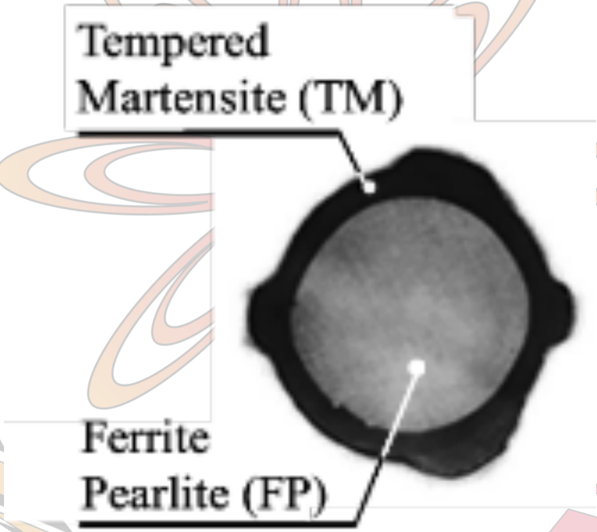
Lecture 3A
TM-Ring Test for assessing the quality of TMT / QST steel rebars



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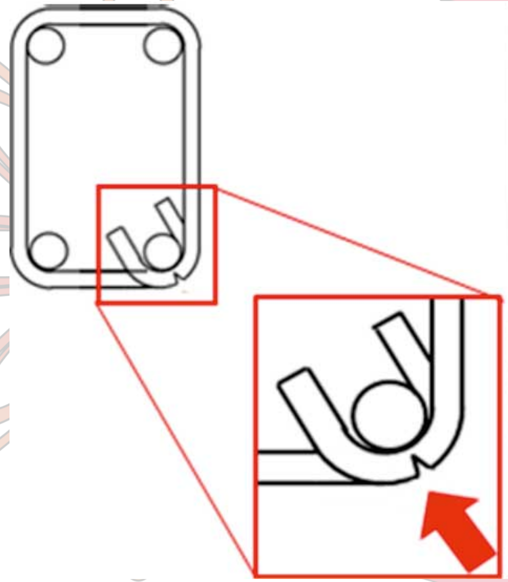
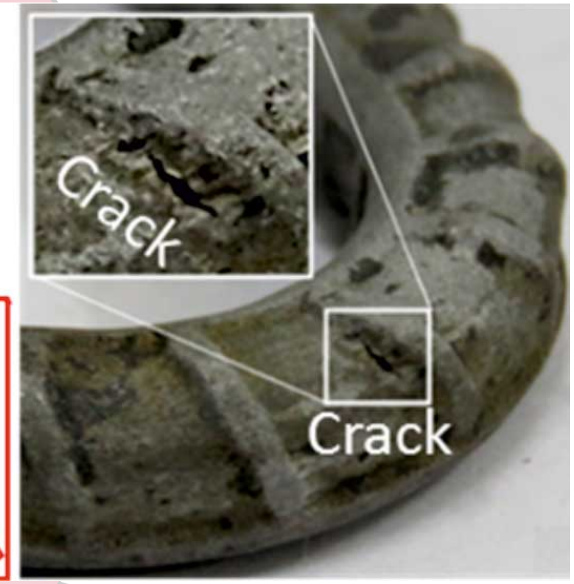
NPTEL – MOOC Course on Maintenance and Repair of Concrete Structures

Shear stirrups with a bend angle of 135°

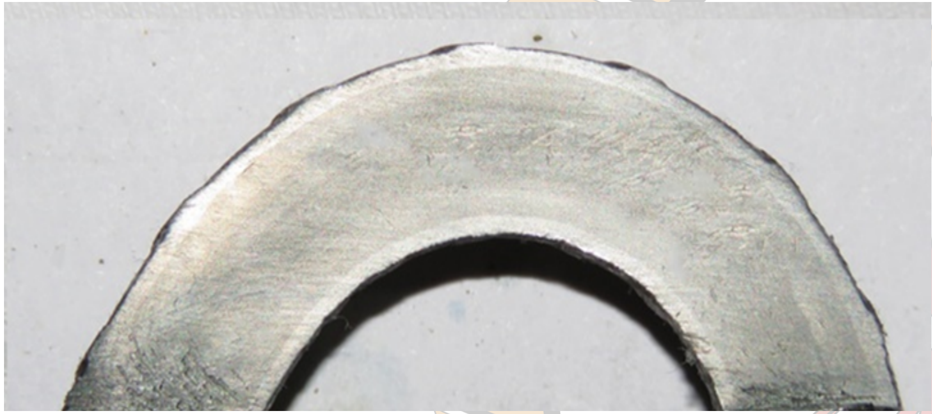




Must check the surface crack resistance if used for shear stirrups with a bend angle of 135°
(as in the case of earthquake resistant designs)

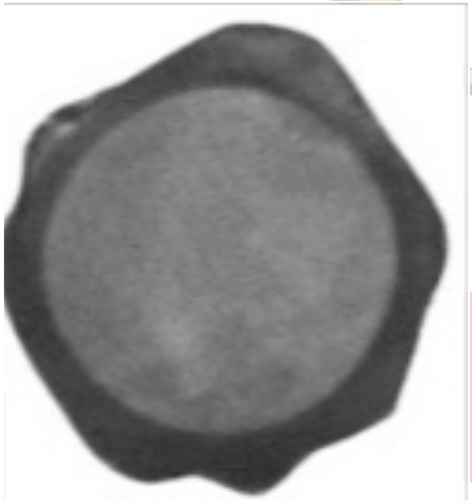
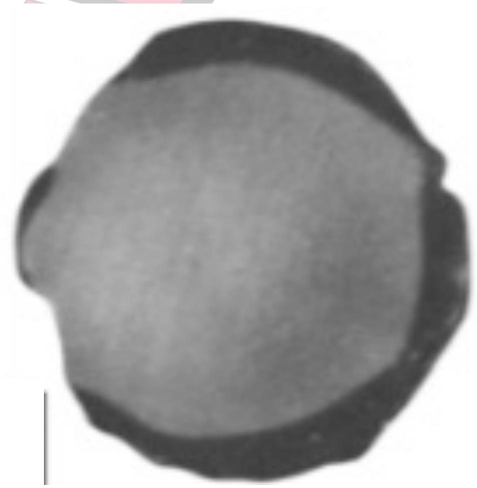
Nair and Pillai (2017), "TM-Ring test – A quality Control test for TMT (or QST) Steel reinforcing bars used in reinforced concrete systems," ICI Journal, April-June 2017

Poor TM-Ring can cause surface cracking

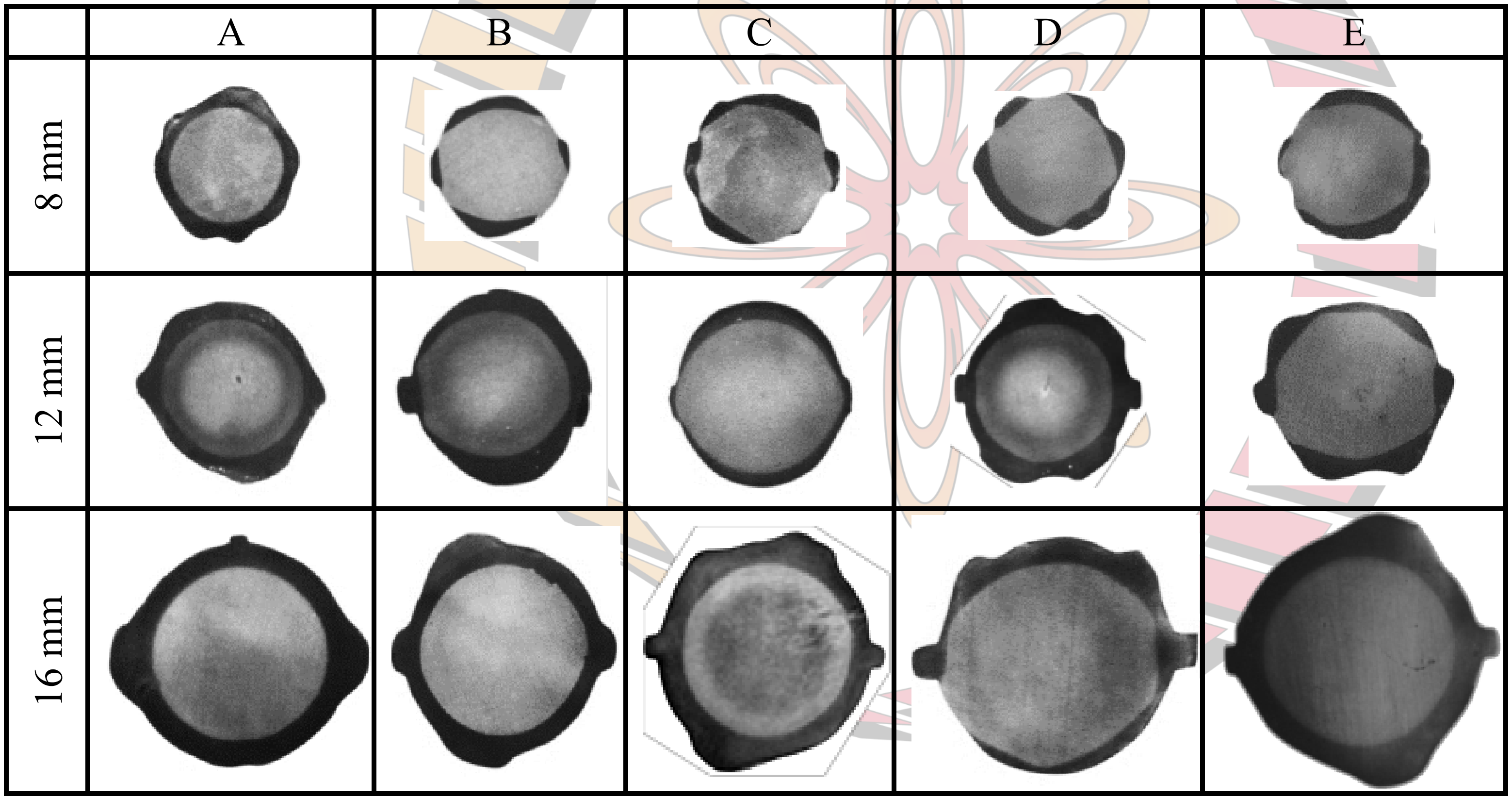


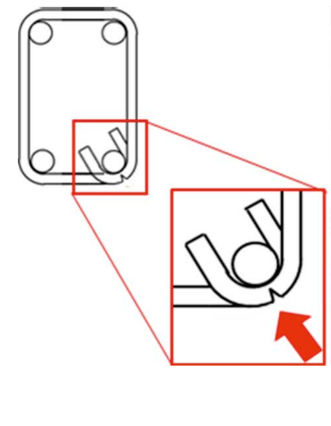

No cracking

Severe cracking

Rebars with discontinuities were observed predominantly in 8 and 12 mm diameter rebars (stirrups)





IS 1786 provides a “non-mandatory” specification to test the TM-ring in TMT rebars

ANNEX A

(*Foreword*)

INFORMATION ON CONTROLLED COOLING PROCESS

A-1 The processing of reinforcing steel is usually through one or combination of processes which may include hot rolling after microalloying, hot rolling followed by controlled cooling (TMT process) and hot rolling followed by cold work.

Heat treatment is a thermal process undergone by the steel in the solid state. The most common practice is finishing online heat treatment while rolling, commonly known as thermomechanical treatment (TMT) process. After leaving the last stand of the rolling mill, the bars are quenched (rapidly cooled) in water from a final rolling temperature of about 950°C. The quenching is partial, only until a surface layer has been transformed from austenite (a steel phase stable only at very high temperatures) to martensite (stable at temperatures below 350°C). This controlled quenching is achieved in one or more online water cooling devices through which the steel passes at a very high speed before reaching the cooling bed.

Because the quenching is only partial, a part of the original heat remains in the core of the steel and, on the cooling bed, this heat migrates towards the surface. This results in an automatic self-tempering process where the surface layer of martensite is tempered; this ‘tempering temperature’ (or equalization temperature) refers to the maximum temperature attained by the bar surface after quenching. Tempering enables a partial diffusion of carbon out of the extremely brittle but strong martensite, thus relieving the inherent stresses locked in during the sudden quenching of the red-hot steel in cold water. The resulting tempered-martensite shows improved deformability compared to the as-quenched martensite.

The core of the heat treated reinforcing bars/wires consist of ferrite and perlite – more ductile but less strong than the martensite. Computerized process control is used to dynamically adjust the many rapidly changing parameters depending on the chemical composition of the steel, the desired grade and size of the reinforcing bar/wire etc. For the larger diameters, small addition of microalloys is usual.

Sometimes it becomes necessary to determine if a particular reinforcing bar/wire, or lot, has undergone proper heat treatment or is only a mild steel deformed bar. Because the two cannot be distinguished visually, the following field test may be used for purposes of identification. A small piece (about 12 mm long) can be cut and the transverse face lightly ground flat on progressively finer emery papers up to ‘0’ size. The sample can be macroetched with nital (5 percent nitric acid in alcohol) at ambient temperature for a few seconds which should then reveal a darker annular region corresponding to martensite/bainite microstructure and a lighter core region. However, this test is not to be regarded as a criterion for rejection. The material conforming to the requirements of this standard for chemical and physical properties shall be considered acceptable.

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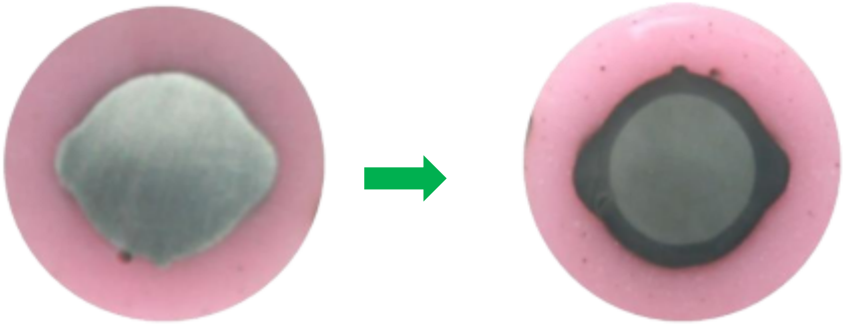
TM-Ring Test

- Ensure durability of steel
- Ensure proper heat treatment
- Easy and replicable
- Ideal for on-site qualification

- Macroetching
- Acceptance criteria



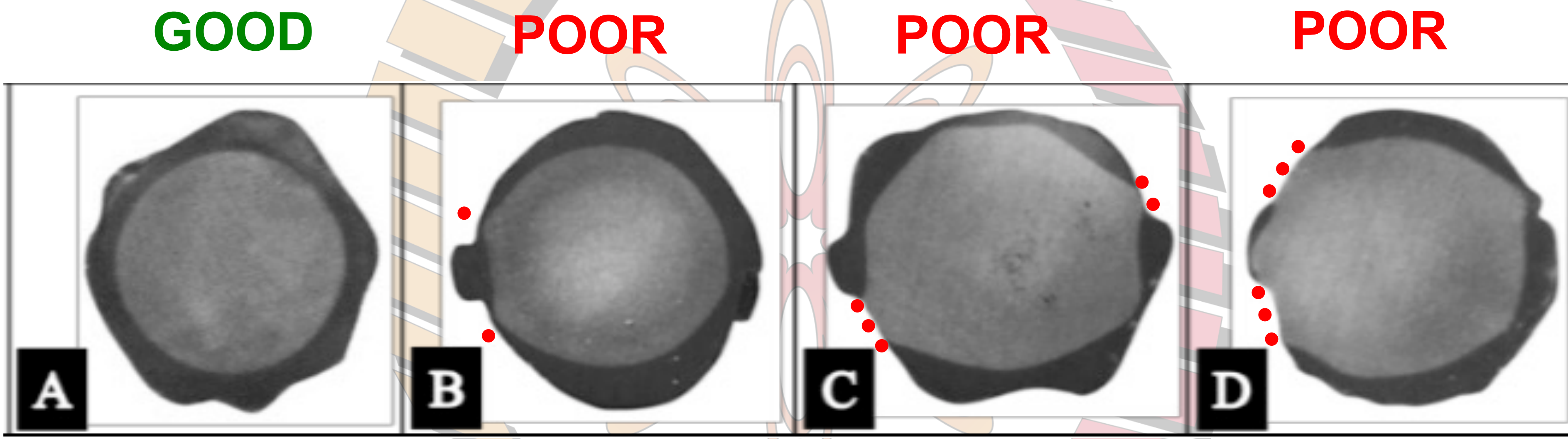
Components/Parts of the TM-Ring test

- Specimen embedded in contrasting cold setting epoxy
- Polished specimen (80-220 or 100 grit size)
- Nital solution (nitric acid, ethyl alcohol) 5% by volume
- Image acquisition setup
  - Lighting conditions (350-450 lux)
  - Adjustable platform

TM-Ring test procedure

- Collect 2-3 mL Nital solution using micropipette
- Deposit the solution on the cold mounted sample surface
- Wait for 3-5 minutes for etching
- Absorb excess solution using paper towel after etching
- Take photo for analysis and quantification

Identifying good and poor quality QST/TMT steel rebars



Red dots indicate the peripheral regions with imperfect TM phase.

Better quality control of TMT steel is essential and possible through regulations and more awareness

Nair and Pillai (2017), "TM-Ring test – A quality Control test for TMT (or QST) Steel reinforcing bars used in reinforced concrete systems," ICI Journal, April-June 2017

Datasheet for acceptance criteria

'TM-Ring Test' – A Quality Control Test for TMT (or QST) Steel Reinforcing Bars Used in Reinforced Concrete Systems

Sooraj A. O. Nair and Radhakrishna G. Pillai

Abstract

The Thermo-Mechanically Treated (TMT) steel is commonly referred to as Quenched and Self-Tempered (QST) steel. The cross-section of good TMT/QST steel reinforcing bars (rebars) is required to have a ductile core of 'ferrite-pearlite' (FP) and a continuous, uniformly thick, and hard 'tempered martensite' (TM) microstructure as the peripheral ring. However, recent studies on TMT/QST steels in the Indian market show the presence of discontinuous, eccentric, and non-uniform TM-phases at the periphery, which can be attributed to the improper quenching. This could result in localized corrosion and variations in the mechanical properties. Although IS 1786: 2008 mentions the etching of steel to identify the microstructural phases, it is an incomplete (lacks necessary test protocols; leads to unreliable results) and non-mandatory provision given in the annexure. In this scenario, a standardized test is essential to assess the quality of TMT/QST steel rebars. This paper fine-tunes and proposes the "TM-ring test" to characterize the cross-sectional phase distribution in TMT/QST rebars. In particular, the details on specimen extraction, preparation, testing and analysis, which are crucial to obtain reproducible and reliable results, and a 2-level acceptance criteria for TMT/QST rebars are provided for further incorporation in the standard specifications.

1 Introduction

The steel market has grown tremendously over the decades and has been meeting the demand for better mechanical and corrosion performance. The need for both high strength and ductility led to the evolution of mild steel to Cold Twist Deformed (CTD) steel rebars, and then to Thermo Mechanically Treated (TMT) steel by the 1990s (Viswanatha 2004). TMT steel rebars are used in other countries as well and known by the name of Quenched and Self-Tempered (QST) steel. In the strict technical sense, TMT could refer to a range of steel products that undergo a thermal and mechanical processing in the manufacturing line like QST, Ultra Fine Grained (UFG), Dual Phase (DP) and Transformation Induced Plasticity (TIP) steels (Islam 2010). The term TMT came from the common usage during its earlier days in the Indian steel market and is being continued thereafter. In this paper, the term TMT/QST is used to refer the TMT steel rebar.

The schematic of QST process is shown in Figure 1 (Varghese 2005). Better mechanical performance at reduced production cost can be achieved through quenching and self-tempering (QST) over cold-hardening or micro-alloying (Augusti 1995). This makes TMT/QST steel rebars being widely used in India today. The cross-section of a typical TMT/QST steel rebar cross-section is given in Figure 2. The QST process is supposed to form a composite cross-section of a hard peripheral ring of tempered martensite (TM) and a soft ductile core of ferrite-pearlite (FP) microstructures in a TMT/QST steel rebar. The hard outer ring and soft inner core are predominantly responsible for the high strength and ductility, respectively, of TMT/QST steel rebar.

1.1 Manufacturing Technology for TMT/QST rebars

The quenching and self-tempering processes are employed in the manufacturing line with the help of various cooling technologies. These patented technologies like Tempcore™, Thermex™, Stelmor™, Thermoquench®, Evcon Turbo™ etc. essentially have a cooling system, which uses air, water, or both at specified temperatures and flow rates. Noville (2015) discusses about the effect of the quenching parameters (line speed, water temperature, quenching time, etc.) on the microstructure and mechanical properties TMT/QST

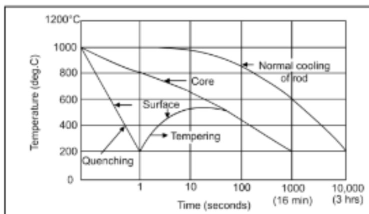
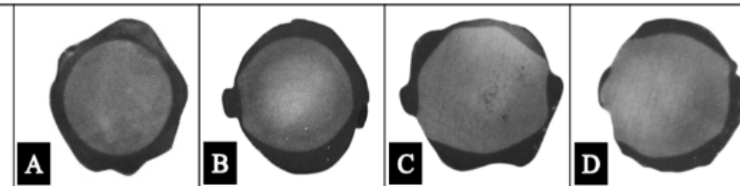


Fig. 1 Schematic of a QST process (Varghese 2005)

Keywords: Concrete, Steel Rebar, TMT, QST, Martensite, Ferrite, Pearlite, Quenching, Tempering, Etching, Quality Control

Datasheet for 'TM-Ring' test

REFERENCE CASES



	A				B				C				D			
L1	Y	Y	Y	Y	Y	Y	N	N	Y	N	N	N	Y	N	N	N
L2	Y		Y		-				-				-			
	Accepted				Rejected				Rejected				Rejected			

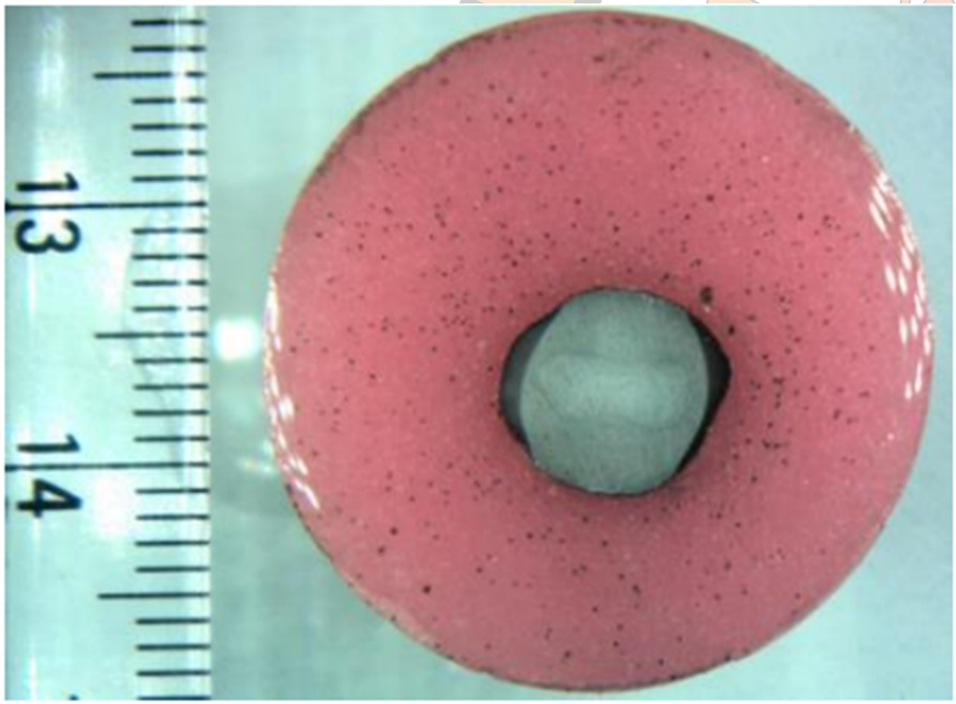
LEVEL 1 (L1) ACCEPTANCE CRITERIA

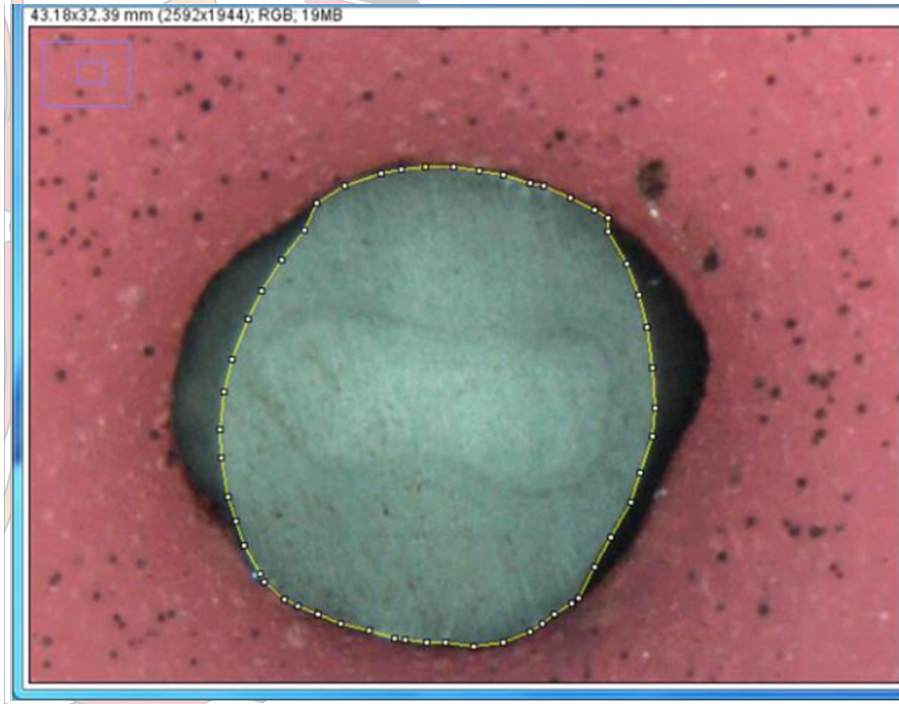
No.	Question	Answer (circle one)
1	Is a dark grey peripheral region and light grey core seen?	Yes / No
2	Does the dark grey peripheral region form a continuous outer ring?	Yes / No
3	Are the dark grey peripheral region and light grey core concentric?	Yes / No
4	Is the thickness of the dark grey peripheral region uniform?	Yes / No
Decision		
If all the answers are **'Yes'**, then accept the rebar lot		
If any one or more answers are **'No'**, then reject the rebar lot		

LEVEL 2 (L2) ACCEPTANCE CRITERIA

No.	Observations	in mm
1	Diameter of rebar, D	
2	Measured thickness of TM, t_{TM}	
No.	**Question**	**Answer (circle one)**
1	Is $t_{TM} \geq 0.07$ D ?	Yes / No
2	Is $t_{TM} \leq 0.10$ D ?	Yes / No
Decision		
If all the answers are **'Yes'**, then accept the rebar lot		
If any one or more answers are **'No'**, then reject the rebar lot		

Quantification of TM-Ring





Area of TM expected to be between >30% and <50% to avoid under/over quenching