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RESEARCH ARTICLE

Effect of corrosion on the strength reduction and stress–strain characteristics of thermo–mechanically treated steel bars exposed to an accelerated chloride–rich environment

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Abstract – This study investigated the detrimental impact of corrosion on the mechanical properties of thermo–mechanically treated (TMT) steel bars, a material widely used in reinforced concrete structures. The primary objective was to identify a crucial threshold level for corrosion, indicating a potential loss of structural integrity. Additionally, this research quantitatively assessed the percentage reduction in tensile strength and the alteration of stress–strain characteristics of TMT steel bars as a function of corrosion intensity. An accelerated corrosion process was conducted by utilizing the TMT bar as an anode and a stainless–steel plate as a cathode within an artificial seawater environment to simulate long–term exposure to chloride–rich coastal conditions. Experimental results demonstrated a significant and non–linear degradation in mechanical performance. At 12% corrosion, yield and ultimate strength reductions of 19.69% and 19.78% were recorded, respectively—beyond this critical threshold, the bars failed to meet the minimum designated yield stress and ultimate strength specified in International Organization for Standardization (ISO) 6935 (Grade G72.5–500). The findings established empirical correlations between corrosion intensity and key mechanical parameters, highlighting that corrosion not only reduces cross–sectional area but also induces localized pitting and brittle fracture initiation sites, which disproportionately affect stress–strain response. Critically, the post–yield behavior was severely affected; corrosion led to a marked loss of ductility, a contraction of the plastic plateau, and a considerable decline in tensile strength. This research provides essential data for evaluating the residual safety and service life of deteriorating coastal concrete infrastructures.

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1. Introduction

The durability and long–term performance of reinforced concrete (RC) structures is intrinsically linked to the integrity of the embedded steel reinforcement. In contemporary construction, thermo–mechanically treated (TMT) steel bars have emerged as the preferred material, especially in harsh environments, owing to their exceptional strength, ductility, and weldability [1], which are attained through a carefully controlled quenching and tempering process. This process results in a composite microstructure that features a hard, robust martensitic rim alongside a soft, ductile ferrite–pearlite core, offering an outstanding balance between tensile strength and elongation [2]. Nevertheless, the vulnerability of all steel within concrete lies in corrosion, a widespread and subtle issue that undermines structural safety and functionality. The elevated salinity levels in soil and water accelerate corrosion of steel reinforcement in concrete, critically jeopardising the long–term integrity of these structures [3] – [5]. In environments rich in chlorides–such as coastal areas, marine environments, and regions where de–icing salts are utilised–this threat is notably intensified. Chloride ions from seawater or salt spray infiltrate the concrete cover, disrupting the protective oxide layer on the steel surface and triggering pitting corrosion [6] - [7]. This localised assault results in an uneven reduction of the bar's cross–sectional area, creating stress concentration points that are significantly more harmful than a uniform loss of metal. Additionally, the substantial corrosion products (rust) generate considerable internal tensile stresses within the surrounding concrete [8], frequently resulting in the cracking and spalling of the concrete cover, which subsequently exposes more steel and worsens the deterioration process. More importantly, corrosion modifies the mechanical properties of the steel itself, especially its stress–strain characteristics [9], which are crucial for the ductility and load–bearing capacity of RC members.

The corrosion process not only diminishes the effective load–bearing area but may also disrupt the microstructural integrity of the various zones within the TMT bar [10] – [11]. Pits function as notches, leading to premature yielding and potentially shifting the failure mode from ductile to brittle [12]. Consequently, critical mechanical properties–including yield strength, ultimate tensile strength, and, most crucially, elongation (which indicates ductility)–are adversely affected. The reduction in ductility of corroded reinforcing steel greatly undermines the seismic safety of concrete structures [13]. Corrosion–induced pitting and the reduction of cross–sectional area renders the steel brittle [14]. This reduction in ductility hinders the essential energy absorption, leading the structure to exhibit more brittle behaviour [15]. Therefore, corroded components are susceptible to abrupt, catastrophic failures during seismic events, which significantly diminishes the overall structure's capacity to endure cyclic loading and its safety margin. Although the widespread issue of steel corrosion is extensively documented, gaining a detailed and mechanistic insight into how accelerated chloride–induced corrosion specifically affects the mechanical properties of contemporary TMT bars is an essential area for research. It is

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vital for researchers and design engineers to comprehend the rate of strength reduction and the alterations in stress–strain characteristics to evaluate the residual capacity and forecast the service life of existing structures. While natural corrosion occurs slowly, this research offers accelerated corrosion methods to investigate long–term degradation in a controlled laboratory environment [16].

Previous studies suggest that most researchers focus on corrosion in natural environments [17], corrosion of bars embedded in RC structures [18]– [19], and the tensile properties of steel bars that have naturally corroded in freshwater [20]. Research has also been directed towards corrosion mitigation techniques [21], various cleaning methods for corroded bars [22], the bond characteristics of corroded reinforcement bars [23]– [24], and the impact of chemical composition on corrosion [25]. Additionally, investigations have been carried out on corroded bars retrieved from RC beams subjected to a chloride environment [26] – [27], on durability assessments of RC samples utilising seawater as mixing water, and on changes in the ductility of steel bars embedded in concrete when subjected to accelerated corrosion [7], [19]. Tariq and Bhargava [9] found that 45% corrosion halved the yield plateau length but didn't specify conditions for maintaining minimum tensile strength. In a separate investigation, Ahmed et al. [28] studied corrosion mechanisms and proposed formulas for structural applications but didn't define a critical safety threshold. Wu et al. [29] showed that corrosion and buckling significantly reduce fatigue performance but didn't identify a corrosion level at which tensile strength falls to the minimum yield strength. Most recently, Dalmora et al. [6] recommended sustainable corrosion-prevention methods for marine environments to enhance the longevity of infrastructure and minimise long–term maintenance costs. Nonetheless, it is essential to comprehend the corrosion threshold level for any improvements in longevity and maintenance efforts concerning coastal and marine structures. Overall, while each study advances knowledge on corrosion effects or prevention, a common gap is the lack of identified critical corrosion thresholds needed to assess structural safety and guide maintenance.

Consequently, this study seeks to determine a significant corrosion threshold level, beyond which the bars fail to meet the requirements of the ISO 6935 standard, indicating a potential loss of structural integrity. Furthermore, this research quantitatively evaluated the percentage decrease in tensile strength and the changes in stress–strain characteristics of TMT steel bars as a function of corrosion intensity when subjected to an accelerated chloride–rich environment. Finally, the study establishes the relationship between the duration of the corrosion test and the extent of corrosion in a chloride–rich environment to predict the time required in natural seawater to achieve a desired degree of corrosion. The results will offer vital information for engineers and asset managers, facilitating more precise assessments of remaining life, enhancing durability design specifications for harsh environments, and aiding in the formulation of effective maintenance and rehabilitation strategies for corrosion–affected RC structures, thus improving their resilience and safety.

2. Materials and Methods

2.1 Reinforcing Bars and Preparation of Corrosive Environment

Commercially available TMT steel bars conforming to ISO 6935 (Grade G72.5–500, with a designated minimum yield strength of 500 MPa) and 16 mm-diameter bars were used. Artificial seawater (ASW) was prepared in the laboratory in accordance with the American Society for Testing and Materials (ASTM) D1141 standard to simulate the aggressive, corrosive environment of the Bay of Bengal. The details of the preparation process were described in the authors' previous works [30]. In summary, ASW was simulated in the laboratory by mixing the exact quantities and proportions of the chemical compounds found in natural sea water with distilled water. The chemical composition of ASW is shown in Table 1.

Table 1. Chemical composition of artificial sea water [30]

Salt	Amount (g/litre)	% of Total Salt
Sodium Chloride ($NaCl$)	27.21	77.74
Magnesium Chloride ($MgCl_2$)	3.81	10.89
Magnesium Sulphate ($MgSO_4$)	1.66	4.74
Calcium Sulphate ($CaSO_4$)	1.26	3.60
Potassium Sulphate (K_2SO_4)	0.86	2.46
Calcium Carbonate ($CaCO_3$)	0.12	0.34
Magnesium Bromide ($MgBr_2$)	0.08	0.23
Total	35.00	100.00

2.2 Accelerated Corrosion Process

An electrochemical accelerated corrosion technique was employed to induce different degrees of corrosion. The test setup consisted of a direct current (DC) power supply with an output of 15V and 5 amps, a container filled with the artificial seawater solution, and the TMT bar specimens. A constant current density of 5 amps was applied to achieve target mass loss percentages (degree of corrosion), calculated using Faraday's law. The degree of corrosion (% Corrosion) was determined after testing by mass loss measurement using Eq. (1).

$$\text{Corrosion (\%)} = \frac{Wo-Wc}{Wo} \text{ x } 100\% \quad (1)$$

where W_o is the original mass of the uncorroded bar, and W_c is the mass of the corroded bar after cleaning the corrosion products. The experimental setup was structured such that steel bars acted as the anode (+), while the stainless–steel plate positioned in the solution functioned as the cathode (-) [31], as illustrated in Figure 1(a). The accelerated time was documented to ascertain the required level of corrosion. The rate of corrosion of TMT steel bars was determined at an interval of 30 minutes during the corrosion process. Once the desired corrosion level was reached, the test specimens were extracted from the solution and rinsed with acetone or a water solution to eliminate the oxides (rust) that had accumulated on the surfaces of the steel bars (Figure 1b), in accordance with ASTM G1-03. Subsequently, the corroded bars were thoroughly dried, and the corrosion levels were quantified as a gravimetric mass loss using a highly sensitive digital balance.

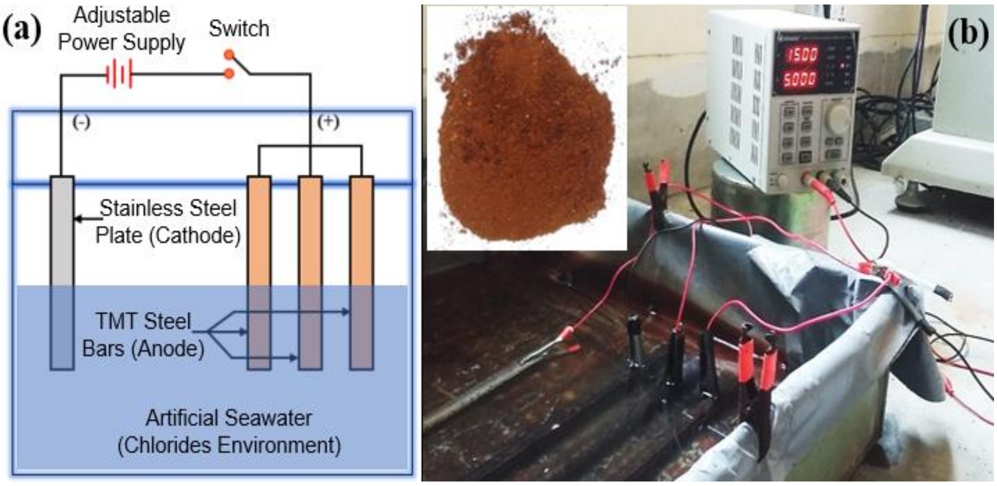

Figure 1. (a) Schematic diagram of the accelerated corrosion process. (b) Real-time electrochemical accelerated corrosion technique (Inset: Rusts accumulated on the surface of corroded TMT steel bars)

2.3 Experimental Procedure

The locally manufactured TMT 500W high–strength reinforcing steel bar was utilised and subjected to varying degrees of corrosion. Each level of corrosion included three samples. In total, 36 TMT steel specimens (33 corroded and 3 non–corroded control specimens) with a diameter of 16 mm were corroded and tested under tension. In accordance with ASTM A370, each steel bar specimen was measured to an overall length of 30 inches (750 mm) to facilitate an 8–inch (200 mm) gauge length, with the remaining length allocated for grips to prevent end–grip effects during tensile testing. The test samples were subjected to corrosion at eleven distinct levels (1.0%, 1.5%, 2.0%, 2.5%, 3.0%, 3.5%, 4.0%, 8.0%, 12.0%, 16.0%, and 20.0%). Initially, the corrosion interval was established at 0.5% up to 4% corrosion for preliminary findings, which served as a foundation for more in–depth analysis. Following the completion of the preliminary findings, the interval was adjusted to 4%-20% for the corrosion levels in the results.

2.4 Tensile Testing

Tensile tests were performed on the corroded and uncorroded (control) specimens using a universal testing machine (UTM) in accordance with the ASTM A370 standard once the target corrosion levels were reached. An extensometer was used to measure the strain. For every specimen, the yield strength (0.2% offset proof stress), ultimate tensile strength, and elongation at failure were noted. Stress–strain curves were plotted and analysed.

3. Results and Discussion

3.1 Visual Inspection and Mass Loss

Non–corroded TMT steel bars exhibit ribs on their surface that ensure adequate bond strength. A visual examination of corroded TMT bars indicates surface degradation manifested as rust, pitting, and loss of section, providing an initial qualitative evaluation. A more precise, quantitative assessment was obtained by measuring mass loss. This process entails thoroughly cleaning the corrosion products to ascertain the bar's remaining mass. The percentage of mass loss directly quantifies the reduction in cross–sectional area, which is a vital factor for precisely estimating the residual strength and load–bearing capacity of the affected steel, thereby guiding crucial structural safety decisions. This observation is in complete agreement with earlier studies documented in the literature [25], which explored the corrosion impacts of Cr and Ni in TMT steel bars in marine environments and noted the development of pits on the steel surfaces. The mass loss corroborated the levels of corrosion attained, which ranged from 0% (control) to 20% for a 16 mm diameter TMT steel bar.

3.2 Effects of Pitting Corrosion

The corrosion process, typically through rusting, creates localised pits and cracks on the bar's surface. These pits act as stress concentrators, initiating fractures under tensile load, thereby posing a serious risk to the mechanical properties of TMT bars, which are widely used in construction for their high strength, ductility and durability [11]. Pitting corrosion was found on localised areas of the surface of TMT bars, attributed to corrosive attack, as illustrated in Figure 2, leading to the formation of small pits or cavities. This can weaken the structure of the bars and ultimately compromise their ability to bear loads and resist external forces [32]. Furthermore, the cross–sectional area is reduced, increasing stress on the remaining sound metal. As the pitting corrosion progresses, the affected areas may experience a loss of ductility, toughness, and tensile strength, making the TMT bars more susceptible to failure under stress [33].

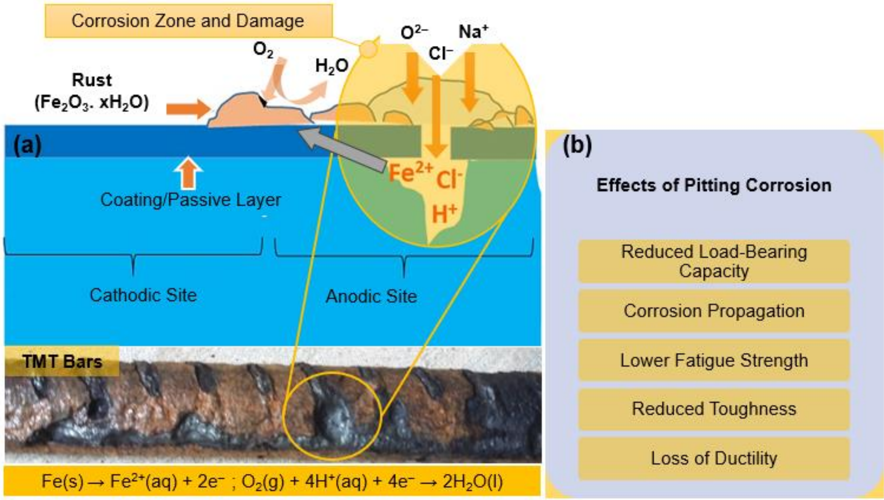

Figure 2. (a) Schematic representation of pitting corrosion. (b) Effects of pitting corrosion on TMT steel bars

3.3 Ductility Reduction in Corroded TMT Steel Bars

Corroded TMT steel bars suffer a significant reduction in ductility, compromising their crucial ability to bend without breaking. Figure 3 illustrates the percentage decrease in ductility of 16 mm TMT steel bars at various degrees of corrosion. This research found that the non–corroded TMT steel bars exhibited a significant degree of yielding prior to their failure. The experimental results clearly showed that the percentage reduction in ductility of TMT steel bars rose with increasing levels of corrosion. Moreover, reinforcing steel bars exhibiting over 8% corrosion suggest a brittle failure. A notable relationship is observed between corrosion and a reduction in ductility, coupled with an increase in the brittleness of steel bars, which subsequently changes the failure mode from ductile to a significantly more dangerous brittle failure. This phenomenon is due to localised pitting that generates stress concentration points, leading to the initiation of cracks that propagate more easily under load, resulting in premature failure. Furthermore, the decrease in cross–sectional area causes the steel to reach its ultimate tensile strength more quickly, with reduced plastic deformation. Additionally, the distinctive tempered martensite outer layer of TMT bars, which enhances ductility, is gradually worn away by corrosion. This degradation of the ductile microstructure compels the material to exhibit more brittle behaviour, greatly reducing its capacity to absorb energy prior to fracturing. Consequently, the corrosive process modifies the surface characteristics of steel bars, progressively reducing their elasticity. This observation is consistent with findings in the literature [19,34], which confirmed a significant reduction in ductility and a marked increase in brittle properties of steel bars as the corrosion rate escalated.

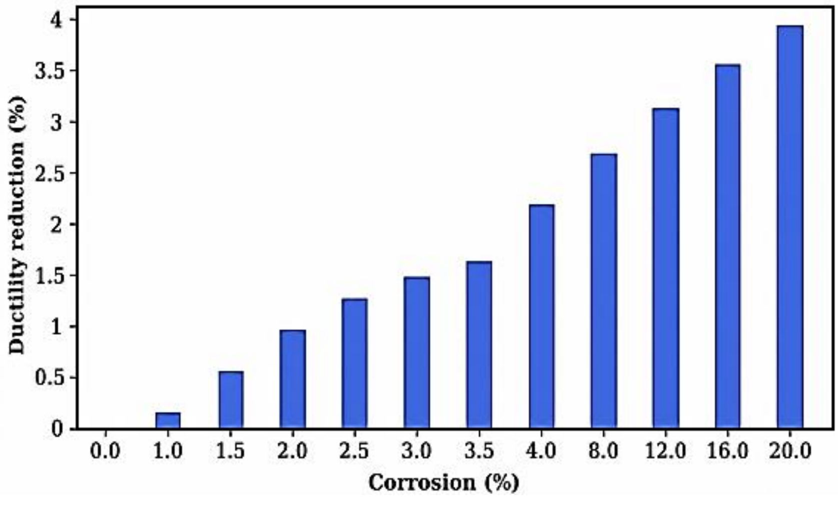

Figure 3. Reduction in ductility of 16 mm TMT steel bars with different degrees of corrosion

3.4 Strength Reduction in Corroded TMT Steel Bars
Corrosion directly undermines the strength of TMT steel bars by attacking their cross–sectional area. The formation of rust and pits effectively reduces the load–bearing capacity, leading to higher actual stress under load. This degradation impacts both yield strength and ultimate tensile strength. The percentage reduction in yield and ultimate strength of 16 mm TMT steel bars subjected to varying levels of corrosion is depicted in Figure 4. Experimental findings indicated that both the yield and ultimate strength of 16 mm TMT steel bars experienced a significant decline as the degree of corrosion increased. Furthermore, the results clearly demonstrated that the yield and ultimate strength diminished gradually up to 4% corrosion, after which the reduction occurred more rapidly. Notably, the maximum reductions in yield and ultimate strength were recorded at 19.69% and 19.78%, respectively, at 12% corrosion, beyond which the reinforcing bars failed to meet the minimum designated yield and ultimate strengths as per ISO 6935 (G72.5–500). The formation of pitting corrosion and the reduction in rebar thickness caused by corrosion significantly lower its tensile strength. Furthermore, corrosion-induced stress concentration in the steel reduces both the yield and ultimate strength. Moreover, prolonged corrosion in a chloride environment also leads to a gradual decline in yield and ultimate strength. Comparable findings have been reported in previous studies [35], confirming that the tensile strength fell below the ASTM A–615 standard of 600 MPa when the corrosion level reached 13%.

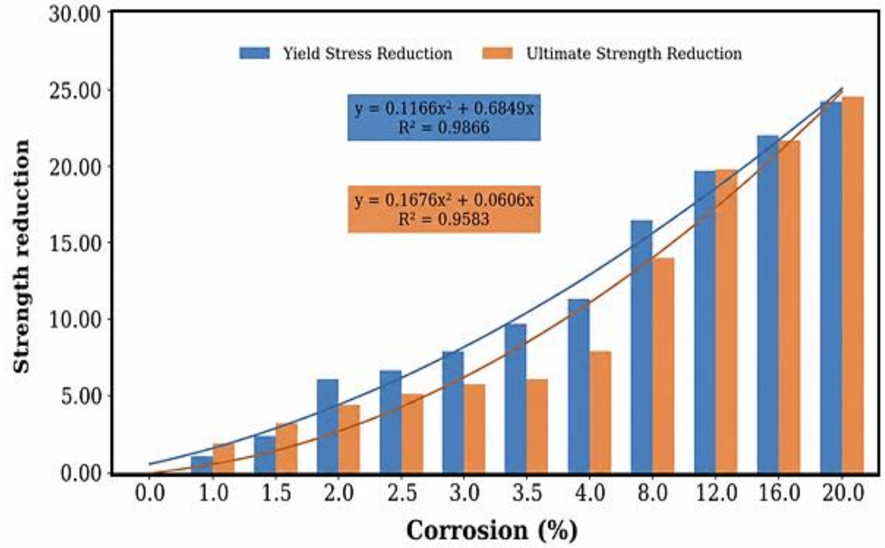

Figure 4. Reduction of yield and ultimate strength of 16 mm TMT steel bars with different degrees of corrosion

Furthermore, regression analysis, an essential statistical method for measuring the reduction in strength of corroded TMT steel bars, was performed. By exposing the bars to accelerated corrosion and then performing tensile testing, data were collected on corrosion levels (e.g., mass loss) and mechanical properties (including yield and ultimate strength). Subsequently, regression models were developed to establish a mathematical correlation between the extent of corrosion and the corresponding strength reduction (Eqs. (2-3)). The coefficients of determination (R^2) were calculated to be 0.9866 and 0.9593 for yield and ultimate strength, respectively, which are very close to 1.0, thereby validating the precision of the models. These predictive equations are vital for structural engineers, enabling them to accurately evaluate the residual capacity and remaining service life of structural steel bars affected by corrosion, thus guiding critical repair and safety decisions.

For yield stress reduction,

$$y = 0.1151x^2 + 0.6982x;\ R^2 = 0.9866 \quad (2)$$

For ultimate strength reduction,

$$y = 0.1675x^2 + 0.0626x;\ R^2 = 0.9593 \quad (3)$$

where, x = Degree of corrosion in percentage and y = Strength reduction in percentage.

3.5 Effects of Corrosion on Stress-Strain Properties of TMT Steel Bars
Corrosion profoundly alters the stress–strain properties of TMT steel bars. More critically, it severely diminishes ductility, evidenced by a shorter plastic plateau and reduced elongation. The stress–strain diagram for 16 mm TMT steel bars subjected to varying degrees of corrosion is illustrated in Figure 5. The findings indicated that up to 4% corrosion, all the corroded bars exhibit nearly identical behaviour up to the proportional limit. Beyond this limit, the bar specimens with 0% and 1% corrosion demonstrate a steeper stress–strain curve. In contrast, the specimens with 1.5% to 4% corrosion display similar characteristics. The stress–strain diagram for 12% corrosion terminates before achieving the maximum stress level attained by the specimen with 8% corrosion. Additionally, the results showed that, despite corrosion-induced degradation of the reinforcing bars, their yield plateaus remained above the specified minimum yield plateau when the corrosion level was below 12%. The yield plateaus of corroded high–strength TMT bars were found to decrease with

increasing corrosion severity. When the corrosion level reached a critical threshold value of 12%, the yield plateaus of the corroded high–strength rebars were eliminated. This finding is consistent with earlier research [36]–[38], thereby validating the diminished stress–strain characteristics of corroded TMT steel bars. The decline in stress–strain properties of corroded TMT steel bars result directly from the decrease in cross–sectional area due to mass loss, which elevates the true stress on the remaining steel. Additionally, and more importantly, the formation of localised corrosion pits generates significant stress concentration points. These pits serve as initiation sites for microcracks, which expand under load, resulting in premature yielding and failure. This deterioration significantly compromises the distinctive tempered martensite structure of the TMT bar, impairing its capacity for uniform plastic deformation and lowering both its yield and ultimate strength as depicted in the stress–strain graph.

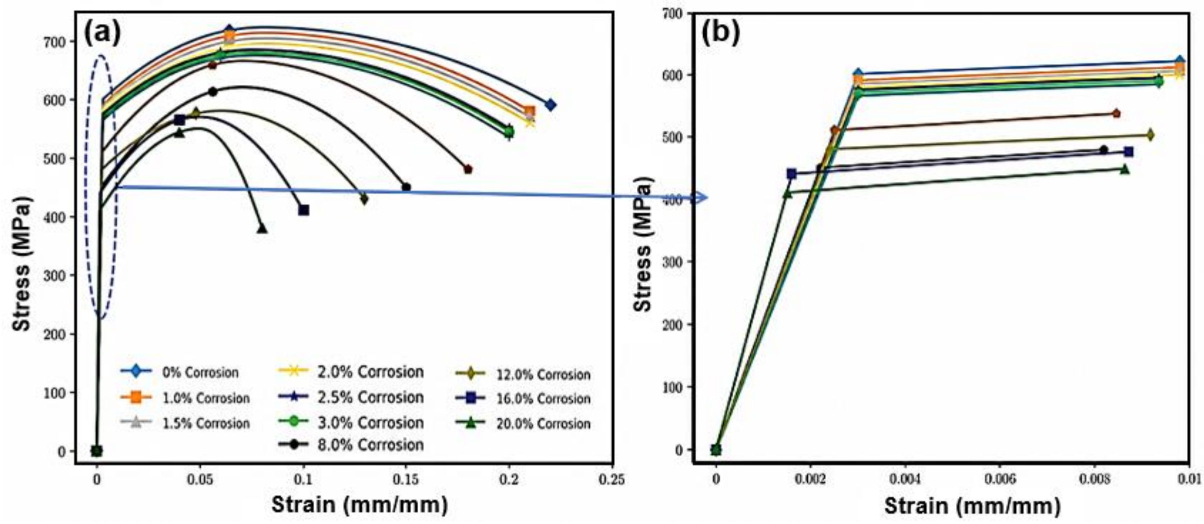

Figure 5. (a) Stress-strain characteristics and (b) Yield stress of 16 mm TMT steel bars at different degrees of corrosion

3.6 Relationship between Corrosion Test Period and Degree of Corrosion in Chloride–rich Environment

The relationship between the duration of corrosion testing and the degree of corrosion observed in TMT bars within a chloride–rich environment is depicted in Figure 6. The results indicated that as the test duration increased, the degree of corrosion also rose in the chloride–rich setting. A numerical correlation was established to quantify a specific level of corrosion in relation to both actual and experimental durations for TMT steel bars exposed to a chloride–rich environment. Eq. (4) describes the relationship between experimental duration and the degree of corrosion in a corrosive environment.

$$y = -2.2377x^2 + 100.36x - 41.25;\ R^2 = 0.9863 \quad (4)$$

where x = Degree of corrosion (in percentage) and y = Experimental time (in minutes). The quantitative correlation between actual time and the extent of corrosion in a chloride environment has also been established, as demonstrated in Eq. (5).

$$y = -0.3211x^2 + 160.92x + 23.118;\ R^2 = 0.9995 \quad (5)$$

where, x = Degree of corrosion in percentage and y = Real time in days.

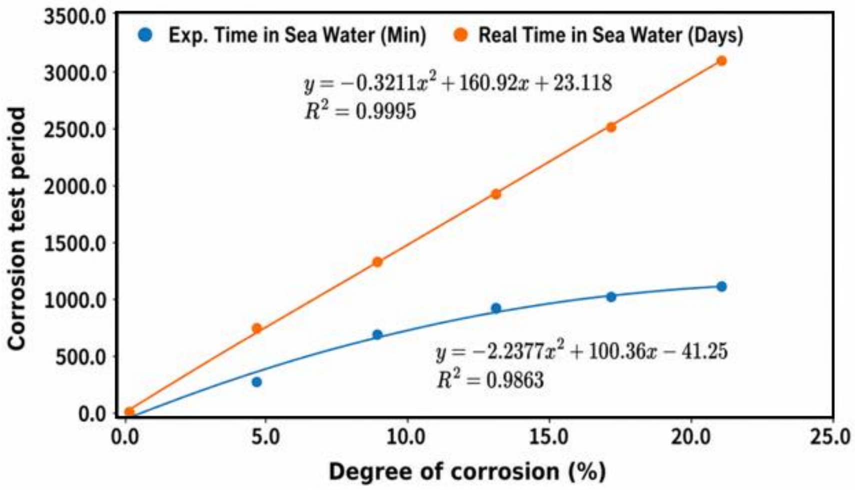

Figure 6. Correlation between corrosion test period and degree of corrosion in chloride–rich environment

From the regression models, the coefficient of determination (R^2) was found to be 0.9863 and 0.9995 for experimental and real–time scenarios, respectively, which is very close to 1.0, thus confirming the accuracy of the models. The models indicated that the 16 mm TMT bars would take 2516 days (6.8 years) to corrode by 16% when exposed to a chloride–rich environment. However, this real–time prediction is influenced by various field factors, including electrical conductivity, chemical composition, and the pH value of the electrolyte solution, which are critical in determining the corrosion rate. Moreover, external environmental conditions such as moisture, oxygen, and temperature, along with the properties of the steel bars, including diameter, exposure conditions, steel composition, and surface characteristics, can influence the development of the passive layer and the initiation of corrosion, thereby affecting the real–time duration required to achieve the desired level of corrosion.

3.7 Critical Corrosion Threshold for Structural Integrity

The experimental findings were evaluated against the specified minimum yield stress of 500 MPa and the ultimate strength, in accordance with ISO 6935. It was observed that for 16 mm bars, the tensile strength remained above the minimum required values when the corrosion level was below 12%. However, at a corrosion level of 12%, the bars' residual yield strength fell below the 500 MPa limit. This indicates a critical corrosion threshold of approximately 12%, beyond which the reinforcing bars can no longer be depended upon to deliver their design strength, thereby posing a significant risk to structural safety. Additionally, the probabilistic assessment of the corrosion threshold value was conducted under defined conditions. The specified threshold of 12% can be achieved after 841 minutes of experimental duration, whereas a real–time of 1908 days is required in a chloride–rich environment to reach 12% corrosion. Throughout the corrosion process, rust accumulated on the surfaces of the steel bars was removed using an acetone-water solution, following ASTM G1–03, at 30–minute intervals, and the corrosion rate of TMT steel bars was evaluated. Nevertheless, the characteristics of the electrolyte influence both the corrosion process and the threshold value established in this research, and these effects must be considered. The correlation between the corrosion rate of TMT bars and the quality of the electrolyte in the electrochemical corrosion process is elaborated upon in the author's previous publications [31].

3.8 Experimental Validation of this Study

The accuracy and validity of experimental results found in this study were confirmed by comparing them with two distinct published cases. The specifics of these two cases are outlined in the subsequent sub–sections. Tariq and Bhargava [9] investigated the mechanical properties of super-ductile reinforcing steel that had sustained corrosion damage. It was found that both the yield and ultimate strength consistently declined as corrosion increased, which was linked to a notable reduction and changes in the distribution of martensite in the outer rim, bainite in the transition zone, and ferrite–pearlite in the core region of the TMT bars. Given that both yield and ultimate strength depend on the hardness of the martensite rim and the core, the observed decrease in these strengths can be attributed to the changes in the surface characteristics of the TMT bars. Consequently, the strength ratio diminished with a higher degree of corrosion. Up to 20% corrosion, the strength ratio varies between 0.7 and 1.0. Comparable results were noted when the findings of this study were contrasted with the data presented by Tariq and Bhargava [9], as depicted in Figure 7.

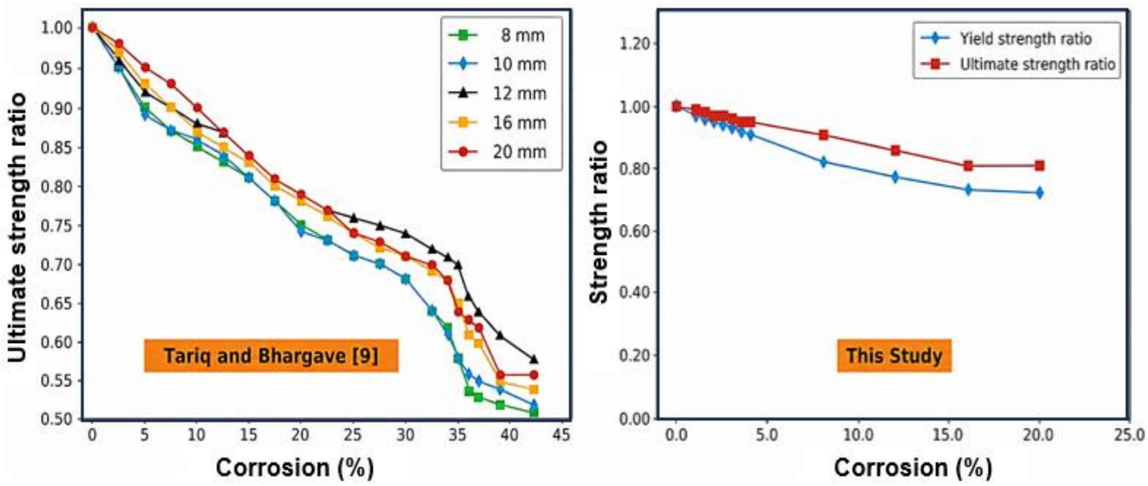

Figure 7. Comparison of strength ratio reduction with the increased degree of corrosion between the present study and the measured results reported by Tariq and Bhargava [9]

In a separate investigation, Wu et al. [29] examined the impact of accelerated corrosion on the stress–strain properties of high–strength steel bars (HSSB HTRB600). The yield strength, ultimate strength, and deformability of the corroded steel bars diminished as the corrosion rate increased. Even at a low corrosion rate, both the ultimate and failure strains decreased significantly. Furthermore, the yield plateau of HSSB HTRB600 progressively shortened as corrosion levels increased, and it completely vanished when the degree of corrosion exceeded 11%. This phenomenon occurs due to non–uniform corrosion leading to various weak sections. Similar findings were observed when comparing this study's results with measurements reported by Wu et al. [29], as illustrated in Figure 8.

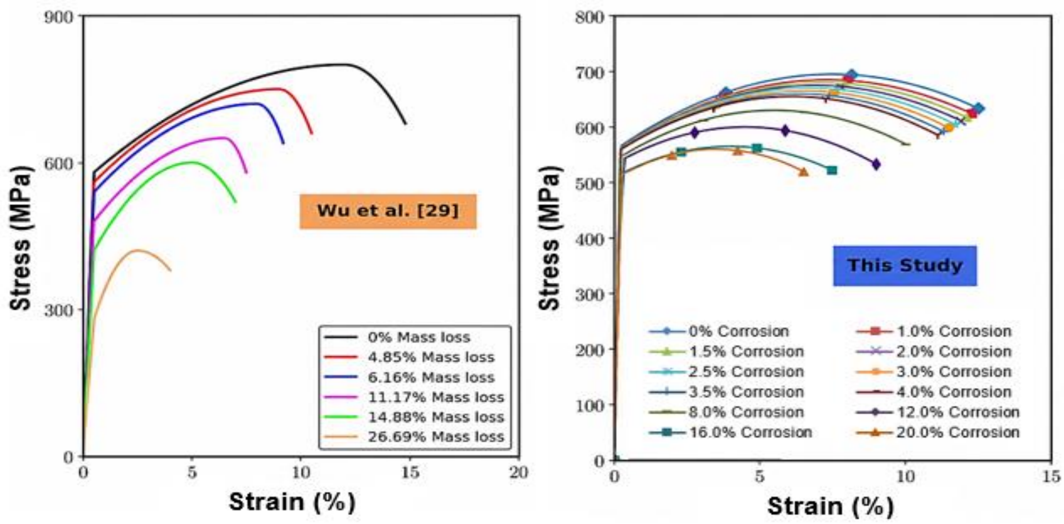

Figure 8. Comparison of stress–strain characteristics of HTRB600 and TMT500W bars with the increased degree of corrosion between the present study and the measured results reported by Wu et al. [29]

4. Conclusions

The exposure of TMT bars to an accelerated chloride–rich environment leads to localised pitting corrosion, which significantly undermines their mechanical properties by diminishing both ductility and tensile strength. Moreover, the corrosion process fundamentally modifies the stress–strain characteristics, indicating a critical shift from ductile to more brittle failure. The distinct yield plateau, a defining feature of TMT steel that facilitates plastic deformation and provides a warning before failure, diminishes and may even vanish at elevated corrosion levels. This phenomenon is accompanied by a decrease in elongation and strain capacity, signifying a substantial loss of ductility. The deterioration of yield and ultimate tensile strength follows a non–linear, two–stage trajectory: a gradual decline up to 4% corrosion, succeeded by a swift acceleration. Importantly, a corrosion threshold of 12% is recognised, beyond which the bars experience a peak strength reduction of nearly 20% and fail to meet the minimum yield and ultimate strength criteria of the ISO 6935 standard, thereby posing a significant risk to structural integrity by diminishing the steel's inherent safety margin. Based on the study's findings on the effects of corrosion on TMT steel bars, it can be concluded that exposure to an accelerated chloride–rich environment significantly undermines both the tensile strength and ductility of the material. Nevertheless, this research investigated the corrosion of bare TMT 500W reinforcing bars in ASW under impressed-current conditions. However, a significant information gap persists regarding the critical impact of corrosion on structural behaviour, specifically the degradation of the bond with concrete, the reduction in buckling resistance of compression members, and the loss of ductility under seismic loads. Consequently, subsequent studies should concentrate on examining corroded steel bars of various grades while embedded in concrete, utilising more advanced and realistic testing methodologies. Emphasis must be placed on developing anti–corrosion designs for reinforcing bars intended for earthquake–resistant structures in marine environments. Furthermore, a crucial direction for future work is to determine how safety factors in design codes—for strength, bond, and buckling—should be judiciously adjusted based on measured corrosion levels, member criticality, and overall structural redundancy.

This research reveals a crucial corrosion threshold of around 12%, beyond which the reinforcing bars do not satisfy the minimum specified yield and ultimate strength according to ISO 6935 (G72.5–500), thus presenting a considerable threat to structural safety. This corrosion threshold value serves as a benchmark for a comprehensive, member–specific condition assessment, evaluation of residual strength, and planning for repairs; however, it should not be regarded as a direct, singular failure threshold. A safety factor is not applied to the 12% value itself; instead, the correct approach is to utilize assessment–grade load and resistance factors (more conservative than those employed in the design of new elements) that take into consideration the increased uncertainties linked to existing, corroded structures and the potential consequences of failure.

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Declaration of Competing Interest

The authors declare no conflicts of interest.

Credit Authorship Contribution Statement

Md Mohshin Ali (Conceptualisation, Methodology, Data collection, Investigation, Analysis, Visualisation, Writing– original draft, Writing– review & editing)
Md. Niamul Bari (Conceptualisation, Investigation, Visualisation, Supervision, Writing– review & editing)
Azrina Abd Aziz (Conceptualisation, Visualisation, Supervision, Writing– review & editing)

Availability of Data and Materials

The data supporting this study's findings are available from the corresponding author on reasonable request.

Ethics Declarations

This study did not involve human participants or animals. Ethical approval was therefore not required.

Generative Artificial Intelligence Declarations

The authors claim that artificially intelligent-assisted technologies, such as generative AI, were not used to generate content, ideas, or theories. We have just utilised AI to enhance readability and refine the language. This was used with extreme human control and oversight. The authors take full responsibility for reviewing and approving the content.

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