# “Study of Mechanical Property and Corrosion Behaviour of Heat Treated Low Carbon steel AISI 1018”

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**by**

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## CERTIFICATE

This is to certify that the thesis work entitled **"Study of mechanical property and corrosion behaviour of heat treated low carbon steel"** submitted by MD WALI AHMAD**, Enrollment No. 1500100166** in partial fulfillment for the award of **Master of Technology** degree in **Mechanical Engineering Department** with specialization in Production and Industrial Engineering, to Integral University, Lucknow (U.P.). He has carried out his thesis work under my supervision and guidance and to the best of my knowledge; the matter embodied in this thesis has not been submitted to any other University/Institute for award of any degree to the candidate or to anybody else.

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# ABSTRACT

Low carbon steels are being used in industries for last three decades. The mechanical properties of low carbon steels can be altered by varying its martensite volume fraction. However, the benefits obtained in mechanical properties have to be viewed in light of other properties such as corrosion resistance. In this work , low carbon steel is heated at different conditions and different volume fraction of martensite are obtained after intercritical heating followed by air, water and oil quenching at different intercritical temperature. The tensile strength of low carbon steels are measured. Corrosion properties are evaluated using immersion test. It was observed that the tensile strength increased with increase in martensite volume fraction .The corrosion rates for low carbon steel is found to be lower than that for ferrite- pearlite steel.

## ACKNOWLEDGEMENT

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# INTRODUCTION

## 1.1 INTRODUCTION

In last three decades dual-phase steels possessing a composite microstructure consisting of hard martensite islands embedded in a soft ferritic matrix have evoked much interest. The early investigations have revealed that dual phase steels possess a number of unique properties making them attractive for applications such as very good quality sheet materials for automotive bodies. Use of dual phase steels is mainly due to their continuous yielding, low 0.2% offset yield strength, high ratio of ultimate tensile strength (UTS) to yield stress, high work hardening rate, and high uniform and total elongations. Because of above properties , thinner gauge sheets of DUAL PHASE steels can be used while maintaining the required strength levels. This is particularly interesting for the automotive industry that faces the contradictory requirements of decreasing vehicle weight while improving the fuel efficiency of automobiles along with maintaining the safety standards. However in order to meet durability of sheet metal products over long periods, the corrosion resistance becomes crucial[1].

Intercritical heat treatment is the way to enhance low alloys steels to dual phase microstructure with superior strength-ductility combination. This thermal treatment contains heating the specimens in intercritical temperature range to obtain ferrite and austenite followed by quenching to obtain dual-phase (martensite + ferrite) structure.

Figure 1.1 shows the microstructure of dual phase steel in which white phase is ferrite and the remainder of the microstructure is a mixture of Martensite and a small amount of retained austensite.

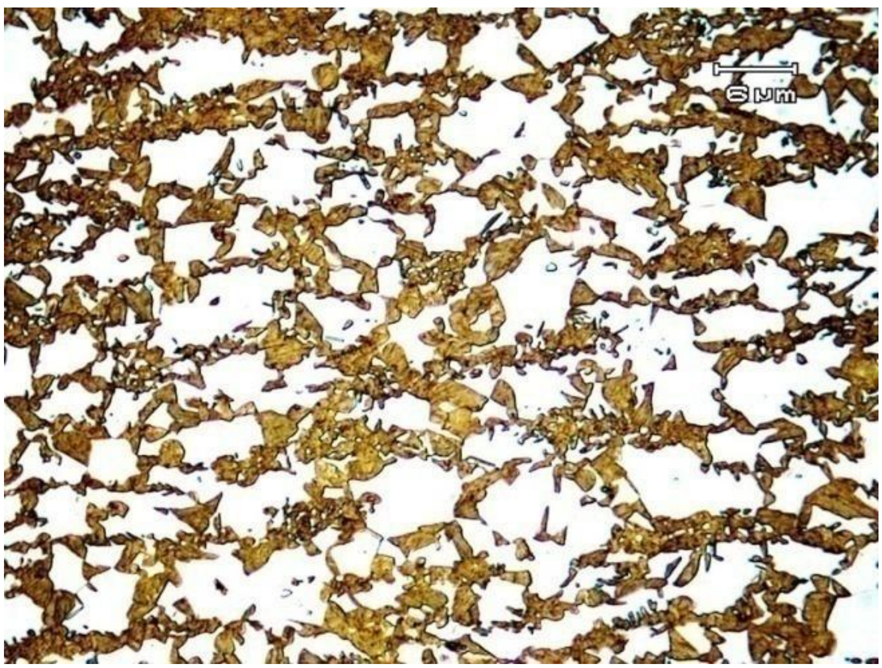

**Figure 1.1 microstructure of steel "ferrite-martensite"**

The present investigation deals with the study of mechanical properties and corrosion behaviour of plain low carbon dual-phase steels with different volume fraction of martensite. Immersion test is conducted in 5% Nacl solution. These results are also compared with the corrosion behavior of as received steel with ferrite and pearlite as micro-constituents.

## 1.2 LITERATURE SURVEY

### 1.2.1 Carbon Steel :-

Carbon steel (plain carbon steel) is steel which contain main alloying element is carbon. Here we find maximum up to 1.5% carbon and other alloying elements like copper, manganese, silicon. Most of the steel produced now-a-days is plain carbon steel. It is divided into the following types depending upon the carbon content.

**1.** Dead or mild steel (up to 0.15% carbon)

**2.** Low carbon steel (0.15%-0.45% carbon)

**3.** Medium carbon steel (0.45%-0.8% carbon)

**4.** High carbon steel (0.8%-1.5% carbon)

Steel with low carbon content has properties similar to iron. As the carbon content increases the metal becomes harder and stronger but less ductile and more difficult to weld. Higher carbon content lowers the melting point and its temperature resistance carbon content cannot alter yield strength of material.

**1.2.1.1 Low Carbon Steel :-** Low carbon steel has carbon content of 0.15% to 0.45%. Low carbon steel is the most common type of steel as its price is relatively low while its provides material properties that are acceptable for many applications. It is neither externally brittle nor ductile due to its low carbon content. It has lower tensile strength and malleable.[2]

### 1.2.2 Heat Treatment :-

The process of heat treatment is carried out first by heating the material and then cooling it in the brine, water and oil. The purpose of heat treatment is to soften the metal, to change the grain size, to modify the structure of the material and to relieve the stress set up in the material after hot and cold working.

The various heat treatment processes commonly employed in engineering practice as follows:-

**1.) Annealing:-**

**a.) Spherodizing:-** Spherodite forms when carbon steel is heated to approximately 700°C for over 30 hours. The purpose is to soften higher carbon steel and allow more formability. This is the softest and most ductile form of steel. Here cementite is present.

**b.) Full Annealing:-** Carbon steel is heated to approximately above the upper critical temperature (550°C -650°C) for 1 hour. Here all the ferrite transforms into austenite. The steel must then cooled in the realm of 38°C per hour. This results in a coarse pearlite structure. Full annealed steel is soft and ductile with no internal stress.

**c.) Process Annealing:-** The steel is heated to a temperature below or close to the lower critical temperature (550°C -650°C), held at this temperature for some time and then cooled slowly. The purpose is to relive stress in a cold worked carbon steel with less than 0.3%wt C.

**d.) Diffusion Annealing:-** The process consists of heating the steel to high temperature (1100°C -1200°C). It is held at this temperature for 3 hours to 20 hours and then cooled to 800°C -850°C inside the furnace for a period of about 6 to 8 hours. It is further cooled in the air to room temperature. This process is mainly used for ingots and large casting. It is also called isothermal annealing.[2]

**2.) Normalising:-** The process of normalizing consist of heating the metal to a temperature of 30°C to 50°C above the upper critical temperature for hypo-eutectoid steels and by the same temperature above the lower critical temperature for hyper-eutectoid steel. It is held at this temperature for a considerable time and then quenched in suitable cooling medium. The purpose of normalizing is to refine grain structure, improve machinibility and improve tensile strength, to remove strain and to remove dislocation.

**3.) Hardening:-** The process of hardening consist of heating the metal to a temperature of 30°C-50°C above the upper critical point for hypo-eutectoid steels and by the same temperature above the lower critical temperature for hyper-eutectoid steels. It is held this temperature for some time and then quenched. The purposes of hardening are to increase the hardness of the metal and to make suitable cutting tools.

**4.) Quenching:-** Material is heated up to the suitable temperature and then quenched in water or oil to harden to full hardness according to the kind of steels.

Material is heated to the suitable temperature for hardening, then cooled rapidly by immersing the hot part in water, oil or another suitable liquid to transform the material to a fully hardened structure. Parts which are quenched usually must be aged, tempered or stress relieved to achieve the proper toughness, final hardness and dimensional stability.

Alloy may be air cooled, or cooled by quenching in oil water, or another liquid, depending upon the amount of alloying elements in the material and final mechanical properties to be achieved. Hardened materials are tempered to improve their dimensional stability and toughness.

### 1.2.3 Grain Refinement

The grain refinement is one of the most effective strengthening mechanism, improving mechanical properties without loss in ductility. It is well known, however, that proper prediction of mechanical properties of fine grained materials is much more complicated because of different deformation and strengthening mechanisms operating in these materials. When the strong grain refinement (below 1 micron) is achieved, some deviations, comparing to the conventional materials have been reported i.e. change in Hall- Petch slope, different deformation and fracture mechanisms , enhanced strain rate sensitivity or lack in the work . Unfortunately, these phenomena and their physical basis are still poorly understood and most of the well known constitutive laws (i.e. Hall-Petch relationship) are no longer effective in description of the deformation process of such materials. Thus the proper understanding of specific mechanisms by which the plastic deformation leads to a refined grain size is of paramount importance.[3]

According to the Hall- Petch relation (which is applicable to a variety of polycrystalline single and dual-phase metals), a decrease in grain size (d) results in an increase in yield strength.

$$\sigma_y = \sigma_0 + Kd^{-1/2}$$

Where, $\sigma_y$ is the yield stress , $\sigma_0$ is a materials constant for the starting stress for dislocation movement , K is the strengthening coefficient (a constant specific to each material), and d is the average grain diameter.

**1.2.4 Metallographic Etching**

Metallographic etching is the process of revealing microstructural details that would otherwise not be evident on the as-polished sample. Etching is not always required as some features are visible in the as-polished condition such as porosity, cracks and inclusions. A properly prepared specimen will reveal properties such as grain size, segregation, and the shape, size, and distribution of the phases and inclusions that are present.

This typically involves immersing the sample in an etchant such or swabbing the surface with an etchant. The etchant selectively corrodes microstructural features. Immersion time or etching time is highly dependent on the system and in most cases requires experience. The selection of the optimum etchant is also very important in sample production.

Deeper etches are preferred for low magnification examinations, while shallow etches are preferred for higher magnification etches.

**Le Pera** etchant is used for the metallographic study of multi-phase steels (DUAL PHASE, TRIP).It differentiates between different phases based on colors.

**1.2.5 Corrosion**

Corrosion is the deterioration or destruction of metals and alloys in the presence of an environment by chemical or electrochemical means. In simple terminology, corrosion processes involve reaction of metals with environmental species.

As per IUPAC, "Corrosion is an irreversible interfacial reaction of a material (metal, ceramic, polymer) with its environment which results in its consumption or dissolution into the material of a component of the environment. Often, but not necessarily, corrosion results in effects detrimental to the usage of the material considered. Exclusively physical or mechanical processes such as melting and evaporation, abrasion or mechanical fracture are not included in the term corrosion."

There is no single figure for loss to the nation due to corrosion. It can be a minimum of 3.5% of the nation's DUAL PHASE. Losses due to corrosion could be around Rs. 2.0 lakh crores per annum in India. Corrosion costs manifest in the form of premature deterioration or failure necessitating maintenance, repairs and replacement of damaged parts.

Corrosion can be classified in different ways, such as –

- Chemical and electrochemical
- High temperature and low temperature
- Wet corrosion and dry corrosion.

Dry corrosion occurs in the absence of aqueous environment, usually in the presence of gases and vapors, mainly at high temperatures.

Electrochemical nature of corrosion can be understood by examining zinc dissolution in dilute hydrochloric acid.

$$Zn + 2HCl = ZnCl_2 + H_2$$

Anodic reaction is Zn = $Zn^{++}$ + $2e^{-}$ with the reduction of $2H^{+}$+ $2e^{-}$ = $H_2$ at cathodic areas on the surface of zinc metal. There are two half reactions constituting the net cell reaction.

The most common method for estimating corrosion rate from mass loss is to weigh the corroding sample before and after exposure and divide by the total exposed area and the total exposure time making sure that appropriate conversion constants are used to get the rate in the required units .The method in mm/yr can be represented by the following equation.

$$Corrosion\ Rate\ (CR) = \frac{(k \times \Delta w)}{(A \times T \times \rho)}$$

Where, CR = Penetration (Corrosion) rate , Δw = Weight loss in gram , A = Exposed area of the sample , T = Time of exposure in hours, k = Constant for unit conversion = $8.76 \times 10^4$ and ρ = density of low carbon steel (7.88 gm/$cm^3$).

Weight loss technique was used in which sample known weight before and after immersing to the solution is analyzed and results are collected.

### 1.2.6 Dual-Phase Steel

Steels whose structures consist of mixtures of ferrite and martensite are often referred to as dual phase steel. DUAL PHASE steels are low carbon steel that posses a microstructure consisting of a ferrite and martensite. In DUAL PHASE microstructure although small amounts of retained austenite, bainite and/or pearlite may also be present.[6]

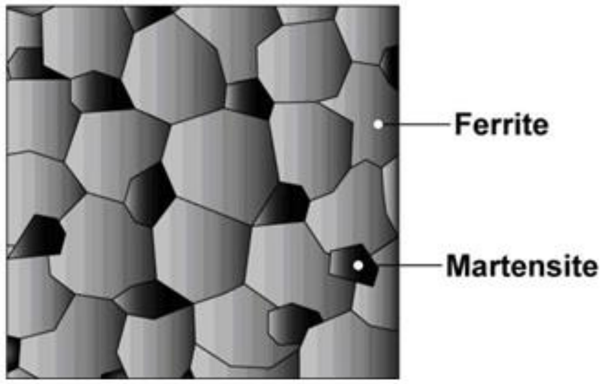


**Figure 1.2 Microstructure of dual phase steel**

Microstructure of dual phase steels in which, soft ferritic network provides good ductility; while, hard particles and martensite phase play the load bearing role.

It can be seen that martensite volume increases by increasing the intercritical heat treatment temperature. This complies with lever rule in the ferrite-austenite dual phase region. According to the liver rule, increasing the temperature increases the austenite volume fraction, which then will transform to martensite upon quenching in the water. By increasing the temperature martensite volume increases at higher rate.

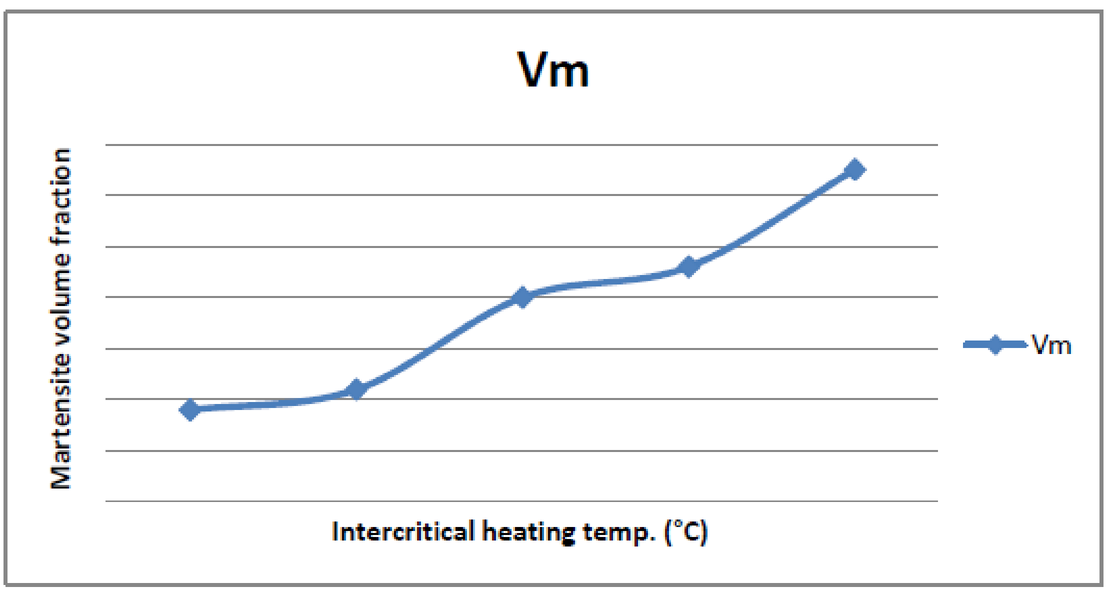


**Figure 1.3 Variation of martensite volume fraction as a function of intercritical temperature**

One of the key controlling parameters for mechanical properties of the dual phase steels in carbon content of the martensite phase. The carbon content of the martensite can be calculated according to the rule of mixtures.

$$C_0 = C_f V_f + C_m V_m$$

Where $C_0$ is the steel mean carbon content and $C_f$ and $C_m$ are the carbon content of ferrite and martensite phases, respectively. $V_f$ and $V_m$ are the ferrite and martensite volume fractions.In this equation carbon content is assumed to be 0.015, which is the solubility limit of the carbon in ferrite phase. Figure shows variation of carbon content of the steels with martensite volume fraction. As can be seen, the carbon content of the martensite phase decreases by increasing the martensite volume fraction.

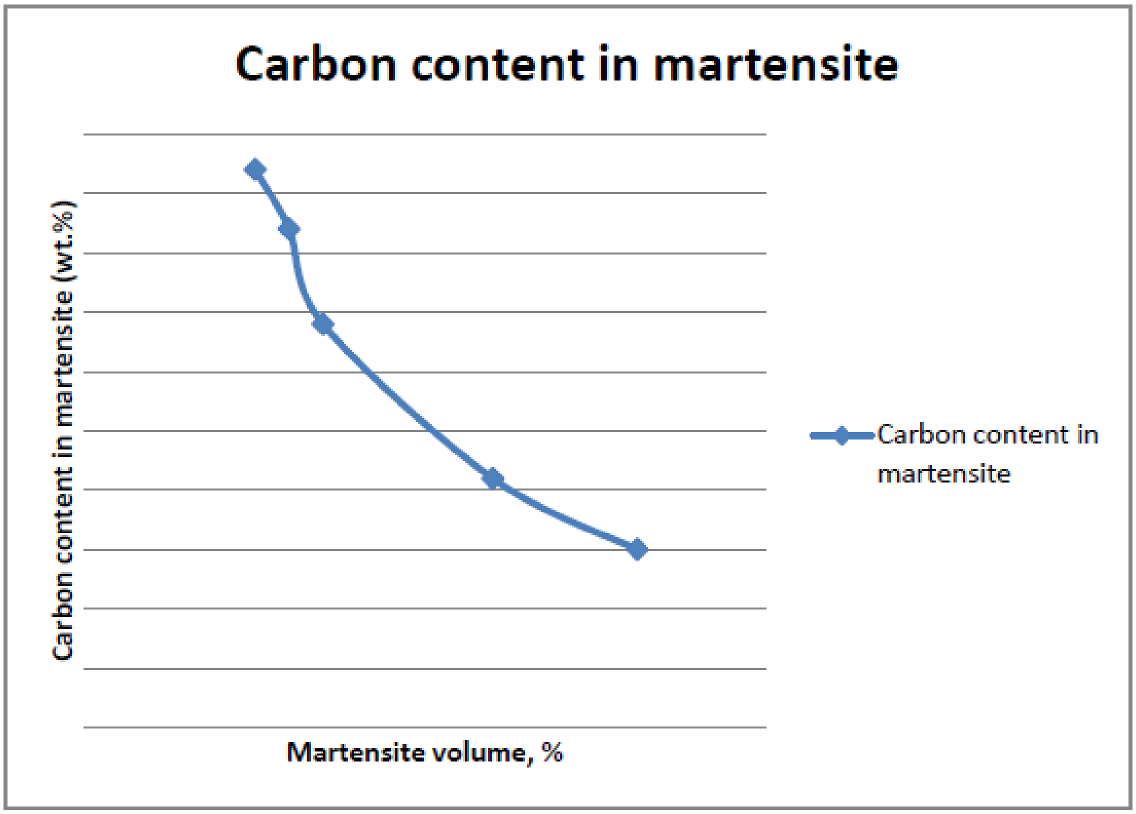


**Figure 1.4 The variation of martensite carbon content as a function of martensite volume,%**

### 1.2.7 Tensile properties of dual-phase steel :-

Yield strength and tensile strength : The strength values of the investigated dual phase steels are higher than that of the as-received (normalised) steel. The higher strengths of the dual phase steels are known to be due to the presence of the harder second phase (martensite).[5]

The variation of yield and ultimate strengths of the heat treated (dual-phase) samples as a function of the martensite volume fraction are given in figure 1.5 and 1.6.

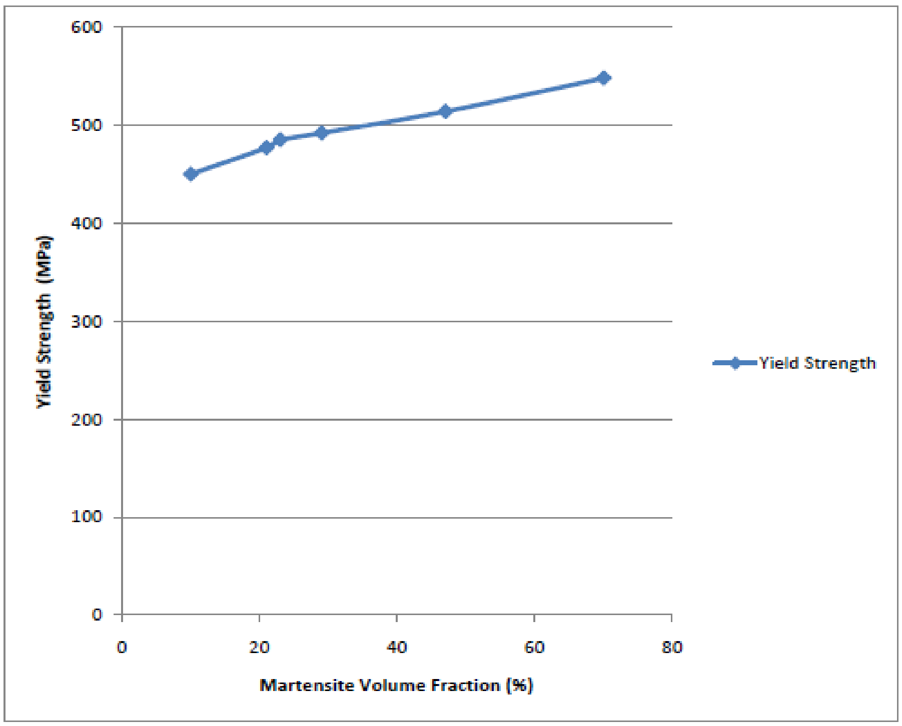


**Figure 1.5 Graph between Martensite volume fraction and yield strength**

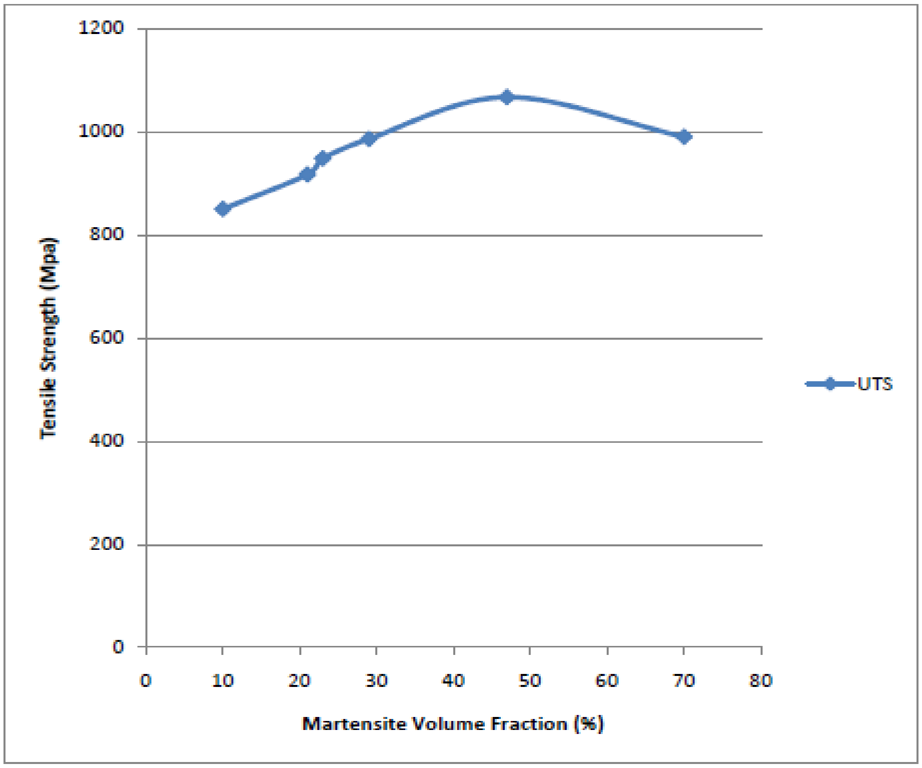


**Figure 1.6 Graph between Martensite volume fraction and tensile strength**

It can be seen that the yield strength of these steels is linearly increased by increasing the martensite volume fraction, while the ultimate strength first increases by increasing martensite volume fraction and then remains nearly constant.

In fact Maximum ultimate strength is obtained at 50% martensite volume fraction. This trend is on contrast to the law of mixture .

According to the law of mixture, tensile strength of a dual-phase steel can be written as :

$$\sigma_{DP} = \sigma_f V_f + \sigma_m V_m$$

Where $\sigma_f$ is the tensile strength of the ferrite, $\sigma_m$ the tensile strength of the ferrite.

Therefore,the strength of a dual-phase steels ia s function of volume fraction of the martensite phase and its strength.

### 1.2.8 Corrosion Behaviour of Dual-Phase Steel :-

In the corrosion of plain carbon steels in neutral 5 % NaCl solution, following corrosion reaction occur simultaneously.

Anodic reaction :$Fe \rightarrow Fe^{+2} + 2e$

Cathodic reaction : $O_2 + 2H_2O + 4e \rightarrow 4\ OH^-$

The cathodic reaction depends on the amount of dissolved oxygen and pH of the solution.It is seen that with the change in microstructure from ferrite-pearlite to ferrite-martensite (dual-phase) the corrosion rate decreases.

# CHAPTER 2

# LITERATURE SURVEY

### 2.1 Literature Survey

Radhiyah Abd Aziz et al [1] in their research on medium carbon steel for mechanical property and corrosion behavior concluded that heat treatment processes composing of lamellarizing, tempering and quenching affecting ferrite-martensite constituent phase. This changes on microstructure reflecting on the mechanical property as observed in hardness value. They observed that the hardness increased with increase in martensite volume fraction. They also concluded that the corrosion rate of medium carbon steel for un-treated sample is the lowest one compared to the heat treated samples which there is no present of ferrite–martensite on that sample. The samples that have higher content of martensite have the ability to corrode faster. Hence the result for corrosion behaviour from this research is different with the previous research which is the mechanical properties of untreated medium carbon steel cannot be improved.

Wilson Handoko et al [2] through their investigation on dual phase high carbon steel concluded that the retained austenite phase was preferred for corrosion attack over the martensite phase. With micro-scale analysis, SEM images strongly confirmed the early loss of the austenite phase in the initial stages of the corrosion process, while the martensite remained intact.

Although the martensitic structure eventually corroded after two hours of corrosion attack, significant damage can be seen to the austenitic morphology. Further nano-resolution analysis by AFM concluded that martensite was more resistant to corrosion attack than retained austenite. Weight loss measurements proved the corrosion rate gradually declined over time, as phases corroded at different rates. It can therefore be predicted that martensitic grains with high carbon content are advantageous for manufacturer applications in corrosive environment, as they enhance hardness, strength and corrosion resistance, thus minimising costs associated with the failure of high carbon steel parts.

S.C. Ikpeseni et al [3] during teir investigation on dual phase low carbon steel observed that the corrosion rate of dual phase steel developed from 0.23%C steel via intercritical annealing heat treatment increases with increase in intercritical annealing temperature and martensite volume fraction in 0.1M HCl solution. They also revealed that martensite volume fraction increases as a function of temperature. Again, the corrosion rate of the duplex microstructure steels was found to be slightly higher than that of normalized steel.

Imtiaz Soomro et al [4] in investigating properties of plain carbon steel came to inference that the amount martensite fraction increases with increasing temperature and time during intercritical annealing. Higher percent martensite volume fraction lowers the martensite carbon content and change the morphology from plateto lath type. Also martensite tetragonality ratio was found be dependent of carbon content. Decrease in carbon content softens the martensite and significantly improves its plastic formability. The hardness and TS was found to increase with increasing Vm% with optimum value of 1277 MPa and 41 HRC. A further increase in Vm% was found to decrease both TS and hardness. The toughness of DUAL PHASE specimens was lower compared to as-received and increase with increasing Vm%.

E. Salamci et al [5] during study of mechanical and corrosion behavior of dual phase steel concluded that the martensite volume fraction increases with an increase in intercritical annealing temperature. The slow cooling rate for FC752 allows the epitaxial ferrite to grow on the existing ferrite attributed to increasing in intercritical annealing temperature or decreasing in cooling rate. Mass loss of all the investigated specimens remained almost similar for the early stages (i.e., up to 3 days) after which the mass loss was deviated as the immersion time prolonged. The mass loss is approximately 30% less for FC752 at 28-day exposure time as compared to WQ725. Corrosion rate increased with increasing martensite volume fraction. However, this phenomenon was inhibited in the epitaxial ferrite containing samples, attributed to the presence of epitaxial ferrite hindering corrosion by smoothing the compositional fluctuations between retained ferrite and martensite as well as reduced dislocation density.

S.C. IKPESENI [6] in his study on low carbon steel found that the 0.23%C steel in 0.1M HCl aqueous solution that step quenching intercritical annealing heat treatment increases corrosion rate; increased soaking temperature within the intercritical annealing (i.e. $\alpha + \gamma$) region increases corrosion rate; and tempering as-quenched step quenched samples reduces corrosion susceptibility. Therefore, for applications where this material will be exposed to chloride environment, tempering after step quenching is strongly recommended.

Ramesh R.Burbure et al [7] studied the tribological wear behavior of dual phase steel and concluded that with increase in the normal pressure, the volumetric wear rate is increased. Oxidative wear mechanism is observed at 3 m/s for all the DUAL PHASE steels. With increase in the volume fraction of martensite up to 50% for 0.4% carbon DUAL PHASE steel, volumetric wear rate is decreased and with further increase in the volume fraction of martensite, volumetric wear rate is increased. It was also observed for all the specimens that specific wear rate is high at low operating conditions of normal pressure and sliding speed. They also observed for all the specimens that specific wear rate is decreased with increase in the operating conditions up to medium level and thereafter increased with further increase in the operating conditions

Og˘uzhan Keles temur et al [8] studied the dual phase heat treatment for corrosion behavior and found that the dual phase steels have lower corrosion resistance than reinforcing steel embedded in concrete. The corrosion rates have been measured as 0.41 lA/cm2 for IQ75, 0.34 lA/cm2 for IQ50 and 0.28 lA/cm2 for IQ25, respectively. Results of the investigation conclude that corrosion rate in concrete of dual-phase steels with ferrite-martensite structure depend upon the volume fraction and morphology of the phase constituents. Increasing the amount of martensite bears an adverse effect on the corrosion behavior of dual-phase steel embedded in concrete. A direct comparison about the corrosion tendency between DUAL PHASE steel and ferrite-pearlite structure is not possible due to the presence of different amounts and morphologies of second phase.

Lakshmana Rao Bhagavathi [9] studied the mechanical and corrosion behavior of dual phase low carbon steel and dual-phase steels with different volume fractions of martensite are obtained after thermal processing using different intercritical soaking times. The mechanical properties of dual-phase steels such as Vickers hardness and tensile properties are measured. Corrosion properties are evaluated using potentiodynamic polarization test and immersion test. It was observed that the tensile strength and hardness increased and ductility decreased with increase in martensite volume fraction. The corrosion rate for dual-phase steels is found to be lower than that for subcritically heat treated ferrite–pearlite steel. The higher corrosion resistance of dual-phase steels is explained on the basis of microstructural features.

David Abimbola Fadare et al [10] through their analysis on NST 37-2 steel in HCl solutions showed that both corrosion rates and electrode potentials of the untreated sample had the highest corrosion rate and shifted more to the positive values as the concentration of acid was increased. For the heat treated samples, the corrosion rate in the test solutions ranked in decreasing order: hardened, normalized, annealed and tempered.

### 1.3 Problem Formulation

On the basis of above literature review, heat treatment will be carried out on low carbon steel so as to analyze the corrosion resistance and ultimate tensile strength of heat treated low carbon steel. Following are the problems that will be covered in this research work:

- To find influence of Heat Treatment on Corrosion Resistance of Low Carbon Steel.
- To find influence of Heat Treatment on Tensile Strength of Low Carbon Steel.

# Chapter – 3

# METHODOLOGY

## 3.1 TAGUCHI METHOD

Taguchi has developed a methodology for the application of designed experiments, including a practitioner's handbook. This methodology has taken the design of experiments from the exclusive world of statistician and brought it more fully into the world of manufacturing. His contributions have also made the practitioner work simpler by advocating the use of fewer experimental designs, and providing a clear understanding of the variation nature and the economic consequences of quality engineering in the world of manufacturing. Taguchi introduces his approach, using experimental design for:

- Designing products/processes so as to be robust to environmental conditions;
- Designing and developing products/processes so as to be robust to component variation;
- Minimizing variation around a target value. This philosophy of Taguchi is broadly applicable. He proposed that engineering optimization of a process or product should be carried out in a three step approach i.e. system design, parameter design and tolerance design. In system design the engineer applies scientific engineering knowledge to produce a basic functional prototype design. In the product design stage the selection of the materials, components, tentative product parameter values etc. are involved. Since system design is an initial step, functional design may be far from optimum in terms of quality and cost.

The objective of parameter design is to optimize the setting of process parameter value for improving performance characteristics and to identify the product parameter values under the optimal process parameter values. In addition, it is expected that the optimal process parameter values obtained from the parameter design are insensitive to the variation of environmental conditions and other noise factors. Therefore, the parameter design is the key step in Taguchi method of achieving high quality without increasing cost. Basically, classical parameter design developed by Fisher is complex and not easy to use especially, a large number of experiments have to be carried out when the number of process parameters increases. To solve this task, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. A loss function is then defined to calculate the deviation between the experimental values and desired values. Taguchi recommends the use of the loss function to measure the performance characteristic deviating from the desired value. The value of the loss function is further transformed into a signal-to-noise (S/N) ratio. Usually there are three categorize of performance characteristic in the analysis of the S/N ratio that is the lower-the-better, the higher-the-better, and the nominal-the –better. The S/N ratio for each level of process parameter is computer based on the S/N analysis. Regardless of the category of the performance characteristic, the larger S/N ratio corresponds to the better performance characteristic. Therefore, the optimal level of the process parameter is the level with the highest S/N and ANOVA analysis, the optimal combination of the process parameters can be predicted. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the parameter design. The Taguchi method is adopted to obtain optimal machining performance in the milling.

1. **Larger is better (maximum) : S/NLB = -10 log ( (1/n) Σ (1/$y_i^2$) )**

2. **Smaller is better (minimum) : S/NSB = -10 log ( (1/n) Σ $y_i^2$ )**

Where, n is the number of observations or repetitions of a trial and y is the observed data. Notice that these S/N ratios are expressed on a decibel scale. We would use S/NT if the objective is to reduce variability around a specific target, S/NL if the system is optimized when the response is as large as possible, and S/N’S if the system is optimized when the response is as small as possible. Factor level that optimizes the appropriate S/N ratio is optimal.

The use of parameter design of the Taguchi method to optimize a process with multiple performance characteristics includes the following steps:

- Identify the performance characteristics and select process parameters to be evaluated.
- Determine the number of levels for the process parameters and possible interactions between the process parameters.
- Select the appropriate orthogonal array and assignment of process parameters to the orthogonal array.
- Conduct the experiments based on the arrangement of the orthogonal array.
- Analyze the experimental results using S/N ratio and ANOVA.
- Select the optimal level of process parameters.
- Verify the optimal process parameters through the confirmation experiment.

**3.2 APPLICATION OF S/N RATIO**

The change in the quality characteristics of a product under investigation, in response to a factor introduced in the experiment design is the signal of desired effect. However, when an experiment is conducted, there are numerous external factors not designed into the experiment which influence the outcome. These external factors are called the noise factors and their effect on the outcome of the quality characteristic under test is termed as noise. The signal to noise ratio measures the sensitivity of the quality characteristic being investigated in a controlled manner, to those external influencing factors (noise factors) not under control. The concept of S/N ratio originated in the electrical engineering field. Taguchi effectively applied this concept to establish the optimum condition from the experiments.

The aim of any experiment is always to determine the highest possible S/N ratio for the result. A high value of S/N ratio implies that the signal is much higher than the random effect of the noise factors. Product design or process operation consistent with highest S/N ratio, always yields the optimum quality with minimum variance.

From the quality point of view, there are three possible categories of quality characteristics. They are:

1. Smaller is better;
2. Nominal is better;
3. Larger is better.

The S/N ratio is designed to measure the quality characteristics.

The Signal to Noise ratio (S/N ratio) expresses the scatter around a target value. The larger the ratio, the smaller is the scatter. Knowing the S/N ratio of the samples before and after the experiment, Taguchi's loss function may be used to estimate the potential cost saving from the improved product.

## 3.3 ADAVANTAGE OF S/N RATIO OVER AVERAGE

To analyze the results of experiments involving multiple runs, use of the S/N ratio over standard analysis is preferred. Analysis using the S/N ratio will offer the following main advantages:

1. It provides guidance to a selection of optimum level based on least variation around the target and also on the average value closest to the target.
2. It offers objective comparison of two sets of experimental data with respect to variation around target and the deviation of the average from the target value.

## 3.4 Role of ANOVA

Taguchi replaces the full factorial experiment with a lean, less expensive, faster, partial factorial experiment. Taguchi's design for the partial factorial is based on specially developed OA's. Since the partial experiment is only a sample of the full experiment, the analysis of the partial experiment must include an analysis of the confidence that can be placed in the results. Fortunately, there is a standard statistical technique called Analysis of Variance (ANOVA) which is routinely used to provide a measure of confidence. The technique does not directly analyze the data, but rather determine the variability (variance) of the data. Confidence is measured from the variance.

Analysis provides the variance of controllable and noise factors. By understanding the source and magnitude of variance, robust operating conditions can be predicted. This is second benefit of the methodology.

## 3.5 ANALYSIS OF VARIANCE (ANOVA):

This method was developed by Sir Ronald Fisher in the 1930's as a way to interpret the results from agricultural experiments. ANOVA is not a complicated method and has a lot of mathematical beauty associated with it. ANOVA is a statistically based, objective decision-making tool for detecting and differences in average performance of groups of items tested. The decision rather than using pure judgment, takes variation into account.

### 3.6 TABLES FOR TAGUCHI DESIGN OF EXPERIMENT

Tables for Taguchi design of experiment are shown below:

**Table 3.1: Process Parameters and their levels**

| **S.No.** | **Parameters** | **Units** | **Level 1** | **Level 2** | **Level 3** |
|---|---|---|---|---|---|
| **1** | **Temperature** | °C | 710 | 730 | 750 |
| **2** | **Quenching Type** | | Air | Water | Oil |

**Table 3.2: L9 Orthogonal Array**

| **Exp. No** | **Parameter 1** | **Parameter 2** |
|---|---|---|
| **1** | 1 | 1 |
| **2** | 1 | 2 |
| **3** | 1 | 3 |
| **4** | 2 | 1 |
| **5** | 2 | 2 |
| **6** | 2 | 3 |
| **7** | 3 | 1 |
| **8** | 3 | 2 |
| **9** | 3 | 3 |

**Table 3.3: L9 Orthogonal Array with experimental details**

| Exp. No | Temperature | Quenching Type |
|---|---|---|
| **1** | 710 | Air |
| **2** | 710 | Water |
| **3** | 710 | Oil |
| **4** | 730 | Air |
| **5** | 730 | Water |
| **6** | 730 | Oil |
| **7** | 750 | Air |
| **8** | 750 | Water |
| **9** | 750 | Oil |

# CHAPTER - 4

# EXPERIMENTATION

## 3.1EXPERIMENTAL SETUP

The low carbon steel AISI 1018 specimens for study were heated upto desired temperature by use of Muffle Furnace. The maximum range of the available muffle furnace is 900°C. In our study the maximum temperature required is 750°C. The Muffle Furnace for our study was available a RR Institute of Modern Technology, Bakshi Ka Talab, Sitapur Road, Lucknow.

**Table 3.1 Technical Specifications of Muffle Furnace**

| Sr. No. | Specification | Value |
|---|---|---|
| **1** | Model | BST/MF/900 |
| **2** | Maximum Temperature | 900°C |
| **3** | Working Temperature | 800°C |
| **4** | Heating Element | Kanthal A-1 |
| **5** | Temperature Accuracy | +/- 1°C |
| **6** | Display | LED |
| **7** | External Chamber Construction | MS with Powder Coating |
| **8** | Internal Chamber Construction | Ceramic Board & Grooved Refractory Chamber as per Temp. Requirement |
| **9** | Insulation | Ceramic Wool Wall |
| **10** | Supply | 220/440 Volts |


**Figure 3.1: Muffle Furnace**


**Figure 3.2 Temperature setup on Muffle Furnace**

**Figure 3.3 Furnace Chamber**

## 3.2 WORK PIECE MATERIAL

The material used for this work is low carbon steel AISI 1018. The samples for experiment were 25mm×25mm×4mm.

Firstly the sample was acquired which was a Low Carbon Steel AISI 1018 having 4mm in thickness. The samples were cut (25 mm each) with the help of hacksaw in order to heat them at various temperature.

AISI 1018 mild/low carbon steel has excellent weldability, produces a uniform and harder case and it is considered the best steel for carburized parts. AISI 1018 mild/low carbon steel offers a good balance of toughness, strength and ductility. AISI 1018 hot rolled steel has significant mechanical properties, improved machining characteristics and has a high Brinell hardness measure.

Specific manufacturing controls are used for surface preparation, chemical composition, rolling and heating processes. All these processes develop a supreme quality product that is suited to fabrication processes such as welding, forging, drilling, machining, cold drawing and heat treating.

**Table 3.2: Chemical composition of Work-piece (AISI 1018) by weight**

| Element | Composition |
|---|---|
| **Iron (Fe)** | 98.9% |
| **Carbon (C)** | 0.16% |
| **Manganese (Mn)** | 0.77% |
| **Phosphorous (P)** | 0.023% |
| **Sulfur (S)** | 0.017% |

**Table 3.3: Properties of low carbon steel AISI 1018**

| Property | Qty. |
|---|---|
| **Melting Point (°C)** | 1427 |
| **Density (gm/cm$^2$)** | 7.88 |
| **Yield Strength (MPa)** | 370 |
| **Ultimate Tensile Strength (MPa)** | 440 |
| **Brinell Hardness** | 126 |
| **Elastic Modulus (GPa)** | 205 |

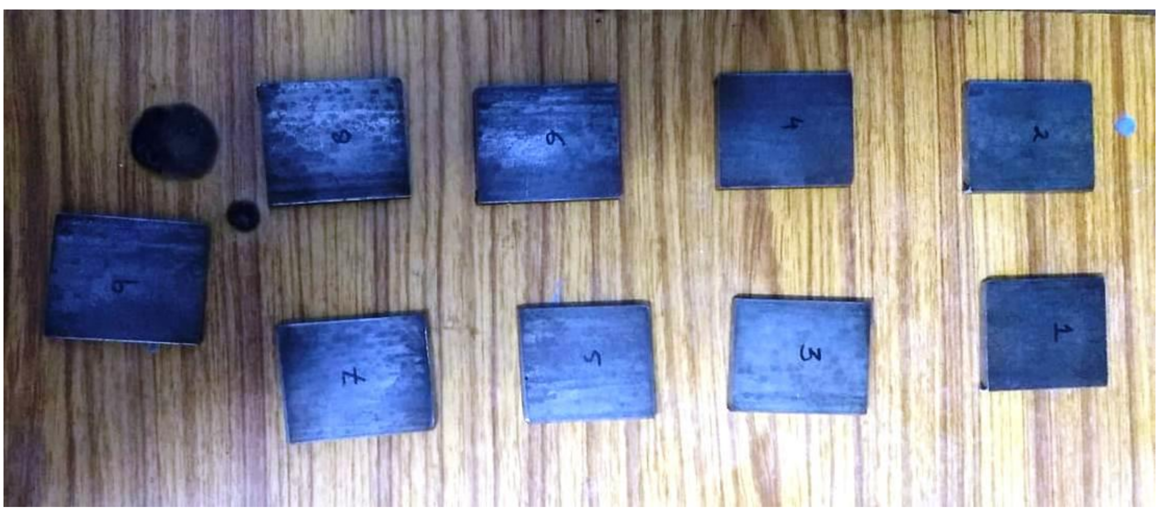

**Figure 3.4: AISI 1018 Specimens before experiments**

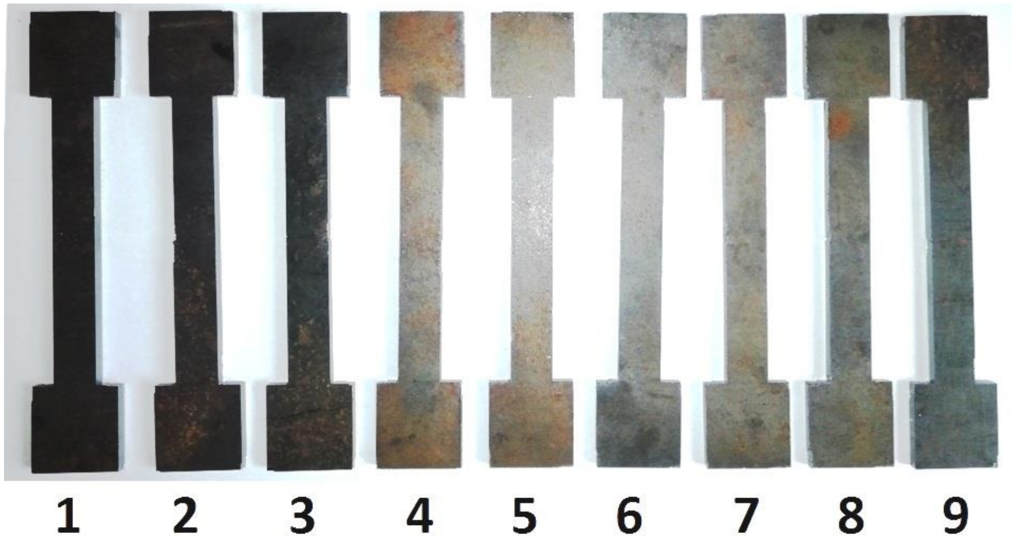


**Figure 3.5: AISI 1018 I-shaped Specimens before tensile test experiments**

**Applications of AISI 1018 Mild/Low Carbon Steel**

- It is used in bending, crimping and swaging processes.
- Carburized parts that include worms, gears, pins, dowels, non-critical components of tool and die sets, tool holders, pinions, machine parts, ratchets, dowels and chain pins use AISI 1018 mild/low carbon steel.
- It is widely used for fixtures, mounting plates and spacers.
- It is suitably used in applications that do not need high strength of alloy steels and high carbon.
- It provides high surface hardness and a soft core to parts that include worms, dogs, pins, liners, machinery parts, special bolts, ratchets, chain pins, oil tool slips, tie rods, anchor pins, studs etc.
- It is used to improve drilling, machining, threading and punching processes.
- It is used to prevent cracking in severe bends.

**Andrew Equations:**

$$A_{c1} = 742-29\cdot C-14\cdot Mn+13\cdot Si+16\cdot Cr-17\cdot Ni-16\cdot Mo+45\cdot V+36\cdot Cu$$

$$A_{c3} = 925-219.C^{1/2}-7\cdot Mn+39\cdot Si-16\cdot Ni+13.Mo+97\cdot V$$

According to Andrew equations , we have calculated the Ac1 and Ac3 temperatures which are 723.7ºC and 834ºC respectively.

**Preparation of Dual-Phase Steels :-**

Plain low carbon steel having 4 mm thickness is used to obtain specimens. With the help of hacksaw the samples were cut. All these samples were heated in a muffle furnace at 710ºC, 730ºC and 750ºC for 45 minutes followed by air, water and oil cooling. These samples are used for developing the dual-phase steels. All of the specimens were heated in intercritical temperature range (between Ac1 and Ac3).

The Specimens were intercritically heated to 710°C, 730°C and 750°C and holding for 25 minutes followed by air, water and oil quenching.

The relationship between $M_s$ temperature and the chemical composition is as shown in the following equation :

$M_s(°C) = 561 – 474(\%C) – 33(\%Mn) – 17(\%Ni) – 17(\%Cr) – 21(\%Mo)$

The $M_s$ temperature calculated for sample is 457.3°C.

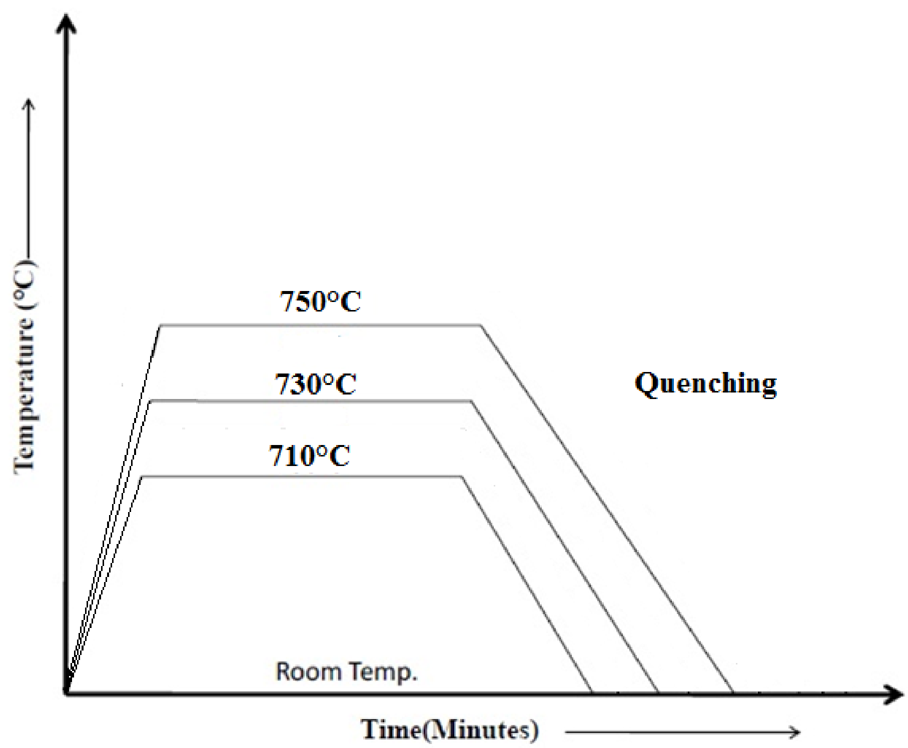


**Figure 3.5 Heat treatment cycle for dual phase steel**

**Table 3.4: Experimentation Array**

| Exp. No. | Temperature (in °C) | Type of Quenching |
|---|---|---|
| 1 | 710 | Air |
| 2 | 710 | Water |
| 3 | 710 | Oil |
| 4 | 730 | Air |
| 5 | 730 | Water |
| 6 | 730 | Oil |
| 7 | 750 | Air |
| 8 | 750 | Water |
| 9 | 750 | Oil |

## 3.3 CORROSION EXPERIMENTS

All the corrosion experiments were conducted at 300 K with corrosive medium open to air. For the study of corrosion behaviour flat samples of (25 x 25) $mm^2$ were cut from the normalised and dual-phase steels after heat treatment. Samples were polished up to 4/0 grade emery paper before performing the corrosion tests. Corrosion test was performed in 5% NaCl solution. Corrosion properties were studied by using immersion test in 5% NaCl solution for 360 hours (15 days). The experiments were performed in the chemistry lab of Integral University, Lucknow. The ASTM established recommended procedure for immersion test as covered by designation G-31 was employed.

**Figure 3.6 Samples dipped in 5% NaCl solution for the corrosion experiment**

**Figure 3.7 Samples after 15 days dipped in 5% NaCl solution**


**Figure 3.8 Samples condition after corrosion test**


**Figure 3.9 Assessing sample condition after corrosion test**

They were weighed before the start of the test and after completion of the test. All the weight measurements were carried out using a analytical balance machine. After the immersion test and before final weighing, the cleaning procedure consisted of holding the specimen under a stream of water and scrubbing the surface with a cloth until the corrosion products on the samples were removed. After removal of corrosion products, the samples were air dried and then weighed.

The corrosion rate was calculated by weight loss method. From immersion test results, corrosion rate is estimated by using the following :

$$CR = \frac{k \times \Delta w}{A \times T \times \rho}$$

Where, CR = Penetration (Corrosion) rate, Δw = Weight loss in gram , A = Exposed area of the sample , T = Time of exposure in hours = 360 Hours, k = Constant for unit conversion = $8.76 \times 10^4$ and ρ = density of low carbon steel (7.88 $gm/cm^3$).

**3.4 TENSILE TEST MEASUREMENT**

After the measurement of corrosion property of heat treated low carbon steel we move toward the influence of heat treatment on mechanical property. The tensile strength of the heat treated I-shaped specimens was measured. All the values of tensile strength of the specimens were calculated by Universal Testing Machine available at Integral University Lucknow.

I-shaped specimens were prepared using laser cutting machine available at Dilawar Engineering Works, Kaiserbagh, Lucknow.

The I-shaped heat treated specimens were tested for tensile strength and all the nine values of tensile strength were calculated post tensile test.

### 3.5 WEIGHT MEASUREMENT

The weight of all specimens is calculated by Wensar Electronic digital weighing measuring instrument available at Integral University, Lucknow. Weight measurement is done for calculating the corrosion rate of the heat treated low carbon steel. Weights were taken pre and post corrosion test in order to measure the weight loss due to corrosion. Figure 3.11 shows the weight measurement of the specimen.

**Table 3.6 Specifications of Wensar Electronic Weight Measuring Instrument**

| **MODEL** | **TTB 20HH** |
|---|---|
| Capacity | 20Kg |
| Readability | 0.1 gm |
| Repeatability (±) | 0.1 gm |
| Linearity (±) | 0.2 gm |
| Pan Size (mm) | 230 × 320 |
| Display | LCD |
| Make | Wensar |
| Operating Temperature | 10°C to 40°C |
| Power Supply | 220V/50-60Hz |
| Dimension (L×B×H) mm | 410 × 370 ×145 |
| Weight | 5Kg |

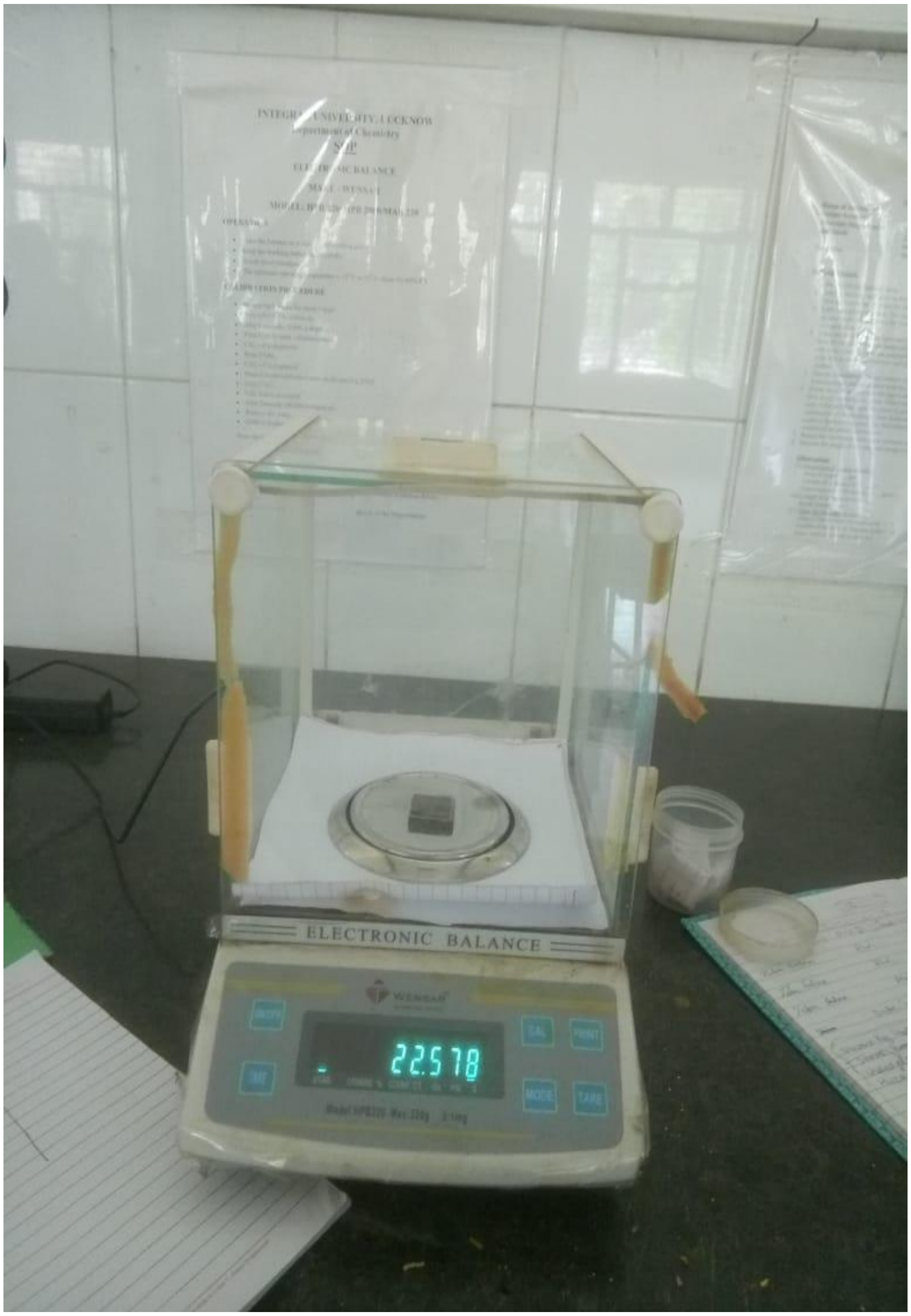


**Figure 3.11 Measurement of Specimen weight on Wensar digital weighing instrument before corrosion test.**

# CHAPTER - 5

## RESULT AND DISCUSSION

## RESULT AND DISCUSSION

### 4.1 CALCULATION FOR CORROSION (PENETRATION) RATE

All the corrosion experiments were conducted at 300 K with corrosive medium open to air. For the study of corrosion behaviour flat samples of (25 x 25) $mm^2$ were cut from the normalised and dual-phase steels after heat treatment. Samples were polished up to 4/0 grade emery paper before performing the corrosion tests. Corrosion test was performed in 5% NaCl solution. Corrosion properties were studied by using immersion test in 5% NaCl solution for 360 hours (15 days). The ASTM established recommended procedure for immersion test as covered by designation G-31 was employed.

The corrosion rate was calculated by weight loss method. From immersion test results, corrosion rate is estimated by using the following :

$$CR = \frac{(k \times \Delta w)}{(A \times T \times \rho)}$$

Where, CR = Penetration (Corrosion) rate, Δw = Weight loss in gram , A = Exposed area of the sample , T = Time of exposure in hours = 360 Hours, k = Constant for unit conversion = 8.76 × $10^4$ and ρ = density of low carbon steel (7.88 gm/$cm^3$).

**Table 4.1 Results obtained from corrosion test performed in 5% Nacl**

| Exp. No. | Temperature | Quenching | Weight in grams | | Weight Loss (Δw) | CPR |
|---|---|---|---|---|---|---|
| | | | Before Corrosion | After Corrosion | | |
| 1 | 710 | Air | 70.026 | 69.872 | 0.154 | 0.76088 |
| 2 | 710 | Water | 72.221 | 72.173 | 0.048 | 0.237157 |
| 3 | 710 | Oil | 72.184 | 72.156 | 0.028 | 0.138342 |
| 4 | 730 | Air | 72.391 | 72.257 | 0.134 | 0.662064 |
| 5 | 730 | Water | 70.212 | 69.953 | 0.259 | 1.279662 |
| 6 | 730 | Oil | 74.411 | 74.287 | 0.124 | 0.612657 |
| 7 | 750 | Air | 74.573 | 74.437 | 0.136 | 0.671946 |
| 8 | 750 | Water | 70.036 | 69.994 | 0.042 | 0.207513 |
| 9 | 750 | Oil | 70.119 | 70.08 | 0.039 | 0.19269 |

### 5.1.1 Calculation of S/N ratio for Corrosion Rate

The S/N ratio condenses the multiple data points of corrosion test after heat treatment within a trial, depends on the type of characteristics being evaluated. For calculation of S/N ratio for corrosion rate Smaller is Better condition is opted. The equation for the calculation of S/N ratio for Corrosion Rate is:

$$S/N_{SB} = -10 \log \left( (1/n) \Sigma y_i^2 \right)$$

**Table 5.2 Calculation of S/N ratio for Corrosion Rate**

| S.No | CPR | Signal to noise ratio (db) |
|---|---|---|
| **1** | 0.76088 | 2.3737 |
| **2** | 0.237157 | 12.4993 |
| **3** | 0.138342 | 17.1809 |
| **4** | 0.662064 | 3.582 |
| **5** | 1.279662 | -2.1419 |
| **6** | 0.612657 | 4.2557 |
| **7** | 0.671946 | 3.4533 |
| **8** | 0.207513 | 13.6591 |
| **9** | 0.19269 | 14.3028 |

### 5.1.2 Calculation of Mean S/N ratio for Corrosion Rate

Mean S/N ratio is calculated by using following formula

$$nf_i = (nf_1 + nf_2 + nf_3)/3$$

Where nf is mean S/N ratio for factor f at the level value i of the selected factor.

$nf_1$, $nf_2$, $nf_3$ are S/N ratio for factor f at level u

The factors which affect the machining parameters show in the table as their respective ranks. Rank of the parameters depends on the value of delta. If the delta value of one parameter is higher than the other that shows first rank. Higher value of S/N ratio of each factor shows the optimal level of the factor. Temperature shows the main effect in the below response table followed by type of quenching.

**Table 5.3 Calculation of mean S/N ratio for Corrosion Rate**

| Level | Temperature | Quenching Type |
|---|---|---|
| **1** | 10.685 | 3.136 |
| **2** | 1.899 | 8.005 |
| **3** | 10.472 | 11.913 |
| **Delta** | 8.786 | 8.777 |
| **Rank** | **1** | **2** |

**Delta = ( Highest mean S/N Ratio – Lowest mean S/N Ratio )**

### 5.1.3 Analysis of Variance for Corrosion Rate

The following table shows ANOVA of Corrosion Rate conducted on MINITAB 16.0. The result shows that the contribution of temperature is most and is 41.91%.

**Table 5.4 ANOVA of Corrosion Rate**

| Source | DOF | SS | Adj MS | F Value | Contribution |
|---|---|---|---|---|---|
| **Temperature** | 2 | 0.4680 | 0.2340 | 2.24 | 41.91% |
| **Quenching Type** | 2 | 0.2302 | 0.1151 | 1.10 | 20.62% |
| **Error** | 4 | 0.4184 | 0.1046 | | 37.47% |
| **Total** | 8 | 1.1166 | | | 100% |

**At least 95% confidence**

Analysis of variance of corrosion rate of heat treated AISI 1018 is shown in the above table 5.4. It is clear from the table that temperature is the most dominating parameter for corrosion rate with a contribution of 41.91%. Quenching type is the least influencing parameter for corrosion rate with a contribution of only 20.62%.

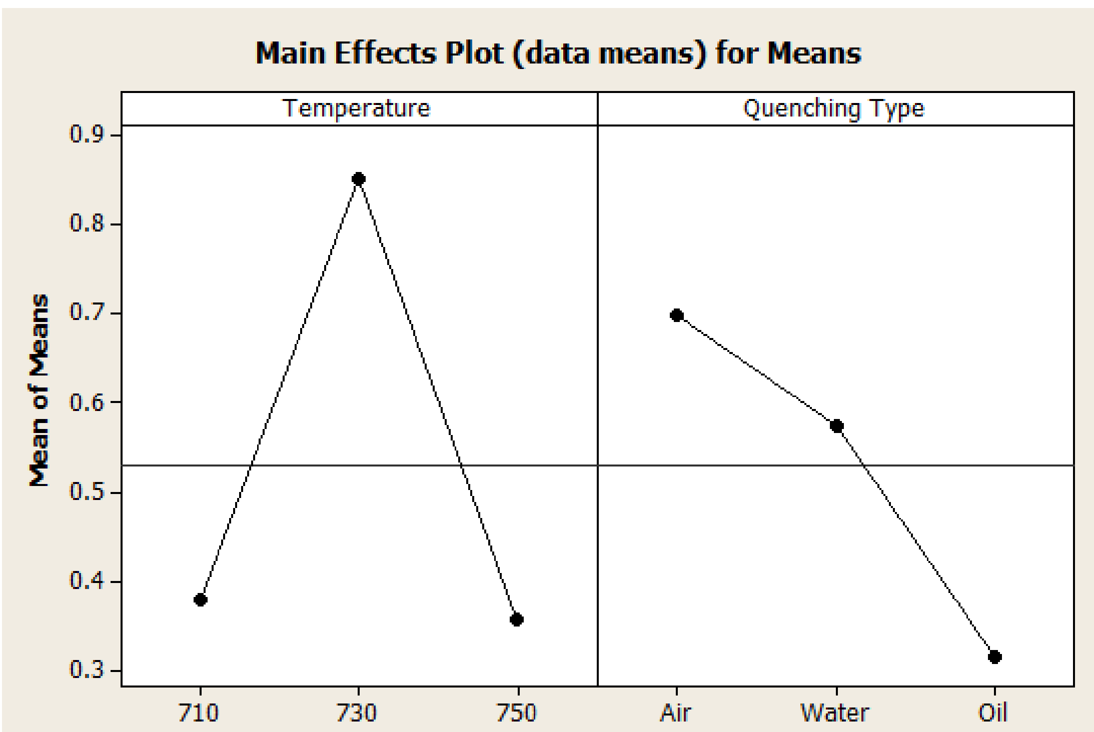


**Figure 4.1 Mean effect plot for Corrosion rate**

The above graph 4.1 shows mean effect plot for corrosion rate with temperature and quenching type. The graph shows that the corrosion rate is highest when the temperature of heat treatment of AISI 1018 is kept 730°C. But at 710°C and 750°C, the corrosion rates obtained is lowest. The average corrosion rate for the present set of experiment is 0.5292mm/year.

Air quenched AISI 1018 is observed to have highest corrosion rate while oil quenching leads to least corrosion rate as observed from the above graph.

**4.2 CALCULATION FOR ULTIMATE TENSILE STRENGTH**

The ultimate tensile strength values of the investigated low carbon steel AISI 1018 are higher than that of un-treated AISI 1018. The higher values of the tensile strength are known to be due to the quenching of specimen.

**Table 4.2 Results obtained for Tensile Strength**

| S.No. | Temperature (°C) | Quenching Type | Ultimate Tensile Strength (MPa) |
|---|---|---|---|
| **1** | 710 | Air | 462 |
| **2** | 710 | Water | 479 |
| **3** | 710 | Oil | 510 |
| **4** | 730 | Air | 458 |
| **5** | 730 | Water | 489 |
| **6** | 730 | Oil | 525 |
| **7** | 750 | Air | 461 |
| **8** | 750 | Water | 484 |
| **9** | 750 | Oil | 538 |

### 5.1.1 Calculation of S/N ratio for Ultimate Tensile Strength

The S/N ratio, which condenses the multiple data points within a trial space, depends on the type of performance measure being evaluated. For calculation of S/N ratio for ultimate tensile strength LARGER IS BETTER condition is considered. The equation for the calculation of S/N ratio for ultimate tensile is:

$$\mathbf{S/NLB = -10 \log \left( \Sigma \left(1/yi^2\right) \right)}$$

**Table 5.2 Calculation of S/N ratio for MRR**

| S.No | Ultimate Tensile Strength | Signal to noise ratio (db) |
|---|---|---|
| **1** | 462 | 53.2928 |
| **2** | 479 | 53.6067 |
| **3** | 510 | 54.1514 |
| **4** | 458 | 53.2173 |
| **5** | 489 | 53.7862 |
| **6** | 525 | 54.4032 |
| **7** | 461 | 53.274 |
| **8** | 484 | 53.6969 |
| **9** | 538 | 54.6156 |

### 5.1.2 Calculation of Mean S/N ratio for Ultimate Tensile Strength

Mean S/N ratio is calculated by using following formula

$$nf_i = (nf_1 + nf_2 + nf_3)/3$$

Where nf is mean S/N ratio for factor f at the level value i of the selected factor.

$nf_1$, $nf_2$, $nf_3$ are S/N ratio for factor f at level u

The factors which affect the machining parameters are shown in the table with their respective ranks. Rank of the parameters depends on the delta value. If the delta value of one parameter is more than the other that indicates first rank. Higher value of S/N ratio of each factor shows the optimal level of the factor. For present set of experiment, type of quenching shows the main influence in the below response table. Temperature is less effective as compared to quenching type.

**Table 5.3 Calculation of mean S/N ratio for Ultimate Tensile Strength**

| **Level** | **Temperature** | **Quenching Type** |
|---|---|---|
| **1** | 53.68 | 53.26 |
| **2** | 53.80 | 53.70 |
| **3** | 53.86 | 54.39 |
| **Delta** | 0.18 | 1.13 |
| **Rank** | **2** | **1** |

**Delta = ( Highest mean S/N Ratio – Lowest mean S/N Ratio )**

### 5.1.3 Analysis of Variance for Ultimate Tensile Strength

The following table shows ANOVA of Ultimate Tensile Strength conducted on MINITAB 16.0. The result shows that the contribution of type of quenching is most and is 53.88%.

**Table 5.4 ANOVA of Ultimate Tensile Strength**

| Source | DOF | SS | Adj MS | F Value | Contribution |
|---|---|---|---|---|---|
| **Temperature** | 2 | 176.2 | 88.1 | 1.28 | 2.62% |
| **Quenching Type** | 2 | 6282.9 | 3141.4 | 45.68 | 93.30% |
| **Error** | 4 | 275.1 | 68.8 | | 4.08% |
| **Total** | 8 | 6734.2 | | | 100% |

**At least 95% confidence**

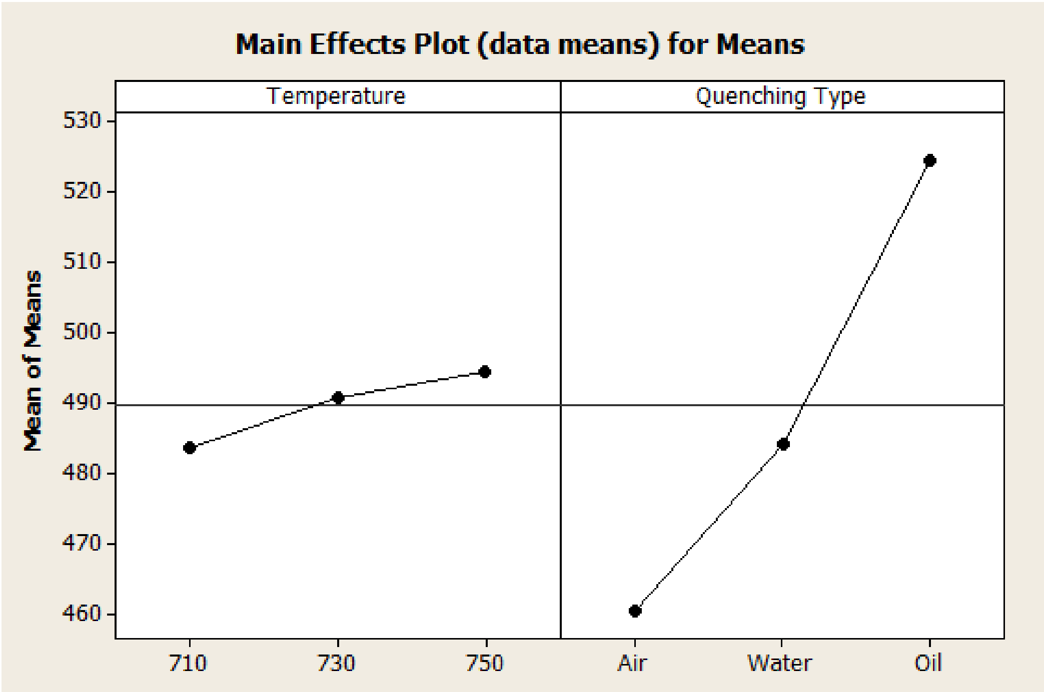


**Figure 5.2: Main effect plot for Ultimate Tensile Strength (UTS)**

Figure 5.2 presents the mean effect plot for UTS. It shows that the UTS increase with both temperature and quenching type. Quenching type has major influence on UTS and Oil quenching imparts highest level of ultimate tensile strength to AISI 1018 under present heat treatment conditions.

Temperature is the least influencing parameter with a contribution of only 2.62%. Thus its effect on UTS is almost negligible.

# CHAPTER - 5

# CONCLUSIONS & FUTURE SCOPE

## 5.1 CONCLUSION

Plain low carbon dual-phase steels with different martensite volume fraction are obtained by heat treatment using different inter-critical temperature (710°C, 730°C and 750°C). The mechanical and corrosion behaviour of the resulting steels is compared and the conclusions are as follows :

1. Increase in intercritically heated temperature increases the martensite volume fraction.
2. With increase in martensite volume fraction, the tensile strength of dual phase steels improved. The hardness values of all DUAL PHASE steel samples were higher than normalised steel and was observed maximum for sample heated to 810°C.
3. Corrosion rated obtained from immersion test of DUAL PHASE steel samples were marginally less than that for normalised steel. This is because the martensite formed in DUAL PHASE steel is structurally and compositionally closer to ferrite matrix phase.Therefore galvanic coupled formed between ferrite-martensite is weaker. This is compared to normalised steel wherein pearlite which consist of ferrite and cementite lamellae is structurally and compositionally inhomogeneous, which resulted in increased corrosion rates.

## 5.2 FUTURE SCOPE

When consumers think of their future vehicle, they expect it to be affordable, safe and fuel-efficient. They imagine faster, stronger and lighter cars. However, people do not see the race of automotive materials to full fill carmakers needs to produce the ultimate lightweight technologies. Since the 1930s, steel has been the material of choice for body and chassis applications in the automotive industry. However, just like any other material, steel has had to develop and advance through the years in order to remain a competitor. The automotive industry considers three major factors when determining the best way to embrace light weighting: materials; process; and design. With these factors in mind, advanced high-strength steel (Dual-phase steel) remains a leading choice for light weighting and durability in the vehicle structure.

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