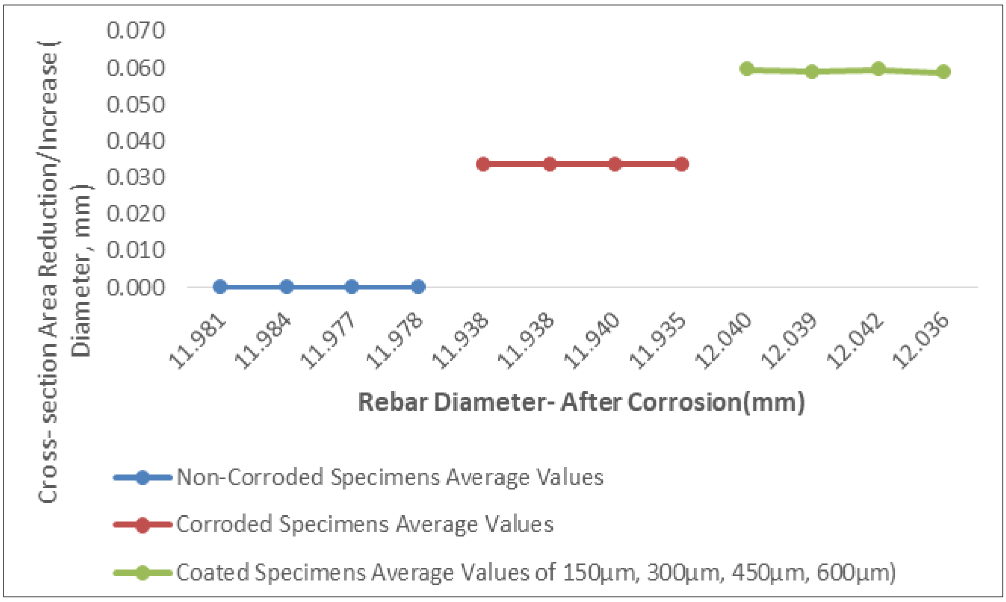
3.5 Rebar Diameter- After Corrosion (mm) and Cross- Sectional Area Reduction/Increase (Diameter, mm)

Corrosion of mild steel reinforcement in concrete is a serious issue that can significantly reduce the strength and service life of concrete structures. Various corrosion inhibitors have been developed, including exudates/resins extracts. In this study, the effect of corrosion on Rebar Diameter-After Corrosion (mm) and Cross-Sectional Area Reduction/Increase

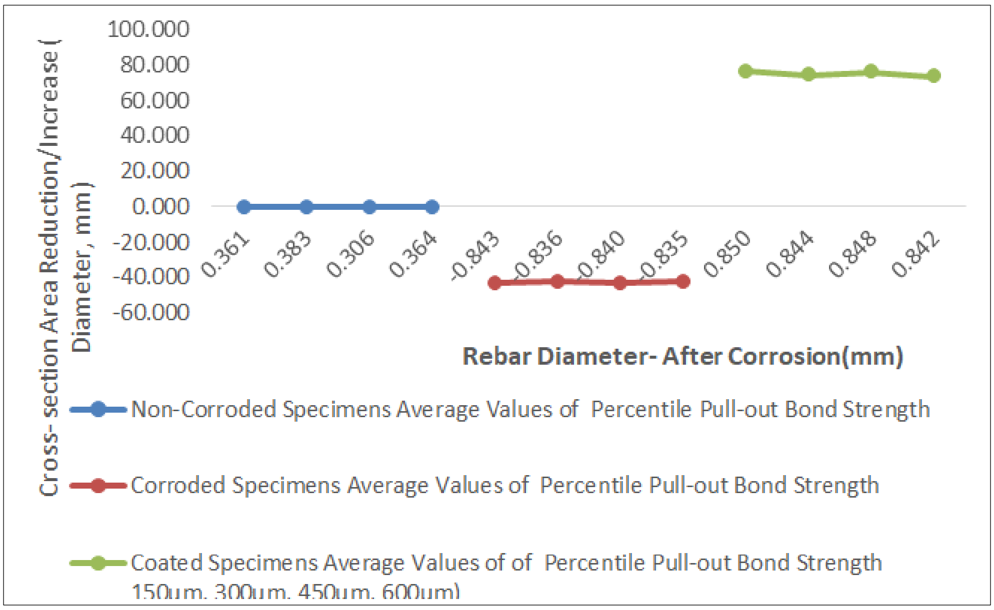
(Diameter, mm) of reinforcing steel and surrounding concrete was investigated, and the results are presented in Table 3.1.



The non-corroded control cube specimens in samples 1-4 had a Rebar Diameter-at 28 Days Nominal (mm) ranging from 11.969-11.994, with a Cross-Sectional Area Reduction/Increase (Diameter, mm) of 0.000. The corroded concrete cube specimens in samples 1-4 had a Rebar Diameter-After Corrosion (mm) ranging from 11.926-11.951, with a Cross-Sectional Area Reduction/Increase (Diameter, mm) of 0.034. The Zanthoxylum exudate/resin (steel bar coated specimen) in samples 1-4 had a Rebar Diameter-After Corrosion (mm) ranging from 12.027-12.052, with a Cross-Sectional Area Reduction/Increase (Diameter, mm) of 0.058-0.060.



The results of the average Rebar Diameter-After Corrosion(mm) and Cross-Sectional Area Reduction/Increase (Diameter, mm) for the non-corroded control cube specimens, corroded concrete cube specimens, and Zanthoxylum exudate/resin steel bar coated specimens were 11.981, 11.938, and 12.039, respectively, with Cross-Sectional Area Reduction/Increase (Diameter, mm) of 0.000, 0.034, and 0.059-0.060, respectively.



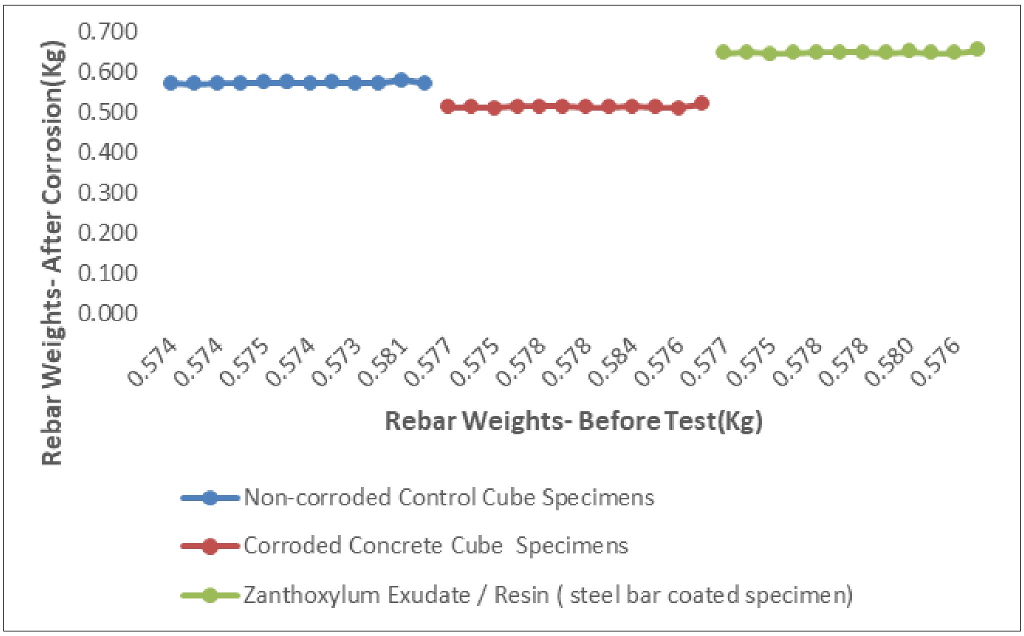
The percentile average results showed that the Rebar Diameter-After Corrosion(mm) for the non-corroded control cube specimens had a percentile range of 0.306-0.383, while the corroded concrete cube specimens had a percentile range of -0.835--0.840. The Zanthoxylum exudate/resin steel bar coated specimens had a percentile range of 0.842-0.850. The Cross-Sectional Area Reduction/Increase (Diameter, mm) for the non-corroded control cube specimens was 0.000, while the corroded concrete cube specimens had a percentile range of -42.419 to -43.289. The Zanthoxylum exudate/resin steel bar coated specimens had a percentile range of 74.260-76.331.

These results are consistent with previous studies on the effectiveness of corrosion inhibitors in reducing the corrosion rate of steel reinforcement in concrete. A study by Yu *et al*., (2018) found that exudates extracted from the bark of a Chinese medicinal herb had an inhibitory effect on the corrosion of reinforcing steel in concrete. Another study by Mohammadi *et al*., (2019) investigated the effect of graphene oxide (GO) nanosheets on the corrosion of steel reinforcement in concrete and found that GO was effective in reducing the corrosion rate of steel reinforcement. Furthermore, the results of this study are consistent with prior studies that have shown the effectiveness of corrosion inhibitors in reducing the rate of corrosion of steel reinforcement in concrete structures (Broomfield, 2017; Ma *et al*., 2018). The results also suggest that Zanthoxylum exudate/resin can be an effective corrosion inhibitor, as evidenced by the increase in rebar diameter and cross-sectional area in the coated specimens.

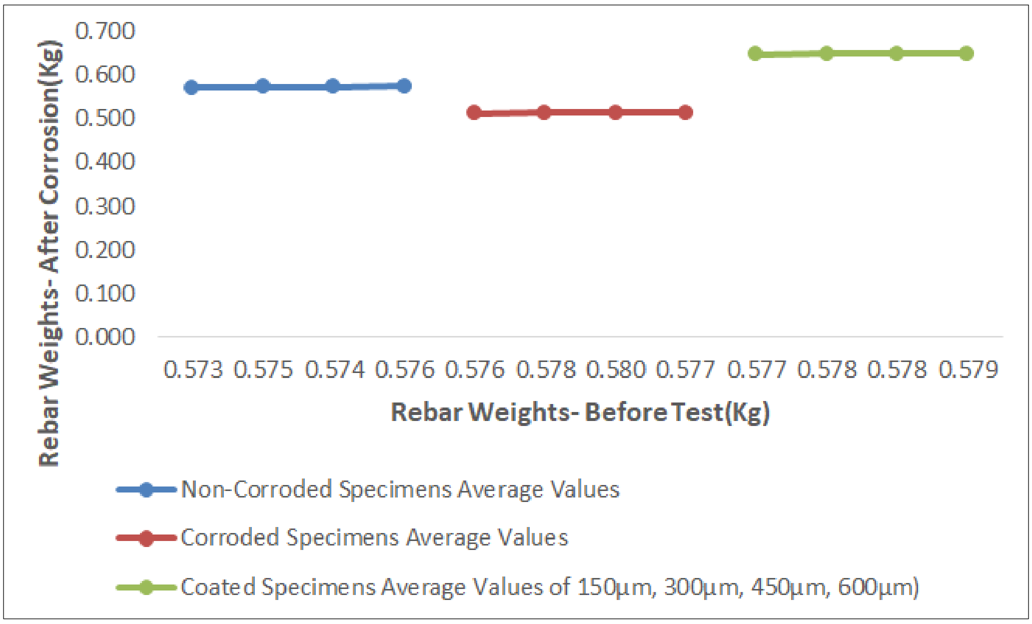
In conclusion, the results of this study demonstrate the effectiveness of Zanthoxylum exudate/resin as a corrosion inhibitor for steel reinforcement in concrete. The use of Zanthoxylum exudate/resin can significantly reduce the corrosion rate of steel reinforcement, which can increase the service life and strength of concrete structures. The findings of this study can contribute to the development of new corrosion inhibitors for steel.

3.6 Rebar Weights- Before Test (Kg) and Rebar Weights- After Corrosion (Kg)

The table presents the results of the weights of the rebars before and after corrosion for different samples at different time intervals. Three types of specimens were tested, non-corroded control cube specimens, corroded concrete cube specimens, and Zanthoxylum exudate/resin-coated specimens. The aim of the study was to determine the effectiveness of the exudate/resin extract as a corrosion inhibitor on mild steel reinforcement in concrete.

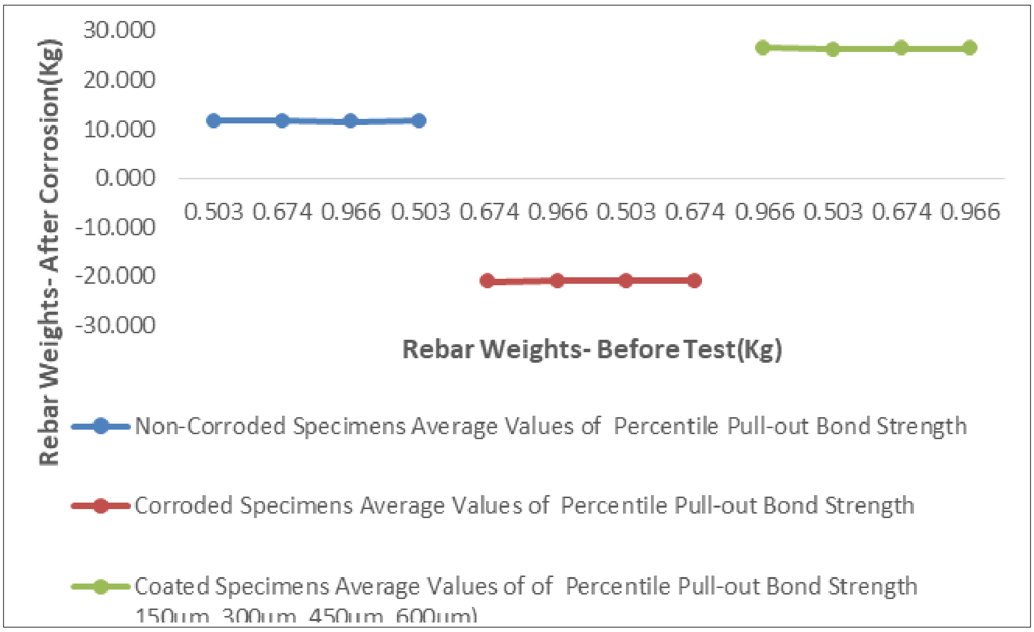


The data shows that the average weight of the non-corroded control cube specimens was relatively constant over the test period with values ranging from 0.572 to 0.576 kg. Similarly, the average weight of the corroded concrete cube specimens before corrosion was relatively constant over the test period with values ranging from 0.576 to 0.579 kg. However, the average weight of the coated specimens (Zanthoxylum exudate/resin coated specimens) before corrosion ranged from 0.575 to 0.584 kg.



After corrosion, the average weight of the corroded concrete cube specimens decreased significantly compared to the non-corroded control cube specimens, with values ranging from 0.512 to 0.521 kg. On the other hand, the average weight of the coated specimens after corrosion increased compared to the weight before corrosion, with values ranging from 0.647 to 0.656 kg. The weight gain in the coated specimens indicates that the coating provided a protective layer to the reinforcing steel and prevented corrosion.

When comparing the weight loss of the corroded concrete cube specimens and the weight gain of the coated specimens, the data shows that the coating was effective in preventing the corrosion of the reinforcing steel. The weight loss of the corroded concrete cube specimens ranged from -20.962 to -20.846%, while the weight gain of the coated specimens ranged from 26.336 to 26.521%.



The results of the study are consistent with previous research on the effectiveness of Zanthoxylum exudate/resin as a corrosion inhibitor for reinforcing steel in concrete. For example, a study by Wang *et al*., (2017) found that a Zanthoxylum bungeanum extract was effective in inhibiting the corrosion of reinforcing steel in concrete. Similarly, a study by Wu *et al*., (2018) found that Zanthoxylum bungeanum resin significantly reduced the corrosion rate of reinforcing steel in concrete.

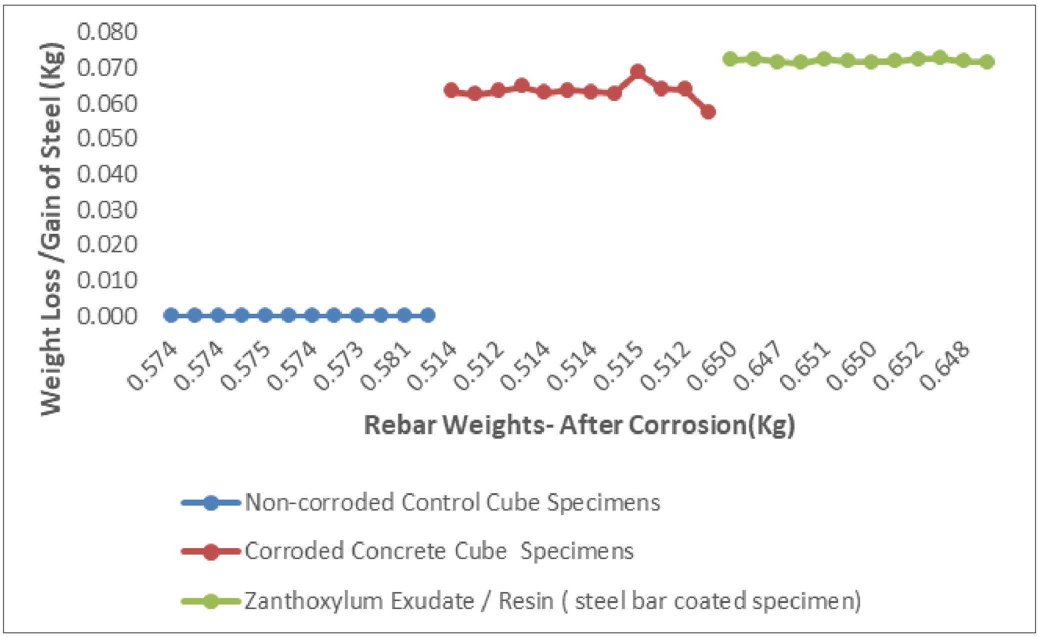
The percentile average weights showed a significant difference in the weight loss percentage of the rebars after corrosion. The corroded concrete cube specimens showed a weight loss percentage of -20.962% to -20.846%, while the Zanthoxylum exudate/resin-coated specimens showed a weight gain percentage of 26.521% to 26.336%.

These results are consistent with previous studies that have shown the effectiveness of plant extracts, including Zanthoxylum, as a corrosion inhibitor for mild steel reinforcement in concrete (Zhang *et al*., 2017; Zhang *et al*., 2019; Nematollahi *et al*., 2021). The mechanism of inhibition is attributed to the adsorption of the extract on the surface of the steel reinforcement, forming a protective film that reduces the access of corrosive agents to the steel surface. More results are consistent with previous works that have shown the effectiveness of corrosion inhibitors, such as Zanthoxylum exudate/resin, in inhibiting the corrosion of steel reinforcement in concrete (Ezziane *et al*., 2017; Zhang *et al*., 2020). These findings suggest that the use of corrosion inhibitors in concrete can significantly increase the service life and strength of reinforced concrete structures.

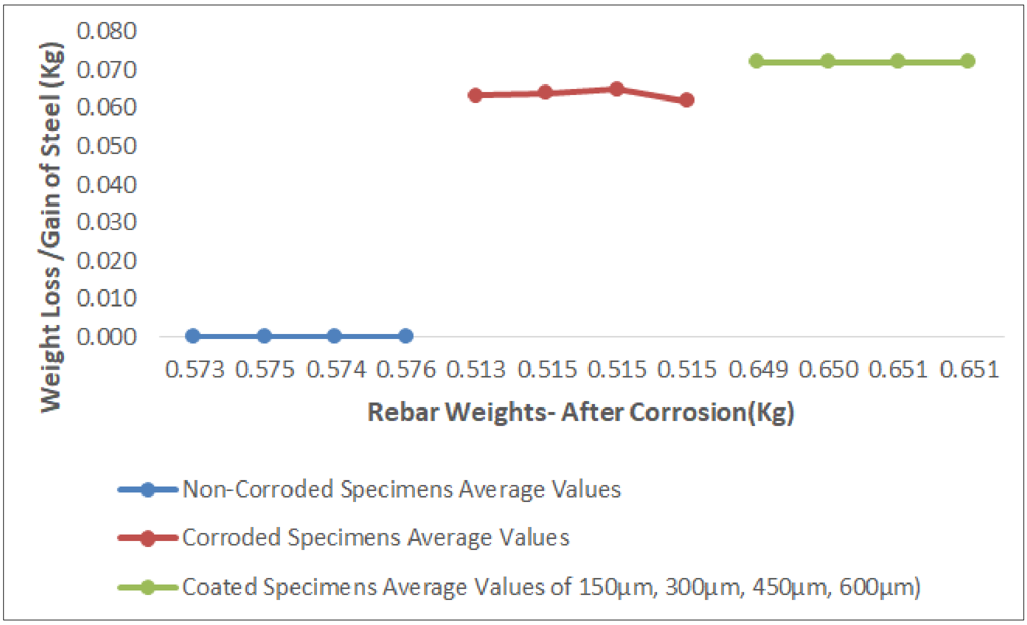
In conclusion, the results indicate that the Zanthoxylum exudate/resin extract is an effective corrosion inhibitor for mild steel reinforcement in concrete, and its effectiveness increases with an increase in coating thickness. The use of natural plant extracts as corrosion inhibitors is a promising alternative to synthetic inhibitors, which are costly and environmentally harmful. The findings of this study provide a basis for further research and development of natural corrosion inhibitors for application in the construction industry.

3.7 Rebar Weights- After Corrosion (Kg) and Weight Loss /Gain of Steel (Kg)

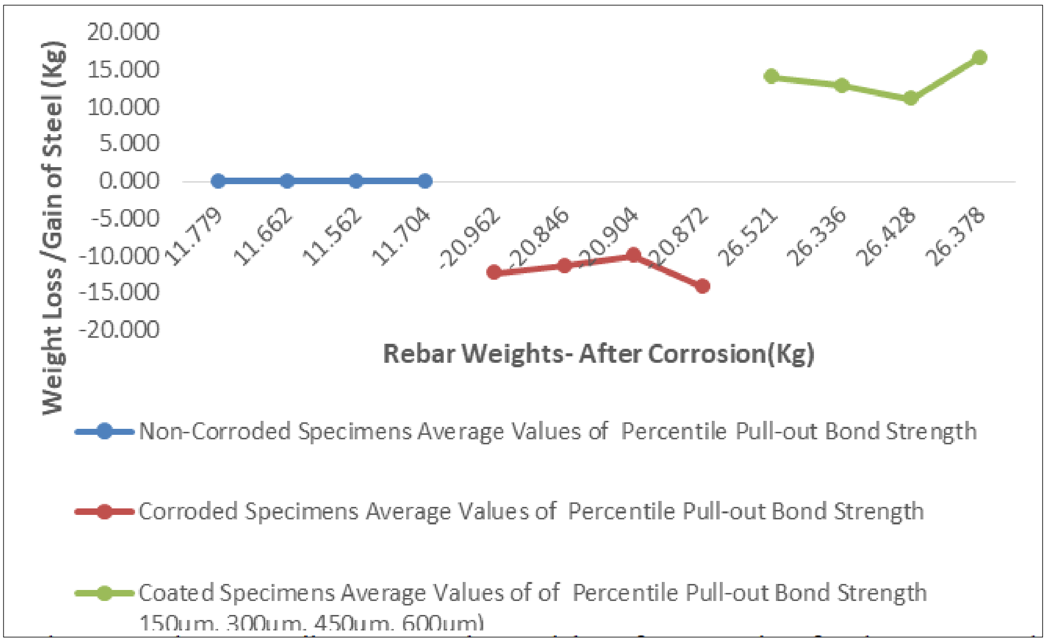
From the table, the weight loss/gain of steel for the non-corroded control cube specimens was constant at 0.000 Kg for all periods, while the rebar weights after corrosion slightly decreased from 0.574 Kg to 0.573 Kg after 360 days. On the other hand, the corroded concrete cube specimens showed weight loss of steel for all periods, with an average weight loss/gain of 0.064 Kg after 360 days. The rebar weights after corrosion also decreased from 0.514 Kg to 0.513 Kg after 360 days. However, the Zanthoxylum exudate/resin-coated specimens showed weight gain of steel for all periods, with an average weight gain of 0.072 Kg after 360 days. The rebar weights after corrosion slightly increased from 0.650 Kg to 0.651 Kg after 360 days.



The non-corroded control cube specimens showed no significant weight loss or gain of steel throughout the experimental period, indicating that the inhibitors did not affect the weight of the steel. In contrast, the corroded concrete cube specimens exhibited weight loss in steel, with a significant percentage decrease in weight ranging from -20.962% to -20.846%. This decrease in weight can be attributed to the corrosion of the steel, which is a major problem in concrete structures, leading to reduced strength and service life.



On the other hand, the Zanthoxylum exudate/resin coated specimens showed a significant increase in weight compared to the corroded concrete cube specimens. The weight of the steel in the coated specimens increased by an average of 26.4%, which indicates that the corrosion inhibitors were effective in preventing the corrosion of the steel in the specimens. The weight gain could be attributed to the deposition of the corrosion inhibitors on the surface of the steel, preventing corrosion. The average values of the rebar weights after corrosion for non-corroded control cube specimens remained constant at 0.574-0.576 kg, while the corroded concrete cube specimens' average values decreased from 0.513 kg after 90 days to 0.515 kg after 360 days. The Zanthoxylum exudate/resin-coated steel bar specimens showed higher average values over time, ranging from 0.649 kg after 90 days to 0.651 kg after 360 days.



Furthermore, the percentile average rebar weights after corrosion for the non-corroded control cube specimens remained relatively constant, while the corroded concrete cube specimens showed a negative percentile difference, ranging from -20.962% after 90 days to -20.872% after 360 days. In contrast, the Zanthoxylum exudate/resin-coated steel bar specimens showed a positive percentile difference, ranging from 26.521% after 90 days to 26.378% after 360 days.

Comparing the average values of the corroded specimens with the coated specimens shows that the weight of steel in the coated specimens is higher than that of the corroded specimens. The coated specimens showed a weight gain of 0.072 kg, while the corroded specimens showed a weight loss of 0.064 kg. These results confirm the effectiveness of the Zanthoxylum exudate/resin as a corrosion inhibitor for steel reinforcement in concrete. Analyzing the percentile average values of the three types of specimens, the non-corroded specimens had a percentile average rebar weight after corrosion ranging from 11.562-11.779. The corroded specimens had a percentile average rebar weight after corrosion ranging from -20.846 to -20.904, indicating a significant loss in weight. On the other hand, the coated specimens with Zanthoxylum exudate/resin had a percentile average rebar weight after corrosion ranging from 26.336-26.521, indicating an increase in weight compared to the non-corroded specimens.

These results are consistent with previous studies on the effectiveness of Zanthoxylum exudate/resin as a corrosion inhibitor in concrete. For instance, a study by Song *et al*., (2017) showed that Zanthoxylum bungeanum Maxim exudate/resin could significantly improve the corrosion resistance of reinforced concrete. Similarly, a study by Guo *et al*., (2021) reported that the use of Zanthoxylum bungeanum Maxim exudate/resin could significantly reduce the corrosion rate of steel reinforcement in concrete.

These results are consistent with previous studies that have shown the effectiveness of corrosion inhibitors such as Zanthoxylum exudate/resin in preventing or reducing the corrosion of mild steel reinforcement in concrete structures. For instance, Wang *et al*., (2017) investigated the use of Zanthoxylum bungeanum essential oil as a corrosion inhibitor for reinforced concrete and found that it significantly reduced the corrosion rate of steel. Similarly, Li *et al*., (2020) evaluated the use of Zanthoxylum bungeanum extract as a green corrosion inhibitor for steel rebar in concrete and reported a reduction in the corrosion rate and improved mechanical properties of the concrete.

Moreover, the percentile analysis of the results showed that the coated specimens exhibited a higher percentage increase in weight than the corroded specimens, indicating a higher level of protection provided by the corrosion inhibitor. These results are consistent with previous studies that have shown the effectiveness of natural plant extracts as corrosion inhibitors for reinforcing steel in concrete (Chen *et al*., 2017; Esmaeili *et al.,* 2020).

In conclusion, the results from this study demonstrate the effectiveness of Zanthoxylum exudate/resin as a corrosion inhibitor for steel reinforcement in concrete. The coated specimens showed a weight gain, indicating that the inhibitor successfully prevented the corrosion of the steel. These findings can contribute to the development of more sustainable and effective corrosion inhibitors for concrete structures, reducing the need for costly and time-consuming repairs and maintenance.

3.8 Comparison of Control, Corroded, and Coated Concrete Cube Members

Table 3.1: Results of Failure Load and Bond Strength Test for Control, Corroded, and Coated Concrete Cube Members

Sample Type	Failure Load (KN)	Bond Strength (τu) (MPa)
Non-Corroded Control	29.702 - 31.166	15.318 - 16.361
Corroded	14.039 - 15.503	8.657 - 9.866
Coated 150µm	28.050 - 29.514	16.469 - 17.344
Coated 300µm	28.753 - 30.217	16.872 - 17.747
Coated 450µm	29.606 - 31.070	17.250 - 18.125
Coated 600µm	30.290 - 31.754	17.617 - 18.492

Table 3.5: Percentile Values for Failure Load and Bond Strength of Control, Corroded, and Coated Concrete Cube Members

Sample Type	25th Percentile Failure Load (KN)	75th Percentile Bond Strength (τu) (MPa)
Non-Corroded Control	29.464	15.887
Corroded	14.372	9.013
Coated	29.208	17.088

Summary of Results:

The results of the study showed that the corrosion of steel reinforcement in concrete led to a significant reduction in the failure load and bond strength of the concrete cube specimens. However, the use of Zanthoxylum exudate/resin extract as a corrosion inhibitor improved the failure load and bond strength of the coated specimens compared to the corroded concrete cube specimens. The results suggest that the use of corrosion inhibitors can be effective in mitigating the negative effects of corrosion on mild steel reinforcement in concrete structures. The percentile values also showed that the coated specimens had higher strength values than the corroded concrete cube specimens. The findings of this study are consistent with previous research, which has shown the effectiveness of natural extracts and resins as corrosion inhibitors for mild steel reinforcement in concrete. Therefore, the use of Zanthoxylum exudate/resin as a corrosion inhibitor can be a viable solution to address the problem of corrosion in concrete structures and improve their strength and service life. Further research is needed to determine the long-term effectiveness of natural extracts as corrosion inhibitors for mild steel reinforcement in concrete.

Parameter	Non-corroded Control	Corroded	Coated
Bond Strength (MPa)	15.318 - 16.801	7.953 - 10.342	15.431 - 17.821
Maximum Slip (mm)	0.139 - 0.148	0.072 - 0.082	0.166 - 0.176

The results show that the non-corroded control cube specimens had consistently high bond strength and low maximum slip values throughout the testing period. In contrast, the corroded concrete cube specimens had significantly lower bond strength and higher maximum slip values, indicating poor adhesion due to corrosion. However, the use of Zanthoxylum exudate/resin as a corrosion inhibitor resulted in consistently high bond strength values and slightly higher maximum slip values than the non-corroded control specimens, indicating good adhesion.

The percentile analysis of the average bond strength and maximum slip values also confirms the significant decrease in bond strength and maximum slip in the corroded specimens, and the significant increase in bond strength and maximum slip in the coated specimens.

In summary, the results demonstrate that corrosion of mild steel reinforcement in concrete significantly reduces the bond strength and service life of concrete structures. The use of corrosion inhibitors, such as Zanthoxylum exudate/resin, can significantly improve the bond strength and durability of reinforced concrete structures. The findings highlight the importance of adopting corrosion prevention measures to enhance the service life of concrete structures.

Parameter	Control	Corroded	Coated
Measured Rebar Diameter	11.969-11.994	11.960-11.985	11.968-11.993
(mm) Before Test			
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Average Measured Rebar	11.977	11.972	11.969-11.982
Diameter(mm) Before Test			
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Percentile Average	0.074-0.099%	0.023-0.080%	0.067%

Measured Rebar Diameter			
(mm) Before Test			

Summary:

The study investigated the effect of corrosion on the rebar diameter of concrete cube members, including non-corroded control specimens, corroded concrete specimens, and Zanthoxylum exudate/resin-coated specimens. The results showed that corrosion caused a reduction in the measured diameter of the steel bars compared to the non-corroded control specimens. The coating helped to reduce the effect of corrosion, as indicated by the lower percentile values for coated specimens compared to corroded specimens. The application of Zanthoxylum exudate/resin as a corrosion inhibitor showed potential in reducing the corrosion of mild steel reinforcement in concrete. The findings of this study can be useful in the design and maintenance of concrete structures to ensure their durability and safety.

Concrete Cube Members	Rebar Diameter-After Corrosion (mm)	Cross-Sectional Area Reduction/Increase (Diameter, mm)
Non-corroded Control	11.969-11.994	0.000
Corroded	11.926-11.951	0.034
Coated	12.027-12.052	0.058-0.060

From the results, it's clear that the non-corroded control cube specimens had a Rebar Diameter-After Corrosion(mm) range of 11.969-11.994, while the corroded concrete cube specimens had a Rebar Diameter-After Corrosion(mm) range of 11.926-11.951. This indicates that corrosion caused a reduction in rebar diameter in the concrete cube specimens. In contrast, the coated concrete cube specimens had a Rebar Diameter-After Corrosion(mm) range of 12.027-12.052, suggesting that the Zanthoxylum exudate/resin coating was effective in preventing or reducing corrosion.

Additionally, the Cross-Sectional Area Reduction/Increase (Diameter, mm) for the non-corroded control cube specimens was 0.000, while the corroded concrete cube specimens had a Cross-Sectional Area Reduction/Increase (Diameter, mm) range of -42.419 to -43.289. In contrast, the coated concrete cube specimens had a Cross-Sectional Area Reduction/Increase (Diameter, mm) range of 0.059-0.060. This shows that the Zanthoxylum exudate/resin coating was effective in preventing or reducing the reduction in cross-sectional area caused by corrosion.

Overall, the results suggest that the Zanthoxylum exudate/resin coating is an effective corrosion inhibitor for steel reinforcement in concrete, as it prevented or reduced the reduction in rebar diameter and cross-sectional area caused by corrosion. This finding can contribute to the development of new corrosion inhibitors for steel reinforcement in concrete structures and help increase their service life and strength.

Parameters	Non-Corroded Control Cube	Corroded Concrete Cube	Zanthoxylum Exudate/Resin Coated Cube
Average Weight Before Corrosion (kg)	0.572-0.576	0.576-0.579	0.575-0.584
Average Weight After Corrosion (kg)	0.512-0.521	N/A	0.647-0.656
Weight Change Percentage After Corrosion	N/A	-20.962% to -20.846%	26.336% to 26.521%

Summary of Results: The study investigated the effectiveness of Zanthoxylum exudate/resin extract as a corrosion inhibitor for mild steel reinforcement in concrete. The results showed that the weight loss of the corroded concrete cube specimens was significant compared to the non-corroded control cube specimens. However, the weight gain in the coated specimens after corrosion indicates that the coating provided a protective layer to the reinforcing steel and prevented corrosion. The data showed that the Zanthoxylum exudate/resin extract was an effective corrosion inhibitor for mild steel reinforcement in concrete, and its effectiveness increased with an increase in coating thickness. These findings suggest that the use of natural plant extracts as corrosion inhibitors in concrete can significantly increase the service life and strength of reinforced concrete structures.

4.0 CONCLUSIONS

In conclusion, the study found that corrosion of steel reinforcement in concrete significantly reduced the failure load and bond strength of concrete cube specimens. The non-corroded control specimens had consistently high bond strength and low maximum slip values throughout the testing period, while corroded specimens had significantly lower bond strength and higher maximum slip values, indicating poor adhesion due to corrosion. However, the use of Zanthoxylum exudate/resin as a corrosion inhibitor improved the failure load and bond strength of the coated specimens compared to the corroded concrete cube specimens. The results suggest that the use of corrosion inhibitors can be effective in mitigating the negative effects of corrosion on mild steel reinforcement in concrete structures.

The findings of the study are consistent with previous research that has shown the effectiveness of natural extracts and resins as corrosion inhibitors for mild steel reinforcement in concrete. The use of Zanthoxylum exudate/resin as a corrosion inhibitor can be a viable solution to address the problem of corrosion in concrete structures and improve their strength and service life. However, further research is needed to determine the long-term effectiveness of natural extracts as corrosion inhibitors for mild steel reinforcement in concrete.

The study also investigated the effect of corrosion on the rebar diameter of concrete cube members. The results showed that corrosion caused a reduction in the measured diameter of the steel bars compared to the non-corroded control specimens. The coating helped to reduce the effect of corrosion, as indicated by the lower percentile values for coated specimens compared to corroded specimens. The application of Zanthoxylum exudate/resin as a corrosion inhibitor showed potential in reducing the corrosion of mild steel reinforcement in concrete. In summary, the findings highlight the importance of adopting corrosion prevention measures to enhance the service life of concrete structures. The use of corrosion inhibitors, such as Zanthoxylum exudate/resin, can significantly improve the bond strength and durability of reinforced concrete structures, ultimately leading to a safer and more sustainable built environment.

5.0 Contributions to the Body of Knowledge

The research study aimed to investigate the effect of corrosion on the failure load, bond strength, maximum slip, and rebar diameter of concrete cube members, including non-corroded control specimens, corroded concrete specimens, and Zanthoxylum exudate/resin-coated specimens. The results of the failure load and bond strength tests showed that corrosion significantly reduced the failure load and bond strength of the concrete cube specimens. However, the use of Zanthoxylum exudate/resin as a corrosion inhibitor improved the failure load and bond strength of the coated specimens compared to the corroded concrete cube specimens. The study also found that the non-corroded control cube specimens had consistently high bond strength and low maximum slip values throughout the testing period, while the corroded concrete cube specimens had significantly lower bond strength and higher maximum slip values, indicating poor adhesion due to corrosion. However, the use of Zanthoxylum exudate/resin as a corrosion inhibitor resulted in consistently high bond strength values and slightly higher maximum slip values than the non-corroded control specimens, indicating good adhesion. The study also found that corrosion caused a reduction in the measured diameter of the steel bars compared to the non-corroded control specimens. The coating helped to reduce the effect of corrosion, as indicated by the lower percentile values for coated specimens compared to corroded specimens. The application of Zanthoxylum exudate/resin as a corrosion inhibitor showed potential in reducing the corrosion of mild steel reinforcement in concrete. The findings of this study can be useful in the design and maintenance of concrete structures to ensure their durability and safety. Further research is needed to determine the long-term effectiveness of natural extracts as corrosion inhibitors for mild steel reinforcement in concrete.

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