JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

COMPARITIVE STUDY OF TENSILE PROPERTIES OF TMT BARS IMMERSED IN WATER WITH VARYING TDS LEVELS: BRAND ANALYSIS AND COST ASSESSMENT

S. Lakminarayanan[1], D.Mohana Prasath [2], KS.Nitthyasri[2], P.Praveen kumar[2], M. Ramya devi [2]

[1]Assistant professor, Department of Civil Engineering, Sri Shakthi Institute of Engineering and Technology, Coimbatore, India

[2]Student, Department of Civil Engineering, Sri Shakthi Institute of Engineering and Technology, Coimbatore, India

ABSTRACT

Thermo-Mechanically Treated (TMT) steel bars play a vital role as reinforcement materials in concrete structures due to their superior strength, ductility, and durability. These bars undergo a special thermo-mechanical treatment process that creates a hard outer martensitic layer and a softer inner core, resulting in an ideal balance between strength and flexibility. Such properties make TMT bars highly suitable for various construction environments, including harsh and aggressive conditions. However, exposure to corrosive environments, especially water containing elevated levels of Total Dissolved Solids (TDS), poses a considerable threat to the mechanical performance and longevity of TMT bars.

High TDS levels often indicate the presence of salts such as chlorides, sulphates, and other minerals, which accelerate corrosion processes. Corrosion not only weakens the steel by reducing its cross- sectional area through rusting but also adversely affects the bond between steel and concrete, leading to compromised structural integrity and eventual failures. This research comprehensively investigates the tensile performance of TMT bars of different diameters (6mm, 10mm, 12mm, 16mm, and 20mm) made by three leading brands in India, exposed to varying water TDS levels of 60 ppm (low), 700 ppm (moderate), and 4000 ppm (high). The study employs tensile testing using a Universal Testing Machine (UTM) to measure key mechanical properties such as Ultimate Tensile Strength (UTS) and elongation at break, which reflects ductility and deformation characteristics under stress. To validate and understand the underlying mechanical behaviour, microstructural examinations are conducted, revealing changes such as pitting, formation of corrosion products, and alterations in the martensitic and ferrite-pearlite phases of the steel. These microstructural changes correlate with the observed tensile properties, explaining the degradation trends due to corrosion. The study's findings provide valuable data enabling engineers and construction professionals to make informed decisions when selecting reinforcement materials, especially in environments prone to high TDS exposure such as coastal areas, groundwater with high mineral content, or industrial sites. By understanding the impact of water quality on TMT bar durability and performance, it is possible to optimize construction design for enhanced safety and cost efficiency, ultimately extending the service life of reinforced concrete structures.

Keywords
Steel corrosion resistance, Microstructural examination, Ultimate tensile strength, Tensile properties, Total Dissolved Solids.

1. Introduction

Reinforced concrete is central to most modern construction, and its performance depends heavily on the quality of the materials that go into it. Among these, Thermo-Mechanically Treated (TMT) steel bars play a crucial role. These bars are produced through a controlled sequence of heating, rapid cooling (or quenching), and tempering. The result is a distinctive structure: a tough, hardened outer layer wrapped around a more flexible, ductile core. This combination gives TMT bars high tensile strength, good ductility, and strong resistance to dynamic forces such as earthquakes and heavy winds. Concrete on its own can withstand compression well but performs poorly under tension. Embedding TMT bars within concrete solves this problem, creating reinforced concrete a composite material capable of carrying both compressive and tensile loads[1]. The ribbed pattern on TMT bars helps them grip the surrounding concrete, which is essential for effective load transfer and long-term durability. However, the durability of these bars can be compromised when they are exposed to water with high Total Dissolved Solids (TDS)[2].Construction water or environmental conditions with elevated TDS can introduce corrosive ions that speed up steel degradation.
Over time, this corrosion can weaken the bond between steel and concrete, reduce structural reliability, and shorten a structure's service life. These concerns highlight the importance of studying how different TDS levels affect the mechanical behaviour and microstructure of TMT bars, especially in the context of sustainable and resilient construction[3].

1.1 Background of the Study

The Thermo-Mechanical Treatment (TMT) process is a specialized technique used to manufacture high-strength steel reinforcement bars. It begins with hot rolling steel billets and then subjecting them to rapid water quenching. This sudden cooling hardens the outer layer of the bar, forming a tough martensitic surface, while the still-hot core cools more slowly and develops a softer ferritic–pearlitic structure. This layered microstructure gives TMT bars their distinctive performance: a hard, wear-resistant exterior combined with a ductile, flexible interior capable of absorbing stress without cracking[4].
In reinforced concrete, TMT bars play a critical role because they compensate for concrete's poor tensile strength. To perform effectively, these bars must exhibit key mechanical properties, including high Ultimate Tensile Strength (UTS) the maximum load the steel can bear before failure along with strong ductility, which allows controlled deformation under stress, and durability to withstand corrosive or demanding environmental conditions. Together, these properties enable TMT bars to maintain structural safety, resist dynamic forces, and perform reliably across a wide range of construction applications[5].

1.2. Impact of Water Quality on Steel Corrosion:

Total Dissolved Solids (TDS) represent the total concentration of dissolved inorganic salts and small amounts of organic matter present in water, typically reported in mg/L or ppm. Among these dissolved substances, chloride (Cl^-) and sulphate (SO_4^{2-}) ions are particularly significant because they are highly corrosive to steel.

When TMT bars come into contact with water containing elevated TDS levels, the risk of corrosion increases. Higher concentrations of dissolved ions raise the water's electrical conductivity, making it easier for electrochemical reactions to occur. Corrosion begins as iron in the steel reacts with oxygen and moisture to form iron oxides (rust). Chloride and sulphate ions accelerate this process by penetrating and breaking down the thin passive film that normally protects steel surfaces. As corrosion progresses, rust accumulates, reducing the effective cross-section of the steel and diminishing its mechanical strength. This deterioration also weakens the bond between the steel and surrounding concrete, ultimately threatening the structural integrity and long-term durability of reinforced concrete systems[6].

1.3 Research Objectives and Scope:

The primary aim of this study is to evaluate how exposure to different Total Dissolved Solids (TDS) levels in water affects the tensile behavior of various TMT bar brands, focusing specifically on Ultimate Tensile Strength (UTS) and elongation. The investigation considers three TDS conditions 60 ppm (low), 700 ppm (medium), and 4000 ppm (high). The scope includes a comparative assessment of major TMT brands used in India, standardized mechanical testing for UTS and elongation, and microstructural analysis to link corrosion- related changes with variations in mechanical performance. In addition, the study incorporates a cost evaluation to help identify the most suitable reinforcement materials for construction applications[7].

2. Materials and Experimental Methodology

The materials used in this study included Thermo-Mechanically Treated (TMT) steel bars sourced from three major Indian manufacturers, with bar diameters of 6 mm, 10 mm, 12 mm, 16 mm, and 20 mm. To simulate different environmental conditions, samples from each brand were immersed in water containing Total Dissolved Solids (TDS) levels of 60 ppm, 700 ppm, and 4000 ppm. Tensile properties were evaluated using a Universal Testing Machine (UTM), with measurements recorded for Ultimate Tensile Strength (UTS) and percentage elongation. Microstructural analyses were also conducted to examine corrosion-related changes and their connection to mechanical behaviour. These examinations followed standard protocols for sample preparation, surface marking, and controlled loading[8].

2.1. TMT Bar Materials

2.1.1. Bar Selection and Specifications

TMT bars from three major Indian manufacturers identified as Brands A, B, and C were selected to provide a representative basis for comparison among widely used market options. The chosen diameters, including 12 mm and 16 mm, reflect common reinforcement sizes used in structural applications, ensuring that the findings remain relevant to practical construction needs. All bars were procured in accordance with IS specifications to maintain consistency in material quality and ensure a fair comparison across brands[9].

2.1.2. Initial Chemical and Microstructural Characterization

To establish a baseline for comparison, each lot of TMT bars underwent chemical analysis to determine the Carbon Equivalent (CE), a key parameter influencing weldability and resistance to corrosion. In addition, microscopic examinations were performed to document the initial, pre-exposure microstructure. These observations confirmed the expected TMT configuration— a hardened martensitic outer layer surrounding a ferritic–pearlitic core. This baseline characterization provides a clear reference point for evaluating changes that occur after exposure to corrosive environments[5]. Fig 1 shows the initial microstructural characterization of the TMT bar, highlighting the hardened martensitic outer layer surrounding the softer ferritic-pearlitic core.

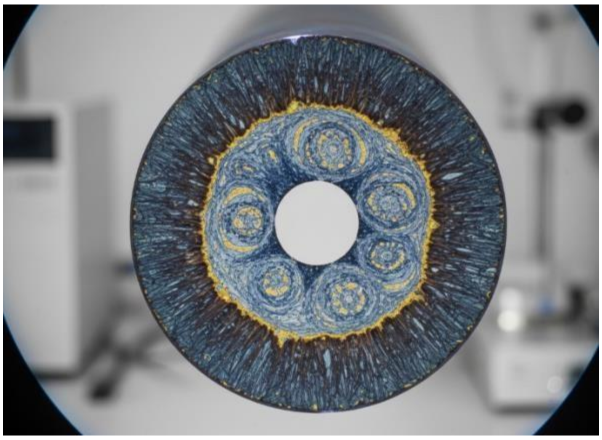

Fig 1: Initial Microstructural Characterization of TMT Bar

2.2. Preparation of Corrosive Environments

2.2.1. TDS Water Simulation

Corrosive environments were simulated by preparing three water baths representing low (60 ppm), moderate (700 ppm), and high (4000 ppm) TDS conditions. These solutions were formulated using measured quantities of sodium chloride (NaCl) and magnesium sulfate ($MgSO_4$), two salts commonly associated with elevated TDS levels and known to promote corrosion in steel. The required amounts of each salt were calculated and dissolved to accurately achieve the target TDS values for each experimental batch[10].

2.2.2. Immersion Protocol

Specimens were prepared by cutting the TMT bars to standardized lengths and cleaning their surfaces to remove any existing scale or rust. Each sample was then weighed and assigned to its designated TDS solution, where it was immersed either partially or fully, as required by the protocol for a defined exposure period (90 days) to simulate long-term field conditions. During the immersion phase, parameters such as temperature and solution composition were regularly checked and maintained to ensure consistent exposure across all samples and to support the reliability of the test results[11].

2.3. Corrosion Assessment

2.3.1. Mass Loss Measurement

To evaluate general corrosion, mass-loss measurements were conducted in accordance with ASTM G1-03 guidelines. At the end of the immersion period, each TMT bar specimen was removed from its respective solution, gently rinsed, and dried. Corrosion products were then eliminated using the prescribed chemical cleaning procedure (typically involving an ASTM-approved acid solution formulated to remove rust without causing appreciable loss of base metal). After cleaning, the samples were dried again and weighed to the nearest 0.01 g using a calibrated analytical balance. The percentage mass loss was calculated using the following expression:

$$\text{Mass loss (\%)} = \left(\frac{\text{Initial mass} - \text{Final mass}}{\text{Initial mass}}\right) \times 100$$

This process provides a quantitative measure of corrosion, with care taken not to over-clean or under-clean, to avoid bias in results.

2.3.2. Pitting and Surface Morphology

For evaluating localized corrosion, the maximum pit depth on each specimen was measured after the cleaning process. A precision digital micrometer or an equivalent surface-profiling instrument was used to scan the exposed surfaces of the bars. The deepest pit identified recorded in either micrometers or millimeters was taken as the representative value, as pitting can critically compromise structural integrity even when overall mass loss is relatively low. In addition, visual inspection and microscopic analysis (such as optical microscopy) were carried out to document pit geometry, distribution, and morphology, providing further insight into the relationship between pitting severity and changes in mechanical performance[12].

2.4. Tensile Testing Procedure

Tensile testing of the TMT bars was performed in accordance with recognized standards IS 1786:2008 for Indian reinforcement steel and ASTM A615/A615M for international reference to ensure uniformity and comparability of results. A Universal Testing Machine (UTM) was used to apply controlled tensile loads to the pre-cut, gauge-marked specimens. During each test, three primary mechanical properties were recorded:

- **Ultimate Tensile Strength (UTS):** the maximum stress the bar can sustain before failure,
- **Yield Strength (YS):** the stress at which permanent deformation begins, identified either by the yield point or as the 0.2% proof stress, and
- **Percentage Elongation at Break:** a measure of ductility, expressed as the percentage increase in the gauge length at fracture.

Together, these parameters provide a comprehensive understanding of how corrosion and varying TDS exposure influence the mechanical performance and structural reliability of TMT reinforcement bars. Fig 2 shows the Universal Testing Machine (UTM) used to measure the mechanical properties of TMT bars.

Fig 2: Universal Testing Machine

3. Results and Discussion

3.1 Corrosion Behaviour under Different TDS Levels

The TMT bar specimens exposed to higher TDS levels exhibited a noticeable increase in corrosion severity compared with those immersed in low-TDS water. Mass-loss results showed a progressive rise in percentage weight loss from 60 ppm to 700 ppm, with the highest losses recorded at 4000 ppm. This pattern confirms that elevated concentrations of corrosive ions—particularly chlorides and sulphates significantly accelerate general corrosion on the steel surface.

Pitting corrosion also intensified as TDS increased. At low TDS levels, pits were shallow and sparsely distributed, whereas specimens exposed to 4000 ppm developed deeper, more numerous pits. Because pitting reduces the effective cross-sectional area of the bar at localized points, these defects act as stress concentrators, directly influencing tensile behaviour and contributing to premature or brittle failure modes.

Table 1 shows the corrosion severity of TMT bars at different TDS levels, expressed as percentage mass loss after exposure.

Table 1: Corrosion Severity of TMT Bars at Different TDS Levels

TDS Level (ppm)	Mass Loss (%)	Pitting Depth (mm)	Surface Observation
60	0.15	0.08	Very slight, few shallow pits
700	0.55	0.22	Moderate, scattered pits
4000	1.35	0.48	Severe, many deep pits

3.2 Effect of Corrosion on Tensile Properties

Tensile testing revealed a clear decline in both Ultimate Tensile Strength (UTS) and Yield Strength (YS) as TMT bars were exposed to progressively higher TDS levels. Specimens immersed in 60 ppm water-maintained values close to their original strengths, whereas those exposed to 4000 ppm showed significant reductions. This loss in strength is linked to the combined effects of general corrosion resulting in uniform metal loss and localized pitting, which reduces the effective load-carrying cross-section.

Percentage elongation at break also decreased with rising TDS levels, indicating reduced ductility. Lower ductility is a concern for reinforced concrete structures because it limits deformation capacity, decreases energy absorption, and reduces the margin of warning before failure, especially under seismic or dynamic loading conditions. Across the evaluated brands, some exhibited smaller reductions in strength and ductility, suggesting comparatively better corrosion resistance, potentially influenced by variations in chemical composition, alloying elements, or manufacturing processes. Table 2 shows the effect of different TDS levels on the tensile properties of TMT bars, including changes in ultimate tensile strength and yield strength. Fig 3 shows the decline in Ultimate Tensile Strength (UTS) of TMT bars as the TDS level increases, illustrating the negative impact of corrosion on mechanical properties. Fig 4 shows that as TDS levels increase, the yield strength of TMT bars decreases.

Table 2: Effect of TDS Levels on Tensile Properties of TMT Bars

TDS Level (ppm)	Ultimate Tensile Strength (UTS, MPa)	Yield Strength (YS, MPa)	Elongation at Break (%)
60	590	515	15.0
700	565	495	13.2
4000	510	460	10.0

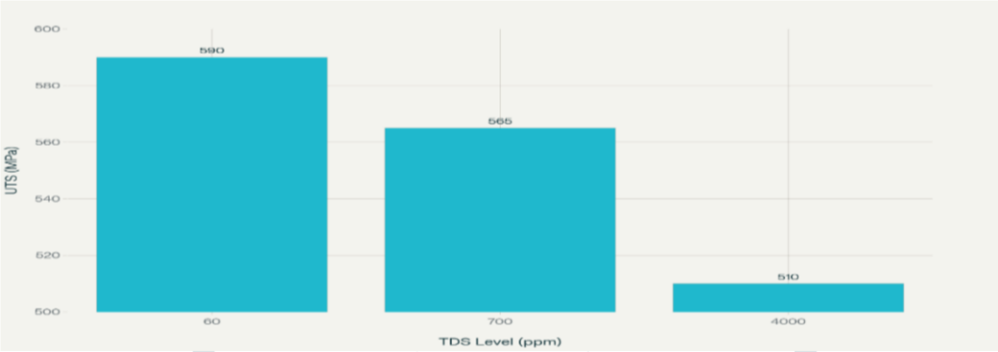

Fig 3: Ultimate Tensile Strength of TMT

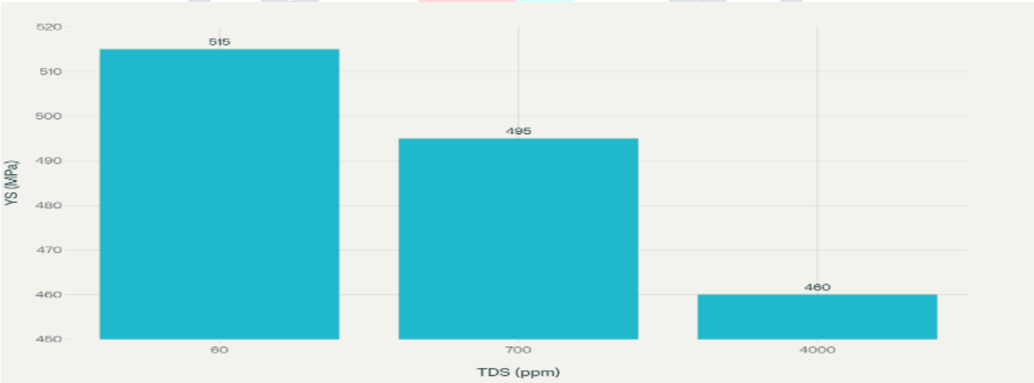

Fig 4: Yield strength of TMT bars

3.3Microstructural Changes and Their Influence

Microstructural observations were consistent with the mechanical test results. The unexposed TMT bars displayed the expected configuration of a hardened martensitic outer layer surrounding a ferritic–pearlitic core. After exposure to high-TDS environments, however, the martensitic rim showed clear signs of degradation, including surface roughening, micro-cracking, and the presence of corrosion products accumulating within pits and voids. In the most severely corroded specimens, sections of the martensitic layer were disrupted or discontinuous, reducing its protective capability.

These microstructural alterations help explain the observed reductions in UTS and elongation. As the outer hardened layer deteriorates, the bar becomes increasingly susceptible to crack initiation during tensile loading. Furthermore, deeper pits and a more irregular surface amplify stress concentrations, promoting earlier crack propagation and premature fracture compared with specimens subjected to lower corrosion levels.

3.4Comparative Performance of Brands and Diameters

Across all TDS conditions, certain brands consistently exhibited lower mass loss, reduced pitting depths, and smaller declines in tensile properties, indicating comparatively stronger corrosion resistance and more stable mechanical performance. These variations may be linked to differences in chemical composition such as controlled carbon content or the presence of microalloying elements as well as improved process control during thermo-mechanical treatment.

Bar diameter also played an important role in the results. Smaller-diameter bars were more susceptible to corrosion because pits of similar depth remove a larger proportion of their cross-sectional area compared with larger bars. As a result, the relative decrease in strength was typically more pronounced in smaller bars, underscoring the need for additional caution when using small-diameter reinforcement in highly corrosive or high-TDS environments. Table 3 shows the comparative performance of different TMT bar brands and diameters at varied TDS levels, highlighting differences in corrosion resistance and mechanical property retention.

Table 3: Comparative Performance of TMT Bar Brands and Diameters under Different TDS Levels

TDS Level (ppm)	Brand	Diameter (mm)	Mass Loss (%)	Max Pit Depth (mm)	UTS Reduction (%)
60	A	12	0.18	0.09	1.0
60	B	12	0.16	0.08	0.8
60	C	12	0.20	0.09	1.2
700	A	12	0.60	0.26	4.5
700	B	12	0.45	0.20	3.2
700	C	12	0.70	0.27	5.1
4000	A	12	1.40	0.52	12.0
4000	B	12	1.02	0.38	8.8
4000	C	12	1.55	0.54	13.5
4000	B	16	0.89	0.32	7.2

3.5Practical Implications for Design and Material Selection

The combined corrosion, tensile, and microstructural findings clearly show that exposure to high-TDS water has a substantial impact on the durability and load-carrying capability of TMT bars. In environments where water contains moderate to high dissolved solids such as areas with saline groundwater, coastal regions, or industrial discharge careful selection of both TMT brand and bar diameter becomes critical. Choosing reinforcement with stronger inherent corrosion resistance can help minimize long-term degradation, reduce maintenance requirements, and enhance structural safety.

These results highlight the need to account for water quality and corrosive exposure as key design and construction considerations. Relying solely on the nominal mechanical properties provided by manufacturers may lead to an incomplete understanding of real-world performance, especially in aggressive service environments.

4. Cost and Practical Assessment

4.1. TMT Bar Cost Analysis

Below is a comparison of current (2025) TMT bar prices for selected brands, per kilogram and per metric ton, based on recent market data. Table 4 shows the market price comparison of leading TMT bar brands in India, listing their steel grade and typical cost per kg and per ton

Table 4: Market price comparison of leading TMT bar brands

Brand	Typical Grade	Price per kg (₹)	Price per ton (₹)
Tata Tiscon	Fe500D/550SD	65–74	65,000–74,000
JSW Neosteel	Fe500D/550D	66–72	66,000–72,000
SAIL	Fe500D/550D	47–49	47,000–49,000
Jindal Panther	Fe550D	60–70	60,000–70,000
Kamdhenu	Fe550D	62–66	62,000–66,000

4.2. Life-Cycle Cost (LCC) Implications

Scenario:
Suppose Brand C (low-cost, lower corrosion resistance) is selected for a coastal project exposed to high TDS.
Initial savings may be ₹15,000–₹25,000/ton compared to a premium, corrosion-resistant brand.
However, accelerated corrosion (from earlier data) will likely lead to earlier repairs or the need for partial replacement within, say, 15 years instead of an expected 50 years for higher-quality bars. Table 5 shows the Life-Cycle Cost (LCC) comparison between economy and premium TMT bar options, accounting for initial costs and long-term maintenance or replacement expenses.

Table 5: LCC Comparison

Option	Initial Steel Cost (₹/ton)	Expected Service Life (years)	Major Repair/Replacement Cost* (₹/ton, present value)	Total LCC Over 50 yrs (₹/ton)
Brand C (economy)	46,500	15	68,000 (at 15th year, discounted)	~1,05,000
Premium Brand (e.g., JSW or Tata)	72,000	50	0	72,000

4.3. Recommendations for Engineers and Policy

For construction in high-TDS or coastal environments, selecting TMT bars with demonstrated corrosion resistance is essential, even if their initial cost is higher. These enhanced reinforcement bars are often alloyed with elements such as copper, chromium, or phosphorus, which help form stable protective layers that slow down oxidation and rust formation. Although the upfront expense may appear significant, such bars offer long-term economic benefits by reducing the need for repairs, minimizing maintenance costs, and extending the overall service life of the structure particularly in regions exposed to high humidity, salinity, or aggressive
chemical conditions. Conversely, in low-TDS or inland environments where corrosion risks are comparatively low, standard Fe500/Fe550-grade TMT bars from reputable, moderately priced manufacturers provide a reliable and cost-effective option, as environmental exposure has minimal influence on their performance.

To enhance structural durability and safety, it is advisable that construction specifications and tender documents explicitly account for site water quality and corrosion risk. In locations with known high salinity or elevated mineral content, building codes should require the use of corrosion-resistant TMT bars or approved protective coatings. Additionally, project planning should incorporate periodic inspection and maintenance schedules to manage long-term corrosion risks. Implementing these measures will contribute to improved reliability, cost efficiency, and longevity of infrastructure across diverse environmental conditions.

5. Conclusion and Future Scope

This study systematically examined how various water TDS levels affect the corrosion behaviour and tensile performance of leading TMT bar brands widely available in India. As documented, higher TDS found in coastal, industrial, and saline groundwater regions significantly accelerates uniform and localized corrosion, resulting in increased mass loss, deeper pits, and visible damage to the martensitic outer layer. These forms of deterioration lead to notable declines in ultimate tensile strength, yield strength, and ductility, with the most extreme reductions seen at 4000 ppm TDS.

Among the sampled brands, higher-grade products like Tata Tiscon, JSW Neosteel, and Jindal Panther (with prices ranging from ₹60,000–74,000 per ton) demonstrated substantially better corrosion resistance and retained mechanical properties more effectively in aggressive environments. This enhanced performance likely stems from improved alloy composition, tighter quality control, and advanced production processes. On the other hand, more economical brands like SAIL and Kamdhenu (₹47,000–66,000 per ton) experienced greater strength reductions and corrosion-related degradation, making them less suitable for exposure to harsh, high-TDS conditions.

The study also confirmed that smaller-diameter bars suffer proportionally greater losses in strength due to pitting and cross-section reduction. From a life-cycle cost (LCC) perspective, the findings reinforce that choosing corrosion-resistant, premium TMT bars is economically justified for infrastructure in high-TDS or coastal regions. Though these bars have a higher initial cost, they noticeably decrease long-term maintenance needs, minimize repairs, and maximize service life in reinforced concrete structures. However, for inland or low-TDS settings, standard Fe500/Fe550-grade bars from reliable manufacturers remain both cost-effective and structurally sound.

Future work should prioritize long-term field trials focusing on chloride ingress, real-time corrosion monitoring, and fatigue behaviour. Deeper studies into coatings, alternative alloys, and environmental stress combinations will help guide refined material choices and more durable construction practices.

Reference

A. Kumar, K. Subedi, A. Kumar Mandal, D. Marasini, A. Budhathoki, and A. Khadka, "Quantitative Comparison of Grain Structure in Heat Treated, Nital-Etched Mild Steel and TMT Bars." [Online]. Available: https://www.researchgate.net/publication/391121993

M. B. Sk *et al.*, "Effect of microstructure and texture on the impact transition behaviour of thermo-mechanically treated reinforcement steel bars," *Mater Des*, vol. 90, pp. 1136–1150, 2016, doi: 10.1016/j.matdes.2015.11.053.

A. Bautista, J. C. Pomares, M. N. González, and F. Velasco, "Influence of the microstructure of TMT reinforcing bars on their corrosion behavior in concrete with chlorides," *Constr Build Mater*, vol. 229, Dec. 2019, doi: 10.1016/j.conbuildmat.2019.116899.

M. N. Bari and M. Mohshin, "Relationship Between Rate of Corrosion of TMT Bars and Quality of Electrolyte in Electrochemical Corrosion Process," in *Lecture Notes in Civil Engineering*, Springer Science and Business Media Deutschland GmbH, 2024, pp. 337–346. doi: 10.1007/978-981-99-3826-1_28.

P. Paudel, H. Lamichhane, and A. Pratap Baniya, "Identification of the Microstructure of TMT rebars and its
impact on Mechanical properties."

M. A. Islam, "Corrosion behaviours of high strength TMT steel bars for reinforcing cement concrete structures," in *Procedia Engineering*, Elsevier Ltd, 2015, pp. 623–630. doi: 10.1016/j.proeng.2015.11.084.

A. Gómez-Parra, F. J. Puerta, E. I. Rosales, J. M. González-Madrigal, and M. Marcos, "Study of the influence of cutting parameters on the Ultimate Tensile Strength (UTS) of UNS A92024 alloy dry turned bars," in *Procedia Engineering*, Elsevier Ltd, 2013, pp. 796–803. doi: 10.1016/j.proeng.2013.08.250.
© September and 2024| Ijirt |, "Accelerated Corrosion Test as a Method to Evaluate Corrosion of Rebar," 2024.

M. Dhongade, "Experimental Evaluation of Quality of TMT/QST Steel Bar by Using TM Ring Test," *Int J Res Appl Sci Eng Technol*, vol. 11, no. 5, pp. 3806–3811, May 2023, doi: 10.22214/ijraset.2023.52235.
L. Yu, R. François, V. H. Dang, V. L'Hostis, and R. Gagné, "Development of chloride-induced corrosion in pre-cracked RC beams under sustained loading: Effect of load-induced cracks, concrete cover, and exposure conditions," *Cem Concr Res*, vol. 67, pp. 246–258, 2015, doi: 10.1016/j.cemconres.2014.10.007.

V. Makarenko, V. Hots, A. Maistrenko, V. Azutov, and O. Chyhyrynets, "Features of reinforced concrete corrosion processes in aggressive environments and methods of corrosion protection of building structures," *Strength of Materials and Theory of Structures*, no. 114, pp. 255–264, Apr. 2025, doi: 10.32347/2410- 2547.2025.114.255-264.

M. A. Islam, "Corrosion behaviours of high strength TMT steel bars for reinforcing cement concrete structures," in *Procedia Engineering*, Elsevier Ltd, 2015, pp. 623–630. doi: 10.1016/j.proeng.2015.11.084.