Comparative study of various crosswire welded structure for Thermo-mechanically Treated Rebar & Cold drawn Plain carbon steel wire

Thesis submitted in partial fulfilment of the
requirementsfor the degree of

Master of Engineering

In

Metallurgical and Materials Engineering

Department of Metallurgical and Material Engineering
Faculty of Engineering and Technology
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By

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CERTIFICATE

This is to certify that the thesis entitled "**Comparative study of various crosswire welded structure for Thermo- mechanically Treated Rebar & cold drawn Plain carbon steel wire**" being submitted by Pratik Raj (Exam Roll No.- M4MET22005 & Reg. no.- 154361 of 2020-2021), for the award of the degree of Master of Technology in Metallurgical & Materials Engineering, is a record of bonafide work carried out under my supervision and guidance in the Department of Metallurgical and Materials Engineering, jadavpur university . The results presented in this thesis have not been submitted elsewhere for the award of any other degree or diploma. This work, in our opinion, has reached the standard of fulfilling the requirements for the award of the degree of Master of Engineering in Metallurgical and Materials Engineering in accordance with the regulations of the institute.

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DECLARATION

Declaration of Originality and Compliance of Academic Ethics

I hereby declare that the work “Comparative study of various crosswire welded structure for Thermo- mechanically Treated Rebar & cold drawn Plain carbon steel wire” contains literature survey and original research work by the undersigned candidate, as a part of his Master of Engineering in Metallurgical Engineering studies. All information in this document have been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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Abstract

There are various welding processes for joining the materials. Arc welding is a prominent joining process in which two steel parts are joined by heat generated due to arc. Many researches have been carried out in joining of different materials by different welding techniques. Our research has been emphasized on TMT bars. For joining these TMT bar perpendicular to each other cross wire spot welding is now available in mass production process .In this paper a study has been made for the effect of welding on microstructure and hardness of joined TMT rods & cooled drawn plain carbon steel which are perpendicular to each other & strength relationship with hardness. In this study three samples of TMT and one plain carbon steel were taken having different diameter . The variations of hardness with respect to different zones were checked using hardness testing machine and it was found that more hardness were in heat affected zone & weld zone than base & hardness & hardness variation is more for cold drawn plain carbon steel than TMT. All these sample microstructure were studied. Microstructural examination has clarified how hardness changes on the surface of material has occurred. Finally a correlations between strength and hardness has been tried to be established which ultimately shows a linear relationship. Also finally observing the % setdown of welded structure of samples were compared which shows welding parameter such as current is essential for more depth and more strength.

Table of Contents:

1.Introduction:

Welding is very old technique to joining steel. It is considered as an extension of hot forging. TMT bar is used in making roof and column because of its high tensile strength and hardness. High Tensile strength of a material to allows a material to withstand large axial loads. While high hardness resists wear and tear of the material. Arc welding use filler material for coalescence to take place. TMT bars are often welded by arc welding. Arc welding is widely used for domestic as well as industrial purposes as it is very convenient to use. Mechanical properties such as tensile and hardness depend on microstructure The filler material has different composition thus the weld joint will have different properties from the base material. Also the Heat Affected Zone (HAZ) being heated during welding suffers microstructural changes. So both these zone will differ in hardness from the base metal. Although the failure of the material will depend on which section is the weakest as stated by strain energy theorem. Thermo-Mechanically Treated bars are composed of a martensitic layer and the core is composed of ferrite and pearlite. The martensitic layer has higher hardness and strength because of its high residual stress.

Various researches have been done in welding of steel using different welding methods. Most of TMT bar’s joining process took place with arc welding. In this paper a study has been made for welded joint of steel rod.joints were made on TMT500 & cold drawn plain carbon steel through spot resistance crosswire welding technique & compare the grain changes,hardness,setdown & ultimately strength with their varying diameter. The superior properties of TMT steel are due to its specialised processing technique which gives it a peculiar micro-structure. It has tempered martensite in the periphery and fine ferrite and pearlite in the core. The properties of steel bars change on being subjected to different levels of cold working and heat treatment processes.As TMT500 was hot rolled while cold drawn plain carbon steel were cold rolled so the knowledge of the processing techniques and the consequent changes in micro-structure help in explaining the variation of properties of the steel bars. Projection welding is a unique form of resistance welding that uses the resistance heating of a small cubic area prior to, and during, its collapse under pressure to weld frequently different thicknesses of metal together. Crosswire welding is widely used in the construction and electrical industry as well as for the manufacturing of metal wire nets and shopping trolleys etc.It usually consist of welding number of parallel wires at right angles.

2.Literature Review:

The literature discussed about the cross-welding welding methods used in steel bar and the parameters one should consider while joining these materials.The usefulness of Spot Welding for TMT is determined in the process as well as the microstructure & hardness analysis previously carried out by various author has also been presented. The effect of welding parameter on structural property changes has been summarized. General mechanisms of phase transformation in TMT rebar & cold drawn plain carbon steel have been presented as well.The heat treatment affecting microstructure of steel was also presented. This is followed by an approach to deal with important factors which are needed for perfect welding to occur. An overview of some key observations and salient objectives of the present investigation is given in this section.All the study were performed on steel.

2.1 Different types of welding used in steel bar:

TIG Welding:

TIG welding, also known as tungsten arc welding, is an extensively utilised technique for joining stainless steel goods due to its low heat input needs. It functions best with thin Steel material. Other gases may be added depending on the needs of the product, but pure argon gas shielding is commonly used. Utilizing this method may result in lesser output, but the aesthetic outcomes are of the highest calibre and are more versatile.

Spot Welding:

Spot welding often referred to as resistance welding, are incredibly adaptable for both small- and big-scale applications & is the most affordable form of welding. Copper alloy electrodes with their tips positioned on the opposing surfaces of the metal pieces are used to apply the electric current and pressure. The metal is heated to a point where it melts, and the electrodes' pressure squeezes the molten metal to form a weld. It works best with steel metals with lower melting points.

MIG Welding:

An argon-rich shielding gas and a solid wire electrode are used which is a semi-automatic method known as gas metal arc welding, or MIG welding, to unite steel grades. It makes use of a pulsed electric current supply, which enables the welders to access and join intricate Steel constructions' corners and edges. Because MIG welding enables the professional welder to employ a pulsed current supply, it is easier to weld in challenging locations on some of the most challenging steel projects. In addition to the gas shield, other gases can be used to improve the overall weld quality and arc stability

Manual arc welding:

When two wires that are a part of an electrical circuit are brought together and slowly pulled apart, an electric spark is created across their ends. This is the manual metal arc process. The temperature of this spark, or arc, can reach 3,600°C. Metal can very rapidly melt because the arc is contained within such a small space. The heat of the arc will melt both the metal of the job and the electrode point if one of these wires is linked to the job and the other to a wire rod or electrode, as it is commonly called. The weld is created when the molten metal from the electrode combines with the metal from the job.

Submerged Arc Welding (SAW):

Although this technique is commonly used for welding carbon steel, it can also be advantageous for thick and massive steel metals joining. Here, a continuously fed electrode is used to weld the base metals using a SAW internal system with the base metals virtually always in a flat position. A neutral or non alloy flux power is applied to the welding area, creating a protective gas barrier that shields the weld zone.

2.2.Selection of welding material

2.2.1Thermo-mechanically Treated Rebar

Thermo-mechanically treated (TMT) rebar produced by Tempcore process is a newer variety of steel for construction purpose for achieving sufficient strength, high UTS to YS ratio, good impactproperties at low cost. This was called “after heat-treated” and “quenching” rebars. High temperature after rolling was used for quenching and residual heat in the central part was utilized for self-tempering. The process controls at each critical operation ensure uniform properties in each rebar and provides the TMT rebar with a soft ferrite and pearlite fine grained core and a strong andtough tempered martensite layer imparting it with high ductility as well as strength thus making itideal for high rises, dams, bridges, individual houses and any critical structures where high yield strength is required without compromising on the elongation properties

2.2.1.1 WHY TMT Bar?

The structural design engineer highly values TMT steel since it helps reduce the overall weight of the building structure, increasing seismic safety.
Due to the presence of martensite at the surface, TMT steel is harder than normalised steel.
High-strength reinforcement bars known as Thermo Mechanically Treated (TMT) bars have a soft inner core and a hard outer core. The martensitic layer of the TMT is very hard while the core is soft due to the fine ferrite-pearlite structure. Therefore, a TMT structure combines qualities of increased ductility and higher yield strength[31]

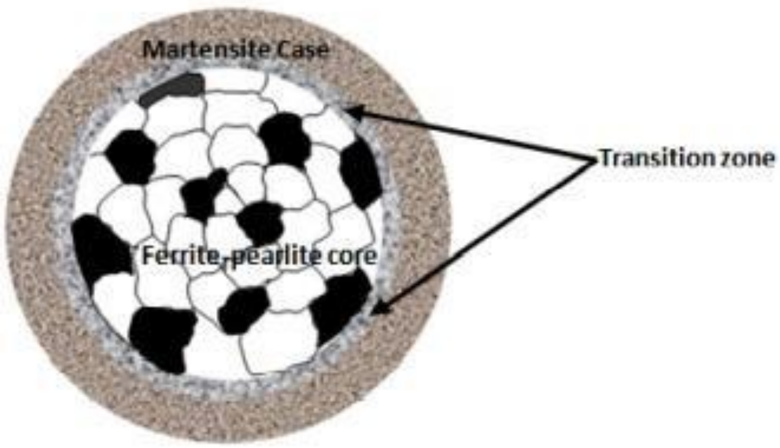


Fig-Microstructure of TMT steel

Raw material for manufacturing the TMT Bar are iron ore, coal, dolomite. In this process raw materials are piled, recovered and mixed in required proportion which gives it properties given below:

2.2.1.2 Properties of TMT bar:

In the TMT process, the steel bars are repeatedly cooled to maintain their full yield strength. They are highly ductile and malleable in nature and are not just steel bars with increased strength. whether the bar is made with the appropriate balance of flexibility and strength. It should bend without difficulty and shouldn't show any surface cracks when it bends. They have a strong thermal resistance and are specifically made for buildings that can withstand earthquakes.

2.2.1.3 Effect of welding at TMT bars

If the carbon ratio is smaller, the steel is easier to weld.
Steel is more prone to cold cracking, or fracturing after the metal has set after it

is welded, the higher its quality and carbon equivalent. Definitely not a good practice is welding; it's ideal to run laps. It is based on the theory that small air bubbles become trapped inside the weld during welding. These bubbles make the weld less strong.
If the weld metal's metallurgical component is intended to have a proportionate carbon content of less than 0.4 percent, welding is allowed.
Thermo Mechanical Treated (TMT) bars are typically used to fortify roofs and other parts of buildings.
They are also used for contemporary activities like rock-dashing in underground mines and other things. The majority of the TMT bars were joined having bend welding. If circular segment welding of TMT bar were to occur, the weld junction would be the most vulnerable. The weld joint's microstructure reveals that there is less pearlite than base material. Fine pearlite can be found in the parent zone, and the HAZ has generated ferrite and pearlite as a result of warming. The weld zone has a huge number of incorporations, which reduces its rigidity and hardness. It is necessary for the weld metal to gain high volume division of acicular ferrite in order to obtain welded connections of low compound good grade steels with pleasant mechanical properties and breaking resistance.
The ideal technique to weld these grades of steel is to use low hydrogen ferritic steel filler wire because the heat affected zone (HAZ) is prone to failure since there is a potential that hydrogen may induce splitting. Intercritical heat treatment, which improves the microstructure by arranging ferrite microstructure with various morphologies, sporadic martensite, and 75% of microstructure with high point grain limits, strengthened the Charpy sway crack of steel.

2.2.2 Cold drawn plain carbon steel:

Fundamentally, cold-drawn steel is hot-rolled steel that has been drawn through dies to create the desired shape. With the aid of some press machines, the dies apply pressure, and once the steel has gone through them multiple times, it will have the necessary dimensions. This procedure, known as cold drawing, improves the accuracy of dimensions (tolerances) and shapes, the tensile strength, and the external appearance of the material by giving the surface a smooth and polished finish. It does this by taking place at room temperature (below the re-crystallization temperature)[39]. Similar to cold rolled steel, cold drawn steel is treated at room temperature. However, cold drawn steel yields a thin shape, similar to a rod or wire, whereas cold rolling yields a flat product. Hot rolled steel is compressed to fit into a die, a rotating tool that pushes the metal into its final, elongated shape. Depending on the die, the resulting shape can have a cross section that is circular, square, rectangular, hexagonal, or

octagonal. For long products, such as shafting and structural pieces, as well as consumer goods that need a nice finish, cold drawn steel is the best option,
Benefits:
1.Cold drawn steel has superior roundness and dimension precision.
2.Compared to hot-rolled steel, cold-drawn steel offers superior mechanical qualities.
3.The surface finish of cold-drawn steel is smooth and ideal for tasks that call for the material to have a polished surface.
Cons:
1.More expensive to make because it takes several steps to achieve the desired final dimensions and forms.
2.Less manageable than hot rolled.

2.3.Cross-wire welding

It is a type of resistance welding process for joining bars or wires in cross joints by directly applying opposing forces with usually flat electrodes. The current and the heat generation are localized at the contact points of the crossed bars or wires. Cross wire welding is actually a type of projection welding. Projection welding is a unique form of resistance welding that uses the resistance heating of a small cubic area prior to, and during, its collapse under pressure to weld frequently different thicknesses of metal together. Crosswire welding is widely used in the construction and electrical industry as well as for the manufacturing of metal wire nets and shopping trolleys etc. It usually consist of welding number of parallel wires at right angles t one or more wires of rod. The primary use of cross-wire welding is in the electronic industry and in the fabrication of wire mesh. These also includes such items such as stove and refrigerator racks,grill of all kinds,heat exchangers, toaster guides, wire meshes for rieinforcing concrete, fences, jail bars. Etc

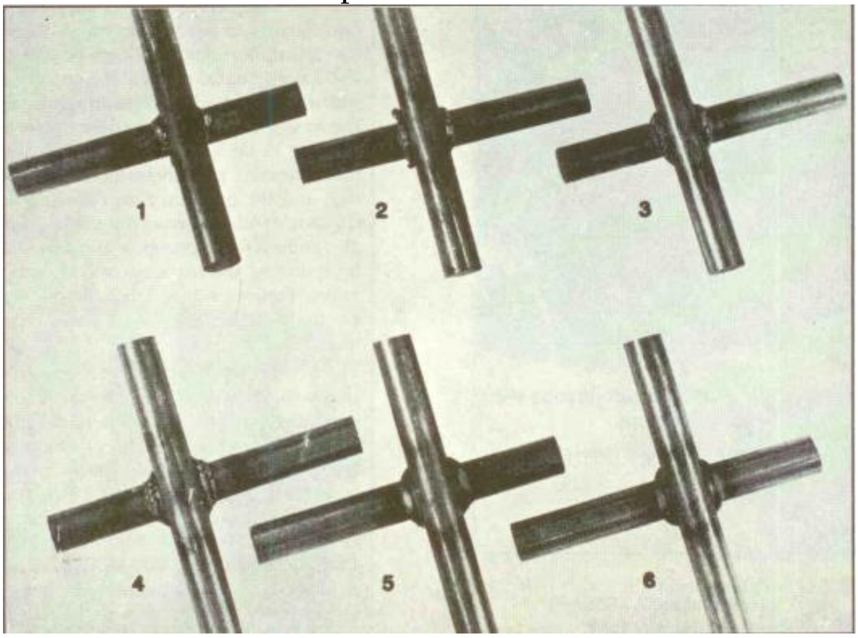
2.3.1Basic Process

Generally, there are two wires or rods welded together, and their combined radii present a challenge and act like the projections in projection welding. The heating is rapid, and deformation occurs almost instantaneous

2.3.2cross wire welding vaiables:

i.Appearance

The quantity of welding time and welding current required will ultimately depend on the welding force. As seen in the following figure, the appearance of the weld also changes as the applied force changes. Samples 1 through 6 demonstrate how the look improved as the labour force increased[26].



ii.welding electrodes

RWMA class 2 alloy is typically used for best results and long life with shaped like flat electrode. Sometimes we may vary the electrode form for better contact between dies and the product, increasing the welding current. Shape and substance of the electrode matter a lot with adequate cooling[26].

iii.welding force or pressure

The welding machine's electrical and mechanical capabilities, wire diameter, the percentage of setdown, the required strength of the weld, and other factors all have a role in the welding force. The recommended amount of force to apply in order to achieve maximum strength is shown in the table below[26].

Cold drawn wire(15 % setdown)

Wire diameter (mm)	Weld time Cycle(60 Hz)	Weld force lb	Welding current lb	Weld strength lb
1.58	5	100	600	450
3.17	10	125	1800	975
4.76	17	360	3300	2000
6.35	23	580	4500	3700
7.93	30	825	6200	5100
9.52	40	1100	7400	6700
11.11	50	1400	9300	9600
12.7	60	1700	10300	12200

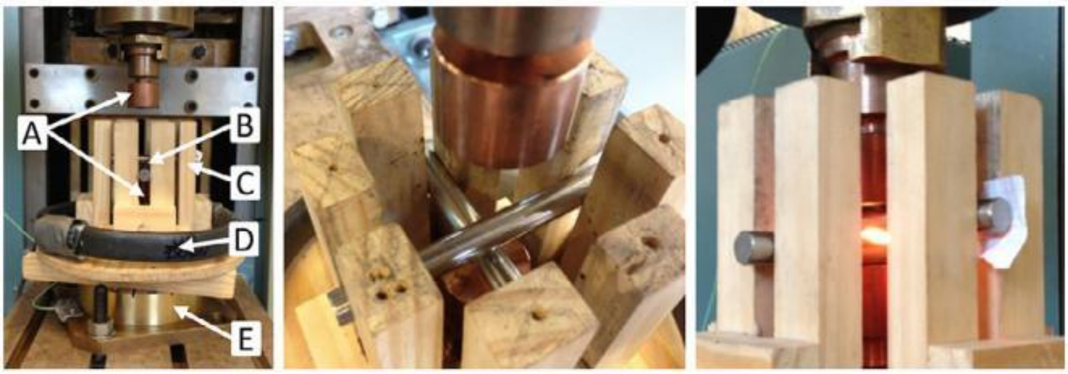
Hot Drawn wire(15 % setdown)

Wire diameter (mm)	Weld time Cycle(60 Hz)	Weld force lb	Welding current lb	Weld strength lb
1.58	5	100	600	350
3.17	10	125	1850	750
4.76	17	360	3500	1500
6.35	23	580	4900	2800
7.93	30	825	6600	4600
9.52	40	1100	7700	6200
11.11	50	1400	10000	8800
12.7	60	1700	11000	11500

iv.weld time
Welding time is primarily influenced by wire diameter. The use of automatic weld timers yields the most reliable results[26].
v.weld current
The diameter of the wire, the percentage of setdown, and the welding time all affect the welding current. The current should be just a little bit stronger and more attractive to obtain good strength. low[26].

2.3.3 Basic setup in cross wire welding machines:

It consist of :
A. Electrode
B. Cross wire
C. Guidance
D. Rogowski coil
E. force transducer



(a) (b) (c)

Using the set up depicted in fig. 1 above, cross-wire welding of wires is carried out. Wire is passed over flat C0-type electrodes. In the guiding system, the wires are positioned so that they are perpendicular to one another and that their junction point is centred in relation to the electrodes (Fig. 1b).. Since the wires can freely move vertically, the guides don't add any stiffness that would interfere with the welding process. The upper wire balances on top of the lower wire using, for example, a piece of paper wedged between the wire and the guiding system (Fig. 1c), which does not provide any useful vertical constraints during the welding process. The lower wire rests on the lower electrode.. As soon as the upper electrode presses toward the wires, the horizontal alignment is spontaneously resolved[26]. The electrode force and welding current are measured during welding (Fig. 1c) by a load transducer and a strategically placed Rogowski coil.

2.3.4.Evaluation parameter (Setdown)

The setdown S, as described by the Resistance Welding Manufacturers' Association, is one of the evaluation criteria for cross-wire welding. For a specific force level, the setdown is an indirect measure of the heat input and a direct measure of compression[26]. It has some connection to the weld strength as well.

setdown (S) parameter:

$S = (A - B)/\mathrm{A}$

where A is the initial wire diameter and B is the final height of the joint subtracted one diameter A

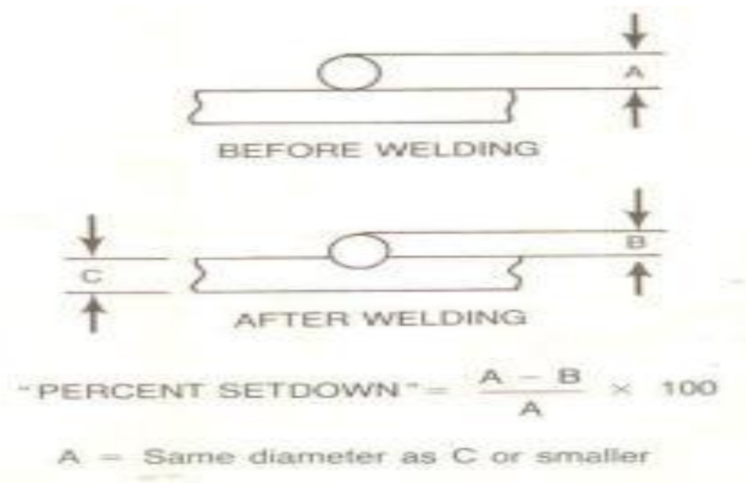


Fig- percentage setdown

2.4 Factors affecting microstructure of steel during welding:

2.4.1.Cooling effect on atomic transformation of steel:

Three phases of thermo-mechanical treatment are applied to steel bars:
1. Quenching: Using a specialised water spraying system, hot rolled bars are rapidly quenched. This causes the development of the martensitic layer on the surface which makes it hard to some depth. The core is still warm and austenitic.

2. Self-tempering: After quenching, the core is still hot and the heat is conducted to the surface layer, causing tempering of martensite.

3. Atmospheric cooling: As the atmosphere cools, the core's austenite structure transforms into a ductile ferrite-pearlite structure.

2.4.2.Importance of postweld conditions for welding of steel:

In order to regulate the final product's qualities, this paper uses computer modelling to anticipate the microstructure development in high carbon steel bar linked by cross wire welding. The microstructures of welded bars with various postweld current schedules were experimentally observed. In order to forecast the initial temperature contour in the heat-affected zone following the introduction of welding current, Jominy test samples were used to generate an empirical grain growth equation.Historically, these meshes for high-carbon steels have been "woven," which refers to the cold-forming of the bars to partially interlock at the mesh connections to add some stability. In the current endeavour, an unique equipment created for this purpose was used to resistance weld the mesh joints. A 15.3 mm (0.625 in.) diameter high-carbon steel rod was the substance employed in this project.
The basic outline of the welding cycle is depicted in Fig. 2.

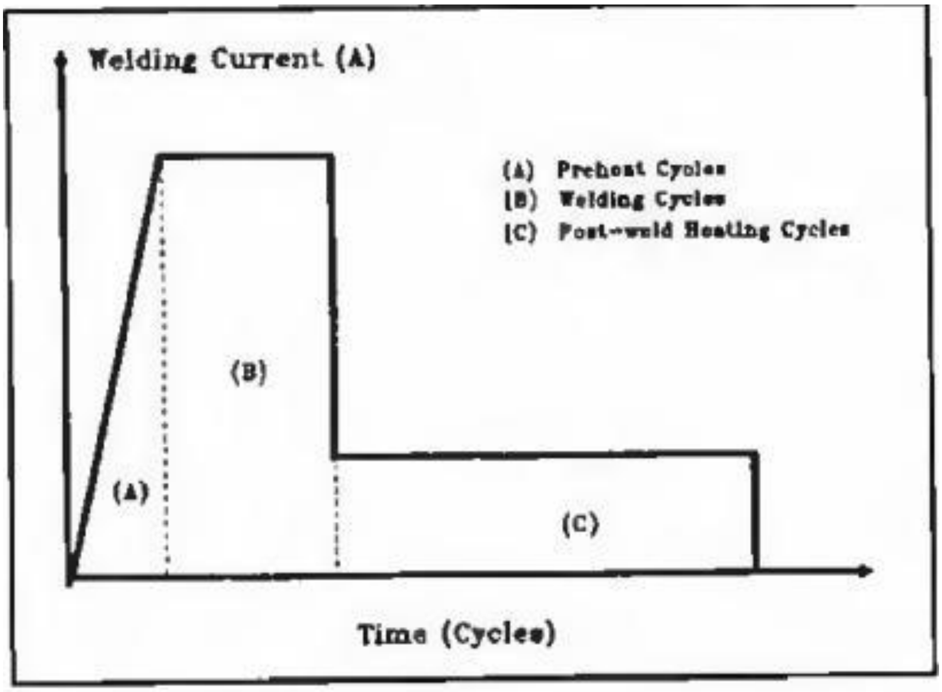


Fig 2-schematic welding schedule applied for the cross-wire welding

Author used a postweld heating cycle because of the high carbon content to prevent cracking at the weld joints during cooling. The postweld method' innovative feature is the application of the postweld current schedule, which allows cooling rates in the HAZ to be managed to be sufficiently slow in order to prevent the development of brittle microstructures, primarily martensite. When postweld cooling and postweld current are applied simultaneously, austenitized metal undergoes breakdown into any of a number of its daughter products, including ferrite, pearlite, bainite, and martensite.. Author conducted a number of experiments to investigate how the post-weld current affected the metallography. First, several postweld current samples are collected. Along the joint's centerline, metallographic samples for various postweld conditions were cut, mounted, and polished. Vilella's reagent, which brings out pearlite, bainite, and martensite, etched the specimens. Optical microscopes were used to analyse the microstructures.

Fig- no postweld heating

A sample with no postweld heat is shown in Figure 12. In this instance, martensite makes up practically the entire microstructure.

It is obvious that the mixed pearlite/bainite/martensite region's breadth gradually increases as the postweld heating current is increased. The mixed zone becomes wider as postweld current is applied for longer and at higher temperatures.

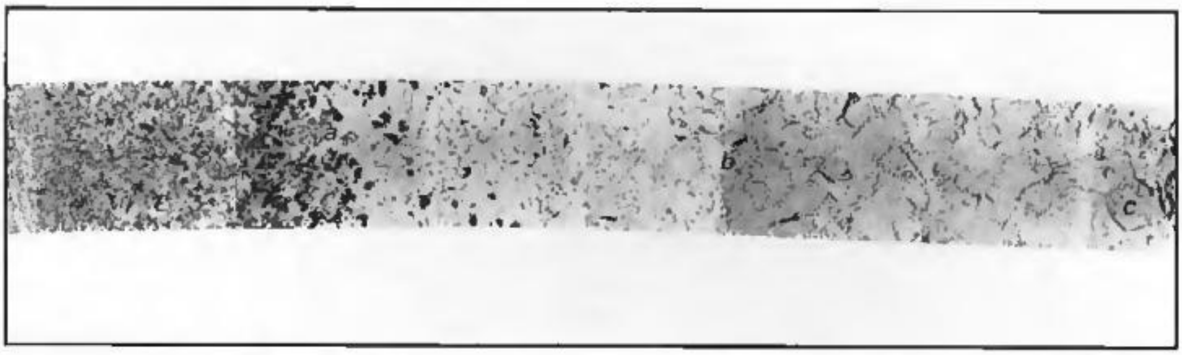


Fig-with postweld heating

According to the modelling outcomes, martensite still dominates the HAZ's central microstructure. Some pearlite and bainite are changed close to the centre of the joint when the postweld heat applied is 15% of the welding current. Because of the high electrical resistance at the weld interface and the huge grain size, it is well known that pearlite and bainite are extremely difficult to nucleate and grow in the central region of the HAZ.

According to Fig. 3, the HAZ in a cross-wire joint has an ellipsoidal shape.

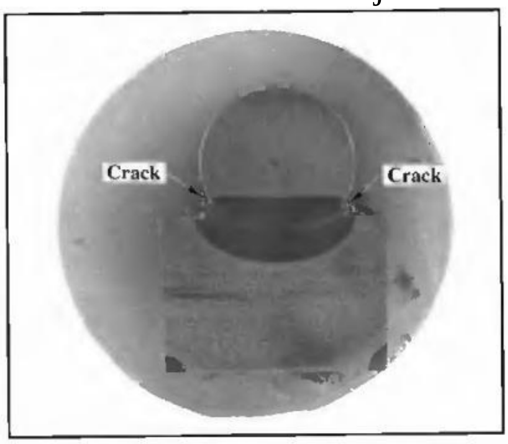


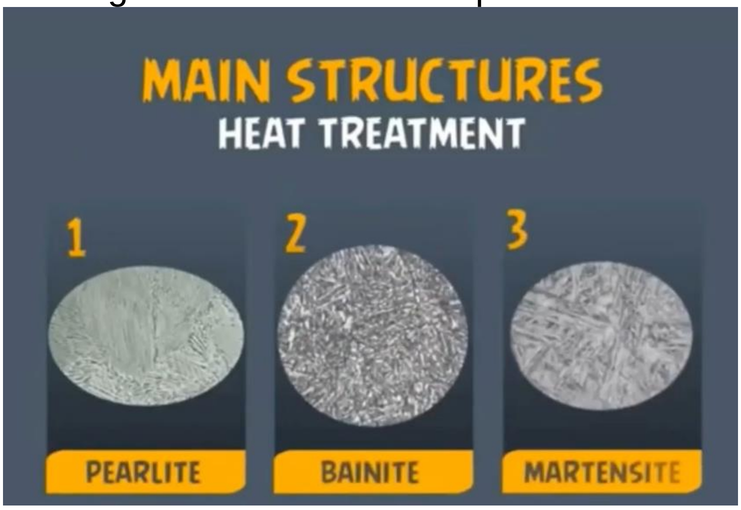
Fig 3-Section of a resistance welded mesh joint with a typical heat affected zone.

It develops over a few millimetres in breadth just next to the extremely thin weld line. The free edge of the HAZ, close to but not on the weld line, where high temperature gradients and a large grain size induce a susceptibility to cracking, is where cracks are most frequently initiated.

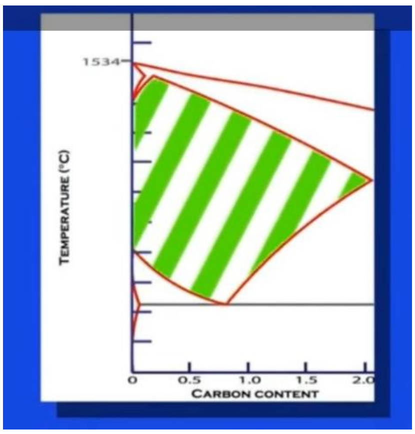
From this paper we concluded that to avoid cracking defects it is important to use post weld current.Also to get a better compostion of pearlite,bainite and martensite it is necessary to have post weld current .HAZ is most heated area so the cracks develop near HAZ .Without postweld current material mostly composed of martensite which would not be so suitable for industrial purpose[25].

2.4.3 Heat treatment and quenching effect on microstructure of steel:

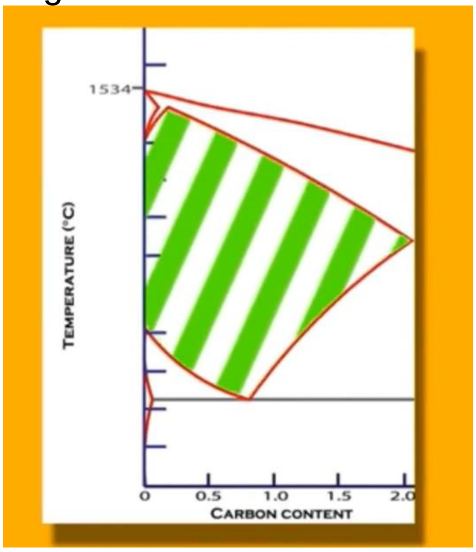
Heat treatment is probably the most important process in controlling the properties of metal it involves heating solid metal to a defined temperature followed by suitable cooling rate in order to achieve the desired material properties.Heat treatments are primarily conducted to either soften or harden the steel depending on its final application and manufacturing process this softening treatment is often referred to as a conditioning process and will lower strength and hardnesswhile increasing toughness and ductility.Conditioning includes two heat treatments called annealing and normalizing.The hardening process does the opposite it increases strength and hardness while lowering toughness and ductility,this includes two processes called quenching and tempering and age hardening.The specific heat treatment used in manufacturing will depend on the metal chemistry,the size of the pot and the required properties.The three main structures that are achievable through heat treatment are perlite binite and martensite



For the majority of heat treatments we cool from the austenitic temperature region.The austenitic region is where most of the alloying additions go back into solution and this is shown here in the iron carbon equilibrium diagram

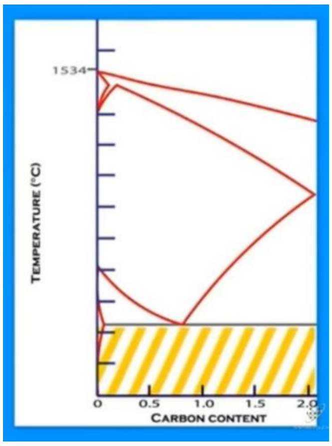


This diagram shows the structures formed under slow cooling in iron as a function of temperature and carbon content.As we cool through the transformationregion and create structures by altering the cooling rate. If we want to achieve perlite the softest structure we need to cool slowly enough so that this is formed.
To achieve martensite the hardest structure we need to cool quickly enough to ensure that perlite or binite is not formed[38]. The speed of these cooling rates depends on a given steel composition.Quenching and tempering is probably the widest used of the heat treatments to harden steel and consist of heating the material to approximately 15 degrees celsius or 60 degrees fahrenheit to the austenitic range.



For steels this is usually somewhere between 700 degrees to 1000 degrees celsius or 1290 degrees to 1800 1830 degrees Fahrenheit. It is then held at this temperature until the material is fully transformed to austenite.This whole time takes into account the dimensions of the component.The material is then removed from the furnace and submerged usually in an agitated liquid in a process called quenching. This causes changes in the microstructure as the component cools rapidly down to around 200 degrees celsius or 390 degreesFahrenheit.
This quenching causes none or very little carbon to precipitate as iron carbide it produces a feather-like structure called martensite which distorts the internal structure.This additional stress makes it .Difficult for the facts on the atomic scale called dislocations to move around in response to the applied load causing the material to become stronger.The formation of martensite is only achieved if the material exceeds a critical cooling rate. If not the micro structure formed will be either by bainite,pearlite or ferrite or a combination of these[38].

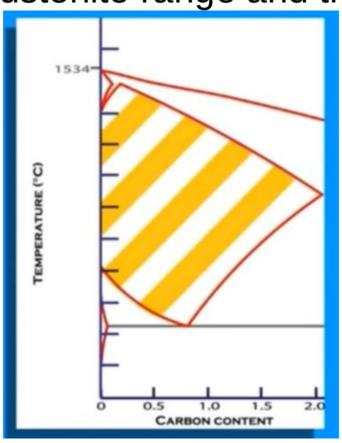
This is the reason why components of different sizes processed the same way may have vastly different properties and also why the surface properties may differ from the center which would cool slower than the surface.The quenching operation will increase the hardness and strength of the steel but will drastically decrease the ductility and toughness.
The aim of tempering is to soften the steel back
achieving the desired combination of properties.
Tempering will considerably improve toughness and ductility while still maintaining a high strength level.
Tempering consists of heating the steel to a temperature
below the austenitic range usually somewhere between 500 degrees to 650 degrees Celsius or 900 degrees to 1200 degrees Fahrenheit and holding at this temperature for a specific time period. During this process the hard brittle martensite associate into ferrite and iron carbide producing a structure called tempered martensite which has lots of fine particles dispersed through the ferrite.[38]



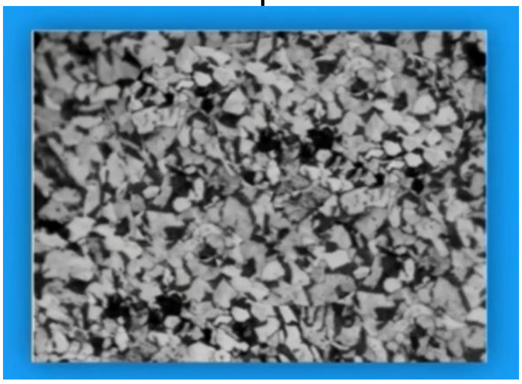
This will give the optimum combination of strength hardness toughness and ductility. The ratios of these properties can be refined through the time and temperature of the tempering. Age hardening sometimes called precipitation hardening is used to increase the strength and hardness of some stainless steels and nickel based alloys.It follows similar steps to quench and tempering and such that the material is heated to a temperature to dissolve all the atoms into solution.

It is then quenched at a cooling rate fast enough for the atoms to remain frozen in solution.

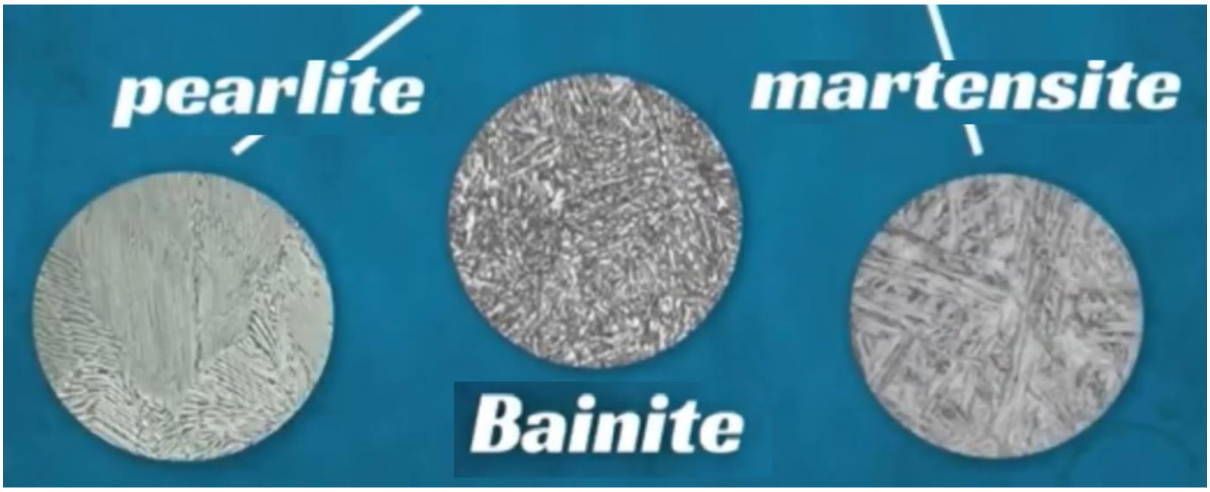
The final step differs from tempering as it is designed to harden the steel as opposed to soften it back. It is called aging and involves the controlled reheating to around 450 degrees to 650 degrees Celsius or 840 degrees to 1200 degrees Fahrenheit.To cause some atoms to precipitate.These create strain in the structure and again this makes it difficult for the dislocation effect move in response to the applied load making the material stronger.Conditioning treatments can be used to obtain the final properties of a steel or it can be used as an intimidate step in order to ensure that the material will not crack following rolling,casting,forming or forging. It can also be used to get the material into a state to aid in machining.In both normalizing and annealing the material is heated to the austenite range and then slowly cool.



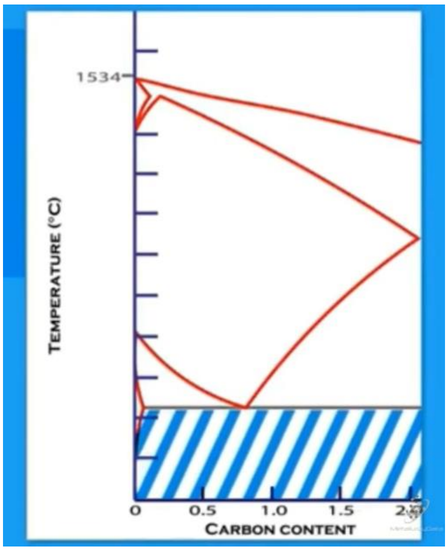
This is done in still air for normalizing and in a furnace for annealing.A normalized structure can also be tempered to alter the properties slightly. Any gases that need removing,for example hydrogen will be done as part of this process both treatments leave the material homogeneous soft and ductile
but because normalizing is cooled in air the strength and hardness of this structure will be greater than the annealed one. Some nickel alloys and stainless steels are used in the annealed condition to aid in corrosion resistance.Due to the slow cooling rates present in normalizing and annealing a perlite structure is likely to form.[38]
Perlite consists of alternate last of iron Carbide also known as cementite and a pure iron Structure ncalled ferrite.During cooling the austenite which has higher solubility for carbon starts to turn to ferrite but because this ferrite cannot accommodate the higher concentration of carbon the structure develops in alternate laths of cementite and ferrite.
This perlite is often present with Ferrite and depending on the carbon content the perlite and ferrite will be present in differing ratios.



If the cooling rate is too fast for perlite but not quick enough to produce martensite a structure called bainite will form[38]. Baunite is of medium hardness and lays at a medium cooling rate in between perlite and martensite



Initially ferrite is produced butbecause the cooling rate is quicker than pearlite nthe structure does not form in less of ferrite and iron carbide but instead the iron carbides start to precipitate from the remaining carbon rich austenite forming a structure
that consists of ferrite and particles of iron carbide.Depending on the cooling rate these iron carbide particles can be more elongated this is called upper bainite and is the slower cooled of the two structures the other lower bainite forms at faster cooling rates and contains ferrite with finer disc-like particles of iron carbide. An annealing process used in cold rolling or formingis a subcritical or process annealing.



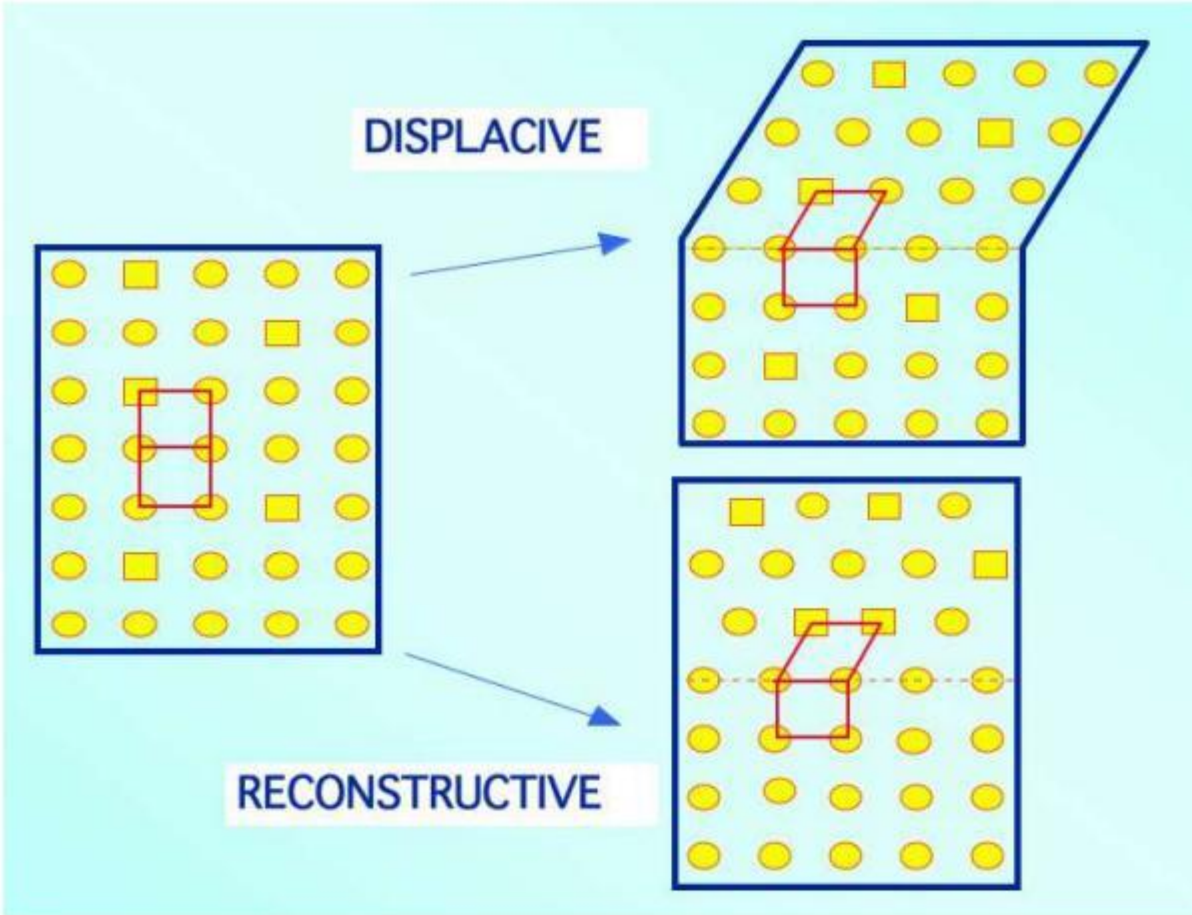
This is used to reduce the internal stresses after manufacture or to enable further processing.In this process the steel is not heated all the way up to the austenitic range but is heated just below the ferrite to the austenite transformation temperature around 500 degrees to 650 degrees celsius or 930 degrees to 1200 degrees Fahrenheit.
The material is then held for the desired amount of time the coast softening through structural changes primarily grain recrystallization and grain growth.Generally the higher the alloy content the easier it is to form martensite and this ability to form mountainside is known as hardenability meaning a steel with low hardenability requires a faster cooling rate to attain the same hardness at a given location than a steel withhigh hardenability.[38]

2.5.Understanding the atomic transformation of steel:

It becomes important to understand the atomic mechanism of solid state transformation of steel for determining the morphology, chemical composition & other characteristics of microstructure. There are two methods to change the crystal structure:

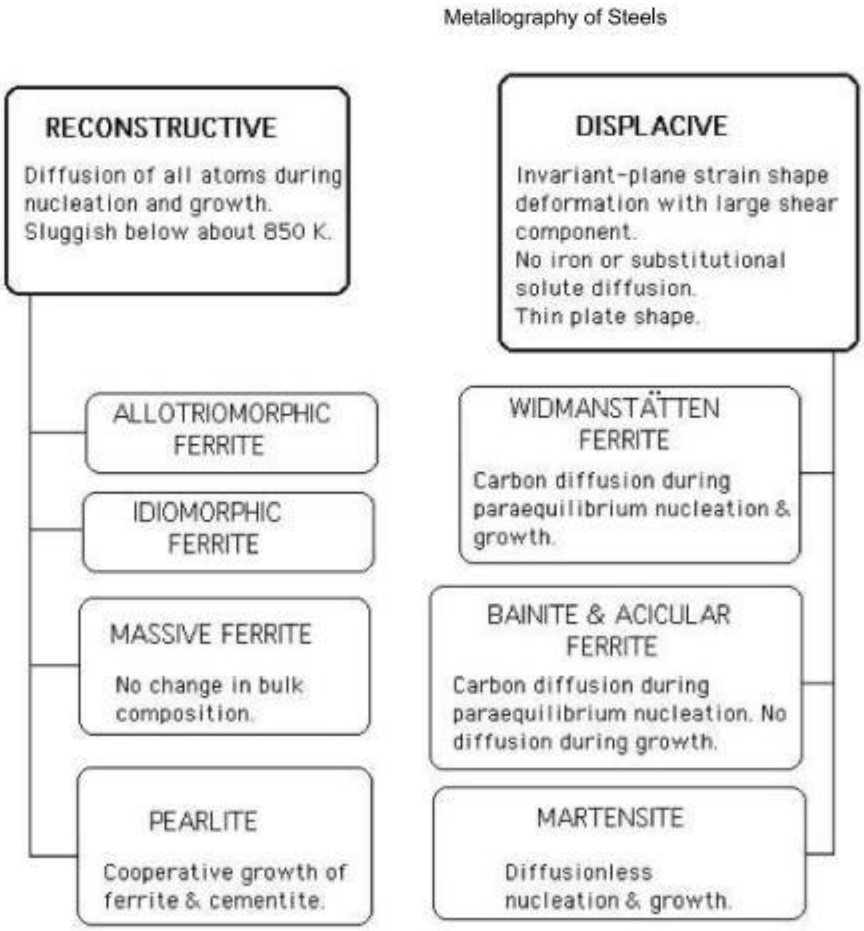
2.5.1. Displacive:

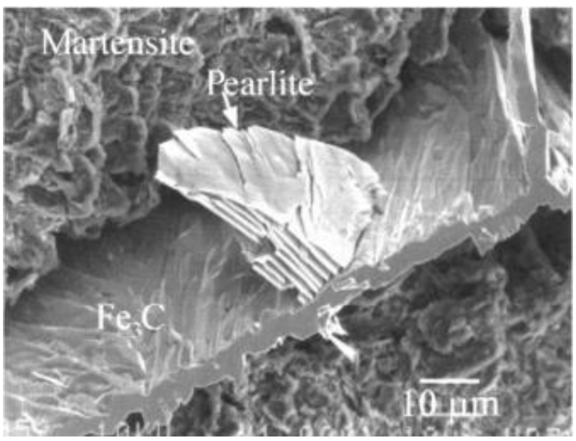
Here crystal structure is achieved by without disrupting the relative order of the atoms.The overall shape of sample changes in a manner consistent with the change in crystal structure.Lot of strain energy is accommodated when this shape deformation occurs in bulk of polycrystalline steel.As transformation occurs here by deformation of atoms which maintain the same sequence as existed in parent phase so there is no change in chemical compostion during transformation.[29]



2.5.2 Reconstructive:

Reconstructive occurs at a temperature where atoms are sufficiently mobile. Here the change is achieved by breaking of bonds in austenite and rearranging the atoms into structure of ferrite while maintaining the overall shape.This requires atoms to diffuse over distance comparable to the size of the transformation product.Here atomic correspondence between the parent and product phase is lost.As atoms are mobile,certain spaces which are more soluable in particular phase will tend to migrate into that phase which leads to a different chemical compostion.[28]





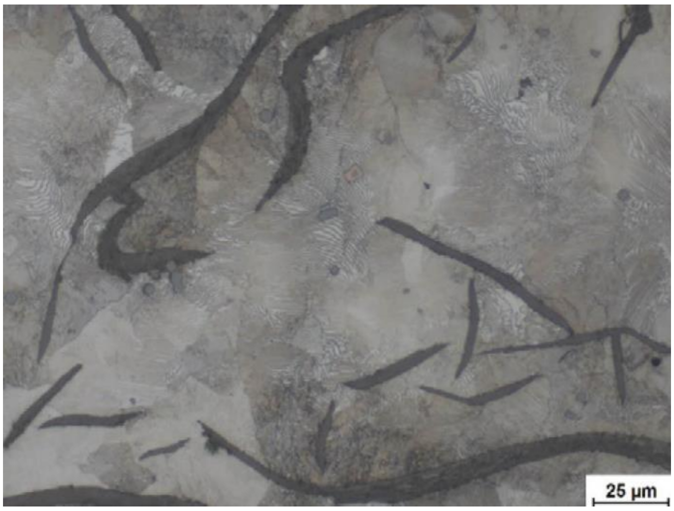
2.6. Understanding of Microstructure & Hardness of steel:

2.6.1 Microstructure:

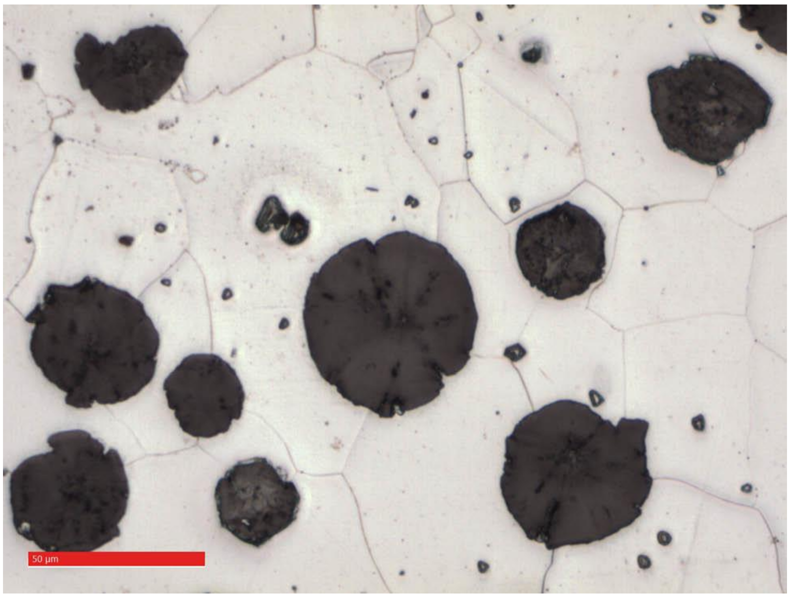
The metallic material is interpreted in terms of their internal structure known as microstructure. Individual crystal clusters, or "grains," make up the interior structure of a metal. These grains' shape, size, and orientation are a function of the alloy's composition and manufacturing process (e.g. forging, casting or additive manufacturing). When the molten material solidifies, grains are created. These grains interact with one another as well as with phases and contaminants. The grain structure is typically adjusted for the technological use.

Grain size and orientation and other structural characteristics are directly linked to the mechanical and technological properties of these materials[28]. Microstructural observations are utilised for a variety of investigations, such as to analyse failures, check for faults, prepare targets for microelectronics, and determine grain sizes.

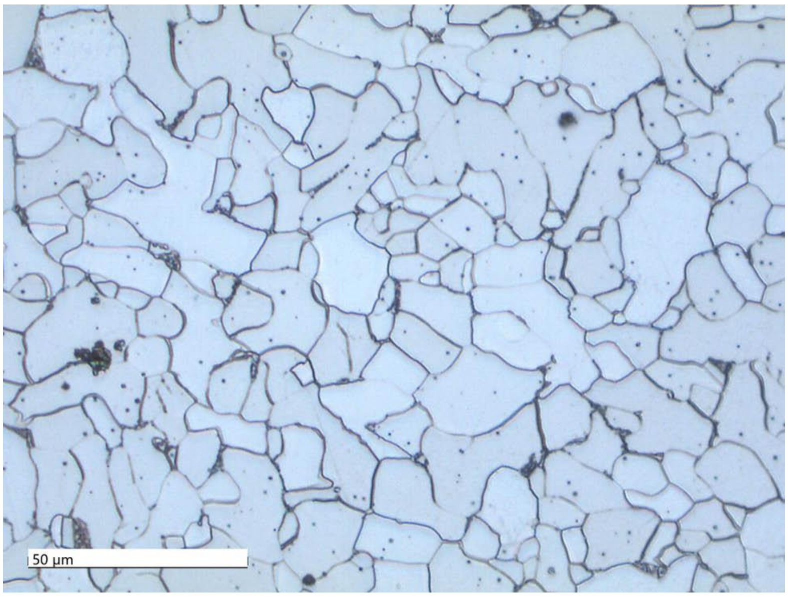
Today's materials for practical uses are alloys, which are mixtures of several chemical elements. For instance, steel and cast iron are essentially alloys based on iron (Fe) with carbon (C) alloying additives, which are in charge of giving the ferrous substance its hardness. Using microstructural analysis, we can infer information about the alloy's characteristics, such as its strength, hardness, and ductility.
Belows shows some grain structure of steel to understand better:



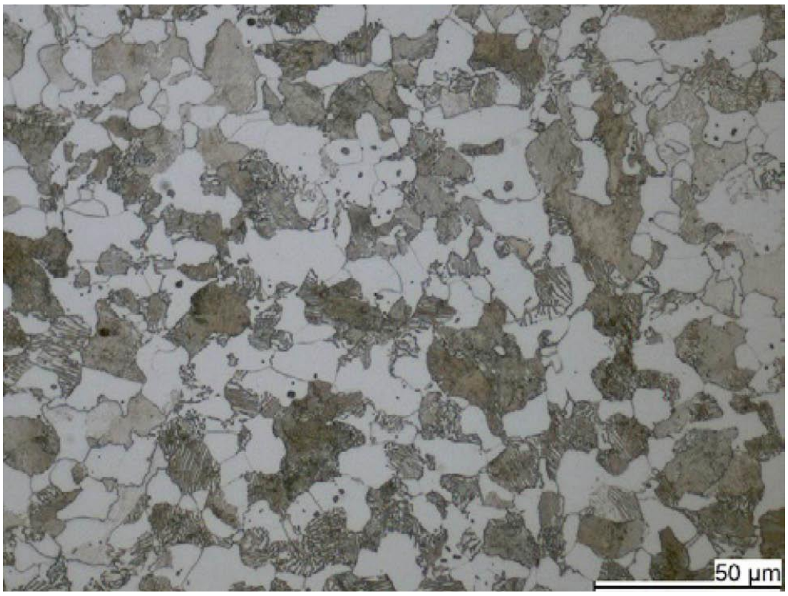
In Above fig shows the pearlitic cast iron with lamellar graphite. The strength is decreased since the carbon is mostly present as lamellar graphite. The pearlitic matrix itself displays an adequate level of hardness.[28]



In above fig. shows ferritic cast iron with spheroidal graphite. The main form of carbon is found as spherical graphite. Comparing the spherical form to lamellar cast iron, the strength is increased, but the material's hardness is decreased because there is no cementite present in the solely ferritic matrix.[28]



In above shows ferritic steel with a C content of about 0.1%. Between the ferritic grains, there is a small amount of pearlite and the most of the carbon is present as cementite. The matrix has a modest degree of hardness but excellent ductility since it is almost entirely ferritic.[28]



In above fig. shows ferritic-pearlitic steel with around 0.2% C. In a harder section of pearlite close to the ferritic grains, the carbon is largely present as a cementite lamellar structure. The cementite becomes streaky as a result. Pearlitic grains seem darker because they reflect less light than ferritic grains. This kind of matrix has greater hardness but less ductility.[28]

2.6.2 Hardness:

Carburizing is one of the most widely used methods of surface hardening for steel. This method offers effective combinations of mechanical qualities. Low carbon steel containing (0.10-0.25% C) is heated to temperatures as high as (900-1100 C) in a carbon-rich environment in the carburizing process. When the iron is in the FCC () form, at temperatures greater than 910 C, carbon atoms from the environment seep into the iron and produce a sufficient thickness of a carbon-enriched coat after holding the iron at that temperature[27]. It is feasible to harden the carbon-enriched layer created by quenching directly from the temperature of carburizing or by reheating and quenching.
Hardness is calculated either by using Vickers or Brinell hardness. They shows same hardness number upto about 300 hardness number.Beyond this the two curves starts diverge and diversity is significant beyond about 600 number[40].To get the strength both Vickers or Brinell hardness number can be used upto about 300 hardness number as in this range they both shows similar strength with small deviation . Plain carbon steel hardness relationship with UTS(kg/mm2) :
UTS=0.36 x BHN………………..(for normalized or annealed condition)[40]
UTS=0.32 x BHN…………………(for hardened or tempered condition)[40]

2.7.Understanding of Microstructure and hardness of TMT bar:

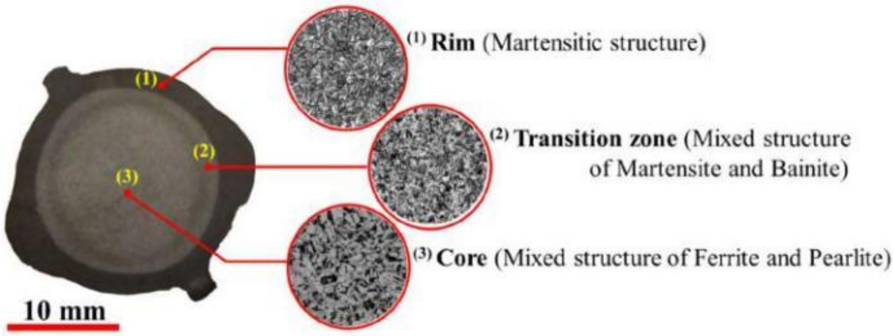
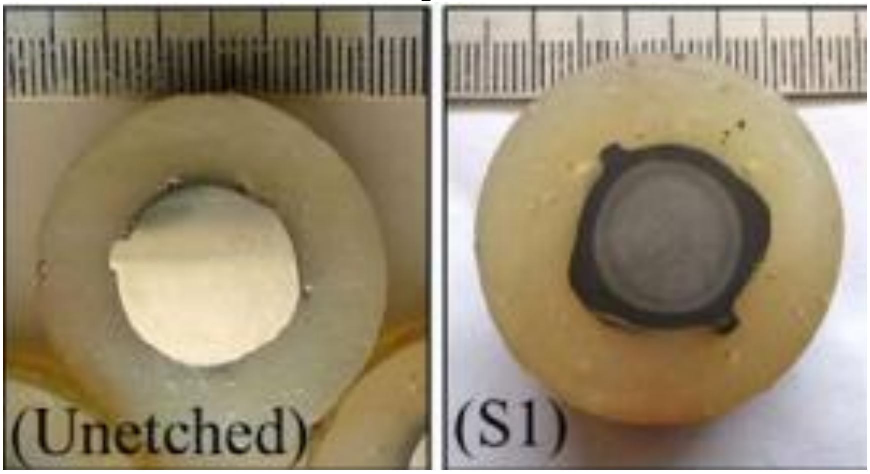


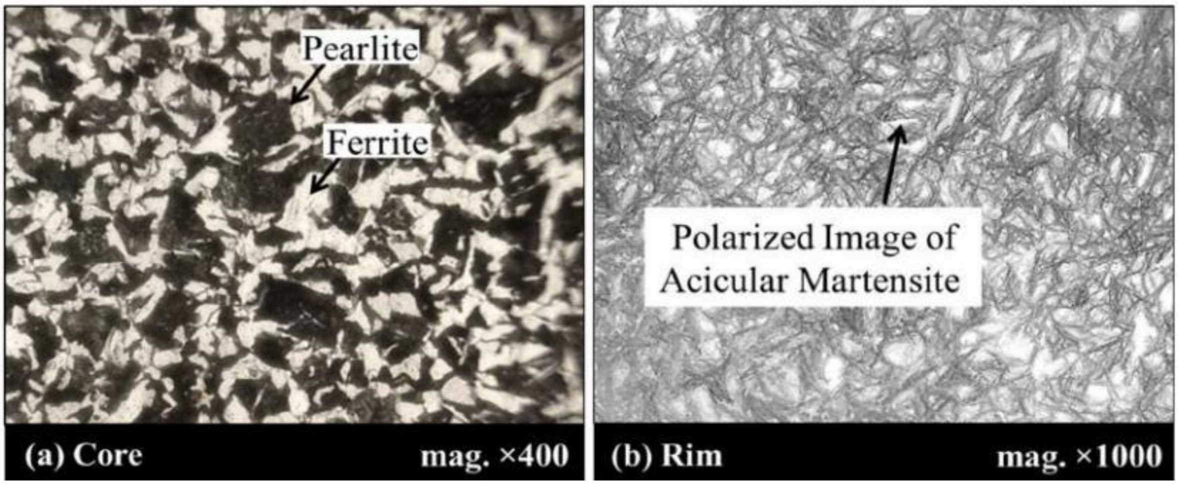
Fig- microstructure of TMT bar after etching

2.7.1 Microstructure study of base of TMT bar:

TMT 500W was etched to observed the different zones and further study under.Figure 6 illustrates how there are differences in the samples' martensitic rim thickness, which is shown as having a dark black tint.



The TMT bar's microstructural characteristics are shown in Figure 7. Since the samples have composition of plain carbon steel, the microstructure in the core (centre) is a hypoeutectoid (ferrite+pearlite) structure. Because the TMT bar's surface is quenched during manufacture, the bar's surface (or rim) is made up of an acicular (needle-like) martensitic structure. The bainite structure seen in the transition zone.



the different proportions of the rim, transition zone, and core microstructure through the cross-section which arise due to different cooling rates during the quenching process which shows cooling affects the area of formation of martensite,pearlite,bainite & ferrite in steel[32].Also this microstructure fig. shows white grains are ferrite while black grains are pearlite.

2.7.2 Hardness study of base of TMT bar:

Different hardness levels at different zones will be present because microstructures vary. The figure below depicts the plot of the hardness value against position and demonstrates how the hardness gradually decreases from the surface to the centre in a U-shaped pattern. Due to the martensitic structure, the surface (points 1 and 7) has the highest hardness, whereas the core (point 4) has the lowest hardness due to the ferrite and pearlite structure.

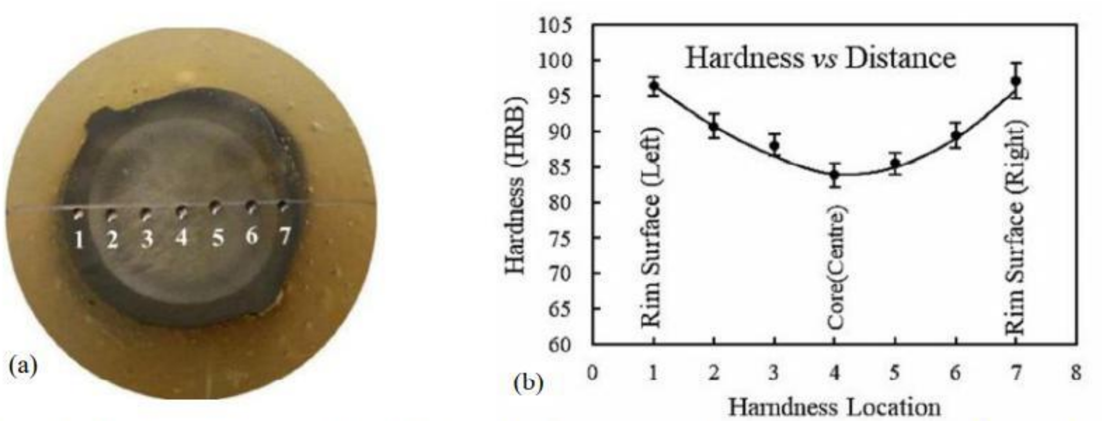


Figure 8: Hardness measurement (a) Different hardness measured position of the mounted sample S1 (b) Hardness variation at different location of the sample's surface

Because martensite is the most unstable phase of a TMT bar, it exhibits the highest hardness in comparison to ferrite and pearlite[32]. As we know, martensite is a metastable phase of the BCT (Body-Centered Tetragonal) structure that is created as a result of lattice distortion of the BCC structure due to incomplete carbon diffuse-out process during quenching.

2.8.Microscopic & Hardness Changes after Resistance spot welding of steel:

Welding is initiated by striking an electric arc between
a flux coated electrode and the metal workpiece to be joined. A combination of melted base metal, and molten core wire from the electrode, forms the welded joint. Welding materials are shielded from contaminants in the atmosphere by gases produced from the flux coating

2.8.1. Effect of welding time, current, and intermediate force on Microstructure & hardness of spot welded cold drawn steel bar:

2.8.1.1 Microstructure study:

Welded mesh typically Projection welding is a process where the joint-creating heat is generated by the resistance of the workpieces to the passage of electric current while mechanical pressure is applied. Pull tests and microhardness profiles were used to assess the macro- and microstructure of welded joints.
A low carbon steel with 0.45% manganese and 0.15% silicon, were presented where the base material's microstructure, which is represented by the below consist of ferrite and pearlite grains[33]:

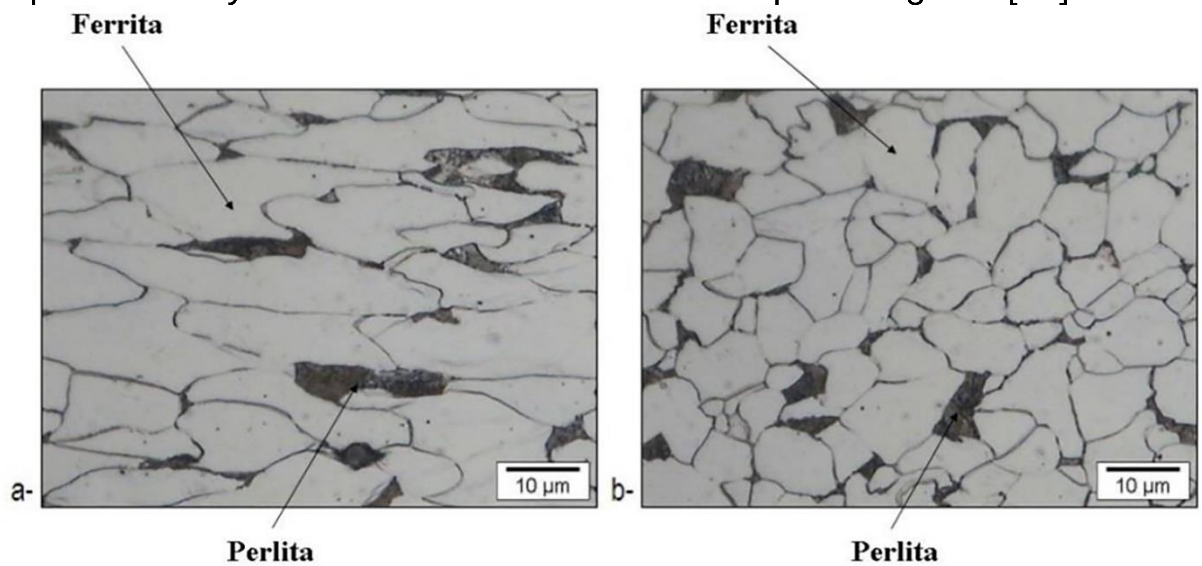
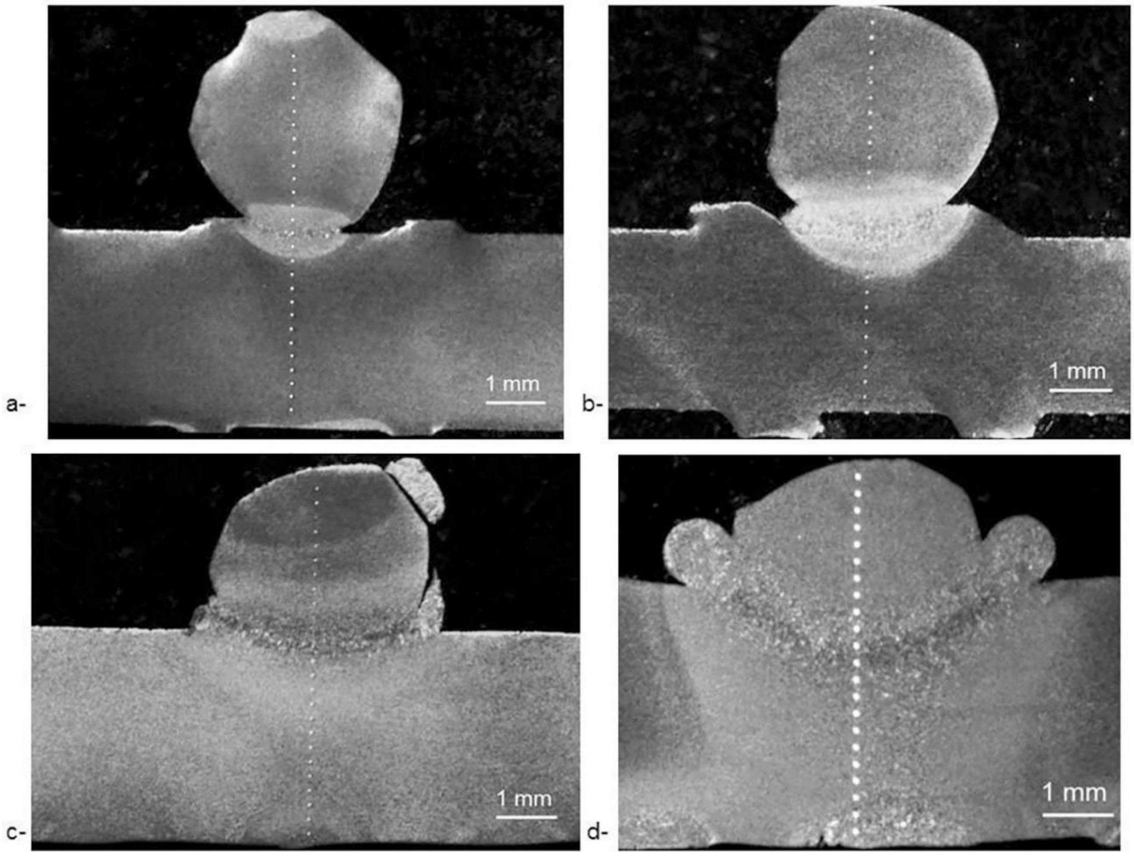


Fig- Microstructure of the base materiala- Longitudinal section, b- Cross section.

2.8.1.2 Depth of indentation

Comparing two welding wires Figure a below depicts a configuration of low welding time (4 cycles), low current (4.5 kA), and intermediate force (1350 N), for which the indentation of the upper wire with respect to the lower one is low, without observing significant plastic flow between both wires and a small union zone, whereas Figure d depicts a joint made with a high welding time (10 cycles) but and intermediate force and current (1000 N and 5.5 kA) where there is excessive indentation and a much greater heat-affected zone than in earlier occurrences. A good compromise between the two severe requirements indicated above may be seen for condition fig c.[33]



Thus the combination of welding time, current, and intermediate force for is very essential to get a proper welded structure with good depth of indentation.[33]

2.8.1.3 Microhardness:

When comparing sample c which have proper depth of indentations,the hardness initially decreases from the base material towards the joint line, until reaching the minimum hardness, which is associated with a recrystallized ferritic structure, and then it starts to increase until reaching the maximum hardness in the area near the joint, associated with the presence of phases of lower transformation temperature.[33] Similar is for sample b.

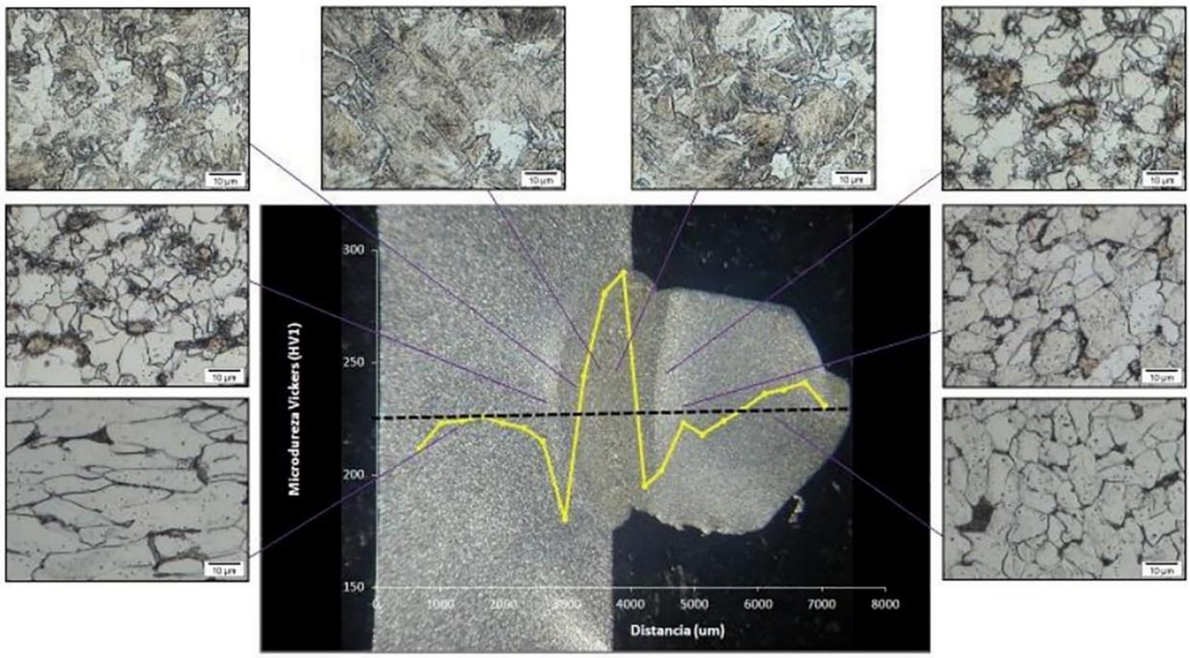


Fig-Sample c

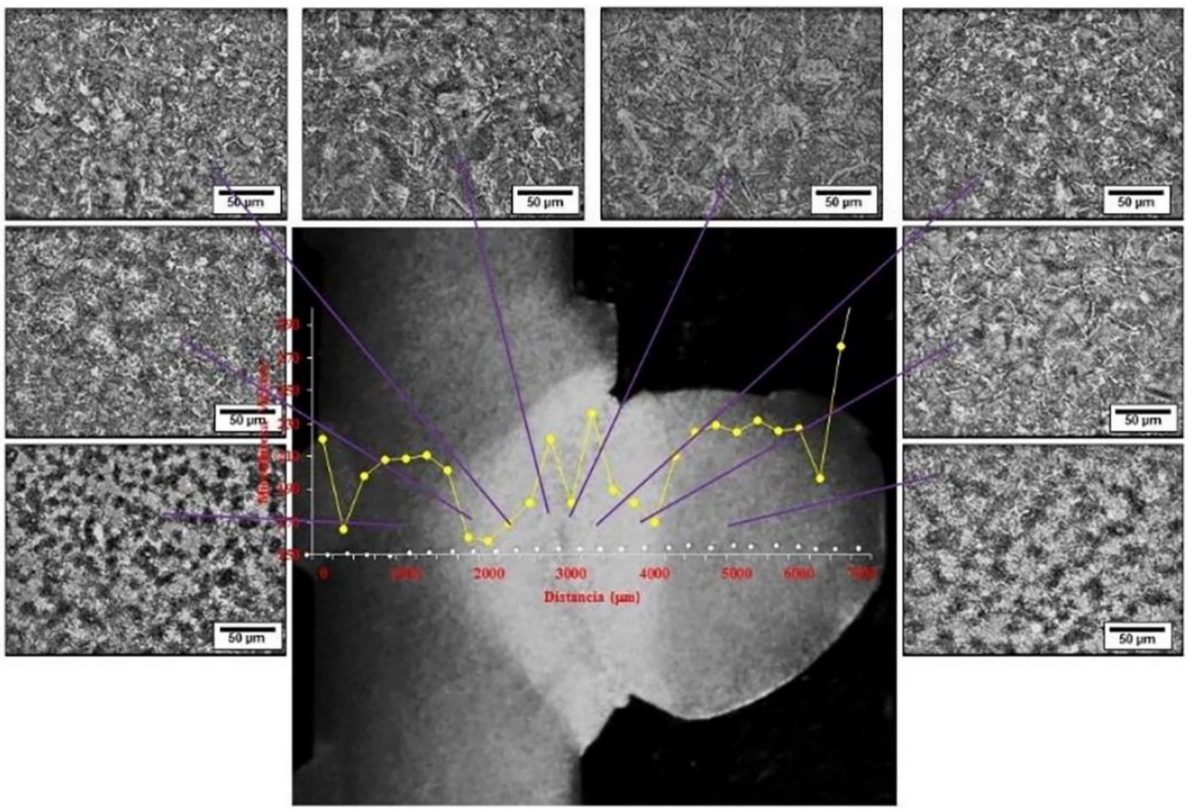


Fig-sample b

For sample d with more depth of indentations(10 cycles 1000 N and 5.5 kA) shows a decline in both microhardness value varies from or increase in softening. This would be because to the slower cooling rate brought on by the greater heat input [33], which results in a higher proportion of soft ferritic phases forming[33]

2.8.2. Effect of spot welding parameters (current, welding time, holding time) on the Hardness Profiles & Microstructure Change Of Resistance Spot Welded Low Carbon Steel:

2.8.2.1. Microstructure study

A low carbon steel sheets having following Chemical composition of the material : C=0,07%, Mn=0,39%, Si=0,007%, P=0,011%, S=0,009%, Al=0,038%, Cu=0,02%, Cr=0,03 % i Ni=0,01%, was spot welded with welding current and time were varied between 4000 – 5700 A, and 0,2 – 0,28 s , respectively. Welding force applied was F=860 N, and force cycle duration was between 0,2 – 0,28 s was ultimately used for spot welding of sheet having thickness 0.8mm, 1mm, and 2mm.The grain growth has quickened in the areas close to the melting region that have seen greater temperatures[35].In addition to microstructure alterations, the heat-affected zone also saw grain size variations depending on the distance from the melting region and the peak welding temperature.[35]

2.8.2.2.Hardness:

Changes in microstructure and grain size in different zones of weld nugget and HAZ have shaped the hardness profiles. Increasing of current,causes raising of average hardness taking into account the hardness of melting zone and heat affected zone as shown in figure below.Thus higher welding heat input results in increased hardness values[35].

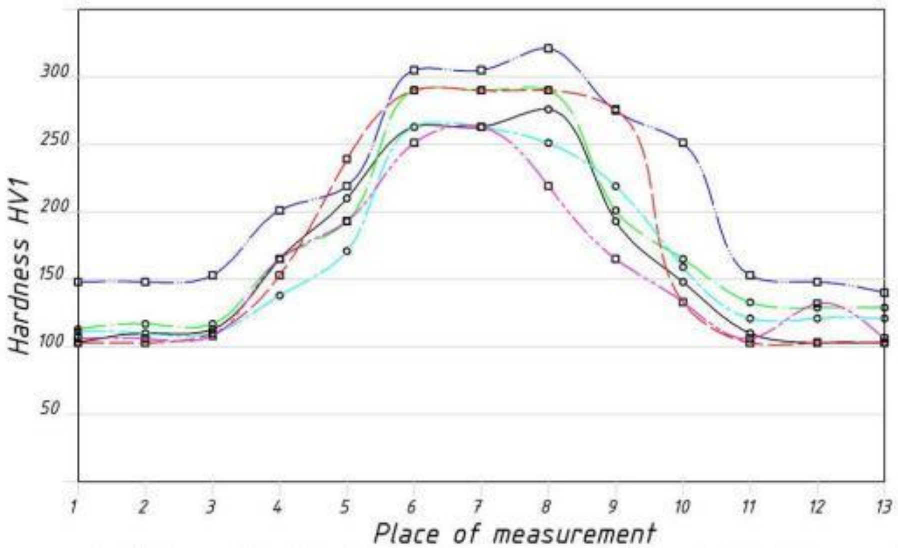


Fig-Spot welding Hardness distribution in weld zone and HAZ

Spot welding is highly dependent on the welding conditions and the material thickness[35]. Welding current and welding duration are the two factors that have the greatest influence, whereas holding time has a less significant impact.[35] Increasing the welding current caused the average hardness to rise. In order to successfully weld material whose thickness increasing , the heat input had to be increased,for this the current has to be increased . Increasing the welding period caused the weld nugget diametar to rise,[35]

3.Experimental Procedures:

This chapter contains the interpretation of the detailed procedures followed by the experimentations of the thermos-mechanically treated steel reinforcing rebars that have been undergone to fulfil the objective of this research.

3.1 Sample Preparation :

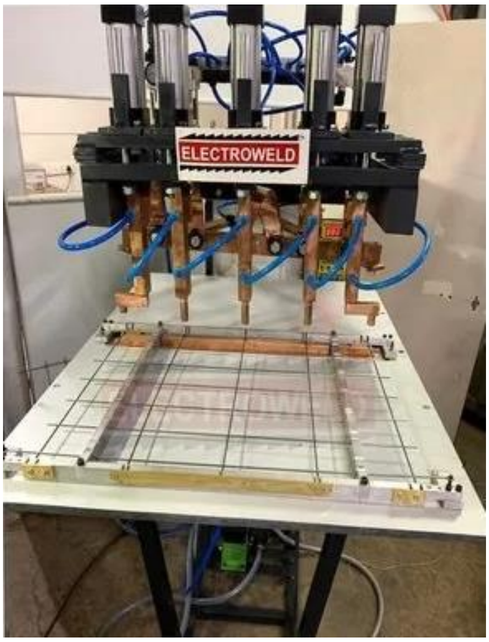
3.1.1Cutting Operation:

Tool Used: Hexa Blade

The panther 550d TMT which we ordered from factory were initially long wire which needed to be cut in small sizes for making the material suitable for cross welding & microstructure & hardness analysis. We performed cutting operation with hexa blade on 3 sample of TMT bar having different dia:6mm,8mm,10mm and one plain carbon steel.

3.1.2 Welding:

Machine used: Electroweld Press Projections/Spot Welding machine



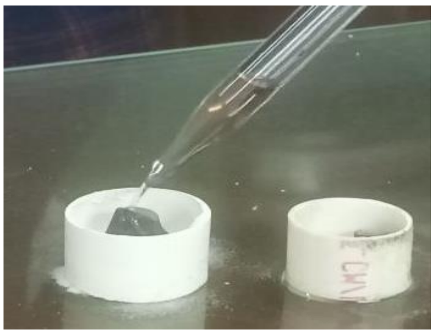
Electroweld Press Projections/Spot Welding m/c

Since TMT bar are circular in shape so the best method to join them cross wirely is by resistance spot welding.For such welding automatic weld wire machine were used.To perform operation we uses automatically weld wire mesh machineSince the sample were difficult to cross weld & the machine present in jadavpur is Twin welding m/c-Migwelder Kempomig 3200W / Feed 400 which can perform manual as well as mig welding,so the samples were taken to factory to perform automatic spot welding with more perfection joint having minimum defects.After welding the Samples were collected as shown below:

6mm TMT 8mm TMT 10mm TMT 6mm cold drawn

3.1.3 Cold Mounting

First all the sample which were cut were cold mounted. A mounting process is used to fix the cut pieces so they can be handled more easily and to standardize their dimensions



3.1.4 Grinding

After mounting gets solidified grinding is done to make surface flat.

3.1.5 Paper polishing

The surface is gently polished with fine to very fine abrasives until nearly all damaged areas are removed.These include papering with silicon carbide abrasive papers from 120 grade to up to 3000 grade

3.1.6 Clothing

The final polishing was carried out by clothing with the help of Twin Disc Grinder/Polisher

3.1.7 Etching

The weld microstructure was revealed with 2% Nital as Etching affects the grain boundaries and makes them visible and then evaluated by optical microscopy (OM). Finally the microstructure were studied with the metallurgical optical microscope

3.2 Depth of penetration measurement:

Tool used: Vernier calliper

Projection welding is generally recommended for those materials where we have controlled penetration. This is a major challenge in our work. We try to maintain depth of penetration to 8%,12%,15%(hence we require min. 3 sample) because in higher depth of penetration strength of metal decreases.

For measuring such penetration we uses Vernier calliper as shown in figure below:

3.3 Microstructure study:

The etched samples are then put on optical microscope to study the surface grains changes occur after welding.

3.4 Hardness Study:

Machine used: Leco Micro Hardness Tester LM248 AT

Leco Micro Hardness Tester LM248 AT scans were performed with 300 gf load across the diameter of one of the welded rods. The hardness machine available in jadavpur contains microscope, so after observing every microstructure structure and comparing with data of microstructure which were taken from optical microscope in metallography lab we determined the weld zone, HAZ zone or base zone, imprints were made and hardness value were calculated.

4.Results & Discussion:

Results

4.1 Percentage Setdown evaluation:

6mm dia TMT bar:

Average base dia=5.58mmx2=11.16mm

Average Welded dia=(9.77+9.85)/2=9.81mm

Setdown =11.16-9.81=1.35mm

% setdown=(1.35/11.16)x100=12.1%

8mm dia TMT bar:

Average base dia =7.71mmx2=15.42mm

Average Welded dia =(13.97+13.95)/2=13.96mm

Setdown =15.42-13.96=1.46mm

% setdown =(1.46/15.42)x100=9.8%

10mm dia TMT bar:

Average base dia =9.69mmx2=19.38mm

Average Welded dia =(17.93+18.1)/2=18.015

Setdown =19.38-18.015=1.365mm

% setdown =(1.365/19.38)x100=7.1%

6mm cold drawn plain carbon steel:

Average base dia =5.92mmx2=11.84mm

Average Welded dia =(10.66+10.62)/2=10.64mm

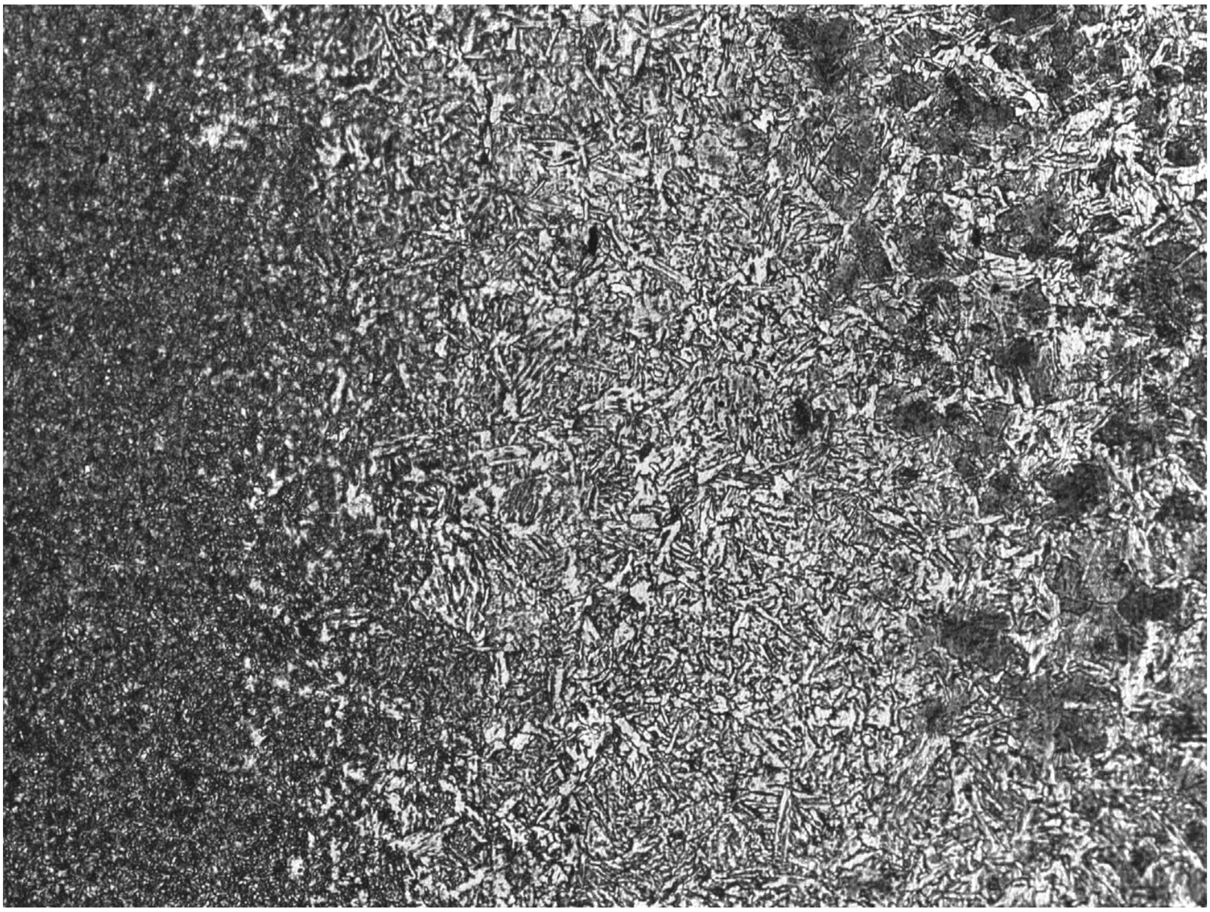
Setdown =11.84-10.62=1.2mm

% setdown =(1.2/11.84)x100=10.1%

4.2 Microstructure:

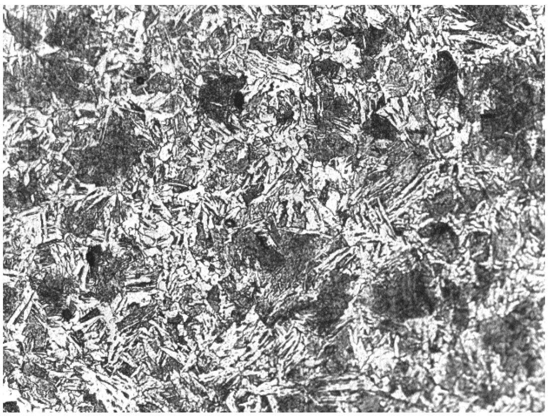
i)6mm Cross welded TMT bar

At 200x



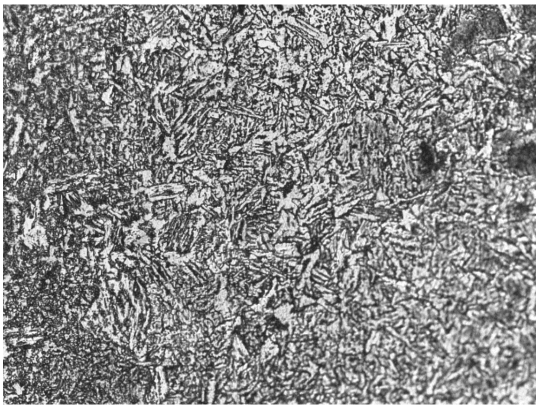
Weld-------------------------------------HAZ----------------------------------Base

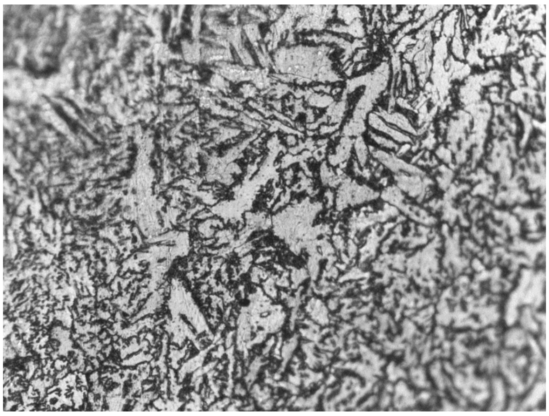
Base



200x **500x**

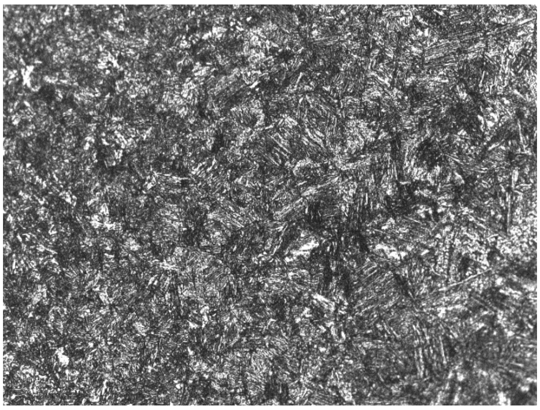
HAZ

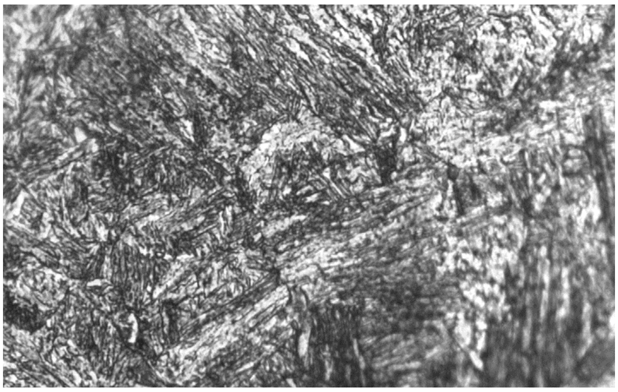




200x **500x**

Weld zone

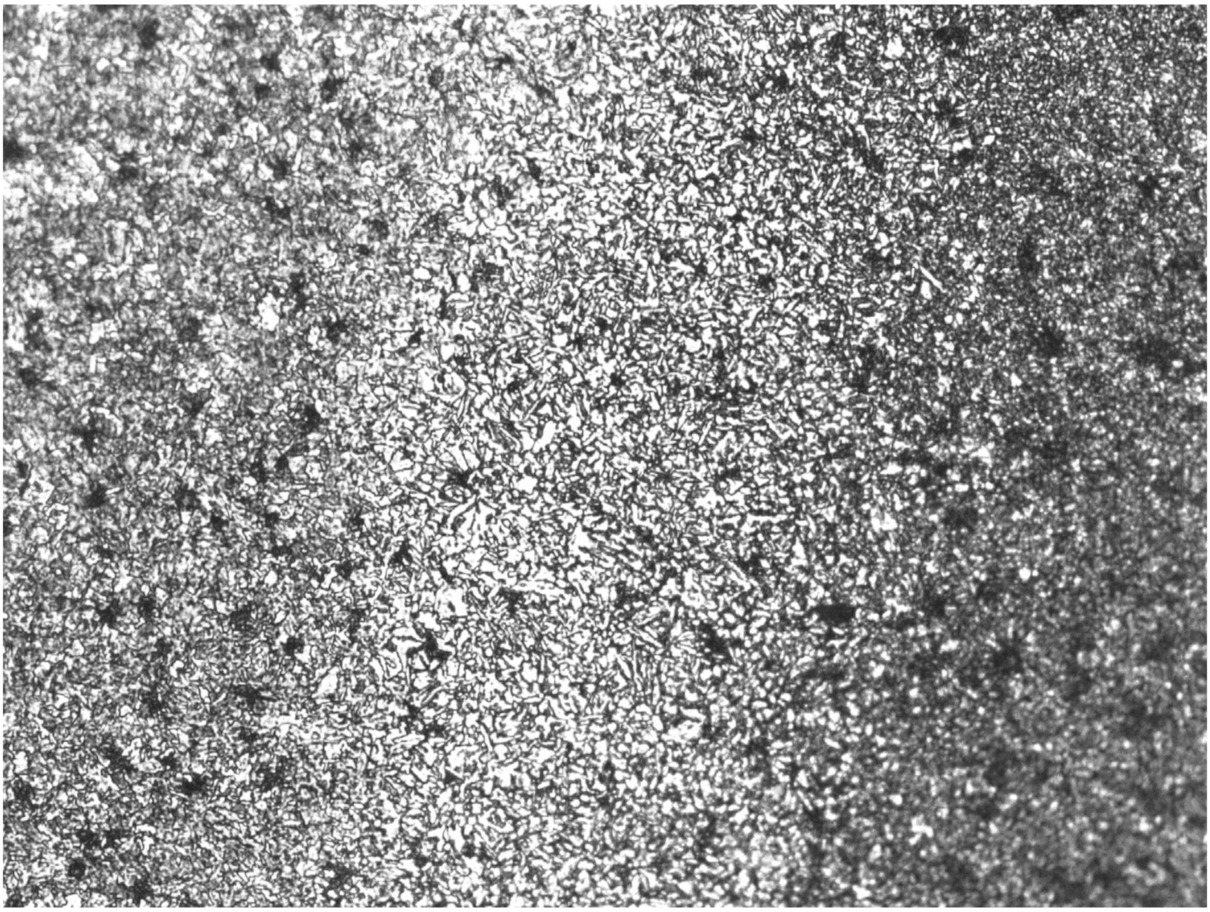




200x **500x**

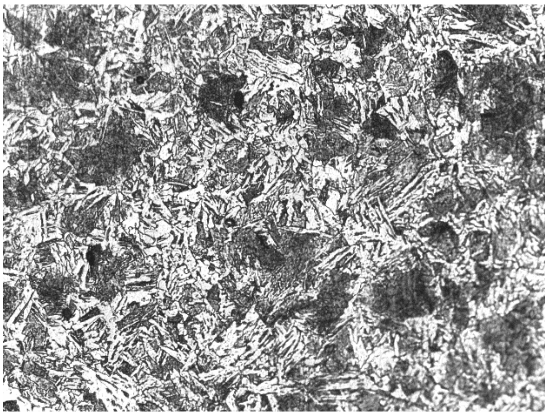
ii)8mm Cross welded TMT bar

At 200x



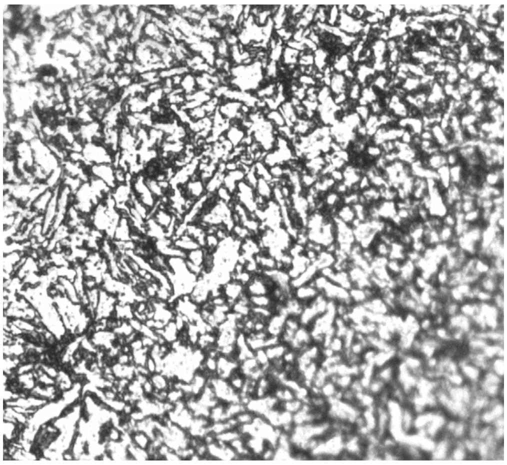
Base---------------------------------HAZ---------------------------------------Weld

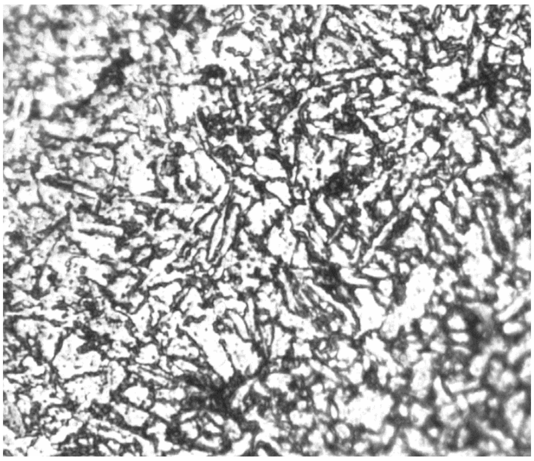
Base



200x **500x**

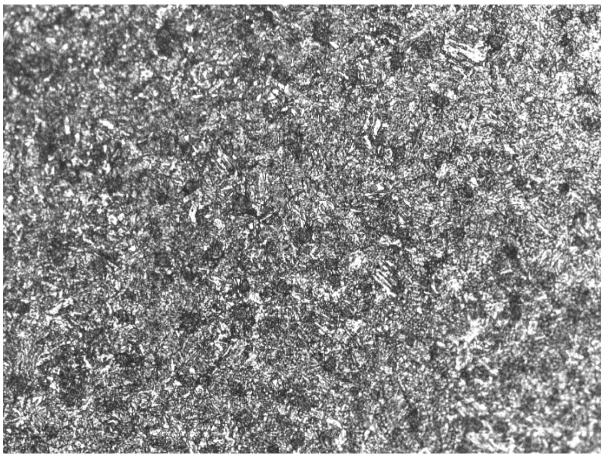
HAZ

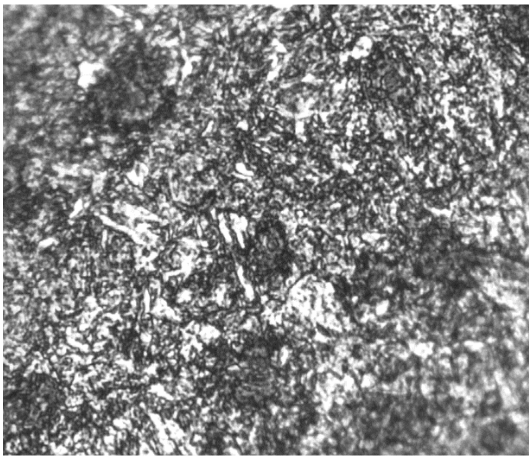




500x **500x**

Weld zone

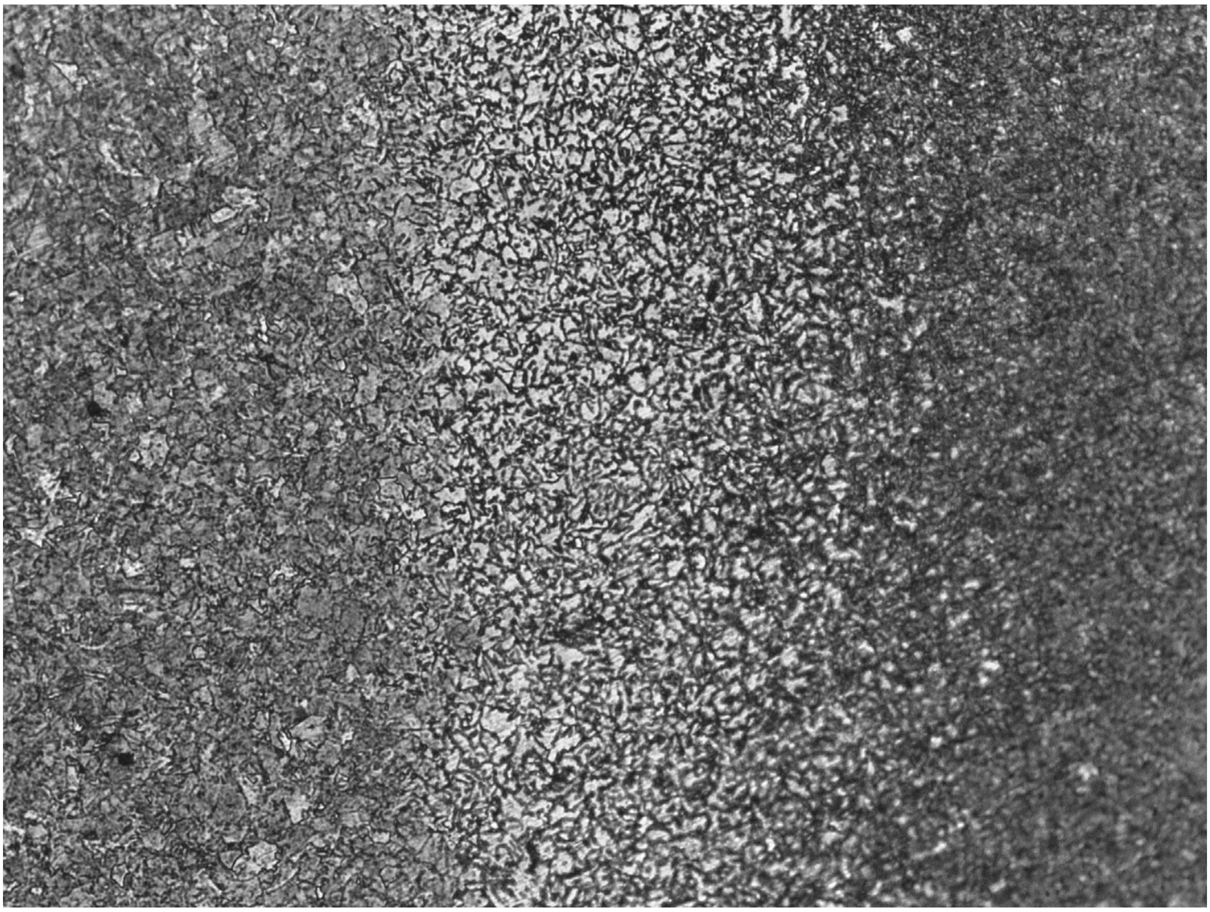




200x **500x**

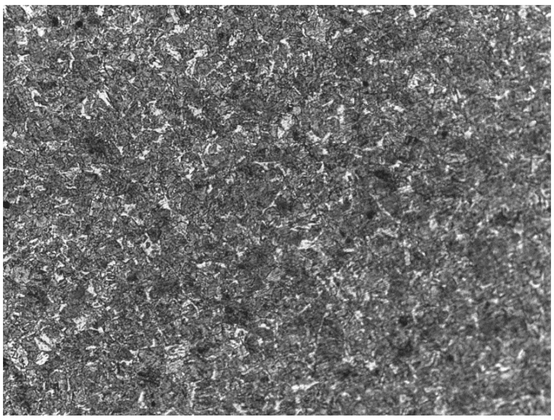
iii)10mm Cross welded TMT bar

At 200x

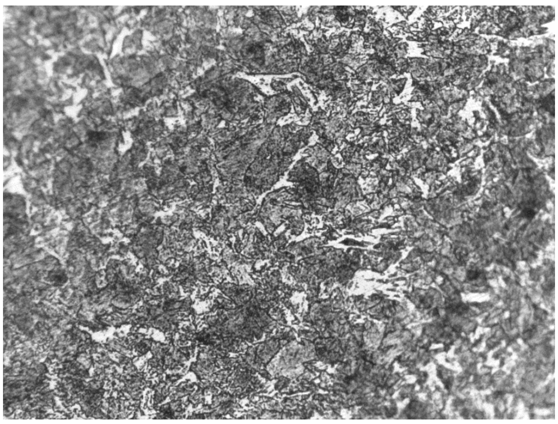


Base--------------------------------HAZ--------------------------------------Weld

Base

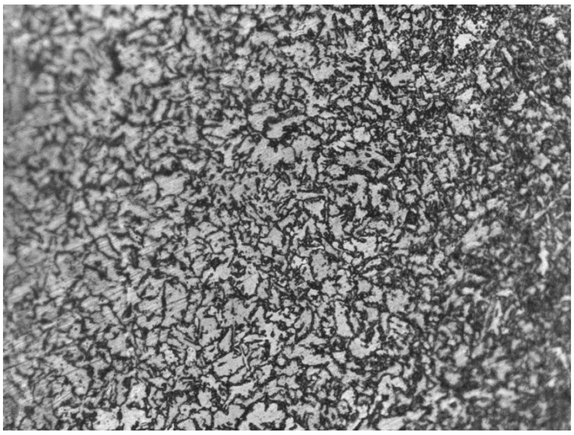


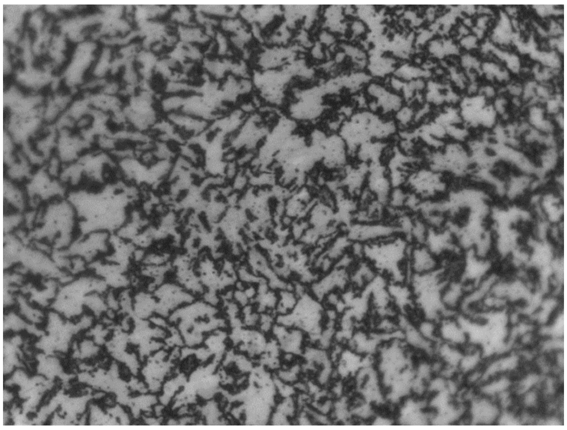
200x



500x

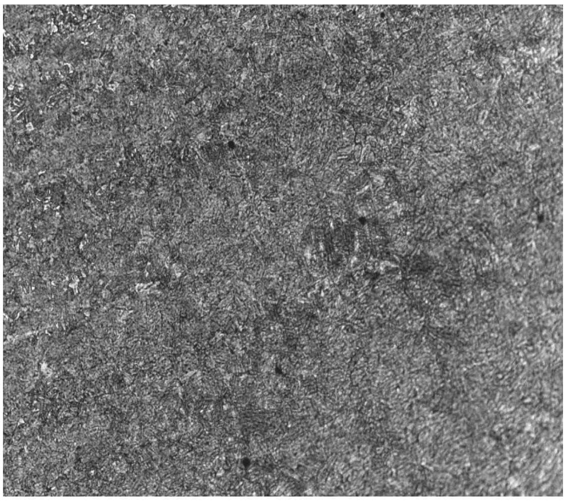
HAZ





500x **1000x**

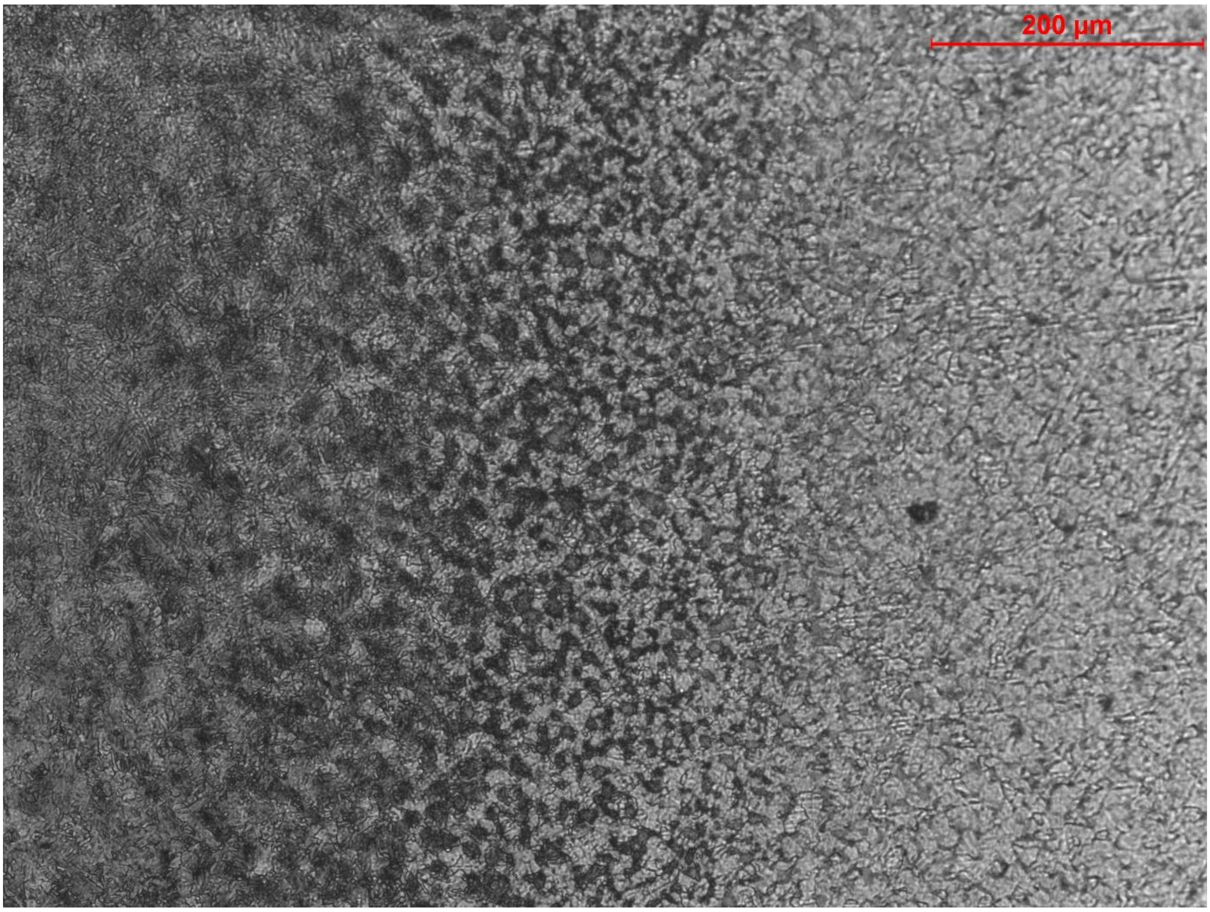
Weld zone



200x **500x**

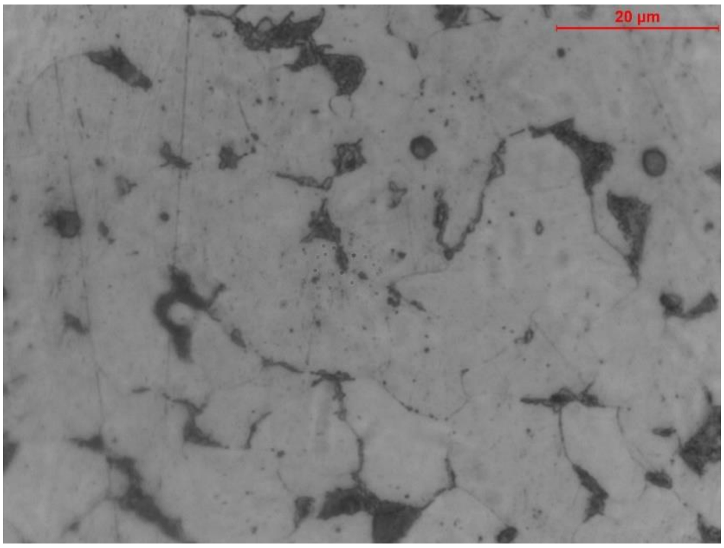
iv)6mm Cross welded cold drawn plain carbon steel

At 200x



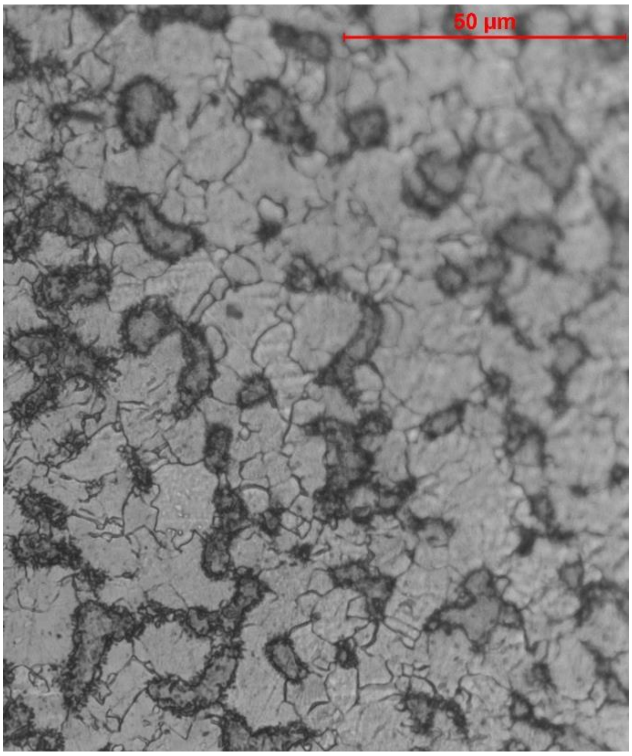
Weld----------------------------------HAZ--------------------------------------Base

Base



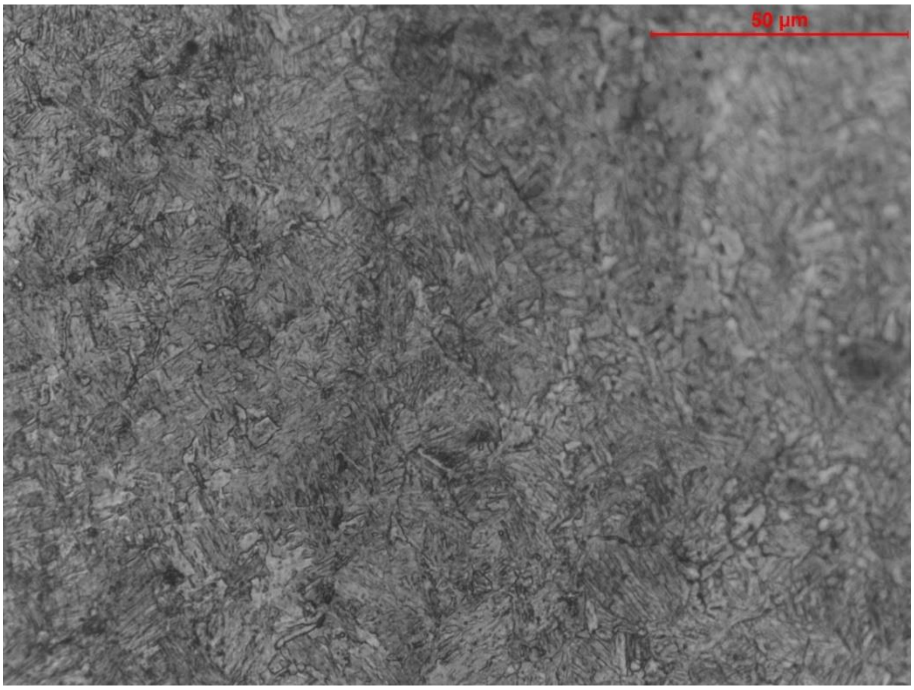
1000x

HAZ



500x

Weld



500x

4.3 Hardness:

i)6mm Cross welded TMT bar

	HV	D1	D2
BASE	184.9	55.88	55.88
	192.7	52.09	52.13
HAZ	221.8	49.51	49.51
	233.4	49.57	49.57
WELD	263.2	46.70	46.25
	266.6	46.04	46.07

ii)8mm Cross welded TMT bar

	HV	D1	D2
BASE	183.6	50.66	50.66
	192.3	49.56	49.71
HAZ	223.4	46.24	46.24
	237.8	47.58	47.53
WELD	263.4	44.51	45.68
	267.2	43.24	43.26

iii)10mm Cross welded TMT bar

	HV	D1	D2
BASE	173.2	57.15	57.15
	184.9	55.88	55.88
HAZ	211.5	51.66	51.66
	204.9	52.09	52.13
WELD	265.6	45.23	45.23
	263.2	44.91	44.98

iv)6mm Cross welded cold drawn plain carbon steel

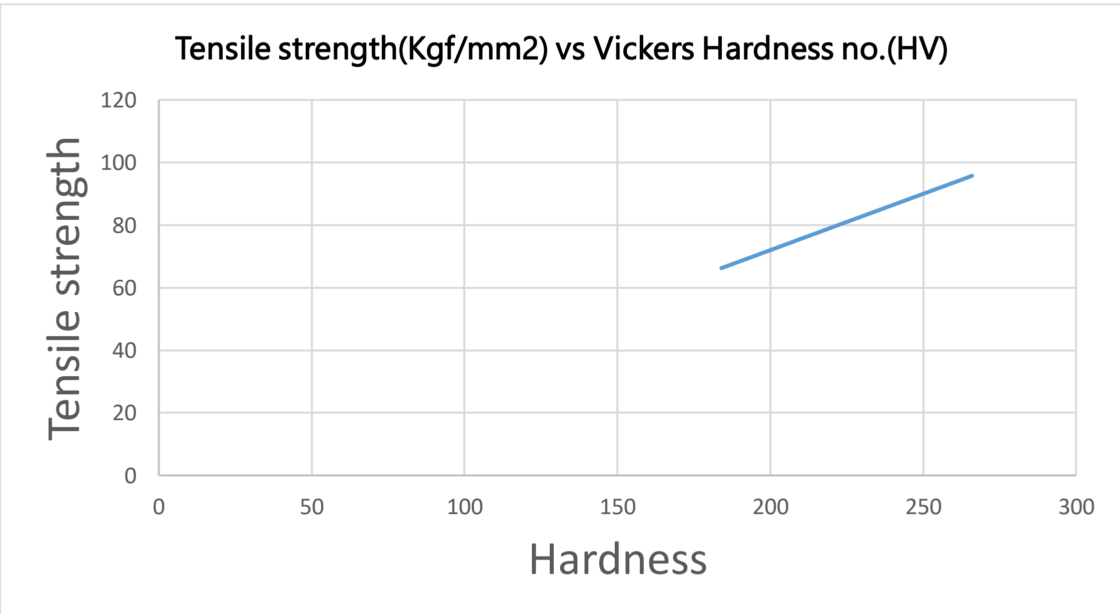
	HV	D1	D2
Weld	354.2	40.38	38.88
	369.4	37.51	39.08
HAZ	303.3	42.96	42.96
	296.1	43.26	42.63
Base	231.2	48.70	49.41
	229.5	49.25	49.25

V) 6mm TMT bar vs 6mm cold drawn plain carbon Hardness difference

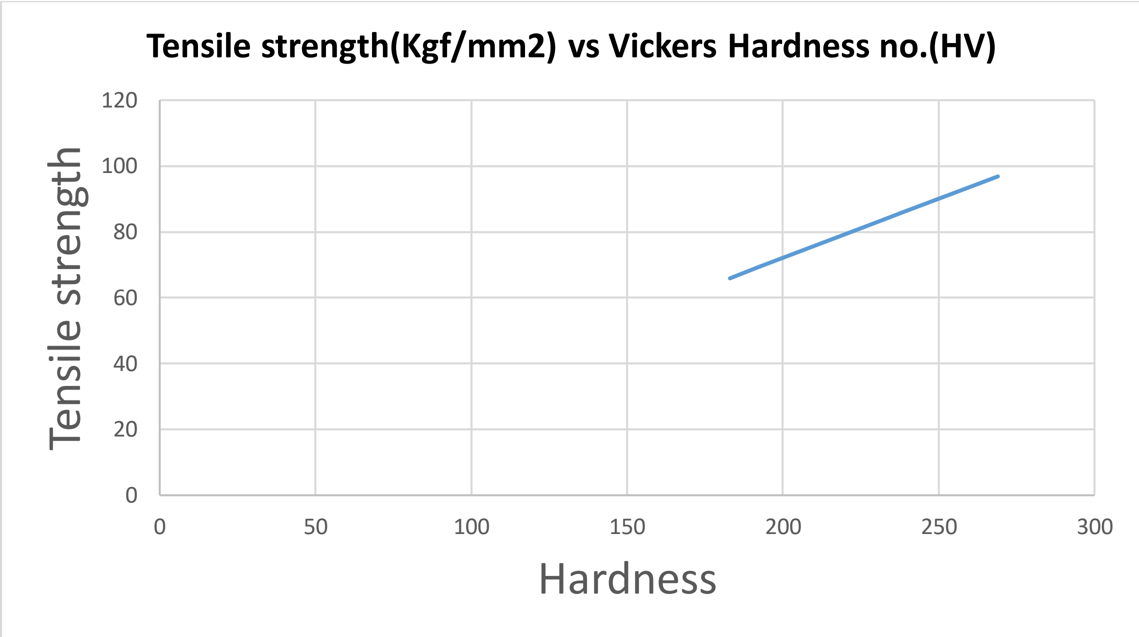
Zone	Hardness difference TMT bar	Hardness difference Cold drawn plain cabon steel
Weld-Base	76.5	131.5
Weld-Haz	37.5	62
Haz-Base	39	69.5

4.4 Microhardness vs strength:

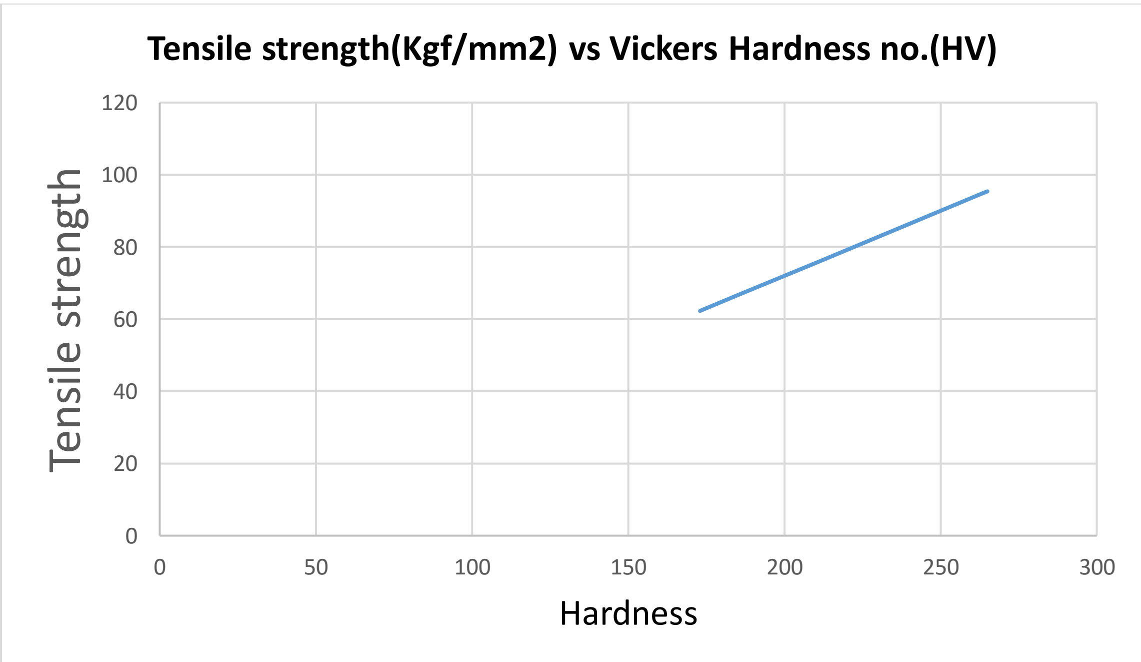
6mm TMT



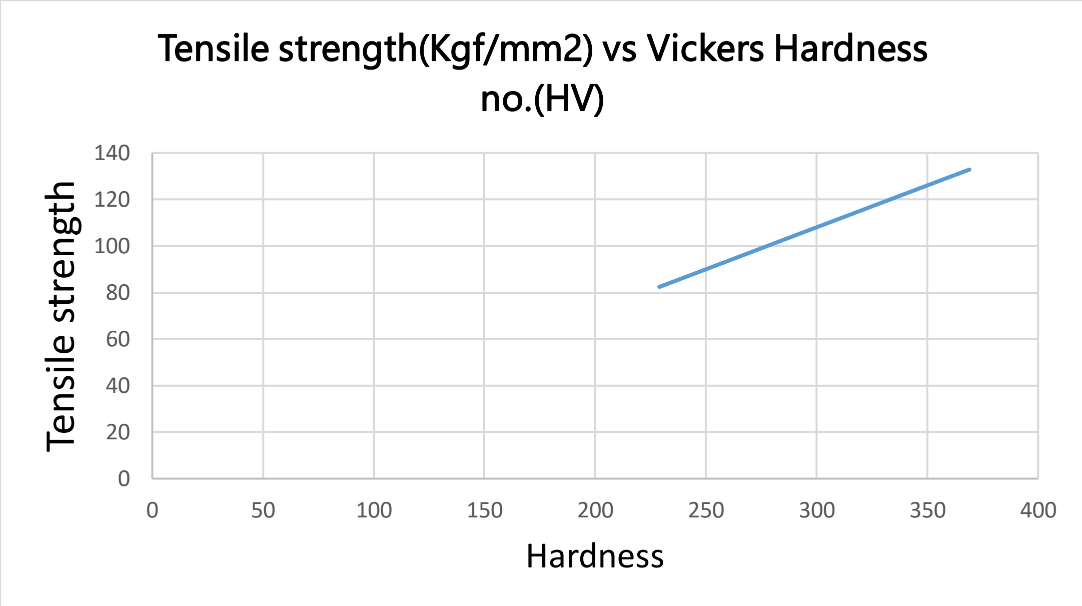
8mm TMT



10mm TMT



6mm Cold Drawn Plain carbon steel:



4.5 Discussion:

i) Increasing dia required high current for high strength welding process to occur.Here welding parameter such as current,time etc were same for all the specimens (6mm,8mm,10 TMT) causing 6mm to have greater setdown percentage compared to others.Cold drawn wires are having high residual stresses due to cold drawn with uniform hardness all over surface which may be cause for less setdown in cold drawn plain carbon steel than TMT.

ii)The base consist of mixture of white grains as ferrite grains and black grains as pearlite grains which contains alpha ferrite & cementite which are more clearly visible without any dendritic structure. More ferrite is seen here which has lower hardness compared to pearlie or bainite. In case of heat affected zone where solid state transformation has occurred such as grain growth, recrystallization, phase transmission, tempering etc due to which it has coarse grain structure and very coarse grain known as widmanstatten structure which is likely near fusion edge. Since coarse grain favour martensite formation so more hardness is seen here than parent material Microstructure in weld zone has significantly change due to remelting and solidification of metal. It consists of columnar dendritic structure of fused metal with higher amount of pearlite than ferrite making the surface more harder. It has heterogeneous structure due to temperature gradient & chemical gradient that evolved during process. It is hard structure due to residual stresses after welding.

A similar pattern is observed in cold drawn plain carbon steel where base has a uniform mixture of pearlite and ferrite. In base unlike TMT widmanstatten structure were not observed here. The ferrite grains have not been altered but pearlite regions have become finer.This occurred because during heating pearlite transform into austenite and by cooling it reformed into pearlite. On weld region the mixture has high amount of pearlite with few bainite might be there which further increases its hardness value.

iii) Maximum hardness were seen in heat welded zone as expected to our theoretical knowledge. As comparing the hardness between TMT bar with cold drawn plain carbon steel it can been seen cold drawn plain carbon steel shows more hardness in all its zone with very high variation in hardness between base, haz and weld. Since plain carbon steel is cold drawn so more residual stress were present in the material which increases its hardness .On the other hand TMT were hot rolled so it shows low hardness.

iv)As seen from the graph between tensile strength and hardness, the tensile strength shows a linear relationship with Vickers hardness for the strength range covered by the experiment. This shows a linear interdependence between strength and hardness for high strength steel. Steep slope of 6mm cold drawn steel is due to more variations in hardness here in difference regions(base,HAZ,weld) as compared to TMT bar.

5. Conclusions:

In the present study a microstructure and hardness comparison between welded structure,the variation of hardness is investigated by characterising the microstructure at the base,weld and the HAZ, of different diameter samples. Major conclusions derived from this work are the following:

i)For same diameter hot drawn wire(TMT) shows more setdown percentage with respect to cold drawn wire(cold drawn plain carbon steel)

ii) Maximum hardness so is strength are in welded zone and heat affected zone with different grain structure between them and with parent material.

iii) More hardness for cold drawn plain carbon steel than TMT500 with more hardness variation between Weld, HAZ and base for cold drawn plain carbon steel than TMT500.

As cold drawn plain carbon steel are homogenous structure having uniform hardness throughout its structure.Also have high hardness & strength after welding so it should show perfect welding.But after cross wire welding it shows more hardness variation between different zones & also theoretically it have more cavity than TMT bar.Further with less hardness variation between different zone of TMT and its unique feature of high toughness and ductility along with high hardness and strength,TMT would be better choice for welding than cold drawn plain carbon steel.

This might not always be the case as comparison was limited to 6mm.Further more samples can be tested to re-verify the result for welding parameters such as setdown,pressure,current etc.

<u>Scopes for future work</u> :

In this study,an initial attempt has been taken to comparative study on various properties of cross welded TMT bars having different dia and further compare with plain carbon welded wire.But this was a starting for this research work in this field which claims further details studies in future to advancement. Some future scopes realized from this study was mentioned below:

1.Further study can be made to establish a relationship between hardness and tensile strength especially for crosswire welding so that the study of hardness–strength relationships will be helpful to measure strength more accurately and also helpful in areas where the direct measurement of tensile properties of a material is not possible

2. A study can be made to establish correlation between setdown and weld tensile & shear strength can be carried out.

3. Further an analysis can be done on whether Over penetration in TMT weld mesh compromise the inherent FE strength when martensite rim is pierced into perlite core.

4. A study can be possible on how welding parameter such as heat & pressure can be related to microstructural change with respect to different diameter of welded structure.

5. More sample with different diameter can be tested for different grade of TMT steel or any crosswire welded steel to measure strength & hardness on varying different welding parameters such as pressure,current etc.

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