

**EFFECTS OF HEAT TREATMENT ON THE
MECHANICAL PROPERTIES AND CORROSION
BEHAVIOUR OF 5SP ROLLED STEEL**

BY



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CERTIFICATION

This is to certify that this project has been read and approved to have satisfied the requirements for the award of Masters of Engineering (M.Eng.) in Metallurgical and Materials Engineering of the Federal University of Technology Akure, Ondo State.



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DEDICATION

This project is dedicated to my beloved parents, chief and Mrs. John Akin Daramola and my beloved wife, Mrs. Olubukola Daramola for their continuous financial and moral support on my education. May God continue to shower his blessing upon them (Amen).



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ABSTRACT

Investigations were carried out to study critically the effect of heat-treatment on the mechanical properties and corrosion behaviour of 5sp rolled steel products. The steel was heated to a temperature of 830°C to completely austenize it and water quenched, it was reheated to the ferrite-austenite two phase region at a temperature of 745°C below the effective AC3 point. The steel was then rapidly quenched in water and tempered at a temperature of 480°C to provide an alloy containing strong, tough lath martensite (fibres) in a ductile soft ferrite matrix. The corrosion behaviour of the steel in marine medium (NaCl) was also studied by weight loss measurement. The weight loss is between 0.02g-0.11g for the as-rolled steel and 0.01g-0.013g for the heat treated specimens. The steel developed has excellent combination of tensile strength, impact strength, ductility and corrosion resistance which is very attractive for structural use.

CHAPTER ONE



1.0 INTRODUCTION

Steel is an alloy of iron and carbon; where other elements are present in quantities too small to affect the properties. The other alloying elements allowed in plain-carbon steel are manganese (1.65 % max.), silicon (0.60 % max.), and copper (0.60 % max). (Oberg, et al., 1996); Steel with a low carbon content has the same properties as iron, soft but easily formed, as carbon content rises the metal becomes harder and stronger but less ductile and more difficult to weld; Higher carbon content lowers steel melting point and its temperature resistance in general (Smith, 2006).

5SP rolled steel products are produced through a forming process called rolling. The process is carried out in a rolling mill which consist of a complex machine for deforming metal in rotary rolls and performing auxiliary operations such as transportation of stock to rolls, disposal after rolling, cutting, cooling, piling or coiling e.t.c. Carbon billets are charged into a preheating furnace with the aid of the charging devices, the roller table takes billet to the heating furnace one at a time, the billets are preheated and latter discharged and made to pas through the working group of stands where reduction is effected.

Heat treatment involves the application of heat to a material to obtain desired material properties (e.g. mechanical, corrosion, electrical, magnetic etc.). During the heat treatment process, the material usually undergoes phase microstructural and crystallographic changes.

The purpose of heat treating carbon steel is to change the mechanical

properties of steel, usually ductility, hardness, yield strength, tensile strength and impact resistance. The electrical, corrosion and thermal conductivity are also slightly altered during heat treatment process.

The standard strengths of steels used in the structural design of building are prescribed from their yield strength.

Tensile strength is defined as the maximum load in tension, which a material will withstand prior to fracture; It is measured in N/mm^2 while yield strength is the maximum load at which a material exhibits a specific deformation. Most engineering calculations for structure are based on yield strength. Hardness is the property of steel which gives it the ability to resist being permanently deformed when a load is applied while toughness of steel is its ability to absorb energy without fracture and is measured by notch impact test.

Recent urban buildings in Nigeria have become taller for more effective utilization of above ground space and have increased in size and complexity through the adoption of new structural design. These trends have led to demand for steels of greater strength, good ductility and toughness.

This project will investigate the effect of heat treatment on the mechanical properties and corrosion susceptibility of 5SP rolled steel product.



CHAPTER TWO



2.0 LITERATURE REVIEW

2.1 DEFINITION

Steel is an alloy of iron and carbon; certain percentages of other elements were also found in steel, some valuable and beneficial, others harmful (Coltrell, 1975).

2.2 CLASSIFICATION OF STEELS

For all practical purposes, steel can be classified into low, medium and high carbon steel.

(a) Low Carbon Steel: Approximately 0.2% C-0.3%C.

It has a relatively low tensile strength, but it is cheap and malleable; surface hardness can be increased through carburizing.

(b) Medium Carbon Steel: Approximately 0.3%C-0.6%C.

It balances ductility and strength and has good wear resistance; used for large parts, forging and automotive components

(c) High Carbon Steel: Approximately 0.6%C-2.04%C.

It is very strong and it is used for springs and high-strength wires.

2.3 METHOD OF STRENGTHENING STEELS

There are four ways to increase steel's strength:

1. Transformation hardening
2. Cold working
3. Solid solution hardening
4. Precipitation hardening

2.3.1 Transformation Hardening

Transformation hardening is the heat-quench-tempering heat treatment cycle used to adjust strength and ductility to meet specific application requirements. There are three steps to transformation hardening;

- i. Cause the steel to become completely austenitic by heating it 10°C - 38°C above its AC_3 transformation temperature.
- ii. Quench the steel; cool it so fast that the equilibrium materials of pearlite and ferrite or pearlite and cementite can't form and the only thing left is the transitional structure martensite. The idea here is to form 100% martensite.
- iii. Reduce brittleness by tempering the martensitic steel, which required heating it, but keep temperature below 180°C - 680°C , which allows some of the martensite to turn into pearlite and cementite, then allow the piece to air-cool slowly.

By using proper heat treatment and choosing a steel with just the right amount of carbon, you can get just about any combination of hardness and ductility to meet a specific requirement (Bob, 2003).

In the hot rolling method for direct production of cold formable dual-phase steel provided by Thomas et al,(1986); The steel is heated to the austenite region and then continuously hot rolled and cooled down to the ferrite-austenite two phase region to a temperature which is just below the effective AC_3 point; The hot rolled steel is then rapidly quenched to provide an alloy containing strong, tough lath martensite (fibers) in a ductile soft ferrite matrix; This method is useful for providing rods in which the alloy is capable of being drawn into high strength wire without any intermediate annealing or patenting, and has excellent strength, ductility and fatigue characteristics.

2.3.2 Cold Working

Cold working a metal deforms and stresses its crystal structures, causing the metal to work-harden. Steel mills cold work steel by running it back and forth through rollers with the steel at a temperature below the plastic state. This distorts the steel's grain structure which increases its hardness and tensile strength while decreasing ductility. Sheet metal fabricator and hammer formers deal with this too. After a piece of tempered sheet or aluminum is worked with a hammer for a while, it begins to get hard and brittle, so you need to temper it again to be able to keep working it without cracking it.

2.3.3 Solid Solution Hardening

Solid solution hardening stresses a metal's crystal structure by adding alloying metals that don't fit easily in the base metal's crystal lattice. This added stress increases tensile strength and decreases ductility.

2.3.4 Precipitation Hardening

Precipitation hardening is an effective way to develop high strength and hardness in some steels, it's most often an aluminum alloy application and is a little more complicated than the others.

2.4 HEAT TREATMENT OF STEELS

The purpose of heat treating plain- carbon steel is to change the mechanical properties of steel, usually ductility, hardness, yield strength, and impact resistance, electrical and thermal conductivity are slightly altered. As with most strengthening techniques for steel, the modulus of elasticity (Young's modulus) never affected. Steel has a higher solid solubility for carbon in the austenite phase, therefore all heat treatments, except spheroidizing and process annealing, start by heating to an austenitic phase. The rate at which steel is cooled through the eutectoid reaction affects the rate at which carbon diffuses out of austenite.

Generally speaking, cooling quickly will give a finer pearlite (until the martensite critical temperature is reached) and cooling slowly will give a coarser pearlite. Cooling a hypoeutectoid (less than 0.8%C) steel results in a pearlitic structure with a ferrite at the grain boundaries. If its hypereutectoid (more than

0.8% carbon steel, then the structure is full pearlite with small grains of cementite scattered throughout the structure.

2.4.1 Iron- Cementite Phase Diagram

In the iron-cementite phase diagram, temperature is plotted against composition. Any point on the diagram therefore represents a definite composition. A point on the diagram therefore represents a definite composition and temperature.

The phase diagram indicates the phases present and the phase changes that occur during heating and cooling.

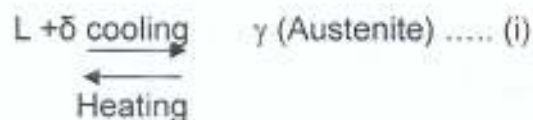
The solubility of carbon varies in different forms of iron. In delta (δ) iron, maximum solubility of carbon is 0.1%, in gamma iron, the maximum solubility of carbon is 2.03%. Austenite is a solid solution of carbon in a face centred cubic γ -iron.

There are three reactions that occur in iron-cementite phase diagram:

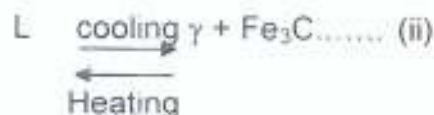
(i) Peritectic reaction

(ii) Eutectoid reaction

(i) Peritectic Reaction: - In the alloy containing 0.15% carbon, the initial crystal of δ iron -solid solution and the whole of liquid phase is completely transformed to form austenite on cooling at 1492°C .



(ii) Eutectic Reaction: - Alloy with carbon content 4.33%, the liquid iron is transformed into austenite and cementite on cooling at 1147°C



(iii) Eutectoid Reaction: - In iron-carbon alloy with 0.8% carbon, the austenite is transformed into δ - iron and cementite by eutectoid reaction on cooling at 723°C

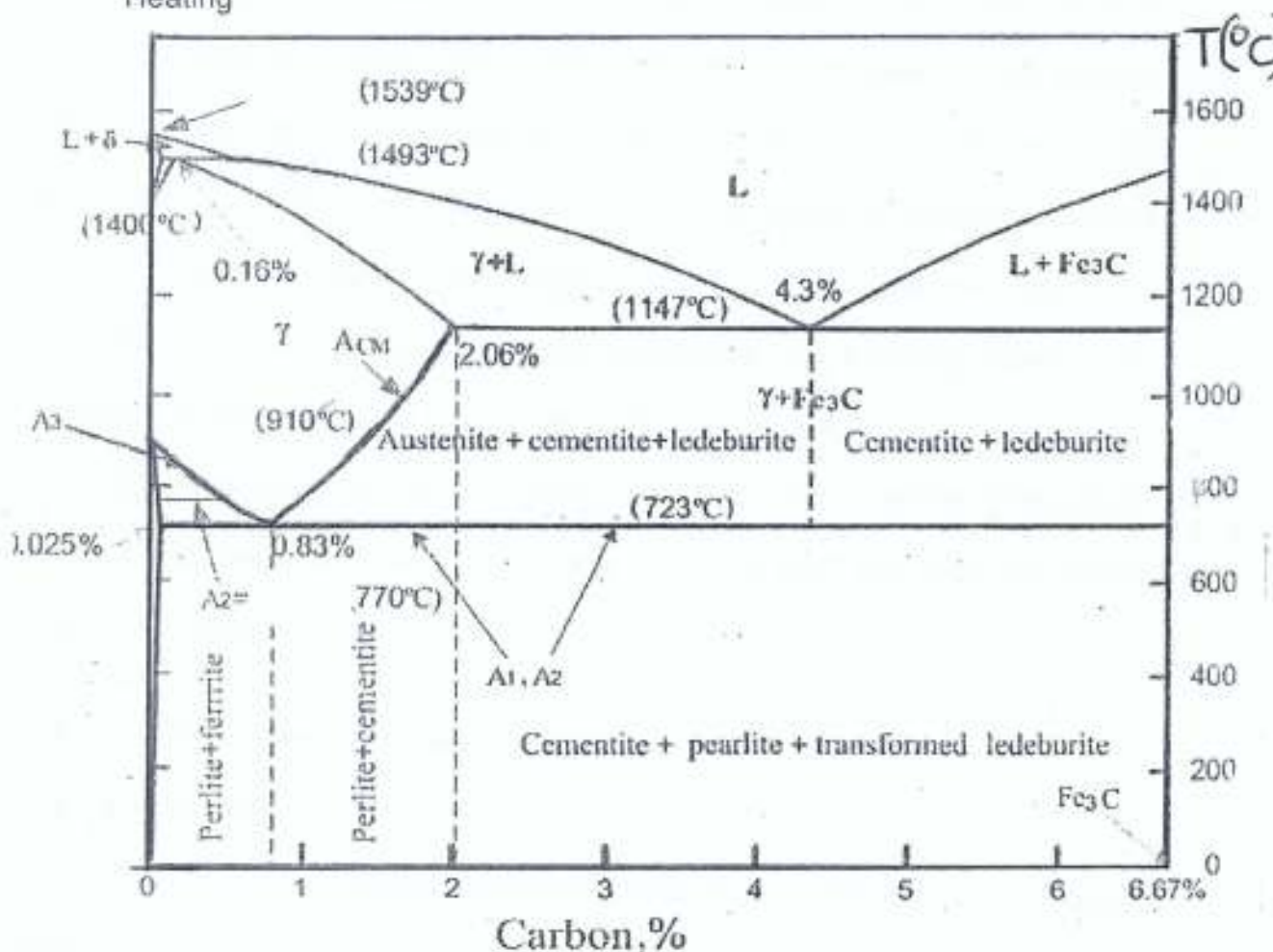
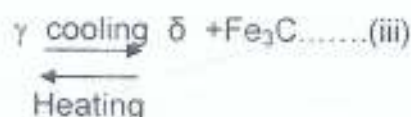


Fig 2-1 Iron - Cementite Phase Diagram

2.4.2 Transformation of Hypoeutectoid Steels

The transformation of gamma iron to alpha iron and the decomposition of austenite. Line GS in the phase diagram shows the temperature where transformation of austenite to ferrite starts. Below this line ferrite is separated out of austenite. The critical points that make up line GS are shown by Ar_3 (in cooling) and AC_3 (in heating). Line ES indicates the variation in the solubility of carbon in austenite with the temperature and, in cooling, corresponds to the temperature at which separation of cementite from austenite starts. Point S is called the eutectoid point and here the degree of freedom is zero. When point S (0.8%) is reached during cooling, the austenite decomposes to 100 percent lamellar pearlite at 723°C . Pearlite is eutectoid mixture of two phases: ferrite and cementite. The critical point where austenite decomposes to pearlite is denoted by Ar_1 (in cooling) and AC_1 (in heating). The line PQ shows the variation in solubility of carbon in alpha iron with the temperature and in cooling, corresponds to starting of precipitation of surplus cementite out of ferrite.

The limiting composition for getting pearlite is 0.025% carbon. With carbon content less than this amount, no pearlite will be formed. The alloy will contain only ferrite grains.

2.4.3 Types of Heat Treatment

2.4.3.1 Annealing

This is a heat treatment process whereby steel is heated to approximately 40°C above AC_3 for 1 hour, this assures all the ferrite transforms into austenite (although cementite might still exist if the carbon content is greater than the

eutectoid), and cooled slowly in the realm of 38°C per hour inside the furnace. The furnace is turned off with the steel still inside. This results in a coarse pearlitic structure, which means the "band" of pearlite are thick. Fully annealed steel is soft and ductile, with no internal stresses, which is often necessary for cost-effective forming.

2.4.3.2 Normalizing

This is a process whereby steel is heated to approximately 55°C above AC_3 for 1 hour, and then air cooled, at a cooling rate of approximately 38°C per minute, this assures the steel completely transforms to austenite. This result in a fine pearlitic structure and a more uniform structure. Normalized steel has a higher strength than annealed steel; it has a higher high strength and ductility.

2.4.3.3 Quenching

This is a heat treatment process whereby steel is heated to normalizing temperature and then rapidly cooled (quenched) in water, brine or oil to the critical temperature. The critical temperature is dependent on the carbon content, but as a general rule is lower as the carbon content increases. This result in a martensitic structure, a form of steel that possesses a supersaturated carbon content in a deformed body-centred cubic (BCC) crystalline structure, properly termed body centred tetragonal (BCT). This crystalline structure has a very high amount of internal stresses. Due to these internal stresses quenched steel is extremely hard but brittle, usually too brittle for practical purposes. These internal stresses cause stress cracks on the surface. Quenched steel is approximately three (lower carbon content) to four (high carbon content) times harder than normalized steel.

2.4.3.4 Tempering

This heat treatment process involves a moderate heating of steel to a temperature below 700°C , usually between 180°C - 680°C after hardening (quenching) to improve toughness and ductility at the expense of hardness and strength and so make the material more suitable for service requirement. The final properties can be precisely determined by the temperature and time of tempering.

The higher the temperature is, the softer and tougher the steel is (Bob., 2003). Tempering increases toughness and reduces brittleness by allowing carbon to precipitate into tiny carbides particles.

2.5 EFFECT OF TEMPERATURE ON HARDENING

To ensure supersaturation (after quenching), it is necessary that sufficient carbon is put into solid solution during heating.

Steel with C% less than 0.83% should be heated above the AC_3 -point to put all the carbon into solid solution (δ); steel with C% > 0.83 should be heated only to above A_1 -point so that only pearlite is converted to γ (austenite) which upon quenching will form martensite. No attempt should be made to convert the free Fe_3C into γ Fe because the Fe_3C is already hard and because the high temperature necessary to convert it to γ Fe would produce coarse structure which would cause the steel to be more brittle after quenching without any appreciable increase in hardness.



2.6 EFFECT OF MARTENSITE ON THE TENSILE STRENGTH OF STEEL

Martensite can have a positive effect on the tensile strength of steel if the martensitic steel was heated to a temperature in the two phase alpha +gamma range for a period of time sufficient to transform the said martensitic steel composition to a volume ratio of ferrite and austenite such that subsequent quenching results in a micro structure having about 10 to 40 volume percent martensite and 60 to 90 volume percent ferrite depending on the properties required.

According to Huang-Chuan and Gwo Hwa (1989) on the effect of martensite on the tensile strength of dual phase steels, it was found that the ultimate tensile strength of dual phase steels increased with increasing the volume fraction as well as the tensile strength of martensite.

2.7 MECHANICAL PROPERTIES OF STEEL

A knowledge of the mechanical properties of both ferrous and non ferrous metals enables one not only to determine whether or not such materials are suitable for certain definite uses, but also to modify the thermal and mechanical treatments of materials in order to obtain a conditioned metal in the desired form. Strength with plasticity is the most important combination of properties a metal can possess.

A number of strength values for steel must be known to fully understand the strength characteristics of the steel. Among these strength values are: Tensile strength and Yield strength. Other mechanical properties are hardness, toughness, ductility, brittleness and malleability.

(a) Tensile Strength

This is defined as the maximum load in tension which a material will withstand prior to fracture. It is measured in N/mm^2 or KN/m^2 .

(b) Yield Strength

This is the maximum load at which a material exhibits a specific deformation. Most engineering calculation for structures are based on Yield strength.

(c) Toughness

This is the ability of a metal to absorb energy without failure. It is measured by notch impact test.

(d) Hardness

This is the property of a steel which gives it the ability to resist being permanently deformed when a load is applied. A steel maximum hardness is a function of its carbon content: more carbon, more hardness.

Hardenability refers to the amount of martensite that forms in the microstructure during cooling (Bob, 2003).

2.8 CORROSION OF STRUCTURAL STEEL

Corrosion is the destruction of a metal by its reaction with the environment; this reaction is an electrochemical oxidation process that usually produces rust or other metal oxide.

Structural steel is used in most metal waterfront structures because it is

strong, readily available, easily fabricated and not excessively costly. The steel is normally used for such accessories as bitts, bollards, cleats, and chocks.

There are many types of marine corrosion that can occur to steel waterfront structure and many methods for corrosion control. Heat treatment of structural steel can improve its resistance to corrosion. The most common types of metal corrosion occurring in a marine environment are described in Table 2.1

TABLE 2.1: TYPES OF MARINE CORROSION.

TYPE	DESCRIPTION	REMARKS
Galvanic Corrosion	Two dissimilar metals connected to each other electrically in an electrolyte (e.g., seawater). Current flows through the electrolyte from the more reactive metal(anode) to the less reactive metal (the cathode) highly stressed area (the cathode), thereby corroding the anode area while protecting the cathode area from corrosion.	(1) New steel is anodic to old steel (2) brightly cut surface (e.g. pipe threads) are anodic to uncut surfaces. (3) steel is anodic to its surface mill scale. (4) Highly stressed area (e.g. pipe bends) are anodic to less stressed areas.
Stray Current	Occurs on metal surfaces wherever stray direct current passes from them to an electrolyte. This current most frequently arises from electric railway and crane systems; improperly grounded welding generators, and adjacent cathodic protection systems.	Stray current corrosion should always be suspected as the cause of accelerated corrosion in areas adjacent to sources DC and current checked for by detection of current flow.
Differential Environment	Occurs from differences of the medium. Usually results from different levels of aeration (oxygen content); less frequently from different salinities.	Corrosion occurs in area of lower oxygen content, on steel piling, this is just below the mean low tide level. Also in crevices and corner because less oxygen is there.

Erosion-Corrosion	Scouring action of sand and other abrasives exposes bright metal and keep the corrosion active.	(1) commonly found at or just above the mud line or steel, piling or riser chains of moorings. (2) Wind in sandy areas.
Biological Corrosion	Marine biological organisms accelerate corrosion by changing the normal environment.	(1) Organisms may create accelerate different oxygen levels in the electrolyte. (2) Organisms may create corrosive products through their metabolism or decomposition. (3) Organisms may remove the protective film of corrosion products from metal surfaces.



CHAPTER THREE

3.0 METHODOLOGY

3.1 CHEMICAL ANALYSIS

The determination of the normal percentage composition of as-received 5SP rolled steel was carried out using metal analyzer (arc fusion 3460).

The polished sample was mounted on a vice and it was sparked twice, the compositions of the elements present in the sample were recorded and the average was found as show in Table 3.1

TABLE 3.1: CHEMICAL COMPOSITION OF 5SP ROLLED STEEL PRODUCT

C	Si	Mn	P	S	Cr	Mo	Ni	Al	Co
0.353	0.290	0.987	0.050	0.057	0.071	0.0050	0.110	0.025	0.015
Cu	Nb	Ti	V	W	Pb	Sn	Zn	Fe	
0.185	0.0050	0.0037	0.0057	0.010	0.0050	0.026	0.0076	97.805	

3.1.1 Carbon Equivalent (CE) and Austenite Carbon in Equilibrium (Co)

The carbon equivalent and estimate of austenite carbon in equilibrium are calculated as given by Mamora(1990), Rajan(1999), and Adewuyi(2005). The calculation results are presented in Table 3.2.

$$CE_1 = \%C + \frac{\%Mn}{6} + \frac{\%(Cr + Mo + V)}{5} + \frac{\%(Ni + Cu)}{15} \dots\dots\dots 3.1$$

$$CE_2 = \%C + \% \left(\frac{Si}{24} + \frac{Mn}{6} + \frac{Ni}{40} + \frac{Cr}{5} + \frac{Mo}{4} + \frac{V}{14} \right) \dots\dots\dots 3.2$$

$$CE_3 = \%C + \frac{1}{3} \% (Si + P) \dots\dots\dots 3.3$$

Estimate of austenite carbon in equilibrium (Co)

$$Co = \frac{T_f - 0.17Si}{420} - 0.95 \quad \dots\dots\dots 3.4$$

Where T_f = Austenite temperature

TABLE 3.2 CARBON EQUIVALENT (CE) AND ESTIMATE OF AUSTENITE CARBON IN EQUIVALENT (CO)

CE ₁	CE ₂	CE ₃	Co(735 ⁰ C)	Co(745 ⁰ C)	Co(840 ⁰ C)
0.55	0.55	0.47	0.790	0.82	1.05

3.2 PREPARATION OF SPECIMENS

5SP rolled ribbed bars were prepared for tensile test, impact test, hardness test, metallographic examination and corrosion test before subjecting them to various heat treatment processes.

3.3 HEAT TREATMENT OF STEEL

3.3.1 Iron-Cementite Phase Diagram

The part of Fe-Fe₃C diagram that is relevant to the heat treatment of steel is shown in Figure 3.1.

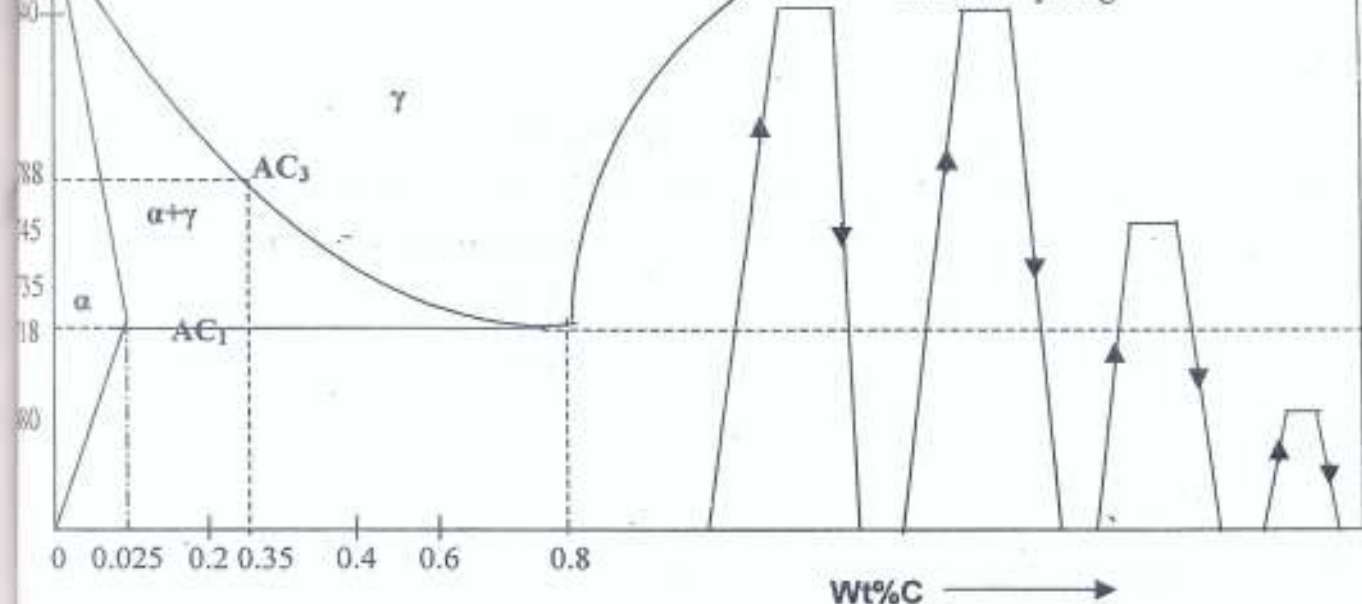


Figure 3.1: Schematic Representation of Cyclic Re-Austenitization and alternate cycling referred to part of iron cementite phase diagram

3.3.2 Determination of Operating Temperature

The lower critical temperature (AC_1) and the upper critical temperature (AC_3) were determined by the Grange empirical formula (Gorni, 2004) as presented here.

$$AC_1(^{\circ}C) = (1333 - 25Mn + 40Si + 42Cr - 26Ni) - (32)^{5/9} \dots\dots\dots 3.5$$

$$AC_3(^{\circ}C) = (1570 - 323C - 25Mn + 80Si - 3Cr - 32Ni) - (32)^{5/9} \dots\dots\dots 3.6$$

AC_1 and AC_3 were found to be $718^{\circ}C$ and $788^{\circ}C$ respectively.

The austenizing temperature studied was $830^{\circ}C$ and the dual phase range temperature studied were $735^{\circ}C$ and $745^{\circ}C$.

The holding times were 20 minutes for austenizing and lamellarizing and 30 minutes for tempering. The tempering temperature was carefully chosen from Table 3.3

**TABLE 3.3: PHYSICAL PROPERTIES OF HEAT TREATED CARBON STEELS
(FROM REPORTS OF IRON AND STEEL DIVISION - SOCIETY OF
AUTOMOBILE ENGINEERS INC.)**

Range of Carbon Content (%)	Austenizing Temperature (°C)	Tempering Temperature (°C)	Tensile Strength (N/mm ²)	Expected% Elongation
0.15 - 0.25	850 – 860	200	550	20
		480	517	26.5
		760	482	32.5
0.20 - 0.30	840 – 850	200	620	17.0
		480	570	23.5
		760	517	30.0
0.30 - 0.40	820 – 840	200	724	15.0
		480	648	21.5
		760	565	28.0
0.40 - 0.50	810 – 820	200	861	12.5
		480	758	17.5
		760	655	22.5

3.3.3 Heat Treatment Processes

Representative samples of as - rolled 5SP steels were subjected to heat treatment processes.

3.3.3.1 Quenching + Quenching + Lamellarizing + Tempering (Q + Q + L + T)

Quenching was done after heating the steel specimens to austenizing temperature of 830°C and soaked for 20 minutes. The quenching process was done twice. The quenching medium used was water; after cooling to room temperature, the specimens were again transferred into the furnace and

reheated to the lamellarizing temperature of 735°C and 745°C each, the specimens were again soaked in the furnace for 20 minutes and quenched in water to room temperature. Finally, the specimens were transferred into the furnace and reheated to a tempering temperature of 480°C. The temperature - time graph for this procedure is shown in Figure 3.2

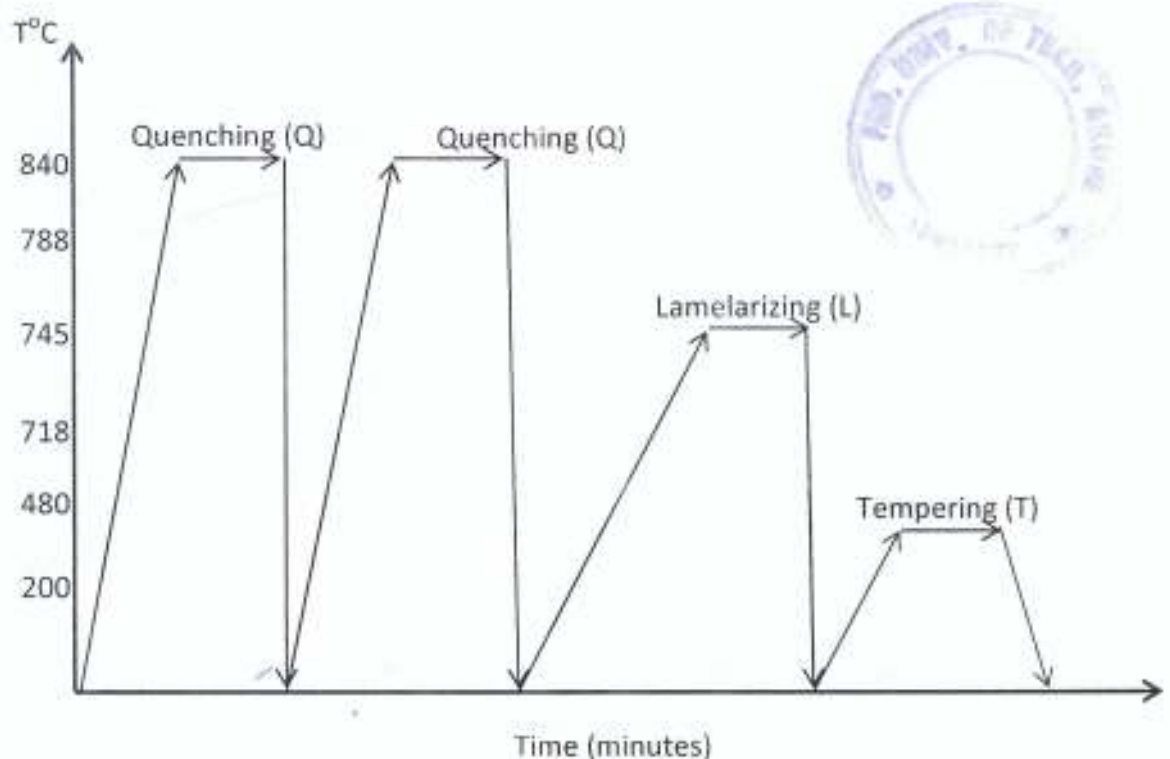


Figure 3.2: Temperature - Time Graph involving Quenching, Quenching, Lamellarizing and Tempering (Q + Q + L + T)

3.3.3.2 Quenching+ Lamellarizing + Tempering (Q + L + T)

Quenching was done after heating the steel specimens to austenizing temperature of 830°C and soaked in the furnace for 20 minutes. The quenching medium used was water. After cooling to room temperature, the specimens were transferred into the furnace and reheated to the lamellarizing temperature of

745°C and 735°C each; The specimens were again soaked for 20 minutes and quenched in water to room temperature. The specimens were again transferred into the furnace and reheated to tempering temperature of 480°C and cooled in air. The temperature - time graph for this procedure is shown in Figure 3.3

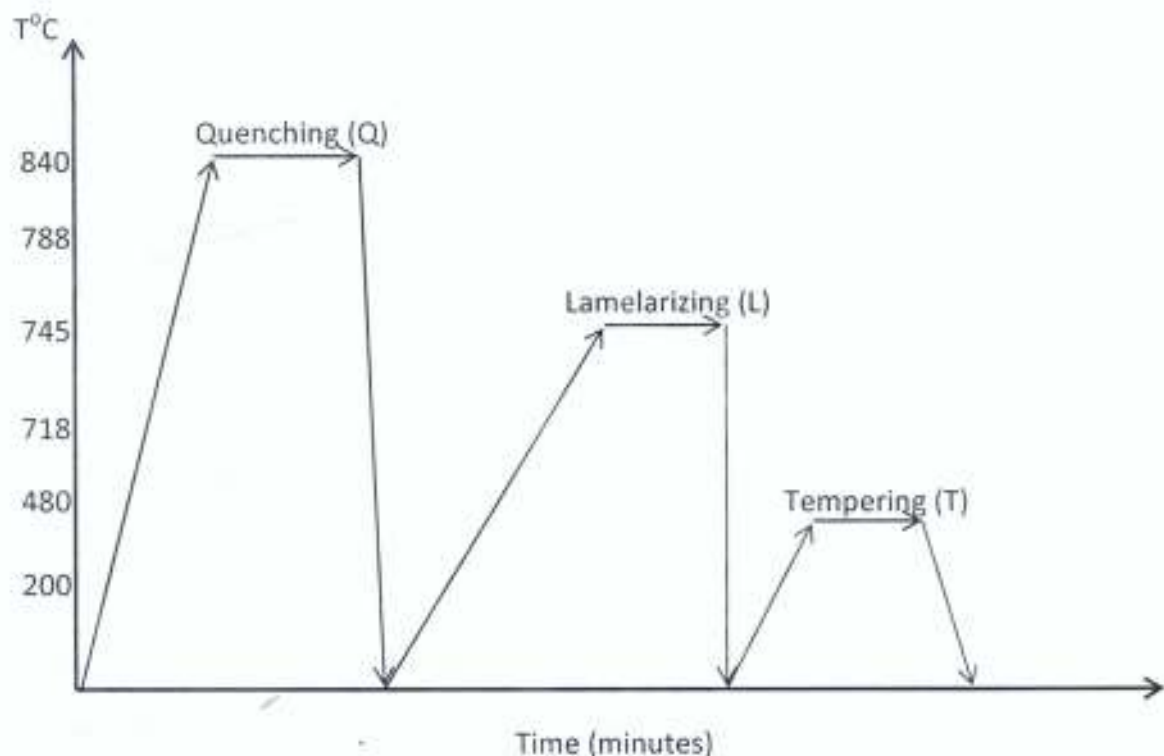


Figure 3.3: Temperature - Time Graph involving Quenching, Lamellarizing and Tempering (Q + L + T)

3.3.3.3 Lamellarizing and Tempering (L + T)

The steel specimens were heated to the lamellarizing temperature of 745°C and 735°C, soaked in the furnace for 20 minutes and quenched in water to room temperature. The specimens were again transferred into the furnace and reheated to the tempering temperature of 480°C and cooled in air. The temperature - time graph for this procedure is shown in Figure 3.4

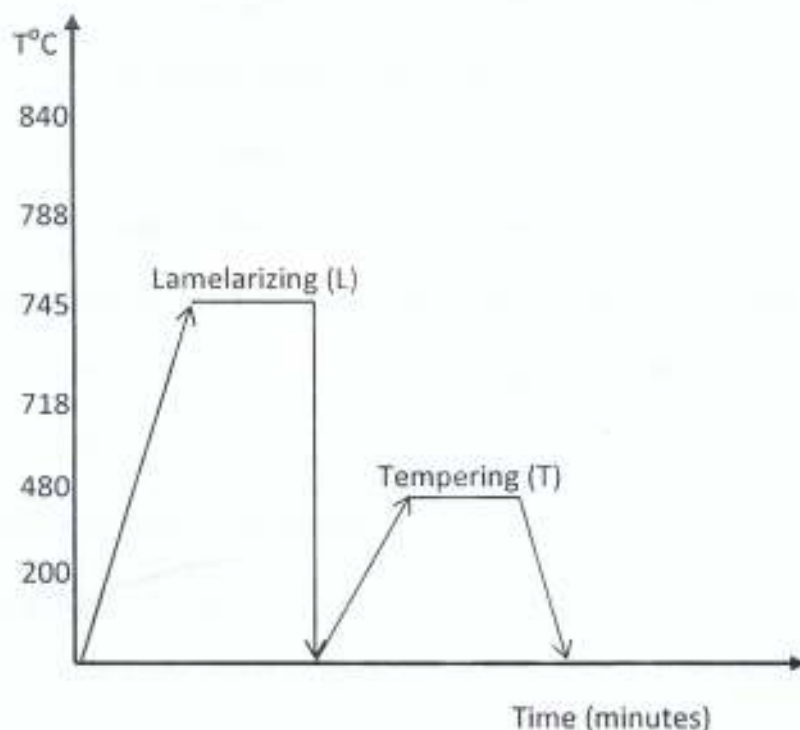


Figure 3.4: Temperature - Time Graph involving Lamellarizing and Tempering

3.4 MECHANICAL TESTING OF SPECIMENS

The designs of metal parts for industrial and commercial use requires precise knowledge of the mechanical and physical properties of the steel. This is obtained by physically testing representative samples of the material in various testing machines.

3.4.1 Tensile Test

The effect of heat treatment on the tensile properties of as - rolled 5SP steel product was studied by preparing seven standard tensile specimens from the as - rolled samples, subjecting them to various heat treatment processes and

testing in tension to failure on the tensometer. The initial gauge length and diameter were measured before subjecting them to tension. The yield and maximum loads were recorded directly from the resulted graph, the broken ends of the specimen were fitted together and the final gauge length and also the smallest diameter of the local neck were measured. The readings thus obtained were used in the determination of the following properties.

- (i) Yield Strength (σ_y)
- (ii) Ultimate tensile Strength (σ_u)
- (iii) Percentage elongation (%E)
- (iv) Percentage reduction in area.
- (v) Yield ratio (YR)

$$\text{Yield strength } (\sigma_y) = \frac{\text{Yield load}}{\text{Original cross - sectional area}} \dots\dots\dots 3.7$$

$$\text{Ultimate tensile Strength } (\sigma_u) = \frac{\text{Maximum load}}{\text{Original cross - sectional area}} \dots\dots\dots 3.8$$

$$\text{Percentage elongation } (\%E) = \frac{\text{Final gauge length} - \text{Original gauge length}}{\text{Original gauge length}} \times 100 \dots\dots 3.9$$

$$\text{Percentage reduction in area} = \frac{\text{Original Area} - \text{Final Area}}{\text{Original Area}} \times 100 \dots\dots 3.10$$

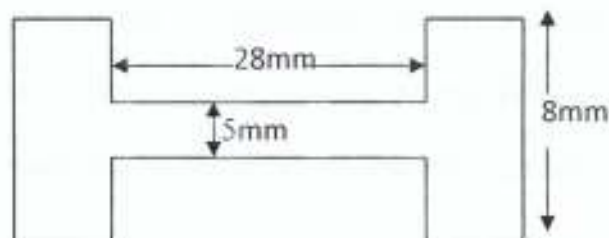


Fig. 3.5: Tensile Test Specimen

3.4.2 Impact Test

The resistance of metal to shock is measured by means of a pendulum type machine, if the pendulum is allowed to swing freely, it will swing through a known angle, if we interpose a specimen which the pendulum breaks, some energy will be used up and it will swing through a smaller angle. Representative samples of as - rolled specimen and heat- treated specimen were subjected to impact test on an Izod V-Notch impact testing machine. The dimension of the specimen is 8mm x 70mm.

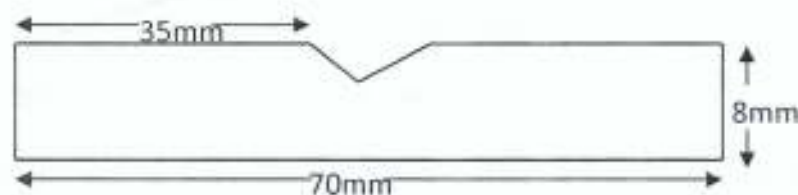


Fig.3.6: Impact test Specimen

3.4.3 Hardness Test

Hardness is the property of a metal, which gives it the ability to resist being permanently deformed when a load is applied. The greater the hardness, the greater the resistance to deformation.

The hardness of as-rolled specimen and heat treated specimens were measured with the aid of Rockwell hardness tester (Indentec, 2007 model). This machine measures the resistance to penetration by measuring the depth of impression and the hardness is indicated directly on the scale attached to the machine. Each specimen was tested three times and the average was calculated and recorded as the hardness.

3.5 METALLOGRAPHIC EXAMINATION

Samples of as-rolled and heat-treated specimens were mounted in hot phenolic powder and were ground on a water lubricated hand grinding set-up of abrasive papers, progressing through from the coarsest to the finest grit sizes. The 240, 320, 400 and 600 grades were used in that order. Polishing was carried out on a rotating disc of a universal polisher. Rough polishing was done with a synthetic velvet polishing cloth impregnated with micron alumina paste. Final polishing was carried out with diamond paste. The specimens were then etched with the standard 2% nital so as to reveal the ferrite grain boundaries.

The optical microscopic examinations were carried out on a metallurgical microscope at a magnification of 400 X. The specimens were illuminated with 100 kilowatts detachable quartz iodine lamp.

3.6 CORROSION TEST

The Corrosion rates of as-rolled specimen and heat-treated specimens were measured by simulating these specimens in a marine medium.

The cross sectional area of each of the specimens was calculated; each of the specimen was also weighed in a chemical balance and the weight recorded. The PH and the electrode potential of the corrosive medium were measured and recorded. The cross sectional area of each of the specimens were calculated.

After every 3 days interval (72 hours), specimens were retrieved, washed properly in water, dried and weighed on a weighing balance to determine the

weight loss during exposure.

The laboratory simulation experiments were carried out in NaCl (0.5M, 1.0M) medium.

Finally, the corrosion rate was calculated using

$$\text{mpy} = \frac{3.45 \times 10^6 W}{ATD}$$

Where W = weight loss in g

D = density of Specimen in g/cm^3

A = Area in cm^2 .

T = Exposure time in hour,





4.0 RESULTS AND DISCUSSION

4.1 RESULTS

4.1.1 Tensile Properties

The tensile properties of as-received 5SP rolled steel and heat treated specimens were assessed and the results were shown in Table 4.1

TABLE 4.1: TENSILE PROPERTIES OF AS –RECEIVED 5SP ROLLED STEEL AND HEAT TREATED SPECIMENS

Heat Treatment Process	Lamellarizing Temperature (0° C)	Test specimen Designation	%Reduction in Area (%)	Yield Strength (N/mm ²)	Ultimate Tensile Strength (N/mm ²)	Yield Ratio %	% Elongation
Q+Q+L+T	735	A1	67	478	603	79	22
	745	A2	72	489	618	79	22
Q+L+T	735	B1	75	401	569	71	27
	745	B2	66	484	614	79	25
L+T	735	C1	65	404	529	76	26
	745	C2	61	444	607	73	24
As-Rolled		D	63	494	598	83	19

4.1.2 Hardness Properties

The hardness of as-received rolled steel and samples of the steel subjected to various heat treatment processes is shown in Table 4.2

TABLE 4.2: ROCKWELL HARDNESS OF AS-RECEIVED 5SP ROLLED STEEL AND HEAT TREATED SPECIMENS

Heat Treatment Process	Lamellarizing Temperature	Test Specimen	Rockwell Hardness (HRA)
Q+Q+L+T	735	A ₁	61.30
	745	A ₂	61.50
Q+Q+L+T	735	B ₁	56.70
	745	B ₂	59.70
L + T	735	C ₁	58.50
	745	C ₂	58.70
As-Rolled		D	51.70

4.1.3 Impact Properties

The impact resistance of as-received 5SP rolled steel sample and heat treated specimens were assessed, and the results are shown in Table 4.3

TABLE 4.3: IMPACT OF AS-RECEIVED 5SP ROLLED STEEL AND HEAT-TREATED SPECIMENS

Heat Treatment Process	Lamarlizing Temperature	Test Specimen	Rockwell Hardness (HRA)
Q+O+L+T	735	A ₁	58.70
	745	A ₂	57.90
Q ₁ +O+L+T	735	B ₁	60.30
	745	B ₂	58.60
L + T	735	C ₁	57.60
	745	C ₂	56.00
As-rolled		D	55.50

4.1.4 Micrographs

The micrographs of as-received 5SP rolled steel and treated specimens are shown in Plates 4.1-4.7.

4.1.5 Measurement of Corrosion Rate

The results of the weight loss and corrosion rate of as-received 5SP rolled steel and heat specimens are as contained in Tables 4.4-4.17 and Figures 4.7-4.18.

TABLE 4.4: AS – ROLLED 5SP STEEL IN NACL (1.0M)

INITIAL WEIGHT = 9.870g

Exposure Time (Hrs)	New Weight (g)	Weight Loss (g)	Corrosion Rate (mpy)	pH	p.d (v)
0	9.870	0.000	0.000	8.190	0.767
72	9.850	0.020	17.825	8.270	0.523
144	9.840	0.030	13.368	8.300	0.586
216	9.830	0.040	11.883	8.490	0.607
288	9.820	0.050	11.141	8.490	0.623
360	9.810	0.060	10.695	8.500	0.644
432	9.800	0.070	10.395	8.630	0.644
504	9.790	0.080	10.186	8.710	0.645
576	9.780	0.090	10.027	8.730	0.712
468	9.770	0.010	9.903	8.760	0.721
720	9.770	0.010	8.913	8.780	0.725
792	9.760	0.110	8.913	8.780	0.738

TABLE 4.5: HEAT TREATED SPECIMEN A2 IN NaCl (1.0M)

Initial Weight = 7.090g

Exposure Time (Hrs)	New Weight (g)	Weight Loss (g)	Corrosion Rate (mpy)	pH	p.d (v)
0	7.090	0	0	8.19	0.767
72	7.080	0.010	11.128	8.27	0.523
144	7.080	0.010	5.564	8.3	0.586
216	7.079	0.010	4.08	8.49	0.607
288	7.079	0.011	3.06	8.49	0.623
360	7.079	0.011	2.448	8.5	0.644
432	7.078	0.011	2.226	8.63	0.644
504	7.078	0.012	1.908	8.71	0.645
576	7.078	0.012	1.669	8.73	0.712
648	7.078	0.012	1.484	8.76	0.721
720	7.077	0.013	1.447	8.78	0.725
792	7.077	0.013	1.315	8.78	0.738

TABLE 4.6: HEAT TREATED SPECIMEN B2 IN NaCl (1.0M)**Initial Weight = 7.470g**

Exposure Time (Hrs)	New Weight (g)	Weight Loss (g)	Corrosion Rate (mpy)	pH	p.d (v)
0	7.470	0.00	0	8.19	0.767
72	7.470	0.00	0	8.27	0.523
144	7.460	0.010	5.284	8.3	0.586
216	7.460	0.010	3.523	8.49	0.607
288	7.460	0.010	2.642	8.49	0.623
360	7.459	0.011	2.325	8.5	0.644
432	7.459	0.011	1.937	8.63	0.644
504	7.459	0.011	1.661	8.71	0.645
576	7.458	0.012	1.585	8.73	0.712
648	7.458	0.012	1.409	8.76	0.721
720	7.458	0.012	1.268	8.78	0.725
792	7.458	0.012	1.153	8.78	0.738

TABLE 4.7: HEAT TREATED SPECIMEN C2 IN NaCl (1.0M)**Initial Weight = 7.270g**

Exposure Time (Hrs)	New Weight (g)	Weight Loss (g)	Corrosion Rate (mpy)	pH	p.d (v)
0	7.270	0.00	0	8.190	0.767
72	7.260	0.010	10.700	8.270	0.523
144	7.260	0.010	5.350	8.300	0.586
216	7.259	0.010	3.923	8.490	0.607
288	7.259	0.011	2.943	8.490	0.623
360	7.259	0.011	2.354	8.500	0.644
432	7.258	0.011	2.140	8.630	0.644
504	7.258	0.012	1.834	8.710	0.645
576	7.258	0.012	1.605	8.730	0.712
648	7.258	0.012	1.427	8.760	0.721
720	7.258	0.012	1.284	8.780	0.725
792	7.257	0.013	1.265	8.780	0.738



TABLE 4.8: AS – ROLLED STEEL IN NaCl (0.5M)

Initial Weight = 8.940g

Exposure Time (Hrs)	New Weight (g)	Weight Loss (g)	Corrosion Rate (mpy)	pH	p.d (v)
0	8.940	0.00	0	8.030	0.776
72	8.920	0.020	18.820	8.250	0.765
144	8.905	0.030	16.470	8.290	0.795
216	8.890	0.040	15.680	8.460	0.801
288	8.880	0.050	14.110	8.470	0.803
360	8.870	0.060	13.170	8.180	0.813
432	8.860	0.070	12.540	8.250	0.814
504	8.850	0.080	12.090	8.360	0.816
576	8.840	0.090	11.760	8.410	0.866
648	8.840	0.0100	10.460	8.470	0.869
720	8.840	0.0100	9.410	8.490	0.876
792	8.830	0.0110	9.410	8.520	0.899

TABLE 4.9: HEAT TREATED SPECIMEN A2 IN NaCl (0.5M)

Initial Weight = 7.540g

Exposure Time (Hrs)	New Weight (g)	Weight Loss (g)	Corrosion Rate (mpy)	pH	p.d(v)
0	7.540	0	0	8.030	0.776
72	7.530	0.010	10.780	8.250	0.765
144	7.528	0.012	6.740	8.290	0.795
216	7.528	0.012	4.314	8.460	0.801
288	7.528	0.012	2.235	8.470	0.803
360	7.528	0.012	2.588	8.180	0.813
432	7.528	0.012	2.157	8.250	0.814
504	7.528	0.012	1.849	8.360	0.816
576	7.528	0.013	1.753	8.410	0.866
648	7.527	0.013	1.558	8.470	0.869
720	7.526	0.014	1.509	8.490	0.876
792	7.525	0.015	1.471	8.520	0.899

TABLE 4.10: HEAT TREATED SPECIMEN B2 IN NaCl (0.5M)

Initial Weight = 8.120g

Exposure Time (Hrs)	New Weight (g)	Weight Loss (g)	Corrosion Rate (mpy)	pH	p.d (v)
0	8.120	0.00	0	8.030	0.776
72	8.110	0.010	9.89	8.250	0.765
144	8.108	0.012	5.936	8.290	0.795
216	8.107	0.013	4.287	8.460	0.801
288	8.106	0.014	2.463	8.470	0.803
360	8.106	0.014	2.770	8.180	0.813
432	8.106	0.014	1.308	8.250	0.814
504	8.106	0.014	1.979	8.360	0.816
576	8.106	0.014	1.731	8.410	0.866
648	8.106	0.014	1.539	8.470	0.869
720	8.105	0.015	1.484	8.490	0.876
792	8.105	0.015	1.349	8.520	0.899

TABLE 4.11: HEAT TREATED SPECIMEN C2 IN NaCl (0.5M)

Initial Weight = 7.750g

Exposure Time (Hrs)	New Weight (g)	Weight Loss (g)	Corrosion Rate (mpy)	pH	p.d(v)
0	7.750	0	0	8.030	0.776
72	7.750	0.0	0	8.250	0.765
144	7.750	0.0	0	8.290	0.795
216	7.740	0.010	3.423	8.460	0.801
288	7.740	0.010	2.567	8.470	0.803
360	7.740	0.010	2.054	8.180	0.813
432	7.740	0.010	2.712	8.250	0.814
504	7.739	0.011	1.614	8.360	0.816
576	7.739	0.011	1.412	8.410	0.866
648	7.739	0.011	1.522	8.470	0.869
720	7.738	0.012	1.232	8.490	0.876
792	7.737	0.013	1.213	8.520	0.899

TABLE 4.12: HEAT TREATED SPECIMEN A1 IN NaCl (1.0M)

Initial Weight = 8.030g

Exposure Time (Hrs)	New Weight (g)	Weight Loss (g)	Corrosion Rate (mpy)	pH	p.d (v)
0	8.030	0.00	0	8.220	0.753
72	8.030	0.00	0	8.400	0.774
144	8.020	0.010	5.124	8.340	0.793
216	8.020	0.010	3.416	8.500	0.823
288	8.019	0.011	2.818	8.150	0.833
360	8.019	0.011	2.254	8.530	0.834
432	8.019	0.011	2.879	8.700	0.835
504	8.018	0.012	1.757	8.750	0.837
576	8.018	0.012	1.537	8.790	0.841
648	8.018	0.012	1.366	8.830	0.843
720	8.017	0.013	1.332	8.850	0.846
792	8.017	0.013	1.211	8.890	0.848

TABLE 4.13: HEAT TREATED SPECIMEN B1 IN NaCl (1.0M)

Initial Weight = 7.240g

Exposure Time (Hrs)	New Weight (g)	Weight Loss (g)	Corrosion Rate (mpy)	pH	p.d (v)
0	7.240	0.00	0	8.220	0.753
72	7.230	0.010	10.724	8.400	0.774
144	7.230	0.010	5.362	8.340	0.793
216	7.229	0.011	3.932	8.500	0.823
288	7.229	0.011	2.949	8.150	0.833
360	7.229	0.011	2.359	8.530	0.834
432	7.228	0.012	2.145	8.700	0.835
504	7.228	0.012	1.838	8.750	0.837
576	7.228	0.012	1.609	8.790	0.841
648	7.227	0.013	1.549	8.830	0.843
720	7.227	0.013	1.394	8.850	0.846
792	7.227	0.013	1.267	8.890	0.848

TABLE 4.14: HEAT TREATED SPECIMEN C1 IN NaCl (1.0M)**Initial Weight = 6.650g**

Exposure Time (Hrs)	New Weight (g)	Weight Loss (g)	Corrosion Rate (mpy)	pH	p.d (v)
0	6.650	0.00	0.00	8.220	0.753
72	6.640	0.010	11.439	8.400	0.774
144	6.640	0.010	5.719	8.340	0.793
216	6.640	0.010	3.813	8.500	0.823
288	6.639	0.011	2.146	8.150	0.833
360	6.638	0.011	2.517	8.530	0.834
432	6.638	0.012	2.288	8.700	0.835
504	6.638	0.012	1.961	8.750	0.837
576	6.638	0.012	1.716	8.790	0.841
648	6.637	0.013	1.652	8.830	0.843
720	6.637	0.013	1.487	8.850	0.846
792	6.637	0.013	1.352	8.890	0.848

TABLE 4.15: HEAT TREATED SPECIMEN A1 IN NaCl (0.5M)**Initial Weight = 6.890g**

Exposure Time (Hrs)	New Weight (g)	Weight Loss (g)	Corrosion Rate (mpy)	pH	p.d (v)
0	6.980	0.00	0	8.030	0.776
72	6.970	0.010	11.275	8.250	0.765
144	6.970	0.010	5.637	8.290	0.795
216	6.970	0.010	3.758	8.460	0.801
288	6.969	0.011	3.101	8.470	0.803
360	6.969	0.011	2.481	8.180	0.813
432	6.969	0.011	2.057	8.250	0.814
504	6.969	0.011	1.771	8.360	0.816
576	6.968	0.012	1.691	8.410	0.866
648	6.968	0.012	1.503	8.470	0.869
720	6.967	0.013	1.353	8.490	0.876
792	6.967	0.013	1.333	8.520	0.899

TABLE 4.16: HEAT TREATED SPECIMEN B1 IN NaCl (0.5M)

Initial Weight = 9.200g

Exposure Time (Hrs)	New Weight (g)	Weight Loss (g)	Corrosion Rate (mpy)	pH	p.d (v)
0	9.200	0.00	0	8.030	0.776
72	9.190	0.010	9.409	8.250	0.765
144	6.190	0.010	4.705	8.290	0.795
216	9.189	0.011	3.450	8.460	0.801
288	9.188	0.012	2.832	8.470	0.803
360	9.188	0.012	2.258	8.180	0.813
432	9.187	0.013	2.839	8.250	0.814
504	9.187	0.013	1.748	8.360	0.816
576	9.187	0.013	1.529	8.410	0.866
648	9.187	0.013	1.359	8.470	0.869
720	9.187	0.013	1.223	8.490	0.876
792	9.186	0.014	1.198	8.520	0.899

TABLE 4.17: HEAT TREATED SPECIMEN C1 IN NaCl (0.5M)

Initial Weight = 6.680g

Exposure Time (Hrs)	New Weight (g)	Weight Loss (g)	Corrosion Rate (mpy)	pH	p.d (v)
0	6.680	0.000	0	8.030	0.776
72	6.680	0.000	0	8.250	0.765
144	6.680	0.000	0	8.290	0.795
216	6.670	0.010	3.492	8.460	0.801
288	6.670	0.010	2.619	8.470	0.803
360	6.670	0.010	2.095	8.180	0.813
432	6.669	0.011	2.920	8.250	0.814
504	6.669	0.011	1.646	8.360	0.816
576	6.668	0.012	1.571	8.410	0.866
648	6.668	0.012	1.397	8.470	0.869
720	6.668	0.012	1.257	8.490	0.876
792	6.668	0.012	1.143	8.520	0.899

4.2 DISCUSSION OF RESULTS

4.2.1 Tensile Properties of the Heat-Treated Specimens

The tensile properties of the steel samples after various heat treatment processes are shown in Table 4.1 and Figures 4.1-4.2. Figures 4.1-4.2 present the stress-strain curve of the heat treated specimens and as-rolled steel; the ultimate tensile strength (σ_u) and the percentage elongation of the steel developed by Quenching + Lamellarizing + Tempering (Q + L + T), Quenching + Quenching + Lamellarizing + Tempering (Q + Q + L + T) and Lamellarizing + Tempering (L + T) processes at lamellarizing temperature 745°C are higher than the ultimate tensile strength and percentage elongation of the As-rolled steel. This is as a result of the strong deformable second phase structure formed during the heat treatment process, which consist of martensite. The strong second phase is dispersed in a soft ductile ferrite matrix. The martensite provides the strength in the composite whereas the ferrite provides the ductility. The increase in ductility and the tensile strength leads to better formability and makes the steels very attractive for use in cold-formed high strength components.

The stress - strain curve is shown Figures 4.1 and 4.2.

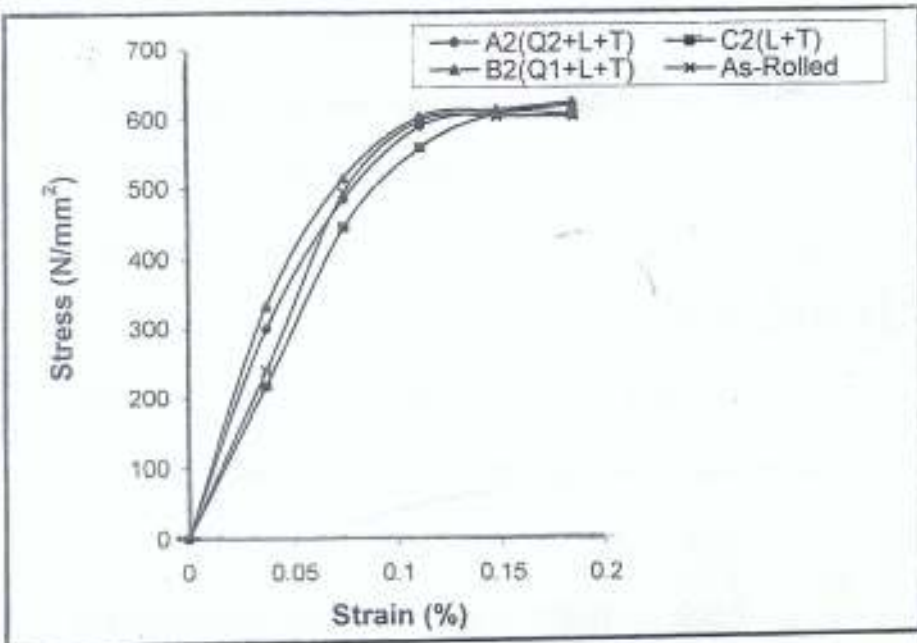


Fig. 4.1: Stress Strain Curves of As – Rolled Steel and Heat treated specimens (A₂, B₂, C₂)

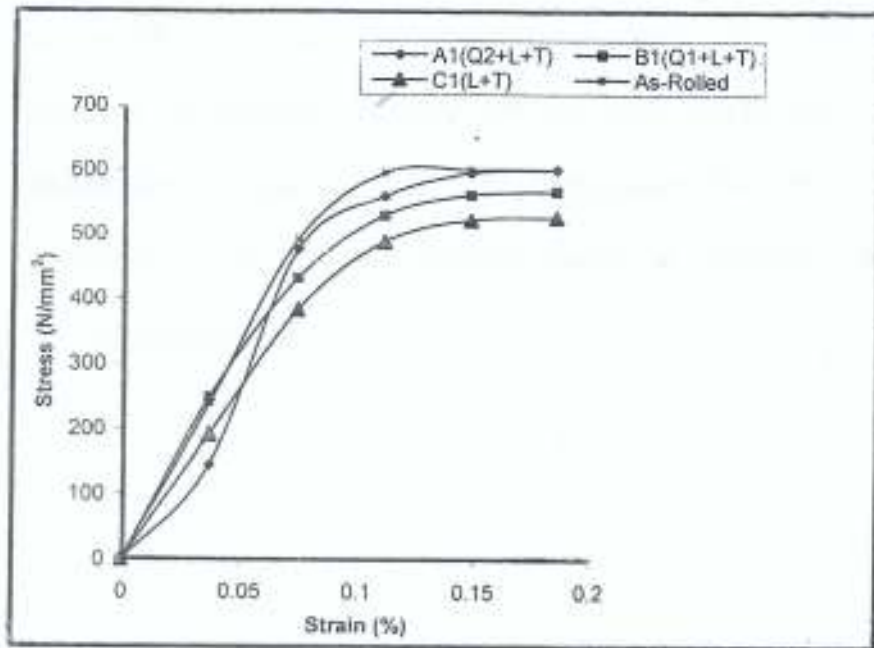


Fig. 4.2: Stress Strain Curves of As – Rolled Steel and Heat treated specimens (A₁, B₁, C₁)

4.2.2 Hardness Properties of the Heat Treated Specimens

Table 4.2 presents the Rockwell hardness number of the steel specimens after the various heat treatment processes. The changes in the hardness values of the specimens is shown Figures 4.3-4.4. The Rockwell hardness of the steels produced by Q + Q + L + T, Q + L + T and L + T processes are higher than the hardness of the as-rolled steel. This was probably due to higher volume fraction of harder martensite in the developed steel.

Conventionally, quenching from austenite range hardens steel. The transformation of austenite to martensite by a diffusionless shear-type transformation in quenching is also responsible for higher hardness obtained and this property is attributed to the effectiveness of the interstitial carbon in hindering the dislocation motion. (Callister, 1999).

The increase in hardness may also be due to the possible incompleteness of the diffusion process in the austenite range as a result of the rapidity of the process. In heating, carbon diffuses from ferrite into the austenite and the attainment of equilibrium is time dependent. The higher carbon content of the austenite solution as the diffusion moves to completion is probably responsible for increasing hardness.

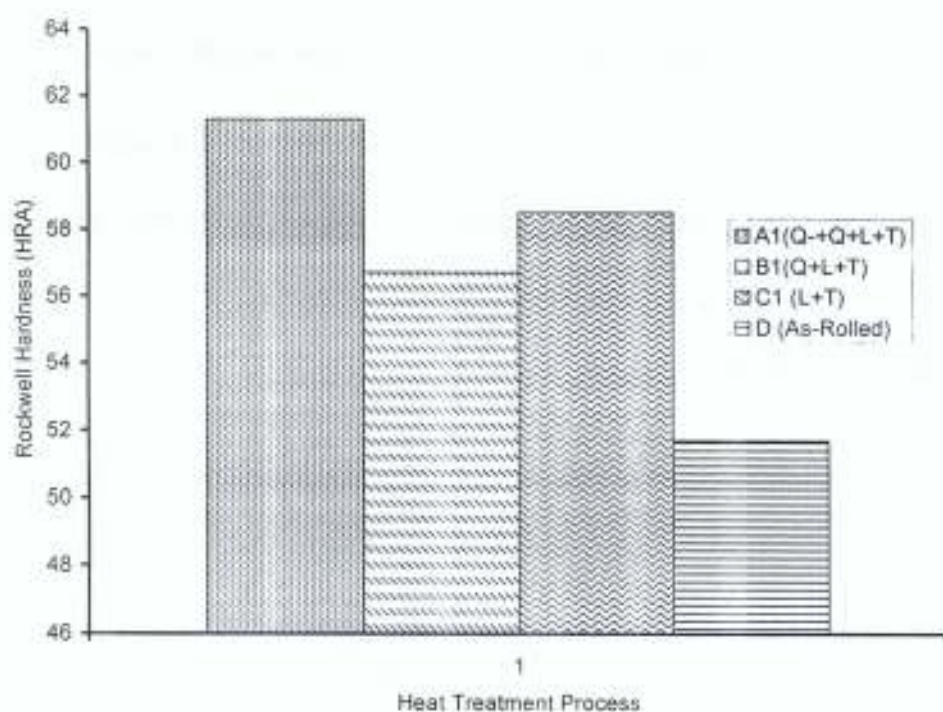


Figure 4.3: Rockwell Hardness number after various Heat Treatment Processes

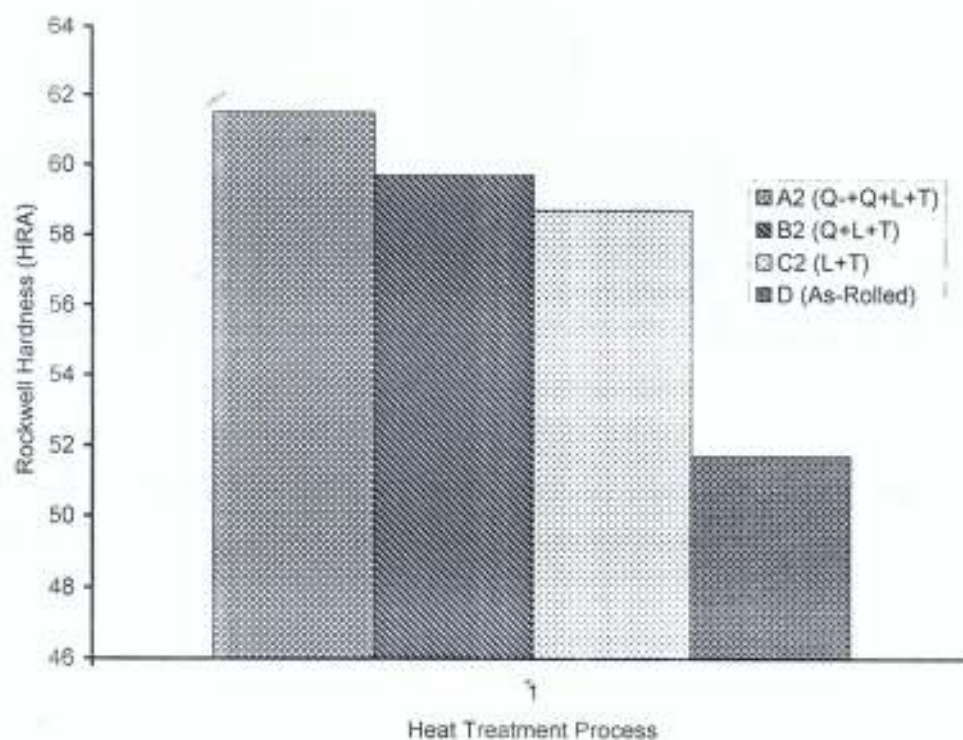


Figure 4.4: Rockwell Hardness number after various Heat Treatment Processes

4.2.3 Impact Properties of the Heat Treated Specimens

Table 4.3 presents the impact strength of the heat treated specimens and as-rolled 5SP steel; the impact strength of the steel developed by Q + Q + L + T, O+L + T and L + T processes are higher than that of the as-rolled steel; Q+L + T process produced steel with the highest impact. This is shown in Figures 4.5-4.6.

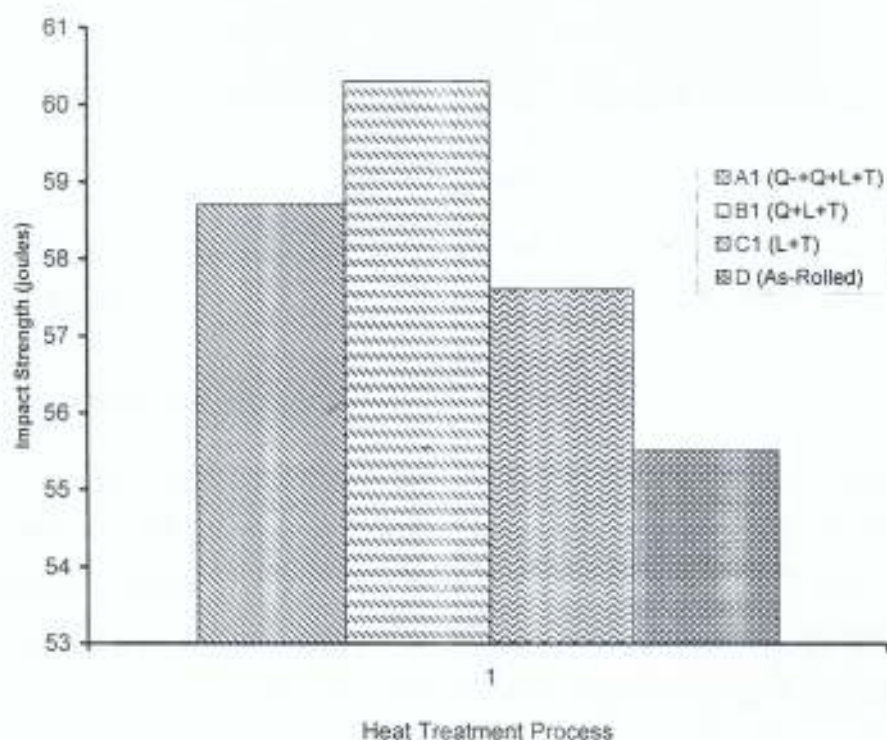


Figure 4.5: Impact Strength of Heat Treated Specimens and As – Rolled 5SP Steel.

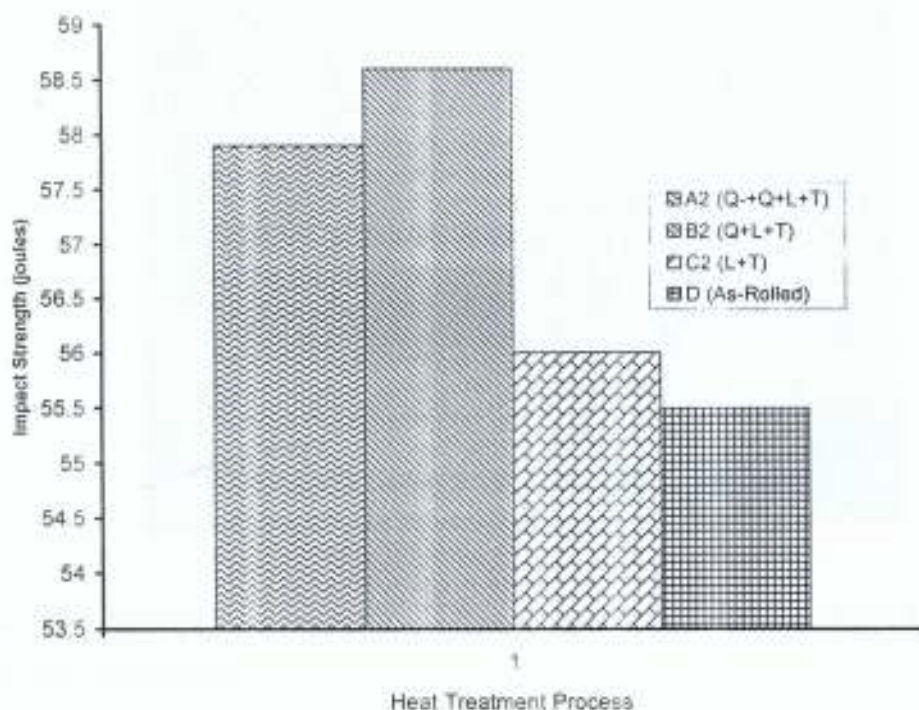


Figure 4.6: Impact Strength of Heat Treated Specimens and As – Rolled 5SP Steel.

4.2.4 Microstructures

The microstructures obtained are shown in the Plates 4.1-4.7. The microstructure produced by the as-rolled steel consist of pearlite while the microstructures produced by Q + Q + L + T, Q + L + T and L + T processes consist of a duplex ferrite martensite microstructure, the strong deformable second phase consists of predominantly of martensite but may contain bainite and retained austenite. The strong second phase is dispersed in a soft ductile ferrite matrix, martensite provides the strength in the composite whereas the ferrite provides the ductility. The L + T and Q+L + T processes increase the ferrite volume fraction resulting in a lower yield strength; Although the volume fraction of the second phase declines, the concentration of carbon raises hardness, which in turn prevents tensile strength from declining. This mechanism allows Q+Q+L + T, Q+L + T, and L + T processes to produce low yield-to-tensile strength ratio of 73% to 79%

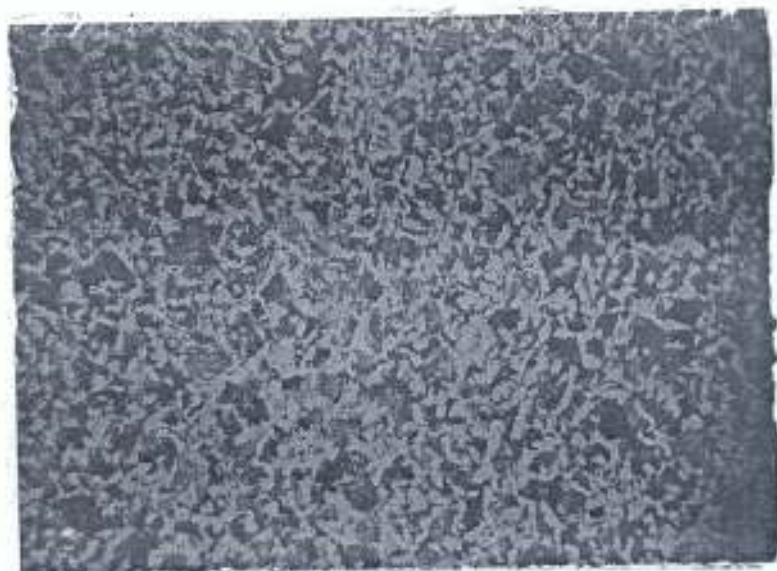


**Plate 4.1: Microstructure of As – Rolled 5SP Steel etched in 2% Nital (400X)
(Pearlitic Structure)**



**Plate 4.2: Microstructure of Heat Treated Specimen A2 (Q+Q+L+T) (400X)
(Duplex Ferrite – Martensite Microstructure)**



Plate 4.3: Microstructure of Heat Treated Specimen B2 (Q+L+T) (400X)
(Duplex ferrite – Martensite Microstructure)



Plate 4.4: Microstructure of Heat Treated Specimen C2 (L+T) (400X)
(Duplex ferrite – Martensite Microstructure)

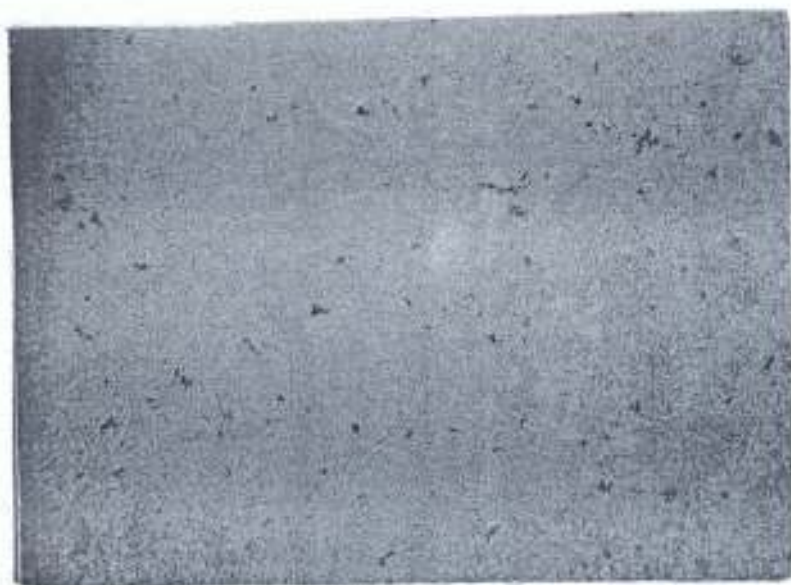


Plate 4.5: Microstructure of Heat Treated Specimen A1 (Q+Q+L+T) (400X)
(Duplex ferrite – Martensite Microstructure)



Plate 4.6: Microstructure of Heat Treated Specimen B1 (Q+L+T) (400X)
(Duplex ferrite – Martensite Microstructure)



Plate 4.7: Microstructure of Heat Treated Specimen C1 (L+T) (400X)
(Duplex ferrite – Martensite Microstructure)



4.2.5 Corrosion Properties

The results of the corrosion rate of the heat treated specimens and as-rolled specimen is shown in Tables 4.4-4.17. The corrosion rates of the heat-treated specimens in marine medium (NaCl) is low when compared to the as-rolled steel, as shown in Figures 4.7-4.18. This is because the as-rolled steel consist of mainly pearlite in which each crystal consist of alternate layers of ferrite and cementite, it was understood that ferrite, is anodic to cementite and this corrode with moisture as the electrolyte (Faleke, 1987). This was confirmed from the microstructure of the as-rolled steel shown in Plate 4.1. In the NaCl environment, the corrosion rate of the as-rolled steel was very high within the first 2 days and after this, the corrosion rate decreases with increase in exposure time; this is because the $FeCl_2$ formed during the process is insoluble and forms a protective film on the corroding surface of the steel which effectively prevent corrosive medium from coming into contact with the metal and greatly reduces the corrosion rate (Scully, 1990).

After 20days of exposure, the corrosion rate becomes uniform, this is because the steel is in the thermodynamically stable phase, the surface of the steel becomes immuned and no corrosion occurs. The Figures illustrating this can be seen in Figures 4.7-4.18.

It could be seen that the same trend of corrosion rate hold for all the specimens but the steel developed by Q + L + T process have the least corrosion rate followed by L + T process and Q+Q +L+ T process.

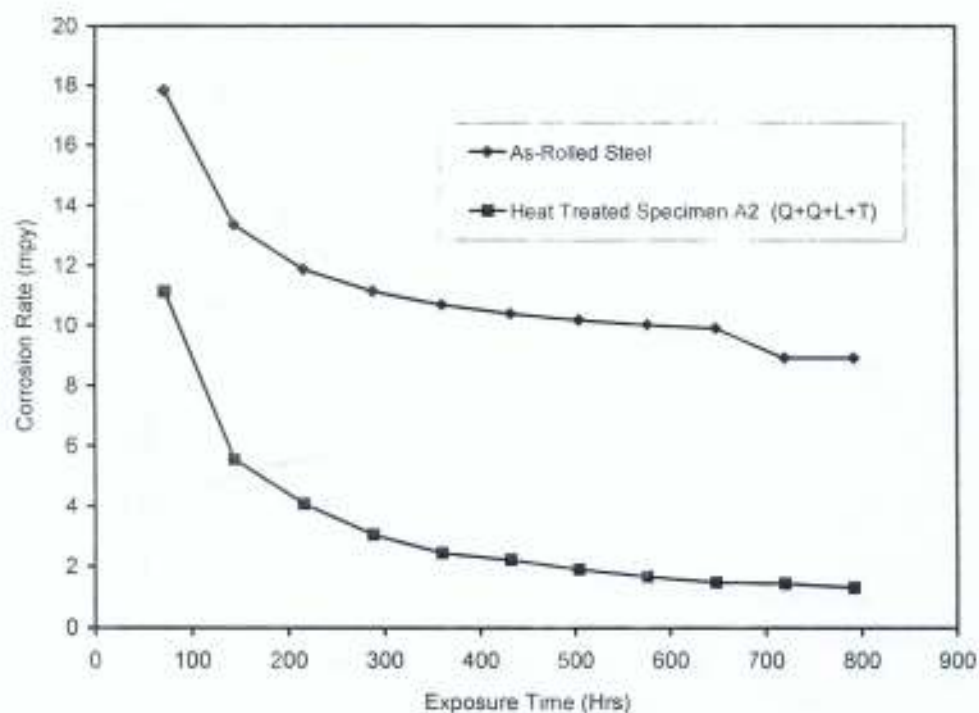


Fig. 4.7: Corrosion Rate of Heat treated Specimen A2 (Q+Q+L+T) and As - Rolled Steel in 1.0M NaCl Environment

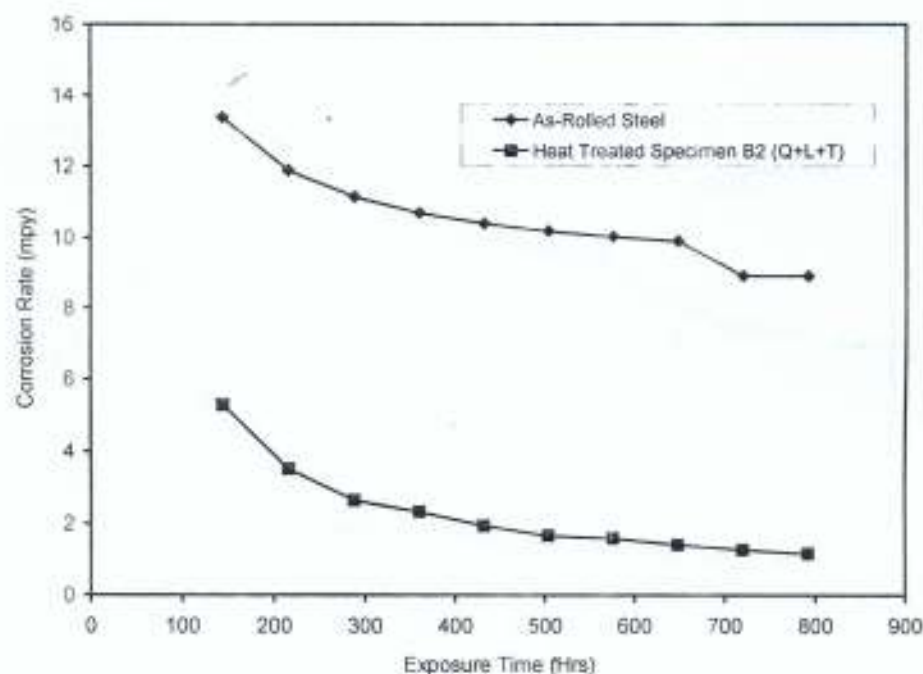


Fig. 4.8: Corrosion Rate of Heat treated Specimen B2 (Q+L+T) and As - Rolled Steel in 1.0M NaCl Environment

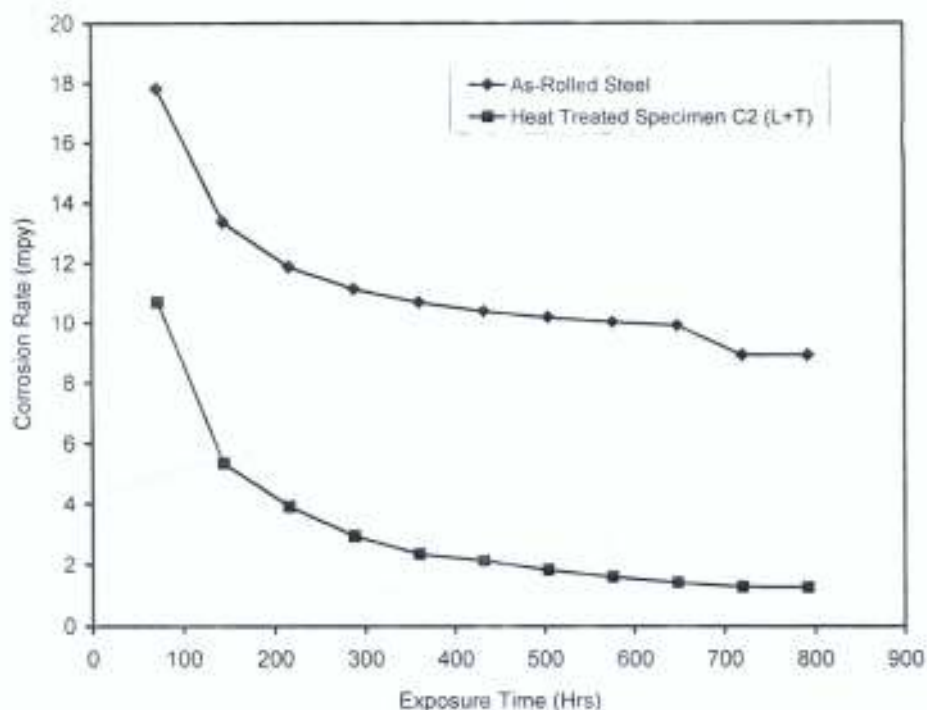


Fig. 4.9: Corrosion Rate of Heat treated Specimen C2 (L+T) and As - Rolled Steel in 1.0M NaCl Environment

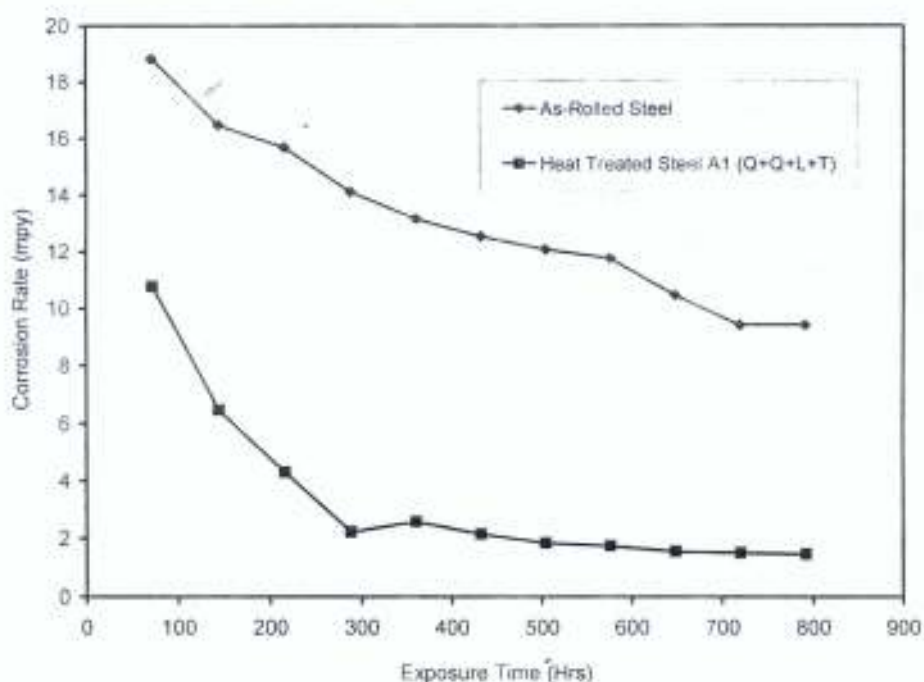


Fig. 4.10: Corrosion Rate of Heat treated Specimen A1 (Q+Q+L+T) and As - Rolled Steel in 1.0M NaCl Environment

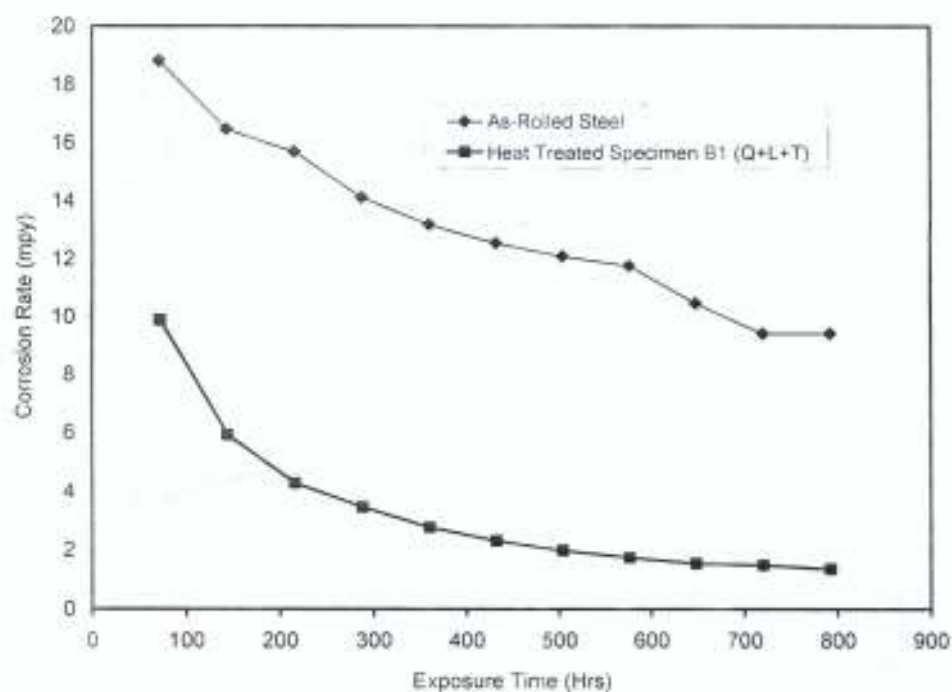


Fig. 4.11: Corrosion Rate of Heat treated Specimen B1 (Q+L+T) and As - Rolled Steel in 1.0M NaCl Environment

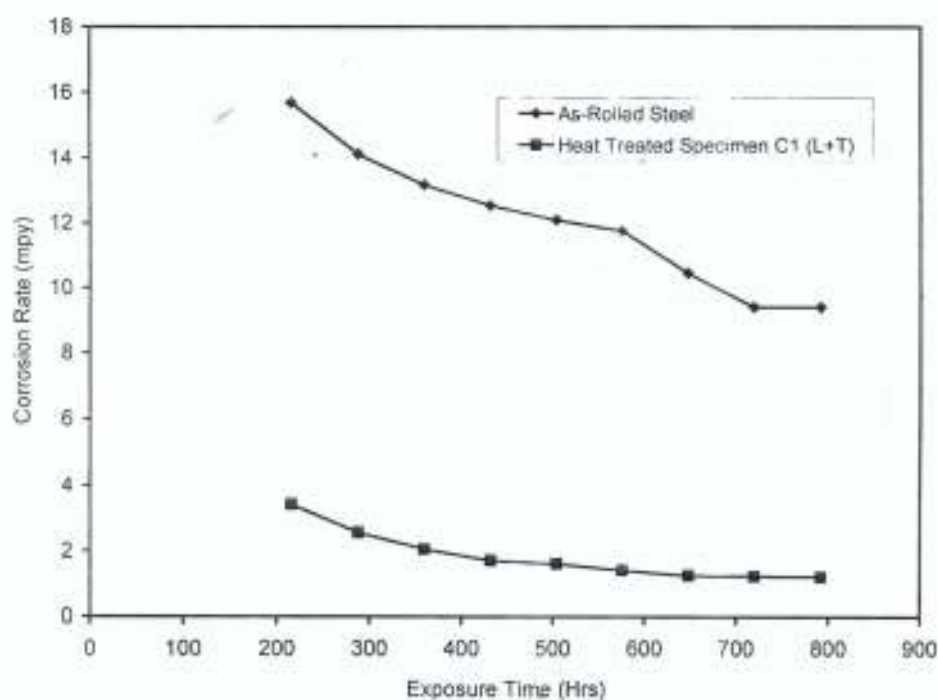


Fig. 4.12: Corrosion Rate of Heat treated Specimen C1 (L+T) and As - Rolled Steel in 1.0M NaCl Environment

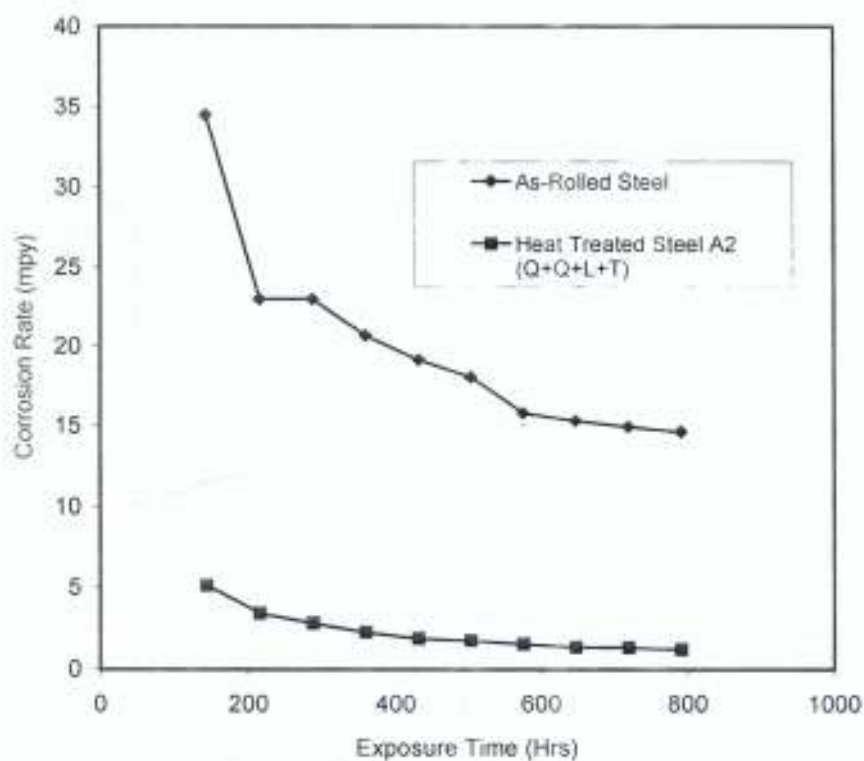


Fig. 4.13: Corrosion Rate of Heat treated Specimen A2 (Q+Q+L+T) and As - Rolled Steel in 0.5M NaCl Environment

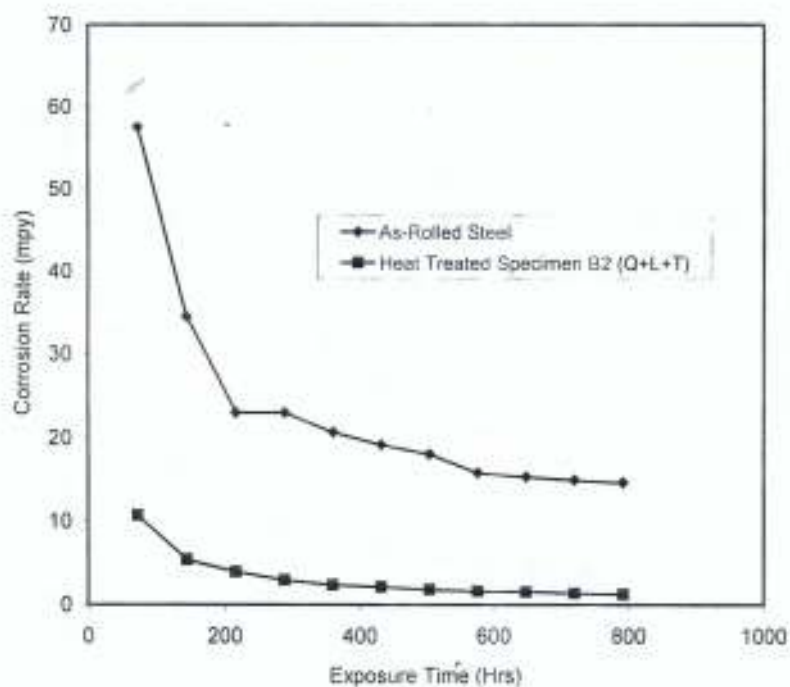


Fig. 4.14 Corrosion Rate of Heat treated Specimen B2 (Q+L+T) and As - Rolled Steel in 0.5M NaCl Environment

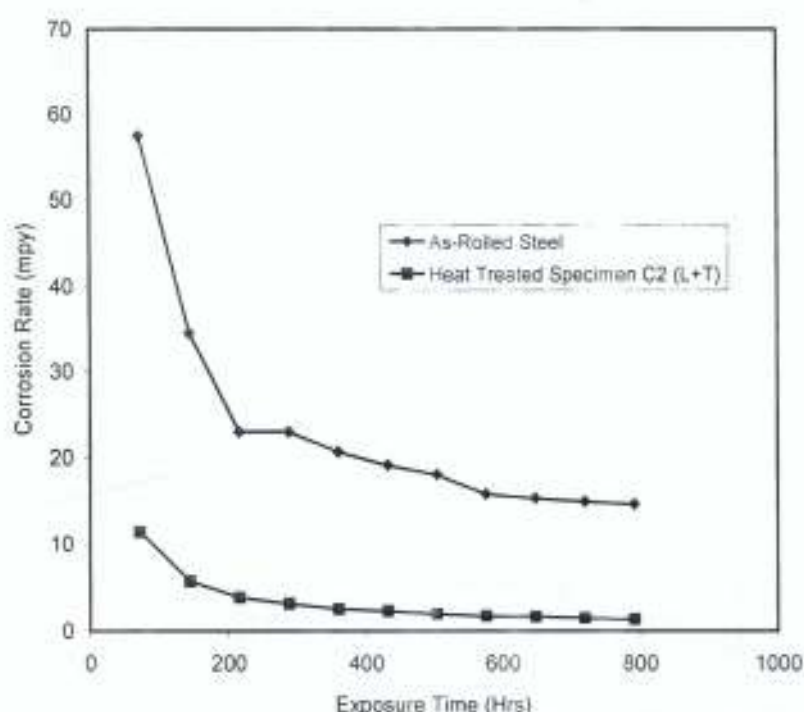


Fig: 4.15: Corrosion Rate of Heat treated Specimen C2 (L+T) and As - Rolled Steel in 0.5M NaCl Environment

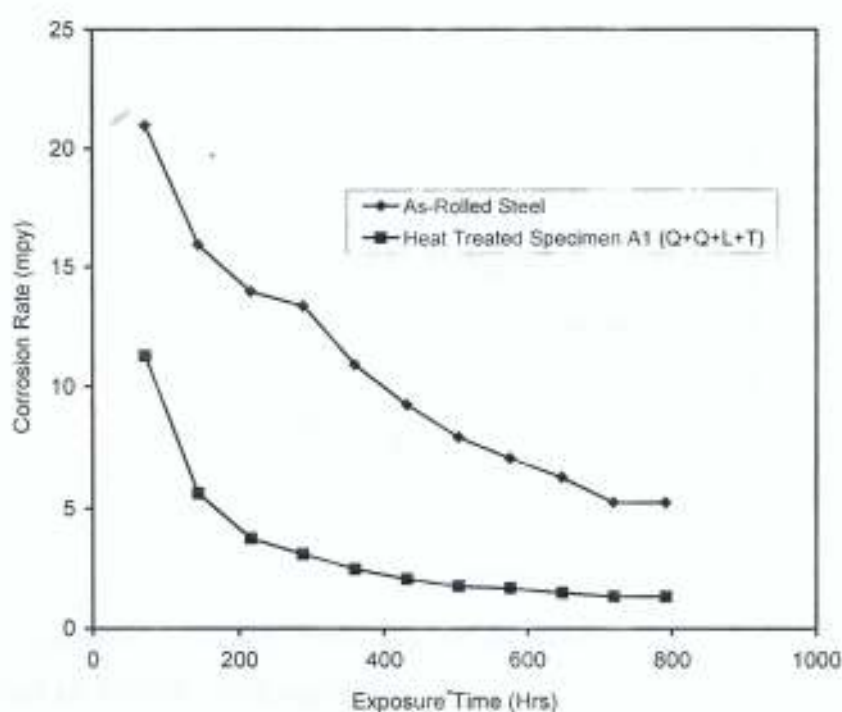


Fig. 4.16: Corrosion Rate of Heat treated Specimen A1 (Q+Q+L+T) and As - Rolled Steel in 0.5M NaCl Environment

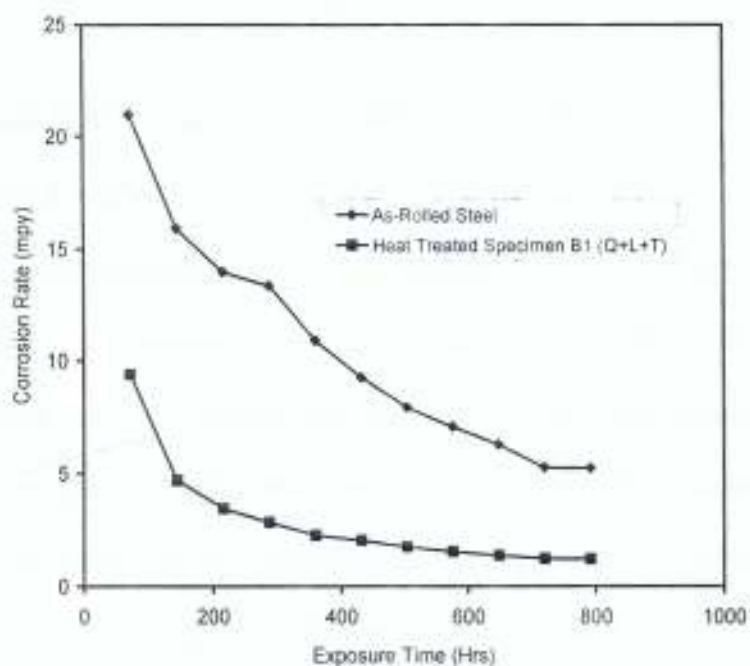


Fig. 4.17: Corrosion Rate of Heat treated Specimen B1 (Q+L+T) and As - Rolled Steel in 0.5M NaCl Environment

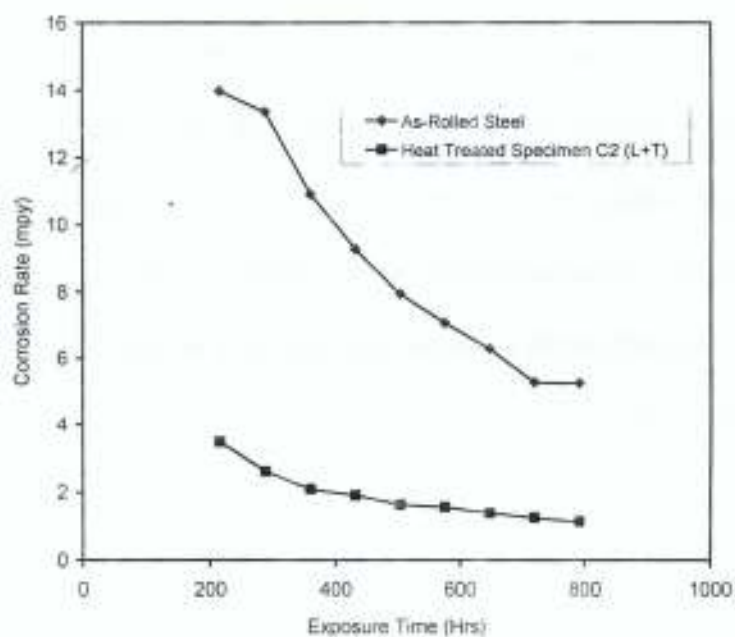


Fig. 4.18: Corrosion Rate of Heat treated Specimen C1 (L+T) and As - Rolled Steel in 0.5M NaCl Environment

CHAPTER FIVE



5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

From the findings, the steel developed by Quenching + Lamerizing + Tempering (Q+L+T) process at a lamelarizing temperature of 745°C has the highest ultimate tensile strength and yield ratio of 79% with excellent combination of cimpact strength, ductility and corrosion resistance which is very attractive for structural use followed by Quenching + Lamerizing + Tempering (Q+L+T) process and Lamelarizing + Tempering (L+T) process.

5.2 RECOMMENDATIONS

The heat treatment procedure used in this research work can be used in the production of steel wire and rods having higher tensile strength and higher ductility as the method is more economical than the oldest and most common method of producing high strength, high ductility wire and rods by patenting a near eutectoid composition pearlitic steel which is more complex and expensive.



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