Comparative study of microstructure and properties of as received, heat treated and welded Mild steel bar (SRMB) and TMT bar (SRMB)

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by

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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 Mild steel bar (SRMB) and TMT bar (SRMB)"** submitted by **Mr. Arnab Samanta(Examination Roll No: M4MAT23002 and Registration No: 160313 of 2021-2022)** in partial fulfillment of the requirements for the award of the degree of **Master of Technology** in **Material Engineering** from **Jadavpur University, Kolkata** is an authentic work carried out by him under my guidance and supervision.

To the best of my knowledge, the information contained in this thesis has not been submitted to any other University/ Institute for the award of any degree or diploma.

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Declaration of Originality and Compliance of Academic Ethics

I hereby declare that this thesis **“Comparative study of microstructure and properties of as received heat treated and welded Mild steel bar (SRMB) and TMT bar (SRMB)”** contains literature survey and original research work by the undersigned candidate, as a part of my M.Tech Degree in Material Engineering during academic session 2021-2023. All the information that has been provided in this document is in accordance with academic rules and ethical conduct. I also declare that, as required by this rules and conduct, I have fully cited and referred all materials and results that are not original to this work.

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The foregoing thesis is hereby approved as a credible study of an engineering subject and presented in a manner satisfactory to warrant acceptance as pre-requisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not necessarily endorse or approve any statement made, opinion expressed or conclusion drawn there in but approve the thesis only for which it is submitted.

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Abstract

India is among the fastest developing nation in the world with major constructions like bridges, dams, airports, residential buildings etc. In a developing economy where infrastructure is getting boom, strength of structural members is of great importance. This is where Thermo Mechanically Treated (TMT) bars scores over Cold twisted bars (or CTD bars). For understanding the proper behaviour of structural members, physical properties, chemical composition, mean projected rib area and macrostructure are very essential. Nowadays there are many companies which supply untreated and twisted deformed bars as TMT bars which would do much harm for structural stability. There is an urgent need to use the phrase "Quenching and Tempering" to label the TMT bars. This project is an effort to showcase the ways to identify good quality TMT bars. This thesis paper attempts to find variation of microstructure configuration of mild steel barandtmtbar (srmb) in metallography laboratory and Hardness variation of mild steel bar and tmt bar (srmb) from it's core to peripheral region by VICKER'S Hardness test method 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 welded tmt bar, how it changes from welding zone to head treated zone(HAZ) and heat treated zone(HAZ) to parent zone

Chapter 1

Introduction

Introduction

Mild steel is a type of carbon steel with a low amount of carbon – it is actually also known as "low carbon steel". Although ranges vary depending on the source, the amount of carbon typically found in mild steel is 0.15% to 0.3%.

Mild steel is not an alloy steel and therefore does not contain large amount of other elements besides iron, will not find vast amount of chromium, molybdenum or other alloying elements in mild steel. Since its carbon and alloying element content relatively low, there are several properties it has that differentiate it from higher carbon and alloy steels.

Less carbon means that mild steel is typically more ductile, machinable, and weldable than high carbon and other steel.

The lack of alloying elements such as those found in stainless steels means that the iron in mild steel is subjected to oxidation if not properly coated. But the negligible amount of alloying elements also helps to be relatively affordable when compared with other steels. It is affordability, weldability, and machinability that make it such a popular choice of steel of consumers.

It is used in many applications, including the building, manufacturing, and automotive industries and has a square cross-section.

Mild steel uses in manufacturing and construction industries. They are ideal for several applications, including brackets, frames, reinforcements, fences, gates, trailers, window and door trims and many more.

It's crucial to consider the application, required strength and durability when choosing a Mild steel square bar.

Under Thermo Mechanical treatment, the steel bars are passed through a specially designed water cooling system where they are kept till the outer surface becomes colder while the core remains hot. This creates temperature gradient in the bars. When the bars come out of the TMT box to the cooling bay, the heat flows from the core to the outer surface, further tempering the bars, which helps them attain higher yield strength. The resulting concentric martenstic grain structure at the surface imparts superior strength and toughness to the bars. The microstructure of the core is a very fined-grained ferrite and pearlite. TMT bars are also known as 'quenched and tempered rebars', because of the quenching and tempering process involved in making the rebars, and thus TMT bars produced by the TMT process scores over Cold Twisted Bars(CTD) and TOR steels. The production of quality TMT bar depends on three major factors: 1. Quality raw materials

2. A properly designed and automated mill.

3. A well designed quenching and tempering technology. Deciding the percentage of carbon content in steel has been a major challenge for engineers. While a minimum level of carbon content in steel is essential to achieve the required strength, excess carbon threatens its weld ability. In TMT bars, this problem has been eliminated by restricting the carbon content to 0.23% to attain weld ability and ensuring that its strength is not lost. The various grades of TMT bars are Fe 415, Fe 415D, Fe500, Fe500D.The following chemistry of steel is used for production of TMT bar.

Chapter 2

Literature Review

Literature Review

There were many types of Mild Steel that had been discovered until recently, among them were A36, High Strength Low Alloy (HSLA) Steel, Abrasion Resistant (AR), Pressure Vessel Quality (PVQ), 4140, 8620 ,1045,1018 and Free Machine Steel (FM 45). The most popular mild steel specification for carbon steel is A36 which normally comes in shapes of plates and bars for bolted and welded construction. High Strength Low Alloy (HSLA) Steel usually contain more than 15% composition of carbon and it is stronger than any ordinary plain carbon steels. HSLA normally comes in the appearance of Corten and Exten material. They are widely used in cars, cranes, bridges and other structures to handle stress at low temperatures. Abrasion Resistant (AR) is commonly used in truck and hopper bodies, shoots, and wear as it is a very hard mild steel that is abrasion or wear resistant. While for the Pressure Vessel Quality (PVQ), because of its properties which are high strength and low weight mild steel it was commonly used in earth moving, transport equipment such as booms, buckets, and pressure vessels. Among the example of PVQ are A514 and T1. 4140 and 8620 perform well under high heat, heavy load wear-resistant material and was used for dyes and molds. 1045 is a standard mild steel which is more durable than A36 though it is harder to machine and weld. It is commonly used for axles, bolts, connecting rods, hydraulic rams and etc. 1018 is the most frequently available of the cold-rolled steels and chemically similar to A36. It come generally in round rod, square bar and rectangle bar. It have good edges such as strength, ductility and ease of machining. Last but not least, Free Machine Steel (FM 45) is a mild steel that has average durability in strength and easy to machine.

In materials science, the ‘strength’ phrase can be assumed as a high resistance to breakage. Mild steel was well known because of its high resistance to breakage and therefore its mechanical properties can be considered as very strong due to the low amount of carbon it contains. Mild Steel also was recognized as having a high tensile and impact strength compared to the High Carbon Steel due to the fact that it can be easily malleable even when in cold. Another distinguished differences of mechanical properties between high carbon steel and Mild Steel was mild steel bends or deforms if being subjected under stress while a high carbon steels usually shatter or crack. This cause Mild Steel was widely preferred in the construction area in the interest of its weldability, machiniability, malleablility and high strength. As a result of its high strength and easy to malleable, the former is actually quite soft which cause its easy to machine and welding both to itself or to other types of steel. Nevertheless, the former cannot be hardened through heat treatment processes unlike the latter.

Nowadays, every objects that are fabricated of steel are using mild steel type of material which includes automobile chassis, motorcycle frames and most cookware product. Due to its poor corrosion-resistance, it must be painted or protected and sealed in order to prevent rust from damaging it. A light coat of oil or grease is able to seal this steel and aid in rust control.Unlike high-carbon steel, mild steel is easily welded. The properties of the steel allow the electrical current to travel through the metal without distorting the makeup of the material. Some types of high-carbon steel such as stainless steel, require special techniques in order to properly weld the material. Being less brittle than high-carbon steels, the mild variant is able to flex and give in construction projects where a higher-carbon version could simply break.

Theory Test

Tensile Test

A tensile test, also known as tension test is the most fundamental type of mechanical test one can perform on the material. This tests are simple, relatively inexpensive, and fully standardized. By pulling on something, one will determine how the material will react to forces being applied in tension. As the material is being pulled, one will find its strength along with how much it will elongate. The objective of conducting Tensile test until the material breaks or rupture is to obtain a complete tensile profile. A curve will result showing how it reacted to the forces being applied. The point of failure is of much interest and is typically called the Ultimate Strength or UTS on the Stress vs Strain diagram. The total of 4 samples of mild steel plate were prepared for this test purposed where all the samples were machined following the standardized dimension given.

Stress vs Strain Diagram

Hardness Test

Rockwell hardness testing is a general method for measuring the bulk hardness of metallic and polymer materials. Although hardness testing does not give a direct measurement of any performance properties, hardness correlates with strength, wear resistance, and other properties. Hardness testing is widely used for material evaluation due to its simplicity and low cost relative to direct measurement of many properties. This method consists of indenting the test material with a diamond cone or hardened steel ball indenter. Only 1 samples of mild steel material plate was prepared for this type of test as this test only required 1 samples indent 10 data on that 1 samples.

Impact Test

The impact properties of samples were measured using the standardized dimension from the strength lab that had been acquired from the lab technician. Then the samples that had complete the machining process will have to undergo two test which are Charpy test and Izod test. These two test were meant to measure the the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given material's notch toughness and acts as a tool to study temperature-dependent ductile-brittle transition. The only distinctive differences between the charpy and izod lies in the way that the specimen are supported in the apparatus machine.

Microstructure Observation

In Microstructure observation, the samples of mild steel plate will be observed under the microscope in order to monitor the microstructure of the specimen. Before the observation start, the sample will have to be prepared by first grinding the sample with grit sand paper starting from 240, 320, 400, 600 and lastly 1200. After that the sample will be polished by using either powder or paste depend on which is more suitable. Only after all these process were done we can start observe the microstructure under the microscope starting from 5x, 10x, 20x, 40x, 50x and etc.

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.

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

A quality control test for TMT (or QST) steel reinforcing bars used in reinforced concrete systems Quenched and Self Tempered (QST) steel is the scientific name for Thermo-Mechanically Treated (TMT) steel. A good TMT/QST steel reinforcing bar (rebar) cross-section should have a ductile core of 'ferrite-pearlite' (FP) microstructure and a continuous and evenly thick peripheral ring of hard 'tempered martensite' (TM) microstructure. Recent tests on TMT/QST steels in the Indian market, however, discovered discontinuous, eccentric, and non-uniform TM-phases near the periphery, which can be related to incorrect quenching. This could lead to localised corrosion and changes in mechanical characteristics. Although IS 1786: 2008 discusses etching of steel to determine microstructural phases, it is an insufficient (lacks requisite test protocols; results in incorrect results) and non-mandatory provision offered in the annexure. Details on specimen extraction, preparation, testing, and analysis, which are critical for reproducible and accurate results, are provided, as well as a 2-level acceptance criteria for TMT/QST rebars for future incorporation into standard specifications.

Thermo-Mechanically-Treated (TMT) steel reinforcing bars with varying microstructures and mechanical properties

Asian Conference on Ecstasy in Concrete, January 2015 In India, Thermo-Mechanically-Treated (TMT) or Quenched-and-Self-Tempered (QST) steel bars are widely utilised in reinforced concrete construction. The distinct microstructure (for example, with a hard exterior and a soft/ductile core) contributes to adequate surface hardness and ductility. To ensure quality construction, the distribution of tempered martensite and ferrite-pearlite in the cross-sectional region should be concentric and consistent, with moderate variations in yield strength and elongation. Four commercially available TMT steel rebars were examined for their microstructure, yield strength, and ductility in this study. Multiple specimens of 500D Grade TMT/QST bars with diameters of 8, 12, and 16 mm were tested. The results demonstrate considerable differences in microstructure features (such as the distribution of martensite and pearlite-ferrite areas) and mechanical properties. (This includes yield strength, tensile strength, and elongation/ductility). These findings indicate that there is an urgent need to revise the existing IS 1786 (2008) criteria in order to provide higher quality TMT/QST steel products.

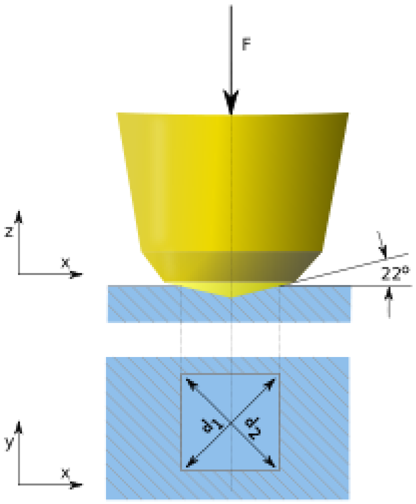
The variability of the physical and mechanical properties of reinforcing steel influences the performance of reinforced concrete structures and falls under the category of material property variations. These qualities have minimum standards in Saudi Arabia, as described by ASTM International Standards A 615. The heterogeneity in the weight and mechanical proper ties of reinforcing steel manufactured throughout Saudi Arabia is evaluated experimentally in this study. The findings were analysed to determine which firms meet the ASTM International minimal standards. 130 ASTM 615 grade 60 samples were collected and evaluated from various manufacturers to determine yield strength, tensile strength, and elongation. The findings were analysed to determine which firms meet the ASTM International minimal standards. 130 ASTM 615 grade 60 samples were collected and evaluated from various manufacturers to determine yield strength, tensile strength, and elongation. There were 96 samples tested for percent of nominal weight.

A statistical examination of the characteristics of steel rebar is performed. To determine the distribution type and conduct the statistical analysis, Easy Fit (5.6) software is used. The results of the investigation revealed that yield, tensile, and elongation all follow various forms of continuous distributions. Finally, control charts for the three tests are constructed in order to identify values above and below the 3 sigma.

VICKERS HARDNESS TEST of mild steel bar and TMT bar(SRMB)

The **Vickers hardness test** was developed in 1921 by Robert L. Smith and George E. Sandland at Vickers Ltd as an alternative to the Brinell method to measure the hardness of materials. The Vickers test is often easier to use than other hardness tests since the required calculations are independent of the size of the indenter, and the indenter can be used for all materials irrespective of hardness. The basic principle, as with all common measures of hardness, is to observe a material's ability to resist plastic deformation from a standard source. The Vickers test can be used for all metals and has one of the widest scales among hardness tests. The unit of hardness given by the test is known as the **Vickers Pyramid Number** (**HV**) or **Diamond Pyramid Hardness** (**DPH**). The hardness number can be converted into units of pascals, but should not be confused with pressure, which uses the same units. The hardness number is determined by the load over the surface area of the indentation and not the area normal to the force, and is therefore not pressure

Implementation



Vickers test schemeThe pyramidal diamond indenter of a Vickers hardness testerAn indentation left in case-hardened steel after a Vickers hardness test. The difference in length of both diagonals and the illumination gradient, are both classic indications of an out-of-level sample. This is not a good indentation.This is a good indentation.

It was decided that the indenter shape should be capable of producing geometrically similar impressions, irrespective of size; the impression should have well-defined points of measurement; and the indenter should have high resistance to self-deformation. A diamond in the form of a square-based pyramid satisfied these conditions. It had been established that the ideal size of a Brinell impression was ⅜ of the ball diameter. As two tangents to the circle at the ends of a chord 3*d*/8 long intersect at 136°, it was decided to use this as the included angle between plane faces of the indenter tip. This gives an angle from each face normal to the horizontal plane normal of 22° on each side. The angle was varied experimentally and it was found that the hardness value obtained on a homogeneous piece of material remained constant, irrespective of load. Accordingly, loads of various magnitudes are applied to a flat surface, depending on the hardness of the material to be measured. The HV number is then determined by the ratio *F*/*A*, where *F* is the force applied to the diamond in kilograms-force and *A* is the surface area of the resulting indentation in square millimeters.

$$A = \frac{d^2}{2\sin(136^\circ/2)},$$

which can be approximated by evaluating the sine term to give,

$$A \approx \frac{d^2}{1.8544},$$

where d is the average length of the diagonal left by the indenter in millimeters. Hence,

$$\mathrm{HV} = \frac{F}{A} \approx \frac{1.8544F}{d^2} \quad [\mathrm{kgf/mm^2}]$$

where F is in kgf and d is in millimeters.

Figure 1: Vickers hardness test machine

Figure 2: Vickers hardness test machine

Corrosion behaviours of mild steel bar and high strength TMT steel rebars(SRMB)

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.

INTRODUCTION

To one degree or another, most materials experience some type of interaction with a large number of diverse environments. Often, such interactions impair a material's usefulness as a result of the deterioration of its mechanical properties (e.g., ductility and strength), other physical properties, or appearance. Occasionally, to the chagrin of a design engineer, the degradation behavior of a material for some application is ignored, with adverse consequences.

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→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.

Corrosion of tmt bars take place accordingly

Fe→Fe^(2+) + 2e^(-)

Where Fe is Iron metal.

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^(-)→H2

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, galvanic, crevice, pitting, intergranular, selective leaching, erosion–corrosion, and stress corrosion. The causes and means of prevention of each of these forms are discussed briefly. In addition, we have elected to discuss the topic of hydrogen embrittlement in this section. Hydrogen embrittlement is, in a strict sense, a type of failure rather than a form of corrosion; however, it is often produced by hydrogen that is generated from corrosion reactions.

Uniform Corrosion

Galvanic Corrosion

Pitting Corrosion

Crevice Corrosion

Intergrannular Corrosion

Selective Leaching

Stress Corrosion

Hydrogen Embrittlement

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.*

Heat treating (or **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.

Physical Process

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 to suddenly 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.[4]

Unlike iron-based alloys, most heat-treatable alloys do not experience a ferrite transformation. In these alloys, the nucleation at the grain-boundaries often reinforces the structure of the crystal matrix. These metals harden by precipitation. Typicallya slow process, depending on temperature, this is often referred to as "age hardening".

Many metals and non-metals exhibit a martensite transformation when cooled quickly (with external media like oil, polymer, water, etc.). When a metal is cooled very quickly, the insoluble atoms may not be able to migrate out of the solution in time. This is called a "diffusionless formation." When the crystal matrix changes to its low-temperature arrangement, the atoms of the solute become trapped within the lattice. The trapped atoms prevent the crystal matrix from completely changing into its low-temperature allotrope, creating shearing stresses within the lattice. When some alloys are cooled quickly, such as steel, the martensite transformation hardens the metal, while in others, like aluminum, the alloy becomes softer.

Effects of composition

The specific composition of an alloy system will usually have a great effect on the results of heat treating. If the percentage of each constituent is just right, the alloy will form a single, continuous microstructure upon cooling. Such a mixture is said to be eutectoid. However, If the percentage of the solutes varies from the eutectoid mixture, two or more different microstructures will usually form simultaneously. A hypo eutectoid solution contains less of the solute than the eutectoid mix, while a hypereutectoid solution contains more.

Eutectoid alloys

A eutectoid (eutectic-like) alloy is similar in behavior to a eutectic alloy. A *eutectic* alloy is characterized by having a single melting point. This melting point is lower than that of any of the constituents, and no change in the mixture will lower the melting point any further. When a molten eutectic alloy is cooled, all ofthe constituents will crystallize into their respective phases at the same temperature.

A **eutectoid alloy** is similar, but the phase change occurs, not from a liquid, but from a solid solution. Upon cooling a eutectoid alloy from the solution temperature, the constituents will separate into different crystal phases, forming a single microstructure. A eutectoid steel, for example, contains 0.77% carbon. Upon cooling slowly, the solution of iron and carbon (a single phase called austenite) will separate into platelets of the phases ferrite and cementite. This forms a layered microstructure called pearlite.

Since pearlite is harder than iron, the degree of softness achievable is typically limited to that produced by the pearlite. Similarly, the hardenability is limited by the continuous martensitic microstructure formed when cooled very fast.

A hypoeutectic alloy has two separate melting points. Both are above the eutectic melting point for the system but are below the melting points of any constituent forming the system. Between these two melting points, the alloy will exist as part solid and part liquid. The constituent with the higher melting point will solidify first. When completely solidified, a hypoeutectic alloy will often be in a solid solution.

Similarly, a **hypoeutectoid alloy** has two critical temperatures, called "arrests". Between these two temperatures, the alloy will exist partly as the solution and partly as a separate crystallizing phase, called the "pro eutectoid phase". These two temperatures are called the upper (A_3) and lower (A_1) transformation temperatures. As the solution cools from the upper transformation temperature toward an insoluble state, the excess base metal will often be forced to "crystallize-out", becoming the pro eutectoid. This will occur until the remaining concentration of solutes reaches the eutectoid level, which will then crystallize as a separate microstructure.

For example, a hypoeutectoid steel contains less than 0.77% carbon. Upon cooling a hypoeutectoid steel from the austenite transformation temperature, small islands of proeutectoid-ferrite will form. These will continue to grow and the carbon will recede until the eutectoid concentration in the rest of the steel is reached. This eutectoid mixture will then crystallize as a microstructure of pearlite. Since ferrite is softer than pearlite, the two microstructures combine to increase the ductility of the alloy. Consequently, the hardenability of the alloy is lowered.

Hypereutectoid alloys

A hypereutectic alloy also has different melting points. However, between these points, it is the constituent with the higher melting point that will be solid. Similarly, a **hypereutectoid alloy** has two critical temperatures. When cooling a hypereutectoid alloy from the upper transformation temperature, it will usually be the excess solutes that crystallize-out first, forming the pro-eutectoid. This continues until the concentration in the remaining alloy becomes eutectoid, which then crystallizes into a separate microstructure.

A hypereutectoid steel contains more than 0.77% carbon. When slowly cooling hypereutectoid steel, the cementite will begin to crystallize first. When the remaining steel becomes eutectoid in composition, it will crystallize into pearlite. Since cementite is much harder than pearlite, the alloy has greater hardenability at a cost in ductility.

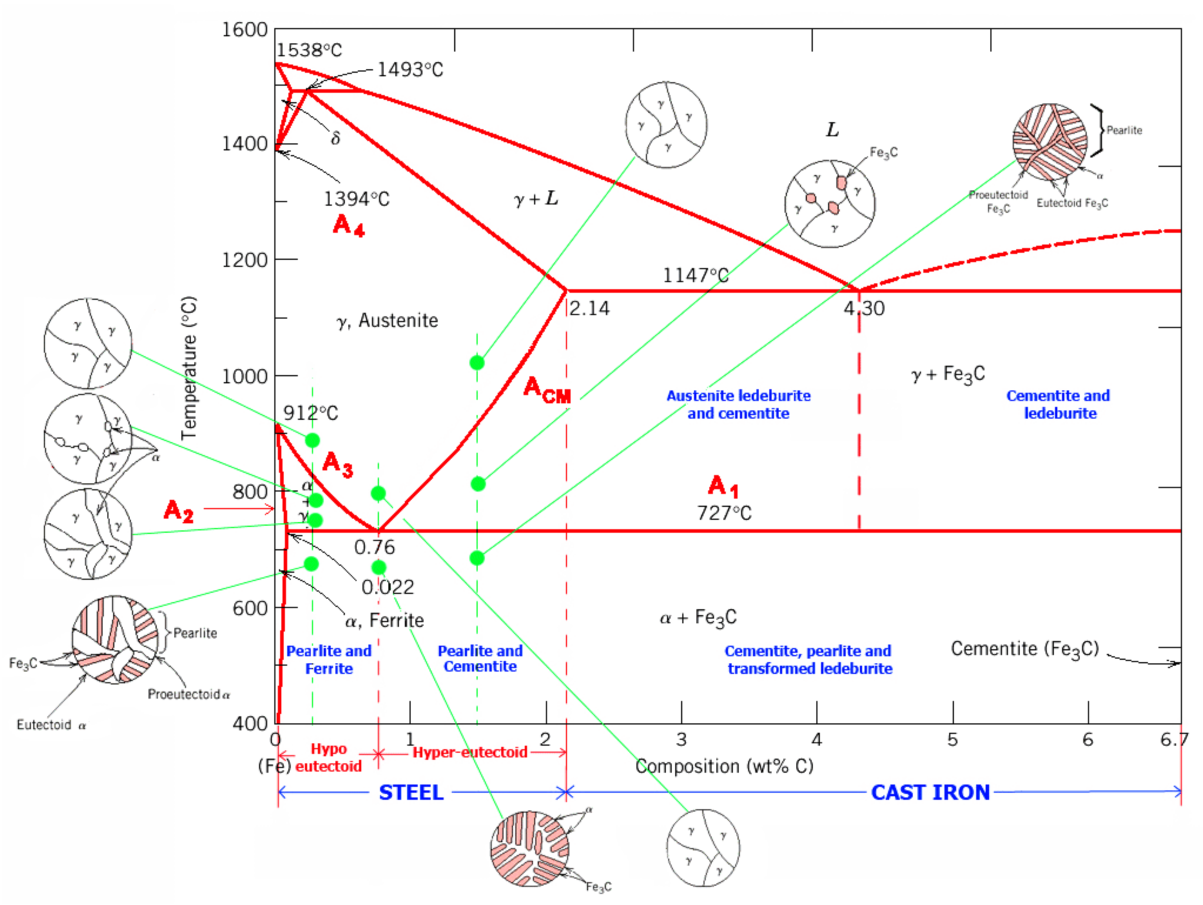


Figure 3: Iron - Carbon Diagram

Constituent in Steel

1. Ferrite ν α and β-phase with the BCC lattice

2. Austenite ν The γ-phase with the FCC lattice.

3. Cementite ν Name given to iron carbide ν having fixed composition Fe3C. ν Cementite is a hard and brittle substance, influencing on the properties of steels and cast irons

4. Pearlite ν fine mixture of ferrite and cementite structure ν forming as a result of decomposition of austenite at slow cooling conditions ν the black lamellae are the Fe3C parts; their thickness is a few µm. ν The name comes from the pearl-like luster of this material. Microstructure of pearlite in 1080 steel, formed from austeniteof eutectoid composition. In this lamellar structure, the lighterregions are ferrite, and the darker regions are carbide. Magnification: 2500X.

5. Martensite ν In steel, under rapid cooling, so that equilibrium is prevented, austenite transforms into a nonequilibrium phase called martensite, which is hard and brittle ν A unique phase consisting of an iron-carbon solution whose composition is the same as the austenite from which it was derived ν Face-centered cubic (FCC) structure of austenite is transformed into body-centered tetragonal (BCT) structure of martensite ν The extreme hardness of martensite results from the lattice strain created by carbon atoms trapped in the BCT structure, thus providing a barrier to slip

OBJECTIVES

1. heat treatment is done to improve the machinability.
2. To improve magnetic and electrical properties.
3. To increase corrosion resistance,wear resistance and heat resistance.

Types of Heat Treatment Processes

Hardening

Normalizing

Annealing

Tempering

Nitriding

Cyanyding

Induction hardening

Flame hardening

Normalization

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 deg C above the upper critical temperature 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 deg C to 930 deg 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 such as rolling and forging etc.

- To modify and improve cast dendritic structures and reduce segregation by homogenization of the microstructure.
- To produce a homogeneous micro structure and to obtain desired microstructure and mechanical properties.
- To improve machinability of low carbon steels
- To improve dimensional stability
- To reduce banding
- To improve ductility and toughness
- To provide a more consistent response when hardening or case hardening.
- To remove macro structure created by irregular forming or by welding.

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Fine grained pearlite is tougher than coarse grained ones. Normalizing imparts both hardness and strength to iron and steel work pieces. In addition, normalizing helps reduce internal stresses induced by such operations as forging, casting, machining, forming or welding. Normalizing also improves microstructural homogeneity and response to heat treatment (e.g. annealing or hardening) and enhances stability by imparting a ‘thermal memory’ for subsequent lower temperature processes. Work pieces that require maximum toughness and those subjected to impact are often normalized. When large cross sections are normalized, they are also tempered to further reduce stress and to control mechanical properties more closely.

Normalization eliminates internal stresses, strains and improves the mechanical properties of the steel, such as improving its toughness and machinability. A better ductility can also be obtained without compromising the hardness and strength.

Comparison with annealing

Normalizing process of steel differ from the annealing process of steel with respect to heating temperature and cooling rate. In case of normalizing the steel is heated to a higher temperature and then removed from the furnace for air cooling. In comparison in case of annealing the heating temperatures are lower and the cooling take place in furnace at a much lower rate. Due to the faster cooling rate in case of normalizing, the steel possesses higher strength and hardness when compared with the steel which has undergone annealing treatment.

Normalizing Process for Steels

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Soaking periods for normalizing are usually one hour per 25 mm of thickness of the work piece but not less than 2 hours at the soaking temperature. The mass of the work piece can have a significant influence on the cooling rate and thus on the resulting microstructure. Thin work pieces cool faster and hence are harder after normalizing than the thicker work pieces. This is different than in the case of annealing where the hardness of thin and thicker work pieces is same after furnace cooling.

Low carbon steels normally do not need normalizing. However there are no harmful effects, if these steels are normalized. In case of castings having uniform wall thickness and section sizes are usually annealed rather than normalized. Other types of castings especially with complex shapes or interconnected thin and thick sections, which are prone to high levels of residual stresses, are benefitted by normalizing. The microstructure obtained by normalizing depends on the composition of the castings and the cooling rate.

Normalizing of steel is often considered both from a thermal and a microstructural viewpoint. From a thermal standpoint, normalizing process consists of austenitizing followed by a relatively slow cool. In case of microstructural standpoint, the areas of microstructure that contain about 0.80 % carbon are pearlite, while areas of low carbon are ferritic.

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

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Both annealing and normalizing do not present significant difference in the ductility of low carbon steels. The tensile strength and the yield point of the normalized steels are higher than the annealed steels except in the case of low carbon steels.As in the case of annealing, normalizing also results into the formation of ferrite, cementite and lamellar pearlite. But in normalizing, since the cooling rates are higher, transformation of austenite takes place at much lower temperatures when compared with annealing. Due to it, the transformation product, pearlite is finer with lower interlamellar distance between the two neighboring cementite plates.

The main difference between full annealing and normalizing is that fully annealed work pieces are uniform in softness (and machinability) throughout the entire part, since the entire part is exposed to the controlled furnace cooling. In the case of the normalized part, depending on the part geometry, the cooling is non-uniform resulting in non-uniform material properties across the part.

Normalizing relieves internal stresses caused by cold work while grain growth is limited by the relatively high cooling rate therefore the mechanical properties (strength, and hardness) of a normalized steel are better than in an annealed steel.

Quality of surface after machining of a normalized part is also better than in an annealed part. This effect is caused by increased ductility of annealed steel favoring formation of tearing on the machined surface.

Quench Hardening

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. Items that may be quenched include gears, shafts, and wear blocks.

Purpose

Before hardening, cast steels and iron are of a uniform and lamellar (or layered) pearlitic grain structure. This is a mixture of ferrite and cementite formed when steel or cast iron are manufactured and cooled at a slow rate. Pearlite is not an ideal material for many common applications of steel alloys as it is quite soft. By heating pearlite past its eutectoid transition temperature of 727 °C and then rapidly cooling, some of the material's crystal structure can be transformed into a much harder structure known as martensite. Steels with this martensitic structure are often used in applications when the work piece must be highly resistant to deformation.

Process

The process of quenching is a progression, beginning with heating the sample. Most materials 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. The recommended time allocation in salt or lead baths is up to 6 minutes. 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, but there is a small chance that it may cause distortion and tiny cracking. When hardness can be sacrificed, mineral oils are often used. These oil-based fluids often oxidize and form sludge during quenching, which consequently lowers the efficiency of the process. The cooling rate of oil is much less than water. Intermediate rates between water and oil can be obtained with a purpose-formulated quenchant, a substance with an inverse solubility that therefore deposits on the object to slow the rate of cooling.

After quenching, an iron or steel alloy will be excessively hard and brittle due to an overabundance of martensite. In these cases, another heat treatment technique known austempering is performed on the quenched material to increase the toughness of iron based alloys. Tempering is usually performed after hardening, to reduce some of the excess hardness.

Welding

Welding is a fabrication process that joins materials, usually metals or thermoplastics, by using high heat to melt the parts together and allowing them to cool, causing fusion. Welding is distinct from lower temperature techniques such as brazing and soldering, which do not melt the base metal (parent metal).

In addition to melting the base metal, a filler material is typically added to the joint to form a pool of molten material (the weld pool) that cools to form a joint that, based on weld configuration (butt, full penetration, fillet, etc.), can be stronger than the base material. Pressure may also be used in conjunction with heat or by itself to produce a weld. Welding also requires a form of shield to protect the filler metals or melted metals from being contaminated or oxidized.

Many different energy sources can be used for welding, including a gas flame (chemical), an electric arc (electrical), a laser, an electron beam, friction, and ultrasound. While often an industrial process, welding may be performed in many different environments, including in open air, under water, and in outer space. Welding is a hazardous undertaking and precautions are required to avoid burns, electric shock, vision damage, inhalation of poisonous gases and fumes, and exposure to intense ultraviolet radiation.

Until the end of the 19th century, the only welding process was forge welding, which blacksmiths had used for millennia to join iron and steel by heating and hammering. Arc welding and oxy-fuel welding were among the first processes to develop late in the century, and electric resistance welding followed soon after. Welding technology advanced quickly during the early 20th century as world wars drove the demand for reliable and inexpensive joining methods. Following the wars, several modern welding techniques were developed, including manual methods like shielded metal arc welding, now one of the most popular welding methods, as well as semi-automatic and automatic processes such as gas metal arc welding, submerged arc welding, flux-cored arc welding and electroslag welding. Developments continued with the invention of laser beam welding, electron beam welding, magnetic pulse welding, and friction stir welding in the latter half of the century. Today, as the science continues to advance, robot welding is commonplace in industrial settings, and researchers continue to develop new welding methods and gain greater understanding of weld quality.

1.1 Different type of welding processes

Based on the heat source used welding processes can be categorized as follows:

1.1.1 Arc Welding: In arc welding process an electric power supply is used to produce an arc between electrode and the work-piece material to joint, so that work-piece metals melt at the interface and welding could be done. Power supply for arc welding process could be AC or DC type. The electrode used for arc welding could be consumable or non-consumable. For non-consumable electrode an external filler material could be used.

1.1.2 Gas Welding: In gas welding process a focused high temperature flame produced by combustion of gas or gas mixture is used to melt the work pieces to be joined. An external filler material is used for proper welding. Most common type gas welding process is Oxyacetylene gas welding where acetylene and oxygen react and producing some heat.

1.1.3 Resistance Welding: In resistance welding heat is generated due to passing of high amount current (1000–100,000 A) through the resistance caused by the contact between two metal surfaces. Most common types resistance welding is Spot-welding, where a pointed electrode is used. Continuous type spot resistance welding can be used for seam-welding where a wheel-shaped electrode is used.

1.1.4 High Energy Beam Welding: In this type of welding a focused energy beam with high intensity such as Laser beam or electron beam is used to melt the work pieces and join them 2 together. These types of welding mainly used for precision welding or welding of advanced material or sometimes welding of dissimilar materials, which is not possible by conventional welding process.

1.1.5 Solid-State Welding: Solid-state welding processes do not involve melting of the work piece materials to be joined. Common types of solid-state welding are ultrasonic welding, explosion welding, electromagnetic pulse welding, friction welding, friction-stir-welding etc. Arc Welding: Among all these types of welding processes arc welding is widely used for different types of materials. Common types of arc welding process are:

a) Shielded Metal Arc Welding (SMAW) or Manual Metal Arc Welding: This is most common type arc welding process, where a flux coated consumable electrode is used. As the electrode melts, the flux disintegrates and produces shielding gas that protect the weld area from atmospheric oxygen and other gases and produces slag which covers the molten filler metal as it transfer from the electrode to the weld pool. The slag floats to the surface of weld pool and protects the weld from atmosphere as it solidifies.

b) Gas Metal Arc Welding (GMAW) or Metal inert or active gas welding (MIG/MAG): In this type of welding process a continuous and consumable wire electrode is used. A shielding gas generally argon or sometimes mixture of argon and carbon dioxide are blown through a welding gun to the weld zone.

c) Gas Tungsten Arc Welding (GTAW) or Tungsten Inert Gas (TIG): GTAW or TIG welding process is an arc welding process uses a non consumable tungsten electrode to produce the weld. The weld area is protected from atmosphere with a shielding gas generally Argon or Helium or sometimes mixture of Argon and Helium. A filler metal may also feed manually for proper welding. GTAW most commonly called TIG welding process was developed during Second World War. With the development of TIG welding process, welding of difficult to weld materials e.g. Aluminium and Magnesium become possible. The use of TIG today has spread to a variety of metals like stainless steel, mild steel and high tensile steels, Al alloy, Titanium alloy. Like other welding system, TIG welding power sources have also improved from basic transformer types to the highly electronic controlled power source today

1.3 Types of welding current used in TIG welding

a. DCSP (Direct Current Straight Polarity): In this type of TIG welding direct current is used. Tungsten electrode is connected to the negative terminal of power supply. This type of connection is the most common and widely used DC welding process. With the tungsten being connected to the negative terminal it will only receive 30% of the welding energy (heat). The resulting weld shows good penetration and a narrow profile.

b. DCRP (Direct Current Reverse Polarity): In this type of TIG welding setting tungsten electrode is connected to the positive terminal of power supply. This type of connection is used very rarely because most heat is on the tungsten, thus the tungsten 5 can easily overheat and burn away. DCRP produces a shallow, wide profile and is mainly used on very light material at low Amp.

c. AC (Alternating Current): It is the preferred welding current for most white metals, e.g. aluminium and magnesium. The heat input to the tungsten is averaged out as the AC wave passes from one side of the wave to the other. On the half cycle, where the tungsten electrode is positive, electrons will flow from base material to the tungsten. This will result in the lifting of any oxide skin on the base material. This side of the wave form is called the cleaning half. As the wave moves to the point where the tungsten electrode becomes negative the electrons will flow from the welding tungsten electrode to the base material. This side of the cycle is called the penetration half of the AC wave forms.

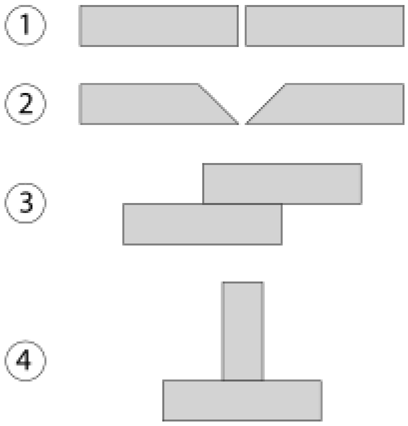
d. Alternating Current with Square Wave: With the advent of modern electricity AC welding machines can now be produced with a wave form called Square Wave. The square wave has better control and each side of the wave can give a more cleaning half of the welding cycle and more penetration

Geometry

Welds can be geometrically prepared in many different ways. The five basic types of weld joints are the butt joint, lap joint, corner joint, edge joint, and T-joint (a variant of this last is the cruciform joint). Other variations exist as well—for example, double-V preparation joints are characterized by the two pieces of material each tapering to a single center point at one-half their height. Single-U and double-U preparation joints are also fairly common—instead of having straight edges like the single-V and double-V preparation joints, they are curved, forming the shape of a U. Lap joints are also commonly more than two pieces thick—depending on the process used and the thickness of the material, many pieces can be welded together in a lap joint geometry.

Many welding processes require the use of a particular joint design; for example, resistance spot welding, laser beam welding, and electron beam welding are most frequently performed on lap joints. Other welding methods, like shielded metal arc welding, are extremely versatile and can weld virtually any type of joint. Some processes can also be used to make multipass welds, in which one weld is allowed to cool, and then another weld is performed on top of it. This allows for the welding of thick sections arranged in a single-V preparation joint, for example.

After welding, a number of distinct regions can be identified in the weld area. The weld itself is called the fusion zone—more specifically, it is where the filler metal was laid during the welding process. The properties of the fusion zone depend primarily on the filler metal used, and its compatibility with the base materials. It is surrounded by the heat-affected zone, the area that had its microstructure and properties altered by the weld. These properties depend on the base material'sbehaviorwhen subjected to heat. The metal in this area is often weaker than both the base material and the fusion zone, and is also where residual stresses are found.



Common welding joint types:

1. Square butt joint
2. V butt joint
3. Lap joint
4. T-joint

Weld Microstructure

When a molten metal solidifies in the gap between components to be joined, this welds the components together. The basic metallurgy of the welded joint can be divided into two major regions: the fusion zone and heat affected zone (HAZ). The fusion zone experiences temperatures above the melting point of the material and represents both the deposited metal and the parts of the base metal melted during welding. The heat affected zone. on the other hand, represents the close proximity to the weld, where the temperatures experienced are below the melting point and there is a change in the microstructure of the base metal.

Weld Metal Solidification

In steels weld metal solidification starts at edge of the fusion zone into the weld metal with d-ferrite as the initial phase (Fe-Cementite Phase diagram). As it cools, d-ferrite transforms into austenite and with further lowering of the weld metal temperature austenite decomposes to ferrite. Most steels contain small quantities of alloying elements and hence show similar crystal structure changes as pure iron. Therefore in weld metal solidification, weld deposits begin solidification with the epitaxial growth of columnar d- ferrite from the hot grains of the base metal at fusion surface. The grains grow rapidly in the direction of highest temperature gradient and hence show an anisotropic morphology. Those grains with directions parallel to the heat How direction dominate the final microstructure. On further cooling, austenite nucleates and grows along prior d-ferrite grain boundaries, thus adopting the columnar shape of the d-ferrite grains. Fine austenite grains providemore grain boundary nucleating sites; on the other hand coarse grains increase the harden abilityof the weld metal. The columnar shape of the austenite results in few grain boundary junctions when compared with an equi-axed structure. This also contributes to an increase in harden ability. The cooling rates in the weld metal depend on the distance from the heat source, heat input, inter pass temperature and the geometry of the joint. Because the cooling rates are in practice quite high, weld solidification is a non-equilibrium phenomenon and thus solidification-induced segregation promotes an inhomogeneous microstructure in the weld metal. The amplitude of these concentration and microstructure variations become larger as the alloy concentration increases.

Another important feature, in Flux based welding processes, is non-metallic inclusions. During welding, the flux reacts with atmospheric oxygen and cleans and protects the weld metal by forming oxides and rejecting them into slag. However, the process is not ideal due to convection and rapid solidification, so oxide particles are entrapped in the fusion zone during solidification. These are called slag inclusions, which can serve as nucleation sites within the weld pool. A small volume fraction of inclusions is desirable in welding, as they serve as heterogeneous nucleation sites for councilorferrite. Large fractions are detrimental to the mechanical properties of weld metal.

As-deposited Weld Microstructure

The as-deposited microstructure is that which forms when the liquid weld pool cools to room temperature. This structure contains allotriomorphic ferrite, Widmanst5tten ferrite and councilorferrite . In a few cases, microstructures containing marten site, banite and traces of pearlite can be found. High- carbon martensite is a hard microstructure with low toughness and ductility.

Allotriomorphic Ferrite

Allotriomorphic ferrite (a) usually forms between 1000 and 650"C during cooling of steel weld deposits. Nucleation occurs heterogeneously at the columnar austenite grain boundaries. As the austenite grain boundaries are easy diffusion paths, austenite grain boundaries are decorated with thin layers of anthropomorphic ferrite and the thickness of which is controlled by the diffusion rate of carbon in austenite. In weld deposits, anthropomorphic ferrite appears to grow without the redistribution of substitutional alloying elements during transformation . This mechanism of growth is termed para equilibrium, and occurs as a consequence of the fast cooling rates experienced by welds. In welds, anthropomorphic ferrite is detrimental to the toughness because the continuous network along grain boundaries offers less resistance to crack propagation than councilorferrite.

Widmanstatten Ferrite

This microstructure results from further cooling below the temperature at which anthropomorphic ferrite forms. Primary Widmanst5tten ferrite nucleates directly from the regions of austenite grain boundaries not covered by anthropomorphic ferrite. Secondary Widmanstatten ferrite nucleates at austenite/ferrite boundaries and grows as sets of parallel plates separated by thin regions of austenite. The austenite remains as retained austenite, or transforms to marten site or pearlite. These latter transformation products are collectively known as micro phases in weld metal terminology, because they are generally present in small fractions. Widmanstatten ferrite is not desirable in weld metals.

Acicular Ferrite

Oxides and non-metallic inclusions serve as nucleation sites for acicular ferrite. Acicular ferrite forms within the columnar austenite grains in competition with Widmanstattenferrite. It appears as a fine grained interlocking array of non- parallel laths. The microstructure is highly desirable in welds. The large number of non- parallel grains improves the weld metal toughness by increasing the resistance to crack propagation .

Microphases

These are last constituents to form in weld metal. Microphases correspond to the small carbon-rich regions in the weld metal where the last remaining volumes of austenite transform, and consist of mixtures of marten site, carbides, degenerated pearlite, bainite and retained austenite.

Secondary Microstructure

In many circumstances it is difficult to fill the gap at the joint by a single weld pass. Therefore thick sections are welded using many layers of deposited metal. The deposition of each successive layer heat treats the underlying microstructure formed during cooling of the previous run. Some regions of the underlying layers are reheated above the austenitisation temperature, whereas others become tempered. All of the reheated regions contribute to the secondary microstructure.

The Heat Affected Zone

The heat affected zone is the portion of the metal which has not experienced melting, but whose microstructure is altered due to welding heat. There are well-defined microstructures in the heat affected zone as illustrated in Fig. 2.12 . The region immediately adjacent to the fusion boundary is heated to very high temperatures (just below melting temperature) and forms coarse austenite. The austenite grain size decreases sharply with distance from the fusion line and the Rue grained zone will have superior mechanical properties than the coarse grained zone. Moving further away, the peak temperature decreases and will result in partial austenite formation and tempered ferrite in that region; this is called the “partially austerities zone”. The region adjacent to this zone, which is not transformed to austenite, will be tempered.

The microstructure and CCT diagram of weld metals

Those features of weld solidification that are most likely to influence the final microstructure of the weld metal after cooling to ambient temperatures have been presented above. The overall picture is complicated by a number of interacting factors which include:

1. The welding process itself which determines the weld pool size and geometry.

2. The final composition of the melt as influenced by the filler wire, the base metal, fluxes, gases, moisture in the air, etc., and its effect on constitutional supercooling and segregation.

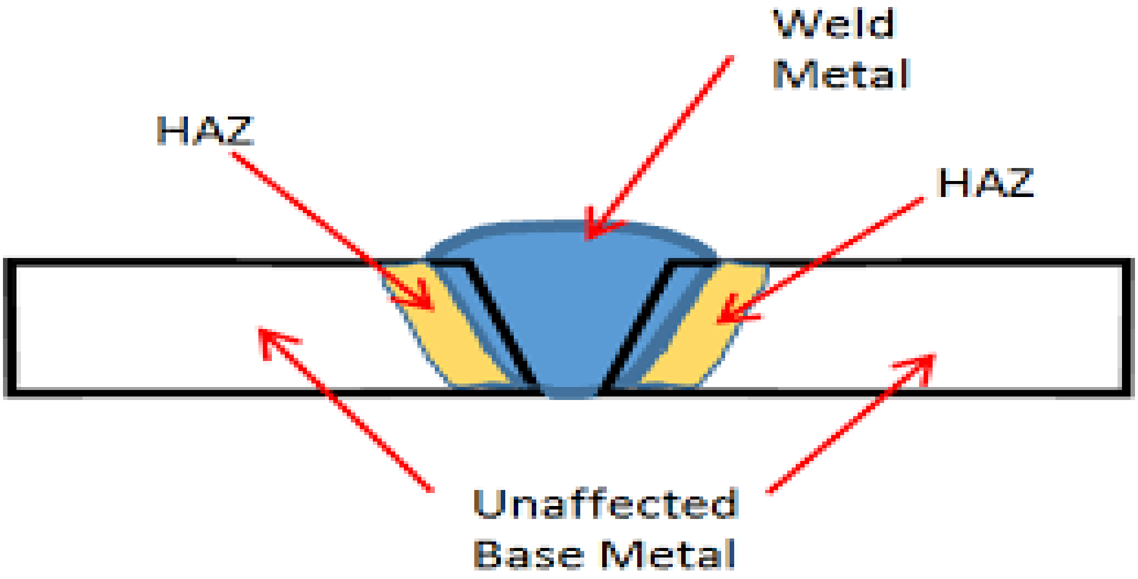
3. The speed of welding and its effect on solidification speeds, crystal morphology and segregation.

4. The weld thermal cycle and its influence on microstructural coarseness and type of transformation product produced during cooling.

5. The effect of weld metal composition, particularly from dilution in high energy welding of microalloyed steels, on precipitation reactions, and especially during reheating or in multi-run welds.

It appears to be unrealistic to attempt to develop CCT diagrams specific to weld metal composition and thermal history. On the other hand, it is useful and informative to express the influence of the various features of welding, as listed above, in a schematic CCT diagram 28 which shows, e.g., the tendency for the C-curves to move to longer or shorter times or the introduction of shape or size changes of the transformation fields, and this is illustrated in Figure.

Arrows that point left in the diagram denote movement of C-curves to shorter transformation times, and arrows to the right indicate the opposite effect. Thus, austenite stabilizers (e.g. C, N, Mn, Ni, Cu), tend to inhibit transformation, pulling the C-curves towards longer times to transformation. Strong carbide or nitride forming elements (e.g. Mo, Cr, Nb, V, Ti, Al), however, tend to suppress blocky and proeutectoid ferrite, but not acicular ferrite or bainite. Indeed, Nb in particular tends to enhance bainite formation. Slag inclusions, particularly if present in sufficient number and size, also tend to promote the nucleation of acicular ferrite



What are the Causes of Heat-Affected Zones?

The heating associated with welding and/or cutting generally uses temperatures up to and often exceeding the temperature of melting of the material in question, depending on the welding process used. However, the heating and cooling thermal cycle associated with these processes is different to whatever processing has occurred with the parent material previously. This leads to a change in microstructure associated with the heating and cooling process.

The size of a heat affected zone is influenced by the level of thermal diffusivity, which is dependent on the thermal conductivity, density and specific heat of a substance as well as the amount of heat going in to the material. Those materials with a high level of thermal diffusivity are able to transfer variations of heat faster, meaning they cool quicker and, as a result, the HAZ width is reduced. On the other hand, those materials with a lower coefficient retain the heat, meaning that that the HAZ is wider. Generally speaking, the extension of the HAZ is dependent on the amount of heat applied, the duration of exposure to heat and the properties of the material itself. When a material is exposed to greater amounts of energy for longer periods the HAZ is larger.

With regard to welding procedures, those processes with low heat input will cool faster, leading to a smaller HAZ, whereas high heat input will have a slower rate of cooling, leading to a larger HAZ in the same material. In addition, the size of the HAZ also grows as the speed of the welding process decreases. Weld geometry is another factor that plays a role in the HAZ size, as it affects the heat sink, and a larger heat sink generally leads to faster cooling.

High temperature cutting operations can also cause a HAZ and, similarly to welding procedures, those processes that operate at higher temperatures and slow speeds tend to create a larger HAZ, while lower temperature or higher speed cutting processes tend to reduce the HAZ size. The width of the HAZ from the cut edge is determined by the cutting process, cutting speed, and the material properties and thickness.

Different cutting processes have differing effects on the HAZ, regardless of the material being cut. For example, shearing and waterjet cutting do not create a HAZ, as they do not heat the material, whilst laser cutting creates a small HAZ due to the heat only being applied to a small area. Meanwhile, plasma cutting leads to an intermediate HAZ, with the higher currents allowing for an increased cutting speed and thereby a narrower HAZ, while oxyacetylene cutting creates the widest HAZ due to the high heat, slow speed and flame width. Arc welding falls between the two extremes, with individual processes varying in heat input.

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. In the case of stainless steel type 1.4301 (AISI 304) heated in open air, 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.

Effects of the HAZ

The heat-affected zone leads to structural changes in the metal that weaken the part in this area. A metal’s mechanical properties such as fatigue resistance, distortion, and surface cracking are affected.

This makes it extremely crucial to learn about the effects of the HAZ. This applies even if you are not cutting or welding metal on your own.

Let us take a look at the different effects of the HAZ on the metal.

Metallurgical & Chemical Changes

In metal cutting, the metal absorbs heat at a very high rate. The cooling provided by the coolant is also immediate. This can significantly change a metal's microstructureand properties in the affected area.

Metals' molecular structures expand when heated. If the heat applied changes over the cross-section of the metal, it leads to uneven expansion and subsequent contraction of the metal body. Deformities such as distortion can occur during the cooling process. For example, production of hot rolled steel has similar results.

Chemical changes are also seen as different phases are created next to each other depending on the specific temperatures achieved by the different sections of the metal.

Surface Nitriding

Surface hardening includes adding nitrogen to a metal surface to improve its hardness. In high-temperature metal cutting and welding operations, this effect is seen inadvertently. As a result, in the heated area, the hardness increases and weldability decreases.

Oxidation

When metals are subjected to high temperatures, they can undergo oxidation among other phenomena. This is responsible for the brightly coloured bands that are characteristic of the HAZ.

Phase Change

Iron carbide diagram help us to understand different phases of steel. Different phases are created depending on the steel's temperature.

When exposed to high temperatures, for example, austenitic stainless steel will change to martensitic steel. Martensitic steel is harder and more brittle than the former. In some cases, heat will weaken the metal.

Hydrogen Embrittlement

Hydrogen embrittlement is the diffusion of hydrogen into the metal lattice that reduce the toughness and ductility of material.

High temperatures can lead to hydrogen embrittlement. Phase transformation may occur in some metals due to this atomic hydrogen. This can cause hydrogen cracking even after 24 hours of the cutting process.

Corrosion

Stainless steel may even corrode in the heat-affected zone. Extreme heat leads to the precipitation of chromium carbides near the grain boundaries. This reduces the chromium content of stainless steel below 10.5 percent.

The result is the loss of self-passivation (the ability to recreate a protective layer of chromium oxide to prevent corrosion) causing intergranular corrosion. It also loses its property of being stainless and in extreme cases, the metal will turn black.

How to Reduce the Heat Affected Zone

Reducing the presence or effect of the heat affected zone can help alleviate the related problems of HAZ cracks, corrosion, embrittlement, and so forth. This can be achieved by heat treatment following the welding or cutting operation. The heat treatment applied will depend upon the required properties and the intended changes required – it may be a precipitation hardening treatment, or a softening treatment, depending on the material. However, this process can be costly and time-consuming and may not offer a complete solution. Heat treating is also limited by the comparative size of the part and the torch or furnace used.

Cutting can also be used an alternative to heat treatment to reduce the impact of the HAZ. This can be achieved through either grinding or cutting, although care needs to be taken not to introduce more heat to the part.

Machining is the most effective way to remove the entire HAZ, but this can reduce the material yield as well as increasing labour and machine time.

Finally, heat tint from oxidation can be ground away or removed with fine sandpaper. This will expose the underlying layer and activate self-passivation of the chromium – although this can also weaken the part.

Ideally, the heat affected zone should be minimised through the selection of the correct welding or cutting process for the material. TWI can help with this type of selection as well as being able to advise on the best materials for your job.

How is mild steel Made?

Mild steel is made similar to how other carbon steels are made. A Common way this is done involves a combination of iron ore and coal. Once the coal and iron ore are extracted from the earth , they are melted together in a blust furnace. Once melted, the mixure is moved to another furnace to burn off any impurities that they may have, as well as to make any other adjusments to the chemical composition. Following that, the steel is allowed to solidify into a rectangular shape. This slab of mild steel is then usually brought down to the desired size using processes called hot rolling or cold working, although there are other methods that can also be used.

Advantages of using Mild steel bar

1. High tensile strength
2. High impact strength
3. Good ductility and weldability
4. A magnetic metal due to its ferrite content
5. Good malleability with cold forming possibilities

6. Suitable for various heat treatment options to improve properties

OBJECTIVE

THE OBJECTIVES OF THIS PROJECT ARE

- ***To study the variation of microstructure of mild steel bar and TMT bar.***
- ***Observation of microstructural change after performing normalization of mild steel bar and TMT bar.***
- ***Observation of microstructural change after performing hardening of mild steel bar and TMT bar.***
- ***Welding of mild steel bar and TMT bar.***
- ***Heat affected zone microstructure analysis of mild steel bar and TMT bar.***
- ***Macro hardness study of mild steel bar and TMT bar.***
- ***Hardness observation of normalized mild steel bar and TMT bar (SRMB).***
- ***Hardness observation of quenched mild steel bar and TMT bar(SRMB).***
- ***Fresh water corrosion penetration calculation of mild steel bar and TMT bar by observing 90 days.***
- ***Sea water corrosion penetration calculation of mild steel bar and TMT bar(SRMB)by observing 70 days.***

- ***Chemical Composition of mild steel bar***

weight percentage	Mild steel Bar
1.Carbon(max)	0.3
2.Sulphur(s)(max)	0.04
3.Phosphorus(P)(max)	0.037
4.Silicon (max)	0.24

The manufacturing process: TMT

TATA STEEL was the first in India to developed thermo mechanically treated (TMT) rebars by using of latest technology of tempcore. The rebars are produced are produced under the close supervision of metallurgists and engineers. The basic steel is made from virgin iron ore through blast furnace- basic steel making –secondary refining –billet casting route with minimum impurities. They are rolled in fully automated mills from world renowned suppliers.

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 composition

Weight percentage	SRMB Fe500D
1.Carbon(max)	0.30
2.Sulphur(max)	0.055
3.Phosphorus(max)	0.055
S&P(max)	0.105

Chapter 3

Observation of microstructutre

Microstructure development process and equipments required.

Aim-:

Preparation and study of the Micro Structure of Mild steel bar and TMT bar

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.

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 .

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 4: 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 HN03; 98 ml ethyl alcohol

Metallographic Observation of normal Mild Steel bar and TMT bar

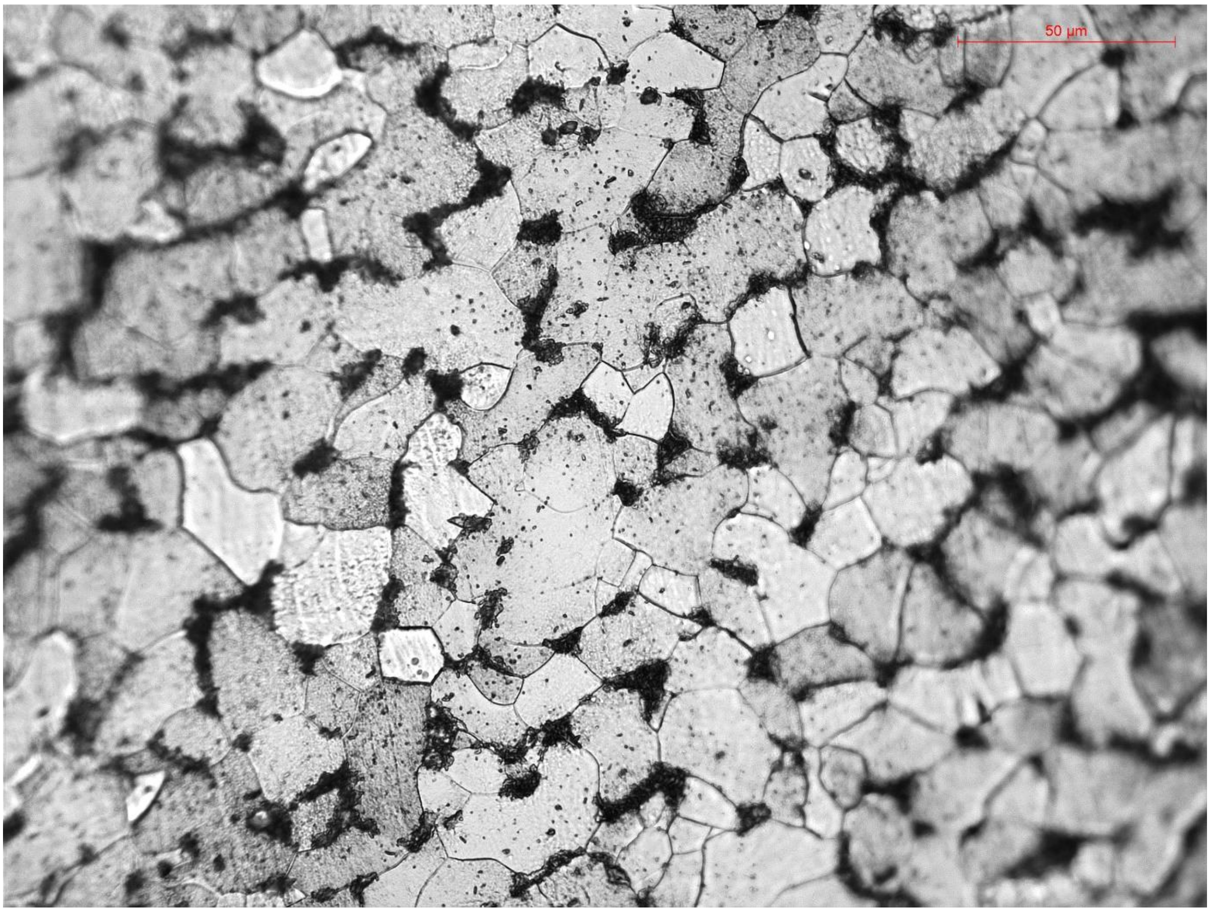


Figure 5: Microstructure of Mild steel bar (500X)

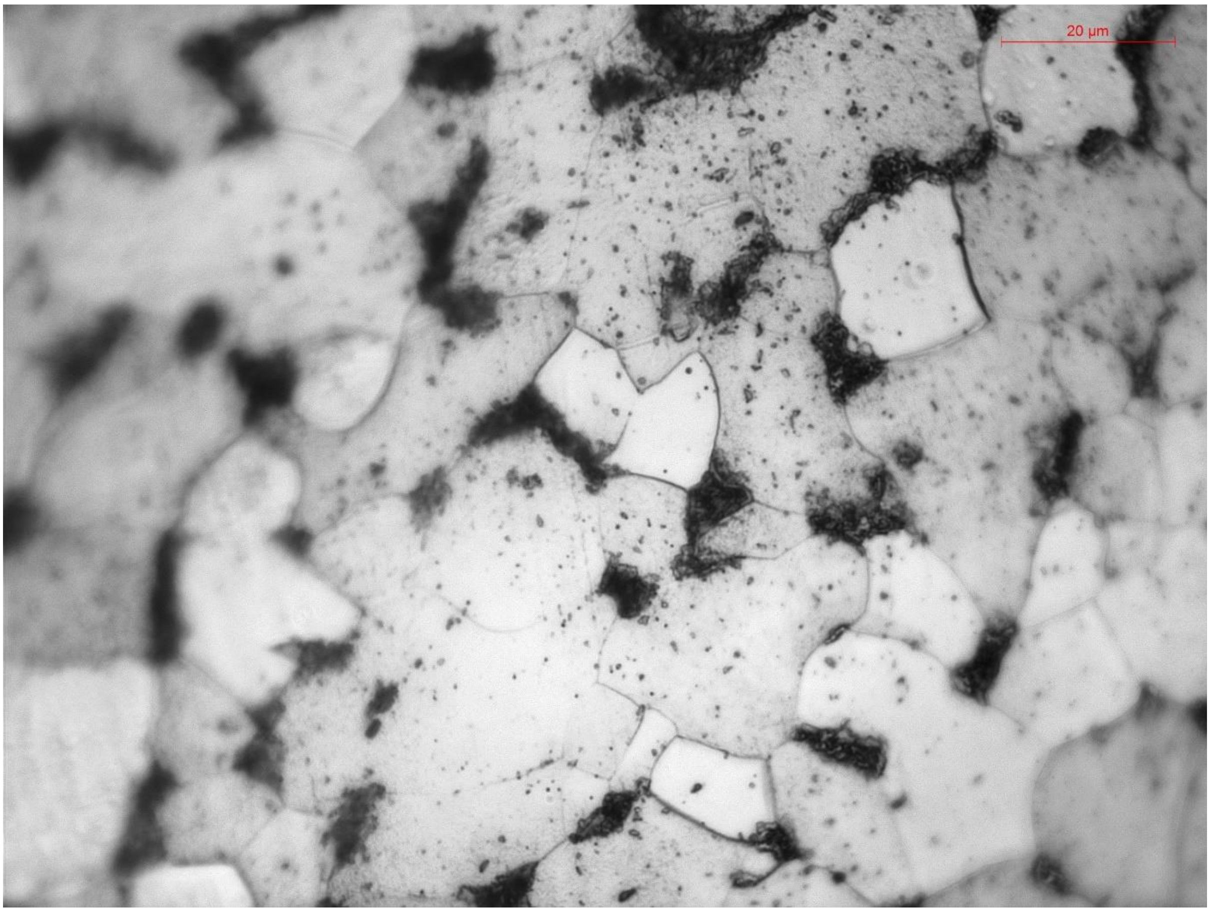


Figure 6:Microstructure of normal mild steel bar (1000X)

Figure 5 and Figure 6 represent microstructure of normal mild steel bar. Light phase being ferrite and dark phase region being pearlite. The pearlite itself consisting of brand (or lamellar structure) of ferrite and cementite. Approximately for microstructure of 0.2 percent carbon steel around 25% of area you will have perlite (dark phase) and 75% of area will be ferrite (light phase). From above figure we can observed that the area of ferrite (light phase) is more than the area of perlite (dark phase).

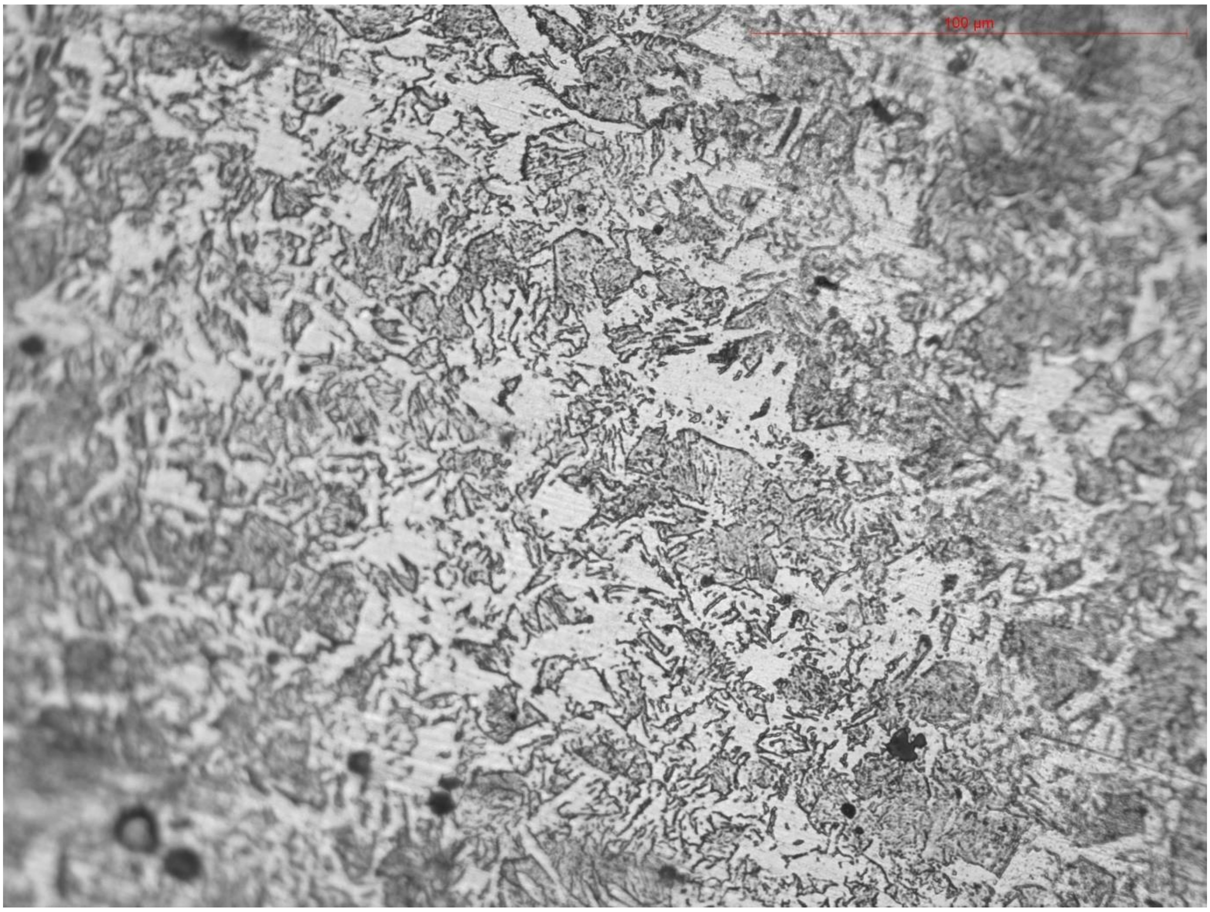


Figure 7: Microstructure TMT bar (500X)

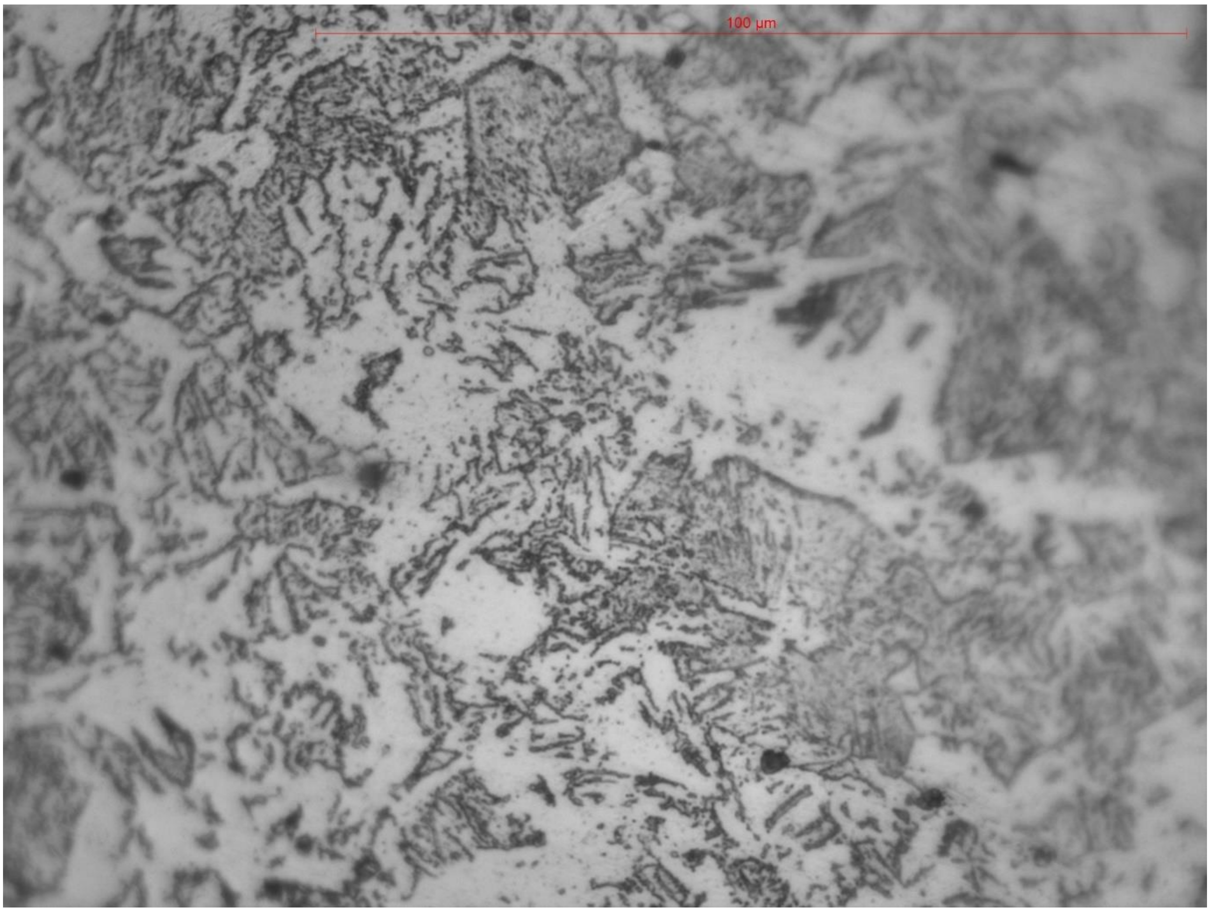


Figure 8: Microstructure of TMT bar (1000X)

From figure 7 and figure 8, the light phase being ferrite and dark phase being pearlite. Ferrite phase provide soft and ductile structure where as pearlite phases provide hard and brittle structure because it contain cementite phases. We observed that from above figure the region of dark phases (pearlite) is more than the region (ferrite) phase. This structure provide more hardness and strength.

Metallographic observation of normalized (air cooling) mild steel bar and TMT bar

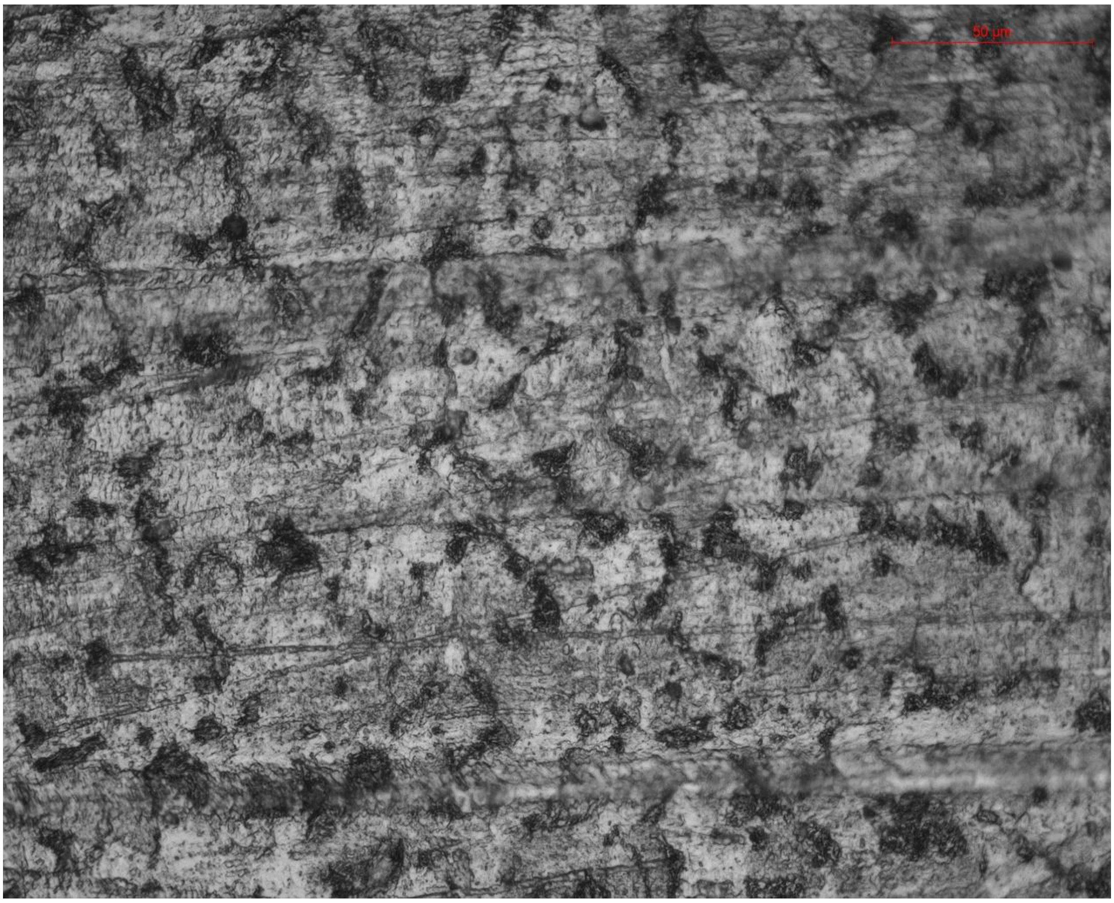


Figure 9: microstructure of normalized mild steel bar (500X)

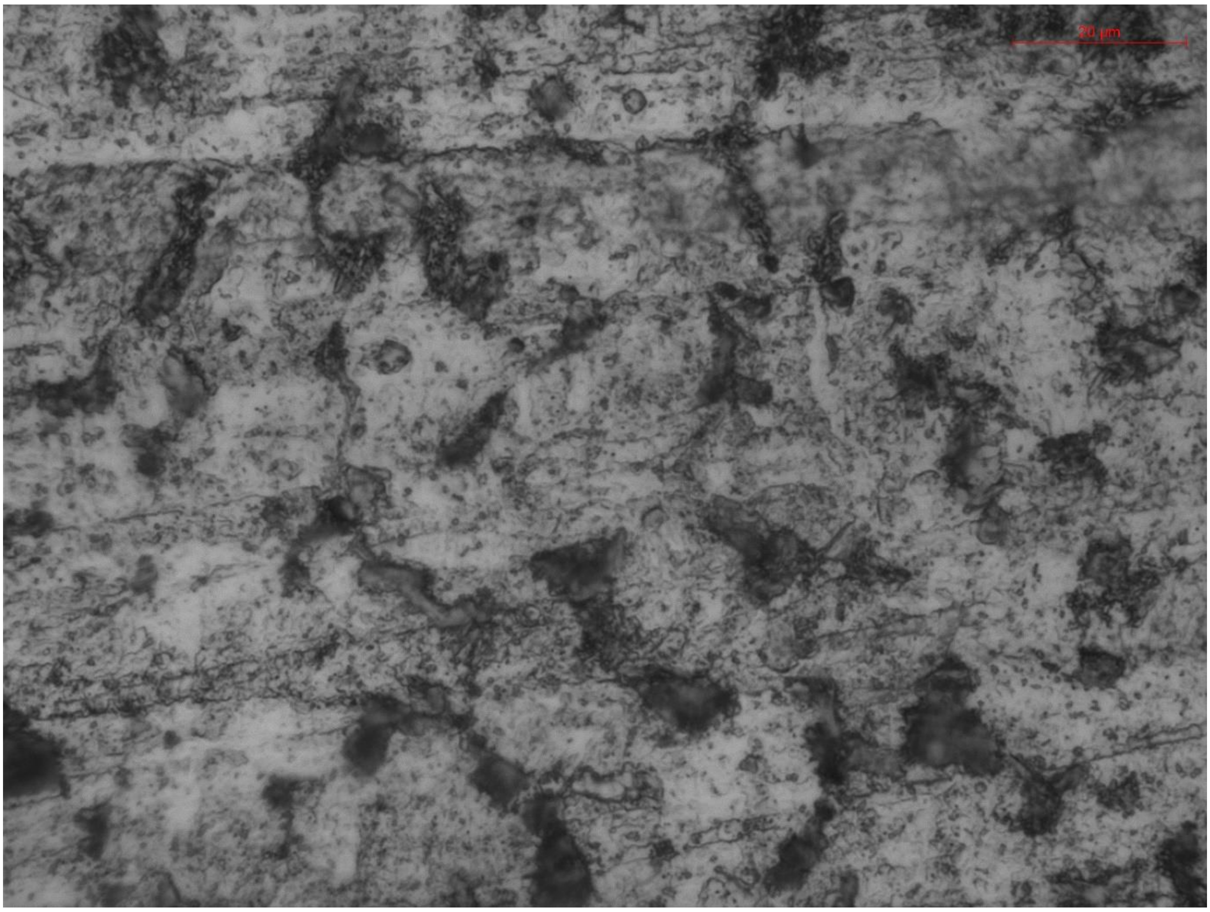


Figure 10: Microstructure of normalized mild steel bar (1000X)

From figure 9 and Figure 10, the pearlite is the dark phase and the light phase is the ferrite. The amount of pearlite in this steel is quite low due to the low carbon contest. At higher magnification, the lamellar eutectoid structure of the pearlite can be observed. This structure is due to the simultaneous formation of ferrite and Fe3C from the austenite. The spacing of the lamellae increases with cooling rate.

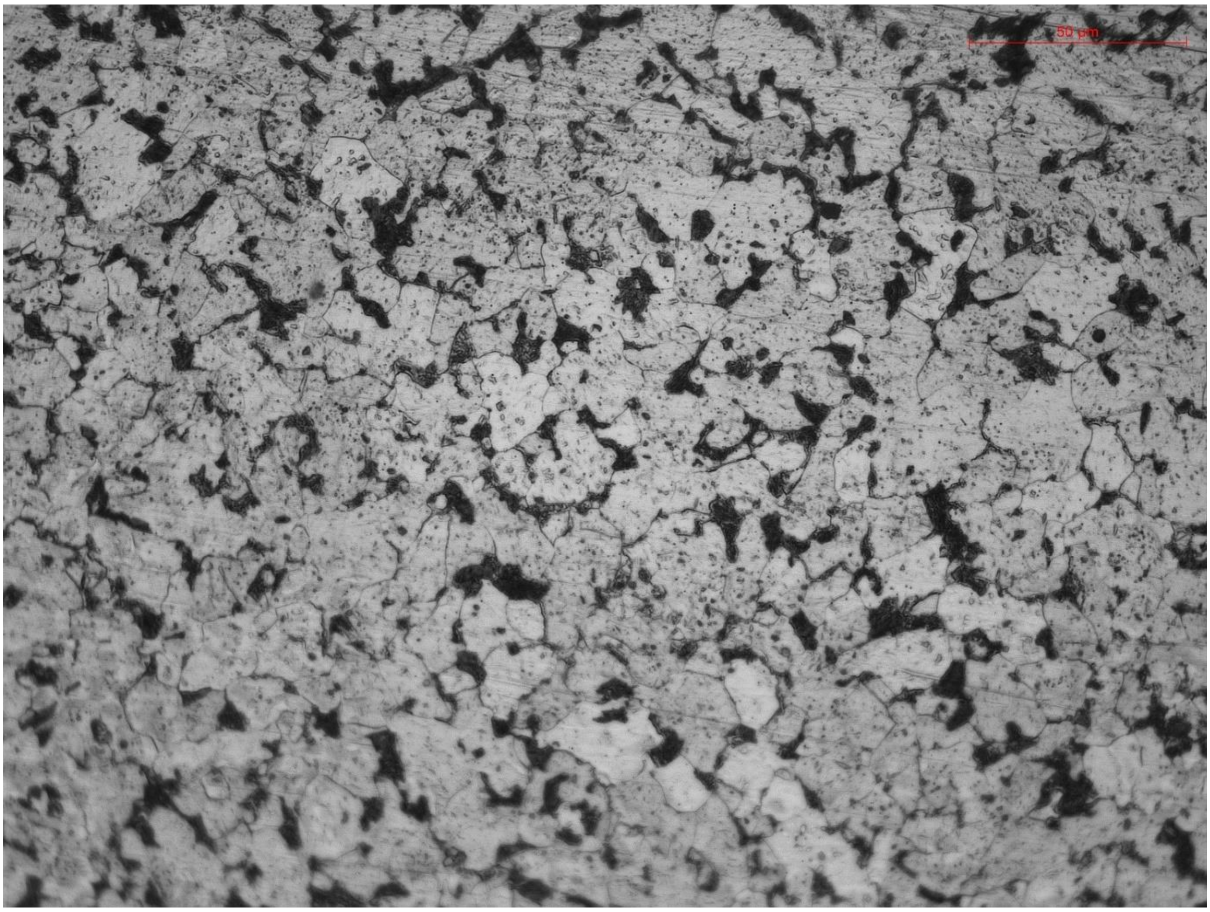


Figure 11 :Microstructure of normalized TMT bar (500X)

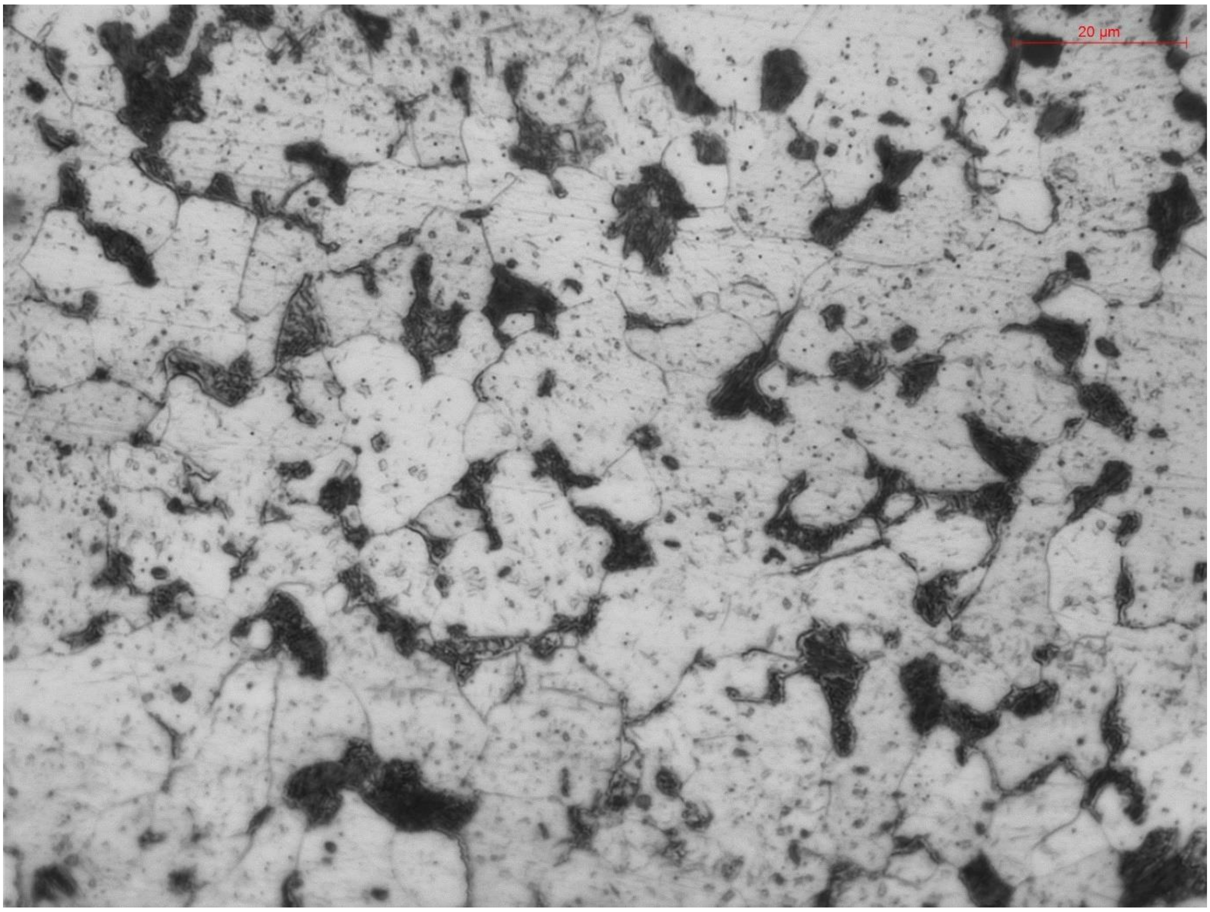


Figure 12: Microstructure of normalized TMT bar (1000X)

From figure 11 and figure 12, we observed that due to air cooling austenitic phase covert into polygonal ferrite and also less amount of pearlite formed.

Metallographic observation of quenched (water cooling) mild steel bar and TMT bar

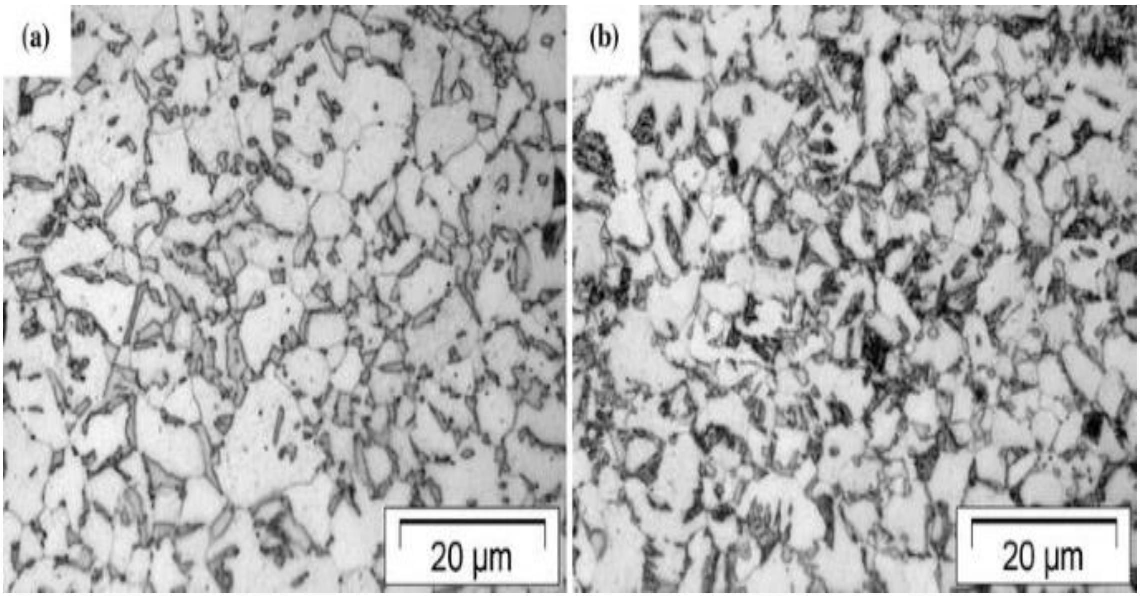


Figure 13 :Microstructure of quenched mild steel bar

In this figure , ferrite is clearly observed as the white matrix, but a detailed observation shows very fine boundaries separating ferrite areas inside the same well defined ferrite grain. The ferritic areas that are closer to the austenite/martensite grains correspond to ferrite that has grown from the ferrite present after the intercritical treatment during the cooling (epitaxial ferrite).

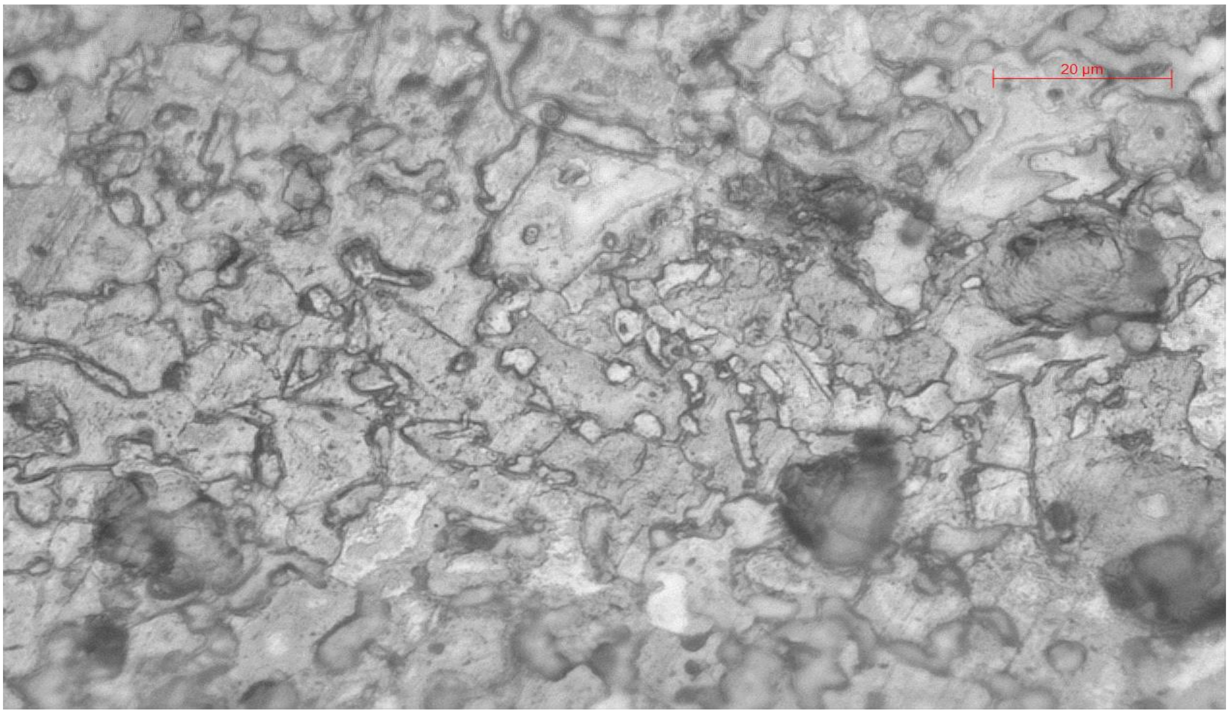


Figure 14: Microstructure of quenched TMT bar (500X)

Quenching (water cooling) converts the rebar surface to a hardened structure (martensite) and subsequently the phase evolves by cooling at ambient temperature to allow the hot core to temper the surface through thermal exchange. This results in a unique composite microstructure comprised of tempered martensite in the peripheral zone/case, transition zone of pearlite and bainite just after the martensite periphery and a fine grain ferrite-pearlite at the central zone/core.

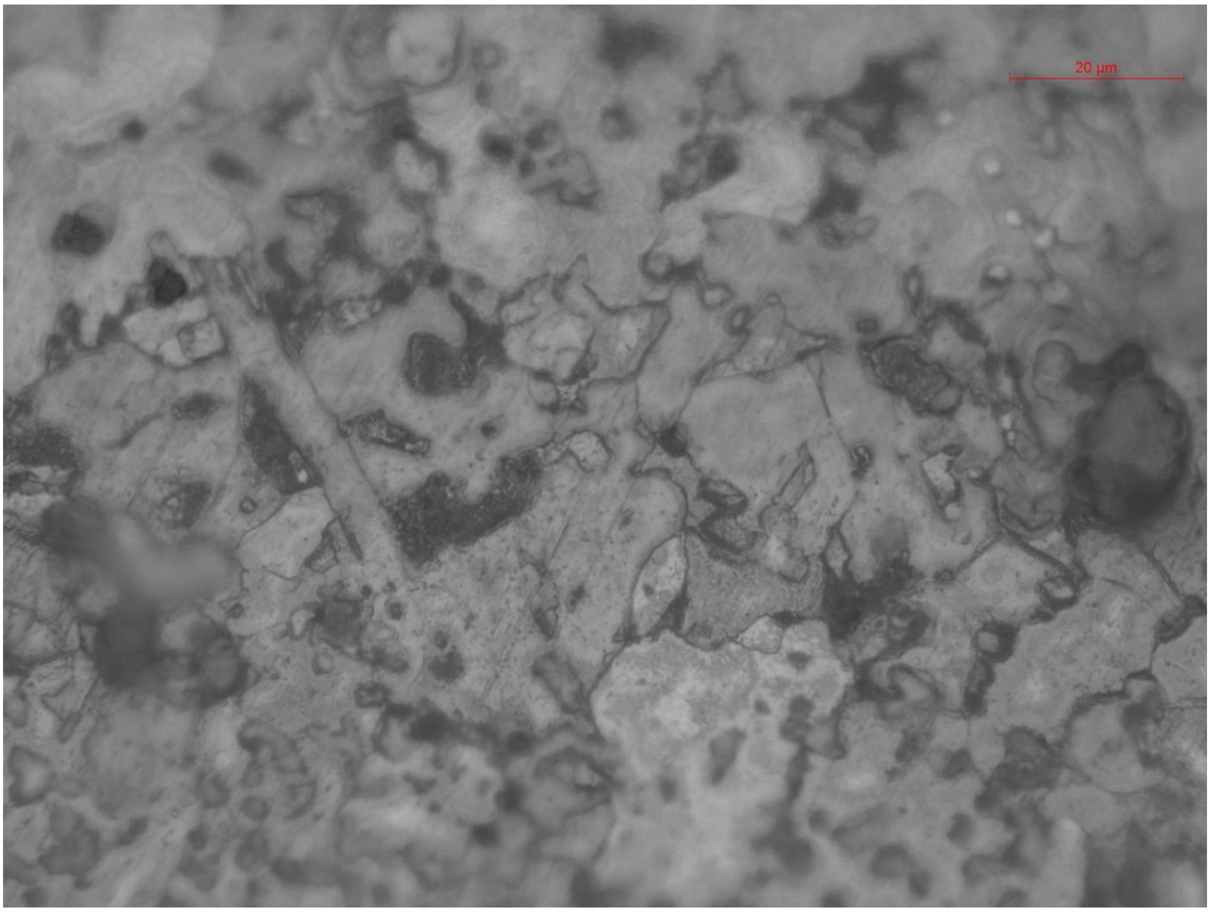


Figure 15: Microstructure of quenched TMT bar(1000X)

Quenching leads to the highest hardness values, as expected. This is due to the formation of huge amounts of martensite, from austenite, as observed in the microstructure.

Observation of microstructure of welded mild steel bar and TMT bar

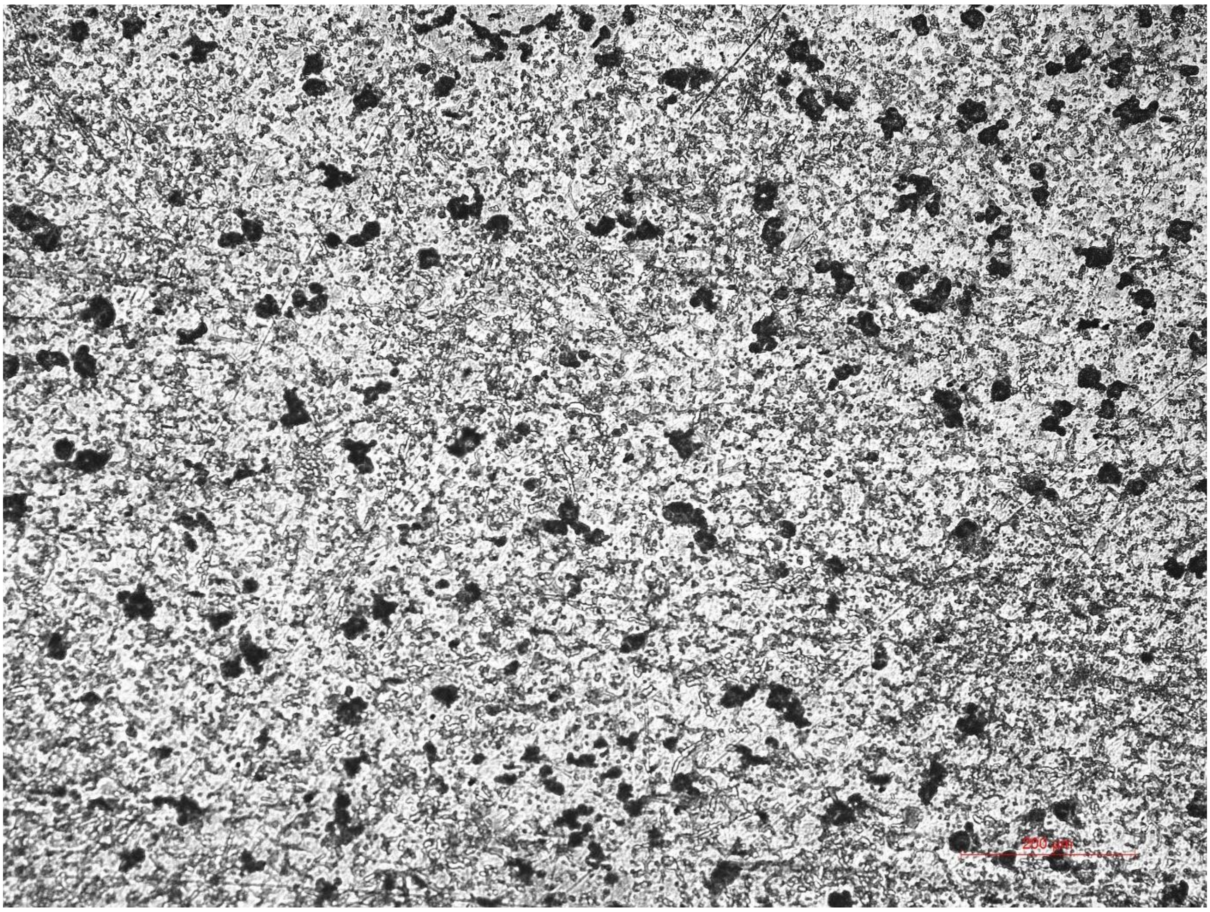


Figure 16 :Microstructure of base metal of mild steel bar

We observed that this microstructure (base metal) is composed of ferrite and small regions of pearlite (α-Fe + Fe3C) at grain boundary edges and corners.

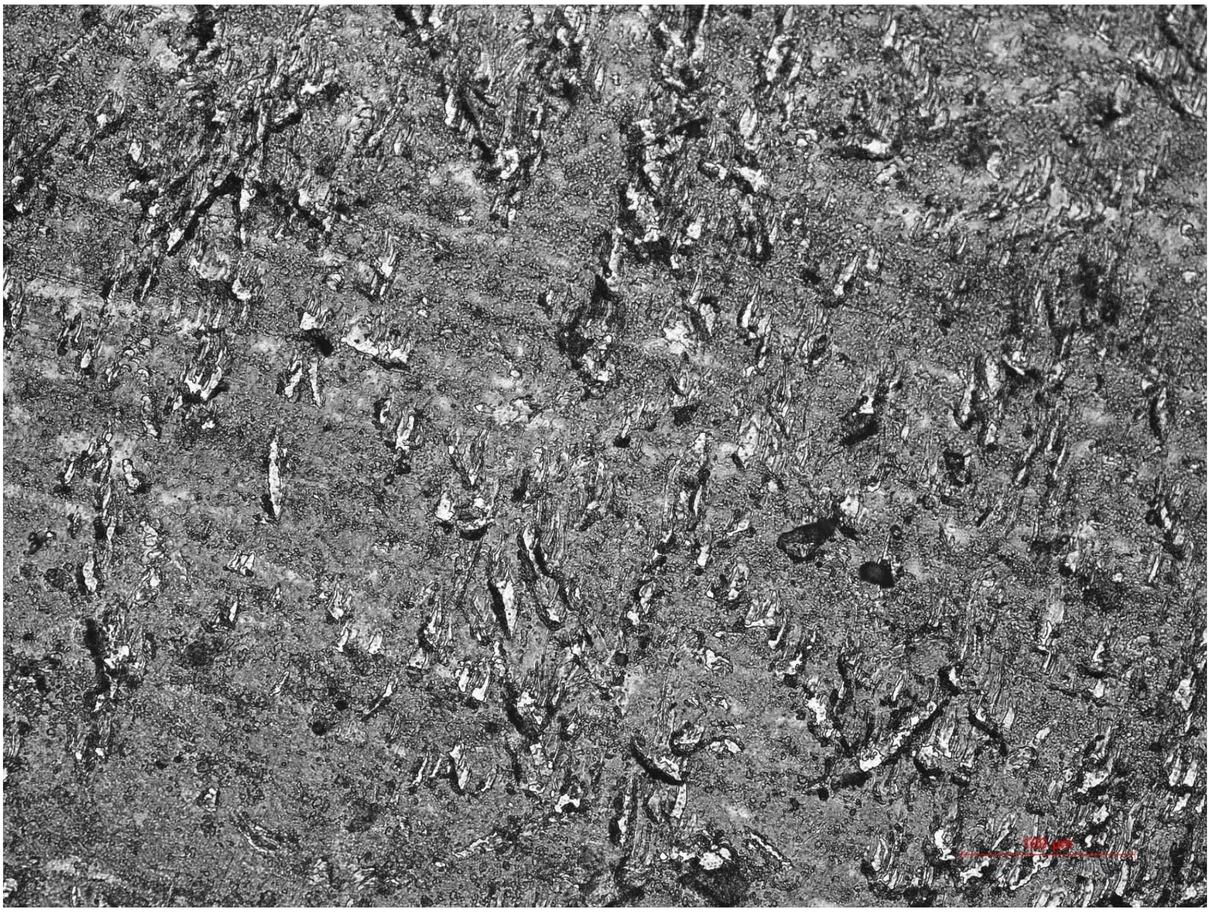


Figure 17: Microstructure of welded zone of mild steel bar

Optical microscope was used to observe the microstructure of welded mild steel bar. The photograph of nearest region to HAZ shows the elongated ferrite grains, this happens due to direction of heat flow. It is observed that large grains are present near the fusion line and they are oriented along the direction of large heat flow.

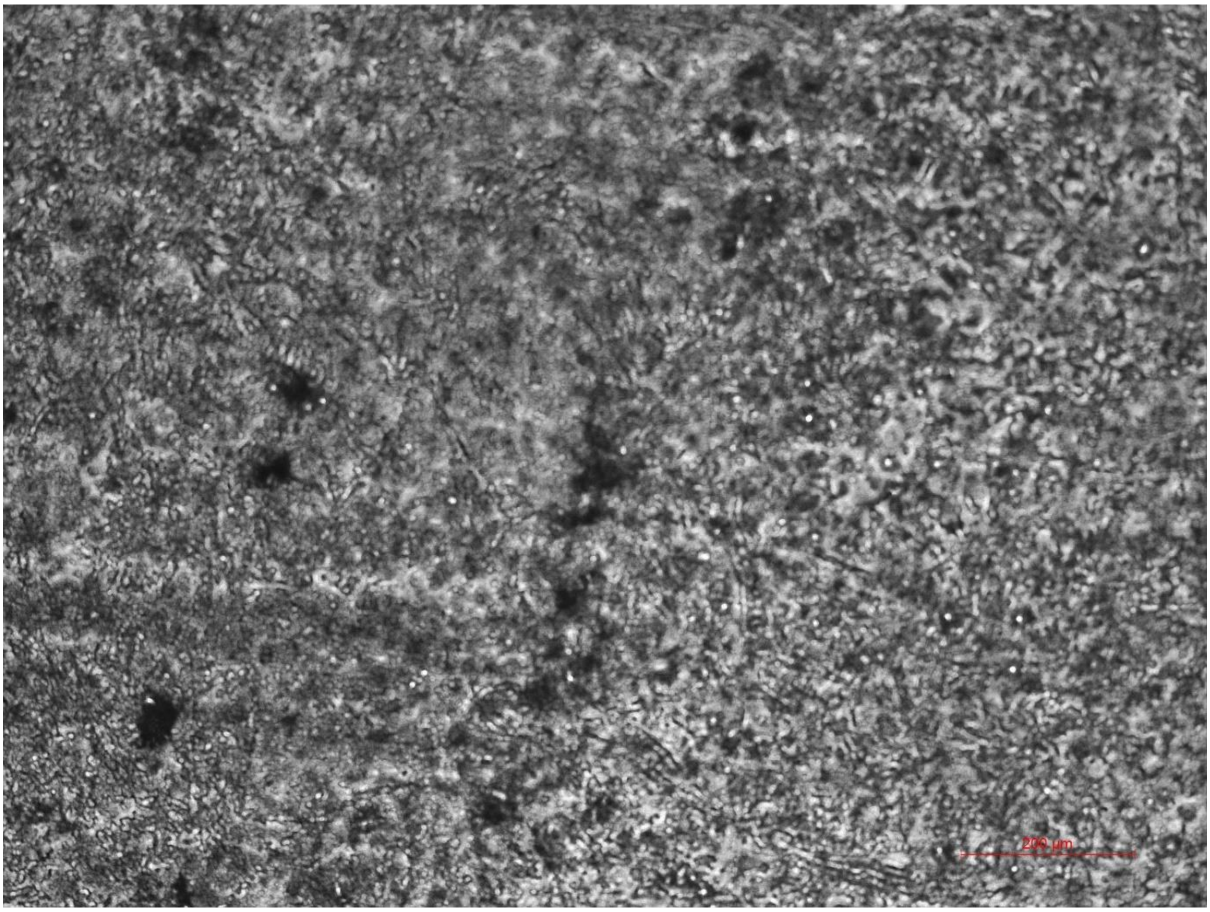


Figure 18: Microstructure of heat effected zone of mild steel bar

The microstructure of heat affected zone is shown in figure 18. It shows some colonies of pearlite and Widmanstatten ferrite. Adjacent to fusion zone, there is a coarse grained region of heat affected zone. The grains in this region are somewhat larger than that of the ones in base metal.

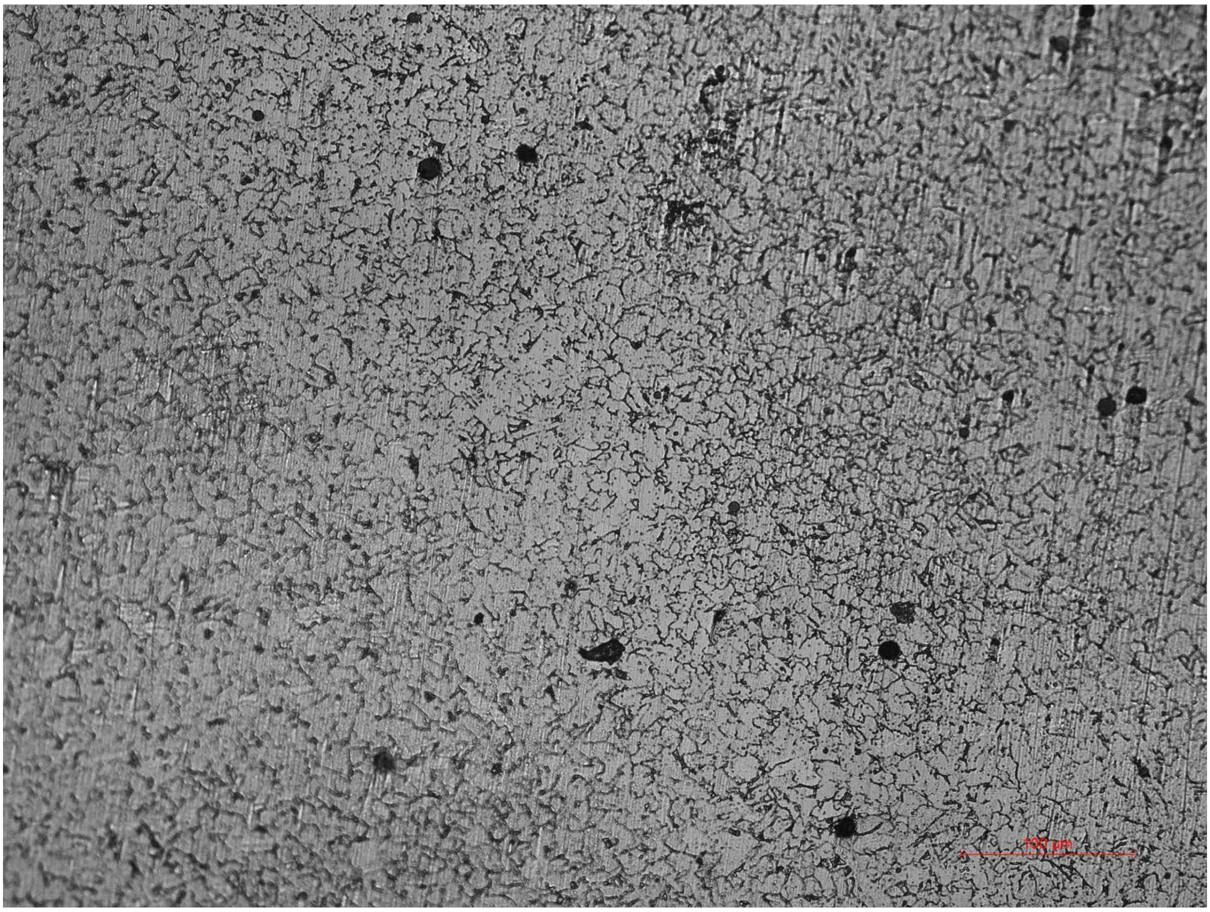


Figure 19 :Microstructure of base metal of TMT bar

Light phases being ferrite and dark phase being pearlite. Here we observed that there small amount pearlite phases present in this microstructure. Mostly large amount light phases(ferrite) present.

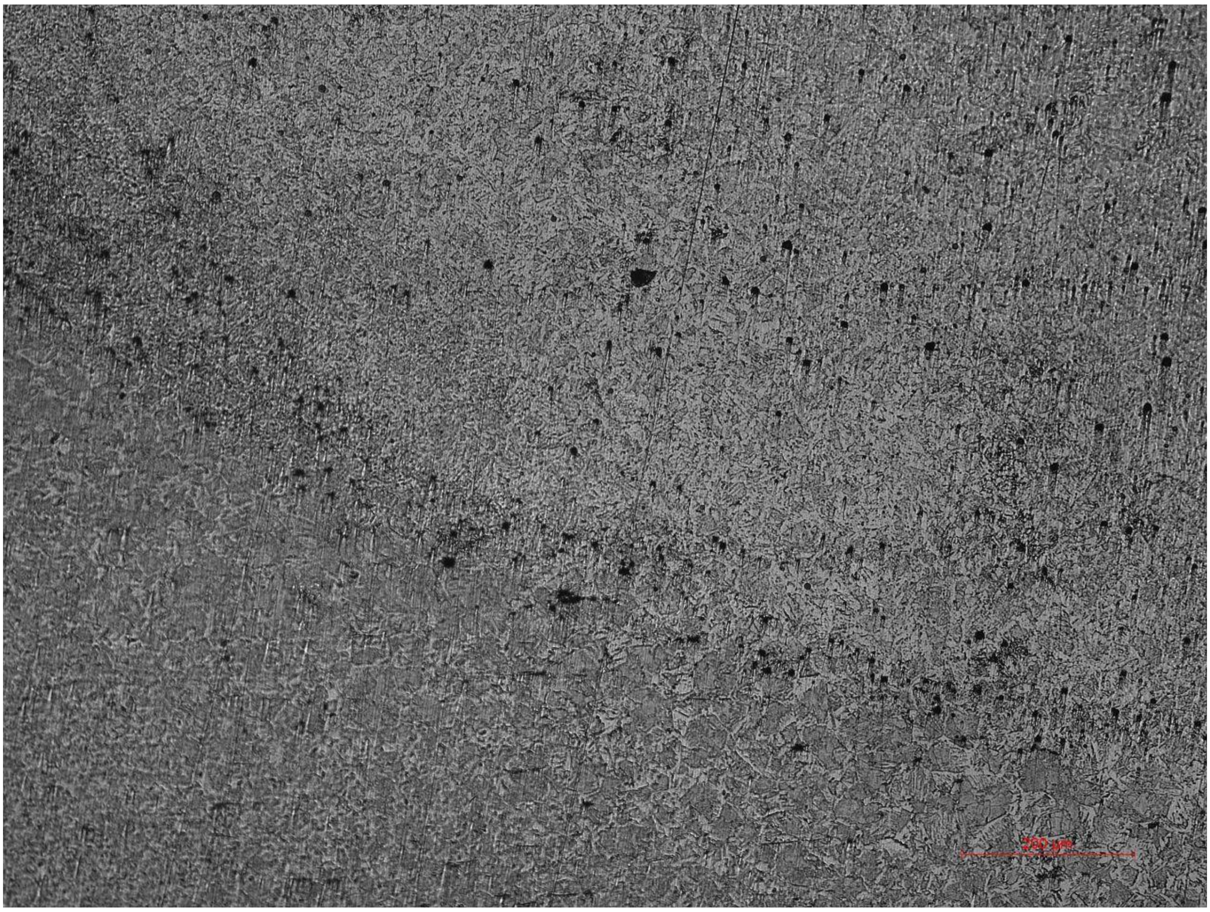


Figure 20: Microstructure of transition zone of TMT bar

In the above region the grain difference between welded zone and heat affected zone can be easily observed. The grains of welded zone are much smaller than heat effected zone. The microstructure of the HAZ was not homogeneous near the fusion line at the root passes a coarse-grained microstructure was observed while closer to the cap passes a fine-grained zone could be distinguished

Chapter 4

Observation of Hardness

VICKERS HARDNESS TEST of mild steel bar and TMT bar

Procedure:

1.Clean 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 the micrometre 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.

VICKER’S Hardness test of normal mild steel bar and TMT bar

VICKERS HARDNESS NUMBER= (1.854P÷ D2)

Where P is applied load and D2 is the area of indentation.

VICKERS Hardness number of mild steel bar

Core region

D1	D2	D=(D1+D2)/2	VHN
.567	.569	.568	172.39
.566	.562	.564	174.85
.562	.564	.563	175.47

Casing Region

D1	D2	D=(D1+D2)/2	VHN
.556	.552	.554	181.22
.555	.557	.556	179.92
.552	.554	.553	181.87

VICKERS Hardness number 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

VICKER’S Hardness test of air cooled mild steel bar and TMT bar

VICKERS HARDNESS NUMBER=(1.854P÷ D2)

Where P is applied load and D2 is the area of indentation.

VICKER’S Hardness test result of air cooled mild steel bar

D1	D2	D=(D1+D2)/2	VHN
0.554	0.556	0.555	180.56
0.551	0.551	0.551	183.200
0.560	0.562	0.561	176.72

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

D1	D2	(D1+D2)/2	VHN
0.561	0.554	0.558	178.633
0.550	0.552	0.551	183.200
0.554	0.557	0.555	180.569

In VICKER'S Hardness test result of quenched SRMB mild steel bar sample

D2	D1	(D1+D2)/2	VHN
0.512	0.510	0.511	213.004
0.506	0.504	0.505	218.096
0.510	0.508	0.509	214.681

In VICKER'S Hardness test result of quenched SRMB TMT bar sample

D1	D2	(D1+D2)/2	VHN
0.515	0.511	0.513	211.347
0.510	0.514	0.512	212.173
0.506	0.514	0.510	213.840

Chapter 5

Observation of Corrosion Penetration Rate

Observation of microstructure of rust formation in mild steel bar and TMT bar

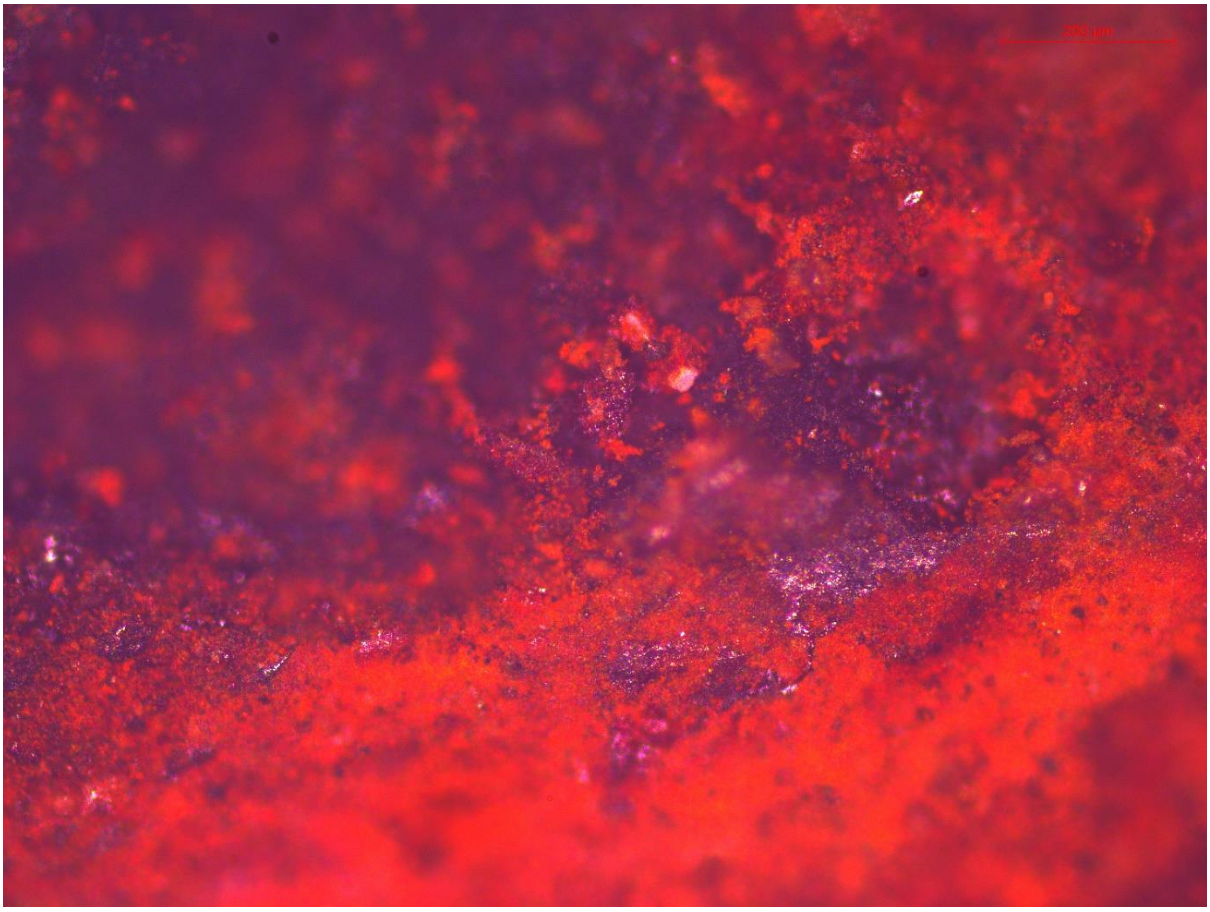


Figure 21: Microstructure of rust formation in mild steel bar

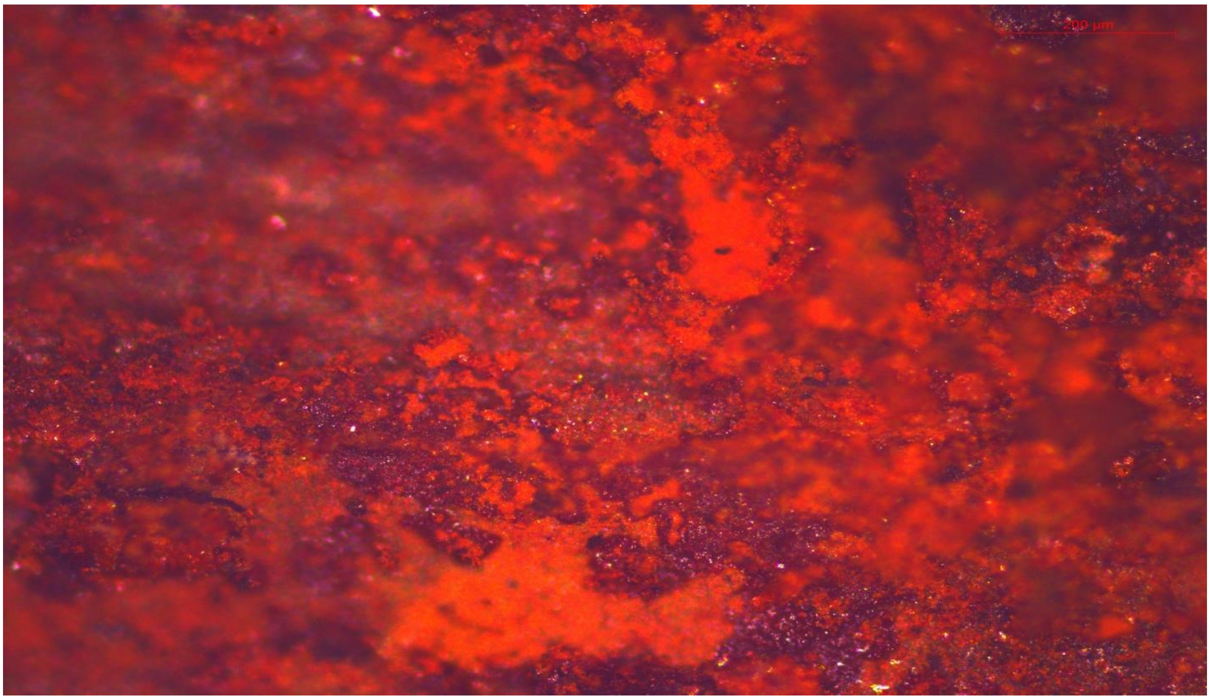


Figure 22 :Microstructure of rust formation in TMT bar

Observation of corrosion penetration rate in mild steel and TMT bar

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

$$CPR = KW / \dot{\rho} A t$$

where W is the weight loss after exposure time t; r 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.

Corrosion test procedure

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 repeated for 90 days, for each sample.

Corrosion of SRMB Mild Steel bar

Mass of specimen=17.5gm=$17.5*10^{-3}$kg/m^3.

=17500mg.

Volume of specimen=(11.80× 11.80) × 16.5

=$2.29*10^{-6}m^3$

Density =7641.92kg/m^3

Remaining mass vs experiment day table

Days	0	15	30	45	60	75	90
mass	17500	17420	173360	17310	17275	17245	17225

Total weight loss=(17500-17225)mg

=275mg.

Total days=90

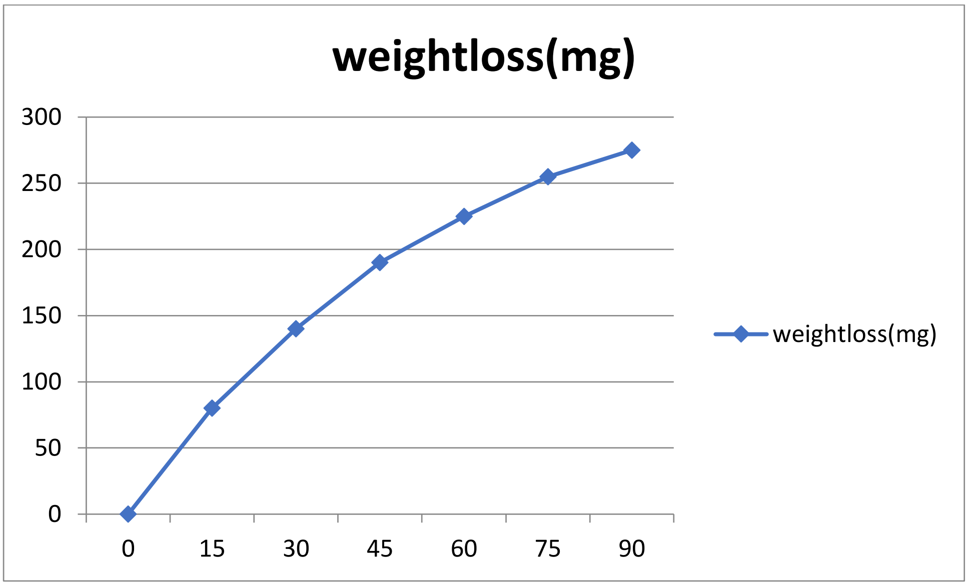


Figure: weight loss versus experiment days.

length of specimen=1.65cm.

thickness of specimen=1.18cm.

exposed surface area=(4×1.18×1.65)+(1.18×1.18)=9.1804

=9.1804cm^2

Value of constant =87.6

Corrosion Penetration Rate of SRMB mild steel bar=.158mm/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

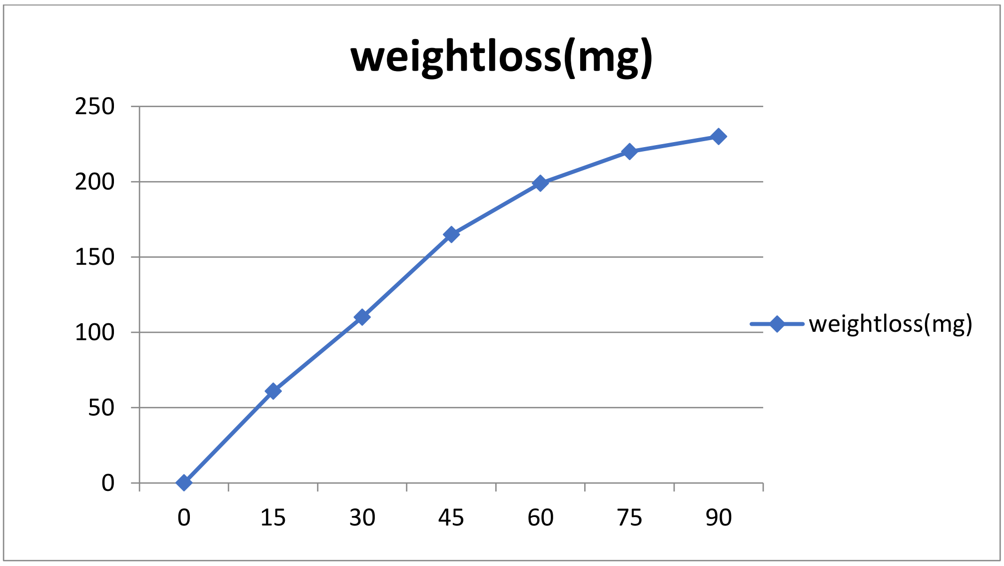


Figure: weight loss versus experiment days.

length of specimen=1.67cm.

radius of specimen=.56cm.

exposed surface area=cylindrical surface area+cross sectional area.

$=7.842\text{cm}^2$

Value of constant =87.6

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

Corrosion of SRMB mild steel bar in saline water

Mass of specimen=24.3gm.

=24300mg.

Density of specimen=7586.637 kg/m^3.

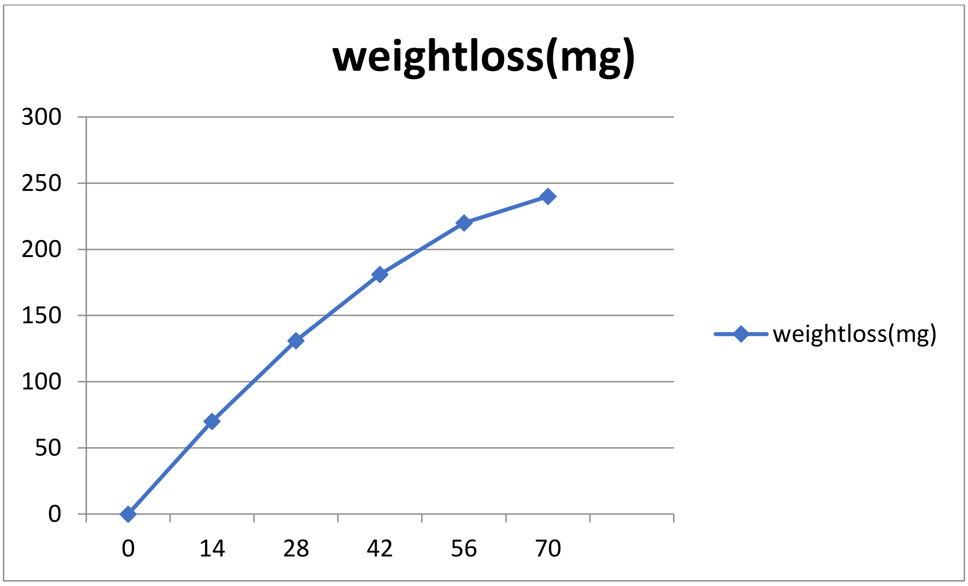
Remaining weight versus days table

days	0	14	28	42	56	70
mass	24300	24230	24169	24119	24080`	24060

Total weight loss=(24300-24060)mg

=240mg

Length of specimen=2.301cm.



Corrosion experiment days versus weightloss(mg) graph

Total surface area of specimen =(4×2×1)+(1×1)

=9cm^2.

Value of constant k for mm per year=87.6

Corrosion penetration rate(CPR) of SRMB mild steel bar=.183 mm/year.

Corrosion of SRMB TMT bar in saline water

Mass of specimen=14.880gm.

=14800mg.

Density of specimen=7588.541 kg/m^3.

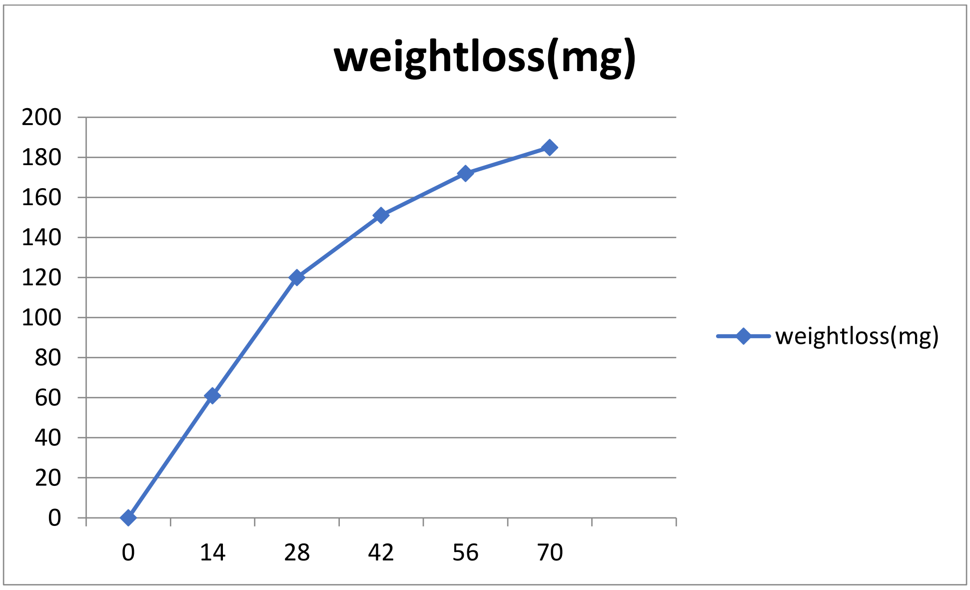
Remaining weight versus days table

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

Total weight loss=(14.880-14.965)mg

=185mg

Length of specimen=1.71cm.



Corrosion experiment days versus weight loss(mg) graph

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

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

Value of constant k for mm per year=87.6

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

Chapter 6

Conclusion

Conclusion

1. The strength of the TMT bar is greater than the normal mild steel bar.
2. We also found that from corrosion test the corrosion penetration rate of normal mild steel bar greater than TMT bar.
3. Microstructure analysis techniques, such as optical microscopy, allow for detailed examination of a material's microstructural features, such as grain boundaries, inclusions, and phase distribution. The parent metal has equiaxed austenite grains and delta ferrite in the austenite matrix in the microstructure of the weld metal. The noticeable dark streaks are ferrite stringers.
4. For normal mild steel bar yield strength near about 250 MPa but for TMT bar yield strength near about 500MPa. For normal mild steel bar yield point around 0.12% of strain but in case of TMT bar yield point 0.2% of strain.
5. The tensile strength of mild steel is relatively low and cannot withstand natural calamities such as earthquakes. In addition to their high tensile strength and low residual strength, TMT steel bars are highly earthquake-resistant.
6. TMT bar when subjected to water quenching result in the formation of martensite at the surface layers of the rebers. During cooling the residual heat flow across the rebar section results in tempering of the initially formed martensite rim and also produces ferrite-pearlite mixed microstructure in the core region.

Chapter 7

Future Scope

Future Scope

1: India’s construction industry has witnessed tremendous growth in recent years, with the demand for durable, cost-effective, and sustainable construction materials on the rise. Among these materials, Steel TMT bars have emerged as the preferred choice due to their superior strength, flexibility, and corrosion resistance.

2: Growth in the industry is driven by the increasing demand for reinforced concrete in the construction of residential and commercial buildings, bridges, and highways. Additionally, the growing focus on sustainable infrastructure and green construction practices has led to the development of high-strength, low-alloy (**HSLA**) TMT bars that offer better ductility, weldability, and fatigue resistance than traditional TMT bars.

3: One of the significant innovations in TMT bar technology is the use of micro-alloying elements such as vanadium, niobium, and titanium to improve the mechanical properties of the bars. These elements form fine sediments in the steel microstructure, resulting in higher strength and toughness. Additionally, the use of advanced thermomechanical processes such as quenching and self-tempering (QST) and thermo-chemical treatments such as nitriding and boronizing has led to the development of ultra-high-strength TMT bars that can withstand extreme loading conditions and seismic activity.

4: Innovation highlight in TMT bar technology is the use of smart materials and sensors to monitor the structural health of buildings and bridges. Smart TMT bars are embedded with sensors that can detect cracks, corrosion, and other defects in real time, enabling early detection and prevention of structural failures. These sensors can also be used to measure temperature, strain, and other environmental factors that affect the longevity and performance of the TMT bars.

5:The future of TMT bar technology in India is impressive, with continued innovation and the development of new materials and processes that will enhance the strength, durability, and sustainability of the construction industry.

Chapter 8

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