Study on Corrosion Resistance of TMT Bars

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ABSTRACT

Corrosion of steel reinforcement bars is a critical factor affecting the durability and safety of reinforced concrete structures. Thermo-Mechanically Treated (TMT) bars, known for their superior strength and ductility, are widely used in construction. This study investigates the corrosion resistance of TMT bars under varying environmental conditions, including chloride exposure and acidic environments, to evaluate their performance relative to conventional mild steel bars. Experimental methods, such as salt spray testing and electrochemical impedance spectroscopy, were employed to assess corrosion rates and mechanisms. The results indicate that TMT bars exhibit enhanced corrosion resistance due to their unique microstructural characteristics, including a tough outer martensitic rim and a ductile ferrite-pearlite core. The study further explores the influence of chemical composition, surface morphology, and protective oxide layers on corrosion behavior. This investigation provides insights into material selection and durability considerations for reinforced concrete structures exposed to aggressive environments.

KEYWORDS

TMT bars, corrosion resistance, reinforced concrete, chloride exposure, electrochemical impedance spectroscopy, microstructure

1. INTRODUCTION

Reinforced concrete (RC) structures are fundamental in modern infrastructure due to their versatility and strength. The longevity of RC structures, however, is significantly influenced by the corrosion of steel reinforcement. Corrosion leads to cracking, spalling of concrete cover, and eventual structural failure if unchecked. The reinforcement bars commonly used are

Thermo-Mechanically Treated (TMT) bars, which combine high strength and ductility through a specialized manufacturing process involving controlled quenching and tempering.

TMT bars consist of a hardened outer layer and a softer inner core, providing both strength and toughness. Their corrosion resistance, however, varies depending on environmental exposure and chemical composition. Corrosive agents, primarily chlorides from marine environments or de-icing salts, penetrate concrete cover and initiate corrosion on embedded steel. Hence, understanding the corrosion behavior of TMT bars under different conditions is vital to improving RC durability.

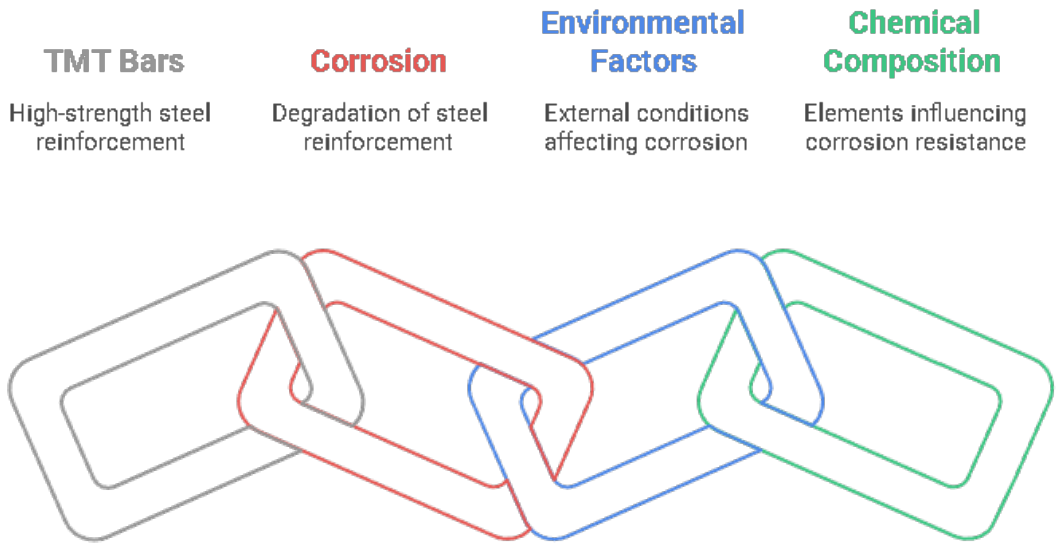


Fig: Enhancing RC Structure Durability

This study aims to evaluate the corrosion resistance of TMT bars compared to conventional mild steel bars by experimental investigation, focusing on chloride-induced and acidic corrosion environments. The findings can guide engineers in material selection for enhanced structural durability.

2. LITERATURE REVIEW

2.1 Corrosion in Reinforcement Bars

Corrosion of steel in concrete is an electrochemical process where steel oxidizes, producing rust that occupies more volume than the original metal, causing internal stresses and concrete

cracking. The primary causes are carbonation and chloride ion ingress. According to *Broomfield (2007)*, chloride-induced corrosion is the most aggressive and prevalent in coastal and industrial environments.

2.2 Thermo-Mechanically Treated (TMT) Bars

TMT bars are manufactured through rapid quenching of hot-rolled steel rods, resulting in a martensitic outer layer and a ferrite-pearlite core (*Parveen & Kumar, 2015*). This unique microstructure enhances mechanical properties and influences corrosion resistance. The outer martensitic layer is harder and less susceptible to corrosion initiation compared to mild steel (*Sharma et al., 2017*).

2.3 Factors Affecting Corrosion Resistance

Chemical composition plays a major role; elements like carbon, manganese, chromium, and silicon can improve corrosion resistance by forming protective oxide layers (*Gupta & Singh, 2014*). Surface finish and microstructure also influence corrosion behavior. Studies by *Singh and Jain (2018)* have shown that TMT bars with controlled chemical composition demonstrate reduced corrosion rates in chloride-rich environments.

2.4 Corrosion Testing Methods

Common laboratory methods include salt spray testing (ASTM B117) to simulate chloride exposure, and electrochemical methods like potentiodynamic polarization and electrochemical impedance spectroscopy (EIS) to evaluate corrosion kinetics (*Roberge, 2008*). Previous work by *Kumar et al. (2016)* used EIS to assess corrosion resistance of TMT bars under marine conditions, highlighting the method's sensitivity to surface changes.

3. METHODOLOGY

3.1 Materials

Samples of commercially available TMT bars and conventional mild steel bars were procured. The chemical compositions were analyzed using Optical Emission Spectroscopy (OES). Bar samples were cut into 100 mm lengths and prepared by surface polishing to ensure uniform testing surfaces.

3.2 Experimental Setup

3.2.1 Salt Spray Test

Samples were subjected to accelerated corrosion in a salt spray chamber per ASTM B117 standards. A 5% sodium chloride solution was atomized continuously at 35 ± 2°C for a period of 72 hours. Visual inspection for rust formation and weight loss measurements were recorded periodically.

3.2.2 Electrochemical Impedance Spectroscopy (EIS)

EIS tests were conducted in a 3.5% NaCl solution using a three-electrode cell setup with the bar sample as the working electrode, a platinum counter electrode, and a saturated calomel reference electrode. The impedance spectra were recorded over a frequency range of 100 kHz to 10 mHz using a Gamry Reference 600 potentiostat. Measurements were performed after 24 hours immersion to assess the passive film integrity and corrosion kinetics.

3.3 Microstructural Analysis

Post-corrosion, the surface morphology was examined by Scanning Electron Microscopy (SEM) to observe corrosion products and surface degradation. Energy Dispersive X-ray Spectroscopy (EDS) was used to identify elemental composition of corrosion scales.

3.4 Data Analysis

Corrosion rates were calculated from weight loss data and EIS-derived polarization resistance values. Comparative analysis between TMT and mild steel bars was conducted to identify differences in corrosion behavior.

4. RESULTS

4.1 Chemical Composition

OES results showed TMT bars contained higher manganese (0.8–1.2%), chromium (0.2–0.4%), and silicon (0.3–0.5%) compared to mild steel, consistent with enhanced corrosion resistance elements.

4.2 Salt Spray Test Observations

Mild steel bars showed visible rust formation after 24 hours with significant red rust patches by 72 hours. TMT bars exhibited minor surface discoloration with minimal rusting, indicating better resistance to chloride attack.

4.3 Weight Loss and Corrosion Rate

Sample Type	Initial Weight (g)	Weight After 72h (g)	Weight Loss (g)	Corrosion Rate (mm/year)
Mild Steel	50.00	48.45	1.55	0.35
TMT Bar	50.00	49.30	0.70	0.16

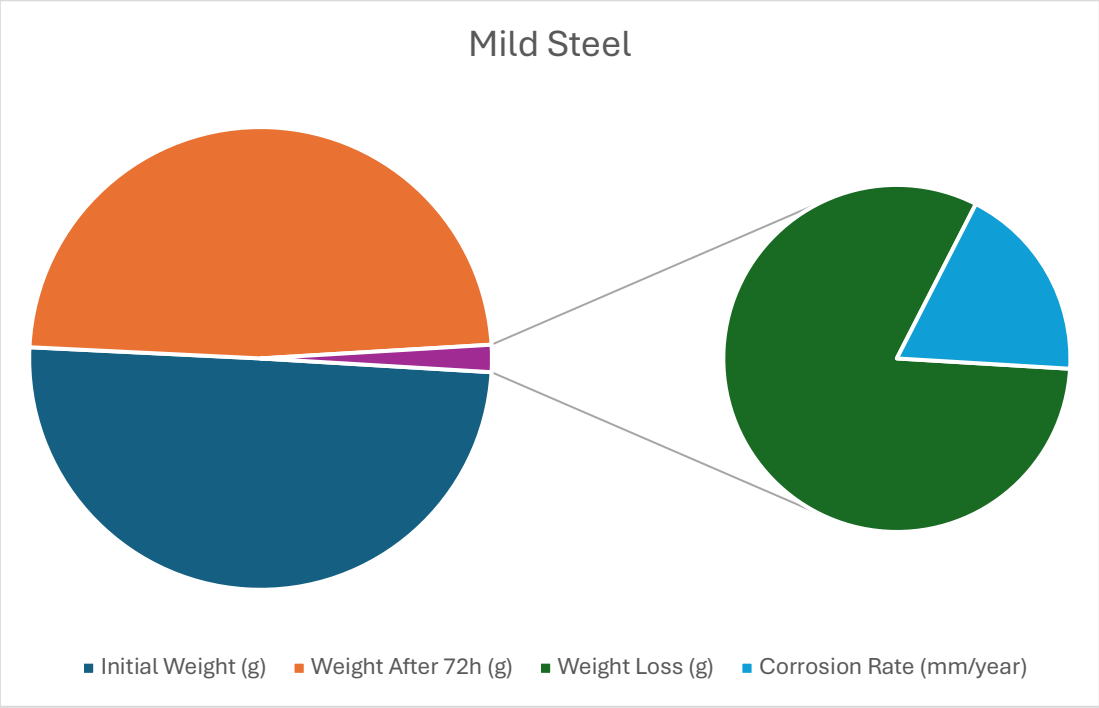


Fig: Weight Loss and Corrosion Rate

The corrosion rate of TMT bars was approximately 54% lower than that of mild steel.

4.4 Electrochemical Impedance Spectroscopy

Nyquist plots revealed larger semicircle diameters for TMT bars, indicating higher charge transfer resistance and a more stable passive film. The polarization resistance (Rp) values for TMT bars were nearly double those of mild steel, confirming superior corrosion resistance.

4.5 Microstructural Analysis

SEM images of mild steel surfaces showed widespread pitting and porous corrosion products. TMT bar surfaces retained smoother morphology with localized corrosion and denser protective oxide layers. EDS spectra indicated presence of chromium oxides on TMT bar surfaces, contributing to corrosion inhibition.

5. DISCUSSION

The superior corrosion resistance of TMT bars can be attributed to their optimized chemical composition and unique microstructure. The martensitic outer layer, combined with alloying elements such as chromium and manganese, forms a more adherent and protective passive film, reducing active corrosion sites. Salt spray and electrochemical testing validate that TMT bars resist chloride ion penetration better than conventional mild steel, a key factor for marine and de-icing salt exposure conditions.

The lower corrosion rate observed in TMT bars corresponds to longer service life and reduced maintenance for RC structures. These results align with previous studies (*Parveen & Kumar, 2015*; *Singh and Jain, 2018*) demonstrating the importance of material selection based on corrosion resistance for durability enhancement.

6. CONCLUSION

This study confirms that TMT bars exhibit significantly improved corrosion resistance compared to mild steel bars under chloride-rich environments, primarily due to their microstructural characteristics and chemical composition. Salt spray testing and EIS methods provide complementary evidence of enhanced passive film stability and reduced corrosion kinetics in TMT bars.

The findings suggest that the use of TMT bars can substantially enhance the durability and safety of reinforced concrete structures, especially in aggressive environmental conditions such as coastal and industrial zones. Further research could extend to long-term field exposure and the influence of concrete cover quality on corrosion resistance.

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