CHARECTERIZATION OF DUAL PHASE PLAIN CARBON STEELS

Thesis
Submitted in partial fulfilment of the requirements for the degree of

BACHELOR OF TECHNOLOGY
IN
METALLURGICAL AND MATERIALS ENGINEERING

BY

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APRIL, 2018

DECLARATION

We hereby *declare* that, the Project Work Report entitled "**CHARECTERIZATION OF DUAL PHASE PLAIN CARBON STEELS**", which is being submitted to the National Institute of Technology Karnataka, Surathkal for the award of the degree of Bachelor of Technology in **METALLURGICAL AND MATERIALS ENGINEERING**, is *a bonafide report of the work carried out by us*. The material contained in this Project Work Report has not been submitted to any other University or Institution for the award of any degree.

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CERTIFICATE

This is to *certify* that the U.G. Project Work Report entitled "**CHARECTERIZATION OF DUAL PHASE PLAIN CARBON STEELS**", submitted by ***K. YUVA SIMHA (14MT25)*** *and* ***Y. SHANMUKHA SRIKANTH (14MT44)***, as the record of the work carried out by them is accepted as the *U.G. Project Work submission* in partial fulfilment of the requirements for the award of **BACHELOR OF TECHNOLOGY** in **METALLURGICAL AND MATERIALS ENGINEERING** in the **DEPARTMENT OF METALLURGICAL AND MATERIALS ENGINEERING, NATIONAL INSTITUTE OF TECHNOLOGY KARNATAKA, SURATHKAL** during the year 2017-18, is a bonafide work carried out by them under my supervision and guidance.

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ABSTRACT

Dual phase steels (D.P.) steels are the high strength steels which constitutes of ferrite-martensite microstructure. It consists of a soft ferritic phase as matrix and islands of martensite as secondary phase. This combination of microstructure gives a good amount of strength, hardness, and strain hardening without losing the properties such as ductility and energy absorption.

These mechanical properties can be altered by altering the martensite and ferrite fractions, grain size and carbon content. This work studied the effect of varying carbon contents and temperatures on the microstructure and mechanical properties of the Dual phase steels. Generally these steels are produced from low and medium carbon steels that are quenched from a temperature that is between A_1 and A_3.

Mild steel, 0.45% C steel, and EN 45 steel were procured in the form of rods and samples were prepared for examination of changes in microstructure and other mechanical properties namely harness and tensile strength after heating them to different temperatures between A_1 and A_3 and soaked there for 30 minutes before quenching them in water.

The microstructure of the “as received” samples as well as the heat treated samples were examined with the help of an optical microscope. To correlate with the microstructural changes, the variations in mechanical behavior have been examined. The tensile strength, percentage elongation, and yield strength have been calculated with the help of Shimadzu Universal Testing Machine and hardness with the help of a Rockwell hardness tester.

Later, the microstructures have been examined for the percentage carbon in the as received samples and the amount of phases (ferrite and martensite) in the heat treated samples. This is done with the help of Image J software.

KEY WORDS: DUAL PHASE, FERRITE-MARTENSITE, CARBON CONTENT, MICROSTRUCTURE

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NOMENCLATURE

MPa = Mega Pascals

KgF = Kilogram Force

KN = Kilo Newton

CHAPTER 1: INTRODUCTION

Dual phase steels, which come under the family of Advanced High Strength Steels (AHSS) which are complex and sophisticated materials, were developed to enhance the strength of steels without losing its property of absorption of energy and formability. The microstructure of these steels which is essentially the combination of ferrite and martensite phases plays a very important role in obtaining a what are called an optimum range properties of both strength as well as ductility.

The microstructure of D.P. steels consists of ferrite matrix which is essentially the primary phase in the microstructure responsible for the ductility of the steel and the martensitic phase which is present as islands surrounded by ferrite phase acts as secondary phase which is responsible for enhancing the strength of the steel.

Generally for obtaining the desired microstructure, D.P. Steels contain 0.06–0.15 wt.% Carbon and 1.5-3% Manganese, Chromium, Molybdenum, Silicon, Vanadium and Niobium in very small amounts, where Carbon strengthens the martensite, and Manganese causes solid solution strengthening in ferrite, while both stabilize the austenitic phase, Chromium and Molybdenum to retard pearlite or Bainite formation, Silicon to promote ferrite transformation, Vanadium and Niobium for precipitation strengthening and microstructure refinement.

The above combination results in low yield strength and high tensile strength of the material. D.P. steels undergo high strain hardening especially at the beginning of plastic deformation. Also, they can be strengthened by static or dynamic strain ageing through the so called bake hardening effect. D.P. steels with low carbon content exhibit excellent resistance to fatigue crack propagation at growth rates close to fatigue threshold thus making them the candidates for the automotive applications.

The microstructures of DP steels are typically not good candidates for applications that require high drawability due to the differences in hardness values between the two phases, namely ferrite and martensite. This drawback, however, can be eliminated by adding Ti with the aim of inducing precipitation strengthening in ferrite to reduce the differences in hardness between the two phases.

The effects of varying parameters such as volume fraction of the phases, temperature of soaking, grain size and carbon content on the properties of these steels and also the applications in the industrial sector for this family of steels has been discussed in the later chapters of this report.

CHAPTER 2: LITERATURE REVIEW

2.1 DUAL PHASE STEELS

A dual phase steel is a high strength steel that has a ferritic martensitic microstructure. Since it is a combination of two phases, the name thus derives itself and is self-explanatory. Generally in these steels, the matrix or the primary phase is the soft ferrite and the secondary phase which is harder is the martensite. The development of these steels started in the 1970s. Dual-phase (DP) steel is the flagship of advanced high-strength steels, which were the first among various candidate alloy systems to find application in weight-reduced automotive components.

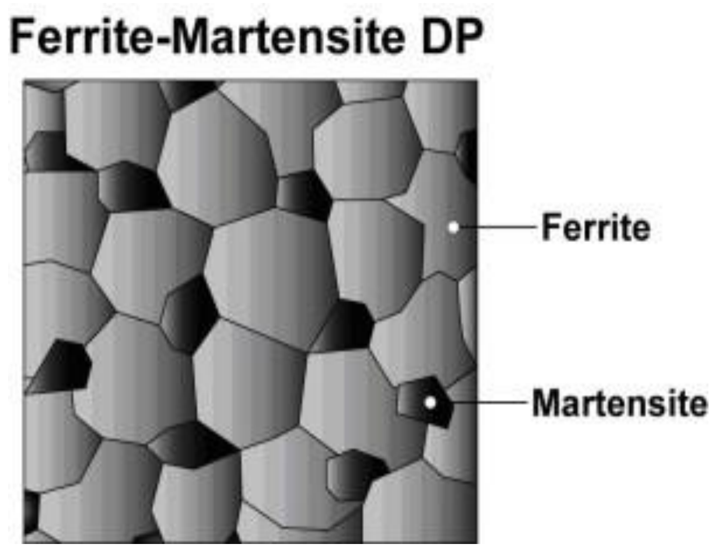


Figure 2.1 Schematic showing islands of martensite in a matrix of ferrite (Ref 1)

On the one hand, this is a metallurgical success story: Lean alloying and simple thermomechanical treatment enable use of less material to accomplish more performance while complying with demanding environmental and economic constraints. On the other hand, the enormous literature on DP steels demonstrates the immense complexity of microstructure physics in multiphase alloys: Roughly 50 years after the first reports on ferrite-martensite steels, there are still various open scientific questions. Fortunately, the last decades witnessed enormous advances in the development of enabling experimental and simulation techniques, significantly improving the understanding of DP steels.

Increasing the volume fraction of hard second phases generally increases the strength. DP steels are produced by controlled cooling from the austenite phase or from the two-phase ferrite plus austenite phase to transform some austenite to ferrite before a rapid cooling transforms the remaining austenite to martensite. Due to the production process, small amount of other phases (Bainite and Retained Austenite) may be present. The work hardening rate plus excellent elongation creates DP steels with much higher ultimate tensile strengths than conventional steels of similar yield strength. These are the second generation steels that are produced in the AHSS family after the conventional first generation steels.

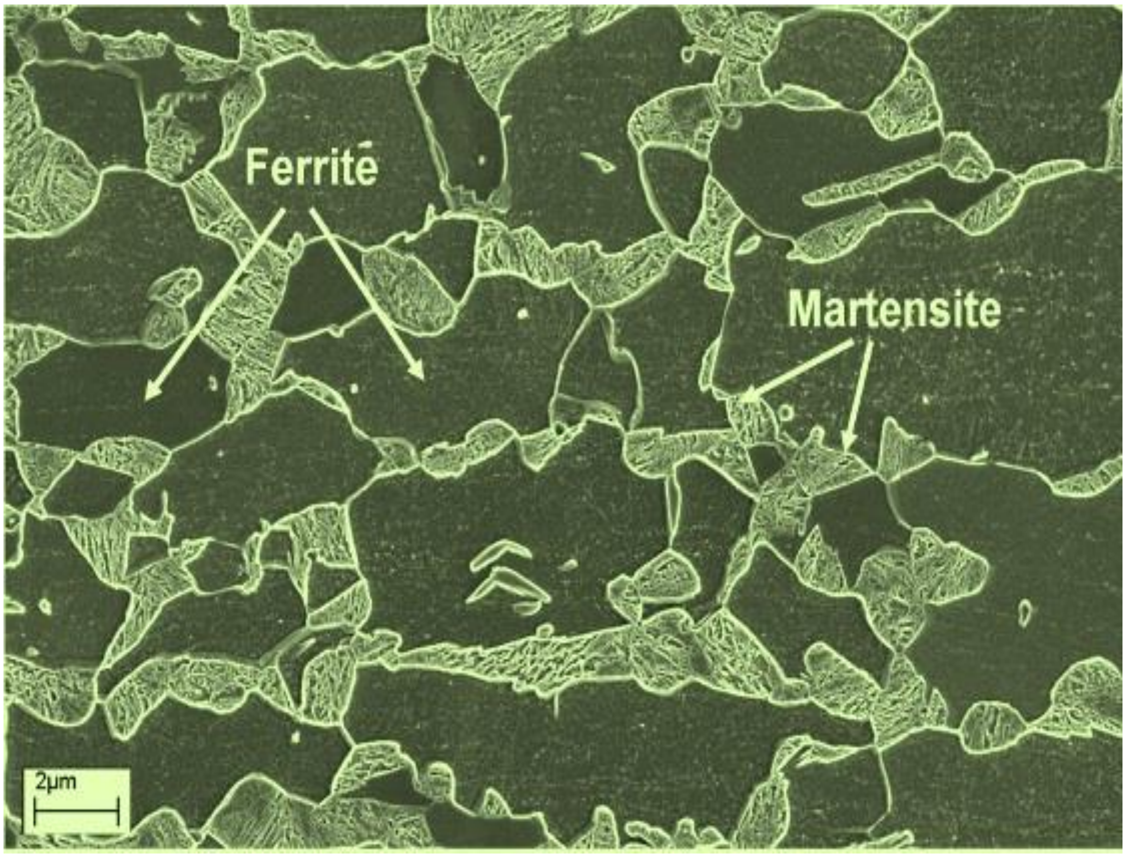


Figure 2.2 Microstructure of Ferrite Martensite Dual phase

The DP steel exhibits higher initial work hardening rate, higher ultimate tensile strength, and higher tensile strength to yield strength (TS/YS) ratio than a similar yield strength HSLA. DP and other AHSS also have a bake hardening effect that is an important benefit compared to conventional higher strength steels. The bake hardening effect is the increase in yield strength resulting from elevated temperature aging after pre straining by the work hardening due to deformation during stamping or other manufacturing process. The extent of the bake hardening effect in AHSS depends on an adequate amount of forming strain for the specific chemistry and thermal history of the steel.

2.2 MANUFACTURING TECHNIQUES

Dual phase steels were developed in the mid-1960s concurrently at BISRA (British Iron and Steel Research Association) in the United Kingdom and the Inland Steel Corporation in the US. The BISRA objective was to develop an annealed process with 500 MPa tensile strength whereas the Inland aimed towards developing a 1000 MPa strength steel. Later, a scientist named Bailey discovered in the mid 1970s that the inter critical heating of the steel into the austenite-ferrite phase followed by quenching and tempering yielded a dual phase microstructure.

2.2.1 CONTINOUS ANNEALING

The continuous annealing processes have three common salient features, namely

1. Rapid heating to above the critical temperature A_1
2. A short time holding at the temperature, and
3. Cooling below martensite start (M_s) temperature.

Some processes also include a short time tempering below 500^0C after cooling from above A_1 to improve the ductility and the toughness of the steel at the expense of tensile strength. The rate of heating for this process has far less importance than the, heating temperature, holding time, or cooling rate. Inter critical heating gives good control over volume fraction and composition.

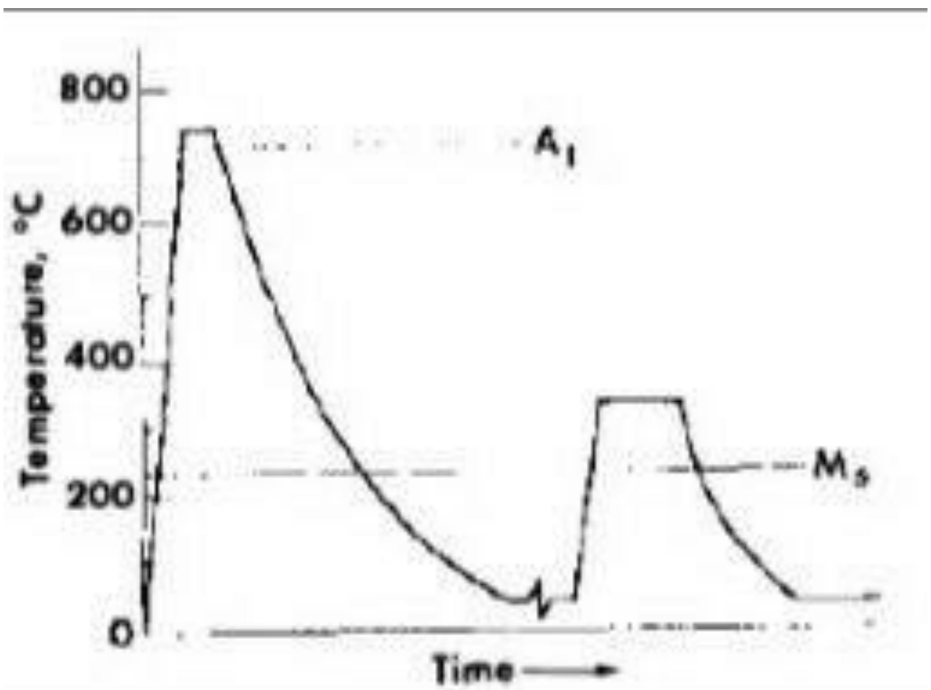


Figure 2.3 Schematic Representation of various steps involved in Continuous annealing process (Ref 3)

2.2.2 AS-ROLLED

In the as-rolled process the steel composition is chosen such that 80-90% steel transforms to ferrite after the final roll pass in the conventional hot rolling. The remaining 10-20% doesn't transform until much later, during slow cooling. This is possible with the steel compositions that exhibit certain special characteristics in their Continuous Cooling Transformation (CCT) Diagram, namely

- an elongated ferrite C curve, i.e., the ability to form ferrite over a wide range of cooling rates
- A suppressed ferrite nose and high pearlite finish temperature to ensure avoidance of pearlite formation during cooling
- A gap between pearlitic and bainitic regions to provide a temperature range within which no transformation occurs.

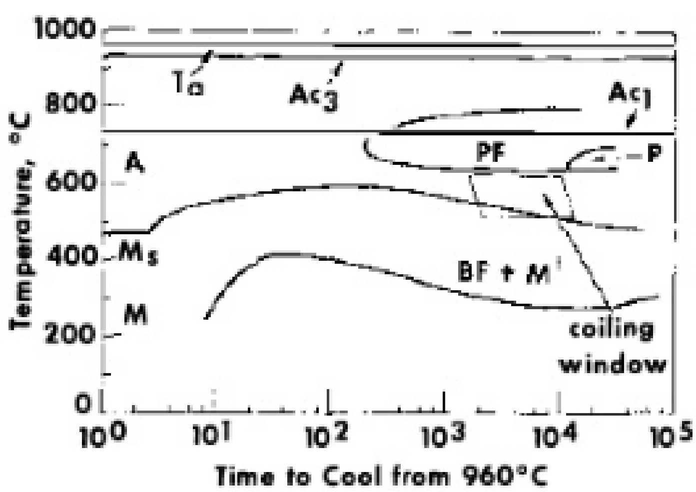


Figure 2.4 CCT of an as-rolled dual phase steel (A= Austenite, PF= Polygonal Ferrite, P= Pearlite, BF= Bainitic Ferrite, M= Martensite, T_α= Austenization temperature)

2.2.3 BATCH ANNEALED

Dual phase steels have also been produced by Batch annealing techniques modified for heating in the inter critical temperature range. The very slow cooling rates inherent in this approach necessitate the use of steels with very high alloy content and high hardenability. This approach is presently the least researched of the three.

2.3 COMPOSITION-STRUCTURE-PROPERTY RELATIONSHIP

D.P. steels have been modeled as two phase composites: the ferrite is treated as a homogenous ductile matrix phase and the martensite is treated as a high strength reinforcing component. Since martensite is the primary load bearing constituent, various attempts have been made to correlate volume percent of martensite with steel strength. The two are linearly related independent to the martensite carbon content. Further work showed that the martensite carbon content is equally important.

A smaller volume of high carbon content martensite produces the same strength as a larger volume of low carbon content martensite. Besides carbon content, the strength of martensite can also be altered by altering it's grain size.

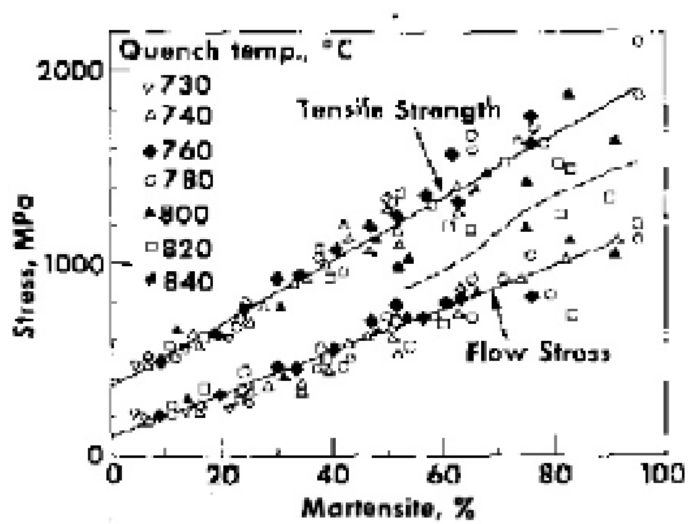


Figure 2.5 Tensile Strength and Flow stress as a function of % of martensite (ref 3)

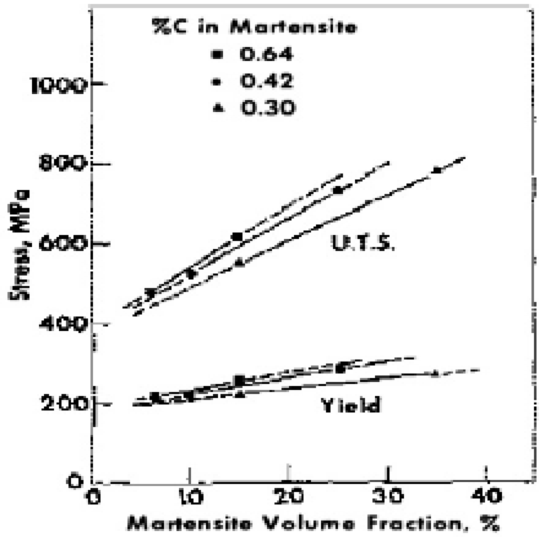


Figure 2.6 Tensile and Yield strength as a function of martensite volume fraction for different carbon contents (ref 3)

2.4 APPLICATIONS

Dual Phase steels offer an outstanding combination of strength and drawability as a result of their microstructure, in which a hard martensitic or bainitic structure is present in the ferritic matrix. These steels have high strain hardenability. This gives them good strain redistribution capacity and thus drawability as well as finished properties including yield strength, that are far superior to those of the initial blank.

High finished part mechanical strength lends these steels excellent fatigue strength and good energy absorption capacity, making them suitable for the use of reinforcements. Given their high energy absorption capacity and fatigue strength, cold rolled Dual Phase Steels are particularly well suited for automotive structural and beams, cross members and reinforcements.

Fully Finished 280 DP (FF 280 DP) can be used to make visible parts with 20% higher dent resistance than conventional high strength steels, resulting in a potential weight As a result of its mechanical strength, hot rolled Dual Phase 600 (DP 600) can be used to reduce the weight of structural parts by decreasing their thickness.

Some of the parts include:

- Wheel webs
- Longitudinal rails

- Shock towers
- Fasteners.
- Bumpers
- B-Pillars

Figure 2.7 Bumper (ref 4)

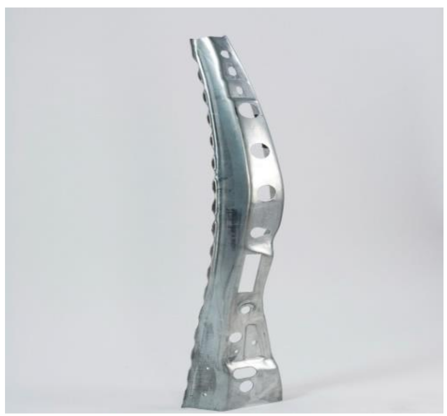


Figure 2.8 B-Pillar (ref 4)

Figure 2.9 Wheel Web (ref 4)

2.5 TECHNICAL CHARECTERISTICS

- **TENSILE CHARECTERISTICS**

Dual phase steels are associated with having excellent tensile charecteristics. They have a low yield strength and very good tensile strength. The tensile strength of a dual phase steel is higher when compared to the high strength alloys of same yield strength.

The service properties of the dual phase steels are guaranteed by controlling manufacturing processes. The controlled temperature and cooling speed helps in the achievement of DP microstructure and desired properties.

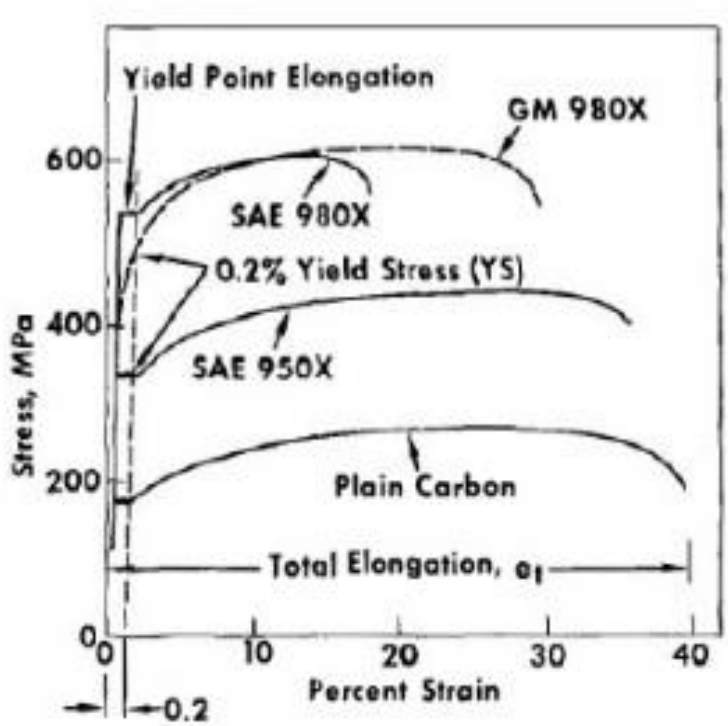


Figure 2.10 Schematic stress strain curves for plain carbon, HSLA, and dual phase steels. SAE 950X and 980X are Society of Automotive Engineers designations for HSLA steels of different strength levels. GM 980X is a General motors developed dual phase steel. (ref 3)

- **FORMING**

  Dual Phase steels offer an excellent combination of strength and drawability as a result of their good ductility and strain hardening capacity to ensure homogeneous strain redistribution and reduce local thinning. The yield strength can be further increased through bake hardening.

  Dual Phase steels can be drawn on conventional tools, provided the settings are properly adjusted. The drawing pressure should be increased for Dual Phase steel, compared to a micro-alloyed (HSLA) type steel of the same thickness.

- **WELDING**

  Although Dual Phase steels are more or less alloyed than HSLA steels, they can be readily welded using conventional resistance spot welding processes.

As a result of their high tensile strength and energy absorbing capacity, they have a very good fatigue strength and impact strength, and are useful for the applications involving high impact resistance, such as the bumper of an automobile, and other such parts, which takes the maximum amount of load when an accident happens.

OBJECTIVES OF THE PROJECT:

- To check whether the dual phase structure and properties can be attained for medium and high carbon steels also along with low carbon steels, because the development of dual phase steels has always been around the low carbon steels mostly, and it is also one of the condition for formation of dual phase that the carbon content should be around or less than 0.2% approximately.
- To correlate between the structure and properties of the after heat treated samples of steels such that the processing parameters can be controlled and optimized in the future to achieve the required properties.

CHAPTER 3: EXPERIMENTAL PROCEDURE

3.1 MATERIALS

The materials selected for the purpose of investigation were mild steel, 0.45 wt. % carbon steel and EN 45 (0.6 wt.%C). Although the investigation is mainly around the plain carbon steels, due to the lack of availability of the material which is 0.6 wt.%C steel, EN 45 a low alloy steel has to be taken for this purpose. The materials were obtained in the form of rods of diameters 12.7 mm (½ inch) for mild steel and 0.45 wt. % C steel and 16 mm for EN 45 respectively.

3.2 COMPOSITION

The exact carbon composition of the materials were found in the following way. Samples of approximately 2 cm were cut off from the received rods and subjected to annealing. This annealing is a cycle where the samples were taken into austenitizing temperatures and were soaked there for sufficient time for homogenization (approximately 1 hour for 1 inch sample). After that they are subjected to furnace cooling. Now that the samples are either plain carbon steels or low alloy steels that are pro eutectic, the microstructure obtained is a combination of ferrite and pearlite of different compositions.

These samples after cooling completely to room temperature are to be observed under optical microscope for the microstructural observation. For this purpose, some amount of sample preparation is necessary. So, the samples were subjected to belt grinding, followed by surface preparation using emery papers of varying abrasiveness ranging from papers 1/0 to 4/0, where 1/0 being very rough and 4/0 being smooth. The samples were then subjected to cloth polishing to obtain mirror finish on the surface of the sample so that the scratches on the sample were eliminated. Now, the sample is ready to be observed under the optical microscope.

After the sample preparation, microstructures have been observed under the optical microscope. Using these microstructures, and with the help of ImageJ software, volume fractions of the phases, namely ferrite and pearlite were found out. With the help of Iron Carbide phase diagram, the amount of Carbon was found out in the obtained materials.

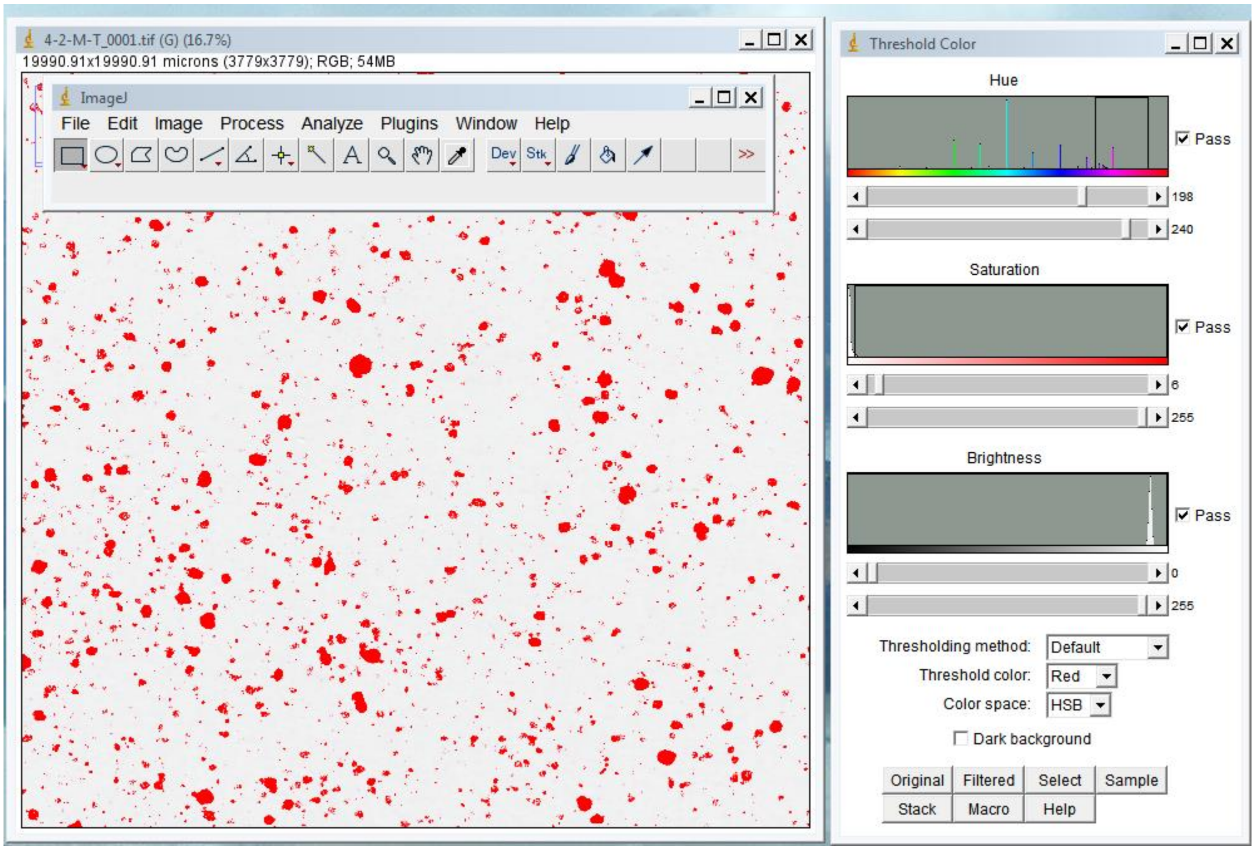


Figure 3.1 Image threshold method to find the percentage of a phase present in the microstructure by highlighting the phase and calculating its fraction.

3.3 HEAT TREATMENT

Three samples of approximately 2 cm in length and three tensile samples were taken for each composition and are subjected to the heat treatment cycle. The cycle consists of heating the samples to a temperature between A_1 and A_3 and soaking there for required amount of time such that all the pearlite in the samples gets converted into ferrite and austenite. These samples are then quenched into water so that the austenite present gets converted into martensite phase and the ferrite remains as such.

The temperature is also varied such that one sample in each composition is heated to a different temperature between A_1 and A_3. The temperatures selected for this purpose were 740, 765 and 790 degrees Celsius for mild steel and 0.45% C steel and 740 and 765 degrees Celcius for EN 45 respectively as they are expected to lie between the range of temperatures specified. To check the variation and adjust the temperature inside the furnace for a good heat treatment, an external thermocouple is used.

Figure 3.2 A Picture showing the furnace set up for heat treatment, including an electrical furnace, a thermocouple, and a voltmeter.

3.4 MICROSTRUCTURAL ANALYSIS

After the heat treatment is done, the first result to check for is the microstructure. For this purpose, the heat treated samples of 2mm length were taken and the surface is prepared by belt grinding followed by polishing with emery paper, and then the cloth polishing. The objective of doing cloth polishing is to obtain a mirror finish on the surface. This is done by polishing with alumina solution (alumina powder in distilled water).After the mirror finish is obtained on the surface of the samples, they were checked for the microstructure under optical microscope and were checked for scratches.

After obtaining a scratch free surface, it is subjected to etching to reveal the different phases present in the microstructure. Here in this experiment 2% NITAL is used as an etchant. It differentiates between ferrite and martensite by reacting with only one phase and not reacting with another. The obtained microstructures were then subjected to metallographic studies and saved as pictures with the help of microscope and the ZEISS Axio Lab software.

Figure 3.3 Zeiss Optical Microscope

3.5 HARDNESS MEASUREMENT

Hardness measurement was done on Rockwell hardness testing machine with a diamond cone indenter. Since, the specimens were of hardened steel, Rockwell C scale is used for the measurement of hardness. The specimen surface has to be exactly perpendicular to the indenter on the hardness testing machine, thus, first the surface need to be made flat. For this purpose, belt grinding is done.

After the sample preparation is done, it is tested for hardness. The procedure includes applying a minor load to the specimen to seat it and then reduce the amount of surface preparation needed. It also minimizes the tendency for ridging or sinking in by the indenter. The major load is then applied and then sufficient amount of time is given for the dial to get into rest position. The load is now released and the reading on the dial is noted down as the hardness number.

Figure 3.4 Rockwell hardness testing machine

3.6 TENSILE TESTING

Tensile testing was done by using a Shimadzu AG-X plus 100 KN universal testing machine. The specimens have to be prepared to meet the requirement of the above testing machine. Thus the samples were machined to meet the standards specified as per ASTM E8 and then tested in the Shimadzu AG-X plus UTM with a head speed of 1mm per minute and the results were noted down.

The relations between the percentage martensite and elongation, and between the percentage martensite and tensile strength were also derived. The ratio of Tensile strength to yield strength (UTS/YS) was also noted down.

Figure 3.5 Shimadzu AG-X plus UTM

CHAPTER 4: RESULTS AND DISCUSSION

4.1 MICROSTRUCTURES

4.1.1 MILD STEEL

4.1.1.1 AS RECEIVED SAMPLE

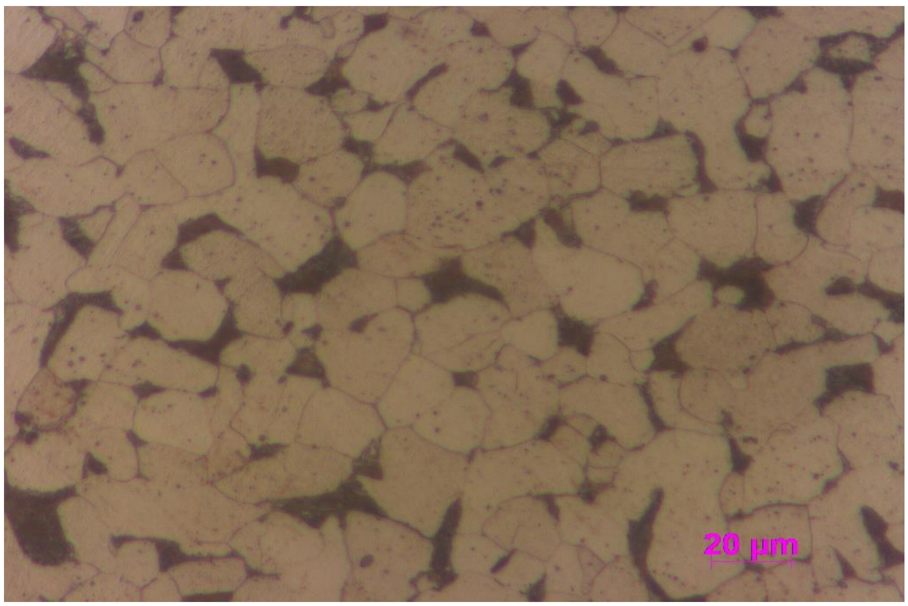


Figure 4.1 Microstructure of mild steel as received sample, after etching, at 500X magnification showing ferrite and pearlite phases.

4.1.1.2 HEAT TREATED SAMPLE (740^0 C)

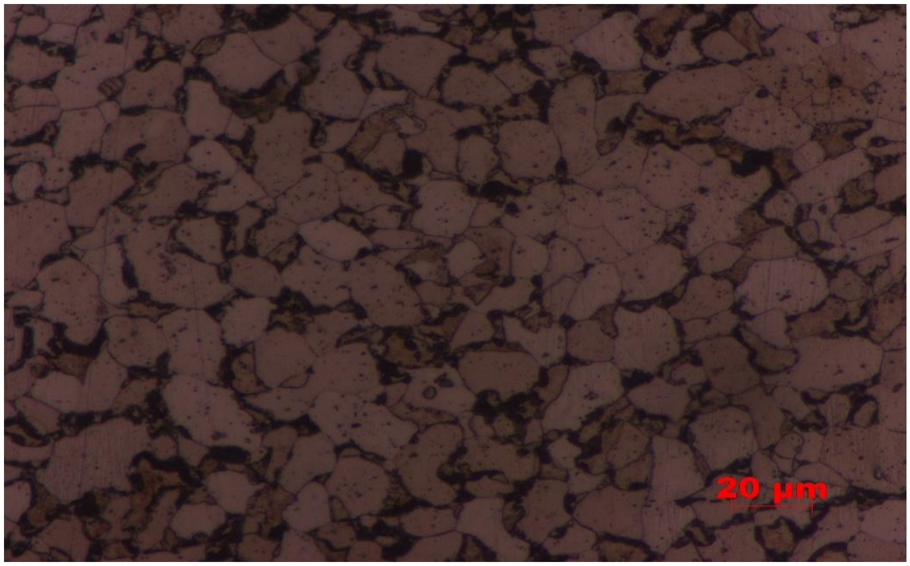


Figure 4.2 Microstructure of after heat treated steel sample showing ferrite and martensite phases, after etching at 500X magnification.

4.1.1.3 HEAT TREATED SAMPLE (765^0 C)

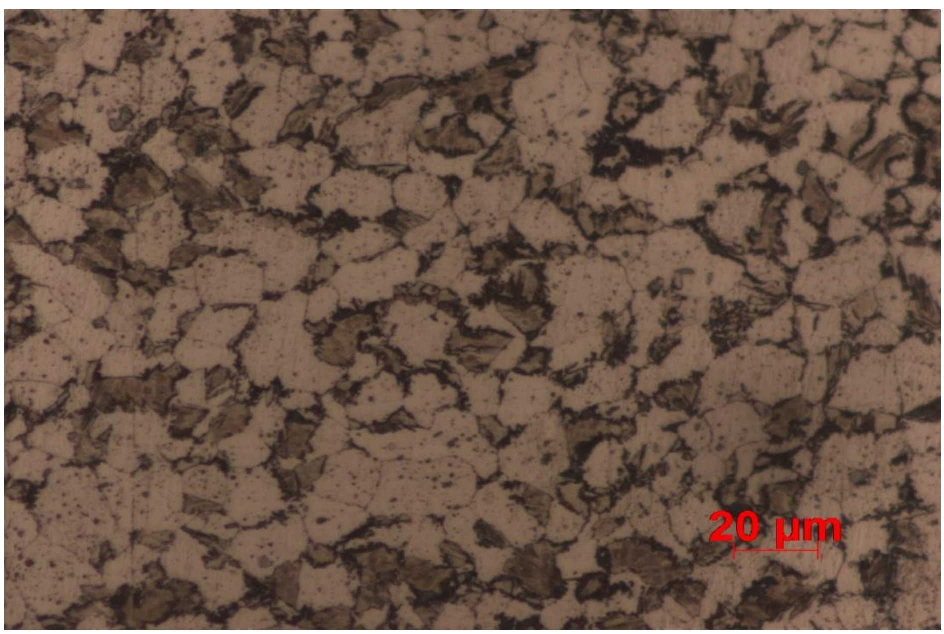


Figure 4.3 Microstructure of after heat treated steel sample showing ferrite and martensite phases, after etching at 500X magnification.

4.1.1.4 HEAT TREATED SAMPLE (790^0 C)

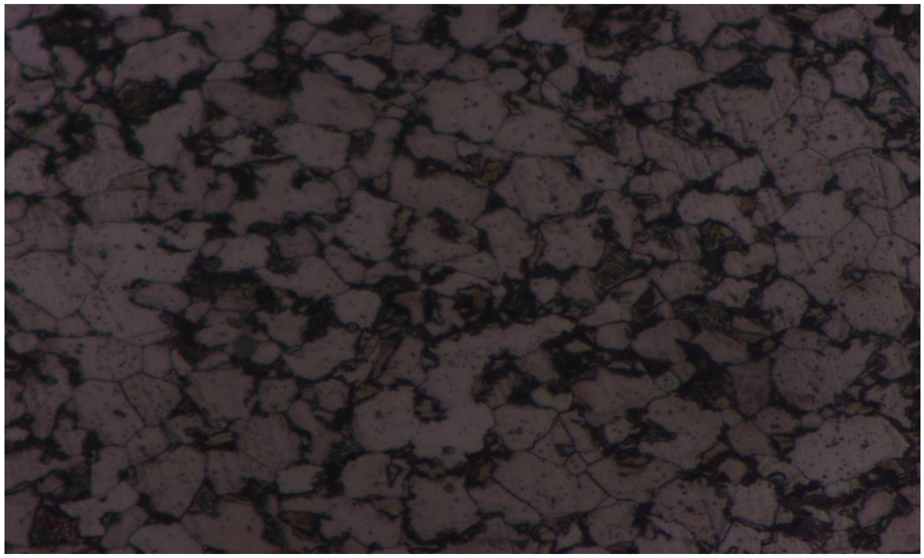


Figure 4.4 Microstructure of after heat treated steel sample showing ferrite and martensite phases, after etching at 500X magnification.

4.1.2 0.45 wt. %C STEEL

4.1.2.1 AS RECEIVED SAMPLE

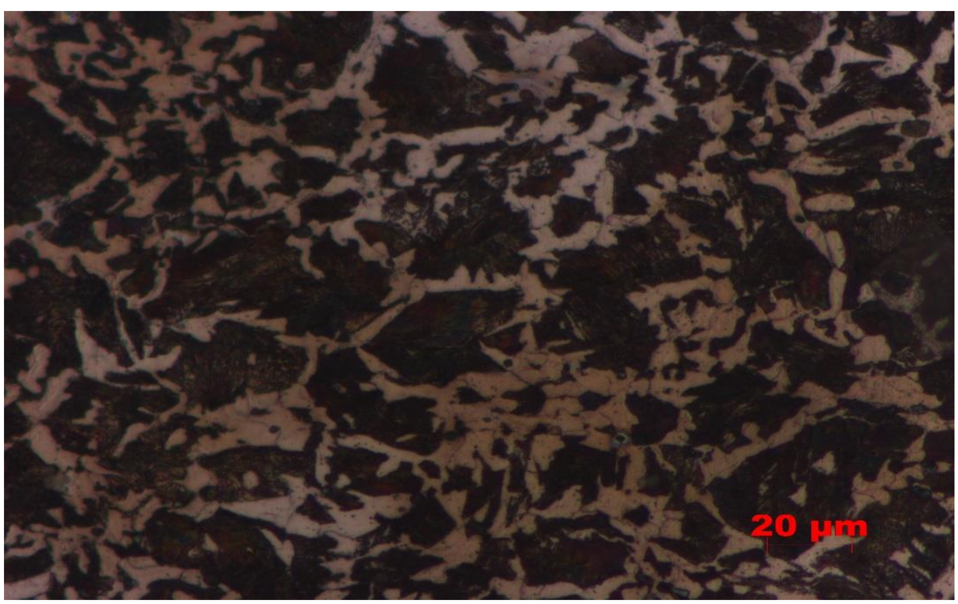


Figure 4.5 Microstructure of as received 0.45%C steel showing ferrite and pearlite phases, after etching at 500X magnification.

4.1.2.2 HEAT TREATED SAMPLE (740^0 C)

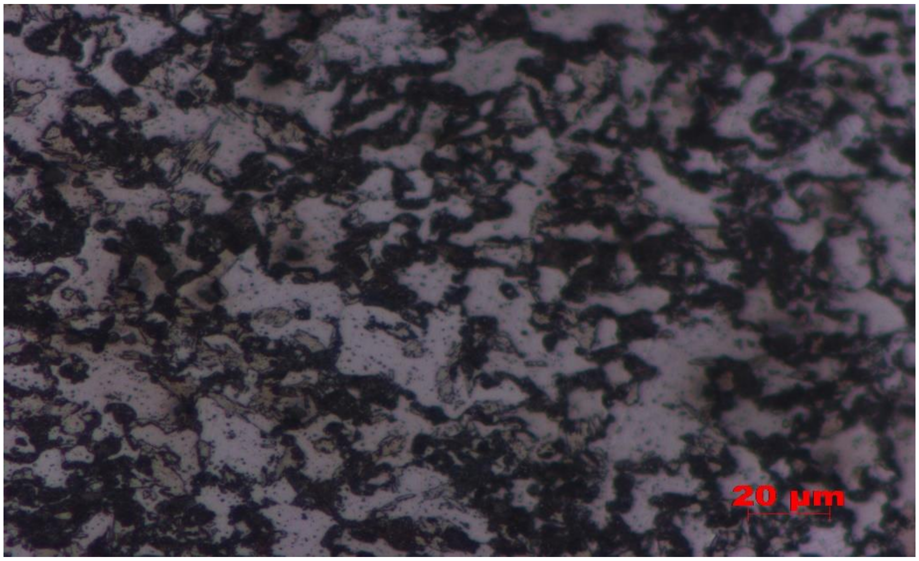


Figure 4.6 Microstructure of after heat treated steel sample, showing ferrite and martensite phases, after etching at 500X magnification.

4.1.2.3 HEAT TREATED SAMPLE (765^0 C)

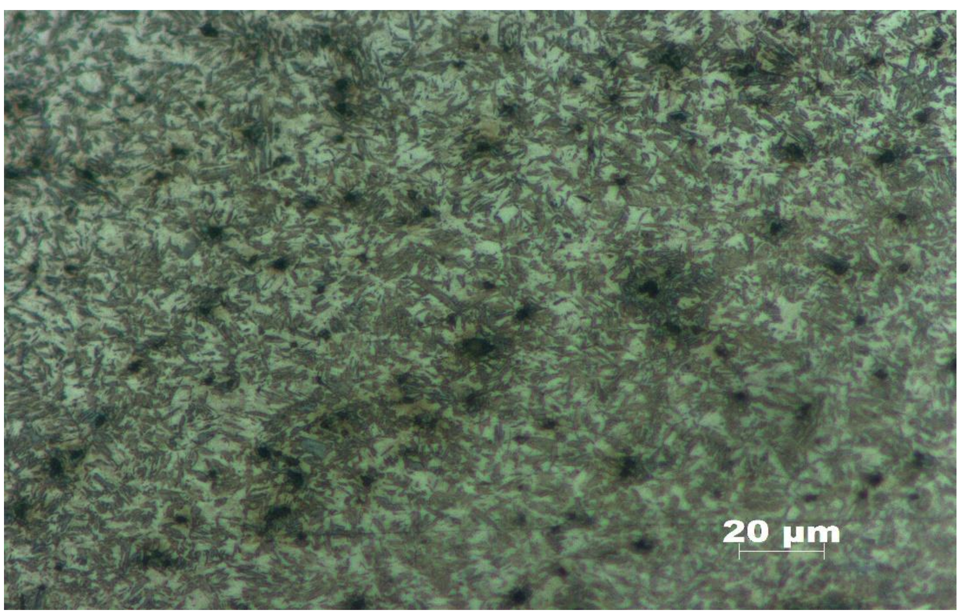


Figure 4.7 Microstructure of after heat treated steel sample, showing ferrite and martensite phases, after etching at 500X magnification

4.1.2.4 HEAT TREATED SAMPLE (790^0 C)

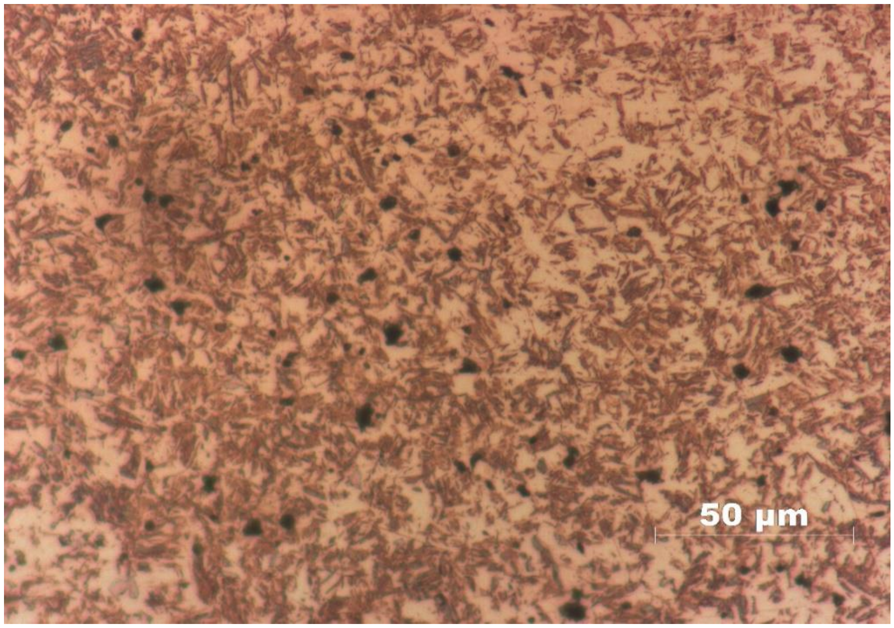


Figure 4.8 Microstructure of after heat treated steel sample, showing ferrite and martensite phases, after etching at 500X magnification.

4.1.3 EN 45 STEEL

4.1.3.1 AS RECEIVED SAMPLE

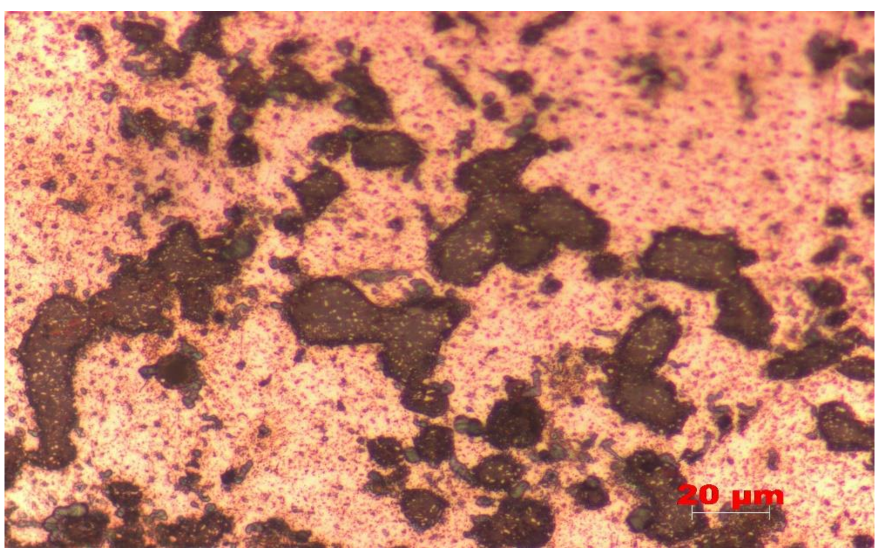


Figure 4.9 Microstructure of as received EN 45 sample, after etching at 500X magnification

4.1.3.2 HEAT TREATED SAMPLE (740^0 C)

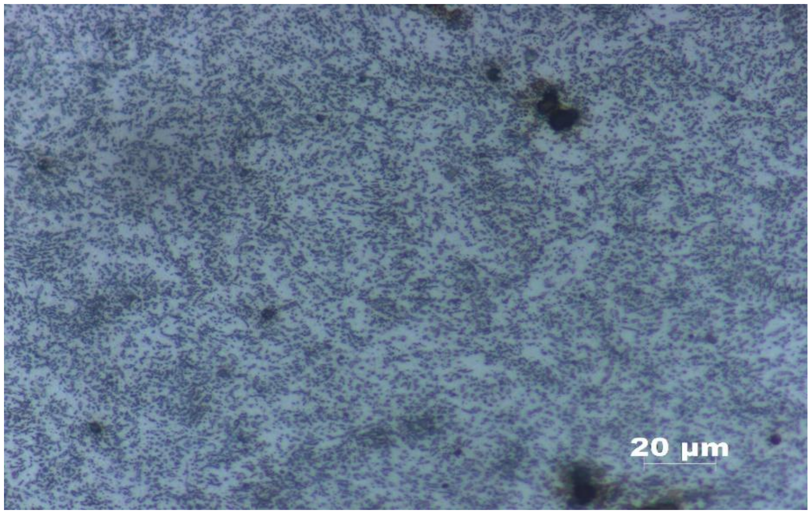


Figure 4.10 Microstructure of after heat treated EN 45 steel sample, at 500X magnification after etching

4.1.3.3 HEAT TREATED SAMPLE (765^0 C)

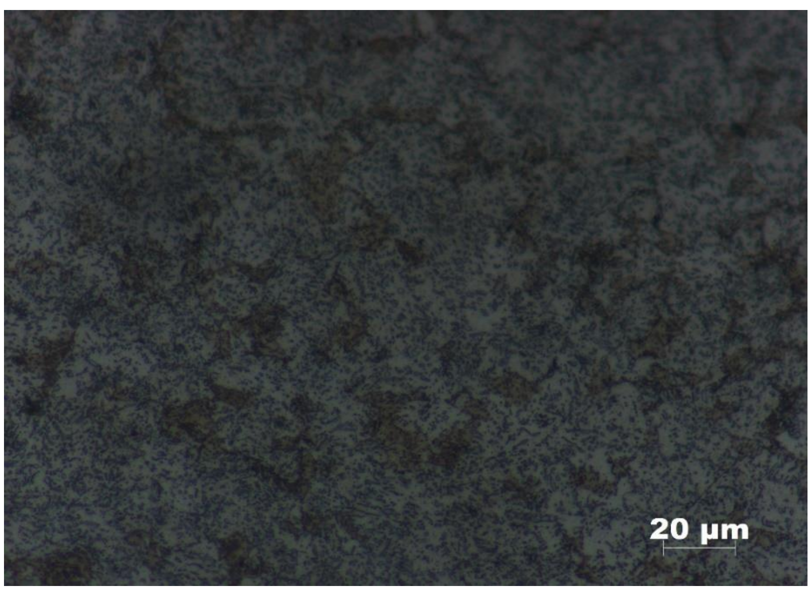


Figure 4.11 Microstructure of after heat treated EN 45 steel sample, at 500X magnification after etching

4.2 COMPOSITION

The composition was calculated through the method of image thresholding and then calculating the percentage area covered under the region. For this purpose, the samples of as received steels have been taken and the standard surface preparation procedure is done and the obtained microstructure is analysed and fed into the software for composition calculation. The carbon percentage carbon was calculated with the help of Iron Carbide phase diagram.

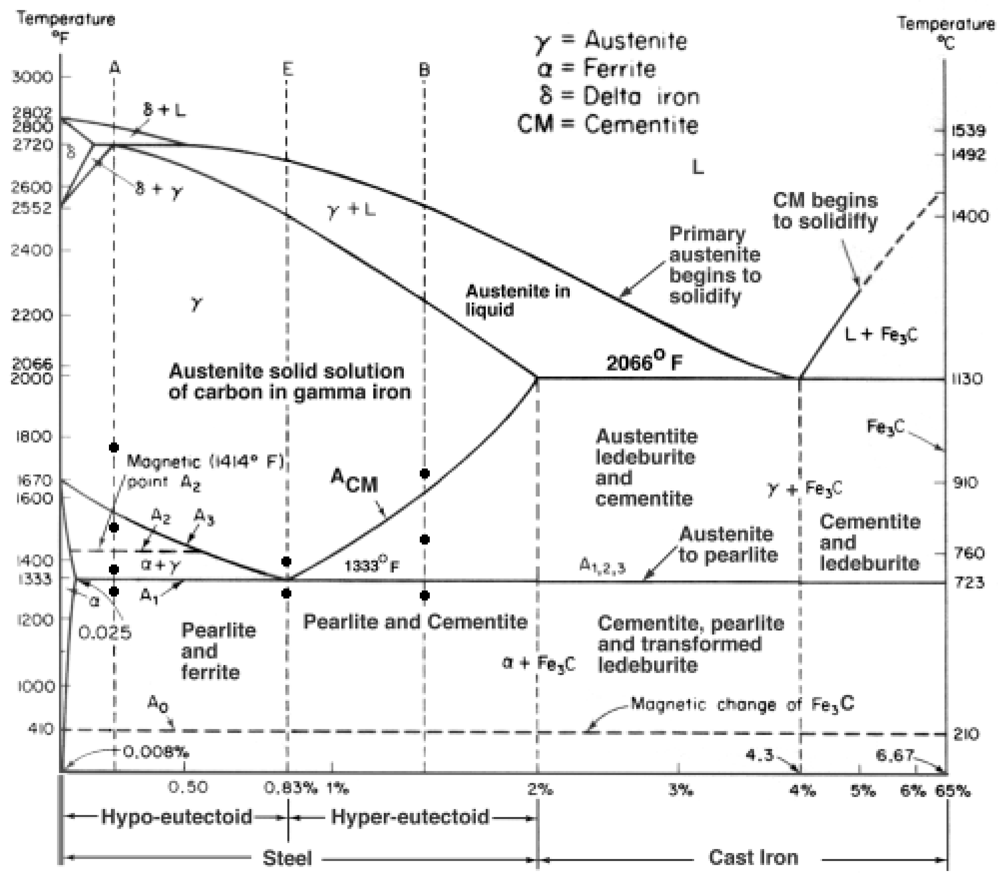


Figure 4.12 Iron Carbide Phase Diagram (ref 5)

4.2.1 AS RECEIVED SAMPLES

4.2.1.1 MILD STEEL:

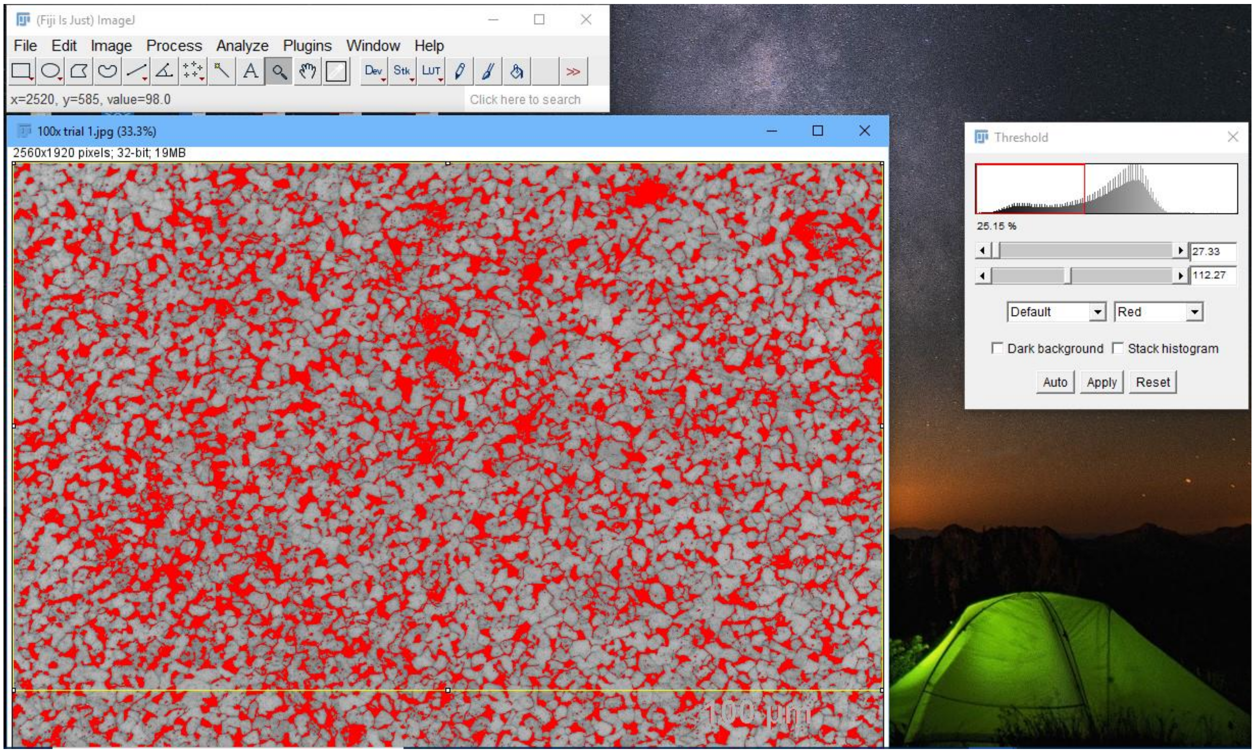


Figure 4.12 Image threshold of mild steel as received sample to calculate the Carbon content through the % area calculation of each phase.

The area fraction of threshold region (red) i.e., pearlite phase is 25.15%

Therefore, the ferrite phase is 100-25.15 = 74.85%

According to Iron Carbide Phase Diagram,

$$\%pearlite = \frac{x - 0.02}{0.8 - 0.02} * 100$$

Where, x is the percentage Carbon in the steel. But %pearlite = 25.15

$$18.36 = \frac{x - 0.02}{0.8 - 0.02} * 100$$

Solving the above equation, $x = 0.21\%$, which is the %C in mild steel sample.

4.2.1.2 0.45%C STEEL:

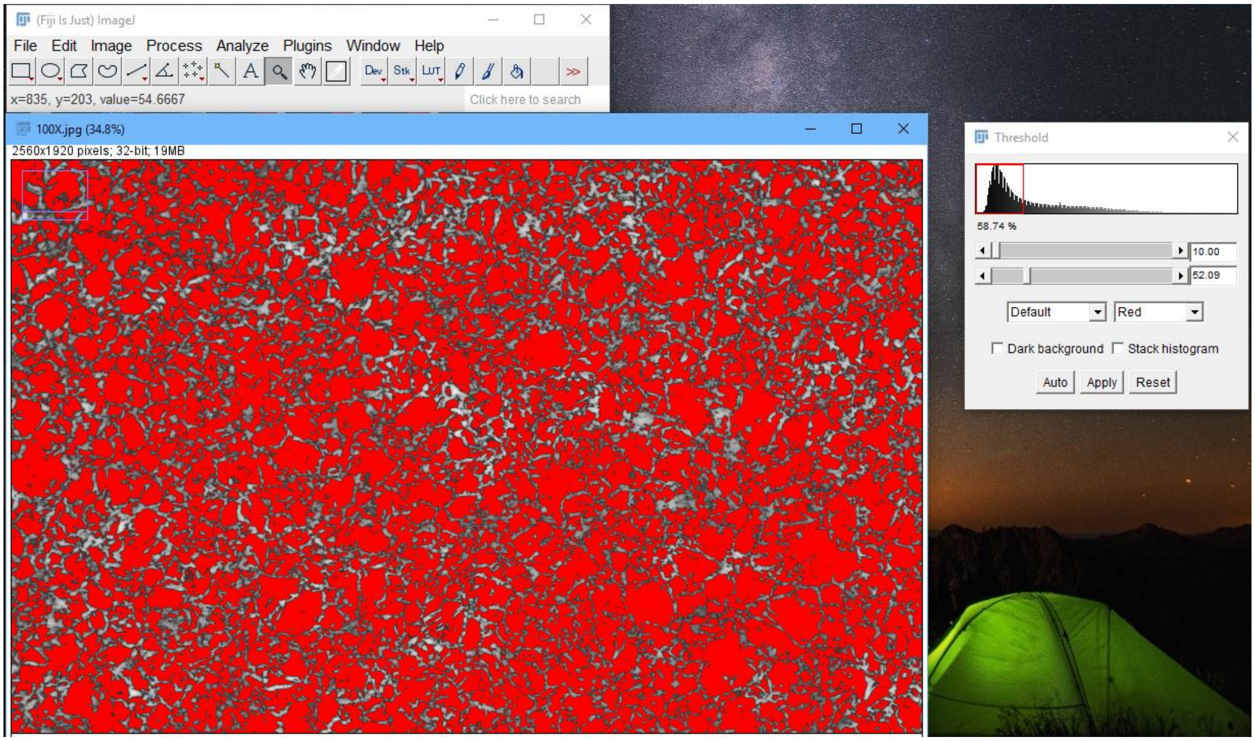


Figure 4.13 Image threshold of 0.45% C steel, as received sample to calculate the carbon content through the %area calculation of each phase

The area fraction of threshold region (red) i.e., pearlite phase is 58.74%

Therefore, the ferrite phase is 100-58.74 = 41.26%

According to Iron Carbide Phase Diagram,

$$\%pearlite = \frac{x - 0.02}{0.8 - 0.02} * 100$$

Where, x is the percentage Carbon in the steel. But %pearlite =

$$58.74 = \frac{x - 0.02}{0.8 - 0.02} * 100$$

Solving the above equation, $x = 0.48\%$, which is the %C in the steel sample

4.2.2 HEAT TREATED SAMPLES:

4.2.2.1 MILD STEEL (740^{0}C)

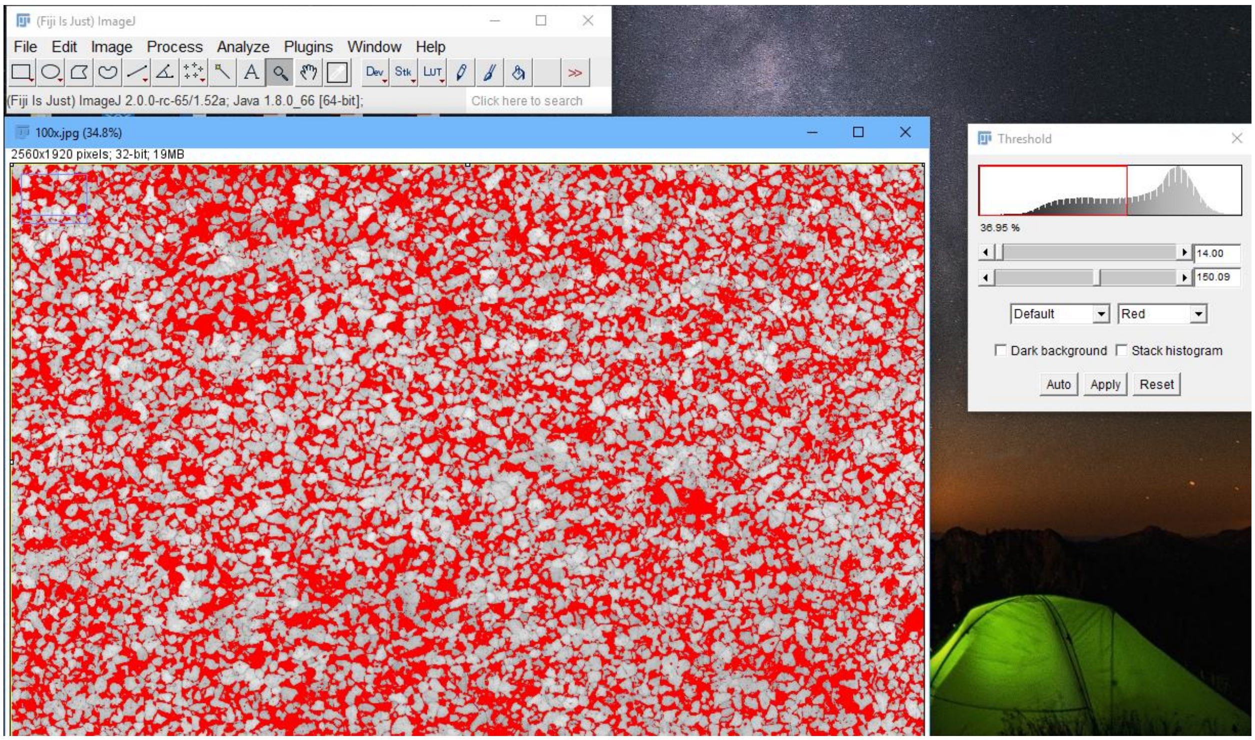


Figure 4.15 Image threshold of after heat treated steel sample (740^{0}C) where the highlighted region represents martensite.

Percentage area highlighted = Percentage martensite formed = 36.95%

Therefore, Percentage ferrite = 100-36.95 = 63.05%

4.2.2.2 MILD STEEL (765^0)

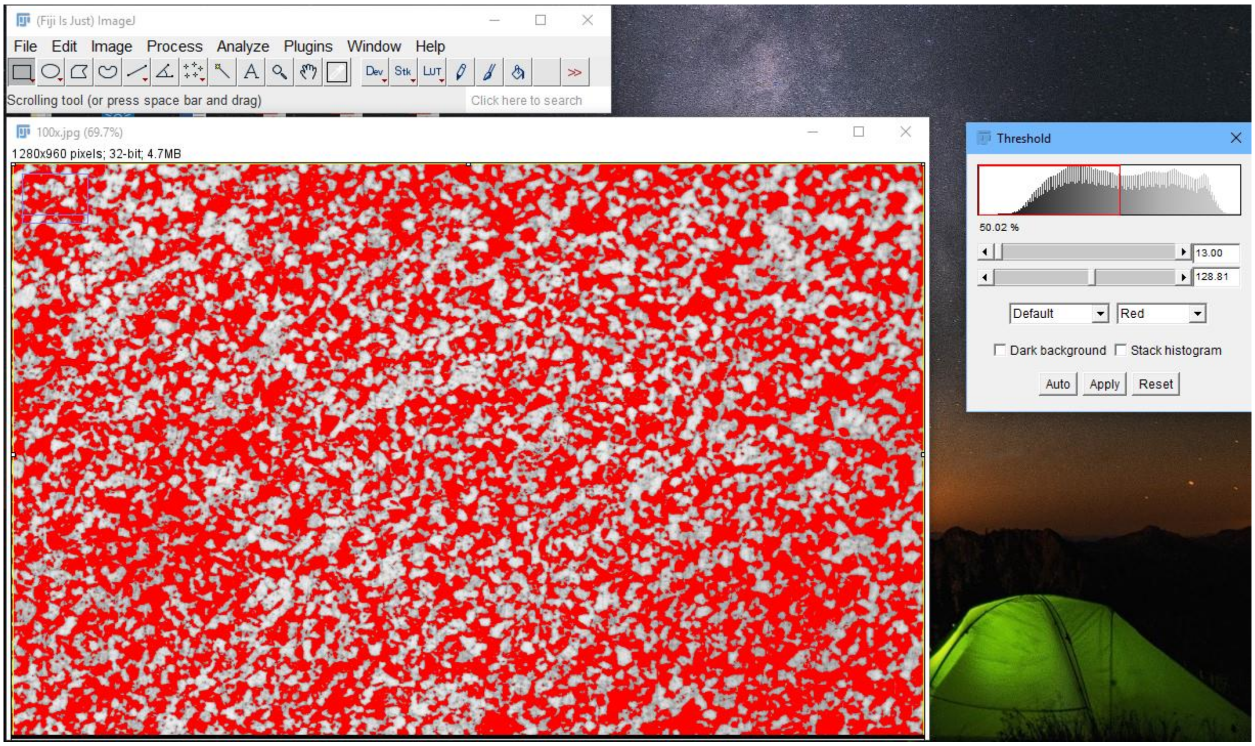


Figure 4.16 Image threshold of after heat treated steel sample (765^0C) where the highlighted region represents martensite.

Percentage area highlighted = Percentage martensite formed = 50.02%

Therefore, Percentage ferrite = 100-50.02 = 49.98%

4.2.2.3 MILD STEEL (790^0)

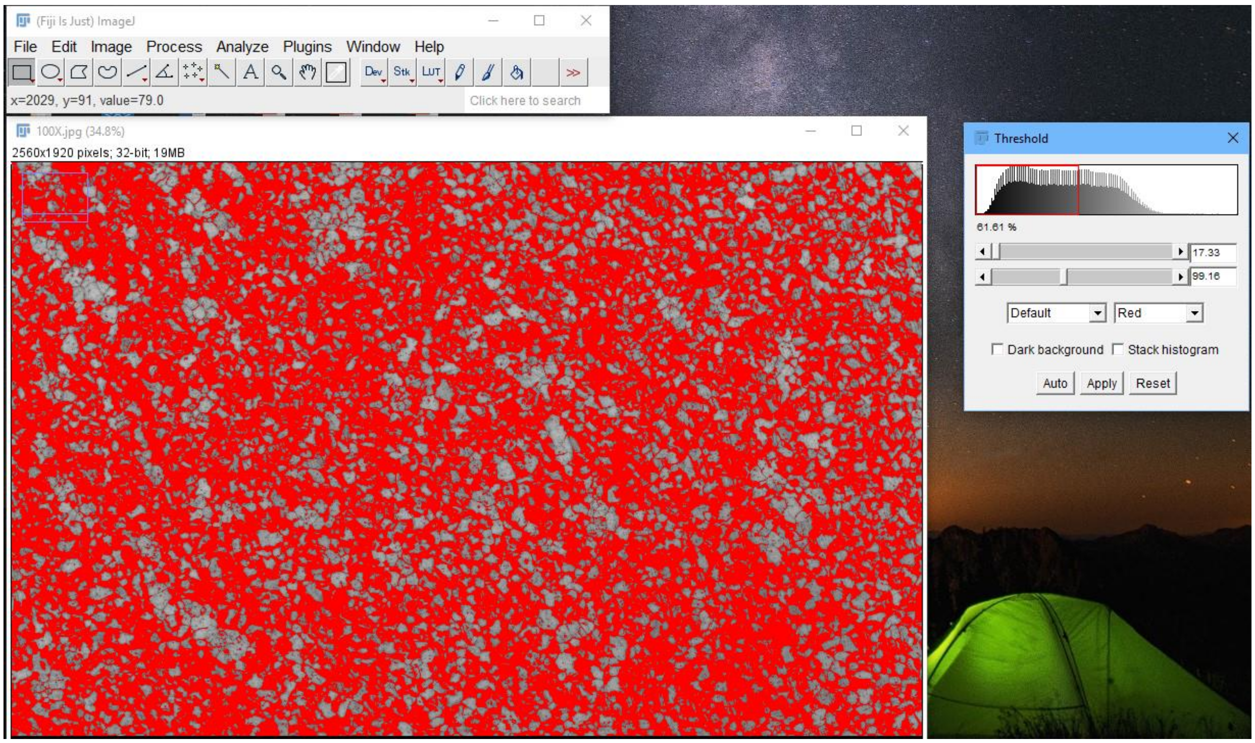


Figure 4.17 Image threshold of after heat treated steel sample (790^{0}C) where the highlighted region represents martensite.

Percentage area highlighted = Percentage martensite formed = 61.61%

Therefore, Percentage ferrite = 100-61.61 = 39.39%

4.2.2.4 0.45 wt.%C STEEL (740^0)

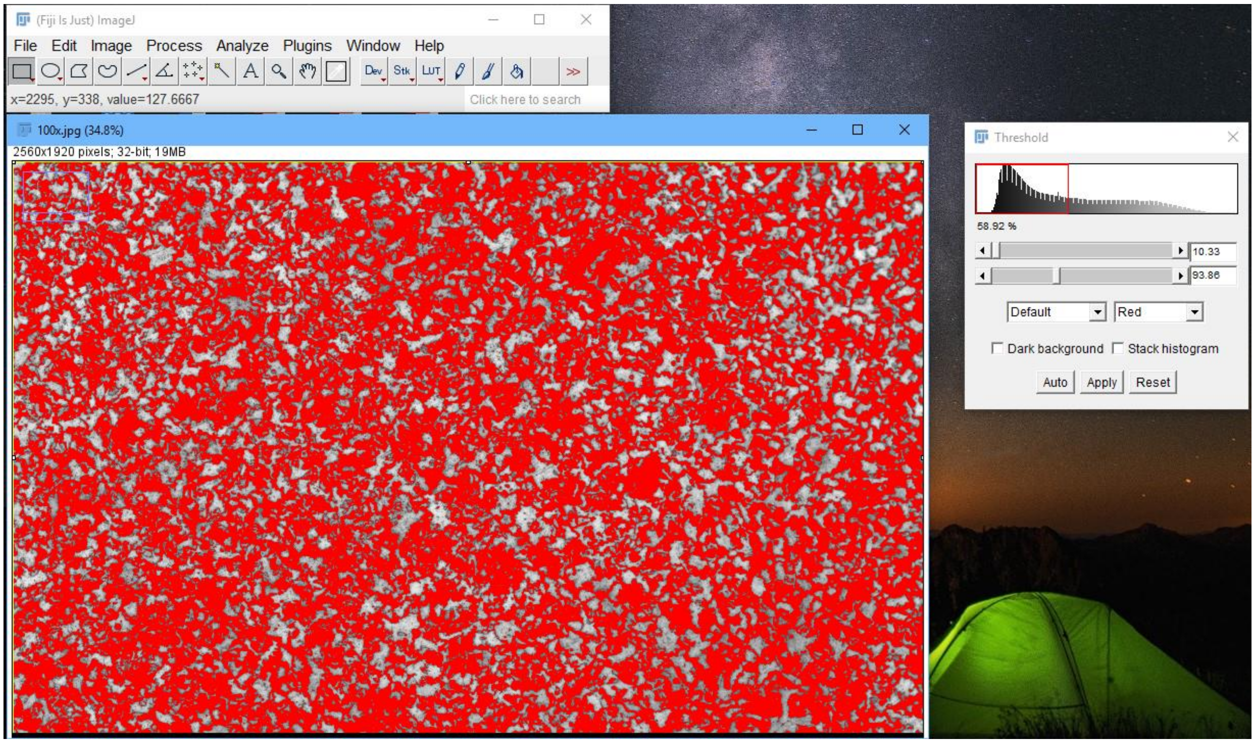


Figure 4.18 Image threshold of after heat treated steel sample (740^0C) where the highlighted region represents martensite.

Percentage area highlighted = Percentage martensite formed = 58.92%

Therefore, Percentage ferrite = 100-58.92 = 41.08%

4.2.2.5 0.45 wt.%C STEEL (765^0)

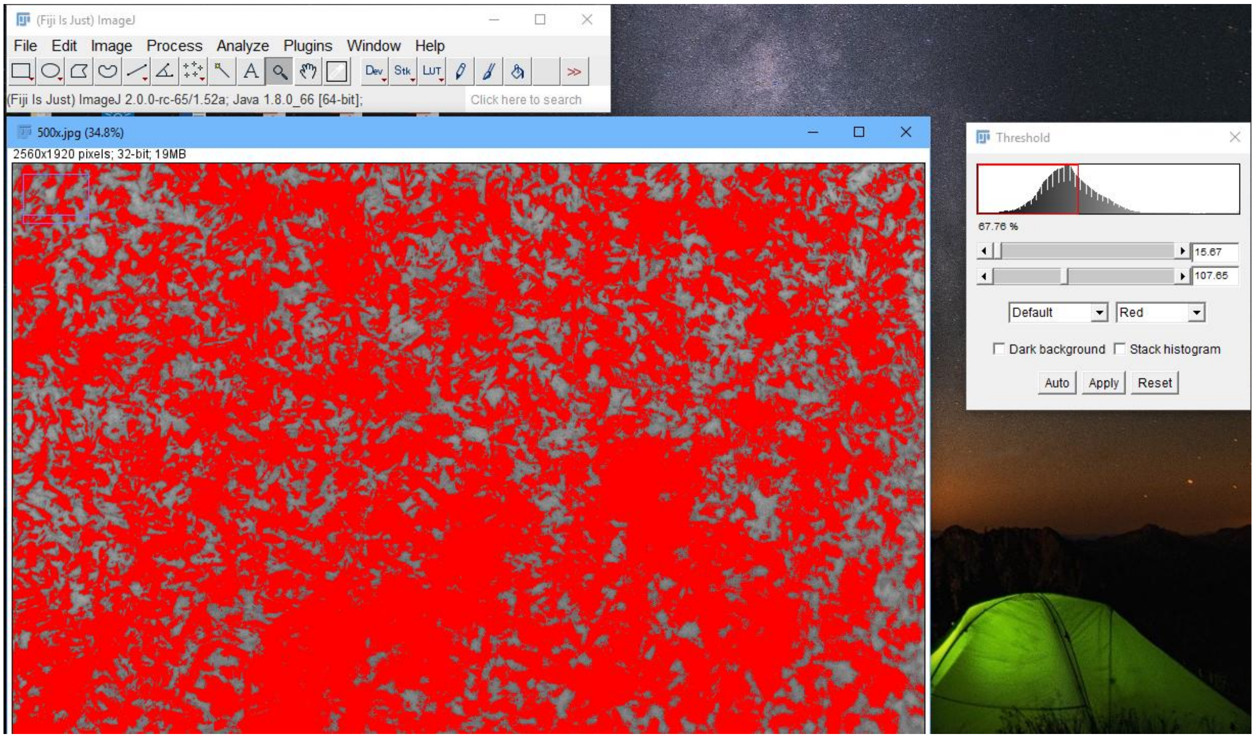


Figure 4.19 Image threshold of after heat treated steel sample (740^{0}C) where the highlighted region represents martensite.

Percentage area highlighted = Percentage martensite formed = 67.76%

Therefore, Percentage ferrite = 100-67.76 = 32.24%

4.2.2.6 0.45 wt.%C STEEL (790^0)

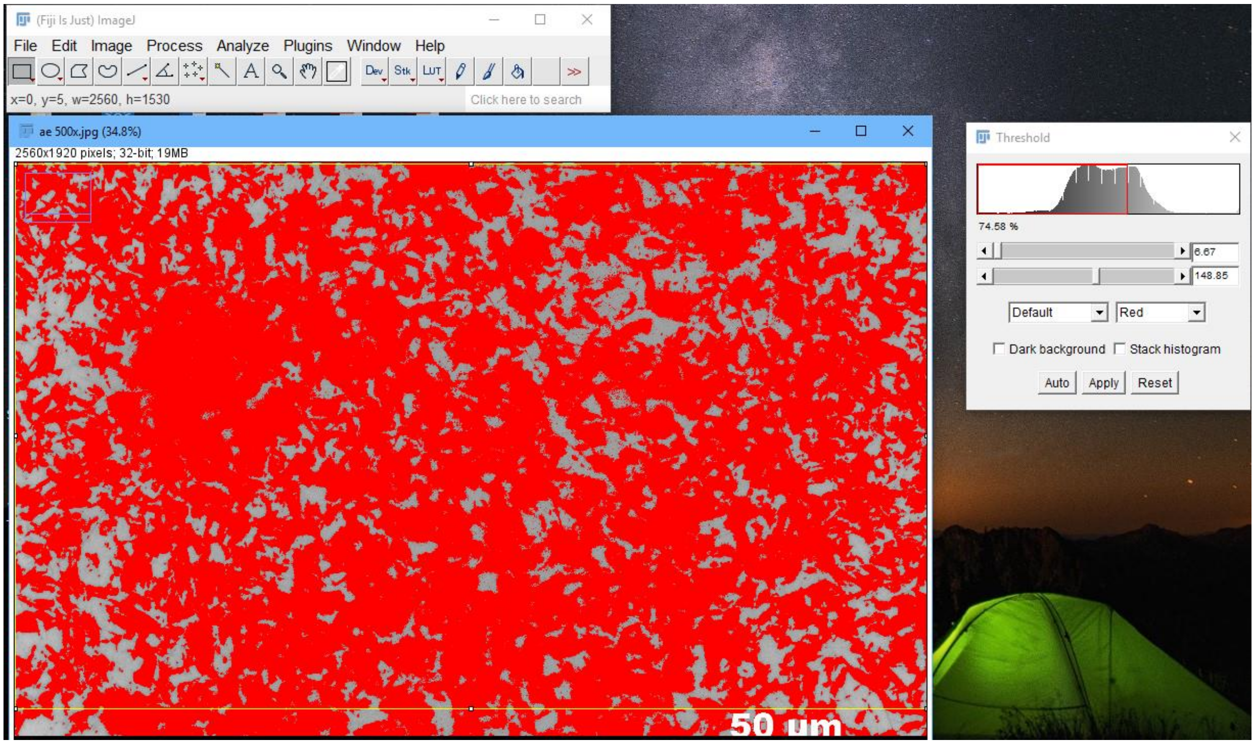
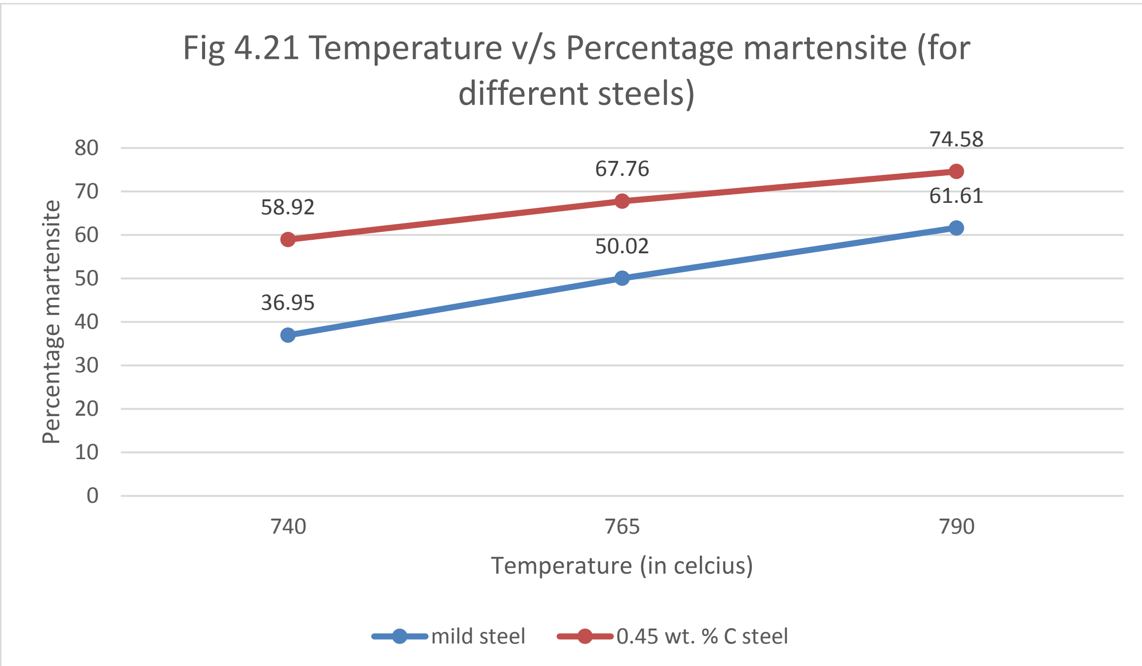


Figure 4.20 Image threshold of after heat treated steel sample (740^0C) where the highlighted region represents martensite.

Percentage area highlighted = Percentage martensite formed = 74.58%

Therefore, Percentage ferrite = 100-74.58 = 25.42%

Through the information obtained from the microstructures with the help of ImageJ software, a variation in the percentage of martensite with temperature and %C in the sample has been plotted.



4.3 HARDNESS

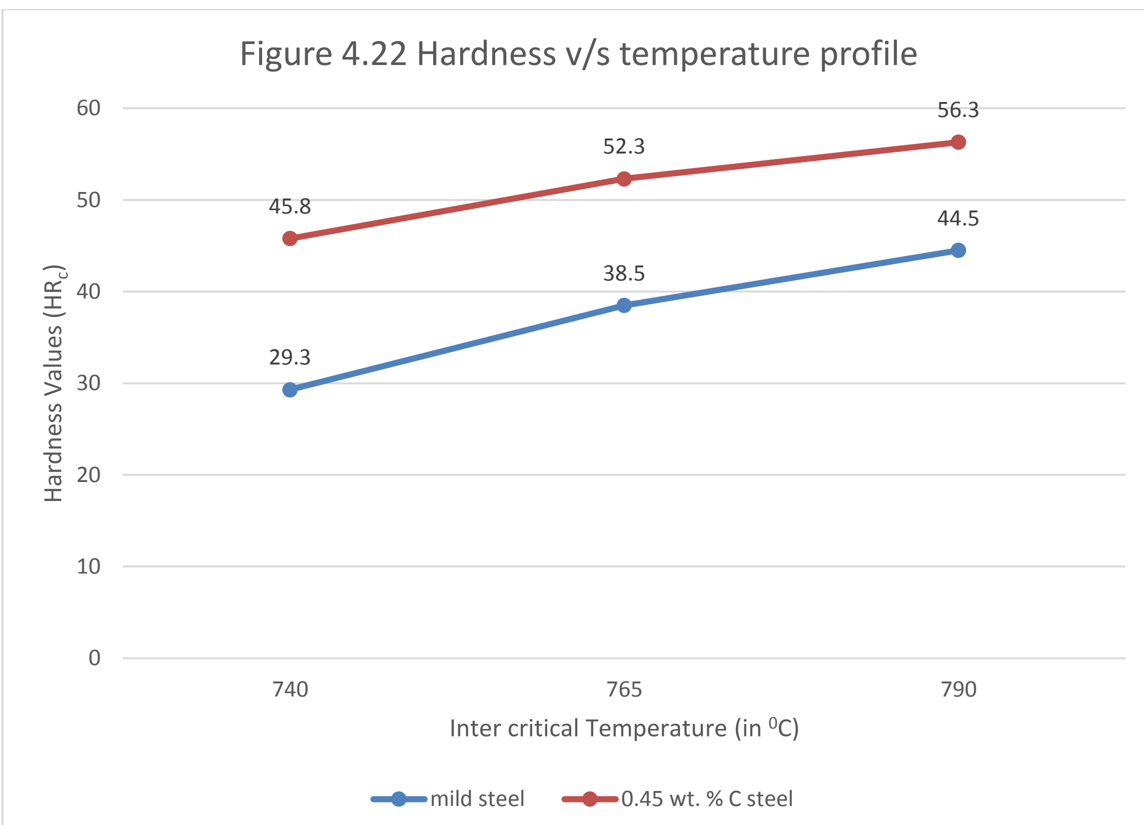
Hardness was measured using Rockwell C scale for the heat treated samples because they were hardened samples containing martensite.

Sl.no	Inter critical temperature (^{0}C)	TRAIL 1	TRAIL 2	TRAIL 3	AVERAGE HARDNESS VALUE
1	740	30.5	28	29.5	29.3
2	765	39.5	37	39	38.5
3	790	44	44	45.5	44.5

Table 4.1: Hardness of mild steel heat treated samples

Sl.no	Intercritical temperature (^{0}C)	TRAIL 1	TRAIL 2	TRAIL 3	AVERAGE HARDNESS VALUE
1	740	47.5	45	45	45.8
2	765	51	52.5	53	52.3
3	790	56	57	57	56.7

Table 4.2: Hardness of 0.45 wt. % C steel heat treated samples



4.4 TENSILE PROPERTIES

Tensile Testing is done with the help of Shimadzu AG-X Plus universal testing machine which has a capacity of 100 kN. The samples were prepared according to the ASTM E8 standard.

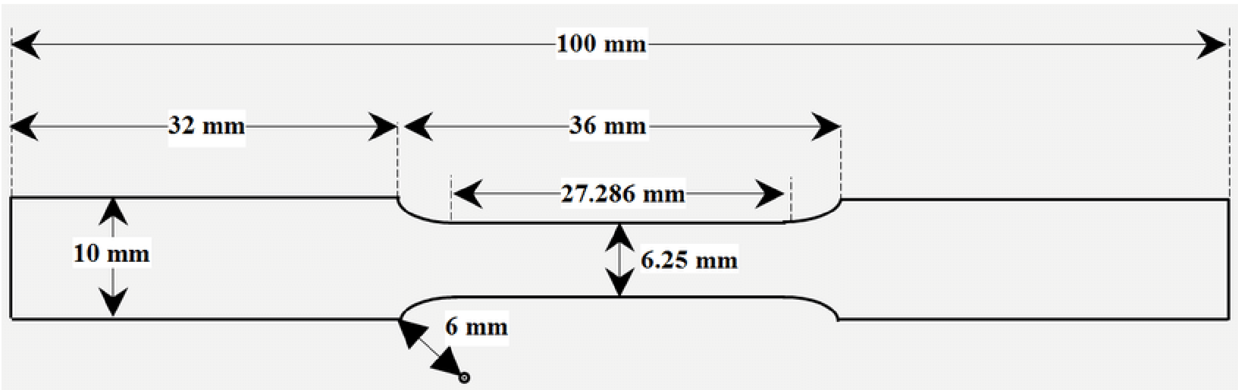


Figure 4.23 Specimen showing ASTM E8 standard dimensions.

4.4.1 MILD STEEL

Sl.no	Sample	Yield stress (MPa)	Ultimate Tensile Stress (MPa)	Breaking Stress (MPa)	Total Strain at Breaking Point (%)
1	As received	158.688	514.472	374.614	25.061
2	740^0 C	85.12	552.223	397.234	24.0963
3	765^0 C	180.099	802.618	661.073	16.9675
4	790^0 C	182.931	1114.58	944.16	17.8725

Table 4.3 Tensile properties of Mild Steel

4.4.2 0.45 wt.% C STEEL

Sl.no	Sample	Yield stress (MPa)	Ultimate Tensile Stress (MPa)	Breaking Stress (MPa)	Total Strain at Breaking Point (%)
1	As received	238.905	561.773	398.711	22.9145
2	740^0 C	503.209	758.296	415.589	28.8777
3	765^0 C	1164.83	1198.35	792.354	22.5202
4	790^0 C	100.663	1346.31	936.055	24.9428

Table 4.4 Tensile properties of 0.45 wt. % C Steel

The following pages contain the data obtained from the tensile testing done on the as received and heat treated mild steel and 0.45 wt. % C steel. The data contains details such as Yield stress, strain at the yield point, Ultimate tensile strength, breaking stress, and strain at the breaking point.

The order is as follows:

1: Untreated mild steel

2: Heat treated MS sample (740^0 C)

3: Heat treated MS sample (765^0 C)

4: Heat treated MS sample (790^0 C)

5: Untreated 0.45 wt. % C steel

6: Heat treated 0.45 wt. % C steel sample (740^0 C)

7: Heat treated 0.45 wt. % C steel sample (765^0 C)

8: Heat treated 0.45 wt. % C steel sample (790^0 C)

A

B

Figure 4.24 (A & B) Tensile testing specimen after fracture.

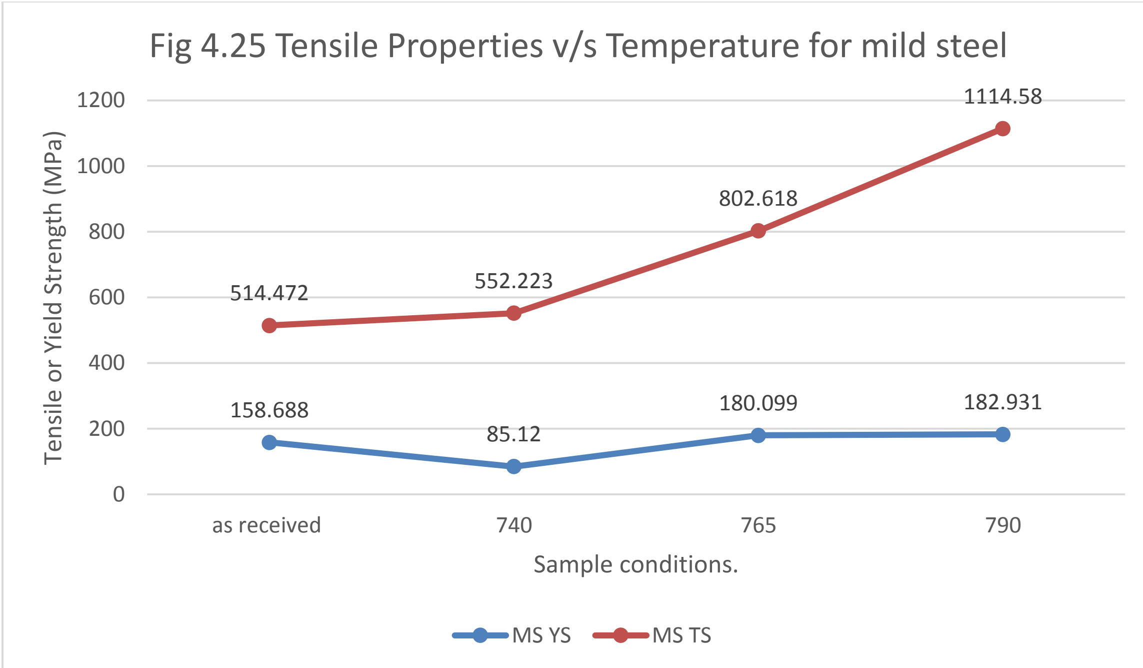


Fig 4.25 Tensile Properties v/s Temperature for mild steel
Tensile or Yield Strength (MPa)
0
200
400
600
800
1000
1200
1114.58
802.618
514.472
552.223
158.688
85.12
180.099
182.931
as received
740
765
790
Sample conditions.
MS YS
MS TS

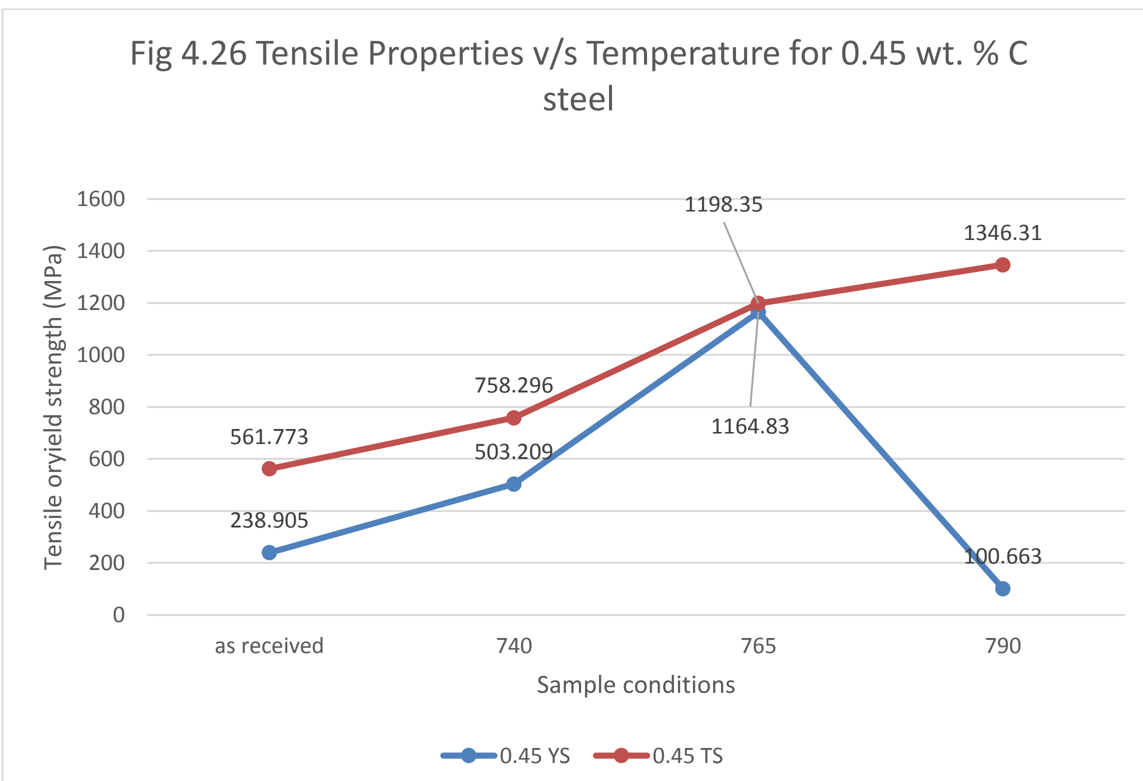


Fig 4.26 Tensile Properties v/s Temperature for 0.45 wt. % C steel
Tensile oryield strength (MPa)
0
200
400
600
800
1000
1200
1400
1600
1198.35
1346.31
758.296
1164.83
561.773
503.209
238.905
100.663
as received
740
765
790
Sample conditions
0.45 YS
0.45 TS

CHAPTER 5: CONCLUSIONS

Dual phase steels can be produced by inter critical annealing for the steel starting from A_1 to anywhere between the temperature A_3, where A_3 temperature depends upon the composition of the steel. The intercritical temperature has a significant role to play on the outcome of the volume fraction of the after heat treated steel. A dual phase microstructures have been observed with martensite islands and ferrite matrix, where the volume fraction of the phases keep changing with varying temperatures.

As the composition studies suggest, the percentage of martensite keeps increasing with the intercritical temperature, both in mild steel and the 0.45 wt. % C. The EN 45 sample being a steel that has high carbon content doesn't have a large range of temperatures between A_1 and A_3. And it doesn't show any significant change in its microstructure even after the heat treatment. A gap of 15 degrees has been given because, the furnace error in temperature might be high.

The hardness values for mild steel and 0.45 wt. % C shows improvement after the heat treatment, because of formation of martensite. The values keep increasing for mild steel and 0.45 wt. % C whereas for the EN 45 steel, no significant change has been observed in the hardness also. The heat treated samples were so hard that the machining of heat treatment for 0.45 wt. % C steel was not possible with the available lathe. The tensile samples of EN 45 also cannot be machined due to their high hardness value.

Thus the samples were heat treated and the surface was then polished of any remains, and then the samples were tensile tested. The trends in the tensile test were a bit different to the hardness. The tensile and yield strengths of the heat treated samples increased almost everywhere with increase in inter critical temperature, except for a few places.

The ratio of tensile to yield strength kept on increasing for mild steel with increase in intercritical temperature, but the trend was different for 0.45 wt. % C steel. The ratio kept increasing till one point and then decreased at 765^0 C, where the Tensile and Yield strengths were similar, but it kept increasing after that point.

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