Rockwell Hardness Lab Report

By Group-II (6th Semester)

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Introduction

Hardness can be defined as the resistance of material to local plastic deformation on the application of some external load or stress (scratch, indentation or abrasion). Although hardness is not a fundamental property of material, hardness testing is widely used in industries because of its simplicity, faster results, near NDT testing properties, cheap procedure and many more advantages. Also, it can give a qualitative relationship to other materials properties like strength, ductility, rigidity etc.

Indentation test is one of the prominently used hardness testing method where we apply a certain predefined load with the help of an indenter which penetrates into the sample surface; thus we get the hardness values by measuring the indentation depth or size of the projected indentation area.

Rockwell hardness test is one of the static hardness testing methods using indentation depth as a measuring criterion. Basically, two types of indenter are used; one Diamond spheroconical (Brale) indenter with an angle of 120^{O} and a spherical tip of 0.2mm; second is steel ball indenter with diameters as 1/16, 1/8, 1/4, ½ inches. Rockwell Test works on the principle of major and minor load where we first apply a minor load (10 kg for regular test and 3 kg for superficial tests) to the sample that minimises the surface preparation and minor defects; then a major load is applied for some dwell time which is removed after the dwell period and a differential depth (incremental depth) is observed.

A dial is attached to the testing machine which gives the arbitrary hardness number during the whole process. To cover a different hardness range with varying penetration, the dial has different scales like A, B, C, D etc. on the basis of indenter and load used. The most general dial has Scale C&A for Brale Indenter and load 150 &60 respectively; a B scale for steel ball (1/16 inches diameter) and 100 kg load. The dial also consists of a minor pointer for minor load indications.

The formula applied to find the Rockwell hardness (HR) are:

Regular Rockwell hardness: $HR = 100 - \frac{h}{0.002}$ (For Brale indenter)

$HR = 130 - \frac{h}{0.002}$ (For Steel Ball indenter)

Superficial Rockwell Hardness: $HR = 100 - \frac{h}{0.001}$ (For Brale Indenter)

$HR = 130 - \frac{h}{0.001}$ (For Steel ball indenter)

Where h is the incremental depth.

Experimental procedure

The materials used for this experimental study was 0.3 wt. % carbon steel (low carbon) and 1.1 wt. % carbon steel (high carbon) both of which were subjected to two different cooling rates after austenitization. In one case, after austenitization, the sample was subjected to furnace-cooling (annealing treatment) while in the other case, it was quenched in water which was maintained at room temperature. Two samples having similar composition and subjected to similar heat treatment for each case were used for performing Vickers' bulk hardness test to increase the statistical reliability. Experiment is carried out with a total 10 samples and each sample is denoted with a sample code for easier understanding and this code will be followed throughout the whole report which has been shown in Table 1, with its respective composition and heat treatment.

Sample Code	Carbon Composition (wt. %)	Heat Treatment
1 2	0.3	Annealed
3 4 5 6	0.3	Water Quenched
7 8	1.1	Annealed
9 10	1.1	Water Quenched

Table 1. Steel samples with their respective composition and heat treatment.

The steel samples were first grinded and were then metallographically polished up to 1500 mesh size SiC paper followed by polishing in cloth up to 2500 mesh size and was finished by polishing in 1µm diamond paste and kerosene. First of all, it is ensured that the sample surface is smooth, flat and parallel. According to the requirement, the suitable indenter (either ball or diamond) is installed. The sample is now placed on the stage. Major and minor loads are set as per requirement. Now the sample is brought in contact with the indenter using a screw system. The screw is rotated until the bigger dial hits zero at the top and smaller dial points towards the red point. (It takes around 3 rotations of the bigger dial to bring the smaller dial to point towards the red point.) Now the lever is pulled and the

machine is loaded. It takes about 15-20 seconds to apply the desired load.) The machine is now unloaded and reading is noted. A few seconds of waiting time is recommended to ensure accurate reading. Suitable scale B scale for soft material and C scale for harder material) for measurement is chosen according to the nature of the sample.

Results and discussion

Measurement of macrohardness of the samples by Rockwell provides us a clear picture about how the hardness of a sample increases on increasing the carbon content from 0.3 wt. % to 1.1 wt. % when subjected to the same heat treatment. The experiment also showed how the hardness of the sample was dependent on the cooling rate. With an increase in the cooling rate, the sample was found to have a greater value of hardness for the same carbon content. Measured hardness value of the given sample has been shown in table2.

Sample	Hardness
1	HRB 74
2	HRB 70
3	HRC 28
4	HRC 30
5	HRC 26
6	HRC 29
7	HRB 94
8	HRB 95
9	HRC 53
10	HRC 54

Table 2. Steel samples with their hardness in rockwell B and C scale.

From the above hardness table it can be seen that all 10 sample hardness can not be measured with the same rockwell scale. So for comparison and plotting, all hardness value is converted to Rockwell B scale[2]. Converted value of hardness to the Rockwell B scale has been shown in table3.

Sample	Hardness(HRB)
1	HRB 74
2	HRB 70
3	HRB 103
4	HRB 105
5	HRB 102
6	HRB 104
7	HRB 94
8	HRB 95
9	HRB 118
10	HRB 119

Table 3. Steel samples with their hardness converted to rockwell B scale .

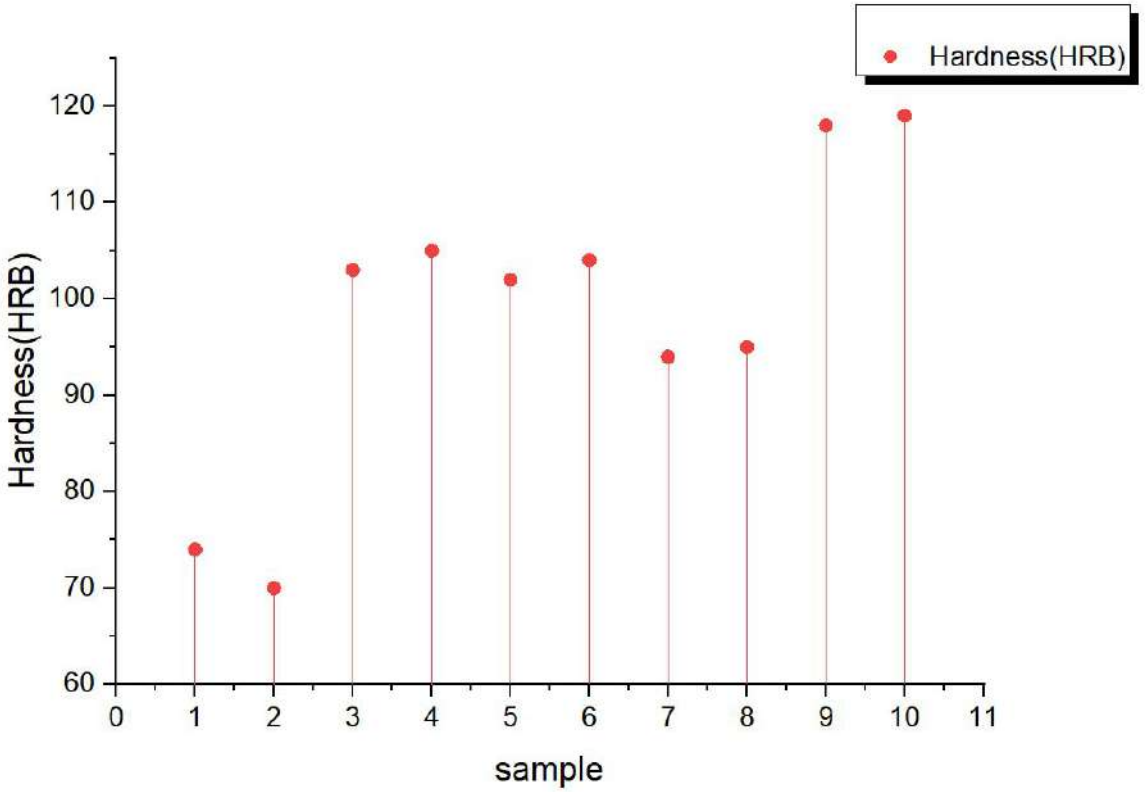

Fig. 1. Variation of hardness based on composition and heat treatment.

A graph which shows how hardness varies among different samples as are shown in the figure above. It can be easily inferred from the experiment that lower percent annealed carbon steel (0.3 wt. %) has low hardness because they are expected to have large and soft ferrite grain after the heat treatment and higher percent annealed carbon steel (1.1 wt. %) has more hardness because of the presence of proeutectoid cementite along with a large amount of pearlite present in the matrix, both of which are hard phases compared to ferrite. The hardness of 0.3 wt. % water quenched carbon steel is higher than that of 0.3 wt. % annealed carbon steel due to faster quenching rate which causes austenite to martensite transformation resulting in build-up of residual stress and lattice strain. Martensite which is a harder phase than ferrite or pearlite and lath martensite is formed here. Highest hardness can


ROCKWELL


HARDNESS TESTER
MODEL TWIN
SR.NO.
DIFFERENT ROCKWELL HARDNESS SCALES
FOR ROCKWELL SUPER FIGIAL TEST
Fine Testing Instruments (India)
MODEL NO.
SERIAL NO.

Fig. 1. The instrument and procedure of measuring hardness by Rockwell Testing Machine.

be seen in 1.1 wt. % carbon steel water quenched because of the fact that with increase in carbon content more lattice distortion and residual stress forms in the martensite and the martensite which is formed is plate martensite which has a high twin density. Because of all these factors mentioned above hardness of 1.1 wt. % carbon steel water quenched sample is higher compared to the rest of the samples. The indentation images of the steel samples are shown in the figures attached above.

Conclusion

With the help of this experiment, we have been able to relate how hardness of steel samples is affected by variation in carbon content and the rate of cooling applied on the sample. From this experiment, we can conclude that,

- Rockwell hardness of a steel specimen increases with increase in the carbon content, keeping the cooling rate constant.

- Rockwell hardness of a steel specimen increases with increase in the cooling rate, keeping the carbon content constant.

Acknowledgement

Help on this lab report received from Md Abu Bakkar, Niraj Kumar of the Department of Metallurgy and Materials Engineering, IIEST Shibpur had been really helpful.

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Vickers' Bulk Hardness Lab Report

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Abstract: The articleillustrates the effect of variation of Vickers' bulk hardness of a sample based on the carbon composition and difference in heat treatment applied to the steel samples. The composition of the steels involved for the study is low carbon (0.3 wt. % C) and high carbon (1.1 wt. % C) in which both these samples are subjected to two different cooling rates after austenitization.

Keywords: Vickers' hardness, steel, indentation, cooling rate, carbon content

1. Introduction

Indentation hardness, as defined, is the material's measure of its resistance to plastic deformation upon indentation. Many quantitative hardness measuring have been devised throughout the years by many scientists to determine the hardness. The process involves penetration of a indenter of a given shape onto the surface of a well-polished, flat and parallel top-bottom surface material using a pre-determined force (or, load) and measuring the indentation depth or the size of the projected area of the indentation using a microscope, and is in turn related to the a hardness of a specified scale based on the type of indenter used. Hardness of a material is not an absolute property and gives an idea of the absolute property of the materials which require further tests. Although hardness is a relative property, it's still used frequently in industries and academic institutes because of its simplicity, faster, inexpensiveness, non-destructive and other mechanical properties (like, tensile strength) can be estimated from hardness values.

Vickers' bulk hardness is a standardized test for measuring the bulk hardness of a material. In this, a square-based diamond pyramid having a face angle of 136^{O} is employed as the indenter with load ranging from 5 kgf-1000 kgf. Depending on the expected hardness of the material to be tested, the load is selected and a specific area (well-polished) to be indented. The sample was indented with a given dwell time for the indentation to take place. After indentation, the projected area of the indentation, the length of the diagonals of the square-shaped indentation, was measured by viewing it under the microscope attached to the macrohardness tester. The formula applied for calculation of the Vickers' hardness (HV) of the material is,

$$HV = 1.854\frac{P}{d_1 \times d_2}$$

Where, P is the applied load (in kgf)

And, d_1 and d_2 are the lengths of the diagonals of the indentation (in mm).

2. Experimental procedure

2.1. Material

The materials used for this experimental study was 0.3 wt. % carbon steel (low carbon) and 1.1 wt. % carbon steel (high carbon) both of which were subjected to two different cooling rates after austenitization. In one case, after austenitization, the sample was subjected to furnace-cooling (annealing treatment) while in the other case, it was quenched in water which was maintained at room temperature. Two samples having similar composition and subjected to similar heat treatment for each case was used for performing Vickers' bulk hardness test to increase the statistical reliability. Each sample is denoted with a sample code for easier understanding and this code will be followed throughout the whole report which has been shown in Table 1, with its respective composition and heat treatment.

Sample Code	Carbon Composition (wt. %)	Heat Treatment
A	**0.3**	**Annealed**
B	**0.3**	**Water Quenched**
C	**1.1**	**Annealed**
D	**1.1**	**Water Quenched**

Table 1. Steel samples with their respective composition and heat treatment.

2.2. Mechanical Characterization

The steel samples were first grinded and were then metallographically polished up to 1500 mesh size SiC paper followed by polishing in cloth up to 2500 mesh size and was finished by polishing in 1μm diamond paste and kerosene. Bulk hardness measurement in Vickers' scale was done using a macrohardness tester (INNOVATEST Macrohardness Tester) having a diamond indenter applying a press load of 10 kgf (approx. 98 N) and 30 kgf (approx. 294 N) depending on the composition and heat treatment provided to the sample, so as to get a visible impression for hardness measurement, with a dwell time of 25 seconds for all samples on the polished surface of each of the samples. An average of 5 indentations were taken for each sample and the average hardness has been reported in Vickers hardness scale for the same. The hardness data obtained for all the samples were plotted using OriginPro 9.0 software.

3. Results and discussion

3.1. Hardness

Vickers macrohardness measurement of the samples provide an insight on how increasing the carbon content from 0.3 wt. % to 1.1 wt. % increases the hardness of the sample when subjected to similar heat treatment. It was also observed that increasing the cooling rate increases the

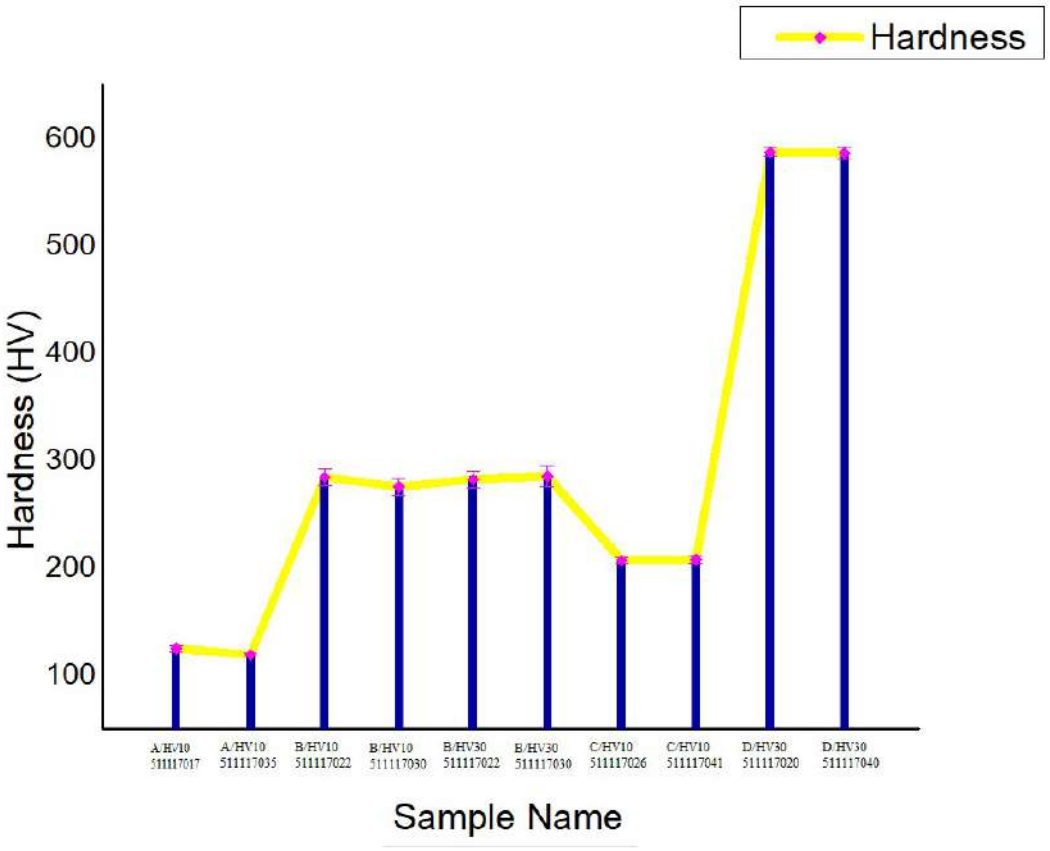

Fig. 1. Variation of hardness based on composition and heat treatment.

hardness of the sample for similar carbon content. The graph of hardness variation as reported by individual student is reported in Fig. 1. It can be easily understood that 0.3 wt. % carbon steel annealed has lowest hardness because of the large and soft ferrite grains expected due to the treatment. The hardness of 1.1 wt. % carbon steel annealed has more hardness than the previous one because of the presence of large amount of pearlite in the matrix along with proeutectoid cementite both of which are hard phase as compared to ferrite. The hardness of 0.3 wt. % carbon steel water quenched is slightly higher than that of 1.1 wt. % carbon steel annealed because of the faster quenching rate causing presence of residual stress and lattice strain due to austenite to martensite transformation. Martensite is a considerably hard phase than ferrite or pearlite and lath martensite is expected to form in this case. Highest hardness as observed in 1.1 wt. % carbon steel water quenched is due to the fact that increase in carbon content causes more lattice distortion and residual stress formation in the martensite and the martensite formed is expected to be primarily plate martensite having a high twin density. All these factors are responsible for the high hardness of 1.1 wt. % carbon steel water quenched sample as compared to the rest of the samples. The indentation images of steel samples are shown in Fig 2. (a-b).

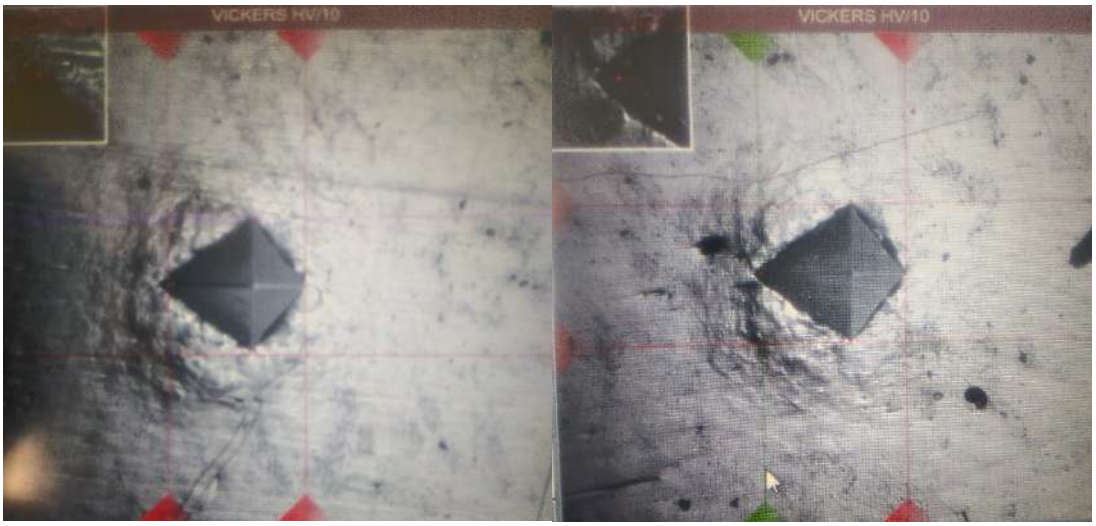

Fig. 2. Indentation marks in (a) 0.3 wt. % carbon steel water-quenched and (b) 1.1 wt. % carbon steel annealed.

4. Conclusion

In this experimental study performed, effects of carbon content and the rate of cooling applied on the corresponding mechanical properties, hardness, have been studied. The conclusions that can be drawn from this study are:

1. When the carbon content in the steel specimen is increased, the Vickers hardness of the specimen increases, keeping the cooling rate constant.

2.When the cooling rate of the samples are increased, keeping the carbon content same, the hardness value of specimen increases.

Acknowledgement

Technical assistance received fromMd Abu Bakkar, Niraj Kumar and from the Department of Metallurgy and Materials Engineering, IIEST Shibpur is acknowledged. The author also want to thank Dr.Debdulal Das for entrusting them with this work.

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Report on

Macro Hardness Testing of Different Steel Samples

Performed under the supervision of Dr. Debdulal Das, Department of Metallurgy and Materials Engineering, IIEST Shibpur

Materials Property Evaluation Lab 6th Semester (2020-2021)

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Contents

Introduction

Hardness is defined as the ability of material to resist plastic deformation, which is often determined by a standard testing method in which the surface resistance to indentation is estimated [1]. Usually these testing methods are defined by the shape, size and type of indenter, and the amount of applied load. These tests are semi-destructive in nature. The hardness measured by each testing is generally represented by a certain number, termed as hardness number which is non-dimensioned and of arbitrary scale. It is pertinent to mention that higher values of hardness numbers represent harder surfaces.

Based on the method of measurement, conventional hardness testing are of three types, namely Scratch Hardness (resistance to scratching or abrasion), Rebound Hardness (energy absorption under impact loading) and the most common method – Indentation Hardness (resistance to indentation). Indentation hardness tests are classified into two categories: firstly, macro hardness testing, where applied load is greater than or equal to 1 kg-f and secondly, micro hardness testing, in which loading less than 1 kg-f. This experiment intends to measure the macro hardness of different steel samples by Vickers and Rockwell method.

Materials & Methods

Plain Carbon Steel samples with different compositions and heat treatment histories were used for hardness measurement. The details of the samples have been given in table 1:

Sl No.	Sample Code	Carbon percentage	Heat Treatment history
1	0.3_A	0.3 wt %	Annealed
2	0.3_WQ	0.3 wt %	Water Quenched
3	1.1_A	1.1 wt %	Annealed
4	1.1_N	1.1 wt %	Normalised
5	1.1_OQ	1.1 wt %	Oil Quenched
6	1.1_WQ	1.1 wt %	Water Quenched

Vickers hardness testing was performed using Innovatest Verzus 750 CCD universal testing machine having a diamond indenter of right pyramidal shape with a square base and an angle of 136 degrees between opposite faces. Fig.1 represents the picture of the hardness tester. Whereas, Fig.2 is the schematic representation of the indenter used during testing.

Fig.1: (a) Overall picture of the Vickers hardness tester and (b) picture of the operating monitor

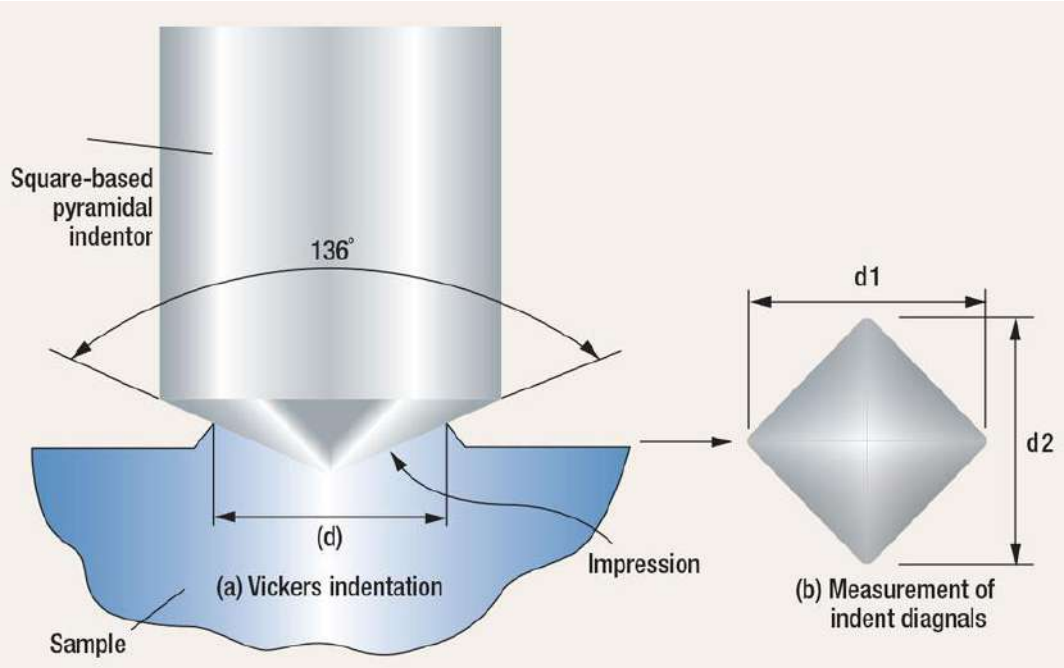

Fig.2: (a) Penetration of the indenter on sample and (b) Impression left on the sample surface

Vickers hardness number (HV) is given by the formula below:

$$HV = \frac{2 \times F \times \sin(\alpha/2)}{d^2}$$; where, F is the value of applied load in kg-f, α is the angle between the opposite faces i.e., 136^0 and d is the average value of the diagonals

of the square impression left on sample surface. Putting the value of α, the above expression can be expressed as: $HV = \frac{1.8544 \times F}{d^2}$. (1)

On the other hand, Rockwell test consists of measuring additional depth to which the ball or diamond indenter is forced by major load beyond depth of the previously applied minor load. In this purpose, C scale Rockwell hardness (HRC) tester made by Fine Testing Instruments (India) having spheroconical diamond indenter was used and the applied load was 150 kg-f. Fig.3 shows the details of a Rockwell hardness tester and Fig. 4 schematically describes the testing procedure.

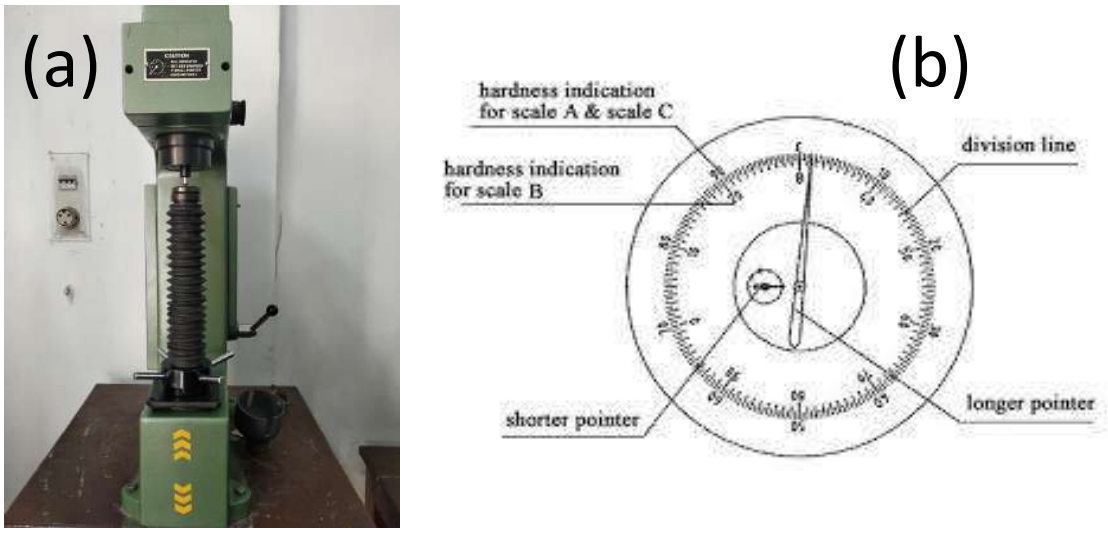

Fig.3: (a) Rockwell hardness tester and (b) schematic diagram of the dial

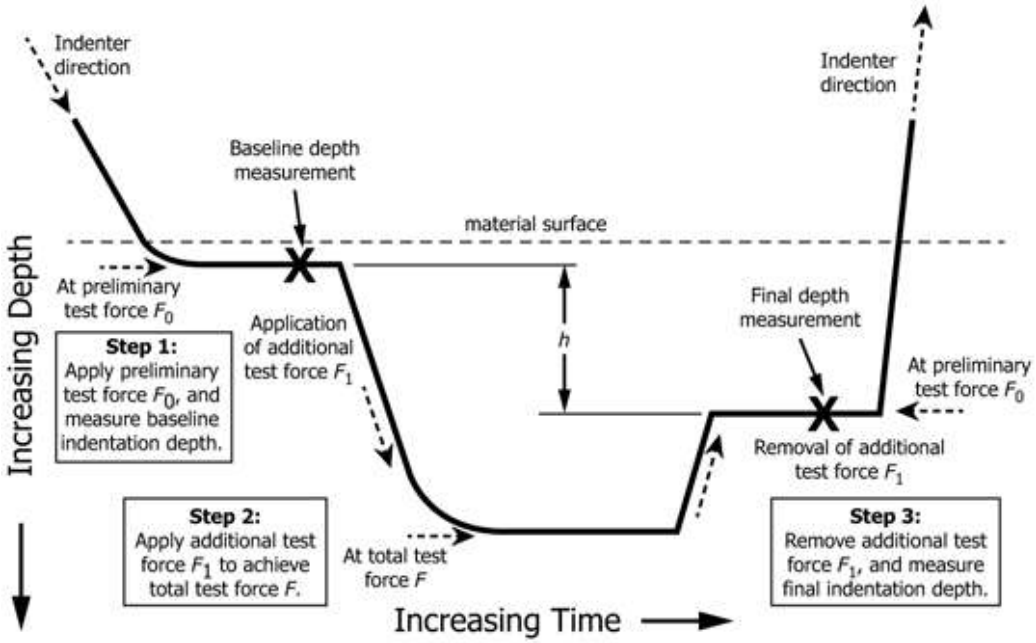

Fig.4: Schematic representation of Rockwell hardness measurement

The major load is applied without removing the minor load, while the indenter is forced beyond the depth of prior applied minor load. The major load is removed after a certain time. Removal of the additional load allows a partial recovery, reducing the depth of penetration. Finally, the depth of permanent indentation is tracked.

Incremental depth (h) is due to major load while the minor load is still in position. After the major load is applied and removed, removed, the reading on dial gauge is the hardness value.

Rockwell hardness value is mathematically expressed as: $HR = 100 - \frac{h}{0.002}$ (2)

Results

Both Vickers and Rockwell hardness were taken at five different locations for each sample and the data have been provided in the table 2.

Sample	Applied Load and Time	HV	HV (Average)	HRC	HRC (Average)
0.3_A	Vickers: 10 kg-f & 30 s Rockwell: 150 Kg-f & 10 s	127.32 127.34 125.21 129.98 116.38	125.25	NA NA NA NA NA	NA
0.3_WQ	Vickers: 10 kg-f & 20 s Rockwell: 150 kg-f & 10 s	310.52 319.28 313.38 302.75 316.86	312.56	29.5 32.5 33.0 28.5 30.5	30.8
1.1_A	Vickers: 30 kg-f & 30 s Rockwell: 150 Kg-f & 10 s	204.49 202.45 202.95 207.67 201.02	203.72	6.5 7.5 8.0 9.0 8.5	7.9
1.1_N	Vickers: 30 kg-f & 30 s Rockwell: 150 Kg-f & 10 s	266.78 260.99 261.34 264.93 268.41	264.49	18.0 22.5 22.5 19.0 22.0	20.8
1.1_OQ	Vickers: 30 kg-f & 20 s Rockwell: 150 Kg-f & 10 s	699.45 699.60 671.46 689.18 662.32	684.40	46.0 47.5 42.0 49.5 45.0	46.0
1.1_WQ	Vickers: 30 kg-f & 20 s Rockwell: 150 Kg-f & 10 s	710.90 716.85 713.67 716.74 708.34	713.30	51.5 54.0 51.5 49.0 52.0	51.6

Discussion

- Effect of Carbon content on hardness

Fig. 5 depicts a cooling curve similar to what the samples would have experienced during annealing. Evidently, since the nose of the TTT curve is closer to the "temperature axis" in case of the 0.3_A than 1.1_A, the pearlite colonies formed in case of the former one, are coarser in nature. Subsequently, the coarser pearlite colonies present in the 0.3_A sample would have offered less resistance to plastic deformation (as forwarded by Hall-Petch relationship [2]) than the finer ones formed in the 1.1_A, thereby exhibiting lower hardness than the latter. This theory has been substantiated by the findings as well.

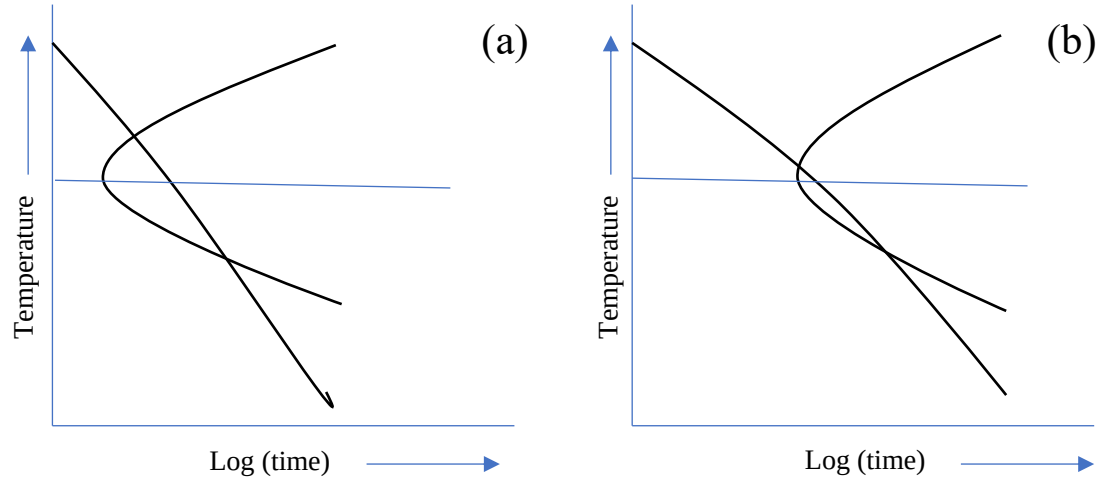

Fig. 5. Schematic TTT plots for (a) 0.3 wt.% C (b) 1.1 wt.% C steel samples

Another analogy based on the difference in carbon content can be drawn to explain the contrasting values of hardness for 1.1_WQ and 0.3_WQ. In this case, it may be conjectured that the greater carbon content present in 1.1_WQ is responsible for a better segregation of carbon clusters below the positive edge dislocations (owing to such regions being areas of equilibrium between tensile and compressive stress regions). Consequently, there is a higher density of sessile dislocations in case of greater carbon content resulting in a better resistance to plastic deformation – and higher hardness. [3]

- Effect of Heat Treatment

Fig.6 is a TTT diagram of a plain Carbon steel having certain C content. Different cooling curves have been shown. Annealing and normalising typically cuts the C curve in such a way that they lead to form coarse and fine pearlites. Whereas, oil quenching and water quenching both yield Martensite, but retained Austenite percentage is more in case of oil quenching. Since fine Pearlitic microstructure gives more hardness than coarse Pearlitic structure and retained Austenite tends to reduce the overall hardness, the recorded hardness values follow the pattern: Annealed (A) < Normalised (N) < Oil Quenched (OQ) < Water Quenched (WQ).

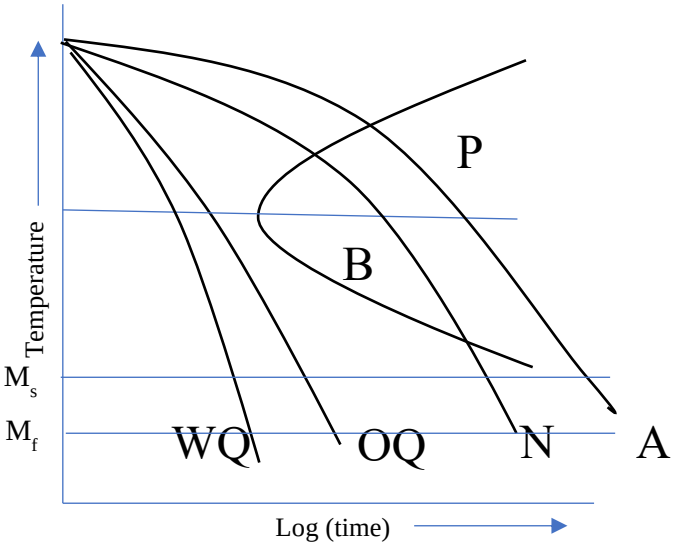

Fig.6: TTT diagram of plain Carbon steel with different cooling curves

- Correlation between HV and HRC

An attempt has been made to correlate the two hardness scales. The hardness values have been plotted using excel and various fitting were performed. Exponential fitting was found to be best considering the fact that its R-square value (0.953) is most close to 1. Fig.7 shows the HV vs HRC profile and an exponential curve has been fitted. The equation of their dependence can be expressed as: $HV = 144.37 \times e^{0.031HRC}$. (3)

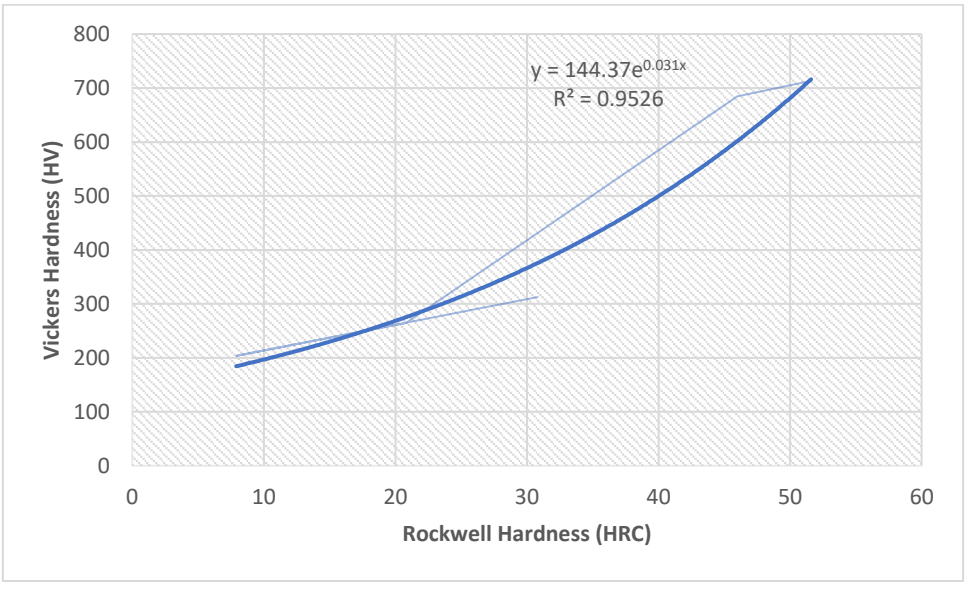

Fig.7: HV vs HRC profile

Conclusion

- Rockwell C scale hardness value could not be measured for soft materials whose Vickers Hardness value lies below 120 HV.
- Hardness numbers increase with increment in Carbon wt% for plain C steel.
- Hardness numbers of plain C steel samples having particular steel samples and varying heat treatment histories follow the pattern: Annealed (A) < Normalised (N) < Oil Quenched (OQ) < Water Quenched (WQ).
- From this experiment, a possible correlation between HV and HRC can be expressed by the equation: $HV = 144.37 \times e^{0.031HRC}$.

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VICKERS MICROHARDNESS TEST

Materials Property Evaluation Laboratory Report

This report is based upon the Vickers Microhardness Test performed on various samples by Group I (6th Semester, 2020)

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Introduction

Microhardness Testing, better known as Microindentation Hardness Testing, can be defined as indentation hardness testing that involves applied loads of 1 kg or less on the indenter or more precisely, as tests which result in indentation depths less than 70 µm to 100 µm. The two most common microhardness testing methods are Vickers and Knoop methods, with the former being more widely used and the latter being more precise and accurate.

Vickers was once a famous name in British engineering works. Founded by Edward Vickers in 1828 and based in London, they manufactured aircrafts, armaments and ships. The Vickers Heavy Machine Gun, a significantly improved version of the battle-hardened Maxim Heavy Machine Gun (not to be confused with the Soviet variant PM1910 of the same name) was a very useful tool in the arsenal of the British infantry during World War II and the Korean War. Even RAF aircrafts like the Supermarine Spitfire came out under the supervision of Vickers Ltd. The company went defunct in 1999 and was acquired by the Rolls-Royce plc.

The Vickers Hardness Test was developed in 1921 by Robert L. Smith and George E. Sandland at Vickers Ltd as an alternative to the Brinell method. It immediately gained popularity as the required calculations were independent of the size of the indenter and it could be used for all materials irrespective of the hardness. Also, it is practically a non-destructive test with the bonus of on-site inspection.

The Vickers Hardness Test is essentially applicable for both macrohardness and microhardness measurements, as it has a wide range of applicable test forces, from 10 gf to 120 kgf.

The Vickers Microhardness Testing Method

The Vickers Microhardness Testing Machine comes with a highly polished and pointed diamond indenter which is shaped into a right pyramid with a square base and an angle of 136º between opposite faces. The four faces of the indenter are equally inclined to the axis of the indenter (within ± 30´) and meet at a sharp point. The line of junction between the opposite faces (the offset) is not more than 0.5 µm in length. An optical microscope of magnification around 20X is slapped on the machine with a filar type eyepiece to view the indentation area.

The Vickers principle is based upon the measurement of the diagonals of the indentation after the removal of the load and calculation of their average value by adjusting the graticules available in the eyepiece of the optical microscope. For microhardness test, it is assumed that the indentation does not undergo any elastic recovery after force removal.

The time from the initial application of the force until the full test force is reached ideally does not exceed 10 s, and the indenter contacts the specimen at a velocity between 15 μms^{-1} and 70 μms^{-1}. The usual dwelling time is between 10 s to 15 s unless otherwise specified. When the machine is in operation, the operator must refrain from contacting it in any manner to avoid vibrations.

The Vickers indenter usually produces geometrically similar indentations at all test forces, with the mean diagonal length about 7 times greater than the indentation depth. The Vickers Hardness Number (VHN) is dependent on the applied load for microhardness testing, especially for loads less than 100 g. Hence, care must be taken when such loads are being applied. As microhardness test is suitable for obtaining local values, a number of measurements are required to obtain the bulk hardness of the material. It is recommended to place consecutive indentations a minimum distance apart to avoid the cold

deformed zone, and that distance is usually 2.5 times of the average diagonal length of the previous indentation.

The Vickers Hardness Number is the coefficient obtained by dividing the applied force (in kgf) by the area of the indentation (in mm), and is denoted by VHN or HV (ASTM E92 or BS 427).

$$VHN = \frac{2F\sin\frac{\theta}{2}}{d^2} = \frac{1.8544F}{d^2}$$

Where F = applied load (kg)

d = mean of diagonal impression (mm)

θ = face angle of the pyramid (136º).

The VHN measurement is performed automatically by the machine itself and the data is reported accordingly.

For optimum accuracy of the measurements the test should be performed on a flat specimen with a polished or otherwise prepared surface, completely free from scratches. The surface must be free of any defects that can affect the indentation or the subsequent measurements of the diagonals. An improper polish is likely to alter the results. For loads less than 100 g, metallographic finish is necessary to complete preparation of the specimen.

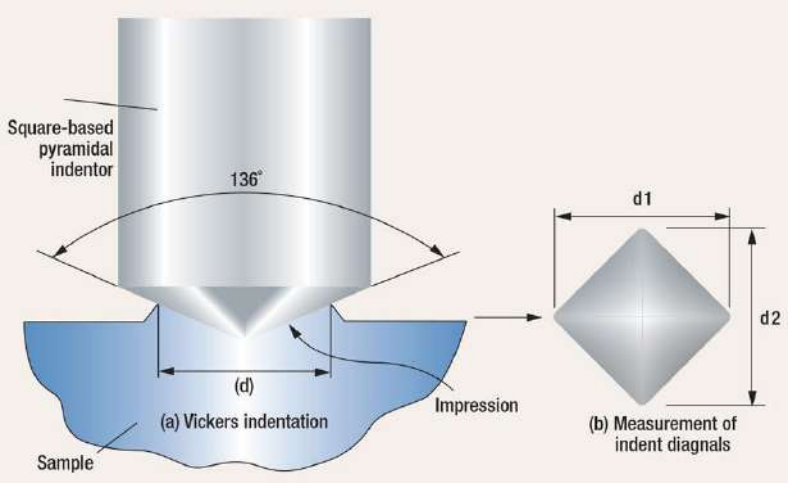

Fig. 1: The operation of the indenter

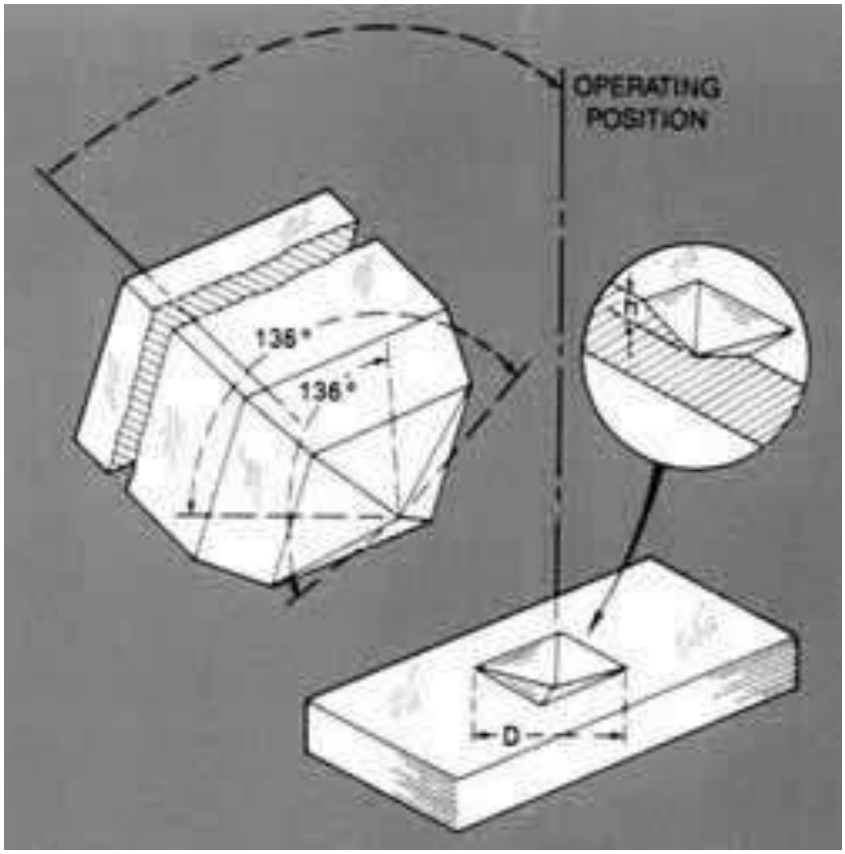

Fig.2: The indenter and the indentation

Fig. 3: A typical Vickers Microhardness Testing Machine

Procedure of the Experiment

Number of samples: 10

Sample materials:

1. 0.3% C Steel Water Quenched
2. 0.3% C Steel Annealed
3. TMT Rebar
4. 1.1% C Steel Water Quenched
5. 1.1% C Steel Annealed
6. 1.1% C Steel Oil Quenched
7. 60-40 Brass
8. Cu 80% Deformation, Annealed at 500℃ for 60 minutes
9. Cu 80% Deformed
10. Bronze Annealed at 700℃

The following procedure was adopted for the experiment for each sample:

1. The sample was prepared for the hardness test by effective grinding and polishing (both coarse and fine).
2. Using proper etchants, the microstructure of the sample was observed.
3. The sample was placed on the working table of the microhardness testing machine and the jaws were used to fix its position under the optical microscope.
4. The graticules of the eyepiece lens were moved to coincide with each other and indentation locations on the sample were identified approximately.
5. The turret was manually rotated to fix the indenter over the sample. The necessary force and dwelling time (depending on the phase under scrutiny) were given as inputs to the machine and indentation was allowed to occur.

6. Once the indentation was over the turret was rotated again to bring up the microscope and the indentation was observed. Using the graticules of the eyepiece lens, the value of d_1 was measured after which the lens was simply rotated by a right angle to repeat the process and measure the value of d_2, both in mm.
7. From the values of d_1 and d_2, the hardness of the considered phase was automatically calculated and displayed by the machine. For each phase, multiple readings were taken and only the three best readings were considered. Loads and dwelling durations were varied depending upon the phase and/or the sample.

Results

Microstructures of the samples:

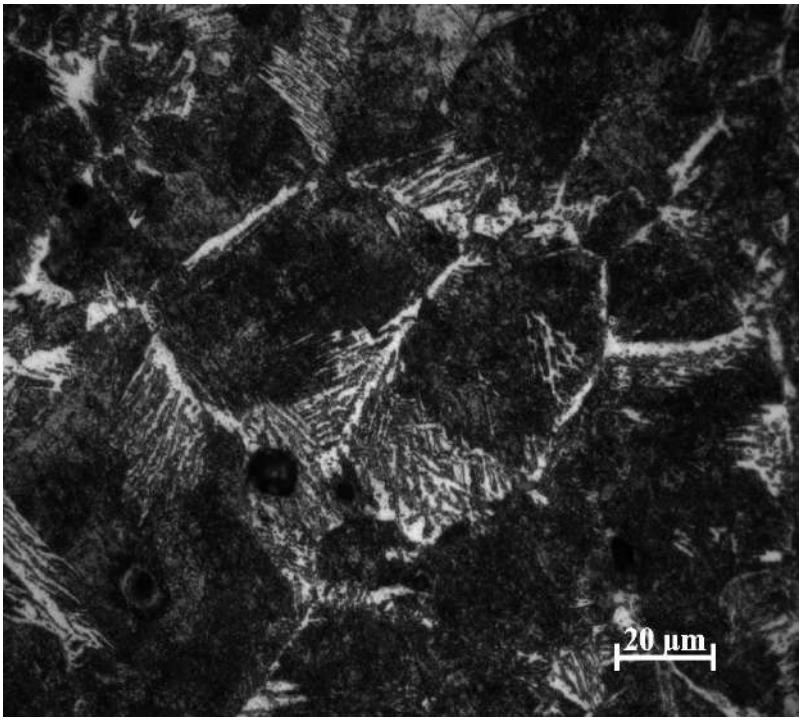

Fig. 4: Microstructure of 0.3% C Steel (Water Quenched)

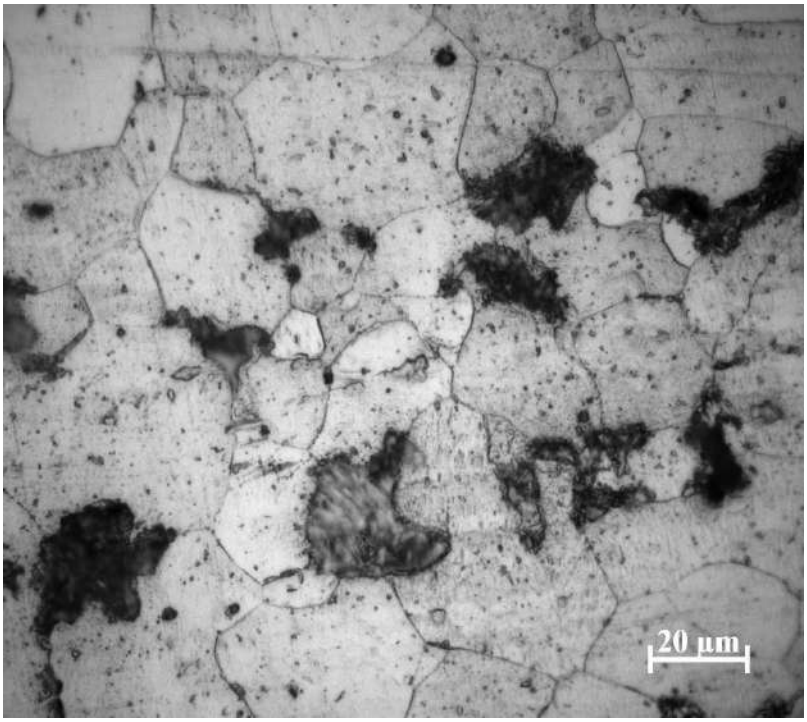

Fig. 5: Microstructure of 0.3% C Steel (Annealed)

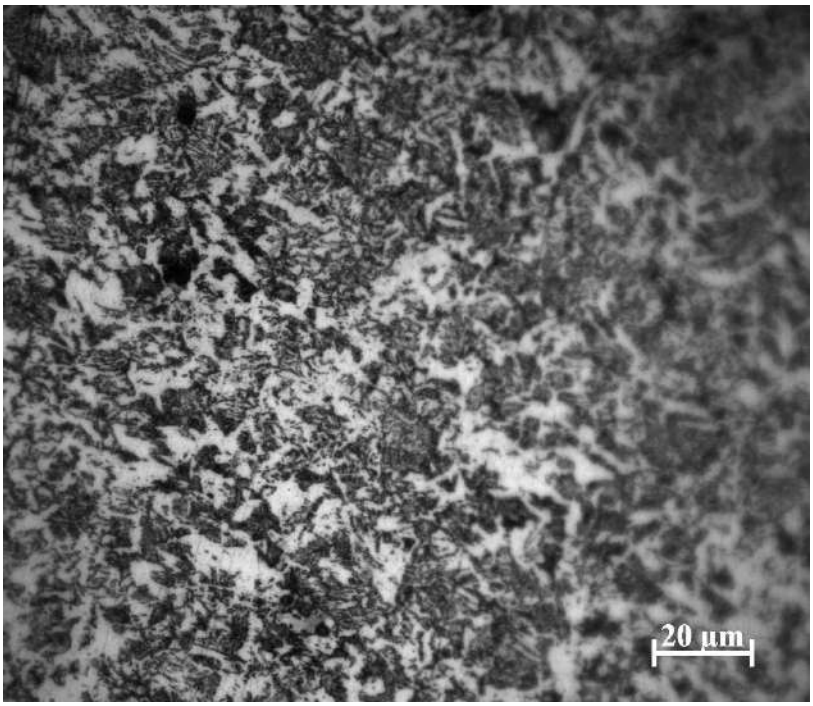

Fig. 6 (a) Microstructure of TMT Rebar (Rim)

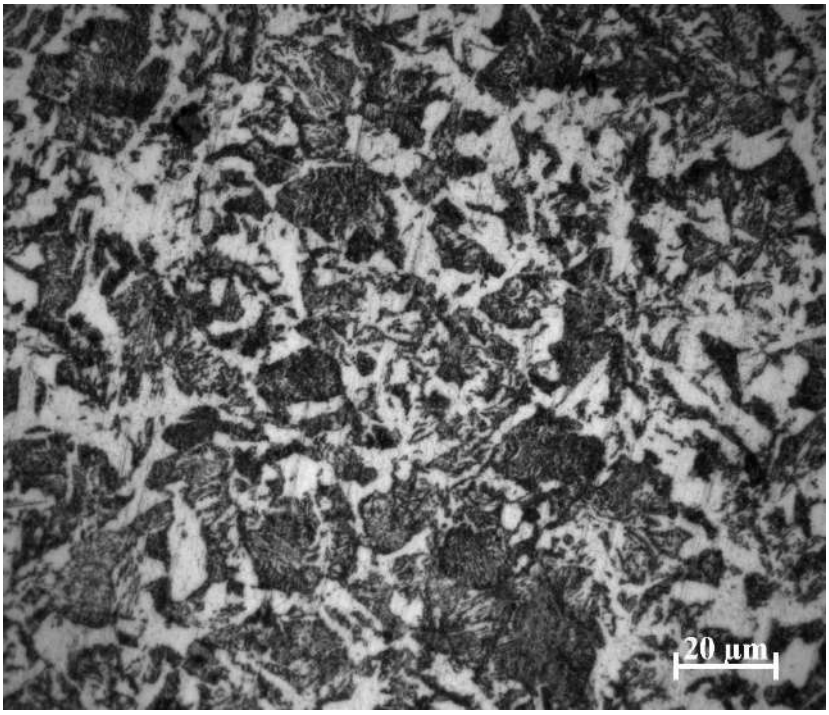

Fig. 6 (b): Microstructure of TMT Rebar (Core)

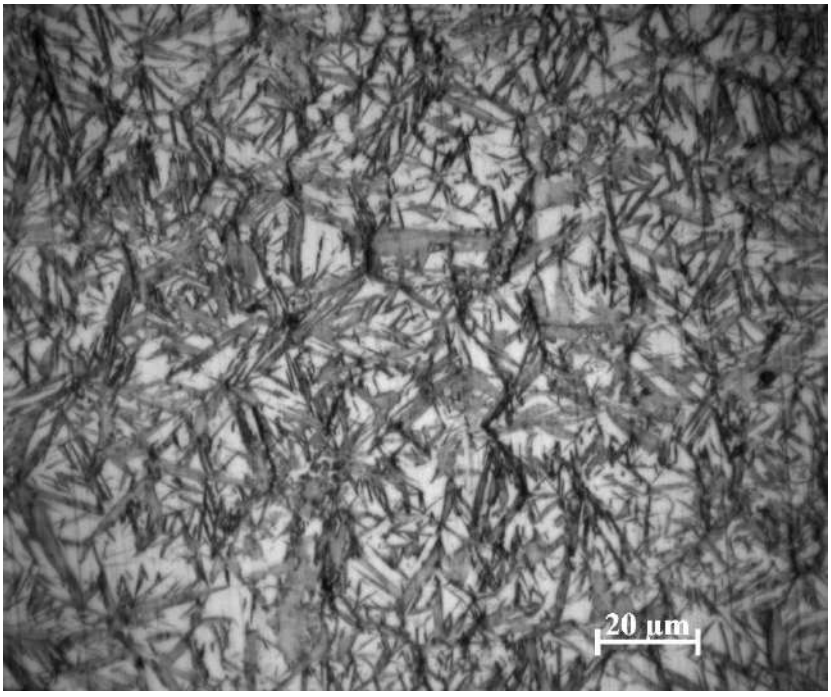

Fig. 7: Microstructure of 1.1% C Steel (Water Quenched)

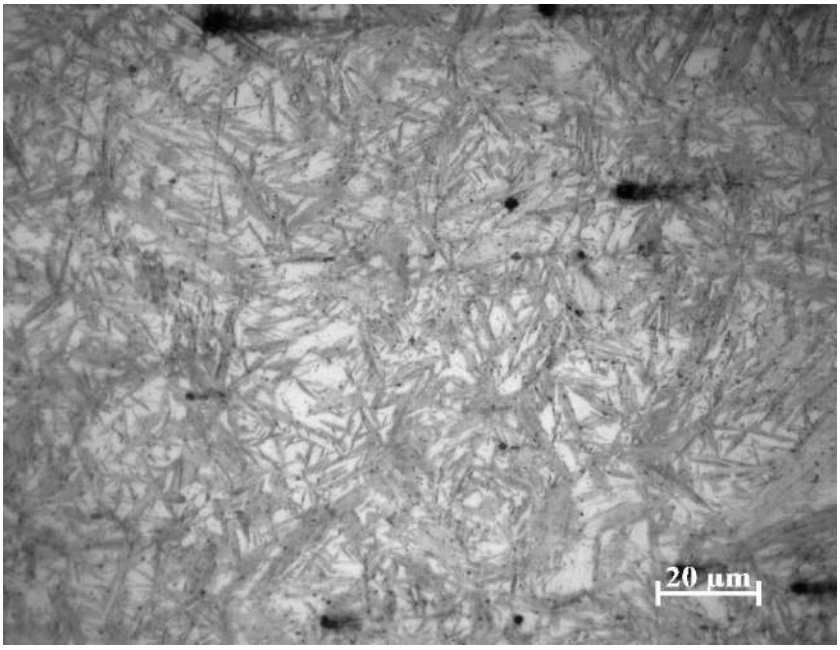

Fig. 8: Microstructure of 1.1% C Steel (Oil Quenched)

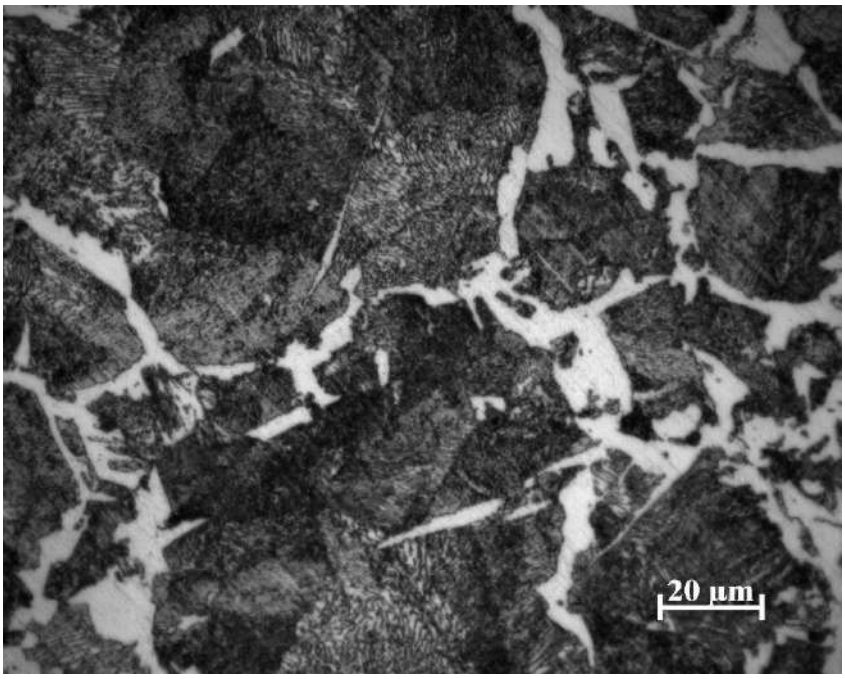

Fig. 9: Microstructure of 1.1% C Steel (Annealed)

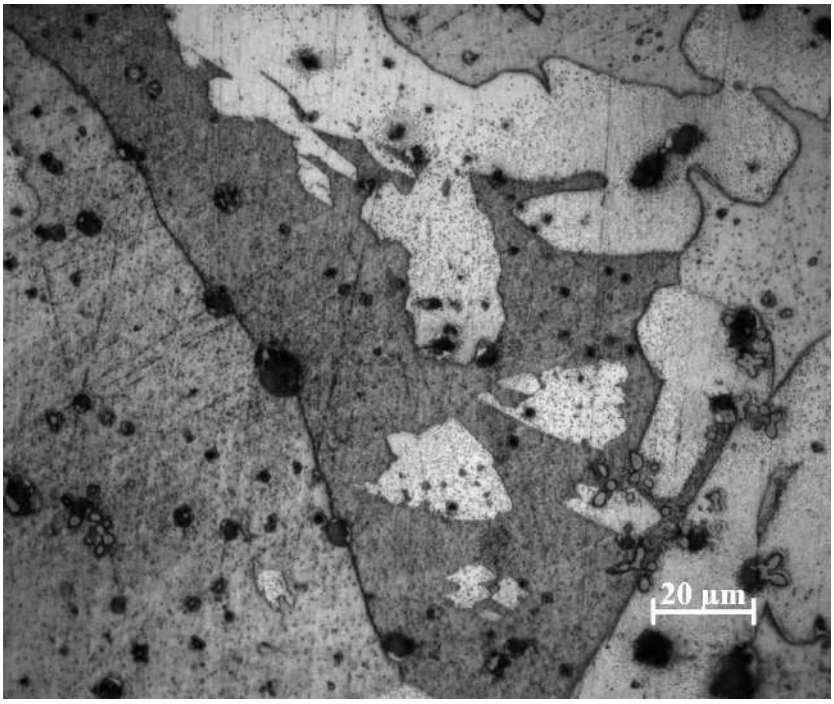

Fig. 10: Microstructure of 60-40 Brass (Annealed)

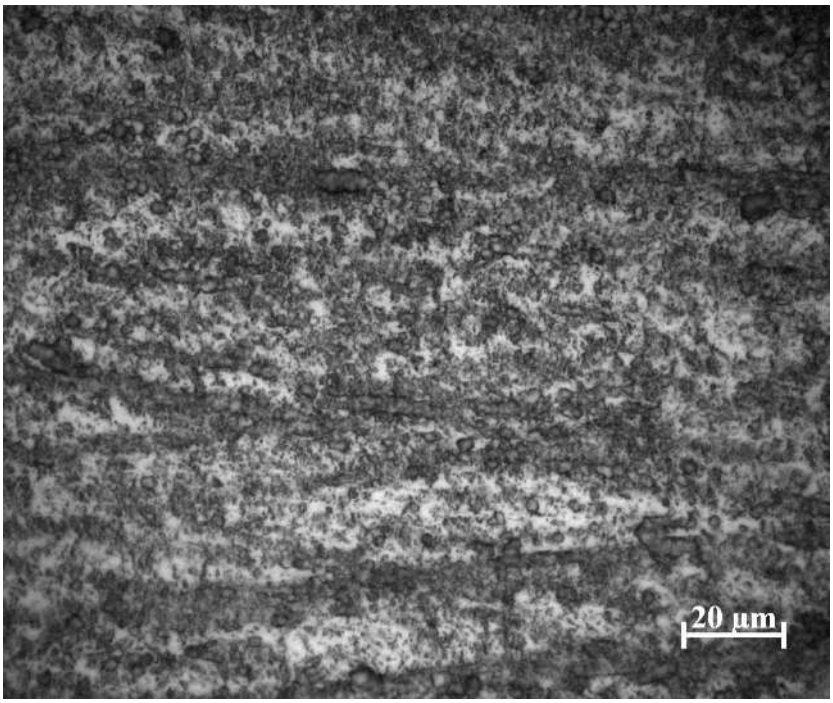

Fig. 11: Microstructure of 80/500/60 Copper

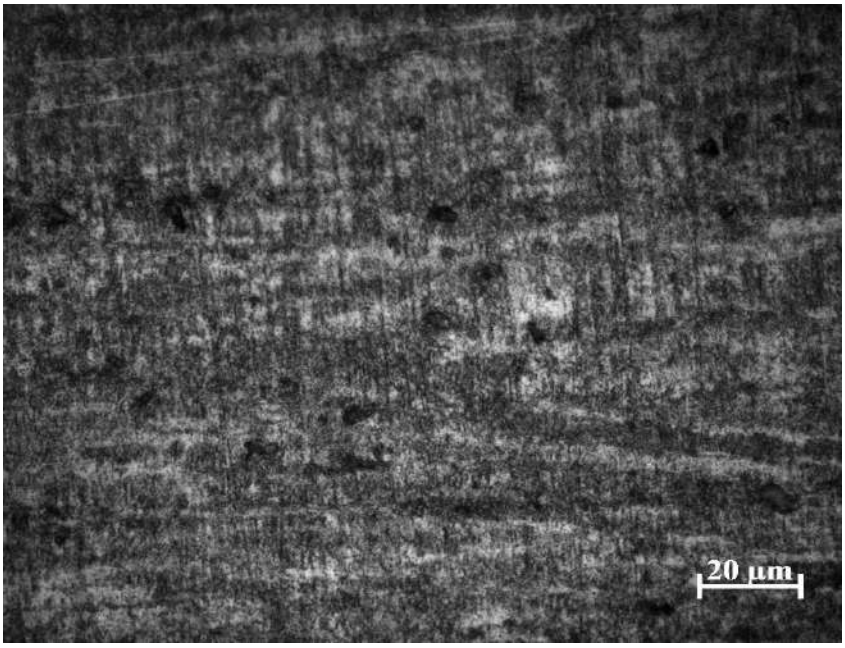

Fig. 12: Microstructure of Cu (80% Deformed)

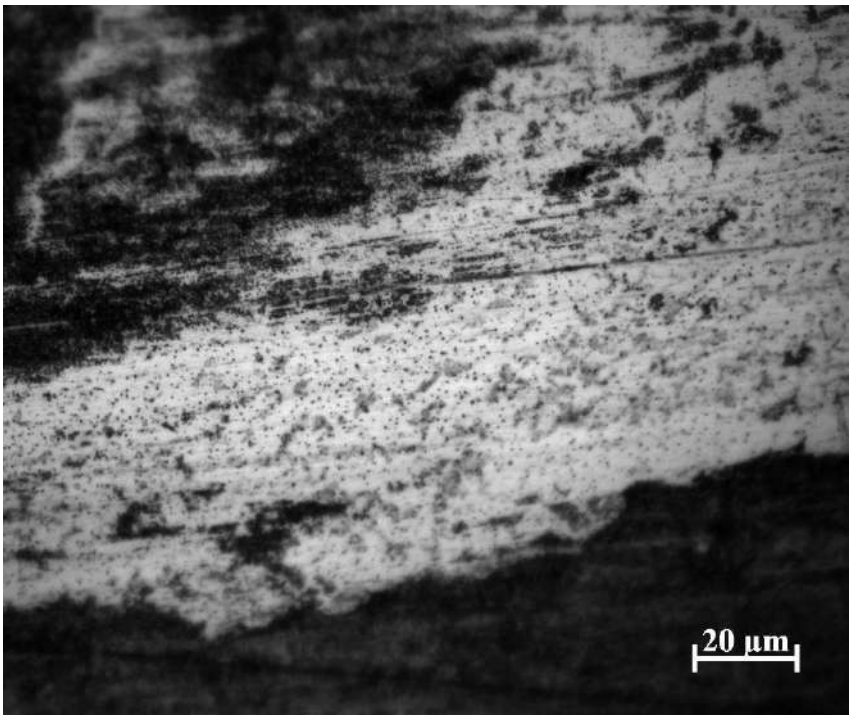

Fig. 13: Microstructure of Bronze (Annealed at 700°C)

Experimental Data:

Sample Name	Load (gf)	Dwelling Time (s)	Phase	d1 (μm)	d2 (μm)	d = (d1+d2)/2 (μm)	Hardness (HV)	Mean Hardness (HV)
				40.6	41.4	41	220.7	
		25	Pearlite	37.5	40.9	39.2	241.4	225.9
0.3% C Steel (Water Quenched)	200			40.7	42.2	41.5	215.8	
				29.9	29.5	29.7	420.4	
		15	Martensite	28.3	28.6	28.5	457.8	434.9
				32	35.4	33.7	426.6	
				35.1	35.3	35.2	149.8	
			Ferrite	36.6	36.9	36.8	137.1	137.2
0.3% C Steel (Annealed)	100	25		39.6	37.6	38.6	124.6	
				27.4	26.9	27.2	252.1	
			Pearlite	28.3	29.5	28.9	220.5	235.5
				27.8	28.5	28.2	233.8	
				12.3	12.4	12.4	306.9	
			Rim (mostly tempered lath martensite)	11.9	13.3	12.6	292.4	295.7
TMT Rebar	25	25		12.3	13.1	12.7	287.8	
				13.6	13	13.3	261	
			Core (mostly pearlite)	12.8	13.2	13	274.5	258.9
				13.5	14.3	13.9	241.3	
				20	20.9	20.5	885.2	
	200	15	Plate Martensite	21	22	21.5	795.8	879.3
1.1% C Steel (Water Quenched)				19.5	19.9	19.7	956.9	
				17.1	16.7	16.9	648.9	
	100	20	Retained Austenite	19.2	18.5	18.9	520.9	520.2
				23.1	20.5	21.8	390.8	
				14.3	13.9	14.1	930.8	
		15	Plate Martensite	14.9	13.7	14.3	907.2	910.5
1.1% C Steel (Oil Quenched)	100			14.2	14.6	14.4	893.6	
				14.9	15.9	15.4	781.5	
		20	Retained Austenite	17.8	18.7	18.3	562.3	581.7
				21	21.9	21.5	401.3	
				18.2	19.6	18.9	257.7	
		25	Pearlite	18.6	18.7	18.7	266.6	257.1
1.1% C Steel (Annealed)	50			19.2	19.5	19.4	247	
				10.9	11.3	11.1	750.6	
		10	Cementite	10.3	10.7	10.5	836.9	794.9
				10.5	11	10.8	797.2	
				18.7	18.6	18.7	133.7	
			α	18.3	18.6	18.5	135.6	134.6
60-40 Brass (Annealed)	25	25		18.5	18.7	18.6	134.4	
				13.4	14.4	13.9	239.7	
			β	14.9	15.5	15.2	201.5	212.8
				15.6	15.4	15.5	197.3	
				23.2	24.9	24.1	82.6	
Cu 80/500/60	25	25	Homogeneous phase	23.3	23	23.2	86.7	84.2
				23.5	24.3	23.9	83.2	
				18.2	17.2	17.7	148.5	
Cu 80% Deformed	25	25	Homogeneous phase	18.6	19.5	19.1	126.4	139.7
				18.3	17.5	17.9	144.3	

Discussions

For 0.3% carbon steel:

1. Water Quenched (Fig. 4)

In the water quenched sample, the phases present are pearlite and martensite. The rapid cooling rate lead to the formation of martensite, and the inevitable differential cooling had allowed formation of pearlite.

From the recorded data, it can be inferred that, martensite has greater hardness value than pearlite. This is contributed from the facts that martensite has few operable slip systems and has a solid solution strengthening, dispersion hardening as well as high stress fields and dislocation tangles

2. Annealed (Fig. 5)

In the annealed sample, the phases present are ferrite and pearlite.

The observation from the recorded data, tells us that the pearlite phase shows greater hardness value than the ferrite phase.

The observed difference in the hardness values of the two samples mentioned above is due to the different heat treatment processes involved in their preparation. In the water quenched sample, the rapid cooling rate result into a finer grain size and formation of martensite phase which gives an overall harder sample.

For TMT Rebar (Fig. 6):

From the recorded data, it can be observed that the hardness value is more at the rim than at the centre, which is expected from the fact that the rim portion comprises of tempered martensite (formed due to the higher cooling rate at the rim portion and autotempering), and the centre comprises of pearlite (due to the slow cooling rate at the centre).

For 1.1% carbon steel:

1. Water Quenched (Fig. 7)

Plate Martensite was found in the sample, resulting in a greater hardness value due to greater carbon content.

A lesser load was recorded over the retained austenite present in the sample, which lacks the dislocation density as well as distortion of the plate martensite, producing a lesser hardness value.

2. Annealed (Fig. 8)

The sample showed presence of pearlite and cementite phases.

The cementite is the hardest phase in steels, with a theoretical expectation of around 1100 HV. The reason that the recorded value falls short can be improper indentation due to machine misalignment.

3. Oil Quenched (Fig. 9)

Plate Martensite is found in the sample, resulting in a greater hardness value due to greater carbon content.

The retained austenite present in the sample showed lesser hardness than the martensite due to less distortions and less dense distribution of dislocations.

For 60-40 Brass Annealed (Fig. 10):

The alpha phase present in the sample shows lower hardness value as compared to the beta phase present. The alpha brass usually contains less than 37% zinc and is much more ductile whereas the beta brass usually contains more than 45% zinc and is much harder and stronger than its alpha sibling. Together, they promote strengthening by two-phase aggregate, giving the overall sample a good blend of mechanical properties.

For 80/500/60 Copper (Fig. 11)

The above designation reveals that the sample was 80% deformed, and then annealed at 500°C for 60 minutes.

The hardness value is contributed by the introduced cold work on the sample. But as it has been annealed at the given suitable temperature for the given time period, the strain-free condition has been somewhat restored which lead to further lowering of hardness value.

For Cu 80% Deformed (Fig. 12)

The high hardness resulted from the strain hardening of the sample. The deformation had elevated the dislocation density, leading to formation of cell walls from the high-density dislocation tangles.

For Bronze Annealed at 700^0 C (Fig. 13)

The data for this sample could not be recorded due to unfortunate malfunctioning of the testing machine prior to recording the measurements.

In general, the recorded data in the samples deviated from the expected values due to a major fault in the testing machine itself. The graticules of the microscope were not in proper alignment with the indenter. So proper indentation on a particular phase was rare.

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VickersMicroHardness Testing

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Objective- To get the hardness of a particular phase present in the microstructure of materials.

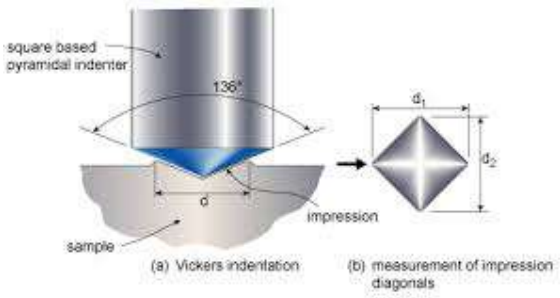
Sample –

I. Dual Phase Steel
II. Re bar
III. α -β Brass
IV. Bronze (Annealed)
V. 0.3 wt % annealed steel
VI. 1.1 wt % w/q
VII. 1.1 wt % w/q

Introduction-Micro hardness test

- Micro hardness refers to indentation test made with load upto1 kg Vickers.
- If we want hardness of a particular phase present in microstructure, we have to use Vickers Microhardness testing.
- It uses diamond indenter to make indentation.
- Load varies from 10 gf to 1 kgf.
- Micro hardness testing can also be used to measure very thin materials like foil and to make hardness -distance profile.

Vickers Micro Hardness Indenter-



- In Vickers Micro Hardness Diamond Indenter is used.
- Shape of indenter is pyramidical.
- Angle between faces is 136 degree.

Sample Preparation-

Requirement-

1- End surface of sample should be parallel to each other.
2- Sample surface should be nicely polished,free from scratches.

Process-

- we make the end surfaces of sample parallel to each other
- Then do paper grinding then go for cloth polishing
- Then we go for etching with proper reagents.

Test Procedure-

1- Place the specimen on specimen holder, make sure specimen is under indenter.
2- Focus the specimen.
3- Select the phase whose hardness is to be measured and focus that part.
4- Select load and indentation time.
5- Apply load.
6- After indentation is completed, measure the diagonal length by focusing nicely under microscope.
7- Find the Vickers hardness number. (In our machine it is shown on the screen).

$$VHN = 1.854 * P/D^2$$

VHN=Vickers hardness number

P= applied load in Kg

D= avg diameter in mm.

Observation-

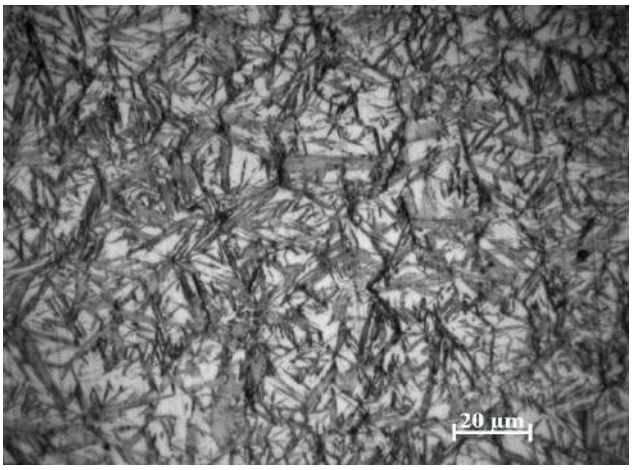
Sample1- 1.1 wt% w/q

Load=500gf, Indentation Time=25 sec

Sr No	Hardness(VHN)	D1(Micro meter)	D2(micrometer)
1	770	34.9	34.2
2	829.9	32.8	34.1
3	837	33.4	33.2
4	872	32.6	32.6
5	824	33.5	33.6
Avg	826.58		

Result- Hardness of 1.1 wt% w/q sample =826.58 VHN

Microstructure of sample-



Microstructure of 1.1 wt % w/q steel at 100 x

Discussion-

Here hardness of a individual phase ie only martensite and only retained austenite is not possible because of overlapping of indentation mark on both phases.

Sample2- 0.3 wt% steel annealed

Hardness of Ferrite phase -

Load -100gf, Indentation time -25 sec

Sr no	Hardness (VHN)	D1(Micro meter)	D2(Micro meter)
1	155.5	34.3	34.8
2	138.8	36.5	36.6
3	155.76	34.5	34.6
Avg	150.02		

Micro Hardness of Pearlite phase-

Load – 50gf, Indentation time -25 sec

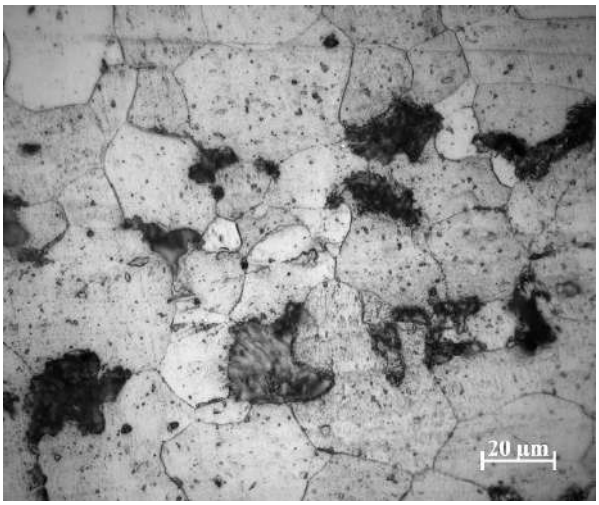
Sr no	Hardness (VHN)	D1 (Micro meter)	D2(Micro meter)
1	526.7	13.4	13.2
2	-	-	-
3	-	-	-
avg			

Discussion-

- In case of pearlite phase, appearance of pearlite phase is black and indentation mark is also black

So, because of contrast problem, it was very difficult to measure the correct reading of d1 and d2.

Microstructure of 0.3 wt% annealed-

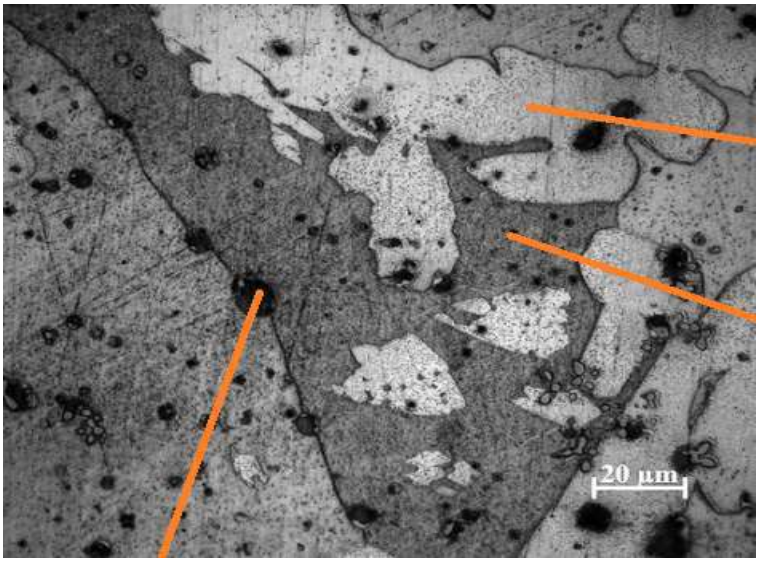


Micro Structure of 0.3 wt % annealed at 100 x

Sample 3- 60/40 brass

Load -50gf, Indentation time -25 sec

Microstructure of 60/40 Brass-



α -phase

β - phase

Pb Particle

Microstructure of 60/40 brass at 100 x

Micro Hardness of phase B-

Sr No	VHN	D1	D2
1	219.9	19.8	19.3
2	186.8	22.5	22.1
3	206.25	21.3	21.5
Avg	204.31		

Micro Hardness of phase A-

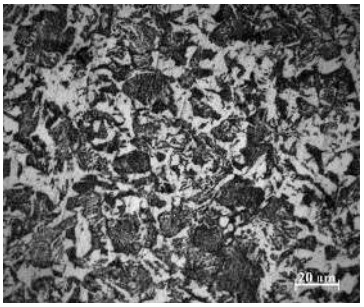
Sr No	VHN	D1	D2
1	137.3	25.6	26.4
2	135.5	26.8	25.5
3	147.14	25.1	25.5
Avg	139.98		

Discussion-

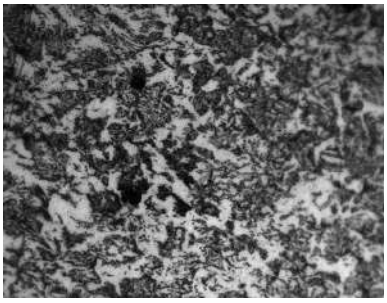
Here it is visible that hardness of phase B is larger than phase A in 60/40 brass .

Sample -4 Re -Bar

Micro Structure of Re-bar core and rim-



Re-bar core at 100x



Re bar rim at 100x

Hardness of Re-bar core-

Load-200gf , Indentation time- 25 sec

Sr no	VHN	D1	D2
1	243.4	39.9	38.2
2	248.0	37.6	39.8
3	255	38.1	38.4

Avg	248.8		

Hardness of Re-bar-Rim

Load-500 gf , Indentation time -25 sec

Sr no	VHN	D1	D2
1	400.6	49.0	48.5
2	402	48.1	48.3
3	419.64	47.0	47.3
Avg	407.41		

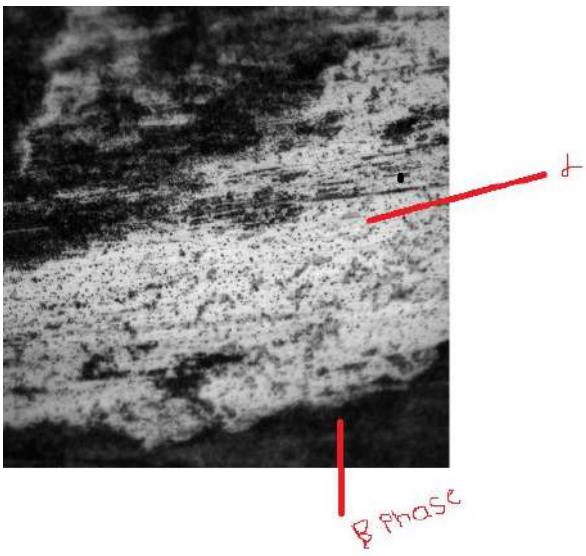
Discussion-

Here we can see that hardness of Rebar -core is lesser than the hardness of rebar-rim.

It is so, because of surface quenching. Rim has the microstructure of martensite and tempered martensite but at the centre of rebar microstructure is ferrite -pearlite.

Sample 5- Bronze Annealed

Microstructure of Bronze annealed-



Microstructure of Bronze at 100 x

Hardness of alpha phase-

Load-100gf, Indentation time -25 sec

Sr no	VHN	D1	D2
1	147.0	35.5	35.5
2	135.3	36.8	37.2
3	138.9	35.7	37.4

Avg	140.4		

Hardness of beta phase-

Load -100gf , Indentation time 25 sec

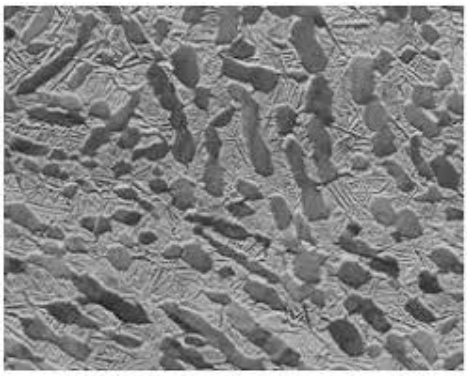
Sr no	VHN	D1	D2
1	95.3	43.0	45.2
2	95.2	43.9	44.4
3	96.64	44.1	43.5
Avg	95.71		

Discussion-

Here we find that hardness of alpha phase is greater than beta phase.

Sample 6 – Dual Phase Steel

Microstructure-



Microstructure of dual phase steel at 100x

Micro Hardness of ferrite phase –

Load-25 gf ,Indentation time -25sec

Sr No	VHN	D1	D2
1	183.4	14.8	17.0
2	181.05	16.0	16.4
3	185.66	15.8	15.4
Avg	183.37		

Discussion –

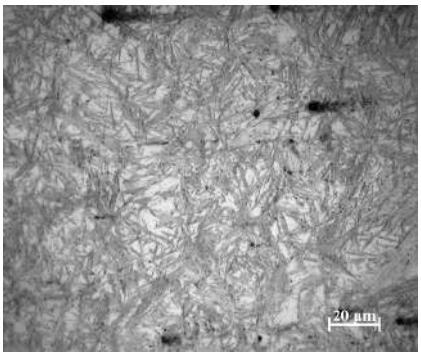
In this sample , Microhardness of Martensite phase was coming about 241.6 VHN

Which is not fitting to the martensite phase

It may be due to overlapping of indentation impression on both phases.

Sample 7- 1.1 wt % o/q

Microstructure-



Microstructure of 1.1 wt% o/q at 100x

Micro Hardness of Martensite Phase-

Load-500gf

Sr No	VHN	D1	D2
1	899	32.3	32.3
2	770	36.2	35.5
3	756	35.4	35.1
Avg	808		

Discussion-

Here we can see, microhardness of martensite phase is appropriate.

Separately we could not find the microhardness of Retained Austenite.

Precautions-

1-Sample preparation should be done nicely, sample should be free from scratches.

2-Sample should be parallel or it may harm the indenter which is very costly.

3-While measuring the diameter,we should be careful. Make sure it is nicely focused.

4-Proper load should be applied for different samples.

5-Sufficient indentation time should be provided.

STATIC TENSILE TESTING LABORATORY REPORT

Materials Properties Evaluation Laboratory (6th Semester)
Performed under the supervision of Dr. Debdulal Das
Department of Metallurgy and Materials Engineering, IIEST Shibpur

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THEORY

Tensile tests are used to determine how materials will behave under tension load. In a simple tensile test, a sample is typically pulled to its breaking point to determine the ultimate tensile strength of the material. The amount of force (F) applied to the sample and the elongation (ΔL) of the sample are measured throughout the test. Material properties are often expressed in terms of **stress** (force per unit area, $\boldsymbol{\sigma}$) and **strain** (percent change in length, $\boldsymbol{\varepsilon}$). To obtain stress, the force measurements are divided by the sample's cross sectional area ($\boldsymbol{\sigma} = F/A$). Strain measurements are obtained by dividing the change in length by the initial length of the sample ($\boldsymbol{\varepsilon} = \Delta L/L$). These values are then presented on an XY plot called a stress-strain curve. Testing and measuring procedures vary based on the material being tested and its intended application.
The idea of a tensile test is to place a sample of a material between two fixtures called 'grips' which clamp the material. The material has known dimensions, like length and cross-sectional area. The tensile testing instrument then begins to apply weight to the material gripped at one end while the other end is fixed. The load is continuously increased, while at the same time, the in-built controller measures the change in length of the sample and simultaneously generates the stress-strain plot.

AIM

To study the tensile test data of 4 specimens – 2 Aluminium and 2 Steel samples.

APPARATUS

- Universal test machine frame
- Load cell
- Controller and/or indicator
- Proper grips
- Rubber bands
- Extensometer
- Specimen samples (dog-bone shaped)

***Fig (1)** : Typical dog-bone specimens*

The universal test machine frame provides the structure and rigidity needed to pull the sample apart at the desired rate. Frames are available in both electromechanical and servo-hydraulic configurations with a wide range of capacities. The frame used must be able to withstand the amount of force needed to test the sample.
Load cells measure the amount of force being applied to the sample.
Depending on the system setup, a controller or an indicator is needed. Controllers, as the name implies, control how the test frame behaves during testing, including test speed and displacement. Indicators capture and display the test data but do not control the machine.
There are many types of grips and fixtures available for tension testing. Different materials require different fixturing to properly hold them. For example, a sample made of metal requires different grips than rubber due to how the materials behave as tensile forces are applied. Selecting the correct grips is crucial in achieving accurate results.

PROCEDURE :

Instron Universal Tensile Testing Machine is used for this experiment.
A material is gripped at both ends by an apparatus, which slowly pulls lengthwise on the piece until it fractures. The pulling force is called a load, which is plotted against the material length change, or displacement. The load is converted to a stress value and the displacement is converted to a strain value.
The gauge width, thickness, and length of each sample was measured with a pair of Vernier calipers before the experiments were performed.
The sample is placed at the bottom grip. While still holding it vertically with one hand, the another hand is used to turn its handle in the closing direction as tightly as possible. It is important that the specimens are tightly gripped onto the specimen grips to prevent slipping, which will otherwise result in experimental errors. Also, the specimen must be vertically aligned, if not a torsional force, rather than axial force, will result. An extensometer is attached carefully to monitor strain.A crosshead speed of 1mm/min is maintained.
The experiment is then initiated with the help of the software, and the load is gradually applied. Simultaneously, the stress-strain curve appears on the screen. A plot of Force (kN) versus Stroke (mm) will be generated in real-time during the experiment. The experiment stops with failure of the specimen.

Fig (2) *– Tensile testing machine at work*

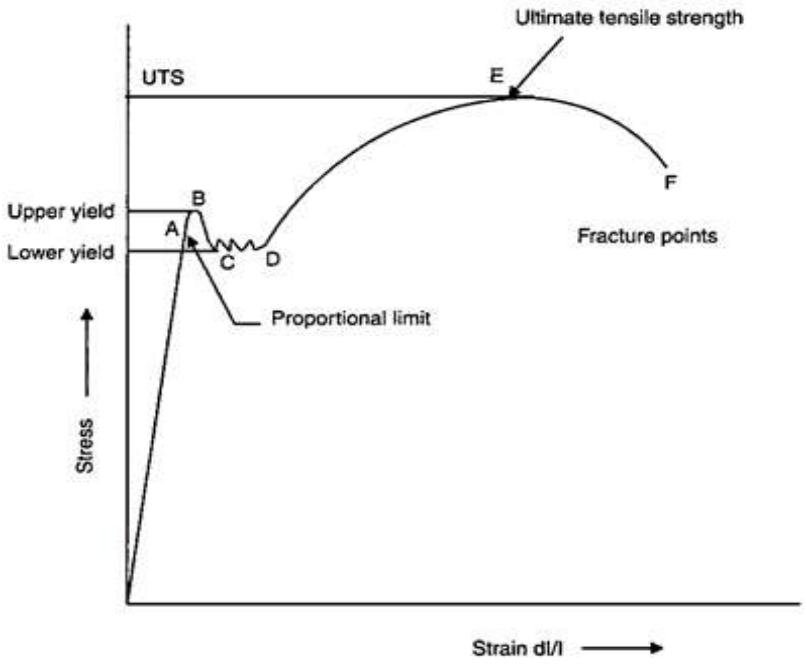
The stress-strain data and the corresponding plot is saved, and the broken specimen is removed from the grips. The software used is **Bluehill Universal Software.**
The two broken fragments are gently joined next to each other, taking care not to affect the fracture surfaces, and the gauge length is measured once again. The initial length is subtracted to find the elongation.
The fracture surface is then viewed and analyzed with the help of a Scanning Electron Microscope.
This procedure is repeated for all the samples.

OBSERVATIONS :
The samples elongate, followed by necking, and then sudden fracture.
Data not available.

DISCUSSION :

<u>Steel</u> :

A typical stress-strain curve or mild steel is shown :



The stress-strain curve is divided into four regions, which are as follows: elastic, yielding, strain hardening and necking. The area under the curve represents the amount of energy required. The total area under the curve (up to the point of fracture) is also known as the modulus of toughness. This represents the amount of energy needed to break the sample, which could be compared to the impact energy of the sample, determined using Impact test. The area under the linear region of the curve is known as the modulus of resilience. This represents the minimum amount of energy needed to deform the sample.

Mild steel exhibits ductile fracture –

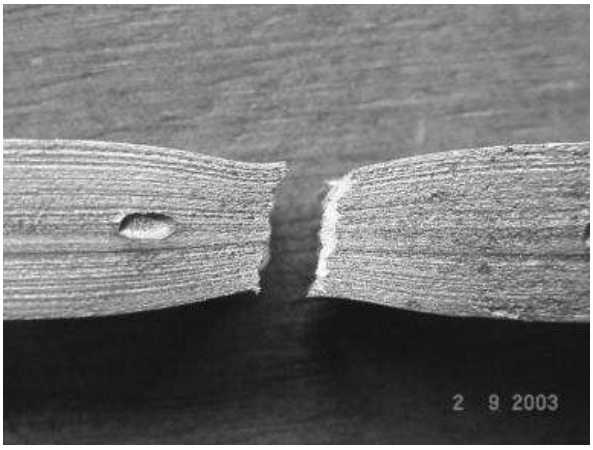
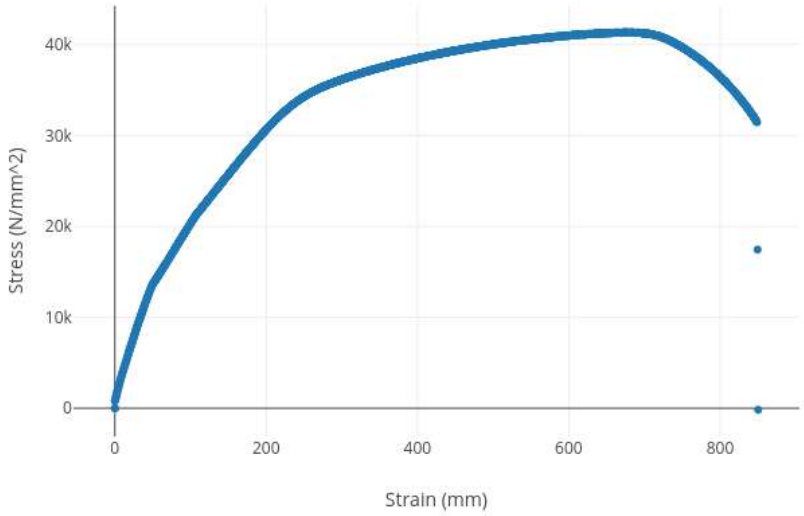


Fig (3) *– Ductile fracture in steel*

Ductile fracture is a type of fracture characterized by extensive deformation of plastic or "necking." This usually occurs prior to the actual fracture. The term "ductile rupture" refers to the failure of highly ductile materials. In such cases, materials pull apart instead of cracking.
In ductile fracture, there is absorption of massive amounts of energy and slow propagation before the fracture occurs.
A microscopic examination of a ductile fracture surface shows that the ductile fracture mechanism includes the formation and coalescence of microvoids, which may be somewhat spherical or parabolic. These microvoids are sometimes called dimples.

Aluminium :

A typical stress – strain plot for an aluminium sample is shown :



Aluminium generally undergoes more necking before fracture due to its ductile nature. It shows ductile fracture, like steel.

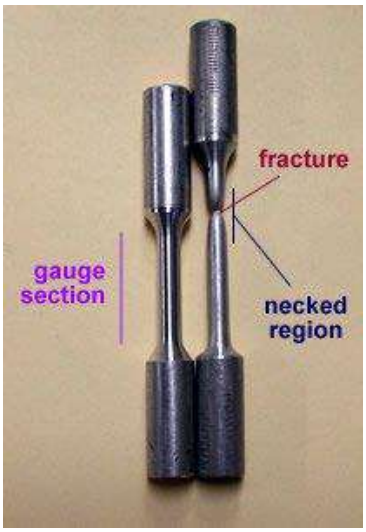
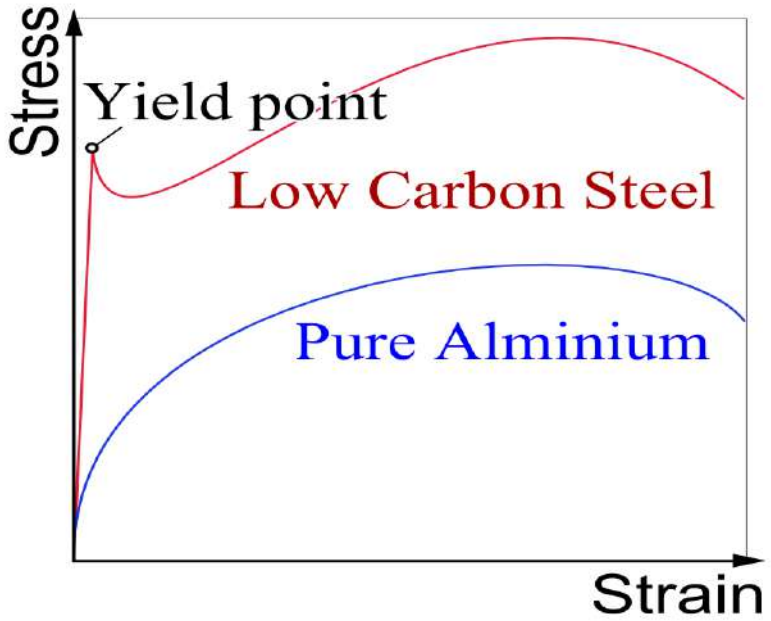


Fig (4) *– Typical Aluminium specimen before and after tensile testing*

A comparison between the stress-strain plots of steel and aluminium are shown below. We can see that both the Ultimate Tensile Strength (UTS) and yield strength (YS) of steel are usually higher. However this can change drastically depending on composition and heat treatment procedures of the materials. The stress-strain plot for steels may show a prominent yield point elongation due to the stress required for overcoming the Cottrell atmosphere.



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