Effect of Heat Treatment on Microstructure and Mechanical Behavior of Medium Carbon Steel

[1]Pavan Krishna Yadav P , [1]Pavan YC ,[1]Pavan Kumar S , [1]Pawan Kumar K, [2]Jagadeesh Babu
[1]Student, School of Mechanical Engineering REVA UNIVERSITY, Bangalore, India
[2] Associate Professor, School of Mechanical Engineering REVA UNIVERSITY, Bangalore, India

Abstract **-** In the present study, effect of heat treatment on microstructure evolution and mechanical behaviour of C45 medium carbon steel was investigated. The samples were solution treated at 900 °C with a soaking time of 3 hrs and 1.5 hrs, tempered at 300 ºC and 500 ºC with a soaking time of 0.5 hrs. Hardness tests were performed for as-received, heat treated samples and the obtained hardness values were ranged from 198 to 290 BHN. Tensile tests were carried out at room temperature and 850 ºC at the strain rates of 1×10^{-2} s^{-1} and 1×10^{-4} s^{-1}. Optical microscopy, SEM and XRD characterisation revealed the changes in the microstructure morphology and formation different phases depending upon the heat treatment temperature and soaking time.

Index terms – Steel, Heat treatment, mechanical behaviour.

I. INRODUCTION

In modern day there is growing demand for the improvement of the properties of the steel for various industrial or manufacturing applications. There were various research studies and experiments carried out in past decades to study the material behaviour due to various heat treatment processes and different strain rates. Steel, in particular is one of the material that have been extensively studied for that purpose due to its wide range of use in industry.

Steel suppliers are providing C45(0.45% carbon steel) mainly to build tools, machines ,or structures that sustain impact loading , sharp cutting edges, corrosion , brittle facture, and to provide high performance and weldability. Also this type of steel exhibit good wear resistance and capable of subjecting to various heat treatment i.e, heat treatable . Different studies [1] were attempting to understand the behaviour of C45 steel in terms of formability, effect of different kinds of processes such as heat treatment and cooling [2].

This research aims at conducting experimental tests to investigate stress-strain behaviour of C45 steel under different combinations of temperatures and strain rates. In addition, optical microscopy, Scanning Electron Microscopy (SEM) images X-ray diffraction (XRD) study were utilised to study the grain sizes and formation of different phases after heat treatment. The hardness of the material was also studied before and after tempering and quenching processes at different temperatures and soaking time.

II. MATERIAL AND EXPERIMENTAL PROCEDURE

a) MATERIAL

The material used for this study is commercially available C45 (0.45% carbon steel) medium carbon steel supplied in the form of sheet plate of thickness of 20mm and 410×410mm length and breadth. The chemical composition is given in Table 1. The microstructure of the as received sample was observed under optical misrocope as shown in Fig. 1. The microstructure consist of ferrite(white phase) and pearlite (dark phase) [2].

Table 1. chemical composition of the studied C45 steel.

	C	Si	Mn	S*	P*	Cr	Ni	Mo	Cr+Mo+Ni	Fe
Min	0.42		0.50							
Max	0.50	0.40	0.80	0.045	0.045	0.40	0.40	0.10	0.63	Bal*

b) EXPERIMENTAL PROCEDURE

The commercially available C45 grade medium carbon steel plate was procured and cut into small pieces of dimension 20×20×20 mm^3. These as received cut pieces were polished manually using commercially available emery paper of different grain sizes (600, 800, 1000, 1200, 1/0, 2/0, 3/0, 4/0) and later on a disc polishing machine as shown in (Figure 2) using a diamond paste until the surface was mirror finished and the surface was etched with nital (ethanol and nitric acid ,in the ratio 10:1) which was applied onto the surface manually using ear buds as shown in the (Figure. 3) for microstructure observation. These samples were subjected to heat treatment in a muffle furnace (Figure. 4) at a temperature of 900 ºC and soaked for 1.5 hrs and 3hrs followed by water quenching. Further the samples were subjected to tempering treatment at a temperature of 300 ºC and 500 ºC soaked for 0.5 hrs followed by water quenching.

Figure. 1. Disc polishing machine.

1. Heat treatment

These samples were subjected to heat treatment in a muffle furnace at a temperature of 900 ºC and soaked for 1.5 hrs and 3hrs followed by water quenching. Further the samples were subjected to tempering treatment at a temperature of 300 ºC and 500 ºC soaked for 0.5 hrs followed by water quenching as shown in Figure 4.

Figure 2 .(a) muffle furnace , (b) heat treatment process ,(c) quenching process.

2.MICROSTRUCTURE STUDY

Each heat treated samples under different temperatures of 900 ºC, tempered for 300 ºC and 500 ºC were polished following the same process mentioned above and the micrographs were taken under optical microscope and studied for changes in grain sizes and phase transformations. SEM characterisation was carried out on the sample which were heated to 900 °C and quenched, tempered at 300 °C for 30min and tempered at 500 °C for 30min.

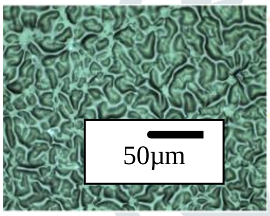

Figure 3. optical micrograph study of C45 steel , the dark phase is pearlite and white phase is ferrite.[5]

1. Hardness Test

The hardness test followed in the present work is Brinell Hardness test. The Brinell hardness test of as received and heat treated samples under load of 187.5kg , it characterizes the indentation hardness of the material through the scale of penetration of an indentor, loaded on a material test piece as shown in the Figure 5. The indentation measured and hardness calculated as

$$BHN = \frac{2P}{\pi D[D - \sqrt{D^2 - d^2}]}$$

Where,

BHN= Brinell Hardness Number (kgf/mm2)

P = applied load in (kgf)

D = diameter of indentor (mm)

d = diameter of indentation (mm)

Figure 4: Brinell Hardness testing machine.

2. TENSILE TEST

The tensile specimen was prepared as per ASTM standards as shown in the figure 6 and further tested in UTM (Universal Testing Machine) machine of 100KN capacity under strain rates of 10^{-2} and 10^{-4} s^{-1} and the results were tabulated in form of graph of stress VS strain.

Figure 5 tensile specimen of ASTM standard.

3. XRD ANALYSIS

X-ray diffraction (XRD) study was performed in the 2θ angle ranging from 20-90º on the selected specimens to analyse for the formation different phases during heat treatment process. The sample which were heated for 900 ºC , tempered for 300 ºC and 500 ºC were studied. The XRD machine is shown in the Figure 7.

Figure 6: XRD machine.

III. RESULTS AND DISCUSSIONS

Tensile results:

After the heat treatment process have been completed at different temperatures as described in the fig 2, tensile strength was checked for each sample in UTM machine in lab for the strain rates of 10^{-2} and 10^{-4} s^{-1}. From these tensile data the stress *vs* strain graph was plotted. The following are the graphs of samples of different conditions.

Table 2: Tensile results of as received samples.

Property	Load at yield (kN)	Elongation at yield (mm)	Yield stress (N/mm²)	Load at peak (kN)	Elongation at peak (mm)	Tensile strength (N/mm²)	Load at break (kN)	% elongation
Strain rate 10^{-2} s^{-1}.	101.754	10.5	403.226	174.606	23.8	691.92	161.55	22.14
Strain rate 10^{-4} s^{-1}.	105.072	13.5	414.682	176.832	27.95	697.892	88.416	23.64

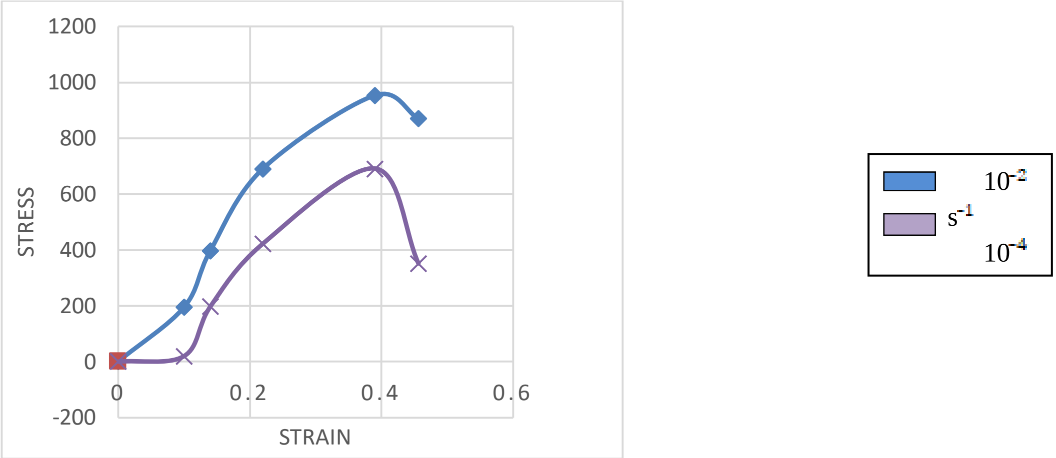

Figure 7: Stress *vs* Strain graph of as received sample.

TABLE 3 Tensile Properties of heat treated samples at strain rate 10^{-2} s^{-1}.

Property	Load at yield (kN)	El ongati on at yield (m m)	Yield stress (N/m m²)	Load at peak (kN)	El ongati on at peak (m m)	Tensil e strength (N/mm²)	Load at break (kN)	% elo ngatio n
900°C heated for 1.5hrs	200.412	10.63	791.995	241.956	12.64	956.169	241.956	1.92
900°C heated for 3hrs,tempered For 300°C.	170.04	10.52	675.254	237.18	19.69	941.876	216.174	18.38
900°C heated for 3hrs,tempered For 500°C	158.232	9.72	625.306	218.466	18	863.341	181.314	20.4

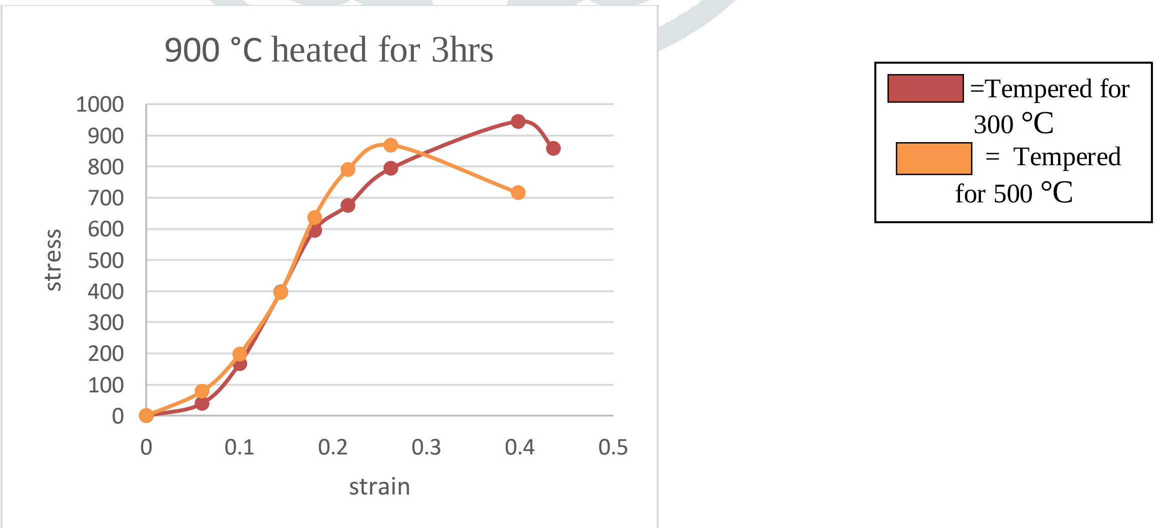

Figure 8: Stress vs Strain graph of heat treated samples.

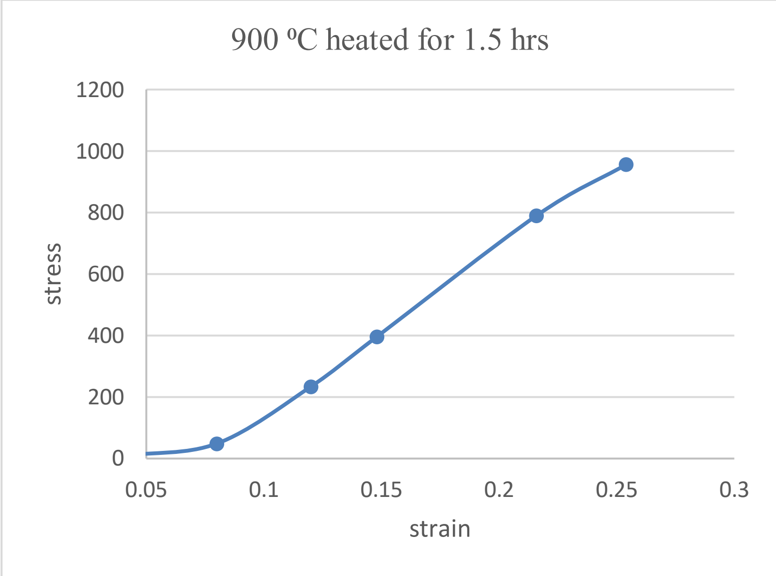

Figure 9 : Stress vs Strain graph of heat treated sample.

SEM micrography:

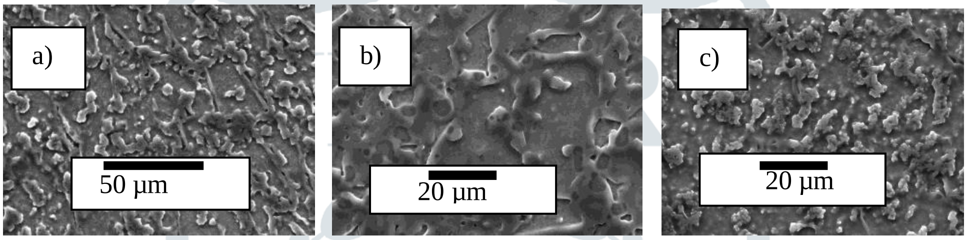

Figure 10 : white= ferrite, black= pearlite, grey= martensite [6]

(a) SEM micrograph of C45 steel heated for 900°C held for 1.5 hours And water quenched.
(b) heated upto 900°C and held for 1.5 hours and tempered for 300 °C temperatureand held for 30min and water quenched.
(c) heated upto 900 °C and held for 1.5 hours and tempered for 500 °C temperature and held for 30min and water quenched.

XRD analysis:

A scattering of X-ray by the atoms of a crystal that produces an interference effect so that the diffraction pattern gives information on the structure of the crystal or the identity of a crystalline substance.[6]

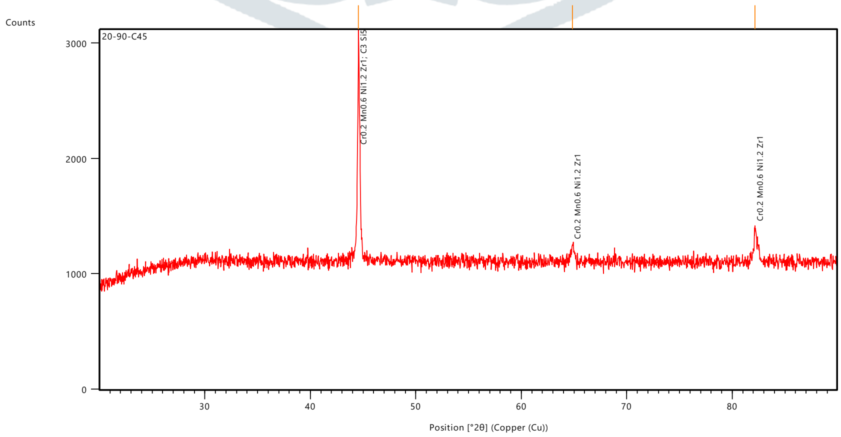

Figure 11: XRD results of as received sample

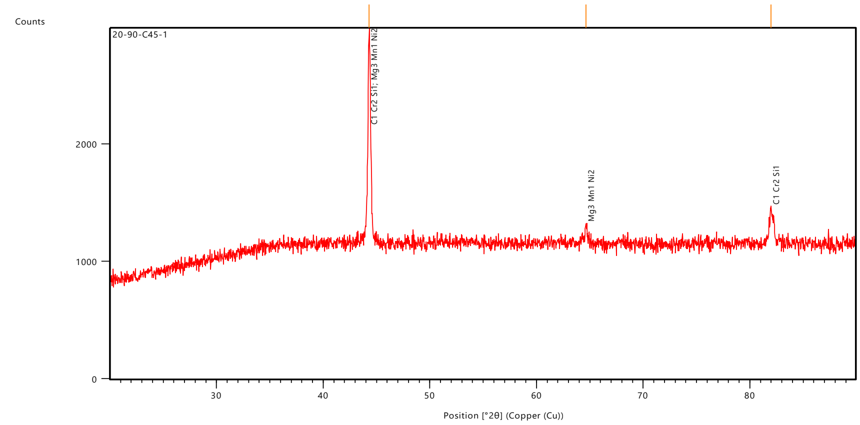

Figure 12 :XRD result of sample heated for 900 ºC and soaked for 1.5 hrs.

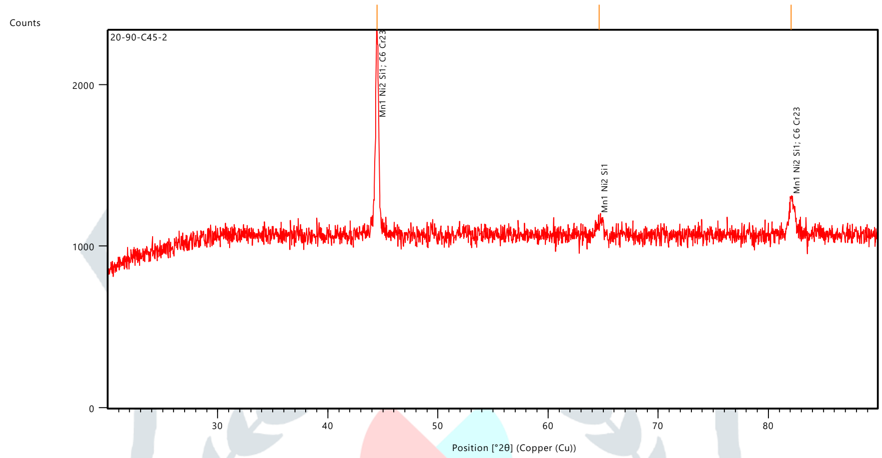

Figure 13: XRD result of sample heated for 900 ºC soaked for 3hrs and tempered for 300 ºC for 0.5hrs

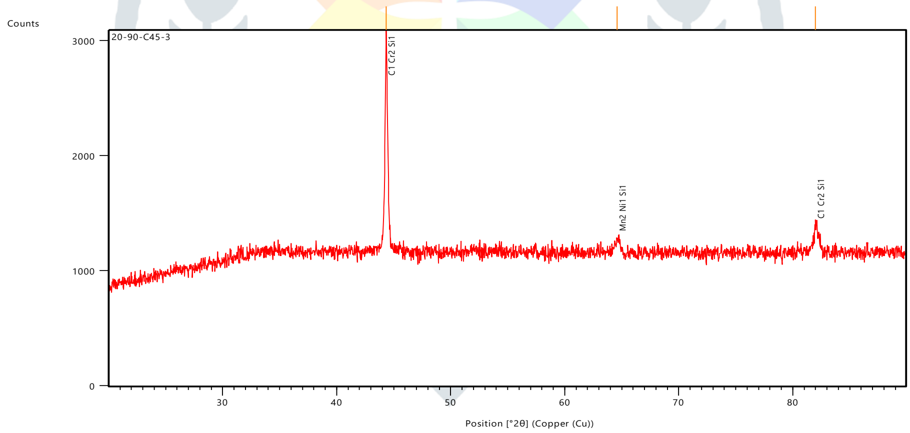

Figure 14 : XRD result of sample heated for 900 ºC soaked for 3hrs and 500 ºC tempered for 0.5 hrs

DISCUSSION:

From the above obtained results it shows that the Brinell Hardness Number of the samples varies as the heating conditions changes as the tempered sample of 500 °C has more BHN (brinell hardness number) when compared with the 300 °C tempered samples. Gradual increase in the hardness as temperature or heat condition changes.

It can be noticed from figure3.2.1 for strain rate of 10^{-4} s^{-1} yield stress and the UTS(ultimate tensile strength) is comparatively more than the sample of strain rate 10^{-2} s^{-1} [7].

The same observation can be made on the stress strain curves shown in fig 3.2.2 for tensile tests performed at strain rate $10^{-2}s^{-1}$, it is clearly shown that stress for the specimen at temperature of 900 °C heated and 300 °C tempered are higher than the specimen at temperature of 900 °C heated and 500 °C. which was also compared and studied from Farid and Mohammad [8] study for flow stress and damage behavior of C45 steel over a wide range of temperatures and loading rates are mentioned.

The heat treated samples characterized using SEM and Leeuwen et al. [6] " Microstructural Features of Austenite Formation in C35 and C45 alloys" .witnessed the presence of white= ferrite, black= pearlite, grey= martensite in the micrograph which is consisted with the present study.

REFERENCES

[1] Farid ,Mohammad, Akrum and George "Flow stress and Damage Behaviour of C45 steel over a range of Temperature and Loading rates" (2016).

[2] Influence of heating rate on Sorbitic Transformation Tempereture of Tempering C45 steel'. Archives of Foundry Engineering. (2011).

[3] Kermouche and Langlade 'mechanical Nano-structuration of A C45 steel under Repeated Normal Impacts' IOP conference series: Material Science and Engineering 63 (2014).

[4] Leppert , Tadeusz. " Effects of cooling and lubrication conditions on the surface Topography and Turning Process of C45 Steel' . International Journal of Machine Tools and Manufacture 51.2 (2011).

[5] Aneta Bartkowska, Dariusz Bartkowski, Damian Przestacki, MałgorzataTalarczyk "Microstructure and selected properties of boronized layers produced on C45 and CT90 steels after modification by diode laser".

[6] Dr. Alessandro Torboli- X-Ray Marketing Manager-Analytical instruments groups Retained Austenite:Non-Destructive Analysis by XRD and ASTM E975-03"