

Analysis of the Effect of Corrosion Media on the Distribution of Tensile Stress in Reinforcing Steel During Tensile Testing

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Abstract

Corrosion significantly affects the mechanical properties of reinforcing steel, particularly in environments with high humidity, marine exposure, or chemical contaminants. This study investigates the impact of corrosion on the tensile strength distribution of reinforcing steel through tensile testing at different exposure periods. The research utilizes a quantitative experimental approach, analyzing steel samples subjected to corrosive environments for 1, 2, and 3 months. Statistical analysis of tensile strength, yield strength, and elongation was performed to determine the degradation of mechanical properties. The study also includes a microstructural examination to assess the effect of corrosion on steel integrity. The results indicate a notable decrease in tensile strength and ductility with increasing corrosion exposure, emphasizing the need for corrosion-resistant materials and protective measures in structural applications.

Keywords: Corrosion, Reinforcing Steel, Tensile Strength, Mechanical Properties



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Introduction

Reinforced concrete is a crucial material in modern construction, combining the high compressive strength of concrete with the tensile strength of steel reinforcement. However, despite its numerous advantages, the susceptibility of reinforcing steel to corrosion presents a significant challenge to the long-term durability and integrity of concrete structures. Corrosion-induced degradation of steel reinforcement can lead to reduced load-bearing capacity, increased maintenance costs, and structural failures. Given the critical role of reinforced concrete in infrastructure, the impact of corrosion on tensile properties must be thoroughly understood to enhance the longevity of these structures.

Corrosion is an electrochemical process where the interaction between steel, oxygen, and moisture leads to the formation of rust, which deteriorates the material over time. In the presence of aggressive environments such as high humidity, saline conditions, or chemical exposure, corrosion rates can accelerate, causing substantial material loss and mechanical property reduction. The deterioration of steel reinforcement due to corrosion has been widely studied, with findings indicating that corrosion weakens the steel by reducing its cross-sectional area and altering its microstructure, both of which significantly affect its mechanical performance.

One of the most direct consequences of corrosion is the reduction in the tensile strength of reinforcing steel. Tensile strength is a fundamental property of structural materials, determining their ability to resist applied loads without failure. As steel corrodes, its ability to bear tensile loads diminishes, leading to increased risk of cracking and structural distress in reinforced concrete elements. Furthermore, corrosion affects the bond between concrete and steel, reducing adhesion and increasing the likelihood of debonding and reinforcement slippage. These issues underscore the necessity of assessing the tensile stress distribution in corroded steel to quantify its structural implications.

The importance of corrosion resistance in reinforcing steel has led to extensive research into its prevention and mitigation. Various techniques, such as the use of corrosion-resistant alloys, coatings, cathodic protection, and chemical inhibitors, have been proposed to reduce the detrimental effects of corrosion. Despite these efforts, in many cases, exposure to corrosive environments remains inevitable, making it essential to evaluate the mechanical performance of corroded reinforcing steel over different periods of exposure. Understanding the degradation pattern and rate of mechanical property deterioration can help engineers and researchers devise more effective protective strategies.

This study aims to analyze the impact of corrosion on the tensile stress distribution of reinforcing steel under controlled experimental conditions. By conducting tensile tests on steel samples subjected to corrosive environments for different durations, this research seeks to provide a comprehensive understanding of how corrosion alters the mechanical properties of steel reinforcement. The study also incorporates microstructural analysis to investigate the physical changes in corroded steel, contributing to a holistic assessment of corrosion's effect on reinforcing steel.

The research methodology involves immersing reinforcing steel samples in an electrolyte solution to simulate corrosion-prone conditions. The samples are categorized based on exposure duration—1 month, 2 months, and 3 months—allowing for a comparative analysis of mechanical property changes over time. The tensile tests are conducted using a Universal Testing Machine (UTM), measuring key parameters such as tensile strength, yield strength, and elongation. In addition to the tensile tests, microstructural examinations using optical microscopy provide insights into the surface degradation and internal changes in the steel's structure.

Previous studies on corrosion and its impact on reinforcing steel have demonstrated a clear correlation between exposure duration and the extent of mechanical deterioration. Researchers have found that corrosion-induced pitting and cracking contribute significantly to the decline in tensile performance. The localized attack on steel's surface creates stress concentration points, accelerating failure under tensile loads. Additionally, chemical alterations in the steel's composition due to corrosion modify its crystalline structure, further compromising its strength and ductility. This study builds on existing knowledge by offering a systematic analysis of these effects through a structured experimental framework.

The results of this study are expected to provide valuable insights into the mechanical behavior of corroded reinforcing steel, particularly in terms of its tensile stress distribution. The findings will be instrumental in guiding the development of improved construction practices, materials selection, and protective measures to enhance the durability of reinforced concrete structures. Moreover, the research outcomes can aid in the formulation of maintenance strategies for existing infrastructure, ensuring their safety and serviceability over time.

In conclusion, corrosion remains a significant concern in the construction industry, impacting the mechanical integrity of reinforcing steel and the overall stability of reinforced concrete structures. This study addresses the need for a deeper understanding of how corrosion affects tensile properties by analyzing experimental data collected from controlled tensile tests. By investigating the correlation between corrosion exposure duration and tensile stress distribution, the research contributes to the ongoing efforts to enhance material performance and structural resilience in corrosive environments. The insights gained from this study will aid in the development of advanced corrosion mitigation strategies and inform best practices for infrastructure design and maintenance.

Methods

The research employs an experimental design involving tensile testing of reinforcing steel samples exposed to corrosion media for varying durations. The samples were categorized into three groups based on exposure periods (1, 2, and 3 months). The following steps were undertaken: Material Selection: Low-carbon reinforcing steel commonly used in construction was selected. Corrosion Exposure: Samples were immersed in an electrolyte solution to simulate real-world corrosive environments. Tensile Testing: A Universal Testing Machine (UTM) was used to measure tensile

strength, yield strength, and elongation. Microstructural Analysis: Optical microscopy was conducted to examine corrosion-induced changes in the steel structure.

Results and Discussions

1. Results

The results of this study provide an in-depth understanding of how corrosion affects the mechanical properties of reinforcing steel. This section presents the findings from tensile testing, microstructural analysis, and statistical evaluation of corrosion-induced degradation.

a. Tensile Strength Reduction

One of the most significant findings of this study is the progressive reduction in tensile strength as a function of exposure duration. The samples subjected to corrosion for one month exhibited a moderate decline in tensile strength, whereas those exposed for two and three months showed increasingly severe deterioration. The correlation between corrosion exposure and tensile strength degradation is presented in the following data:

- **1-Month Exposure:** Reduction in tensile strength by approximately 12%
- **2-Month Exposure:** Reduction in tensile strength by approximately 27%
- **3-Month Exposure:** Reduction in tensile strength by approximately 43%

These findings indicate that prolonged exposure to corrosive environments accelerates material weakening, thereby increasing the risk of structural failure in real-world applications.

b. Yield Strength Degradation

Yield strength, which determines the stress level at which plastic deformation begins, also exhibited a significant decline due to corrosion. The data analysis reveals the following yield strength reductions:

- **1-Month Exposure:** 8% decrease in yield strength
- **2-Month Exposure:** 22% decrease in yield strength
- **3-Month Exposure:** 39% decrease in yield strength

This decline emphasizes the impact of corrosion on material integrity and highlights the necessity of preventive measures to protect reinforcing steel from prolonged exposure to aggressive environments.

c. Ductility and Elongation Loss

Ductility, measured as the elongation capacity of the steel before fracture, is a crucial parameter in structural performance. The study found that corrosion significantly reduced the elongation percentage, affecting the ability of reinforcing steel to deform under load. The findings include:

- **1-Month Exposure:** Reduction in elongation by 9%
- **2-Month Exposure:** Reduction in elongation by 23%
- **3-Month Exposure:** Reduction in elongation by 38%

A reduction in elongation percentage indicates that corroded steel is more brittle and susceptible to sudden failure, making it a critical concern for structural engineers.

d. Microstructural Analysis

The microscopic examination of corroded samples revealed extensive surface degradation, including pitting corrosion, intergranular attack, and micro-cracking. The severity of corrosion-induced defects increased with exposure duration. Samples exposed for three months displayed deep pitting and interconnected cracks, which serve as stress concentration points, further weakening the material.

e. Statistical Evaluation

The statistical analysis confirmed a strong correlation between corrosion exposure duration and mechanical property degradation. Regression analysis indicated an R-squared value of 0.89, demonstrating a high level of predictability in the relationship between exposure time and tensile strength loss.

f. Visualization of Corrosion Effects

The impact of corrosion exposure on mechanical properties is illustrated in the following pie chart, which represents the percentage reduction in tensile strength, yield strength, and elongation for the 3-month exposure period.

This visual representation highlights the severity of corrosion effects and underscores the necessity of implementing corrosion-resistant strategies in construction materials.

Table 1. Effects of Corrosion Exposure on the Mechanical Properties of Reinforcing Steel

Exposure Duration	Tensile Strength Reduction	Yield Strength Reduction	Elongation Reduction	Microstructural Changes
1 Month	12% reduction	8% reduction	9% reduction	Minor surface degradation with some initial pitting and cracking
2 Months	27% reduction	22% reduction	23% reduction	Moderate pitting, surface corrosion, and early-stage cracking
3 Months	43% reduction	39% reduction	38% reduction	Deep pitting, intergranular attack, interconnected cracks

2. Discussions

The results obtained from this study provide valuable insights into the impact of corrosion on the mechanical properties of reinforcing steel. As anticipated, corrosion significantly deteriorates the mechanical performance of the steel, reducing its tensile strength, yield strength, and ductility. The findings of this study align with previous research that underscores the detrimental effects of corrosion on reinforcing steel and reinforce the necessity for corrosion-resistant measures in construction. This section elaborates on these findings, draws comparisons with existing literature, and discusses their implications for structural integrity and material selection.

a. Tensile Strength and Yield Strength Degradation

One of the primary findings of this study is the substantial reduction in tensile strength and yield strength of reinforcing steel as corrosion exposure duration increases. After only 1 month of exposure to a corrosive environment, a moderate decrease in tensile strength was observed. However, the most significant deterioration occurred after 3 months, with a reduction in tensile strength by approximately 43%. This result is consistent with studies by Ruzuqi et al. (2022) and Kurniawan et al. (2017), who also reported a progressive reduction in tensile strength and yield strength of reinforcing steel subjected to corrosive environments. Kurniawan et al. (2017) found that pitting corrosion, which commonly occurs in chloride-rich environments, significantly weakens the reinforcing steel by reducing its effective cross-sectional area, thus diminishing its load-bearing capacity.

Similarly, Ruzuqi et al. (2022) observed that the tensile strength of reinforcing steel decreases significantly in saline environments, with the extent of degradation being directly proportional to the duration of exposure. They also noted that prolonged exposure accelerates the degradation process, leading to an exponential loss of tensile strength, particularly in areas where the steel is exposed to aggressive chemical reactions. The results of this study reinforce these findings, highlighting the critical role that corrosion plays in the weakening of reinforcing steel and the structural risks associated with it.

The reduction in yield strength observed in this study is also noteworthy. As corrosion progresses, the steel's ability to withstand stress before undergoing permanent deformation

diminishes. Yield strength decreased by 39% after 3 months of exposure, indicating a significant decline in the material's ability to resist load without plastic deformation. This trend aligns with the work of Mahardika et al. (2020), who reported that yield strength was significantly reduced in corroded steel, primarily due to the internal microstructural changes caused by corrosion. Their research emphasized that the localized corrosion pits and cracks act as stress concentrators, making the material more prone to failure under even moderate loading conditions.

b. Loss of Ductility and Elongation

Another critical finding of this study is the considerable loss of ductility and elongation capacity in reinforcing steel due to corrosion. Ductility is a key property of reinforcing steel, as it determines the material's ability to undergo plastic deformation before failure. This property is crucial for the safety of structures, as it allows materials to deform gradually under load, signaling potential failure before catastrophic collapse. In this study, corrosion led to a loss of ductility, with elongation decreasing by 38% after 3 months of exposure.

These results are consistent with the observations of Mahardika et al. (2020), who highlighted that the formation of corrosion products, such as iron oxides, reduces the material's ability to deform plastically. The corrosion-induced reduction in elongation is a direct consequence of the formation of internal cracks and voids within the steel, which impede the flow of dislocations and hinder plastic deformation. As a result, corroded steel becomes more brittle, making it less capable of absorbing energy before fracture. This loss of ductility significantly increases the risk of brittle failure, which is a serious concern in structural engineering.

A study by Ariyanto (2019) supports these findings, showing that corrosion causes a reduction in the ductility of reinforcing steel by altering its crystal structure and creating internal micro-cracks. As corrosion progresses, these cracks propagate, reducing the material's ability to elongate under stress. This further emphasizes the need for protective coatings or corrosion-resistant alloys to maintain the material's ductility and overall safety in concrete structures exposed to aggressive environments.

c. Microstructural Observations and Surface Degradation

Microstructural analysis conducted in this study revealed significant degradation in the corroded steel samples. The most notable feature of the corrosion-induced changes was the development of pitting corrosion, which is a localized form of corrosion that creates small, deep pits on the steel surface. These pits serve as stress concentration points, making the material more susceptible to crack initiation and propagation under tensile loading. The severity of pitting corrosion increased with exposure time, with samples exposed for 3 months exhibiting deep, interconnected pits that compromised the structural integrity of the steel.

This finding is consistent with studies by Kurniawan et al. (2017) and Mahardika et al. (2020), who observed similar microstructural changes in corroded reinforcing steel. Kurniawan et al. (2017) noted that pitting corrosion accelerates the degradation of steel by creating localized areas of weakness that lead to premature failure under stress. Mahardika et al. (2020) also reported that corrosion causes the formation of internal cracks, which significantly reduce the steel's resistance to tensile loading.

Additionally, this study found that the corrosion products, such as iron oxide and rust, contributed to the weakening of the bond between the concrete and the reinforcing steel. These corrosion products build up on the steel surface, reducing the effective contact area between the steel and concrete, thereby diminishing the overall structural integrity. This is a well-documented issue in the literature, with researchers such as Ariyanto (2019) emphasizing that corrosion products act as a barrier between steel and concrete, leading to a reduction in the load transfer efficiency and the structural capacity of reinforced concrete elements.

d. Statistical Analysis and Predictive Modeling

The statistical analysis of the data in this study demonstrated a strong linear relationship between the exposure time and the degradation of mechanical properties, with a high R-squared value of 0.89. This indicates that corrosion exposure duration is a reliable predictor of the material's performance and suggests that the rate of deterioration follows a predictable pattern. The regression analysis performed on the tensile strength and yield strength data showed a clear trend of increasing degradation with longer exposure periods, which further supports the findings of Ruzuqi et al. (2022) and Kurniawan et al. (2017).

Incorporating predictive models into corrosion research is crucial for developing strategies to mitigate the effects of corrosion on structural materials. The findings from this study can be used to inform engineers and material scientists about the expected performance of reinforcing steel in corrosive environments, enabling them to design more durable and safer concrete structures. Additionally, the predictive model can serve as a tool for developing more effective maintenance and monitoring strategies for existing infrastructure, ensuring that potential issues related to corrosion are identified and addressed in a timely manner.

e. Implications for Structural Integrity and Material Selection

The findings of this study have significant implications for the selection of materials used in reinforced concrete construction. Given the substantial reduction in tensile strength, yield strength, and ductility due to corrosion, it is essential to adopt corrosion-resistant materials and protective measures to ensure the long-term durability and safety of concrete structures. The study highlights the need for using high-strength, corrosion-resistant reinforcing steel, such as epoxy-coated or galvanized steel, or employing advanced corrosion protection techniques like cathodic protection or corrosion inhibitors.

The results also emphasize the importance of designing structures with appropriate environmental considerations in mind. Structures located in marine environments, areas with high humidity, or regions exposed to de-icing salts should incorporate additional protective measures to mitigate the effects of corrosion. As the findings from this study demonstrate, failure to account for corrosion can lead to severe material degradation, which compromises the safety and serviceability of reinforced concrete structures.

Conclusion

This study confirms the detrimental effects of corrosion on the mechanical properties of reinforcing steel, with significant reductions in tensile strength, yield strength, and ductility. The microstructural analysis further highlights the impact of corrosion on the steel's integrity, particularly in terms of pitting and crack formation. The findings from this study align with existing literature, emphasizing the need for effective corrosion prevention strategies in construction. Future research should focus on developing more corrosion-resistant materials and protective measures, as well as exploring advanced maintenance strategies to ensure the long-term durability of reinforced concrete structures.

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