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Microstructural and Mechanical Properties of TMT/QST Steel Bars for Concrete Applications

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A B S T R A C T

This dataset highlights the variability in cross-sectional phase distribution (CSPD) of thermo-mechanically treated (TMT) or quenched and self-tempered (QST) reinforcement bars (rebars or bars) available in the market. TM-Ring test data were collected from multiple locally available brands across a range of diameters (8 to 20 mm) to emphasize the significance of strict quality control during manufacturing, and to identify potential durability concerns, particularly in smaller diameter bars. The data also emphasizes the critical role of periodic maintenance of the Quenching Box nozzle assembly in ensuring consistent TM-Ring quality. Furthermore, the data reveals significant scatter observed in the tensile properties of Poor-Quality TMT/QST bars. Collectively, these insights aim to facilitate further research into the variability in quality among commercial bars, and the relationship between TM-Ring integrity, mechanical properties, and durability.

Keywords : *Concrete; quenched; Tempered Martensite; TMT/QST steel bar; ductility; durability*

1. Value of the Data

The compiled data constitutes a significant knowledge base for the manufacturers, specifiers, and users of TMT/QST bars, which would help achieve the target specifications in IS 1786 standard and microstructure phase distribution essential for achieving good resistance against corrosion resistance and bending-induced cracking.

2. Background

The transition from Cold Twisted Deformed (CTD) bars to TMT/QST technology since the 2000s has led to improved ductility. TMT/QST bars feature a distinct microstructure, comprising an outer ring of Tempered Martensite (TM) that imparts strength and an inner Ferrite–Pearlite (FP) core that provides ductility, resulting in a composite tensile behaviour (Nair, 2017) (Figure 1). Good quality bars exhibit a concentric and uniform TM-Ring (see Case A in Table 1), whereas poor-quality bars show eccentric or discontinuous TM phase at the periphery (see Cases B, C, and D in Table 1). Notably, the bars of small diameters (≤12 mm) frequently possess inadequate or discontinuous TM-Rings, which can result in surface cracking at bends (Figure 2) and increased susceptibility to crevice and chloride-induced corrosion, particularly for stirrups with lower cover concrete than the other bars in concrete structures (Nair et al., 2020). Also, a 2-year long study by Karuppanasamy and Pillai (2016) on chloride-induced corrosion of CTD and TMT/QST bars revealed that the overall corrosion rates could be similar (see Figure 3), if the TM-Ring or the cross-sectional phase distribution (CSPD) is inadequate as in Cases B, C, and D in Table 1 – thereby not reaping the full benefits of good TMT/QST steel bars.

The CSPD of TMT bars is highly sensitive to manufacturing parameters such as rolling speed, chemical composition, and heating–cooling rates (Markan, 2005). To ensure adequate CSPD, industry recommendations for manufacturers include: (1) maintaining controlled, synchronized, and uniform cooling rates during quenching to yield a hardened periphery up to 30 % of the total cross-sectional area and thus avoid excessive and non-uniform quenching, which can lead to high yield strength but poor ductility; and (2) periodic cleaning of the Quenching Box extrusion nozzle assembly to prevent non-uniformity in the TM phase at the periphery of the bars (Figure 4). Table 2 provides the typical manufacturing or process parameters used in steel rebar industry for quality control (data obtained from ARS Steels and Alloys International Pvt. Ltd., Chennai, India).

Also, the mechanical performance and durability of TMT/QST bars are highly dependent on the quality of TM-Ring, specifically its uniformity, continuity, and concentricity. International standards (NZ, JS, BS, BIS, ASTM) account for variations in yield stress arising from CSPD differences by specifying both minimum and maximum permissible values (Figure 5). Such upper-limit restrictions indirectly regulate the manufacturing process, preventing excessively hardened bars that may promote brittle failure in reinforced concrete applications. Also, this inadequacy in CSPD can lead to more scatter in the mechanical properties of TMT/QST bars. These issues are found to be more prevalent in smaller diameter bars than in larger diameter bars. Hence, it is utmost important to assess the TM-Ring on smaller diameter bars used as transverse reinforcement, which are usually having less concrete cover, to ensure durability. The following section discusses the materials and methods adopted in this data collection followed by a section on the description of data.

3. Materials and Methods

The TM-Ring test shall serve as a two-level technical acceptance criterion for evaluating the percentage area and uniformity of the TM-ring within the Cross-sectional Phase Distribution (CSPD) of TMT/QST steel bars. Performing this test can help ensure adequate heat treatment leading to proper tempering and enhanced durability performance.

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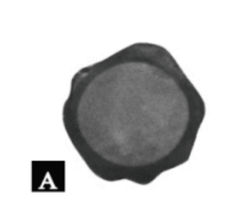
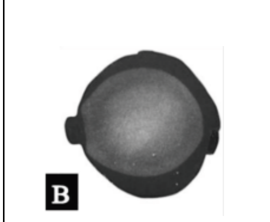
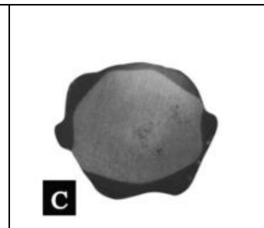
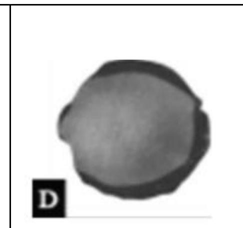
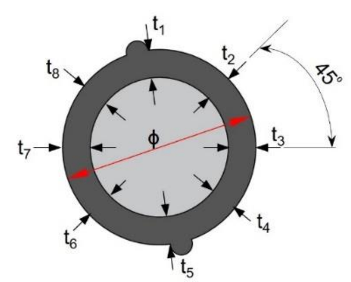
Table 1 Datasheet with the acceptance criteria of TMT/QST bars

Level 1: Visual analysis of etched cross-section				
				
	Acceptable	*Not acceptable*	*Not acceptable*	*Not acceptable*
1	Is a dark grey peripheral region and light grey core seen as in Case A?			Yes/No
2	Does the dark grey peripheral region form a continuous outer ring?			Yes/No
Level 2: Dimension analysis of TM-Ring thickness				
3	Diameter ϕ *(mm)* of steel bar			
4	Geometry 		t_1	
			t_2	
			t_3	
			t_4	
			t_5	
			t_6	
			t_7	
			t_8	
			Measured t_{min} *(mm)*	
			Measured t_{max} *(mm)*	
5	Is the measured $t_{min} \geq 0.05\ \phi$?		Yes / No	
6	Is the measured $t_{max} < 0.15\ \phi$?		Yes / No	

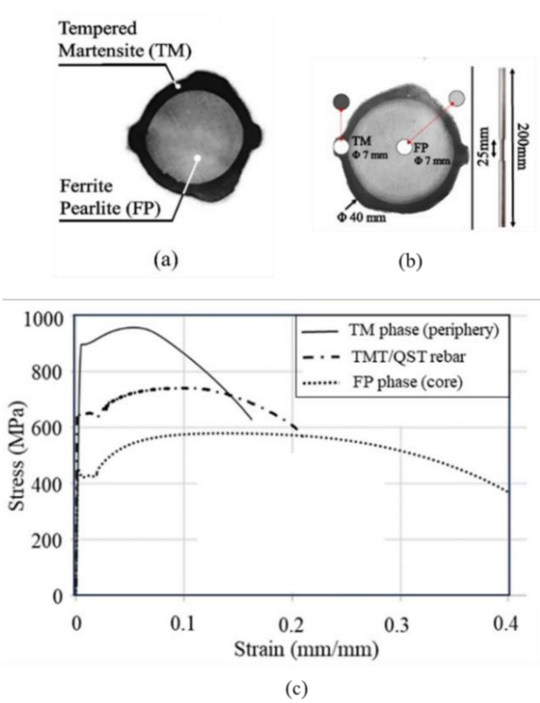


Figure 1 Composite nature of TMT/QST bars (a) Cross-sectional phase distribution (b) Sample extraction of TM and FP, (c) Stress-strain behaviour (adapted from Nair (2017))

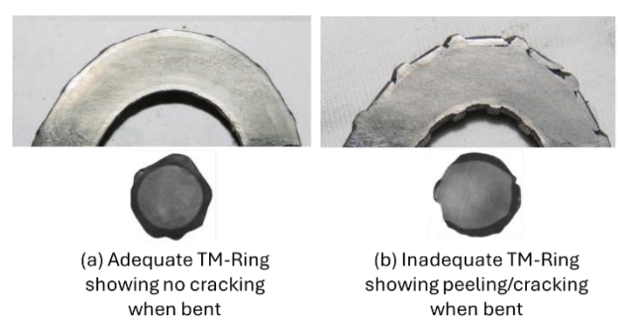


Figure 2 Bent TMT/QST bars

The test is relatively simple, reproducible, and suitable for both laboratory and on-site quality assessment of TMT/QST bars. It involves macro-etching the polished steel bar cross-section with a 5 % Nital solution (nitric acid in ethyl alcohol), where the use of ethyl alcohol (ethanol) ensures superior etching quality. The macro-etching part of TM-Ring test is followed by image acquisition (preferably with a magnification ratio of 1:1) and further analysis are carried out in two stages: Level 1 – Visual examination of the etched cross-section and Level 2 – Dimensional measurement of TM-ring thickness at eight critical locations including the root of ribs (where the susceptibility of chloride-induced corrosion is high), as detailed in Table 1.

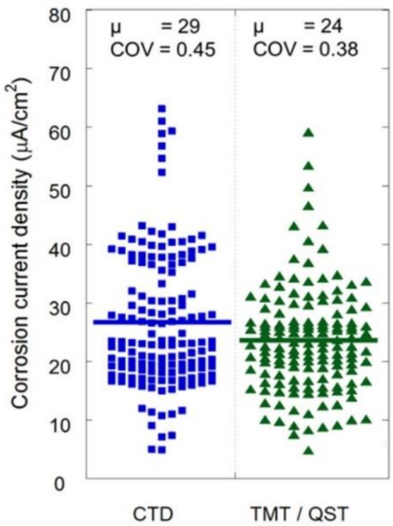


Figure 3 Corrosion rates of CTD and TMT/QST steel bars after about 1.5 to 2 years of chloride exposure (Karuppanasamy and Pillai, 2016)

Figure 4 Nozzle assembly used for spraying water onto the bar surface (Courtesy: ARS Steels and Alloy International Pvt. Ltd., Chennai, India)

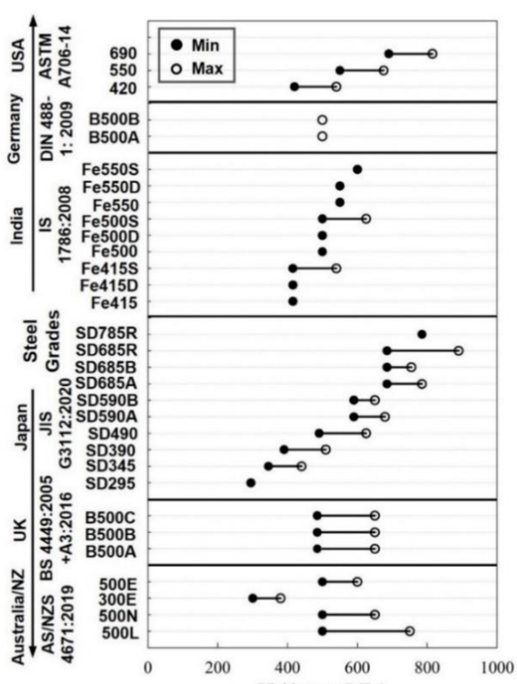


Figure 5 Minimum and maximum limits on yield stress of TMT/QST bars available in different international standards

4. Data Description

The dataset consists of steel bars of locally available brands of TMT/QST bars. The entire dataset is organised into the following domains:

1. TM-Ring test data of Fe550D steel bars ranging diameters from 8 to 20 mm collected from six commercially available brands (denoted as A to F) (Figure 6 and Table 3).
2. TM-Ring test data of Fe550D steel bars ranging diameters from 8 to 32 mm collected from one commercially available brand, which is being used as a quality control data (Figure 7 and Table 4).
3. TM-Ring image data before and after cleaning of nozzle assembly during the manufacturing of 12 mm diameter Fe550D TMT/QST bars (Figure 8).
4. 8 Tension test data of Good Quality (GQ) and Poor Quality (PQ) Fe500D TMT/QST bars of 12 mm diameter to substantiate its higher variability in the case of Poor Quality bars (Table 5).

5. Data Availability

[Microstructural and Mechanical Properties of TMT/QST Steel Bars for Concrete Applications](#)

6. Acknowledgement

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