Comparative study of Microstructure and Properties of As received, Heat treated and Welded TMT bars of different companies

A thesis submitted in the partial fulfillment of the requirements for the award of degree of Master of Technology in Material Engineering

Submitted By

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Declaration of originality and Compliance of Academic Ethics

I do hereby solemnly declare that this thesis "**Comparative study of Microstructure and Properties of As received, Heat treated and Welded TMT bars of different companies**" contains literature survey and original research work by the undersigned candidate under the supervision of Prof. Akshay Kumar Pramanick,Department of Metallurgical and Material Engineering,Jadavpur University,Kolkata,India as a part of my M.Tech degree in Material Engineering during academic session 2021-2023. All information in this document has been obtained and presented inaccordance with academic rules and ethical conduct.To the best of my knowledge and belief,this work has not been presented for any degree or distinction under any other university.

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CERTIFICATE

This is to certify that the thesis entitled "**Comparative study of Microstructure and Properties of As received, Heat treated and Welded TMT bars of different companies"** has been carried out by Nirban Bera (Examination Roll:M4MAT23007 and Registration No. 160306 of 2021-2022) under my guidance and supervision and accepted in partial fulfillment for the degree of Master of Technology in Material Engineering from Jadavpur University. To the best of our knowledge the contents of this thesis or any part thereof have not been previously submitted for the award of any degree or diploma.

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Certificate of Approval

The forgoing thesis "**Comparative study of Microstructure and Properties of As received, Heat treated and Welded TMT bars of different companies"** by Nirban Bera is hereby approved as credible study of an engineering subject carried out and represented in a manner satisfactorily to warrants its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinion expressed or conclusion drawn therein but approved the thesis only for which it has been submitted.

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Evaluation of Thesis

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ABSTRACT

Thermo Mechanically Treated bar has a lot of importance in modern day's construction technology.We are using TMT bar to make monstrous buildings to heavy bridges throughout the world in various climatic condition(variation of temperature and humidity).This thesis paper attempts to find variation of microstructure configuration of different tmt bar samples (tata tiscon,srmb,captain) in metallography laboratory and Hardness variation of tmt bar samples(tata tiscon,srmb,captain) from it's core to peripheral region by VICKER'S Hardness test method and VICKER'S micro hardness test method in our hardness test laboratory. We have tried to examine corrosion behavior of the samples in both fresh water and marine water via corrosion penetration method to determine the change of corrosion penetration rate with the change of salinity. It was attempted to heat treatment(air cooling and quenching in water) to demonstrate the micro structural change(by metallography), hardness change(by VICKER'S hardness number) and corrosion behavior change(by corrosion penetration method).By observing the result we can make some comparison how their micro structural behavior ,hardness number and corrosion behavior changes with various temperature and climatic condition. At the last we have made attempt to examine the heat treated zone microstructure of weldedtmt bar, how it changes from welding zone to head treated zone(HAZ) and heat treated zone(HAZ) to parent zone.

INTRODUCTION

TMT bars or Thermo-Mechanically Treated bars are high-strength reinforcement bars having a hard outer casing and a soft inner core. Thermo-Mechanically Treated bars or TMT bars are widely used for different construction projects. Made from high strength steel, TMT bars possess several qualities that make them the most preferred material for various construction projects.

With a unique metallurgical process that combines work hardening along with heat-treatment to create robust and high strength bars from low-carbon steel, TMT bars have a great demand.

TMT bar has been used for many years in structural applications because of its good combination of various mechanical properties like ductility,toughnes ,high strength,corrosion resistance . As per recent concept to reduce steel consumption in reinforced cement concrete (RCC) structures, designers recommend high strength steel bars. There are various routes for their production such as microalloying, thermomechanical treatment, cold working, etc. For steel bars of thermomechanical treatment (TMT) route, some designers believe these steel bars to be more sensitive to corrosive environment.

It is used for many decades in structural and engineering purposes both in land and marine environments because of its good combination of mechanical properties. The main problem of structural steel is its corrosion by various environmental species like water vapour,humidcondition,acid rain in terrestrial region.In marine environment the reasons are high salinity of marine water,high velocity of current,high impact of particles within current and various reaction with different chemical species.

Thermo-Mechanically Treated Bars (TMT Bars), are Extra High Strength Reinforcing bars which replaced any form of cold twisting, the technology of yesteryears. In this process, the steel TMT bars receive a short, intensive cooling as they pass through the specially designed Tempcore Water Cooling System after the last Rolling Mill Stand. The sudden quenching converts the surface layer of the steel bar to a hardened structure.

This phase of intensive cooling by the Tempcore System is followed by further cooling in atmosphere, so that the temperature between the core (which is steel hot) and the cooled surface layer is equalized, and the surface layer gets tempered by the heat from the core. The resulting structure is a tempered martensite zone at the periphery and a fine grain ferrite pearlite structure in the central zone.

Literature Review

For an effective output in any research field, literature review plays a vital role for foundation of the future work. So the purpose of this chapter is to record briefly the established knowledge and the findings of earlier researches, conducted on related problem areas.

What is TMT bar?

Thermo-Mechanically Treated Bars (TMT Bars), are Extra High Strength Reinforcing bars which replaced any form of cold twisting, the technology of yesteryears. In this process, the steel TMT bars receive a short, intensive cooling as they pass through the specially designed Tempcore Water Cooling System after the last Rolling Mill Stand. The sudden quenching converts the surface layer of the steel bar to a hardened structure.

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Technical Description Breakdown

Fe 415 grade

Fe 415 grade was the first innovation in TMT series which replaced conventional CTD(cold twisted deformed) bars with much better yield strength ductility and elongation. The journey of modern day construction steel started with the introduction of Fe-415 grade TMT bars.

Features of Fe 415 grade TMT Bars are as follows

0.2% Proof Stress / YS (N/mm²) Max=415

Tensile Strength (N/mm2) Min=485

Elongation %=14.5

Fe-415 D

The D variety of TMT bars were introduced by BIS in their latest armament in the year 2008. This category of TMT Bars demonstrate higher tensile strength and ductility on and above normal grade TMT bars. The D variety TMT bars are manufactured through special category of billets and critically controlled thermal treatment during manufacturing process. The best partof the D variety TMT bars is these are the ideal product for earthquake resistance and totally free of mechanical fatigue.

Features of Fe 415 grade TMT Bars are as follows

0.2% Proof Stress / YS (N/mm^2) Max= 415

Tensile Strength (N/mm2) Min= 500

Elongation %= 18

Fe 500 Grade

Fe 500 grade TMT Bars were introduced as an one step up technological marvel over conventional fe 415 grade product . The superior tensile strength in Fe 500 TMT bars resulted in approximately 17% lesser consumption in steel in construction.

Features of Fe 500 grade TMT Bars are as follows

0.2% Proof Stress / YS (N/mm^2) Max= 500

Tensile Strength (N/mm2) Min= 545

Elongation %= 12

Fe 550 Grade and Fe 600 grade

Fe 550 grade & Fe 600 grade TMT Bars were introduced to further increase the technical excellence of TMT bars and propensity of consumption of steel in construction projects drastically got reduced due to much higher tensile strength and load bearing capabilities of these technologically superior grade of TMT bars .Gradually the structural engineer fraternity is inclining towards these high end TMT Bars.

Features of Fe 550 & Fe 600 grade TMT Bars are as follows

Fe 550 Grade

0.2% Proof Stress / YS (N/mm^2) Max= 550

Tensile Strength (N/mm2) Min= 600

Elongation %=14.5

Fe 600 Grede

0.2% Proof Stress / YS (N/mm²) Max= 600

Tensile Strength (N/mm2) Min= 660

Elongation %=10

CRS TMT BAR

CRS(corrosion resistance steel) TMT Bar is produced by adding alloying elements like Cr, Cu, Ni, Mo and P, either individually or in combination, to improve allied product properties. In the Electric Furnace, corrosion resistant elements like phosphorus, copper/chromium are added to the molten steel, while carbon and sulphur is reduced further through refining and deslagging. The microalloyed molten steel are then casted into billets and rolled in a controlled quenching and tempering process to impart the desired corrosion resistant properties to the end product.

Deterioration of reinforced concrete by corrosion of the carbon steel reinforcing bars (Rebars) is a worldwide problem. The corrosion product (rust) occupies a greater volume than the original steel bar and this creates a pressure which causes cracking and subsequent bleeding of the surrounding concrete.

Corrosion of carbon steel rebars is greatly accelerated when chlorides are present in the concrete (coupled with requisite moisture and oxygen levels to sustain the corrosion reactions). This situation gets aggravated in constructions at the coastal areas due to inherent extra salinity in its surroundings.

However, there is increasing interest in the use of reinforcing materials that have inherently good corrosion resistance, thus minimizing the need for maintenance and monitoring of the structure. Faced with the problems of costly repair / replacement of important structures, the governing authorities are increasingly demanding a greater emphasis on Life Cycle Costs for new construction projects, as opposed to considering only the initial capital costs.

Billets manufactured from steel containing desired quantities of Copper and Chromium / Copper and Phosphorus having inherent corrosion-resistant properties are used for hot-rolling of CRS TMT rebars. The bars then undergo controlled quenching and tempering to impart the desired corrosion-resistant properties to the end production.

Super Ductile Reber

Super ductile TMT reinforcing steel bars are commonly used these days for RC construction given there excellent thermal properties. SD TMT rebars are superior due to their distinct cross-sectional phase distribution (CSPD) of martensite, bainite, and pearlite..

In ductile irons, graphite is in the form of nodules rather than flakes as in grey iron. Whereas sharp graphite flakes create stress concentration points within the metal matrix, rounded nodules inhibit the creation of cracks, thus providing the enhanced ductility that gives the alloy its name.

Ductility is the ability of the TMT bar to be elongated without loosing its strength. Ductility in TMT Bar is more important because it determines how much it can bend as per the construction requirement.

The rebars available in Indian market are ductile steel with elongation percentage of 12% and utilization ratio of 1.12. There is a new grade of steel which has elongation percentage of 18% and utilization ratio of 1.15. This new grade is called super ductile.

A brief definition of all the terms defining the mechanical properties of super ductile rebars

YS – (Yield Stress) is the stress at which a 0.2% of plastic deformation is produced in steel rebar in tension.

UTS – (Ultimate Tensile Stress) is the maximum amount of stress sustained by a rebar in a tensile test before rupture.

Utilization ratio is the ratio of UTS and YS.

% Elongation is the ratio of total elongation of rebar and its original length expressed in percentage.

Utilization ratio and % Elongation together gives an estimate of amount of energy absorbed by the rebar specimen in a tensile strength before failure.

Manufacturing Process of TMT Bars

TMT bars are one of the essential parts of all types of construction. TMT bars so flexible and ductile to be considered as one of the integral parts of construction.To know this, we need to understand how the best quality TMT bars are manufactured in India.
TMT Bar stands for Thermo Mechanically Treated bars and passes through a set of processes that determine the flexibility and strength of the TMT Bars.

The quality of TMT bars depends on various factors such as:

The equipment used for the self-tempering and quenching process.
The used material quality and
The rolling mill shapes material.

Steps Involve in the Manufacturing Process of TMT Bars:

Iron Ore/Raw material to Billet:

The raw material is placed in the furnace and treated with hot gas while in its liquid form. The molten state of iron is pre-processed and converted into steel. The liquid form of steel is then poured into a casting machine to get the billets. At this point, the iron ore gets purified, and all the impurities get accumulated in the form of slag.

Conversion of Billets to steel:

Once the billets attain desired rolling temp it is ejected from the furnace. Then with the help of a rolling conveyor, these billets are made to pass through 1 stand i.e.Roughing stand. Temperature prior to rolling is also monitored by St optical pyrometer. This begins the process of gradual size reduction of billets. Following roughing mill, the size is further reduced in intermediate & finishing Mill. This gradual reduction is an important factor to ensure the finer grain structure of the bar. The rolling continues till the required size is achieved with the help of Roller Bearing Fitted roll, it prevents any unnecessary deformation of the bar. The loop scanners in the flow of the bar ensure a perfectly tensionless rolling process & result in the perfectly round shape of the bar. The surface characteristics of the steel are finalized in this section only.

Thermo Mechanical Treatment:

Thermo Mechanical Treatment is the final step in the manufacturing process of the TMT bar. It

involves three sub-steps.
These three essential steps are:

Quenching
Self Tempering
Atmospheric cooling

Quenching: The process of quenching is intended to provide the hardness and ductility to the steel bars and assure the right and desired properties. As the hot rolled steel bars come out from the mill, they enter into a water spray system called 'Thermex System'. In this process, the temperature of the outer layer of the steel bars decreases rapidly, which leads to hardening it, while the inner core remains hot and flexible. The entire process is called 'quenching' of the TMT bars.

Self-tempering: After the quenching process of the bar, the material cools down and the core of the bar is at a higher temperature than the outer surface. The heat is transferred from the core to the outer surface, as a result, the outer structure is get tempered. This causes a flow of temperature from the core to the outer surface area which creates the structure called 'Tempered Martensite'.

Atmospheric cooling: In this process, TMT bars are put on a cooling bed, where bars are arranged to be cooled at the normal atmospheric temperature, during this austenitic core of the bars turns into a ferrite-pearlite structure. This step makes sure that the tensile strength of the bar develops weldability. During this, the austenitic core of the bars turns into a ferrite-pearlite structure.

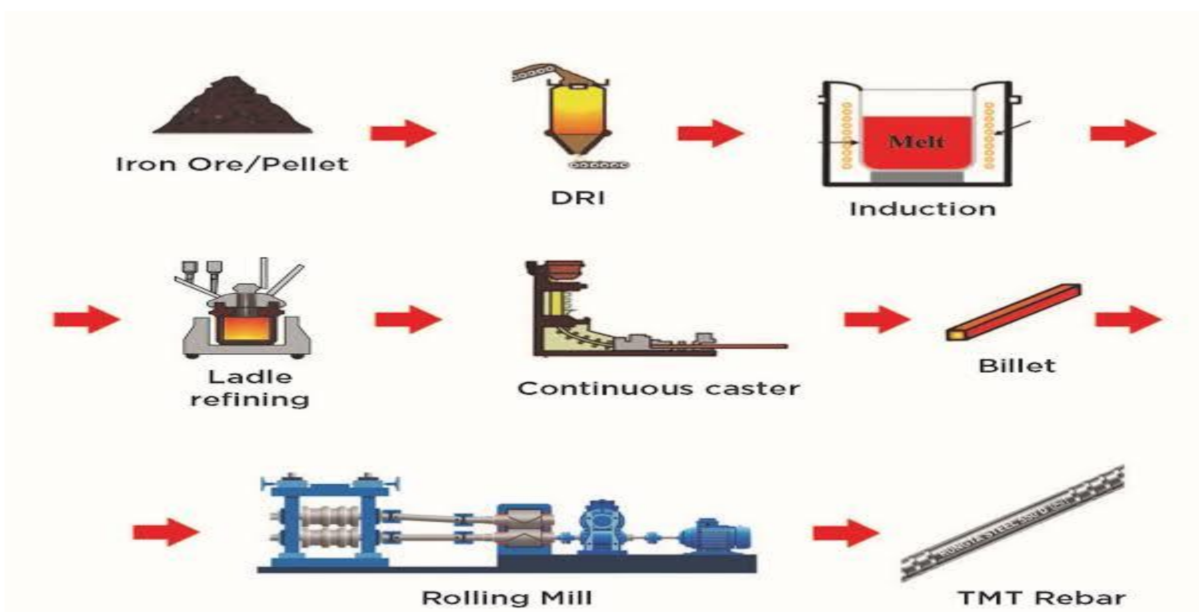


Figure 1: manufacturing process of tmt bar

Seismic requerment of TMT bars

Seismic demands on a reinforced concrete structure under a massive earthquake are enormous. Modern limit sate design principles allow deliberately for controlled damage of the structure to occur. This design principle allows for economic building and no to very low damage for the standard earthquake and controlled but not catastrophic damage in the case of a very severe earthquake.

In order to achieve the required plastic deformation under high earthquake loads, for seismic grade reinforcement bars limits are set not only for the yield strength, but also for the UTS to yield stress (YS) ratio in both directions. The minimum value of the ratio UTS/YS is to ensurethat yielding will not be confined to where it first commences, thereby permitting greaterelongation of the bar before fracture and hence greater ductility of the structural member. The maximum value is to ensure that when the steel commences to strain harden the stress in the bar does not lead to a significant over strength of the structural member. This is important for the applied capacity design procedure to work, which is intended to ensure an appropriate balance of capacity of members and failure modes securing satisfactory post elastic (plastic) behaviour in a major earthquake.

The guiding principle for the welded connection is that the weld should have sufficient tensile strength for not to be the weakest link. However the weld should also contribute to the deformation requirements and therefore the weld should provide yielding close to the yield of the parent bar combined with acceptable elongation. As a result the minimum value for the tensile to yield ration UTS/YS has been set as also being valid for the welded region. However, following the rule that the tensile capacity of the welded region should exceed the tensile capacity of the bar, there is no maximum limit for UTS/YS set for the welded joint.

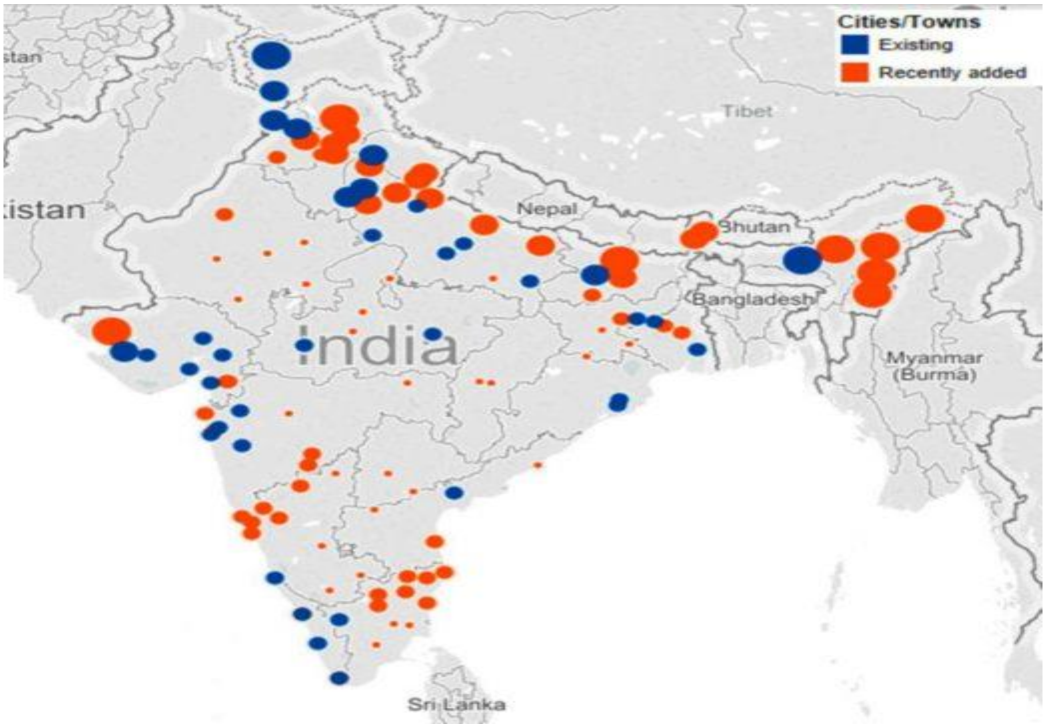


Figure 2: seismic zones in India.

Very severe intensity zone

Entire northeastern India, parts of Jammu and Kashmir, Himachal Pradesh, Uttaranchal, Rann of Kutch in Gujarat, parts of North Bihar and Andaman & Nicobar Islands.

Severe intensity zone

The remaining parts of Jammu & Kashmir and Himachal Pradesh, Union Territory of Delhi, Sikkim, northern parts of Uttar Pradesh, Bihar and West Bengal, parts of Gujarat and small portions of Maharashtra near the west coast and Rajasthan.

Advantages of using TMT bar

Super Ductility: TMT bars are made more ductile through a special chemistry and post rolling treatment. This enhances the gap between yield strength and ultimate tensile strength. They offer superior properties with respect to percentage elongation and (UTS/YS) ratio compared to the specifications and in line with the international standards of high ductile specialty rebars. The uniform elongation ensures that even after large plastic deformation ,therebars do not start necking(a phenomenon which initiates ultimate failure).

Thus super ductile rebars possess a tremendous capacity to absorb energy beyond the yield limits and resist collaps of structures during earthquakes.

Resistant to Earthquakes: TMT bars are resistant to earthquakes thanks to their soft pearlite core. Because of this, they can bear seismic and dynamic loading. TMT bars boast of high fatigue resistance to seismic loads because of high ductility and therefore they are widely used in earthquake prone areas.

Great Ductility and Bend Ability: One of the distinct advantages of using TMT bars is that they have great ductility and bend ability properties. Because of this, one can create pre-welded meshes that are used to eliminate the need of manual binding. This brings down construction and fabrication time.

Resistant to Corrosion: The TMT process gives these bars anticorrosive properties. These bars undergo controlled water-cooling process that resists formation of coarse carbides. Coarse carbides are the main reasons for the corrosive nature of a common bar. Absence of surface stresses is another reason for these bars to be corrosion resistant. Thus, using them increases the longevity of a structure.

Great Bonding Strength: Another major advantage of TMT bars is their superior bonding strength. There are external ribs running across the entire length of these bars and this fosters great bonding strength between the concrete and the bar. Fire resistant: Fire safety of a structure is one of the primary concerns for engineers and residents. TMT bars boast of high thermal stability and can resist temperatures ranging from 400 to 600 degrees Celsius. Thus, they are perfect for resisting fire and provide safety.

Fine Welding Features: TMT rebars (having low carbon content) can be used for butt and other weld joints without reduction in strength at the weld joints.

Cost-Effective and Malleable: High tensile strength and better elongation make these bars highly cost-effective than normal bars. They are easy to transport and malleable.

VICKERS HARDNESS TEST

The Vickers hardness test uses a square-base diamond pyramid as the indenter. The included angle between opposite faces of the pyramid is 136°.

The diamond-pyramid hardness number (DPH), or Vickers hardness number (VHN, or VPH), is defined as the load divided by the surface area of the indentation. In practice, this area is calculated from microscopic measurements of the lengths of the diagonals of the impression. The DPH may be determined from the following equation.

$VHN=2P\sin(\Theta/2)\div D2$.

where P = applied load IN kg.

D = average length of diagonals in mm.

Θ = angle between opposite faces of diamond = 136°.

Very Hard materials (e.g. Mild steel, case hardened steel, etc,) can be tested by the Vickers' method. If the moderately hard materials like Brass, Copper and Aluminum are tested in this machine, the indentor makes a deep impression. Hence, a proper indentation cannot be made on the specimen and correct value of the hardness cannot be obtained for these materials by VICKER'S Hardness test.

Corrosion behaviours of high strength TMT steel rebars

Steel has been used for many decades in structural applications because of its good combination of mechanical properties. As per recent concept to reduce steel consumption in reinforced cement concrete (RCC) structures, designers recommend high strength steel bars. There are various routes for their production such as microalloying, thermomechanical treatment, cold working, etc. For steel bars of thermomechanical treatment (TMT) route, some designers believe these steel bars to be more sensitive to corrosive environment.

Deteriorative mechanisms are different for the three material types. In metals, there is actual material loss either by dissolution (corrosion) or by the formation of nonmetallic scale or film (oxidation). Ceramic materials are relatively resistant to deterioration, which usually occurs at elevated temperatures or in rather extreme environments; the process is frequently also called corrosion. For polymers, mechanisms and consequences differ from those for metals and ceramics, and the term degradation is most frequently used. Polymers may dissolve when exposed to a liquid solvent, or they may absorb the solvent and swell; also, electromagnetic radiation (primarily ultraviolet) and heat may cause alterations in their molecular structures.

Corrosion is defined as the destructive and unintentional attack on a metal; it is electrochemical and ordinarily begins at the surface. The problem of metallic corrosion is significant; in economic terms, it has been estimated that approximately 5% of an industrialized nation's income is spent on corrosion prevention and the maintenance or replacement of products lost or contaminated as a result of corrosion reactions. The consequences of corrosion are all too common. Familiar examples include the rusting of automotive body panels and radiator and exhaust components.

ELECTROCHEMICAL PROCESS OF CORROSION

For metallic materials, the corrosion process is normally electrochemical, that is, a chemical reaction in which there is transfer of electrons from one chemical species to another. Metal atoms characteristically lose or give up electrons in what is called an oxidation reaction. For example, a hypothetical metal M that has a valence of n (or n valence electrons) may experience oxidation according to the reaction.

Oxidation

$M \rightarrow M^{n+} + ne^{-}$

In which M becomes annpositively charged ion and in the process loses its n valence electrons; e is used to symbolize an electron.

Reduction

The electrons generated from each metal atom that is oxidized must be transferred to and become a part of another chemical species in what is termed a reduction reaction. For example, some metals undergo corrosion in acid solutions, which have a high concentration of hydrogen (H) ions; the Hions are reduced as follows

$2H^{2+} + 2e^{-} \rightarrow H_2$

Types of Corrosion

It is convenient to classify corrosion according to the manner in which it is manifest. Metallic corrosion is sometimes classified into eight forms: uniform corrosion, galvanic corrosion, crevice corrosion, pitting corrosion, intergranular corrosion, selective leaching, erosion–corrosion, and stress corrosion.

Heat treatment

Heat treatment is a group of industrial, thermal and metal working processes used to alter the physical, and sometimes chemical, properties of a material. The most common application is metallurgical. Heat treatments are also used in the manufacture of many other materials, such as glass. Heat treatment involves the use of heating or chilling, normally to extreme temperatures, to achieve the desired result such as hardening or softening of a material. Heat treatment techniques include annealing, case hardening, precipitation strengthening, tempering, carburizing, normalizing and quenching. Although the term heat treatment applies only to processes where the heating and cooling are done for the specific purpose of altering properties intentionally, heating and cooling often occur incidentally during other manufacturing processes such as hot forming or welding.

Metallic materials consist of a microstructure of small crystals called "grains" or crystallites. The nature of the grains (i.e. grain size and composition) is one of the most effective factors that can determine the overall mechanical behavior of the metal. Heat treatment provides an efficient way to manipulate the properties of the metal by controlling the rate of diffusion and the rate of cooling within the microstructure. Heat treating is often used to alter the mechanical properties of a metallic alloy, manipulating properties such as the hardness, strength, toughness, ductility, and elasticity.

There are two mechanisms that may change an alloy's properties during heat treatment: the formation of martensite causes the crystals to deform intrinsically, and the diffusion mechanism causes changes in the homogeneity of the alloy.

The crystal structure consists of atoms that are grouped in a very specific arrangement, called a lattice. In most elements, this order will rearrange itself, depending on conditions like temperature and pressure. This rearrangement called allotropy or polymorphism, may occur several times, at many different temperatures for a particular metal. In alloys, this rearrangement may cause an element that will not normally dissolve into the base metal tosuddenly become soluble, while a reversal of the allotropy will make the elements either partially or completely insoluble.

When in the soluble state, the process of diffusion causes the atoms of the dissolved element to spread out, attempting to form a homogenous distribution within the crystals of the base metal. If the alloy is cooled to an insoluble state, the atoms of the dissolved constituents (solutes) may migrate out of the solution. This type of diffusion, called precipitation, leads to nucleation, where the migrating atoms group together at the grain-boundaries. This forms a microstructure generally consisting of two or more distinct phases. For instance, steel that has been heated above the austenizing temperature (red to orange-hot, or around 1,500 °F (820 °C) to 1,600 °F (870 °C) depending on carbon content), and then cooled slowly, forms a laminated structure composed of alternating layers of ferrite and cementite, becoming soft pearlite. After heating the steel to the austenite phase and then quenching it in water, the microstructure will be in the martensitic phase. This is due to the fact that the steel will change from the austenite phase to the martensite phase after quenching. Some pearlite or ferrite may be present if the quench did not rapidly cool off all the steel.

Normalization process for steel

Normalizing process for steels is defined as heating the steel to austenite phase and cooling it in the air. It is carried out by heating the steel approximately 50° C above the upper critical temperature for hypoeutectoid steels or Acm in case of hypereutectoid steels , followed by cooling in air to room temperature, or at no greater than 1 bar pressure using nitrogen if the process is being run in a vacuum furnace. Normalizing temperatures usually vary from 810°C to 930°C. After reaching the soaking temperature the steel is held at that temperature for soaking. The soaking time depends on the thickness of the work piece and the steel composition. Higher temperatures and longer soaking times are required for alloy steels and larger cross sections.

In normalizing, steel is uniformly heated to a temperature which causes complete transformation to austenite. Steel is held at this temperature for sufficient time for the formation of homogenous structure throughout its mass. It is then allowed to cool in still air in a uniform manner. Air cooling results into faster cooling rate when compared with the furnace cooling rate. Thus, the cooling time in normalizing is drastically reduced as compared to annealing.

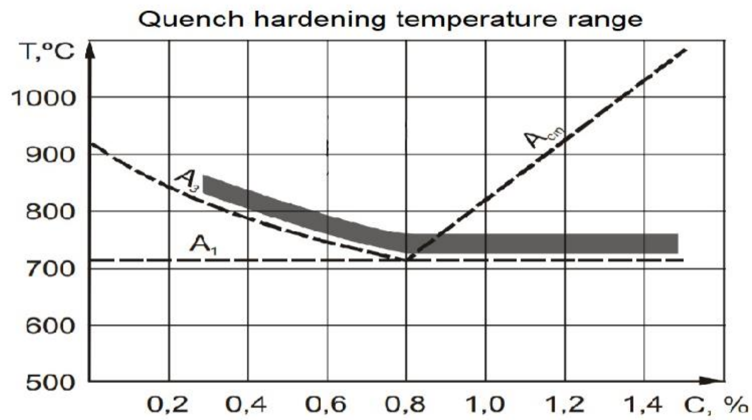
Normalizing is normally done to achieve any one of the following purposes:

- To modify and/or refine the grain structure and to eliminate coarse grained structures obtained in previous working operations.
- To improve machinability of low carbon steel.
- To improve ductility and toughnes.
- To improve dimensional stability.

Quenching

Quenching is the rapid cooling of a work piece in water, oil, polymer, air, or other fluids to obtain certain material properties. A type of heat treating, quenching prevents undesired lowtemperature processes, such as phase transformations, from occurring. It does this by reducing the window of time during which these undesired reactions are both thermodynamically favorable, and kinetically accessible; for instance, quenching can reduce the crystal grain size of both metallic and plastic materials, increasing their hardness.

In metallurgy,, quenching is most commonly used to harden steel by inducing a martensite transformation, where the steel must be rapidly cooled through its eutectoid point, the temperature at which austenite becomes In steel alloyed with metals such as nickel and manganese, the eutectoid temperature becomes much lower, but the kinetic barriers to phase transformation remain the same. This allows quenching to start at a lower temperature, making the process much easier. High-speed steel also has added tungsten, which serves to raise kinetic barriers, which among other effects gives material properties (hardness and abrasion resistance) as though the work piece had been cooled more rapidly than it really has.



Quench hardening is a mechanical process in which steel and cast iron alloys are strengthened and hardened. These metals consist of ferrous metals and alloys. This is done by heating the material to a certain temperature, depending on the material. This produces a harder material by either surface hardening or through-hardening varying on the rate at which the material is cooled. The material is then often tempered to reduce the brittleness that may increase from the quench hardening process.

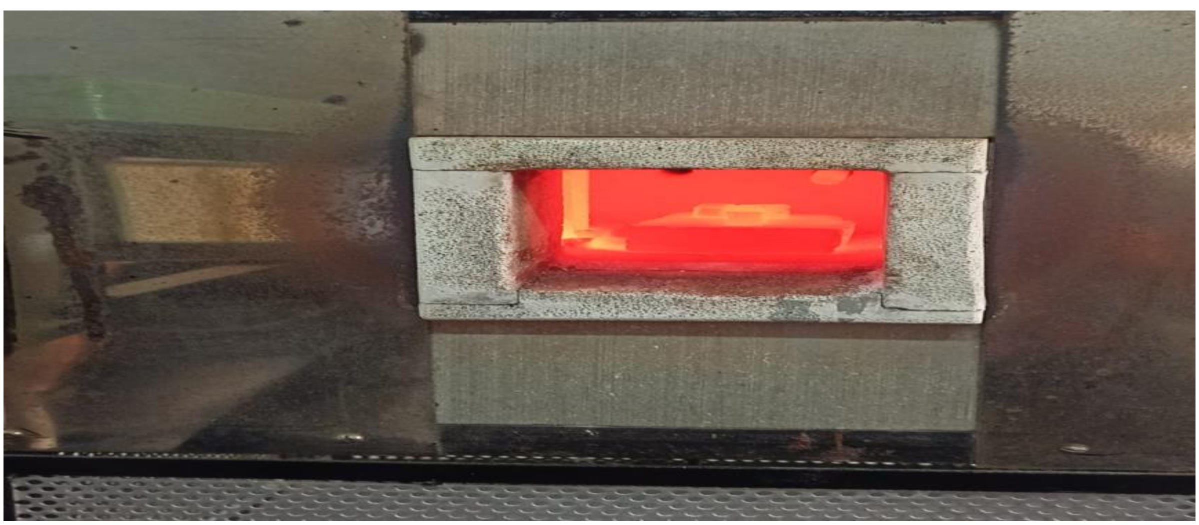


Figure3 : furnace heat generation zone

Process

The process of quenching is a progression, beginning with heating the sample. Most hypo eutectoid steels are heated to between 815 and 900 °C (1,500 to 1,650 °F), with careful attention paid to keeping temperatures throughout the work piece uniform. Minimizing uneven heating and overheating is key to imparting desired material properties.

The second step in the quenching process is soaking. Workpieces can be soaked in air (air furnace), a liquid bath, or a vacuum. Soaking times can range a little higher within a vacuum. As in the heating step, it is important that the temperature throughout the sample remains as uniform as possible during soaking.

Once the work piece has finished soaking, it moves on to the cooling step. During this step, the part is submerged into some kind of quenching fluid; different quenching fluids can have a significant effect on the final characteristics of a quenched part. Water is one of the most efficient quenching media where maximum hardness is desired.

Mechanism of heat removal during quenching

Heat is removed in three particular stages

Stage 1 : Vapor bubbles formed over metal and starts cooling

During this stage the object is fully surrounded by vapor which insulates it from the rest of the liquid.

Stage 2 : Vapor-transport cooling

Once the temperature has dropped enough, the vapor layer will destabilize and the liquid will be able to fully contact the object and heat will be removed much more quickly.

Stage 3 : Liquid cooling

This stage occurs when the temperature of the object is below the boiling point of the liquid.

Effect of Welding at TMT bars

Thermomechanically treated (TMT) welded metal rebars for uniform quality keeping up all through the thickness of welded rebars and welded rebars produced thereof containing the means of welding lap joint (single side) of TMT rebars of same or distinctive breadth at level, vertical or slanting position .The steel is more weldable if the carbon ratio is lower. The higher the quality and the carbon equivalent of the steel, the more susceptible it is to cold cracking that breaking that happens after the metal has solidified when welded. Welding is definitely not a decent practice, best is to give laps. It is on the grounds that welding causes microscopic air bubbles to be trapped inside the weld. These bubbles weaken the weld. Welding is permitted if the metallurgical component of the weld metal is designed to have a proportionate carbon content of less than 0.4 percent. There are different welding forms for joining the materials. Arc welding is a noticeable joining process in which two steel parts are joined by heat produced because of bend. Numerous inquiries have been completed in joining various materials by various welding systems. Our examination has been underlined on TMT bars. A Thermo Mechanical Treated (TMT) bar is normally utilized for making fortified rooftops and sections of structures. They are additionally utilized for modern purposes, for example, rock dashing in underground mines and so on. The greater part of TMT bars joining procedure occurred with bend welding. Right now study has been made for the impact of welding position on quality of joined bars. TMT bar is utilized in making rooftops and segments due to its high elasticity and hardness. High Elasticity of a material to permit a material to withstand huge pivotal burdens. While high hardness opposes mileage of the material. Welding is an old method for joining steel. It is seen as a supplement to hot manufacturing.

The weld joint is the most vulnerable joint if there should arise an occurrence of circular segment welding of TMT bars. The microstructure of the weld joint shows there is less pearlite than the base material. The parent zone has fine pearlite and because of warming the ferrite and pearlite in the HAZ has developed. The weld zone contains an enormous no of incorporations which diminishes the hardness and rigidity. So as to contemplate the pliable mechanical conduct of the lap welded joints, the impact of the different geometric qualities of the steel bars and of the welds, alongside the showing up sideways developments of the parts of the bargains, were inspected through impressive direct and non-straight investigations. Since the quality of aluminum will in general increment as administration temperature diminishes dissimilar to steel, which turns out to be increasingly weak as administration temperatures decline aluminum is ordinarily utilized in chilly temperature applications, for example, cryogenics and fluid flammable gas transportation While iron is a primary amalgam in steel, aluminum materials are mostly aluminum with the expansion of an assortment of components. Execution of weld metal relies upon its microstructure which is affected by concoction creation of weld metal and welding parameters. So as to pick up welded joints of low compound high quality steels with agreeable mechanical properties and breaking opposition, it is essential for weld metal to acquire high volume division of acicular ferrite.

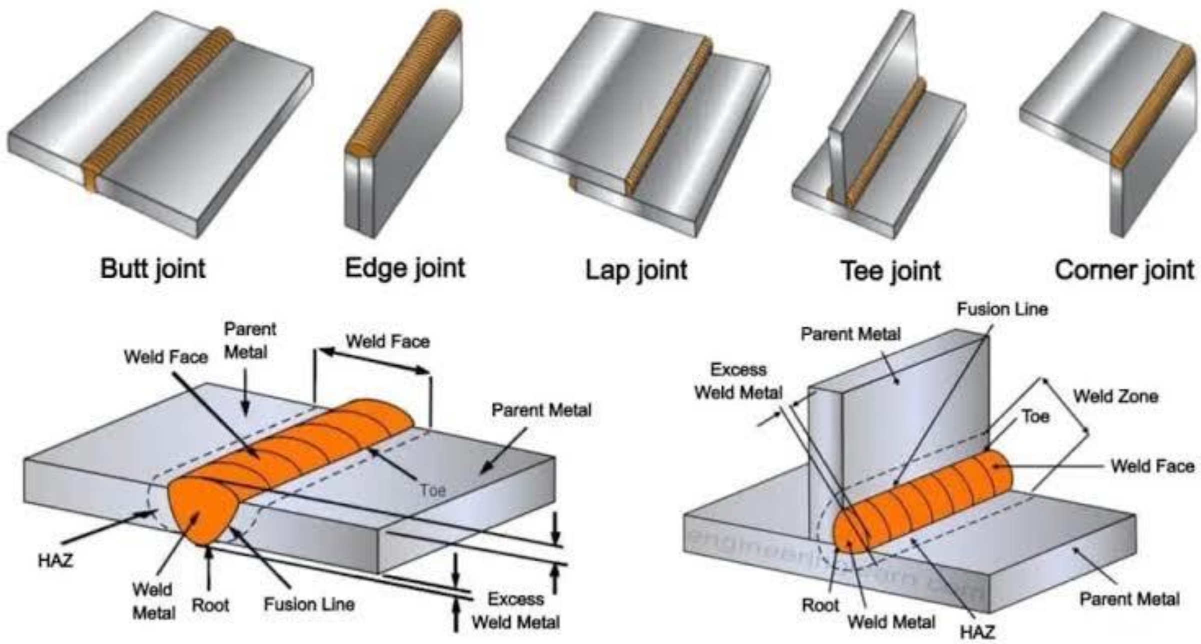
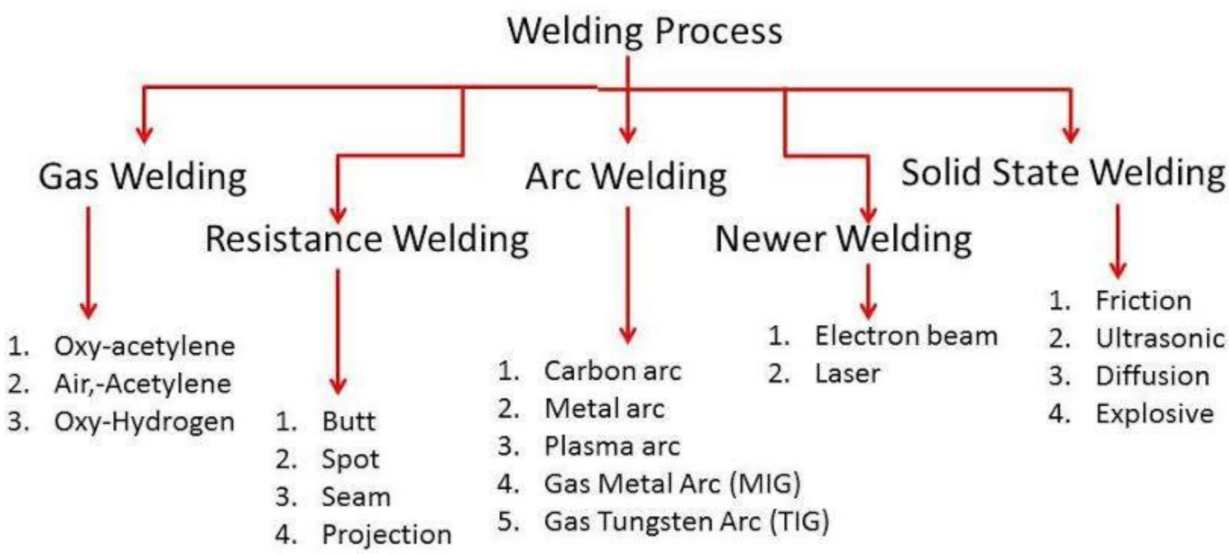


Figure 4: types of welding joints



Welding Power Supplies

There are two types of welding power source used to supply current for metal arc welding.

Alternating Current (AC) type.

Direct current (DC) type.

The AC power source

This power source takes its power directly from the main electricity supply. It uses a transformer to supply the correct voltage to suit the welding conditions. A special device in the transformer allows the current in the secondary coil to be adjusted. The primary coil is connected to the electricity power supply and the secondary coil is connected to the earth clamp and the electrode holder.

The DC power source

The DC generator uses a motor (electric, petrol or diesel powered) to generate electricity. The generator provides DC current for the arc. A Transformer-rectifier is basically a transformer with an electrical device for changing the alternating current into a direct current output. This device is known as a rectifier. The transformer-rectifier has the advantage that it can be made to supply AC or DC.

Figure 5: metal arc welding set up in welding technology laboratory

Welding Electrodes

When a piece of metal is heated in the atmosphere it combines with the oxygen and nitrogen to form oxides and nitrides which combine with the metal. If these were allowed to form in the weld it would result in a poor quality, weak and brittle weld. It is therefore necessary to protect the weld area from the air. This can be done either by surrounding the weld area by an inert gas or by the use of suitable fluxes. It is usual, with manual metal arc welding, to use coated electrodes. These electrodes consist of a metal core surrounded by a layer of suitable flux coating.

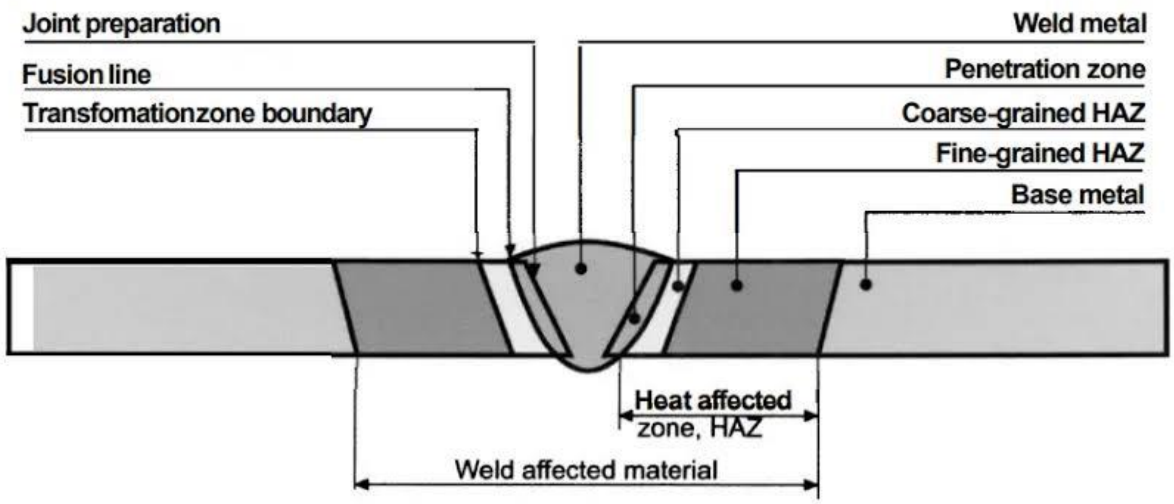
Functions of the Electrode Coating

- To form a protection layer (slag) over the weld, which prevents contact with the air as it starts to cool down. This stops the weld forming brittleness and provides a smoother surface by preventing ripples caused during the welding process.
- It forms a neutral gas atmosphere, which helps to protect the molten weld pool from oxygen and nitrogen in the surrounding air.
- To act as a flux and remove the impurities from the surfaces being welded.
- It helps to stabilize the arc, allowing Alternating Current (A.C) to be used.
- It can speed up the welding process by increasing the speed of melting of the metal and the electrode.

HEAT AFFECTED ZONE IN WELDING

Welding processes are divided into thermal fusion joining processes and solid-state joining processes. The most common processes of welding are thermal fusion joining processes such electric arc welding. This welding method is performed under high temperature conditions.

Heat generated during welding induces an important temperature gradient in and around the welded area. Generally, the metallurgy of the welded joint can be divided into two main zones,the fusion zone and the heat-affected zone (HAZ). The HAZ is a zone which is outside the fusion zone of the welded joint that is thermally affected by the welding treatment. The HAZ is considered as a transition zone, because it is composed with the microstructure of the base metal and the fusion zone. The properties of the HAZ are very important after performing a weld, because it is considered as a weaker zone, it is the area of failure when the welded metal is submitted to hard conditions. For this reason, it is important to understand this critical zone in welded joint.



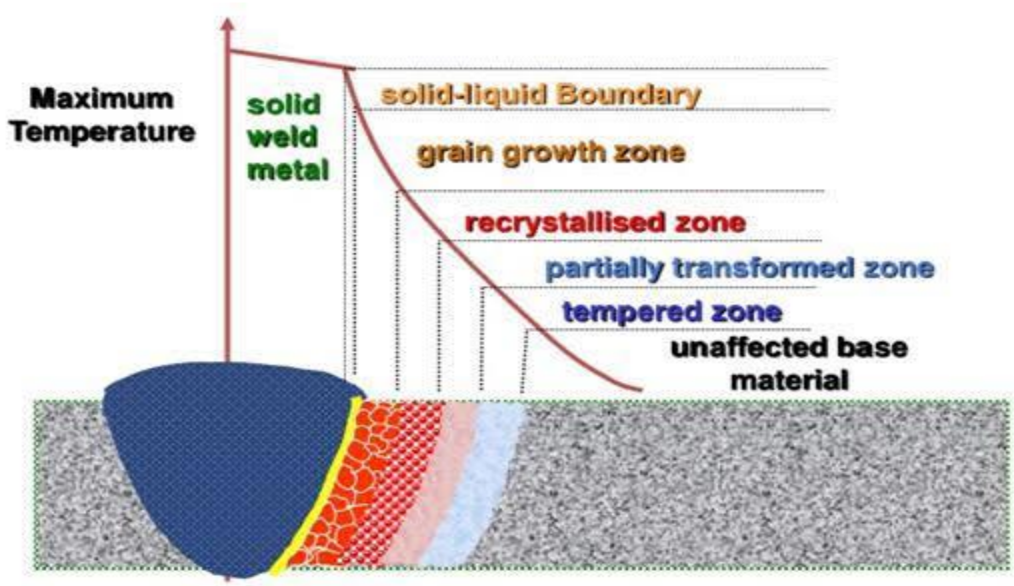


Figure 6: different zone of welding material

The heat-affected zone (HAZ) is an area generated when a metal is subjected to very high temperatures (Example: Welding, Mechanical Cutting, Laser Cutting etc). This is the nonmelted zone near the exact worked area. The mechanical properties of the heat-affected zone are altered due to being exposed to high temperatures. So, the heat-affected zone or HAZ can be defined as the area between the melted metal and the base metal where microstructural changes occur.

The Fusion zone is a mixture of molten metal and filler metal. Next, the narrow mushy zone consisting of partially melted metal is the weld interface. The next region that suffers a peak temperature below the melting point temperature creating microstructural changes is known as the heat-affected zone. The parameters that decide the extent of microstructural changes are

- Amount of heat input
- Maximum temperature reached
- Duration of elevated temperature and
- the cooling rate

A heat-affected zone weakens the metal by reducing its mechanical strength and is the weakest section in a weldment. Depending on various factors like material properties, heat concentration, intensity, welding, or metal cutting process, the HAZ area can vary in size and severity.

HAZ Areas

While the HAZ occurs between the weld or cutting zone and the unaffected parent metal, the HAZ itself has different areas according to how close they are to where the cutting or welding heat was applied to the material.

The cutting or weld zone is the liquid region where the process itself takes place and is adjoined by the fusion boundary. The fusion boundary is the border of the fusion zone where the liquid and solid phases of the metal coexist. Further from the weld or cutting zone is the HAZ itself, which is where the non-melted parent metal has experienced changes to the microstructure. In conventional steels, the HAZ can be broken down into the grain coarsened zone (closest to the heated area), the grain refined zone, the partially transformed (intercritically heated) zone and the tempered zone. In other materials, which do not undergo a solid-state phase transformation during cooling, it is common to see a grain growth zone and a recrystallized zone, with some evidence of a tempered zone. Outside of these HAZ areas is the unaffected base material.

The various HAZ areas are formed by differing temperatures in the base metal further from the weld or cut itself. This should not be mistaken for the series of visible coloured bands, caused by surface oxidation, near a weld in stainless steel. The 'temper colours' represent much lower temperatures than those which form the heat affected zone, and extend for some distance beyond the actual heat affected zone. These different colours, also known as heat tint, offer an approximate indication of the temperature reached by the metal.

The band colours and associated temperatures are as follows:

Light yellow 290 °C / 550 °F

Straw yellow 340 °C / 640 °F

Yellow 370 °C / 700 °F

Brown 390 °C / 735 °F

Purple brown 420 °C / 790 °F

Dark purple 450 °C / 840 °F

Blue 540 °C / 1000 °F

Dark blue 600 °C / 1110 °F

The heat tint colours depend on the material's resistance to oxidation, with those metals with a higher steel chromium content showing less intense colouration as they are more resistant to oxidation. The use of protective gas and electrode coatings can also reduce heat tint as they partially shield the metal from oxidation. Conversely, rougher surfaces oxidise faster, causing darker colours. In addition, paint, oil, rust and even fingerprints can alter the heat tint, although they do not impact the extent of the HAZ itself.

Microstructures of HAZ

The HAZ is the unavoidably heat treated area in the parent metal near the fusion zone during welding where structural transformations occur. HAZ formed during welding is an area in which some structural changes in the welded material take place as the result of experienced temperature. There was a development of a recrystallization reaction in HAZ, with the partial dissolution of the colonies of pearlite (dark color). Depending on the distance from the weld, the different parts of the HAZ can be affected differently during the welding process.There are many descriptions of the HAZ, because it can be divided in different subzones and each subzone has its own microstructure. It has been considered that the HAZ can be divided into four different zones, which are subjected to different heat treatments

- Coarse grain zone
- The normalized zone
- The partially transformed zone
- The annealed zone

However the HAZ was subdivided into two regions, the partially melted zone (PMZ) and the "true" heataffected zone (T-HAZ). The PMZ exists in all fusion welds made in alloys since a transition from 100% liquid to 100% solid must occur across the fusion boundary, there are many possible metallurgical reactions in the HAZ: recrystallization, grain growth, phase transformations such as precipitation, and residual stress and stress relaxation.

The amount of heat input during the welding or cutting process normally exceeds the melting temperature and subsequent cooling leads to microstructural changes. Thermal diffusivity is the single most important factor influencing the size of the heat-affected zone. The level of thermal diffusivity is dependent on the metals.

- The thermal conductivity
- Density
- Specific heat ,and
- Amount of heat input

Materials with high thermal diffusivity are capable of transferring the heat variation rapidly and cooling quicker, thus reducing the heat-affected zone width. On the contrary, materials with a lower thermal diffusivity coefficient retain the heat and the HAZ region becomes wider. Also, the duration of heat exposure has a direct impact on the HAZ region. When a metal is exposed to greater amounts of energy for longer periods the heat-affected zone is larger. With respect to the welding process the HAZ is dependent on:

- Heat Input: Low heat input will cool faster resulting in a smaller HAZ.
- Cooling Rate: Slower cooling rate will increase the size of the HAZ.
- Welding Speed: Faster welding speed will reduce the HAZ area.
- Welding Geometry: Weld geometry affects the heat sink. A smaller heat sink leads to slower cooling means larger HAz.

Effects of Heat-Affected Zones

Due to the heat experienced in the heat-affected zone, major undesirable microstructural changes occur that impacts the metal in various way

- Lower strength
- Residual stress
- Lower toughness
- Reduced corrosion resistance
- Hydrogen embrittlement
- Susceptibility of cracking
- Phase change
- Oxidation
- Surface nitriding
- Localized hardening

All these factors normally weaken the material creating challenges for the use of that material during the design of components.

Methods of Investigation of HAZ

It has been found that the study of the HAZ of real welded joints is not easy because of the narrowness of the HAZ . Welding simulation is the appropriate technique to determine the different sub-zones in HAZ. This allows the prediction of the microstructure and the properties of these sub-zones. Consequently, thermal cycle simulation in which the HAZ can be geometrically extended is the appropriate method in order to determine the different microstructures, which can be developed in real welded joints. The HAZ is also a heterogeneous zone, because it is composed with different subzones and each subzone has a specific microstructure.

OBJECTIVE

THE OBJECTIVES OF THIS PROJECT ARE

- ***To study the variation of microstructure of different tmt bars(tata tiscon,srmb,captain)***
- ***To observe the percentage of pearlite, ferrite and cementite zone of different tmt bars.***
- ***Macro hardness study of various as received TMT bar samples(tata tiscon,srmb,captain)***
- ***Micro hardness observation of various as received TMT bar samples(tata tiscon,srmb,captain)with load 1000gf.***
- ***Fresh water corrosion penetration calculation of as received different TMT bar samples(tata tiscon,srmb,captain)by observing 90 days.***
- ***Sea water corrosion penetration calculation of different as received TMT bar samples(tata tiscon,srmb,captain)by observing 70 days.***
- ***Observation of microstructural change after performing normalization of different TMT bar sample(tata tiscon,srmb,captain).***
- ***Observation of microstructural change after performing quenching of various TMT bar samples(tata tiscon,srmb,captain).***
- ***Corrosion penetration rate calculation of quenched tmt bar samples(tata tiscon,srmb,captain).***
- ***Hardness observation of different normalized TMT bar sample(tata tiscon,srmb,captain).***
- ***Comparative hardness analysis of different quenched TMT bar sample(tata tiscon,srmb,captain).***
- ***Welding of various TMT bar samples.***

- ***Heat affected zone microstructure analysis of TMT bar samples.***

TMT BAR SAMPLES

Tata tiscon 550D

About TATA STEEL

Established in 1907 as Asia's first integrated private sector steel,Tata steel group is among the top ten global steel companies with an annual crude steel capacity of over 29 million tonnes per annum.

Tata steel offers a bouquet of world class products covering rebars designed tmt with different composition of carbon and iron.Thereabers are made in the marchent mill and the new bar mill.

In 2008 TATA steel India became the first integrated steel plant in the world and awarded the deming application prize for excellence in total quality management.

TATA Tiscon rebars are available in several categories:TATATiscon Fe 500D,TATA Tiscon Fe 550D,TATA Tisconfe 600D,TATA TISCON CRSD,TATA TISCON SD.Together ,they easily cover all requirements of reinforcing tmtbars.All tata tiscontmt bars adhere to all the mandatory requirements of the BUREAU of INDIAN STANDARDS IS 1786.The are made in accordance with tmt process.

Chemical Composition of TATA Tiscon TMT bar

TATA Tiscon Fe 500D	Weight percentage
1.Carbon(max)	.250
2.Sulphur(s)(max)	.035
3.Phosphorus(P)(max)	.035
S&P (max)	.070

About SRMB Fe 500D

Thermo mechanically treated SRMB TMT Bars are extra high strength bars which replace any form of cold twisting.The steel tmt receive a short ,intensive cooling as they pass through the specially designed tempcore water cooling system after the last rolling mill stand.The sudden quenching coverts the surface layer of the steel barto a hardened structure.

After intensive cooling by the tempcore system is followed by further cooling in atmosphere,so that the temperature core and casing is equalized,and the surface layer gets tempered by the heat from the core.

The resulting structure is a tempered martensite zone at the periphery and a fine grain ferrite perlite structure in the central zone.

Chemical compositionof SRMB TMT bar

Chemical composition	Weight percentage
1.Carbon(max)	.30
2.Sulphur(max)	.055
3.Phospphorus(max)	.055
S&P(max)	.105

About CAPTAIN 550EQR

CAPTAIN STEEL INDIA LIMITED is a steel fabricator industry of Kolkata,WEST BENGAL.

In 2007, Captain Steel established its first manufacturing plant at Kalyaneshwari, in the Paschim Bardhaman district of West Bengal. Soon after, we set up two manufacturing units in Bihta, in Patna district of Bihar, and at Barjora, in Bankura District of West Bengal. Our aim was to supply industry-leading TMT bars throughout the country. Today, we have a 5,25,000 MT annual production capacity, making our product one of the top TMT bars in India.

Captain 600 **EQR(EARTHQUAKE RESISTANT)**is one of our flagship products. Renowned for quality, this TMT bar is regarded as one of the top quality TMT bars in India today. Built stronger to last longer, Captain 600 EQR is created to provide strength and protection to constructions over generations. It is used in large constructions like industries, dams, bridges, highways, and other infrastructural projects. Our TMT rebars are regularly supplied to government bodies, public enterprises, and large developers, and are equally popular among individual house builders, retailers, contractors, engineers, and masons.

Chemical Compositionof CAPTAIN TMT bar

Chemical composition	Weight percentage
1.Carbon(max)	.25
2.Sulphur(max)	.40
3.Phosphorus(max)	.40
S&P(max)	.75

Microstructure Development

TMT bars, often known as TempCoreTMT bars, are manufactured by passing the red heated steel -just after the rolling process- through a chamber with a control water flow that quenches the outer surface of the bars, while their core remains hot as ***austenite.A martensite*** case is formed in the outer part of the bar. Then, in the core, ***the austenite*** is transformed into ***ferrite*** and ***perlite*** through a slow cooling, while the heat dissipated from the center of the bar to the surface causes the self-tempering of the previously formed ***martensite***. The ***martensitic*** case formed in the outer surface of the bars increases their hardness, while the remaining ***ferritic-perlitic*** core maintains the typical ductility of hot rolled bars. The final strength of the TMT rebars depends on the thickness of the outer ***tempered martensitic*** case as well as on the distribution of other phases inside the core of bar. Nowadays, the use of TMT carbon steel bars has become common for reinforcement of concrete structures through worldwide.

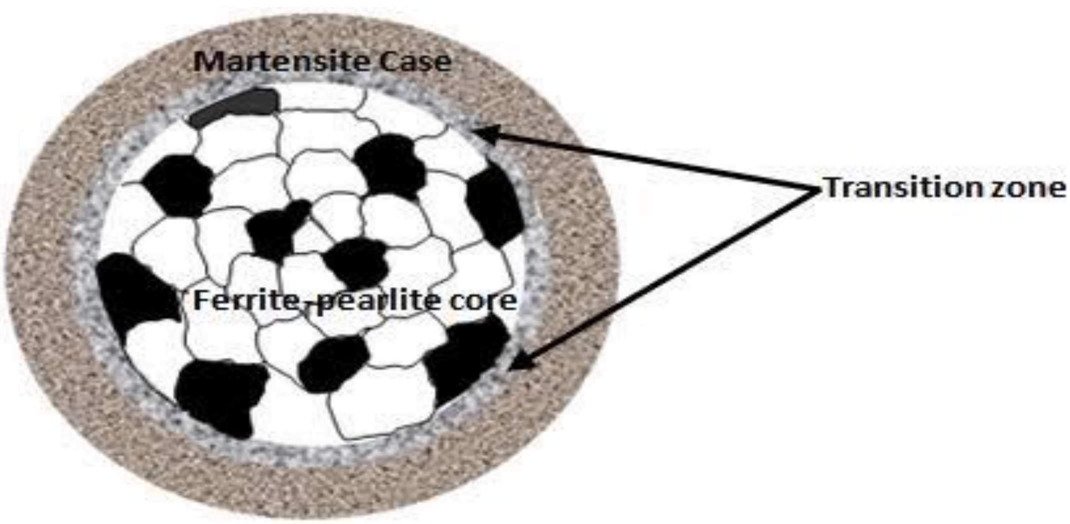


Figure 7: microstructure of tmt bar

The study on the influence of the microstructure of TMT carbon steel bars on the fracture mode and ultimate tensile strength of the bars . Moreover, TMT bars have shown better results in tensile and impact tests than direct air-cooled microalloyed hot rolled bars. The influence of high-temperature exposure on the mechanical properties of the TMT bar is a point that has also been studied, with their results being worse than those shown for traditional hot-rolled carbon steel bars .

Microstructure development process and equipments required.

Aim

Preparation and study of the Micro Structure of different tmtreabers(tata tiscon,srmb,captain)

To Learn the preparation of specimen for microscopic observation.

PROCEDURE

The preparation of metallic or other materials for microscopic examination and micro structural characterization is in principal very simple. There are four basic processes that you will need to become familiar with: sample cutting and sectioning, Surface grinding and surface polishing.

Sectioning

Sectioning means removal of convenient size specimen from large sample with minimal damage to microstructure with the help of abrasive cut off machine. Abrasive cutting wheel/saw is attached to cutting machine and for work piece holding proper vice is provided on machine. The primary concern in this process is to minimize the heating of the sample due to the cutting. For this reason, the cut-off saws that is equipped with either water-cooling systems.

Sample Surface Polishing

The goal of the surface polishing is to end up with a planar cross section of sample free from scratches or disturbed metal introduced by the cutting and sectioning. This process is a step-wise process that can be broken into three loosely separate parts: grinding, coarse polishing, and final polishing.

Grinding

The first step in preparing your sample is to ensure that you have a flat surface to begin with. A water-cooled abrasive grinder is available to form a flat initial surface from which to begin. After getting a flat sample on the belt grinder, WASH sample thoroughly. The hand lapping station has four graded abrasive papers to produce a sequentially finer surface finish. Be sure the water is turned on and flowing uniformly over the abrasives. Start with the coarsest grit (240) and, using a firm and uniform pressure, slowly move the specimen forward and back across the abrasive. This will produce parallel scratches of uniform size. Continue this step until the entire surface of your sample is flat and contains only scratchesof the size of 240 grit abrasive. When the sample is flat and the only scratches remaining are those due to the 240 grit abrasive, WASH your sample and your hands thoroughly, and move to the 320 grit abrasive. Repeat this procedure for the 400 grit and the 600 grit abrasive, checking after each step to be sure that only those scratches remain that are due to the smallest grit.

Figure 8: belt grinder machine

Polishing

This wheel uses a 0.05 micrometer A1203 abrasive in a water suspension. At this point, the sample will be very smooth to the eye and even the oils and dirt on your fingers will scratch it with larger scratches than the abrasive. DO NOT TOUCH THE SAMPLE SURFACE FROM THIS POINT ON.

The last step in the process is to etch the sample to bring out the microstructure.

Use a cotton swab and a petri dish for the etching. Gently swab the surface of your sample with the etchant. Roughly spreading the etchant will scratch your surface. Let the etchant stand for 15 seconds or so and rinse the sample with water to stop the etching, and rinse again with methanol. Rinse the swab with water and throw into the trash bin.

Examine specimen under the microscope. You may require several etching steps to bring out the microstructure.

If the sample is over-etched, repeat the final polishing step and re-etch for a shorter time. Samples to be examined at high magnification generally require shorter etching times than those to be viewed at lower magnifications,After last polishing stage the sample looks mirror like.

Figure 9: cloth polishing.

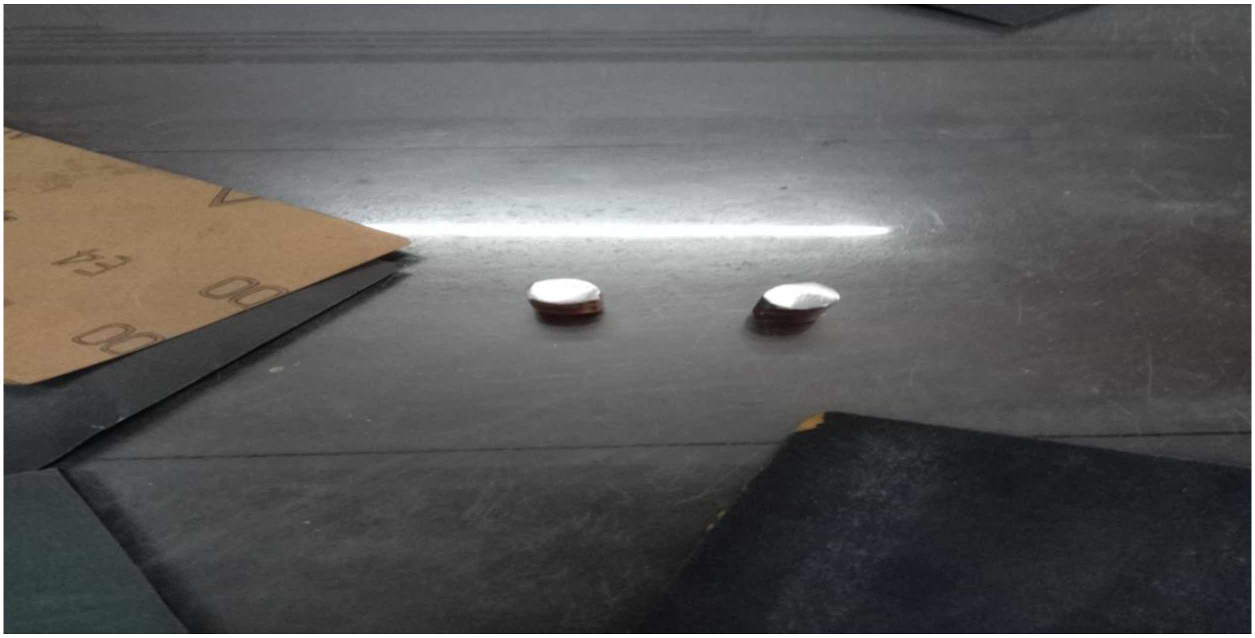


Figure10:polished tmt bar sample.

Etching

Grains cannot be seen without etching. Cracks, pores and defects are observed without etching. Etchant reacts with atoms and dissolves them. Atoms at grain boundaries dissolve quickly.

Dissolved grain boundaries appear dark.

Steps:

1) Apply enchant to polished surface for some time.
2) Rinse with distilled water.

Enchants:

2% Nital: 2 ml concentrated $HN0_3$; 98 ml ethyl alcohol.

Metallographic Observation

Observe microstructure, Place specimen on metallograph and adjust magnification, focus and position s adjust micro High magnification - to study phases and Low magnification -to study grain size.

Microphotography

In this laboratory, you will report the microstructures of prepared samples in specific formats. You will be expected to sketch the microstructure that you see under the microscope by hand. In sketching the microstructure there are several things to keep in mind. First, the magnification that you use depends upon the scale of the microstructure you are looking for. It is IMPORTANT to know in advance of the lab class what the expected microstructure for your samples are and at what scale they should appear. In sketching the microstructure, you should indicate only the important features of the structure that you observe-don't make a photographic reproduction of the microstructure. Simple sketches show that you know what the important structures are and have identified them in the cross section.

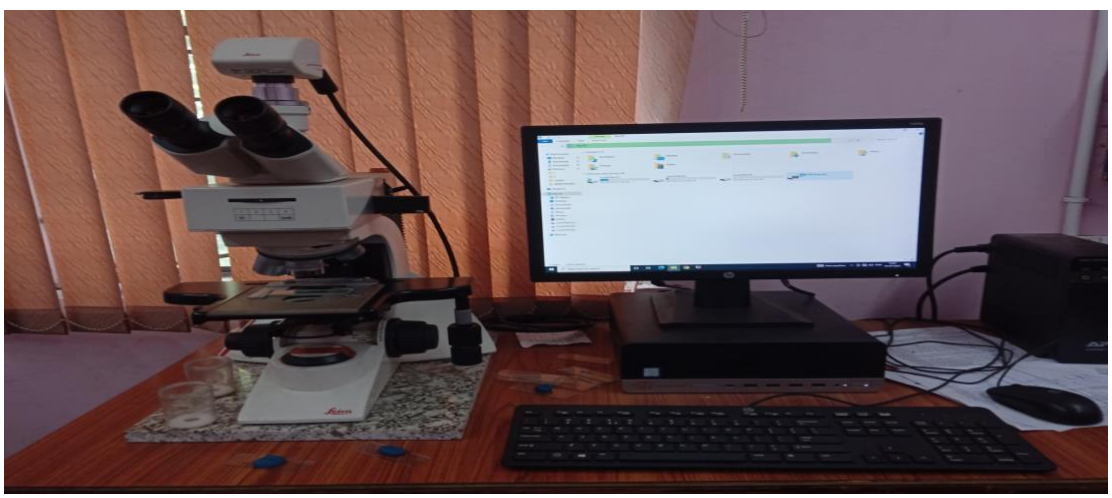


Figure 11: microphotography set up of laboratory

Figure 12: different parts of optical microscope

Microstructure of TATA tmt bar

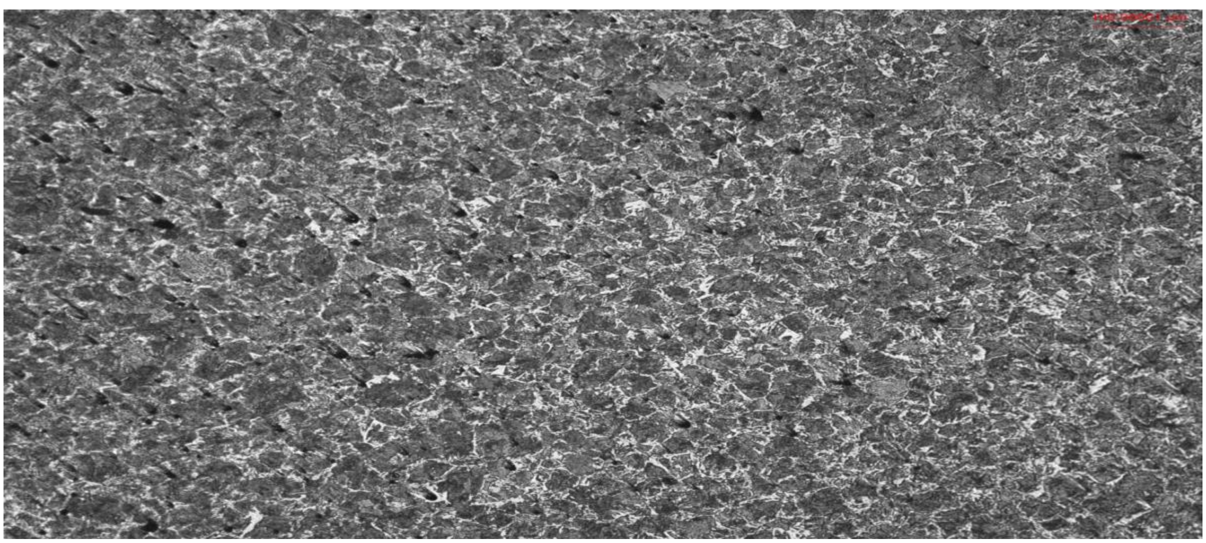


Figure13 : as received tata tmt(200x)

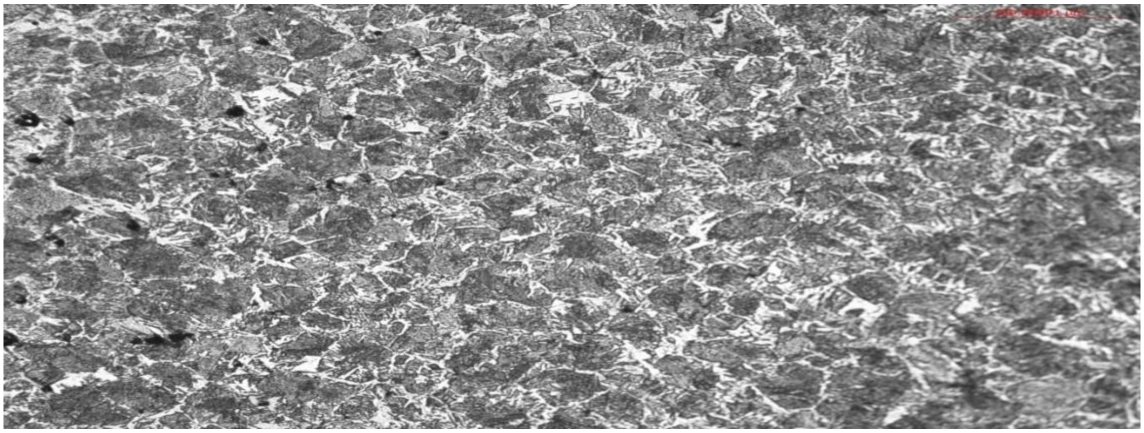


Figure14:microstructure of as received TATATiscon (500x resolution)

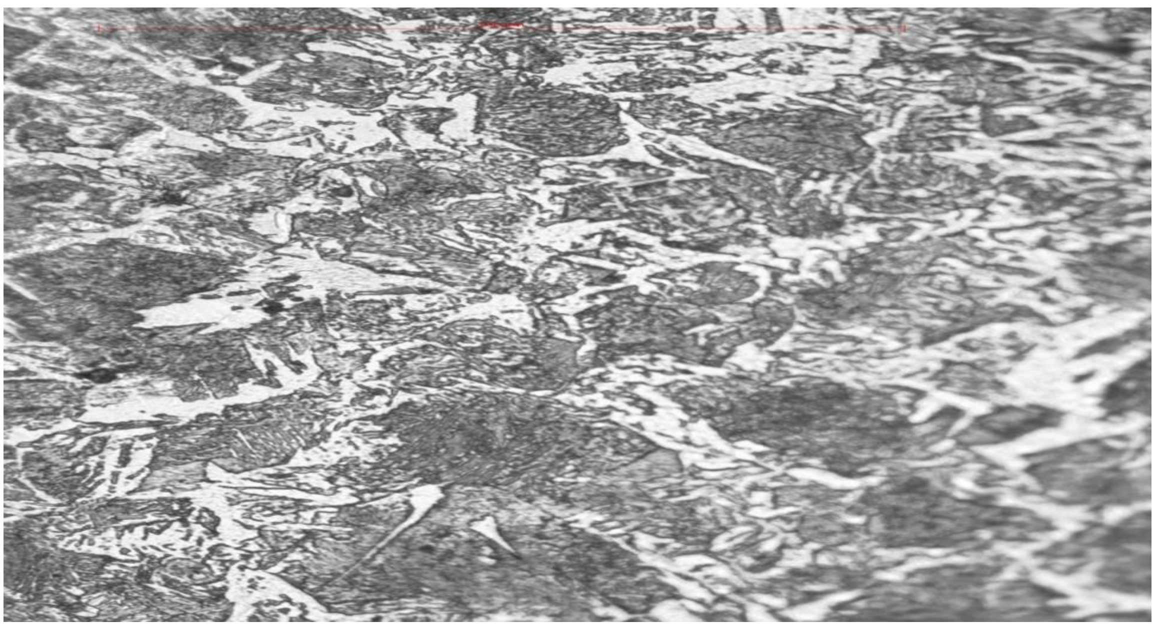


Figure15 ::microstructure of as received TATATiscon with (1000x resolution)

The microstructure of TATA tiscon TMT bar shows higher amount of black region which made up of pearlite and the white region is comparatively less and made up of ferrite.

Microstructure of SRMB Fe550D

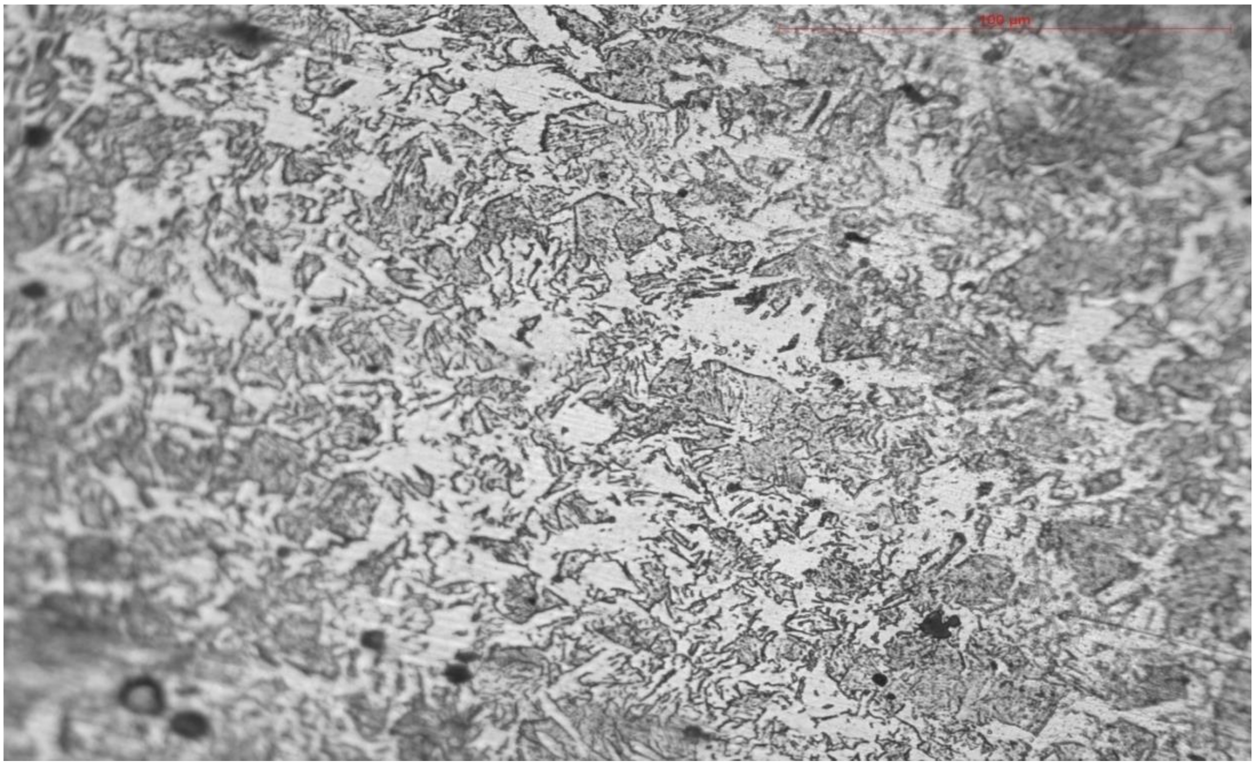


Figure16 :microstructure of as received srmbtmt(500x resolution)

The microstructure of SRMB TMT shows almost equal amount of white and blackish region.

The black region consists pearlite and white region made up of ferrite. It is ferrite-pearlite microstructure throughout the image.

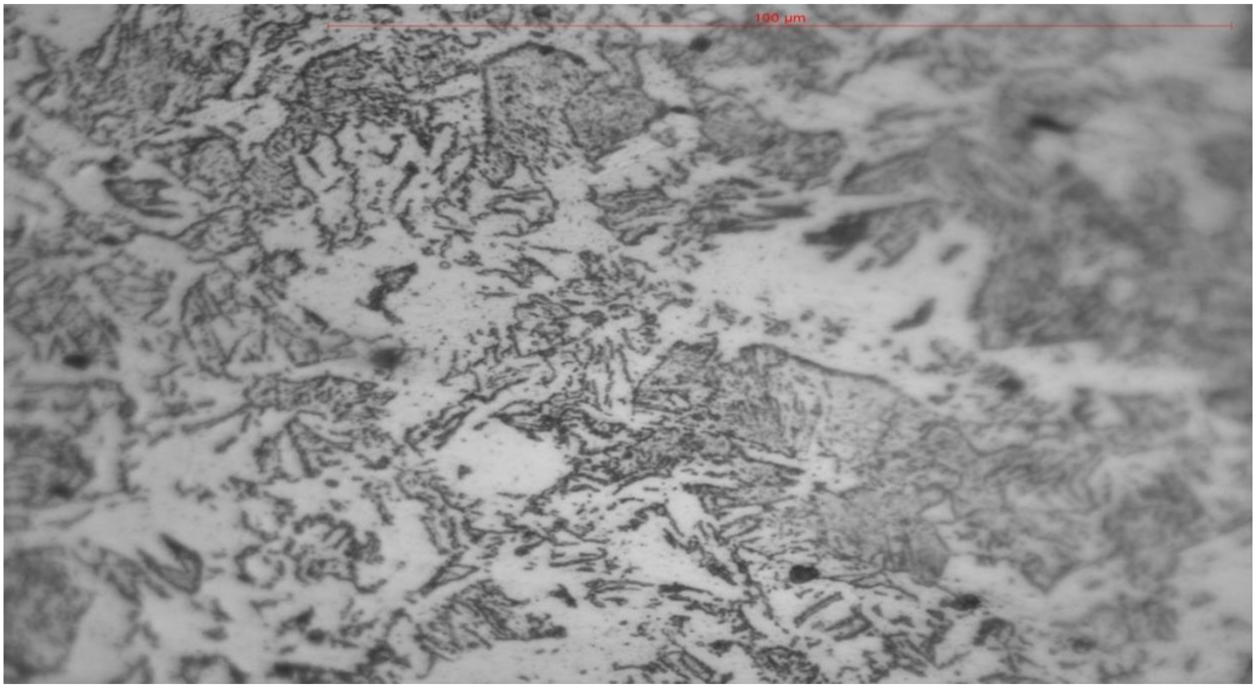


Figure17:microstructure of as received srmbtmt rebar with 1000x resolution

Microstructure of CAPTAIN tmt bar

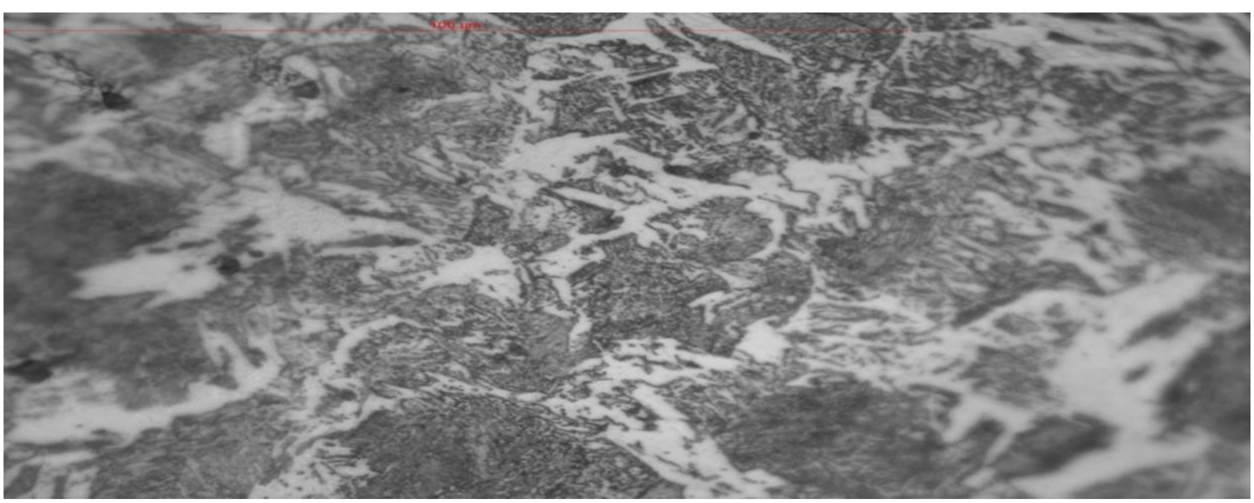


Figure 18: microstructure of as received captain tmt bar (1000x)

The above microstructure of CAPTAIN tmt bar showing higher amount of blakish region than TATA Tiscon TMT and SRMB TMT bar.

There is comparatively more amount pearlite region than the ferrite region in CAPTAIN TMT bar microstructure.

Where as microstructure of all TMT bar consist an outer martensitic rim with an intermediate narrow bainitic transition zone followed by ferrite-pearlite inner core.

Microstructure of Air Cooled sample

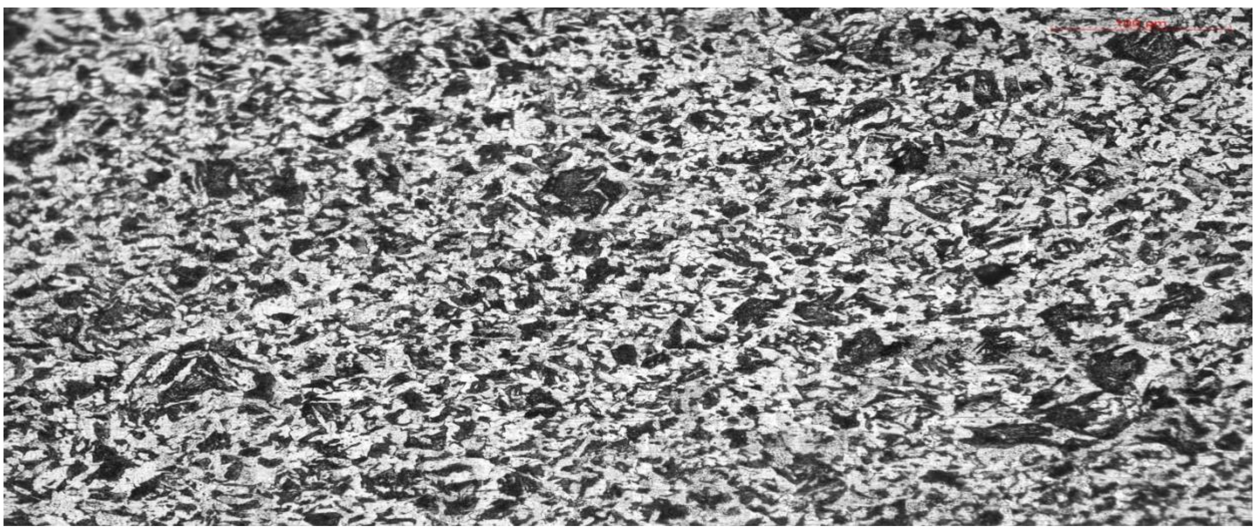


Figure 19: microstructure of air cooled tata tmt bar (200x)

Figure21 : tata air cooledmicrostructure (1000x resolution)

From the above microstructure of air colled tata TMT bar we can observe that higher amount of white region than as received tata tmt bar sample which indicates more amount of ferrite generation when the sample cooled from its austenitic temperature.

The microstructure contains more amount of ferrite than pearlite.

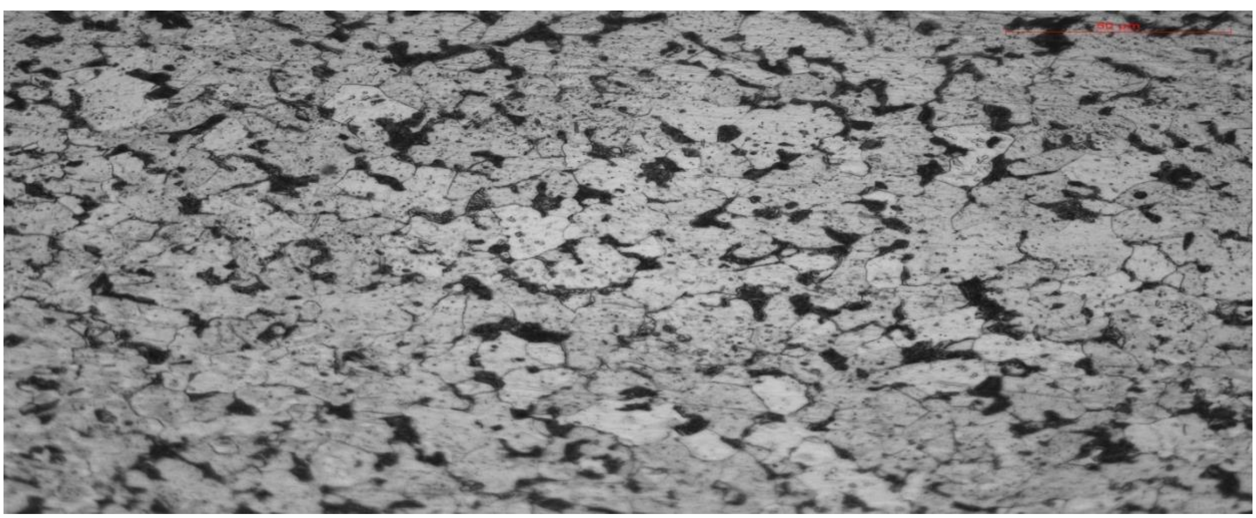


Figure22 :srmb air cooled tmt bar microstructure (500x)

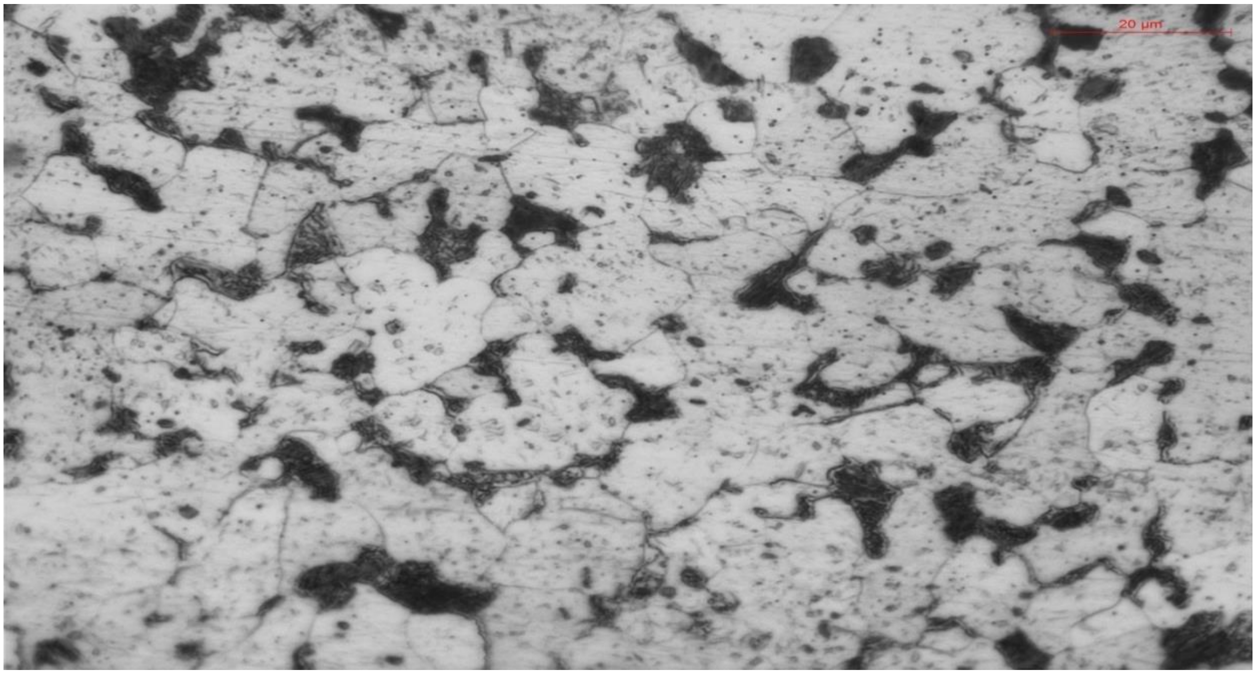


Figure23 :srmb air cooledtmt bar(1000x resolution)

The above high magnified air cooled microstructure of SRMB TMT bar shows a lot of ferritic region and very less amount of pearlite region. The region of ferrite is more than it's as received sample and also more than air cooled TATA tiscontmt bar sample.

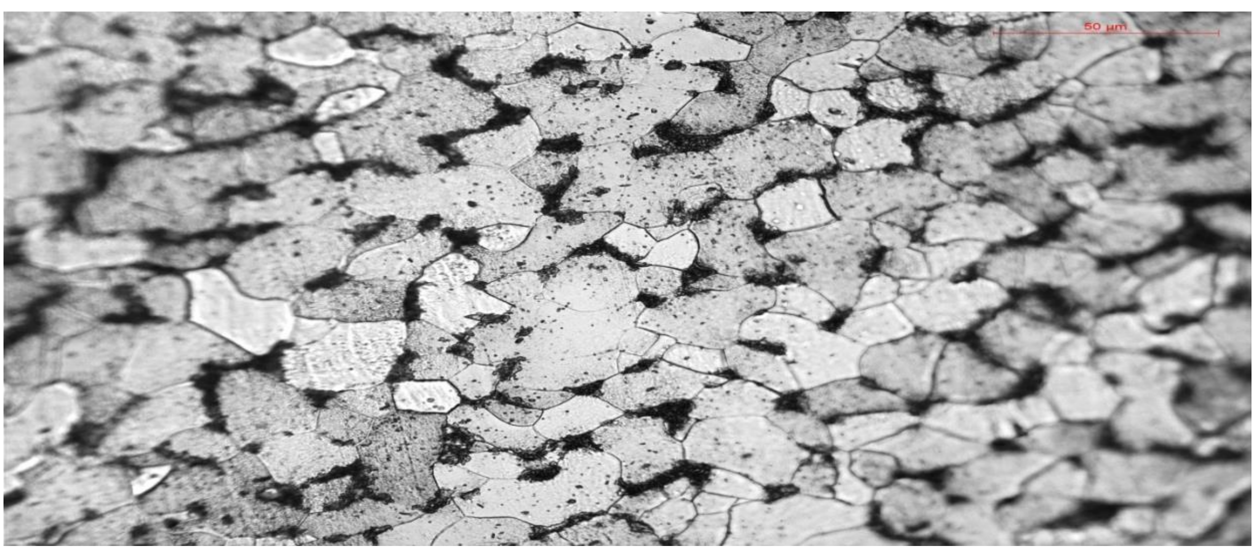


Figure 24: air cooled captain TMT bar microstructure(1000x)

The microstructure of air cooled TMT bar consist higher amount of ferrite as compared to it's as received sample. The pearlite region is much less than ferritic region.

Slow cooling in air from austenitic temperature generates a higher amount of ferrite.

Microstructure of Quenched samples

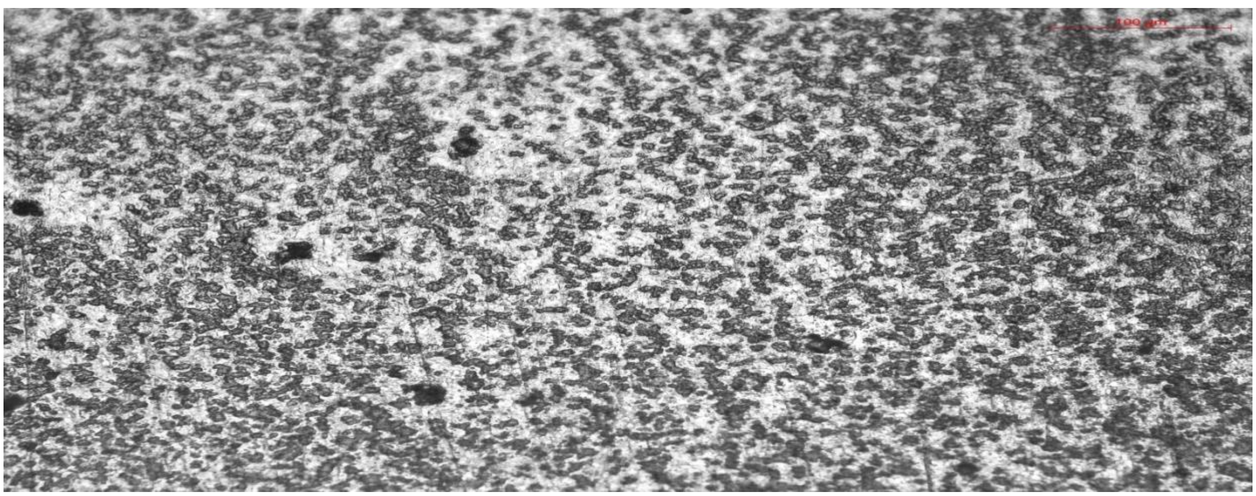


Figure 25:quenched tata tmt (200x)

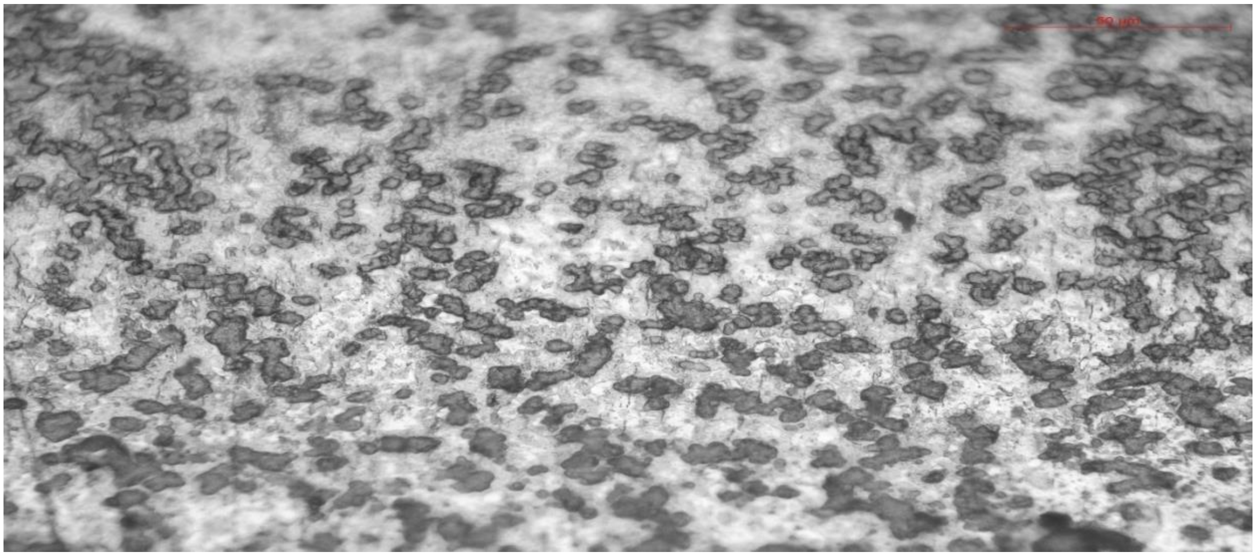


Figure 26: quenched tatatmt(500x resolution)

It can be seen that the above microstructure of quenched tata tiscon TMT bar consists mainly of white ferrite grains and dark grey martensite with less amount of pearlite. Sudden quench of sample from austenitic region is the reason behind the formation of martensite.

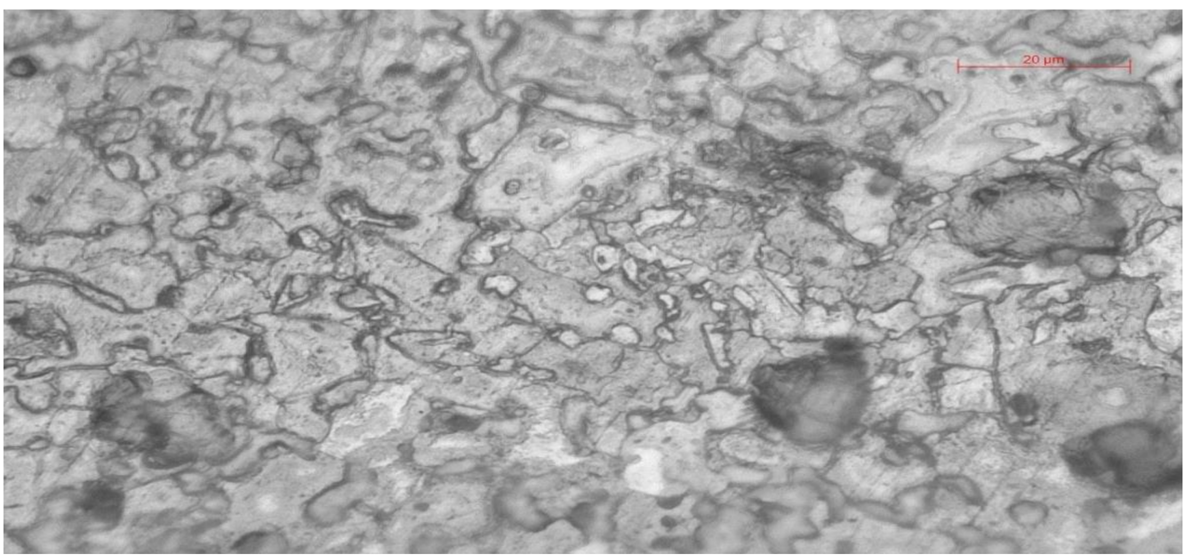


Figure 27: quenched srmbtmt (500x resolution)

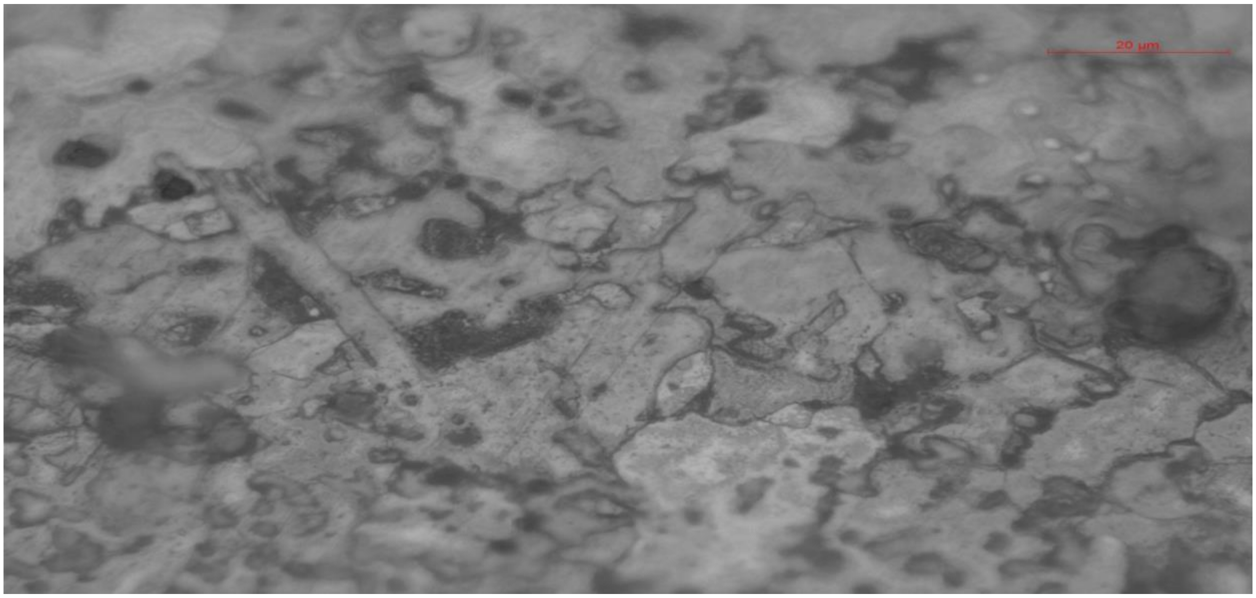


Figure28 :quenched srmb tmt(1000x resolution)

The above magnified microstructure of srmb TMT bar we can observe that the ferrite-pearlite region is less as compared to it's as received and air cooled samples.

The dark grey region which is more in amount is martensite. The sudden cooling from austenitic temperature is the reason behind generation of martensite.

Microstructure of welded and Heat affected zone

HAZ formed during welding is an area in which some structural changes in the welded material take place as the result of experienced temperature. There was a development of a recrystallization reaction in HAZ, with the partial dissolution of the colonies of pearlite (dark color). Depending on the distance from the weld, the different parts of the HAZ can be affected differently during the welding process.There are many descriptions of the HAZ, because it can be divided in different subzones and each subzone has its own microstructure.

Figure 29 : welded sample and polished welded sample

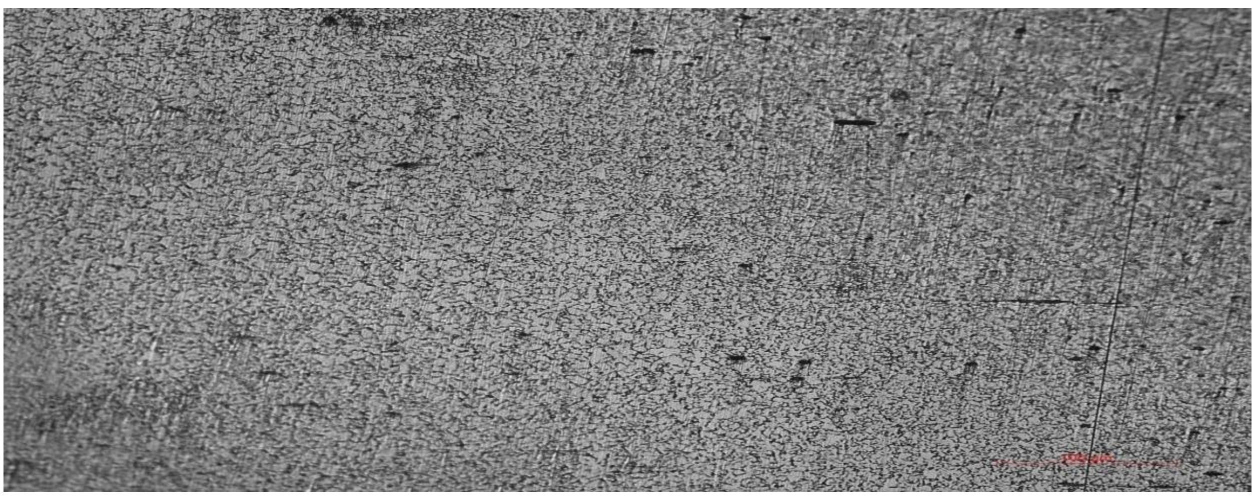


Figure 30 :parent metal (tmt bar) 200x

Microstructure of parent metal tmt bar consists high amount of white grain ferrite and black grain pearlite,ferrite-pearlite transition zone throughout the sample.

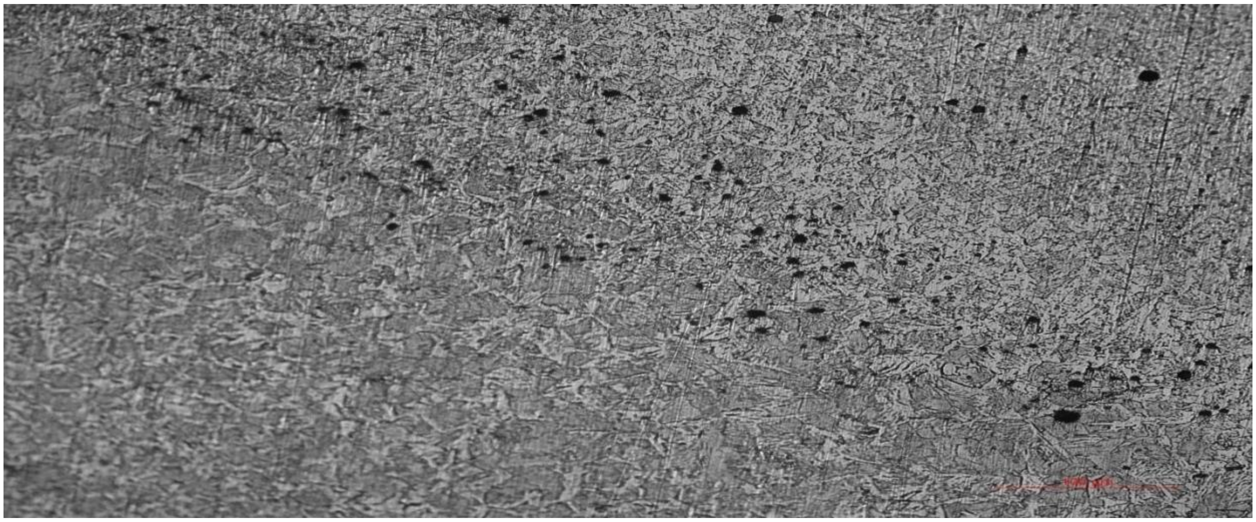


Figure 31: transition zone of heat affected zone and welding zone 500x

In the above image the grain difference between welded zone and heat affected zone can be easily observed.The grains of welded zone are much smaller than heat affected zone.In this metal arc weldingprocess we used mild steel electrode.

Microstructure of the transition zone of HAZ predominantly self-tempered martensite ,pearlite ferrite

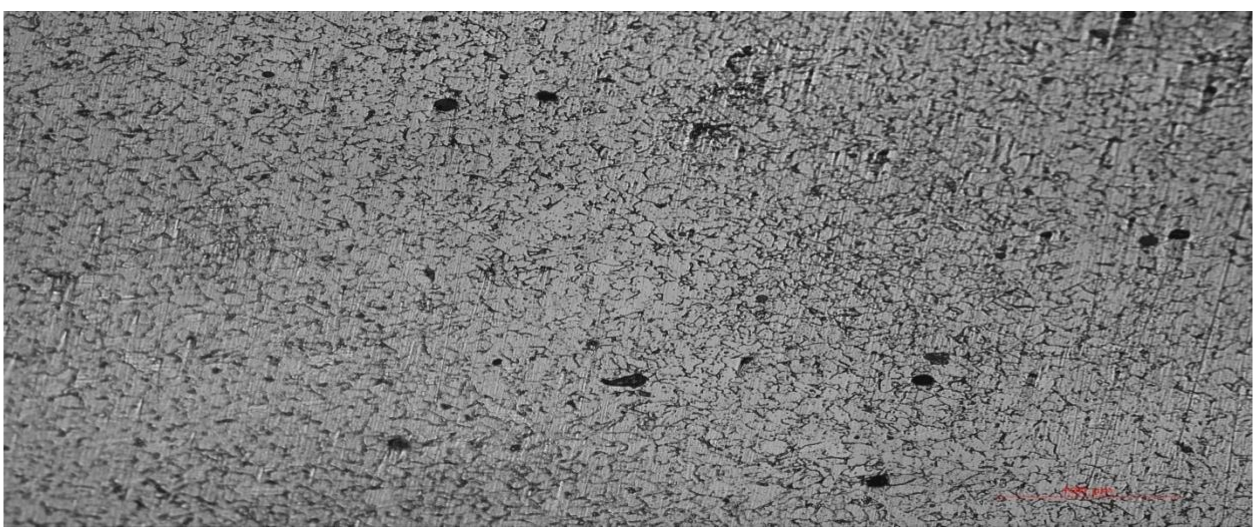


Figure 32: welded zone

The weld metal microstructure of fusion welded joints is greatly influenced by the chemical composition of filler metal and the heat input of the process.

In our welding process we used stainless steel as the filler metal, the microstructure of the welding zone here contains largely ferrite, pearlite and dark gray martensite.

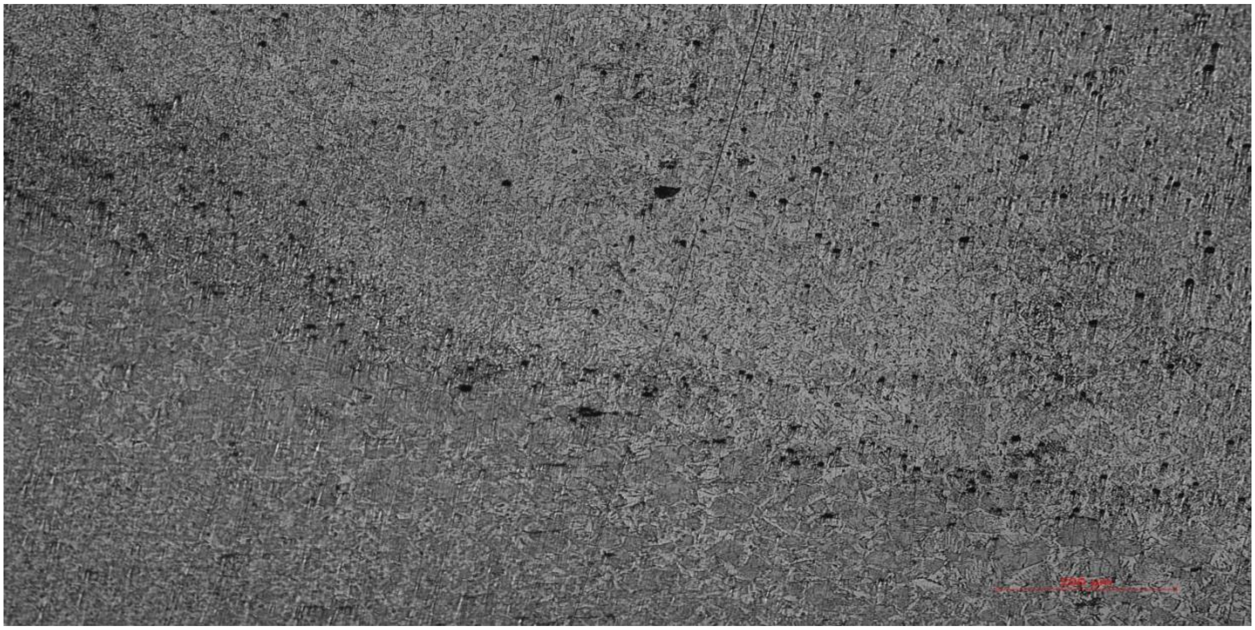


Figure 33 : microstructural view of transition zone between heat affected zone and partially transformed zone.

The HAZ was subdivided into two regions, the partially melted zone (PMZ) and the “true” heataffected zone (T-HAZ). The PMZ exists in all fusion welds made in alloys since a transition from 100% liquid to 100% solid must occur across the fusion boundary, there are many possible metallurgical reactions in the HAZ: recrystallization, grain growth, phase transformations such as precipitation, and residual stress and stress relaxation.

VICKERS HARDNESS TEST of different tmt bars(tata tiscon,srmb,captain)

Objectives

To study the variation of hardness of different tmt bar samples by VICKERS hardness test.

Procedure:

1Clean the surface at the specimen .
2. Fix the indentor in the hardness tester and switch on the power supply.
3. Place the specimen with a cleaned surface facing the indentor on the anvil at work table.
4. Focus the workpiece surface for clean visibility by rotating the hand wheel at the work Table upwards and downwards.
5. Select the load specified (P) push button available on the right side at the hardness Tester.
6.Actuate the electric push button (Green Button) at the front for loading, the loading lever starts moving up words and reaches the study position.
7.Now release the loading lever slowly and bring it to the downward position.
8. For major reading adjust the display at the indentation made by the indentor to coincide with themicrometre on the display screen.
9. For major (minor) reading adjust the movable side at the micrometre and note down the total reading.
10. The measurement is to be made for two opposite corners of the diagonal indentation denoted as d1 and d2.
12. Repeat the above procedure for different tmt rebars.

Figure34:Vickers hardness test machine

Figure35:Vickers hardness test machine

RESULT of VICKERS Hardness test of different tmtrebars(TATA Tiscon 550D ,SRMB 550D,Captain 550D).

The Vickers number (HV) is calculated using the following formula:

$HV = 1.854(P/D^2)$,

with P being the applied load (measured in kilograms) and D^2 the area of the indentation (measured in square milimeters).

VICKER’S values are generally independent test load.

In our experiment the applied load was 30 kg.

VICKERS Hardness number test result of TATA Tisconfe550D tmt bar

For Core region

D1	D2	D=(D1+D2)/2	VHN
.563	.561	.562	176.124
.562	.561	.5615	176.41
.565	.567	.566	173.649

For Casing region

D1	D2	D=(D1+D2)/2	VHN
.543	.547	.545	187.256
.543	.545	.544	187.97
.539	.543	.541	190.036

VICKERS Hardness number test result of SRMB tmt bar

Core region

D1	D2	D=(D1+D2)/2	VHN
.541	.535	.538	192.19
.542	.538	.540	190.74
.541	.549	.545	185.21

Casing Region

D1	D2	D=(D1+D2)/2	VHN
.528	.526	.527	200.267
.532	.536	.534	195.089
.527	.523	.525	201.796

VICKERS Hardness number test result of CAPTAIN tmt bar.

Core Region

D1	D2	D=(D1+D2)/2	VHN
.554	.557	.555	180.569
.564	.560	.562	176.124
.561	.555	.558	178.633

Casing Region

D1	D2	D=(D1+D2)/2	VHN
.552	.544	.548	185.212
.543	.547	.545	187.256
.540	.548	.544	187.97

Conclusion

From the VICKER’S Hardness test result we can conclude that hardness of outer region/ casing region is higher than core region by 10-15 VICKER’S Hardness number.

The outer portion of tmt bar is more harder than core ,that’s the reason behind corrosion resistance behavior of outer or casing region and core region is less harder which makes tmt bar to absorb shock.

From the above VICKER’S Hardness test result we can also say that SRMB TMT bar is more harder than CAPTAIN TMT bar and TATA Tiscon TMT bar.

VICKER’S MICRO HARDNESS test of TMT bar

Micro hardness Testing is a method of determining a material's hardness or resistance to deformation when test samples are not suitable for macro-hardness. Microhardness testing is ideal for evaluating hardness of very small/thin samples, complex shapes, individual phases of a material, and surface coatings/platings.

In micro hardness testing, an indentation is made on the specimen by a diamond indenter through the application of a load P . The size d of the resultant indentation is measured with the help of a calibrated optical microscope and the hardness is evaluated as the mean stress applied underneath the indenter. The measurement of hardness with a microscope attachment, comprising the indenter and means for applying small loads, dates back more than 50 years. Initially used for small components (watch gears, thin wire, foils), microhardness testing was extended to research studies of individual phases, orientation effects in single crystals, diffusion gradients, ageing phenomena, etc. in metallic and ceramic materials.

Micro hardness tests need to be very carefully controlled and replicated, using as large a load as possible. The surface of the specimen should be strain free (electropolished), plane and perpendicular to the indenter axis. The indenter is lowered slowly at a rate of <1 mm min^{-1} under vibration-free conditions, eventually deforming the test surface in a manner analogous to steady-state creep. This condition is achieved within 15 s, a test period commonly used.

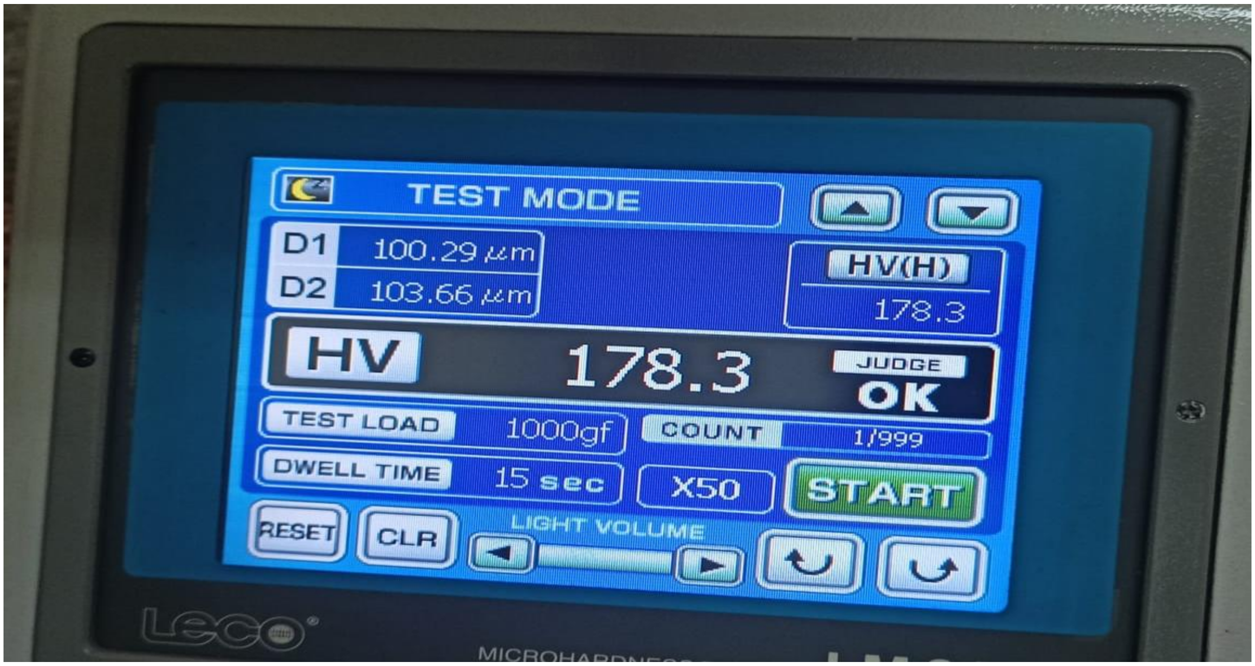
VICKER'S MICRO HARDNESS test result of TATA TISCON TMT bar

The Vickers number (HV) is calculated using the following formula:

$HV = 1.854(F/D^2)$,

with F being the applied load (measured in kilograms-force) and D^2 the area of the indentation (measured in square millimeters).

Load(gf)	Dwell time(sec)	D1(micro meter)	D2(micro meter)	HV
1000	15	100.29	103.66	178.3
1000	15	102.84	102.84	177.8
1000	15	100.44	102.64	179.9

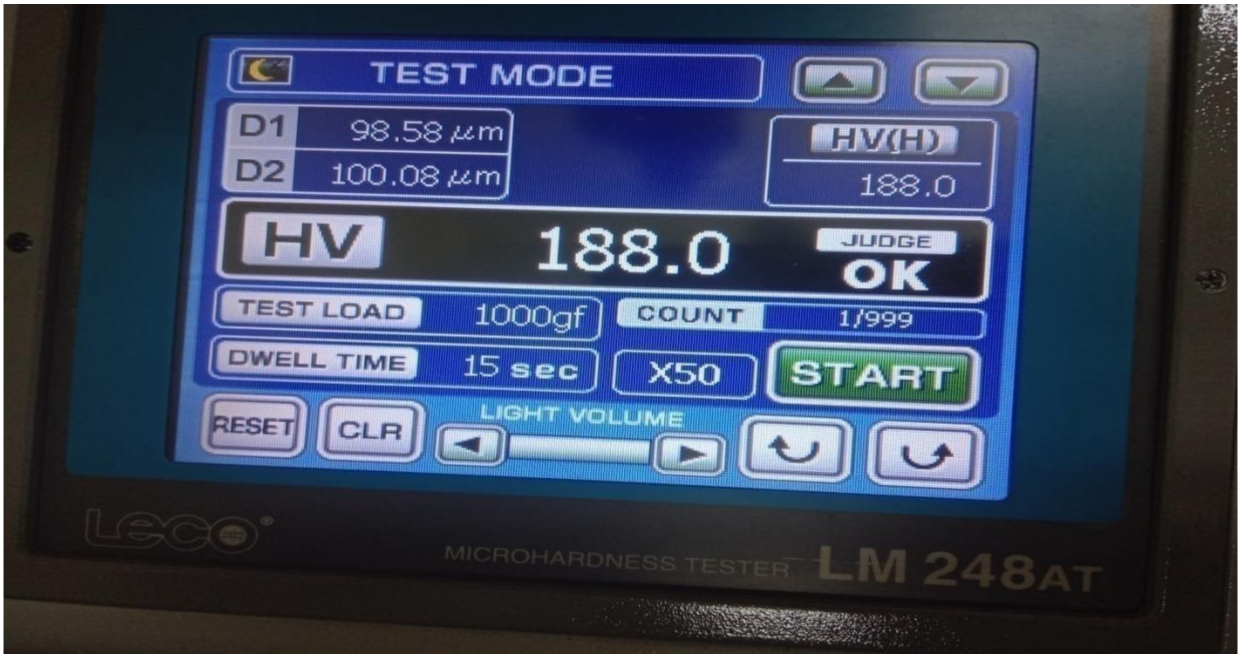


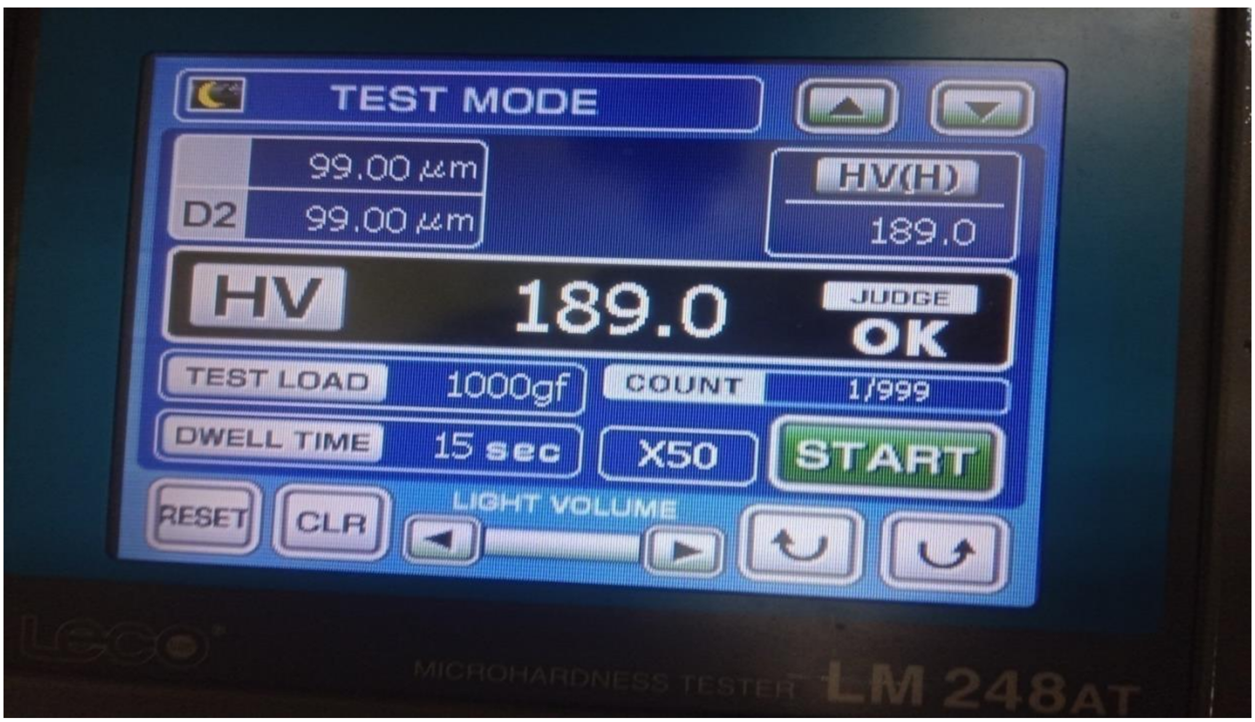
VICKER"S micro hardness test result of tata tiscontmt bar

VICKER"S micro hardness test result of tata tiscontmt bar

VICKER'S MICRO HARDNESS test result of SRMB TMT bar

Load(gf)	Dwell time(sec)	D1(micro meter)	D2(micro meter)	HV
1000	15	99.25	99.25	188.2
1000	15	98.58	100.08	188
1000	15	99	99	189





VICKER'S micro hardness test result of srmbtmt bar

VICKER'S MICRO HARDNESS test result of CAPTAIN TMT bar

Load(gf)	Dwell time(sec)	D1(micro meter)	D2(micro meter)	H V
1000	15	100.23	101.27	182.7
1000	15	100.59	100.44	185.4
1000	15	100.15	101.29	183.6

VICKER'Smicro hardness test result of CAPTAIN tmt bar

Comparision

The VICKER'S hardness test which is independent of load, from the above micro hardness test result we can say that the hardness number of VICKER'S hardness test and hardness number of VICKER'S micro hardness test almost near to each other for all the TMT bars (tata tiscon, srmb ,captain) in the core region.

VICKER'S Hardness test of air cooled tmt bar samples

Formula used

VICKERS HARDNESS NUMBER=($1.854P \div D^2$)

Where P is applied load and D^2 is the area of indentation.

In our test the load was 30 kgf.

VICKER'S Hardness test result of air cooled TATA TISCON TMT bar

D1	D2	D=(D1+D2)/2	VHN
.572	.568	.570	171.19
.579	.567	.573	169.403
.581	.572	.5765	167.352

VICKER'S Hardness test result of air cooled SRMB TMT bar

D1	D2	D=(D1+D2)/2	VHN
.561	.555	.558	178.633
.550	.552	.551	183.200
.554	.557	.555	180.569

VICKER'S Hardness test result of air cooled CAPTAIN TMT bar

D1	D2	D=(D1+D2)/2	**VHN**
.563	.569	.566	173.649
.565	.567	**.566**	173.649
.567	**.573**	**.570**	171.190

Comparison

The above VICKER'S Hardness test result gives us hardness number of air cooled tmt bar samples (TATA Tiscon ,SRMB ,CAPTAIN) is lower than as received samples ((TATA Tiscon ,SRMB ,CAPTAIN).

The decrease of hardness number of air cooled samples indicate that the toughness (shock absorbing property) increase a little. The increasing order of VICKER'S Hardness number of air cooled samples are tata tiscon< captain <srmb.

VICKER'S Hardness test of water quenched tmt bar samples

Formula used

VICKERS HARDNESS NUMBER=($1.854P \div D^2$)

Where P is applied load and D^2 is the area of indentation.

In our test the load was 30 kgf.

VICKER'S Hardness test result of water quenched TATA TISCON TMT bar

D1	D2	D=(D1+D2)/2	VHN
.525	.519	.522	204.122
.521	.525	.523	203.342
.516	.524	.520	205.695

VICKER'S Hardness test result of water quenched SRMB TMT bar

D1	D2	D=(D1+D2)/2	VHN
.515	.511	.513	211.347
.510	.514	.512	212.173
.506	.514	.510	213.840

VICKER'S Hardness test result of water quenched CAPTAINTMT bar

D1	D2	D=(D1+D2)/2	VHN
.519	.523	.521	204.906
.517	.523	.520	205.695
.518	.521	.5195	206.091

Comparison

The above VICKER'S Hardness test result gives us hardness number of water quenched tmt bar samples (TATA Tiscon ,SRMB ,CAPTAIN) is more than as received and air cooled samples (TATA Tiscon ,SRMB ,CAPTAIN). The higher the number in each sample have a tendency to increase brittleness.

The decreasing order of VICKER'S hardness number of the result is SRMB TMT > TATA Tiscon = CAPTAIN TMT.

Corrosion behaviours of high strength TMT steel rebars(tata tiscon,srmb,captain)

Steel has been used for many decades in structural applications because of its good combination of mechanical properties. As per recent concept to reduce steel consumption in reinforced cement concrete (RCC) structures, designers recommend high strength steel bars. There are various routes for their production such as microalloying, thermomechanical treatment, cold working, etc. For steel bars of thermomechanical treatment (TMT) route, some designers believe these steel bars to be more sensitive to corrosive environment. To verify this, corrosion behaviours of high strength steel bars of 550D (Ductile bar of yield strength 550MPa) grade of three different industries have been studied in fresh water and sea water. However, strength levels have no influence the corrosion rate. A relation has also been found the severity of corrosion damage among different tmt bars.

Uniform Corrosion

Uniform attack is a form of electrochemical corrosion that occurs with equivalent intensity over the entire exposed surface and often leaves behind a scale or deposit. In a microscopic sense, the oxidation and reduction reactions occur randomly over the surface. Familiar examples include general rusting of steel and iron and the tarnishing of silverware. This is probably the most common form of corrosion. It is also the least objectionable because it can be predicted and designed for with relative ease.

In our experiment of corrosion of different tmt bars the dominating corrosion types are ***Uniform corrosion*** *over the entire exposed surface.*

Equipments

To calculate corrosion penetration rate(CPR) via Uniform Corrosion method equipments needed are ***bekers,freshwater,marinewater,sutures,hackshaw,tmt bar sample,sutures,verniercaliper,weight machine.***

Objective

Calculation and comparison of corrosion penetration rate of differenttmt(tata tiscon,srmb,captain) samples.

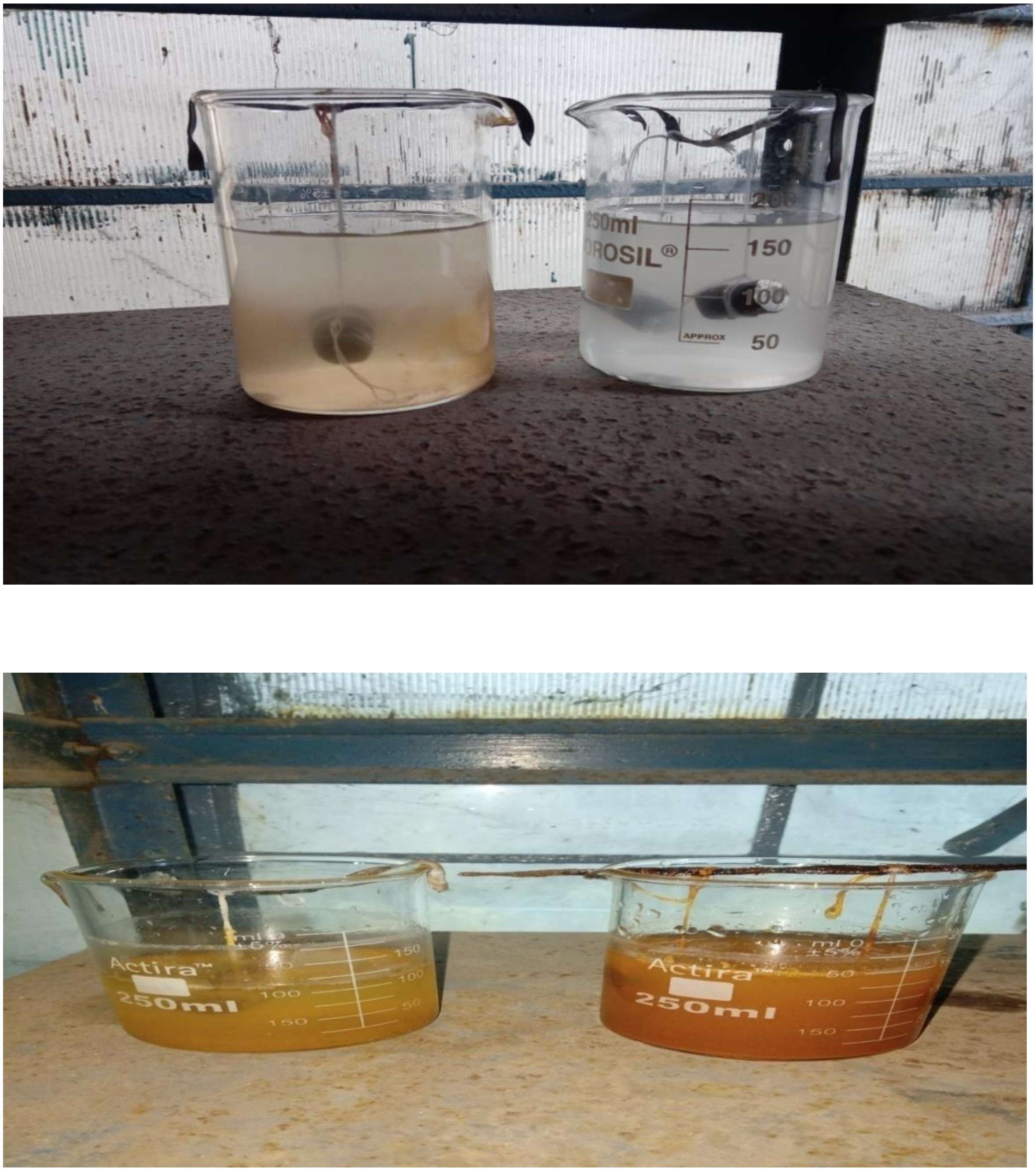


Figure36:corrosion of tmt bars

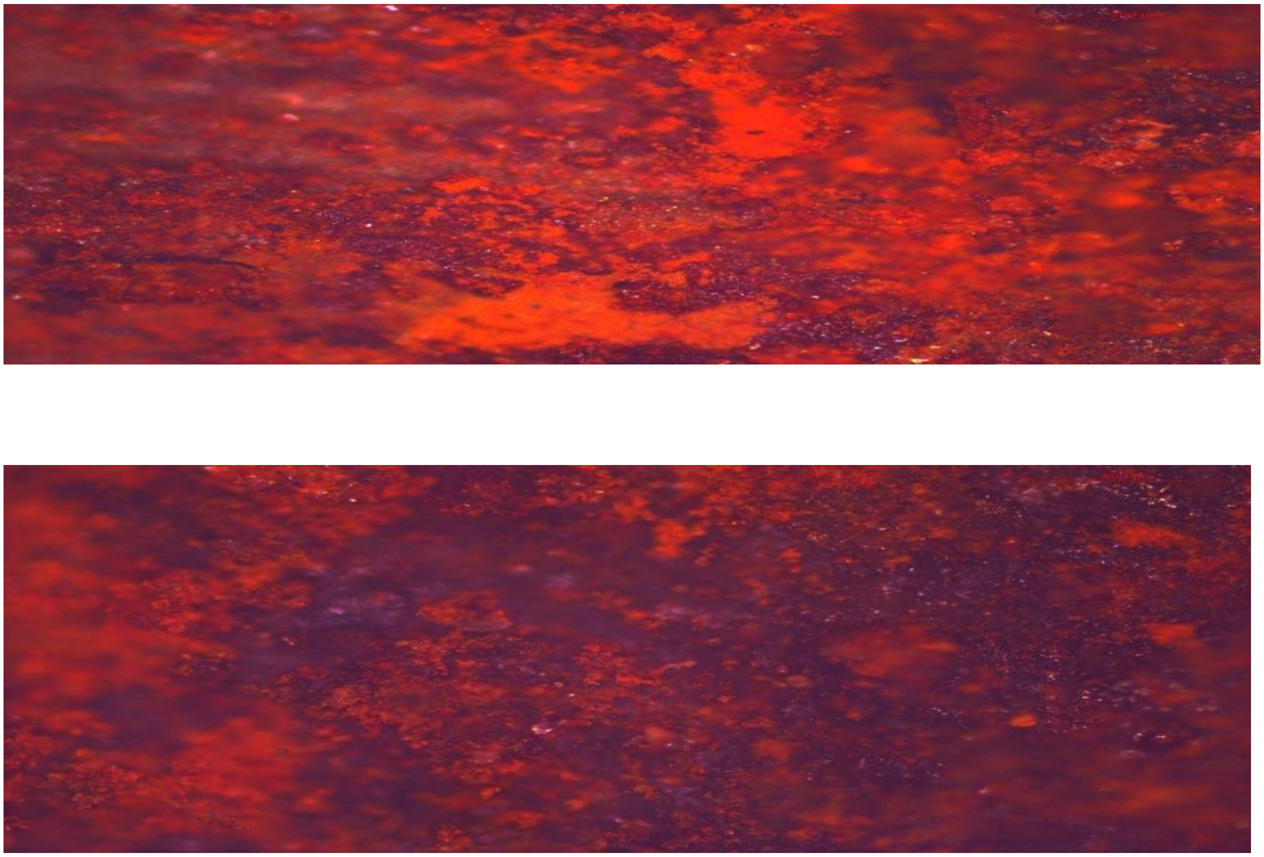


Figure 37 :rust formation microstructure of tmt bar.

The above image of microstructure contains reddish brown iron oxide formed by the reaction of iron and oxygen in the catalytic presence of water or air moisture.

Here the rust consists of hydrous iron oxides ($Fe_2O_3.nH_2O$) and iron oxide hydroxide , and is typically associated with the corrosion of refined iron.

Formula Used

Corrosion Penetration Rate

The corrosion rate, or the rate of material removal as a consequence of the chemical action, is an important corrosion parameter. This may be expressed as the corrosion penetration rate (CPR), or the thickness loss of material per unit of time. The formula for this calculation is

$$CPR = KW / \rho At$$

where W is the weight loss after exposure time t ,ρ and A represent the density and A is exposed specimen area, respectively, and K is a constant, its magnitude depending on the system of units used. The CPR is conveniently expressed in terms of either mils per year (mpy) or millimeters per year (mm/yr). In the first case,(K = 534)to give CPR in mpy (where 1 mil 0.001 in.), and W, r, A, and t are specified in units of milligrams, grams per cubic centimeter, square inches, and hours, respectively. In the second case,(K = 87.6) for mm/yr, and units for the other parameters are the same as for mils per year, except that A is given in square centimeters. For most applications, a corrosion penetration rate less than about 20 mpy (0.50 mm/yr) is acceptable.

Several pieces of data must be collected to calculate the corrosion penetration rate for any given metal:

1. The weight lost (the decrease in weight of the metal during the period of reference).
2. The density of the metal.
3. The total surface area initially present.
4. The time taken for the metal to corrode.

Corrosion test

For corrosion tests, simple immersion mass loss process for determining the corrosion rates has been used. The corrosion rates of different types of tmt bars of each company in various test media (fresh water and sea water) have been compared. Here it is to be mentioned that for corrosion tests steel bars were used in the as received conditions and for all cases, corrosion tests were continued for 90 days. However, after every 15 days (one week) of immersion, test samples were taken out of the solution, washed in water to clean the rusts accumulated on the tmt bar surfaces and they were then completely dried. After that the mass losses were measured using a very sensitive digital balance. This experimental cycle has been observed for 90 days, for each sample.

Corrosion of TATA TISCON TMT bar

Initial mass=16.491gm=16491mg.

Volume of specimen=2.21*$10^{-6}m^3$

Density=7461.538kg/m^3

=7.461gm/cm^3

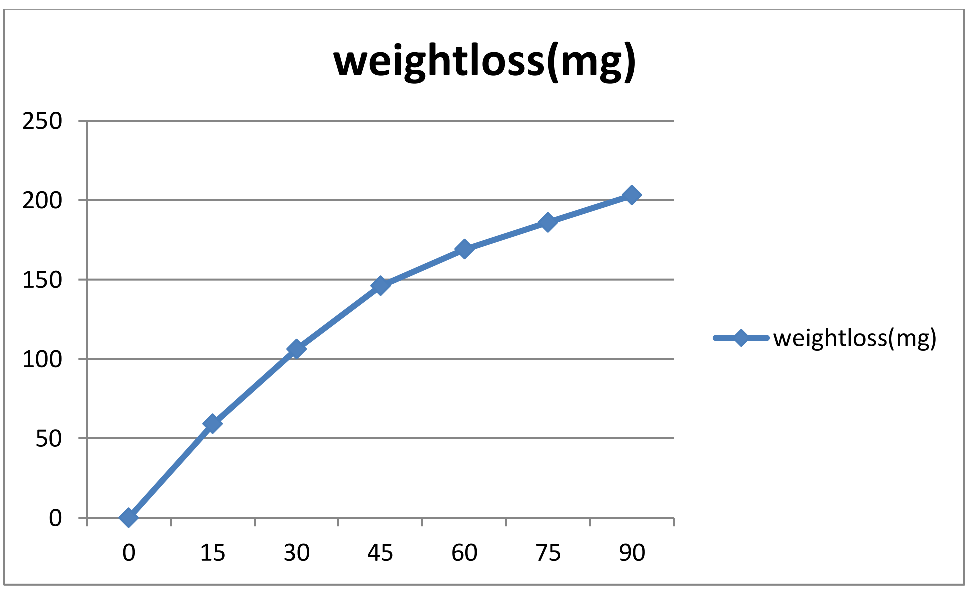
Remaining mass vs experiment days table

days	15	30	45	60	75	90
mass	16432	16385	16345	16322	16305	16288

Total mass loss=(16491-16288)mg=203mg.

Total days=90

Time of experiment = 90× 24 hours



Weight loss(Y axis) versus time in days(X axis) graph of corrosion

Length of specimen=1.98cm.

Radius of specimen=.57cm.

Total exposed surface area=(cross sectional area + cylindrical surface area)

$$= (2\pi r^2 + 2\pi rh) = (2\times 3.14\times .57^2 + 2\times 3.14\times .57\times 1.98)$$

$$=9.1273cm^2$$

Corrosion penetration rate=(kW/ῤAt)

Where,k is constant

k =534 in mills per year.k=87.6 in mm per year.

W=weight loss after exposure time.

A= exposed area.

t =time.

ρ=density of specimen.

CPR can be calculated by two units such as MILLS PER YEAR and mm per YEAR.

CPR of TATA Tiscontmt bar=.1208 mm/year.

Corrosion of SRMB TMT bar

Mass of specimen=14.57gm=14.57*10^{-3}kg/m^3.

=14570mg.

Volume of specimen=1.92ml

=1.92*$10^{-6}$$m^3$

Density =7588.541kg/m^3

Remaining mass vs experiment day table

Days	0	15	30	45	60	75	90
mass	14570	14509	14460	14405	14371	14350	14340

Total weight loss=(14570-14340)mg

=230mg.

Total days=90

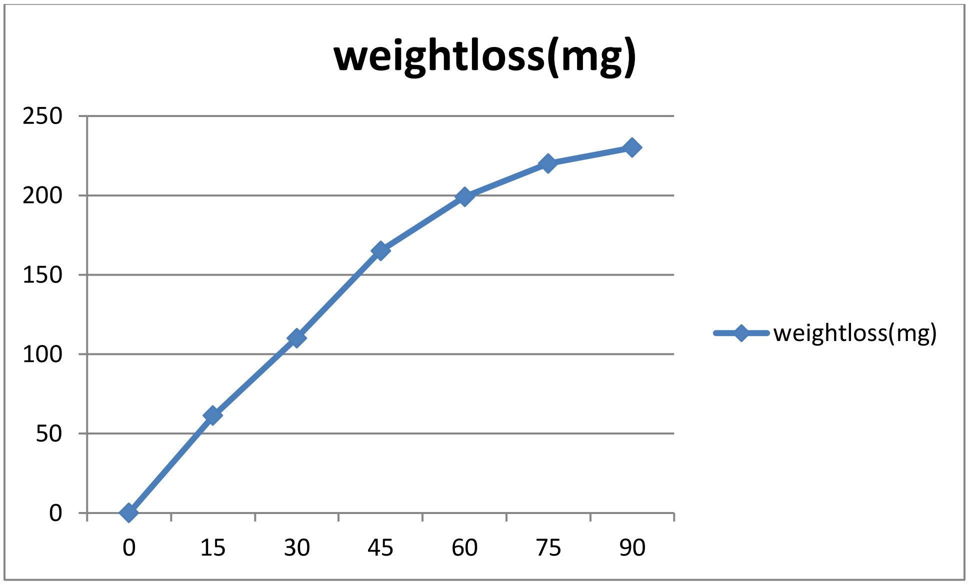


Figure:weight loss(Y axis) versus experiment days (X axis) graph of corrosion

length of specimen=1.67cm.

radius of specimen=.56cm.

exposed surface area=(cross sectional area + cylindrical surface area)

$= (2\pi r^2 + 2\pi rh) = (2\times 3.14\times .56^2 + 2\times 3.14\times .56\times 1.67)$

$=7.842cm^2$

Value of constant =87.6

Corrosion Penetration Rate of SRMB TMT bars=.1567mm/year.

Corrosion test of CAPTAIN TMT bar

Mass of specimen=15.161gm.

= 15161mg.

=$15.161*10^{-3}$kg.

Volume of specimen=$2.07*10^{-6}m^3$.

Density of specimen=7323.681kg/m^3.

Remaining weight versus days table

Days	0	15	30	45	60	75	90
mass	15161	15092	15031	14969	14941	14922	14903

Total weight loss=(15161-14903)mg.

=258mg.

Total days=90.

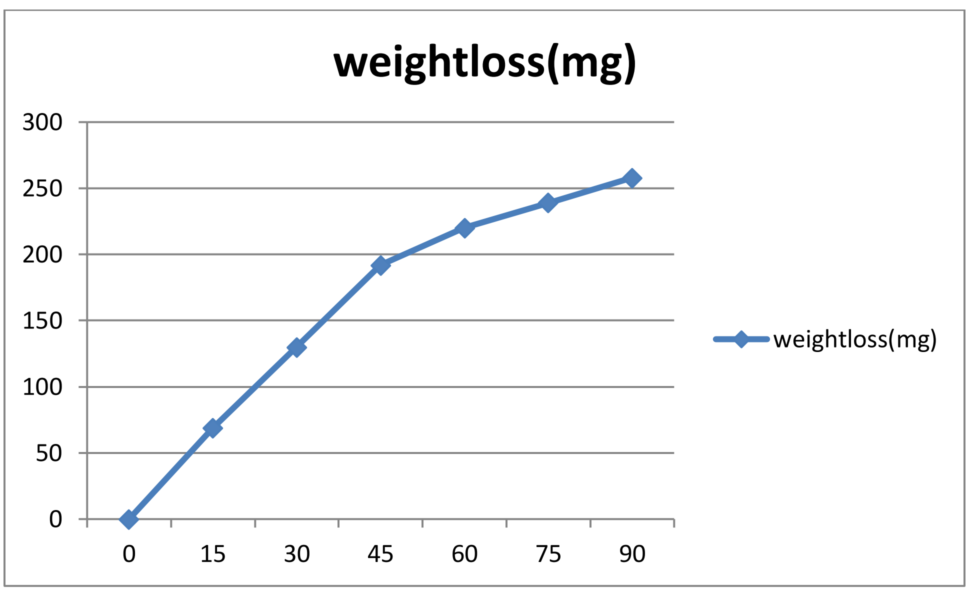


Figure: weight loss(Y axis) versus experiment days (X axis) graph of corrosion

Length of specimen=1.85cm.

Radius of specimen=.57cm.

Total exposed area= (cylindrical surface area+ cross sectional area)

$$= (2\pi r^2 + 2\pi rh) = (2\times 3.14\times .57^2 + 2\times 3.14\times .57\times 1.85)$$

$$=8.661\text{cm}^2.$$

Value of constant k=87.6.

Corrosion Penetration Rate of

CAPTAIN TMT bar=.1649mm/year.

Conclusion

Corrosion penetration rate of TATA Tiscon TMT bar is .1208 mm/ year ,SRMB TMT bar is .1567 mm/ year and CAPTAIN TMT bar is .1649 mm/ year. The corrosion penetration rate results of all three types of TMT bar are very close to each other.

For most applications, the acceptable range of corrosion penetration rate is less than .50 mm /year.

From our experimental corrosion penetration rate value we can conclude that all different companies samples are acceptable and have very good corrosion resistance property .

Corrosion test in marine water

Corrosion is the gradual destruction of materials by chemical reaction with their environment. In the most common use of the word, this means electrochemical oxidation of metal in reaction with an oxidant such as oxygen. Corrosion is a major problem in desalination plants as well as other industrial applications. In parts of the world with short supply of fresh water, there is an increasing use of sea water for fresh water production.Most metal structures used in sea water (ships, oil platforms, piers, pipelines, etc.) are traditionally made of mild low-carbon and low alloy steels as well as copper based alloys. The salt content in the water causes both corrosion and abrasion in piping, tanks and process equipment. Protecting these valuable assets from the effects of exposure to seawater is a critical challenge for corrosion engineers in these regions.

Various construction with TMT bars also done like bridges ,harbours,portsetc.Thistmt bar tolerate marine environment and saline water.In our experiment we have tried to observe the weight loss of TMT bar samples with days by immersing the samples in saline water which collected from diamond harbor,west Bengal to calculate corrosion penetration rate.

Corrosion of tata tiscontmt bar in saline water

Mass of specimen=17.111 gm.

=17111 mg.

Density of specimen=7461.538 kg/m^3.

Remaining weight versus days table

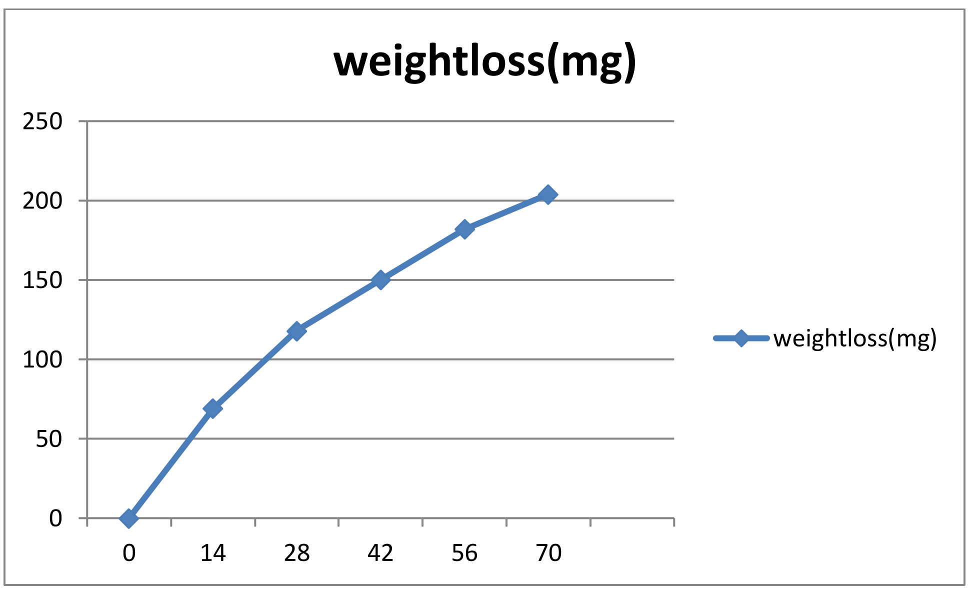
days	0	14	28	42	56	70
mass	17111	17042	16993	16961	16929	16907

Total weight loss=(17111-16907) mg

=204 mg.

Experiment days = 70

Experiment time =70× 24 hours



Corrosion experiment days (X axis) versus weight loss (mg) (Y axis) line graph.

Length of specimen=19.15 mm=1.915cm.

Exposed area of the specimen=(cylindrical surface area + cross sectional area of the specimen)

$= (2\pi rh + 2\pi r^2)$

$=8.9913\ cm^2$.

Value of constant k=87.6

Corrosion penetration rate of TATA TISCON TMT bar= .158 mm/year.

Corrosion of SRMB TMT bar in saline water

Mass of specimen=14.880gm.

=14800mg.

Density of specimen=7588.541 kg/m^3.

Remaining weight versus days table

days	0	14	28	42	56	70
mass	14.880	14.819	14.760	14.729	14.708	14.695

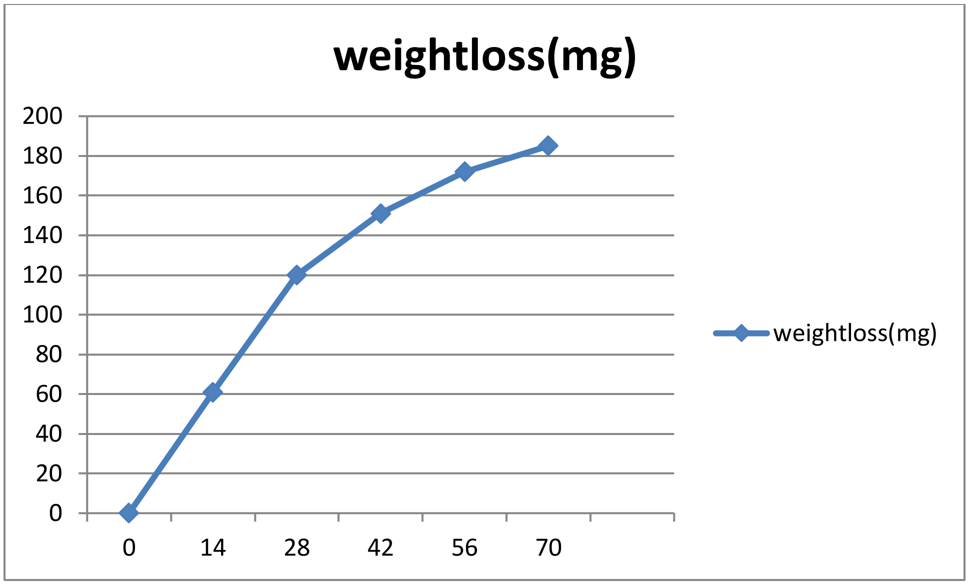
Total days =70

Experiment time = 70× 24 hours

Total weight loss=(14.880-14.965)mg

=185mg

Length of specimen=1.71cm.



Corrosion experiment days (X axis) versus weightloss(mg) (Y axis) graph

Total surface area of specimen =(cylindrical surface area+cross sectional area)

$$= (2\pi rh + 2\pi r^2)$$

$$=7.8767 \text{ cm}^2.$$

Value of constant k for mm per year=87.6

Corrosion penetration rate(CPR) of SRMB TMT bar=.1714 mm/year.

Corrosion of CAPTAIN TMT bar in marine water

Mass of specimen=16.611 gm.

=16611 mg.

Density of specimen=7323.681 kg/m^3.

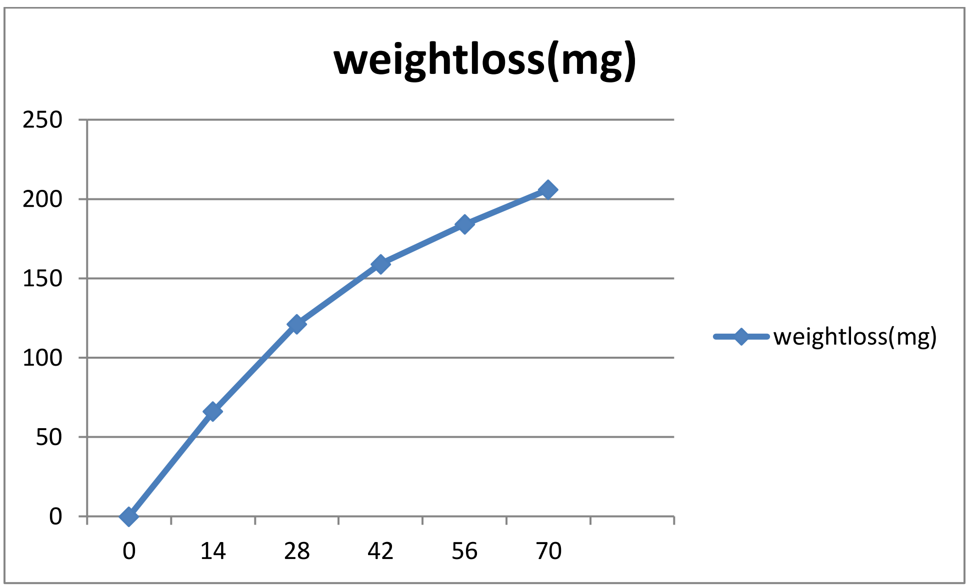
Remaining weight versus days table

Days	0	14	28	42	56	70
mass	16611	16561	16515	16475	16430	16405

Total weight loss=(16611-16405)mg

=206 mg.

Experiment time = 70× 24 hours



Corrosion experiment days (X axis) versus weightloss(mg) (Y axis) line graph

Length of specimen=1.912 cm.

Total surface area=(cylindrical surface area + cross sectional area)

$$= (2\pi r h + 2\pi r^2)$$

=8.6174 cm^2.

Corrosion penetration rate(CPR) of CAPTAIN TMT bar =.1726 mm/year.

Conclusion

Although the corrosion penetration rate values of all three types of TMT bar are higher in marine water with respect to fresh water but the values are much lower than acceptable range of .50 mm/year. So we can say that we can use all the three types (TATA Tiscon ,SRMB ,CAPTAIN) of TMT bar in saline region as well.

Corrosion test of quenched TMT bars in marine water

CPR is Corrosion Penetration Rate (mpy) or reduction in the thickness of the material per time unit. Unit: mile per year (mpy) or millimeter per year (mm/yr). W is weight loss during testing (mg) = mo – m, m is weight after corroded, mois weight before corroded.

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Several pieces of data must be collected to calculate the corrosion penetration rate for any given metal:

The weight lost (the decrease in weight of the metal during the period of reference).
The density of the metal.
The total surface area initially present.
The time taken for the metal to corrode.

CPR =(KW/ ρ At)
K= constant =87.6 ,for mm/ year unit
W = weight loss
ρ= density of specimen in gm/ cm^3
A = exposed surface area in cm^2.

t= time in hours

Corrosion penetration rate of quenched TATA TISCON tmt bar

Initial weight= 9.975 gm

Final weight after 60 days=9.909 gm

Experiment days = 60

Experiment time = 60× 24 hours

Remaining mass versus experiment days table

days	0	15	30	45	60
remaining mass	9975	9949	9929	9918	9909

Total weight loss= (9975-9909) mg

=66 mg.

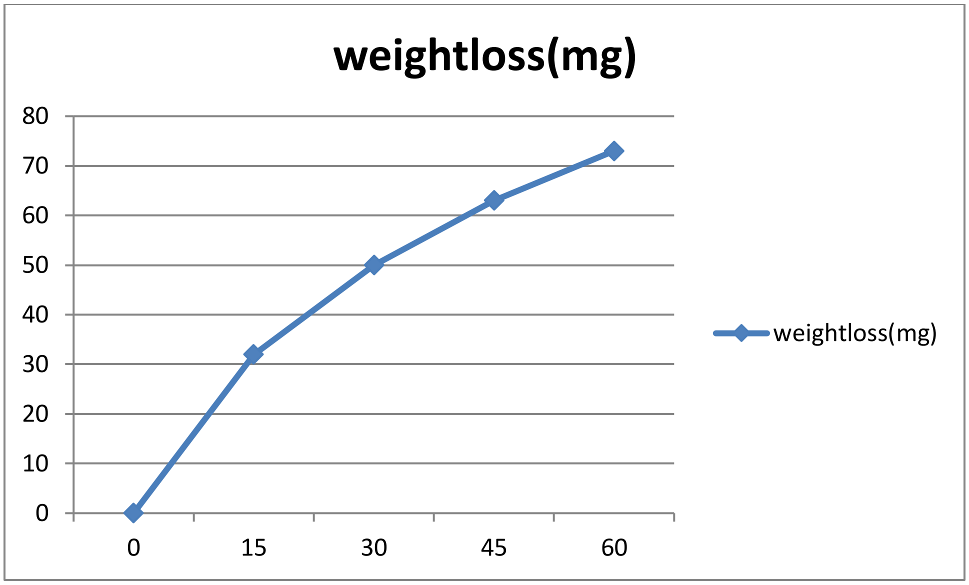
Length of the specimen= 1.219 cm

Radius of specimen =.57 cm

Exposed area of the specimen = (cylindrical surface area + cross sectional area of the specimen)

= 6.403 cm^2

Corrosion penetration rate of quenched tata tiscontmt bar =.0837 mm/ year.



Corrosion experiment days (X axis) versus weight loss(mg)(Y axis) line graph

Corrosion penetration rate of quenched SRMBtmt bar

Initial weight= 9.395 gm =9395 mg

Final weight after 60 days=9.331 gm= 9331 mg

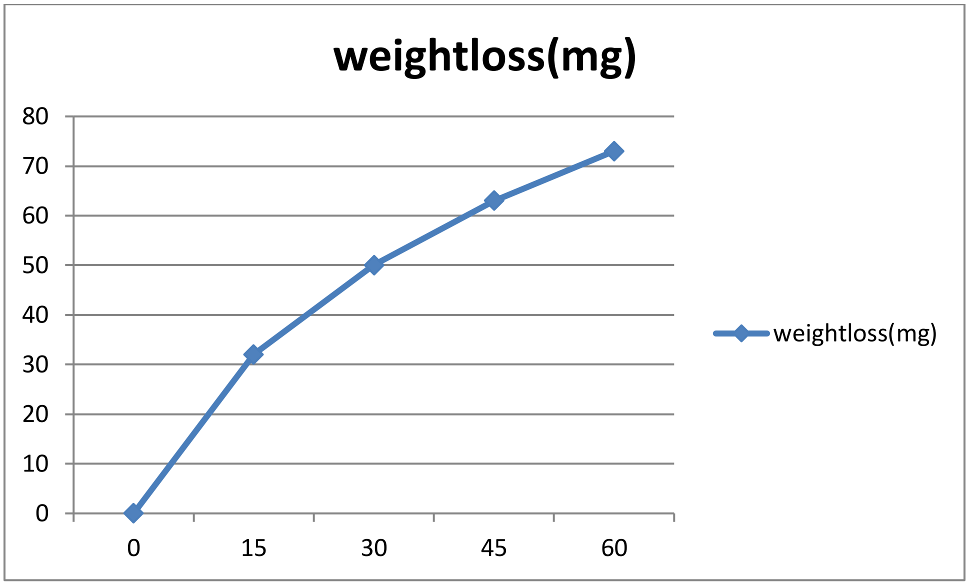
Experiment time = 60× 24 hours

Remaining mass versus experiment days table

days	0	15	30	45	60
Remaining mass	9395	9375	9356	9339	9331

Total weight loss= (9395-9331) mg

=64 mg.



Corrosion experiment days(X axis) versus weight loss (mg) (Y axis) line graph

Length of the specimen= 1.083 cm

Radius of specimen =.56 cm

Exposed area of the specimen = (cylindrical surface area + cross sectional area of the specimen)

= 5.778 cm^2

Corrosion penetration rate of quenched SRMB bar =.0888 mm/year.

Corrosion penetration rate of quenched CAPTAIN tmt bar

Initial weight= 10.135 gm = 10135 mg

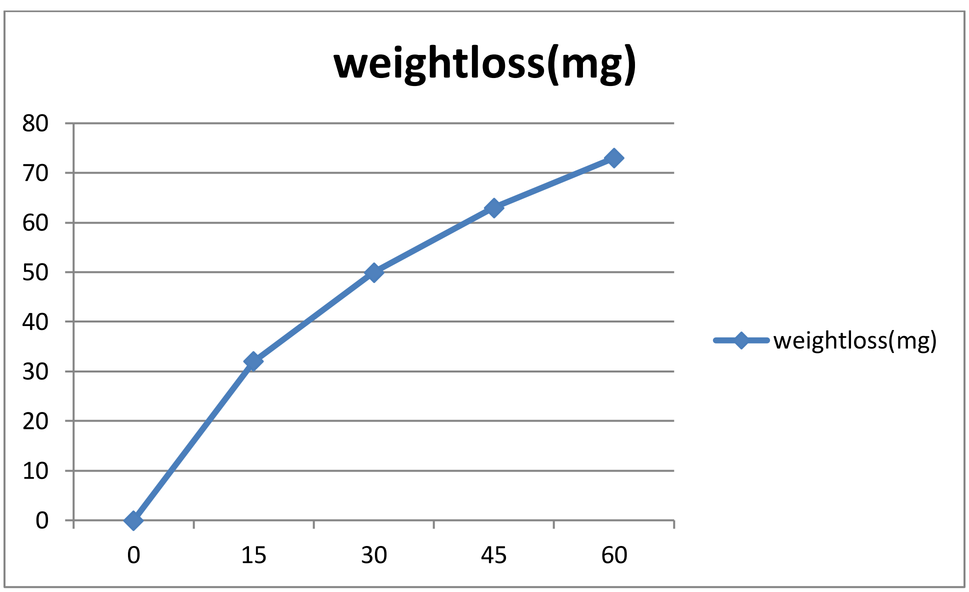
Final weight after 60 days=10.062 gm= 10062 mg

Remaining mass versus experiment days table

days	0	15	30	45	60
Remaining mass	10135	10103	10085	10072	10062

Total weight loss= (10135-10062) mg

=73 mg.



Corrosion experiment days (X axis) versus weight loss (mg) (Y axis) line graph

Length of the specimen= 1.296 cm

Radius of specimen =.57 cm

Exposed area of the specimen = (cylindrical surface area + cross sectional area of the specimen)

= 6.679 cm^2

Corrosion penetration rate of quenched CAPTAIN tmt bar =.0921 mm/year.

Comparision

From the result of quenched tmt bar corrosion penetration rate we can conclude that the CRP value of quenched samples is almost half of as received samples oftmt bars in saline water. By which we can say water quenching made the surface more resistive against corrosion.

The decreasing order of CPR values of water quenched TMT bar samples are

CAPTAIN TMT >(SRMB TMT = TATA TISCON TMT)

Conclusion

1. By high resolution optical microscopic image of microstructure we can say that core of tmt bar contains mainly ferrite and pearlite at the core and peripheral region contains martensite.

2. There is a difference in hardness nember of core and casing of tmtbar ,which we obtained from VICKER'S Hardness test.

3. By doing air cooling heat treatment we can see a little bit decrease in hardness value which tends to increase shock absorbing property.

4. Water quenching of tmt bar gives microstructure of white ferrite grains and dark grey martensite with more amount. The volume fraction of martensite increases with the of water quenching temperature.

5. Water quenching of all three samples of TMT bars (TATATiscon ,SRMB ,CAPTAIN) give more hardness value than as received sample by VICKER'S hardness test.

6. By examine corrosion penetration rate result we can say that the the value of corrosion penetration rate is much lower than the acceptable range of .50 mm per year. So we can say that TMT bar is highly resistive against corrosion.

7. By observing fresh and saline water corrosion test of TMT bars (TATATiscon ,SRMB ,CAPTAIN) we conclude that there is a high corrosion rate in saline water than fresh water and the corrosion penetration rate value of saline water is also much less than the acceptable range of .50 mm per year. So we can say that we can use TMT bar easily in saline environment.

8. The corrosion penetration rate of quenched TMT bar samples is much than As received TMT bar samples.

9. By welding of TMT bar we observed that Heat Affected Zone is the unavoidable heat treated area in the parent metal near the fusion zone during welding where structural transformation

occurs. The heat affected zone showed acicular ferrite , bainite ,martensite and retained austenite, which influenced the mechanical properties of this region.

References

[1]. Material science and Engineering, an introduction by WILLIAM D. CALLISTER,JR.AND DAVID G.RETHWISCH.

[2].Manufacturing Engineering & Technology by SeropeKalpaljain and Steven R.Schmid.

[3].K. Bandyopadhyay *et al.*

Modeling and experiment on microstructure evolutions and mechanical properties in grade 600 MPa reinforcing steel rebar subjected to TempCore process
Mater. Sci. Eng. A
(2019)

[4].M. Mukherjee *et al.*

Prediction of hardness of the tempered martensitic rim of TMT rebars
Mater. Sci. Eng. A
(2012)

[5].A.Y. Elghazouli *et al.*

Experimental evaluation of mechanical properties of steel reinforcement at elevated temperature
Fire Saf. J.
(2009)

[6]Reinforcement for concrete Materials and applications, Developed by Committee E-701, Materials for Concrete Construction, ACI Education Bulletin E2-00 (Reapproved 2006).

[7]. S. K. Paul, S. Majumdar and S. Kundu: 'Low cycle fatigue behaviour of thermo-mechanically treated rebar', Mater. Des., 2014, 58, 402–411.

[8]. URL: https://en.wikipedia.org/wiki/Thermomechanical_processing

[9]. A. Shetty, K. Venkataramana, I. Gogoi and B. B. Praveen: 'Performance enhancement of TMT rebar in accelerated corrosion', J. Civil Eng. Res., 2012, 2 (1), 14–17.

[10]. 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., 2015, 67, 246–258.

[11]. C. A. Apostolopoulos, S. Demis and V. G. Papadakis: 'Chlorideinduced corrosion of steel reinforcement – mechanical performance and pit depth analysis', Constr. Build. Mater., 2013, 38, 139–146.

[12]. URL: http://ispatguru.com/boron-in-steels/

[13]. A. Ray, D. Mukerjee, S. K. Sen, A. Bhattacharya, S. K. Dhua, M. S. Prasad, N. Banerjee, A. M. Popli and A. K. Sahu: 'Microstructure and properties of thermomechanically strengthened reinforcement bars: a comparative assessment of plain-carbon and low-alloy steel grades', J. Mater. Eng. Perform., 1997, 6 (3), 335–343.

[14]. F. H. Samuel: 'Crystallographic study of pearlite growth in steels', Trans. ISIJ., 1983, 23, 403–409.

[15].AshishBhateja,Aditya Varma, Ashish Kashyap , Bhupinder Singh,2012."Study of the effect on the hardness of three sample grades of tool steel after heat treatment process",International Journal of Engineering And Science (IJES),Volume 1, Issue 2,pages 253-259,

[16] Alawode, A.J., 2002, Effects of cold work and stress relief annealing cycle on the mechanical properties and residual stresses of cold-drawn mild steel rod. M. Eng. Thesis, Mechanical Engineering Department, University of Ilorin, Nigeria.

[17]. A. N. Isfahany, H. Saghafian and G. Borhani, "The effect of heat treatment on mechanical properties and corrosion behaviour of AISI420 Martensitic Stainless Steel," Journal of Alloys and Compounds, Vol. 509, No. 9, 2011.

[18]. Adnan, Calik 2009. Effect of cooling rate on hardness and microstructure of AISI 1020, AISI 1040 and AISI 1060 steels. Int J of Physics Sciences, vol. 4(9), pp. 514 – 518.

[19].B.S.Motagi,Ramesh Bhosle 2012, "Effect of heat treatment on microstructure and mechanical properties of medium carbon Steel",International Journal of Engineering Research and Development, Volume 2, Issue 1, July.

[20].D.A.Fadare, T.G.Fadara , O.Y.Akanbi, 2011 Effect of heat treatment on mechanical properties and microstructure of NST 37-2 Steel,Journal of Minerals & Materials Characterization & Engineering, Vol. 10, No.3, pp.299-308,

[21]. Eric O., Sidjanin L., Miskovic Z. l 2004 Microstructure and toughness of cu- ni-moaustempered ductile iron; materials letters, Volume 58, Pages 2707– 2711.

[22]. E. F. Strobel, N. A. Mariano, K. Strobel and M. F. Dionízio, 2012 "Effect of the heat treatment in the resistance corrosion of a martinsitic stainless steel CA6NM," 2 nd Edition, Mercosur Congress on Chemical Engineering.

[23]. F. M. F. Al-Quran and H. I. Al-Itawi, 2010 "Effects of the heat treatment on corrosion resistance and micro hardness of alloy steel," European Journal of Scientific Research, Vol. 39, No. 2,.

[24]. Harpreet Singh, Er.B.S.Ubhi, Er. Harvinder Lal. 2013"Improvement in the corrosion rate and mechanical properties of low carbon steel through deep cryogenic treatment", International Journal of Scientific& Technology Research Volume 2.

[25].IRONMAKING AND STEELMAKING Theory and Practice by Ahindra Ghosh and Amit Chatterjee.

[26].Nandi S K, Tewary N K, Saha J K and Ghosh S K 2016 Microstructure, mechanical properties and corrosion performance of a few TMT rebars, *Corros. Eng. Sci. Technol.* **51** 476–88.

[27].ASM Handbook, ‘Corrosion: fundamentals, testing, and protection’, Vol. 13A; 2003,Materials Park, Ohio 44073–0002, ASM International.

[28]. W.–J. Chitty, P. Berger, P. Dillmann and V. L’Hostis: ‘Long-term corrosion of rebars embedded in aerial and hydraulic binders – mechanisms and crucial physico-chemical parameters’, Corros. Sci., 2008, 50, 2117–2123.

[29]. P. Montoya, I. Díaz, N. Granizo, D. de la Fuente and M. Morcillo: ‘An study on accelerated corrosion testing of weathering steel’, Mater. Chem. Phys., 2013, 142, 220–228.

[30].W.F. Perenchio, Corrosion of Reinforcing Steel, ASTM STP 169C, (1994) 164-172.

[31]. N.S. Berke, Corrosion Inhibitors in Concrete, Concrete International, 13 7(1991) 24-27.

[32]. Report on Materials and Methods for Corrosion Control of Reinforcement and Prestressed Concrete Structures in New Construction, Publication Number 00-081, (2000), US Department of Transportation, Federal Highway Administration.

[33]. A. Etmanc, Reinforced Concrete Corrosion and Protection, Concrete Research Letter, 3 1(2012) 359-372.

[34]. M.S. Bari, Use of 500 Grade Steel in the Design of Reinforced Concrete Slab, http://www.bsrm.com/resources/Dr.S.Bari_BSRM_Paper_on_Slab.pdf

[35] R. Bob, H. Scott, High-Strength Reinforcing Steel: Next Generation or Niche?, Concrete Construction Magazine, January, (2008).

[36] Plain and Reinforced Concrete, Indian Standard - Code Of Practice, (Fourth Revision), IS 456 (2000).

[37] M.S.Z. Bosunia, Design of Reinforced Concrete Structures and the Use of Various Grades of Steel, https://docs.google.com/file/d/0B9KlrbgHz5XRWtXckNHUkpDb3c/edit?pli=1

[38] M.F. Bernezhnitskaya, Influence of Residual Stress on the Resistance of Steel to Corrosion-Mechanical Failure, Soviet materials science, a transl. of Fiziko-khimicheskayamekhanikamaterialov/Academy of Sciences of the Ukrainian SSR, 23 1(1987) 19-23.

[39] N. P. Zhuk, Theory of Corrosion and Protection of Metals, Moscow Metallurgiya, (1976) 472-479.

[40] M. Yu. Ambrazhey, E. E. Chigirinets, G. Yu. Galchenko, A.V. Ivchenko, Effect of Technology Factors on Corrosion Resistance of ColdRolled Reinforcing Bar, Metallurgical and Mining Industry, 2 4 (2010) 302-308.

[41] Report on Corrosion Resistant TMT Steel Bars; http://priyankironsteel.com/electro_crs.pdf

[42] O.N. Mohanty, G. Jha, Corrosion Control Through Surface Modification, R&D, TATA STEEL: http://eprints.nmlindia.org/4100/1/O_N_Mohanty-1.PDF

[43] R. Manoharan, P. Jayabalan, K. Palanisamy, Experimental Study on Corrosion Resistance of TMT Bar in Concrete, International Conferenceon Construction and Building Technology (ICCBT), (2008) 239-250.

[44] B.K. Panigrahi, S. Srikanth, G. Sahoo, Effect of Alloying Elements on Tensile Properties, Microstructure and Corrosion Resistance of Reinforcing Bar Steel, J. Mat. Engg. Perform, ASM International, 18(2009) 1102-1108.

[45] Report on TMT Rebars, Dedicated to Build a Strong Nation, 2014: http://www.thebig5constructindia.com/media/191965/TMT-Rebars_- dedicated-to-build-a-strong-nation.pdf

[46] M.A. Razzak, Heat Treatment and Effects of Cr and Ni in Low Alloy Steels, Bull. Mater. Sci., 34 7(2011) 1439–1445.

[47] C. Wang, M. Wang, J. Shi, W. Hui, Effect of Microstructure Refinement on Strength and Toughness of Low Alloy, J. Mat. Sci. Tech.., 23 5(2007) 659-664.

[48] N. Radović, A. Koprivica, D. Glišić, A. Fadel1, D. Drobnjak, "Influence of Cr, Mn And Mo On Structure and Properties of V Microalloyed Medium Carbon Forging Steels, Association of Metallurgical Engineers of Serbia (AMES), 16 1(2010) 1-9.

[49] T.U. Mohammed, H. Hamada, T. Yamaji, Performance of Seawater-mixed Concrete in the Tidal Environment, J. Cement and Concrete Res., 34(2004) 593-601.

[50] V.T. Ngala, C.L. Page, L.J. Parrott, S.W. Yu, Diffusion in Cementitious Materials: Further Investigations of Chloride and Oxygen Diffusion in Well-Cured OPC and OPC/30% PFA Pastes, Journal of Cement and Concrete Research, 24(1995) 819-826.

[51] Shin-ichi Miyazato1, Nobuaki Otsuki2, Steel Corrosion Induced by Chloride or Carbonation in Mortar with Bending Cracks or Joints, Journal of Advanced Concrete Technology, 8 2(2010) 135-144.

[52] M. Rifai, H. Miyamoto, H. Fujiwara, Effects of Strain Energy and Grain Size on Corrosion Resistance of Ultrafine Grained Fe-20%Cr Steels with Extremely Low C and N, International Journal of Corrosion, 2015(2015) 1-9.

[53] Report on TMT Rebars, Dedicated to Build a Strong Nation, 2014: http://www.thebig5constructindia.com/media/191965/TMT-Rebars_- dedicated-to-build-a-strongnation.pdf

[54]. Smallbone C (2019) IIWAP2019: The 8th Asia-Pacific IIW International Congress, March 20-22, QSNCC, Bangkok, Thailand.

[55]. Back M (2015) Welding of dissimilar metals in different welding positions, Examensarbette I Material Design 300 HP, AvanceradNiva Stockholm, Sverige.

[56]. Śloderbach Z, Pająk J (2015) Determination of ranges of components of heat affected zone including changes of structure. Archive of Metallurgy and Materials 60(4): 2607-2612.

[57]. Krishnasamy RK (2012) A computational approach to thermomechanical fatigue life predictions of dissimilarly welded superheater tubes, Grin Verlag, Germany.

[58]. Lippold JC (2014) Welding Metallurgy and Weldability. John Wiley & Sons, Inc, Hoboken, New Jersey.

[59]. Stemne D, Narstrom T, Hrnjes B (2010) Welding Handbook: A guide to better welding of Hardox and Weldox. SSAB, pp. 132, Stockholm.

[60]. Digheche K, BoumerzougZ ,Diafi M, Saadi K (2017) Influence of heat treatments on the microstructure of welded of APX70 pipeline steel. Acta metallurgicaSlovaca 23(1): 72-78.

[61]. Gunaraj V, Murugan N (2002) Prediction of Heat-Affected Zone Characteristics in Submerged Arc Welding of Structural Steel Pipes. Welding research, 94-98 .

[62]. Guo YH, Lin L, Zhang D, Liu L, Lei MK (2018) Microstructure and Mechanical Properties of Heat-Affected Zone of Repeated Welding AISI 304N Austenitic Stainless Steel by Gleeble Simulator. Metals 8(10): 1-14.

[63]. Parmar A, Dubey A (2017) Study of heat affected zone for SMAW process for low carbon steel specimen with controlled parameters, IJMTER.