"Analysis of the effect of Carburizing & Tempering on Mechanical Properties of Mild Steel"

Pranjal Kumar Sahu, Dr. Shabana Naz Siddique
Department of Mechanical Engineering
Bhilai Institute of Technology, Durg.

ABSTRACT

Carburization is a heat treatment process which is used to increase the surface hardness of metal. The main objective of this experiment is to determine the effects of different carburization temperature and tempering process on mechanical properties of carburized mild steel. Solid carburization method is used for carburizing the mild steel. In solid carburization method coal is used as a carburizer. Carburization process is done in different temperature 860^0C, 900^0C 940^0C for 2 hours soaking time, then water quenching process is done. In quenching process, the brittleness and hardness value suddenly increases but, this is not required for application. After this, tempering process is applied at 200^0 C for 30 minutes of soaking time. Tempering process removes internal stresses and brittleness from carburized mild steel. Carburized and tempered mild steel test specimen is used for various mechanical testing (Hardness testing, tensile testing and toughness testing). Analysis the effect of carburization and tempering process in testing result. The testing result show that the value of hardness and tensile strength increases with increasing the carburization temperature but, the toughness value of mild steel decreases with increasing the carburizing temperature. The highest hardness and tensile strength value is obtained at 940^0C carburization temperature. So, it shows that the carburization temperature at 940^0C provide the best result for mechanical properties of carburized and tempered mild steel.

1 . INTRODUCTION

1.1 An Overview

Carburization can be defined as a heat treatment whereby the carbon content on the surface of the ferrous property material is increased. In order to increase the carbon content on the steel surface, the following factors should be taken into account.

(i) This unit should be placed in a carbon rich atmosphere.

(ii) The carbon molecules surrounding this part must be dissociated into assets. [1]

Heat treatment and carburizing improve mechanical strength and wear property of metal. In Carburization process addition of carbon content to the surface of low carbon steel whose temperature is usually between 860°C and 940°C. At this temperature, austenite has a high carbon solubility and a stable crystal structure. Wear-resistant and fatigue-resistant mounted on a tough mild steel core [2]

Carburization process is generally used for surface hardening .this process is used to increase the percentage of carbon in low carbon steel . In this process steel absorb the carbon when heat the metal in presence of carburizer (coal, charcoal etc.). this type of materials is widely used in automobiles sector , templates, machine tools etc.

Among them, it should have excellent strength, hardness , toughness. These mechanical properties of metal can be achieved through carburizing and cooling processes .[3]

Today, mild steel is used in many applications due to the high availability and low cost as compare to other steel . Unfortunately, the properties of low-carbon steel have several short comings that limit the use of low-carbon steel in today's manufacturing processes. Because % of carbon is low as compared with other types of steel, this reduces the surface hardness of low carbon steel . this type of steel is not very brittle or ductile, it has low tensile strength, and ductile due to its low carbon content. [4]

Mild steel have a 0.1% of carbon that's why this steel is tough and soft, and high-carbon steel where percentage of carbon more than 0.87% is hard and brittle. The carburizing of Case involves the transmission of carbon into the surface layer of steel when it is heated in contact with carbonaceous materials. Carburizing, this ancient hardening process takes advantage of the fact that carbon diffuses into iron , and iron exists in face-centered cubic (FCC) gamma form at temperatures above 910°C. [5]

2. LITERATURE REVIEW:-

Hesham et al.[6] investigated the changes on the mechanical properties of mild steel when subjected to carburizing process at a temp. range 850^{o}C to 950^{o}C , followed by tempering process for 30 minutes. The results revealed that due to carburizing and tempering process, there is improvement in the hardness and tensile strength of mild steel and these properties increased with the temperature of carburization. The results also revealed that toughness of mild steel decreased and there is further decrement with the increase of temperature. The highest tensile strength and hardness were obtained at carburizing temperature of 950^{o}C. Hence this temperature should be preferred for the application of carburization.

Fatai Olufemi et al [7] performed the carburization treatment on mild steel using pulverized bone as carburizer, to find out the effects of the process on the mechanical properites of mild steel. The carburization temperature selected was 850 ^{o}C, 900 ^{o}C and 950 ^{o}C, followed by soaking for 15 minutes and 30 minutes at the carburizing temperature. Then mild steel was quenched in oil and was tempered at 550 ^{o}C. Before the carburization process, tensile and impact tests were done on the standard test samples prepared from the as received specimen. After carburizing, standard tests were performed on the samples, and the data obtained were used to calculate the maximum tensile strength, engineering strain, impact resistance and Youngs' elastic modulus.

Aramide et al.[8] investigated the effects of carburizing temperature and time on the mechanical properties of mild steel using activated carbon as carburizer, at 850, 900 and 950°C.The mild steel was further soaked at carburizing temperature for 15 and 30 minutes, quenched in oil, and tempered at 550 °C and hold for 60 minutes. Before the carburizing process, standard samples for tensile and impact tests were produced from the obtained samples. After the carburizing process, standard tests were performed on the samples, and the maximum tensile strength, engineering strain, impact strength and Young's modulus were calculated based on the obtained data.

Emmanuel et al.[9] performed the experiment to investigate the effects different carburizing medium on the mechanical properties of mild steel. The carburizing material selected were coal, bone charcoal and wood charcoal. The mechanical properties studied were hardness, tensile and impact strength. Test samples were prepared from mild steel and were carburized with coal, bone charcoal and wood charcoal and then case hardened. Conventional testing machines were used to test and measure hardness, tensile and impact strength. The results obtained were analysed using the method of Analysis of Variance with significance level of 0.01. Each of the carburizing medium had a significant increasing effect on hardness and tensile strengths but showed a decreasing effect on impact strengths of mild steel.

Jaykant Gupta et al [10]The heat treatment and carburization has been recognized by certain method for dealing

with the various properties of metals and mixes. In the current assessment the mechanical and wear practices of delicate plans carburized at different temperature extent of 850, 900 and 950C have been thought of and it is found that the direct warmth treatment fundamentally deals with the hardness, strength and wear resistance of the mild steel . The point has been to investigate the effects of these carburization temperatures and conditions on the mechanical and wear properties of the carburized steel.

3. Objective of the present work :-

The main objective of this experiment is to improve the mechanical properties of mild steel with the help of pack carburizing technique and to determine the impact of carburizing and tempering processes on mild steel properties.

The carburization heat treatment process is commonly used to improve the surface hardness of mild steel. During the carburizing process, coal is used as a carburizer.

First, we select material for test specimen and selecting coal and preparation for carburization process.

- The solid carburizing method is used to perform a carburization process for mild steel sample at various temperature and soaking time. After this quenching process applied.
- Tempering process can perform on carburised steel sample for a particular temperature and time period.
- Determining the mechanical properties (hardness, toughness and tensile strength) of this carburized and tempered mild steel sample at different temperatures.
- Analysis of the result and effect of carburizing and tempering process on mild steel properties hardness toughness, tensile strength.

4 .METHODOLOGY:-

4.1 Material Selection :-

In present work, we purchased mild steel according to required size of test `specimen. Chemical composition (weight %) of mild steel is shown in table.

Table no. 1

Chemical composition (weight %) of mild steel

Element	C	Mn	S	P	Fe
Content (weight %)	0.18	0.60	0.05	0.04	balance

4.2 Preparation of test specimens:-

4.2.1 Hardness test specimen:-

A standard size of test specimen is (5cm x 3.5cm x 0.5cm) for hardness testing .
Where length = 5 cm, width = 3.5 cm and thickness = 0.5 cm .

4.2.2 Toughness test specimen :-

For toughness testing the standard size of test specimen is :-

Length (L) – 7.5 cm
Width (b) – 1 cm
Thickness (t) – 1 cm
Notch depth – 0.2 cm

4.2.3 Tensile strength test specimen :-

For a tensile testing the standard size of test specimen is depend on this equation

$$L = 5.65\sqrt{A}$$

Length of gauge (L)→36 mm
Width(b) → 8 mm ,
Thickness(t) →5 mm

Grip distance → 100 mm

,

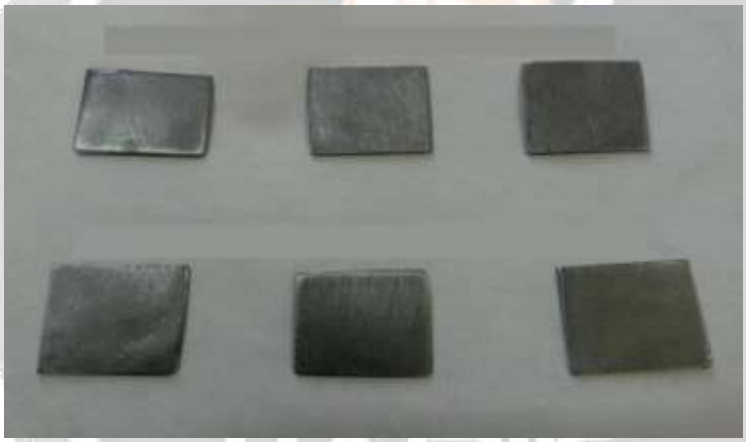

Fig. 4.1 : Test Specimen for hardness testing

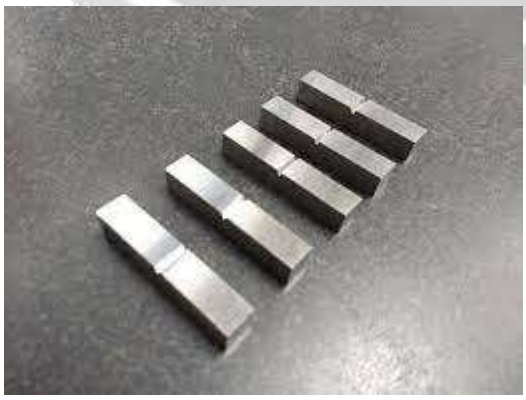

Figure 4.2: Toughness test specimen

Fig. 4.3: tensile test specimen

4.3 Selection of coal and preparation:-

Coal sample is used as a carburizer in the carburization process .So coal was selected and converted into powder form , a crusher and test sieve is used to achieve a -52 mesh size. For this experiment work 3.5 kg coal was used to prepare.

4.4 Carburization of test specimen:-

In this experiment we used to pack carburization process for heat treatment of mild steel sample. the coal is used as a carburizer in this process all the test specimen sample are surrounded by thick carburizing mixture and placed in a stainless steel box which is tightly covered from all side after this the container is placed in a muffle furnace .In muffle furnace the container is heated at various required carburizing temperature of 860^{o}C, 900 ^{o}C ,940 ^{o}C soaking time 2 hour. After heating process the mild steel sample is carburized then the quenching process is done . A hot carburized specimen was cooled in water. A water quenching process highly influence mechanical property of Steel.

Fig. 4.4: Muffle furnace

4.5 Tempering of test specimen :-

After carburization and quenching process the carburized steel is more brittle and harder which is not required for many application . during the quenching process internal stress increase in carburized steel. For removing the brittleness and internal stress we applied tempering process . In tempering process the steel is heated at 200^{o}C for half hour soaking time , then cooled in air .this is complete heat treatment process of mild steel sample. After this process we obtained a carburized and tempered steel test specimen is ready for hardness , tensile strength , toughness testing.

4.6 Hardness test:-

In this testing process the hardness value is measure a mild steel test specimen which is carburized in various temperature range 860, 900 and 940^{o}C.

Table no. 2
Rockwell hardness testing machine specification

Scale	Indenter	Total load	Dial	Test material
C	Diamond	150 kg	black	Hardness steel, hardened and tempered steel

Fig. 4.5 Rockwell hardness test machine

4.7 Tensile test:-

In this test, tensile tests were performed on tempered mild steel samples processed in various temperature ranges of 860, 900 and 940°C . This tensile testing was conducted on UTM machine.

Table no. 3:- **UTM machine Specification**

Maximum capacity	100 tons
Minimum graduation	20 kgf
Ram stroke	200 mm

Fig.4.6: UTM machine

4.8 Toughness (Charpy impact) test

The test was performed on three different samples that carburized at three different temperatures: 860, 900 and 940°C This testing process was done on impact testing machine. 3 times, take the average of all samples as the respective observation value.

Machine specifications:- The specification of charpy machine used for the toughness test

Weight of hammer	20.59 kg
Striking of hammer	5.3465 m/s
Swing of hammer both ways	$0 – 160^{0}$

Fig .4.6: Izod –Charpy test machine

5. RESULT & ANALYSIS

5.1 Hardness test result

- In Rockwell Hardness Test the hardness value obtained between 50 Rc – 55 Rc and the highest value of hardness obtained at carburization temp. of 940^0C and low hardness value obtained at 860^0C, so with increment of carburization temperature the value of hardness also increase.

Table – 4

Rockwell hardness Testing Result in C scale, 150 kg load applied

Carburization		Tempering		Hardness value (R_c)
Temperature in (^{0}C)	Soaking time in (Hrs)	Temperature (^{0}C)	Soaking time in (Hrs)	
Simple mild steel	–	–	–	–
860^0C	2	200^0C	0.5	50

900^0C	2	200^0C	0.5	53
940^0C	2	200^0C	0.5	55

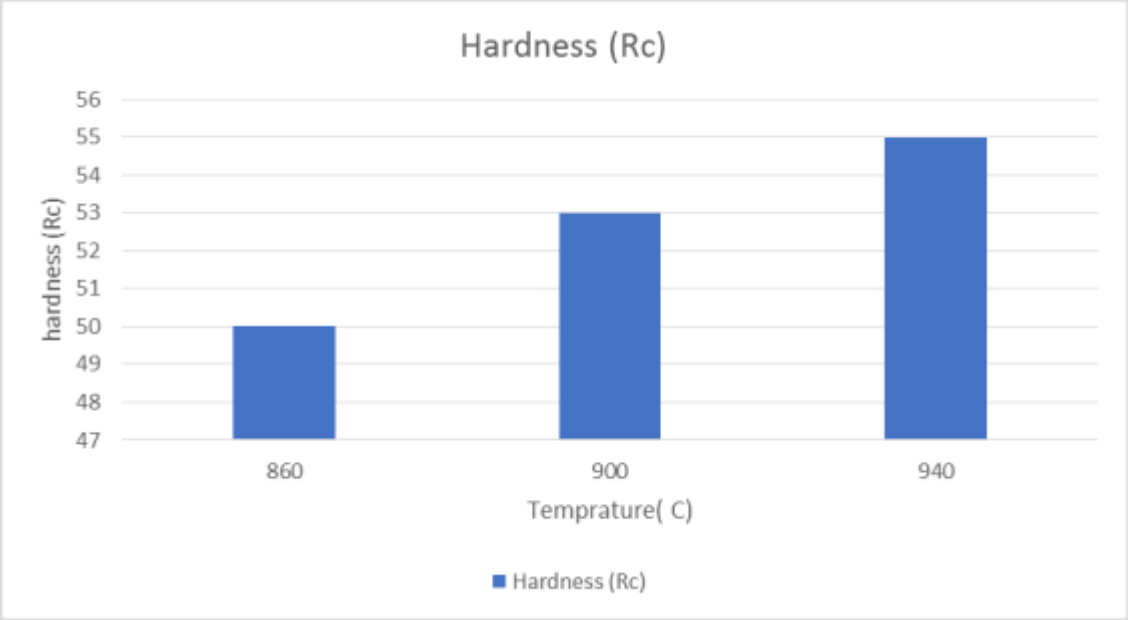

Fig.5.1 hardness vs different carburised temperature

5.2 Toughness test result :-

- The toughness testing is done in charpy impact testing machine . Carburization and tempered process really affected the the toughness property of mild steel sample.
- In graph show carburization temperature increase from 860^0C to 940^0C and toughness value decrease from 39 J to 33 J. So overall outcome show increasing carburization temperature decreasing the toughness property of material

Table:- 5

Toughness test Result

Carburization		Tempering		Toughness value in Joule(Nm)
Temperature (^{0}C)	Soaking time(Hrs)	Temperature (^{0}C)	Soaking time (Hrs)	

Simple mild steel	–	–	–	56
860^{0}C	2	200^{0}C	0.5	39
900^{0}C	2	200^{0}C	0.5	36
940^{0}C	2	200^{0}C	0.5	33

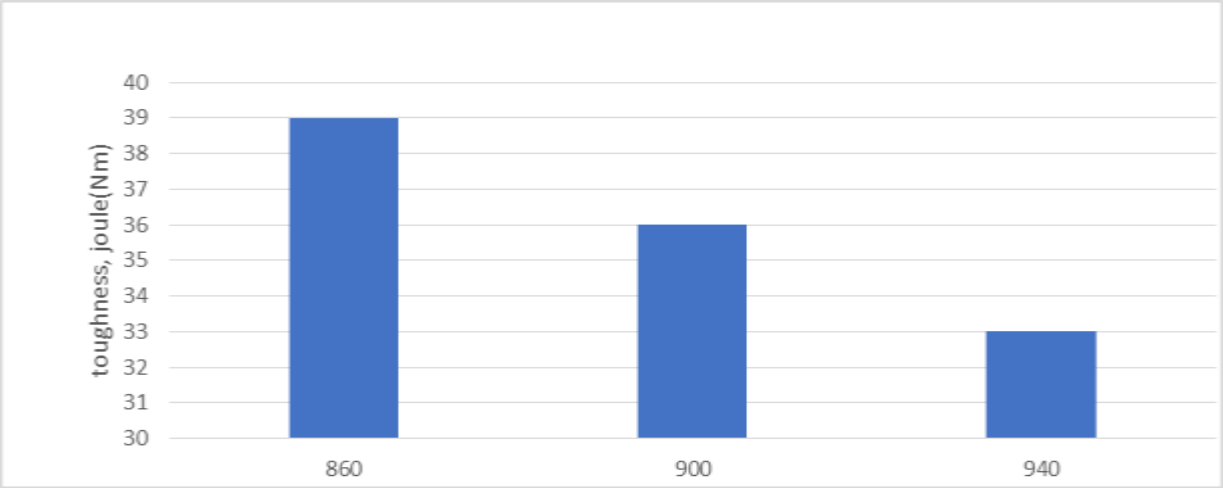

Fig:- 4.2 toughness VS diff. carburised temperature

5.3 Tensile strength test result:-

In the case of carbonization temperature 860^{0}C , 900^{0}C, 940^{0}C . highest tensile strength value 1880 Mpa is obtained at 960^{0}C degree and lowest value 1725 MPa for 860^{0}C . Which means increasing the carburization temperature the tensile strength of mild steel is also increase.

Table :-6

Tensile Strength Result

Carburization		Tempering		Tensile strength(Mpa)
Temp (^{0}C)	Soak time (hrs)	Temp(^{0}C)	Soak time (hrs)	

Simple mild steel	–	–	–	440
860^0C	2	200^0C	0.5	1725
900^0C	2	200^0C	0.5	1800
940^0C	2	200^0C	0.5	1880

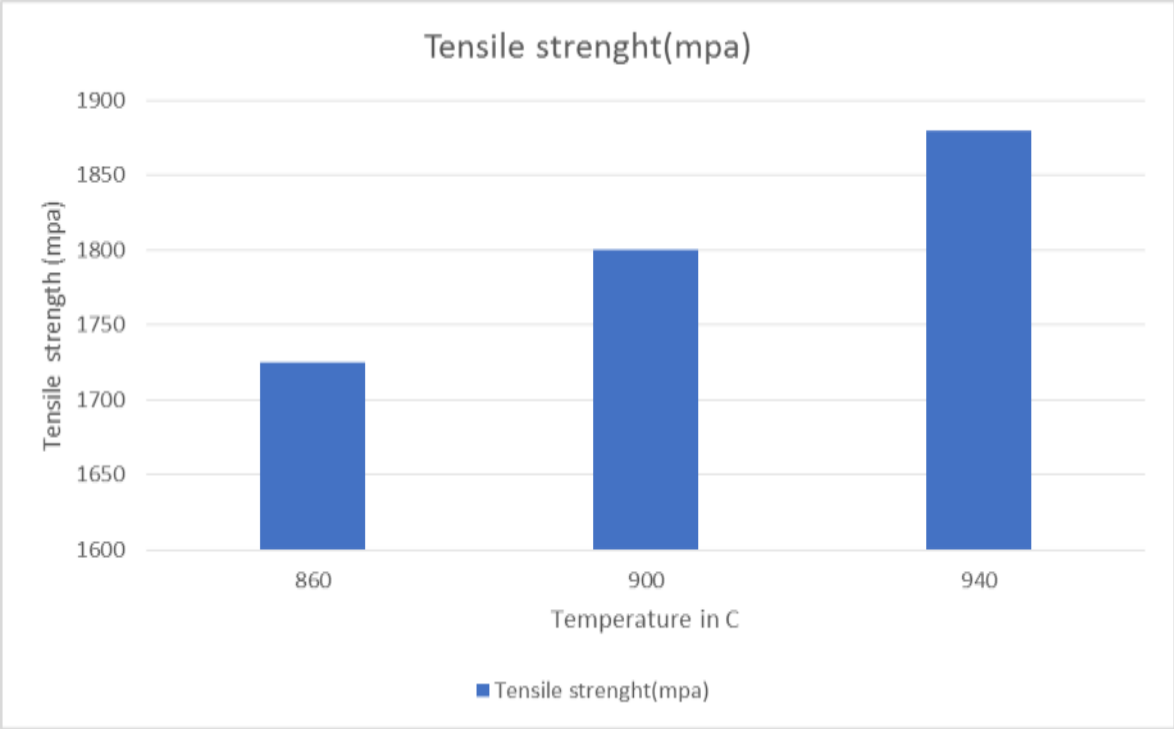

Fig . 5.3 Tensile strength VS different carburized temperature

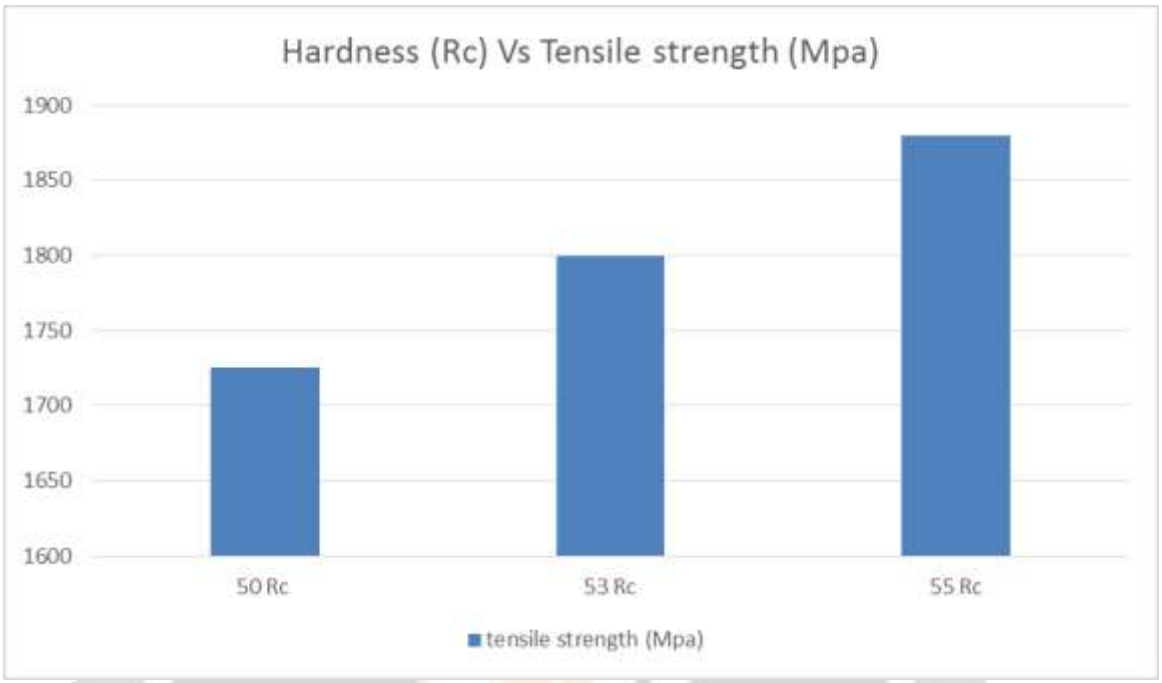

Fig. 5.4 Result comparison between Hardness (Rc) **Vs** Tensile strength (Mpa)

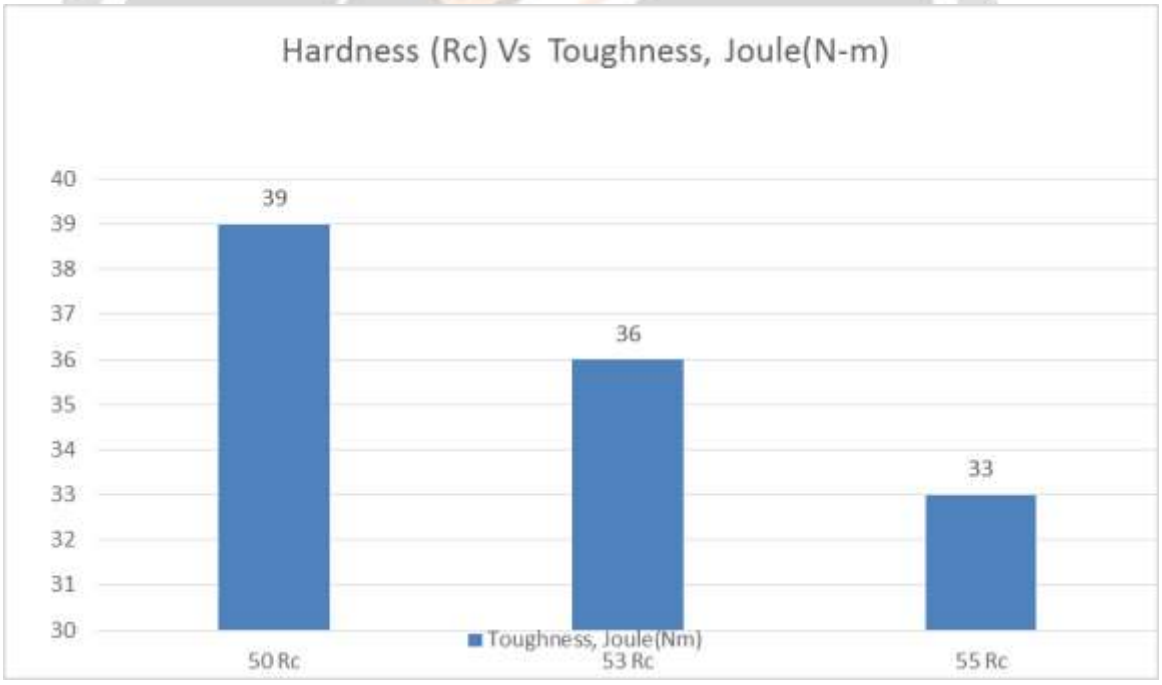

Fig . 5.5 Result comperision between Hardness (R_c) VS Toughness , Joule(N-m)

5.4 Hardness Result Validation by ANSYS

For case 1 pack carburization process is performed at 860 ^{o} C and for the soaking time of 2 hours after that the quenching process is done in water at normal temperature and then the tempering process is done at 200 ^{o} C and for 30 minute.

In the image we can see that the Y displacement for the node is -0.094652 mm. this is actually the depth of penetration of tool in to the workpiece.by this value we can calculate the hardness value in HRC scale.

$$Rockwell\ Hardness = 100 - (\frac{h}{.002})$$

h = depth of case (mm)

Rockwell hardness (HRC) in **C** scale

Hardness = 100 – (.094652/.002)

= 52 Rc

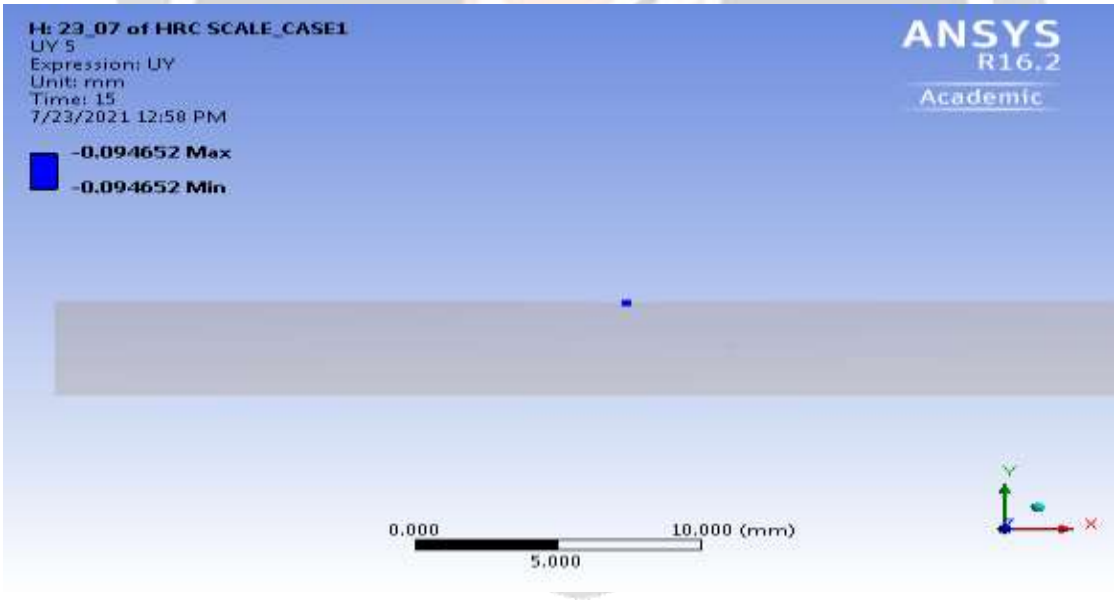

Fig. 5.6 :- Case 1 Y – displacement

For case 2 pack carburization process is performed at 900 ^{o} C and for the soaking time of 2 hours after that the quenching process is done in water at normal temperature and then the tempering process is done at 200 ^{o} C and for 30 minute.

In the image we can see that the Y displacement for the node is -0.091594 mm. this is actually the depth of penetration of tool in to the workpiece.by this value we can calculate the hardness value in hrc scale

.

Hardness = 100 – (.091594/.002)

= 54 Rc

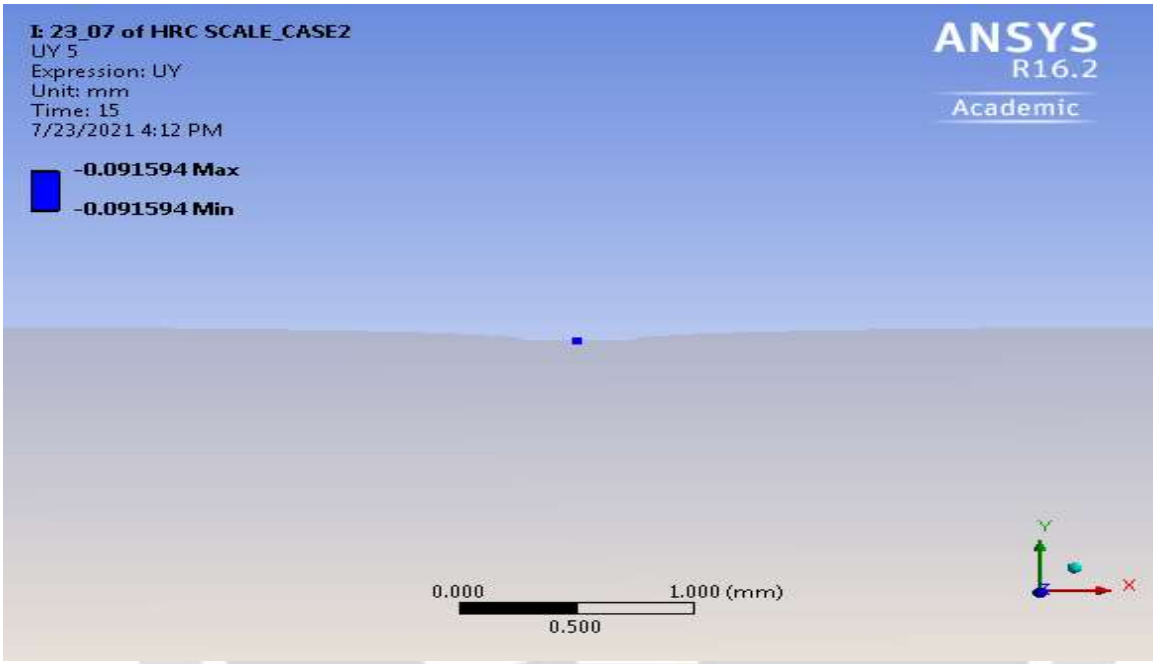

Fig. 5.7 :- Case 2 Y – displacement

For case 3 pack carburization process is performed at 940 ^{o} C and for the soaking time of 2 hours after that the quenching process is done in water at normal temperature and then the tempering process is done at 200 ^{o} C and for 30 minute..

In the image we can see that the Y displacement for the node is -0.088728 mm. this is actually the depth of penetration of tool in to the workpiece.by this value we can calculate the hardness value in hrc scale .

Hardness = 100 – (.088728/.002)

= 56 Rc

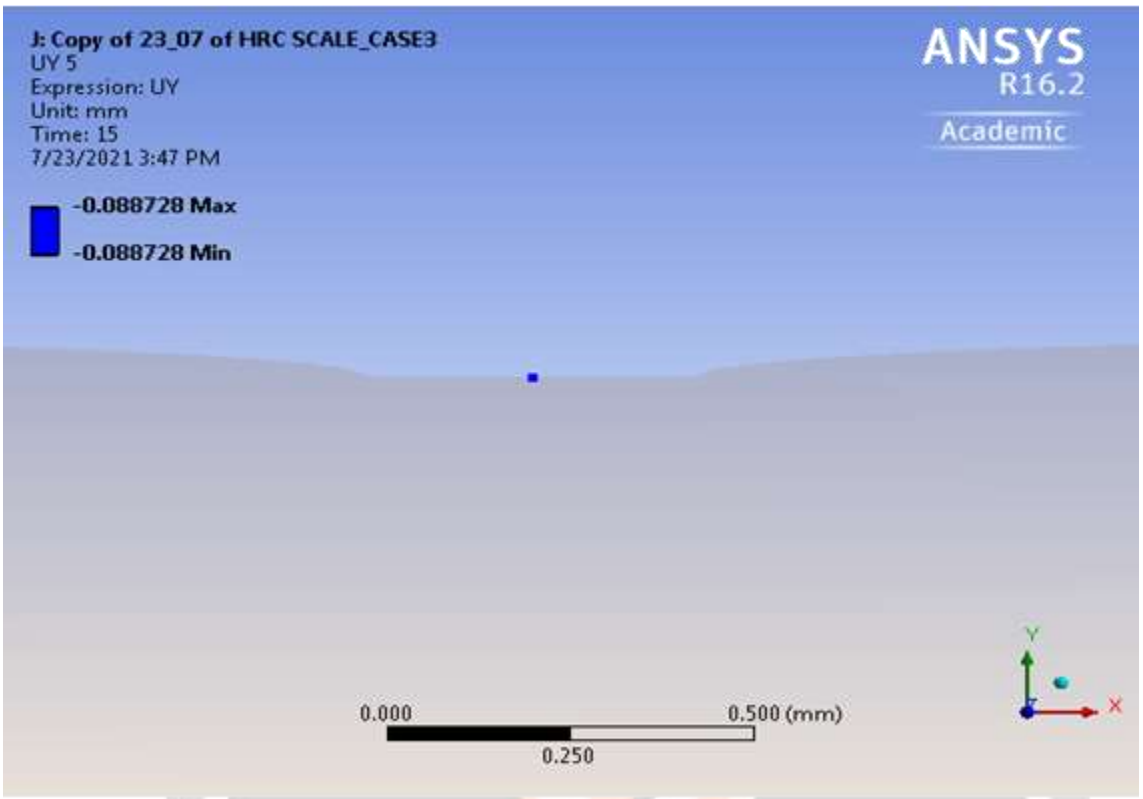

Fig. 5.8 :- Case 3 Y – displacement

Table no. : 7

Hardness value comparison between Experimental result and ANSYS

Carburization temperature	Hardness value (HRC) in Experimental	Hardness value (HRC) in ANSYS
Case 1 (860 ^{0} C)	50	52
Case 2 (900 ^{0} C)	53	54
Case 3 (940^{0}C)	55	56

6.

Conclusions:-

- In this experiment, the mechanical property of mild steel highly influenced by carburization process at different temperature, quenching and tempering process.

- After carburization process the hot metal rapidly cooling in water. This water quenching process increasing brittleness and hardness property of steel.

- Hardnesss value of carburized mild steel is increasing when carburization temperature increase . the highest value of hardness is 55 Rc which is obtained at 940^0C .

- Tensile strength value is increasing when carburization temperature increasing. The highest and lowest value of tensile strength is 1880 -1725 MPa. which is obtained at 940^0C - 860^0C .
- But toughness value of carburized mild steel is decreasing when carburization temperature increasing . the lowest value of toughness is 33 J , which is obtained at 940^0C carburization temp.
- In hardness test result analysis show the depth of penetration decrease when value of hardness increase.

- In this carburization process quality of carburizer, medium of quenching, carburization temperature soaking time and tempering temperature and soaking time really effect the mechanical property of carburized mild steel.

- So overall result of this experiment show that the highest value of hardness , tensile strength is obtained at 940^0 C carburization temperature. So 940^0C temperature is good condition for achieving a optimized value of mechanical property of carburized mild steel.

7. Future Scope :-

- The comparable examinations can be performed by changing the carburization temperature, soaking time, tempering temperature.

- The same experiment can be perform other type of case hardening process exp. Flame hardening , induction hardening , nitriding.

- Comparatively experiment can be perform between different type of carburizer coal and wooden charcoal because carbon content also change.

- Other mechanical property(brittleness ,plasticity, compressive strength , elasticity) can also determine by this similar experiment process .

- The same experiment can also perform for determine the erosive wear and adhesive wear . Rotational speed, time can also change and perform .

8 . REFERENCES

1. BK Agrawal , Introduction to Engineering material , Mc Graw hill publisher, page- 158

2. Akita M. and Tokaji K. , Effect of carburizing on notch fatigue behavior of AISI 316 austenitic stainless steels, Surface and Coating Technology, 200 (2006) : pp. 6073 – 6078.

3. Baldissera P. and Delprete C., Effect of deep cryogenic treatment on static mechanical properties of 18NiCrMo5 carburized steel, Material and Design, 30 (2009): pp. 1435 – 1440.

4. Sanjib Kumar Jaypuria, Heat Treatment of Low Carbon Steel. Thesis submitted to Department of Mechanical Engineering National Institute of Technology Rourkela-769008 2008

5. Higgins RA. Engineering Metallurgy. (part 1, Applied physical metallurgy).5th ed. Kent: ELBS; Edward Arnold Publishers Ltd. 1991; pp. 40-162.

6. Hesham elzanaty, Effect of Carburization on the Mechanical Properties of the Mild Steel, International Journal of Innovation and Applied Studies ISSN 2028-9324 Vol. 6 No. 4 July 2014, pp. 987-994

7. Fatai Olufemi, Simeon Ademola IBITOYE , Isiaka Oluwole OLADELE1 and Joseph Olatunde BORODE1, Pack Carburization of Mild Steel, using Pulverized Bone as Carburizer: Optimizing Process Parameters , Leonardo Electronic Journal of Practices and Technologies ISSN 1583-1078 Issue 16, January-June 2010 p. 1-12

8. Aramide FO, Ibitoye SA, Oladele IO, Borode JO. Effects of Carburization Time and Temperature on the Mechanical Properties of Carburized Mild Steel, Using Activated Carbon as Carburizer. Mater Res 2009; 12(4): 483-87. http://dx.doi.org/10.1590/S1516-14392009000400018

9. Emmanuel Jose Ohize, Effects of Local Carbonaceous Materials on the Mechanical Properties of Mild Steel AU J.T. 13(2): 107-113 (Oct. 2009)

10. http://ethesis.nitrkl.ac.in/1397/1/final_thesis_jaykant_gupta_(combined_123).pdf

11. BK Agrawal , Introduction to Engineering material , Mc Graw hill publisher.

12. Principles of Material Science and Engineering ,Navneet Gupta ,Dhanpat rai & Co.

13. Dr. Swadesh Kumar Singh , A text book on PRODUCTION ENGINEERING .

14. Sanjib Kumar Jaypuria, Heat Treatment of Low Carbon Steel. Thesis submitted to Department of Mechanical Engineering National Institute of Technology Rourkela-769008 2008