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Effect of Austempering and Martempering on Mechanical Properties and Structure of Bearing Steel (En31)

Vijay Kant Yadav[1*], Vineet Kumar Tripathi[2]

[1]Research Scholar, Suyash Institute of Information Technology Gorakhpur, India-273001
[2]Assistant Professor Suyash Institute of Information Technology Gorakhpur, India-273001

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***Corresponding author:** Vijay Kant Yadav
Research Scholar, Suyash Institute of Information Technology Gorakhpur, India-273001

Abstract **Original Research Article**

EN31 steel is easily available and cheap having all material properties that are acceptable for many applications. Heat treatment on low carbon steel is to improve ductility, to improve toughness, strength, hardness and tensile strength and to relive internal stress developed in the material. Here basically the experiment of harness and ultimate tensile strength is done to get idea about heat treated low carbon steel, which has extensive uses in all industrial and scientific fields.
Keywords: Austempering Temperature, Bainite, Impact, Toughness.

1. INTRODUCTION

Heating, soaking and cooling are the main three parts of heat treatment process. When the steel is exposed to the pre-hardening, then the rate of heating is important else the rate of heating had no significance on the property of steel. The rate of heating should be slow, when the steel is exposed to pre-hardening, the furnace may be at operating temperature so this is not imaginable and when low temperature steel is situated in the high temperature furnace it would cause alteration. Due to pre-heating the steel, the difficult of alteration can be lowered and then put it in to furnace at vital operating temperature.

Heating, soaking and cooling of the work piece are three steps of heat treatment process to accomplish needed properties required for particular applications at same time preserved the original shape and size of the work piece. Iron and carbon are main element of steel and steel contained approximately less than 2%ofcarbon. Eutectoid steel contains carbon less than 0.8% and hypereutectoid steel contain carbon more than 0.8%. One or more alloying elements are added to increase the properties of the steel are called alloy steel. It is sufficient to be familiar with that the steel having less than 2% of carbon when cool instantly it contained a single phase of austenite while cast iron contained austenite and cementite when cooled instantly.

Swapnil Nimbhorkar and Prof. B. D. Deshmukh (2013) explored the effect on the structure and properties of automobile gears by case hardening process, which contains of a carburizing process which is a part of case hardening process. A comparative study of the various type of gear that are EN353, SAE8620 and20MnCr5 made by them and due to higher hardening temperature, they concluded that the retained austenite in EN353 is more effective than SAE8620,20MnCr5.

M. H. Shaeri (2011) explored the effect on the micro structure and mechanical properties of Cr-Mo steel by the austempering and martempering process. They compared the obtained result with the process used in industry. After completing the austenitization process, the sample were quenched in a salt bath at 3000 C and 2000 C in the austempering and martempering process, similarly for 2,8,30, and 120 min and then cooled down to room temperature in still air. Scanning electron microscopy (SEM) in an addition to X-ray diffraction was used for study the micro structure and mechanical properties of Cr-Mo steel. By evaluating the hardness, impact, toughness and wear resistance, mechanical properties of the austempered and martempered samples were inspected. The specimen austempered for 2 h have verified the best impact toughness while thesample martempered for 2 h shown higher values of wear resistance are shown by the result. Compressed air showed a better combination of wear resistance and toughness besides using salt bath.

T. Z. Wozniak (2010) by the acoustic emission (AE) process, he studied the martensite- bainite structure in the bearing steel. A special set up of heat treatment performed by him that allows austempering and recording acoustic effect during the process. An acoustic emission analyzer was used for record the signals and a broadband piezoelectric transducer with a sampling frequency of1200 kHz received the signals. By measuring the ultrasound signal that forms during isothermal martensite transformation take place at 130-160 0C, it is a process for selection of optimal austempering temperature and established by them. Lower bainite plates with a midrib and the area around the plates suggesting their enhancement with carbon have been detected above1300C.

Volkan Kilicli and Mucahit Kaplan (2012) explored the effect on micro structure and mechanical properties of bearing steel by austempering temperature, which is used in producing bearings. At 9500 C for 30 min, they austenitized the samples and then quenched in a salt bath which is held at various temperature (2500 C, 2750 C and 3000 C). Also the specimen is austempered for different time i.e. 90sec, 180 sec, 360 sec and 720 sec. An optical microscope used for inspection of microstructure. The mechanical properties were determined by conducting the impact test and hardness test. Bainite + martensite Duplex micro structure can be formed via the combination of austempering and quenching process which is shown by result, and for increasing the hardness (55-64 HRC) and toughness (24-54 joule), this structure is helpful. Austempering temperature is more effective than Austempering time displayed by the result also.

A. Krzynska (2013) has explored the effect of austempering process on ductile iron. Except changing time, the temperature of austenitizing and isothermal quenching, direct quenching, and two steps quenching followed solution heat treatment was proposed. They decided that precipitation of iron-carbide due to high temperature annealing and distribution of which depends on temperature.

Karthikeyan Rajan (2013) has explored the effect on endurance life of the ball bearing produced from SAE 52100 bearing steel by carbonitriding process. By optical emission spectroscopy – ARL fisons 3460 Metal analyzer, they observed the average chemical composition of the steel and performed carbonitriding, which is austenitization at temperature 800-9000C for 110-230 min followed by oil quenching at 60-800 C. By using x ray diffraction (XRD) P analytical, Expert, Prodifferacto meter with a rotating Cu Ka radiation, retained austenite and phase analysis were carried out to determine the hardness of the steel. Mitutoyo hardness tester- ARK-F1000withtheload of 1000g and dwell time of 10 sec was employed. When the endurance test performed, the bearing was exposed to the high speed rotation (1000-11000 rpm) under heavy load in the presence of oil lubrication. The rate of transformation of retained austenite was faster on the surface than the core of the component concluded by him. The carbonitriding bearing exhibit nearly ten times more life than the non carbonitriding bearing shown by Endurance test at 90% reliability.

Mohamed Ramadan and Nagalaa Fathy (2014) have explored the effect on microstructure and mechanical properties of ductile cast iron by semi solid isothermal heat treatment process. They have studied that spheroid graphite shown by heat treated air-cooled ductile iron; the decrease in the amount of graphite and increase in the amount of cementite shown by cementite and fine pearlite iron the ductile iron shows slightly decrease in the amount of graphite and slightly increase in the amount of cementite along with these hardness value also increases and toughness decreases, when heating time raise above 20 min. At temperature 11650 C for heating time 10 to 150 min reasonable structure and mechanical property can be found that is decided by them. Andrew Clark (2013) compared the result obtained by austempering and quench-and-tempering process for carburized automotive steels. He performed carburizing process on three carburized grade steels, SAE 8620, 4320 and 8822and heat treated by both the processes. He used twelve austempering and three quench- and tempering parameter and inspected the effect of heat treatment on the case and core micro structure. before and after the carburizing process distortion was measured and heat treatment process using navy c-ring samples, residual stresses and retained austenite was measured with the help of X-ray diffraction. He measures the toughness and hardness by conducting the Charpy, impact and Rockwell c hardness test. Austempering can reduce distortion along with maintaining mechanical properties shown by him.

A. Chennakesyan Reddy (2015) studied the effect on impact toughness and hardness of medium carbon and high alloy steel by austempering time and temperature. The empirical formula of the martensite start temperature (285.760C) calculated by him. The hardness value decreases when the austenitization take place within a salt bath a temperature of 300 0C and 325 0C for one hr. At last he decided that the best mechanical properties are achieved at 320 0C for 1 hr period.

2. EXPERIMENTATION

2.1 AUSTEMPERING:- Austempering of steel was founded by Edgar C. Bain and Edmund Davenport in1930. Because of certain limitation in metallographic techniques the existence of Bainite cannot be identified at that time. Because of an unintentional condition, Bain was inspired to study isothermal phase transformations and it was also obtained that austenite can be retained at room temperature. A new microstructure containing of a dark a circular aggregate was the result of the research of Bain and Davenports in to the isothermal transformation of steel. Without comprising the hardness, the new microstructure was tougher than the tempered martensite. Because of the development of new heat treatment process called austempering, Bainitic steel was commercially used. To help sufficient transformation takes place, the new process contains soaking the work-piece at a fixed at a temperature for period.

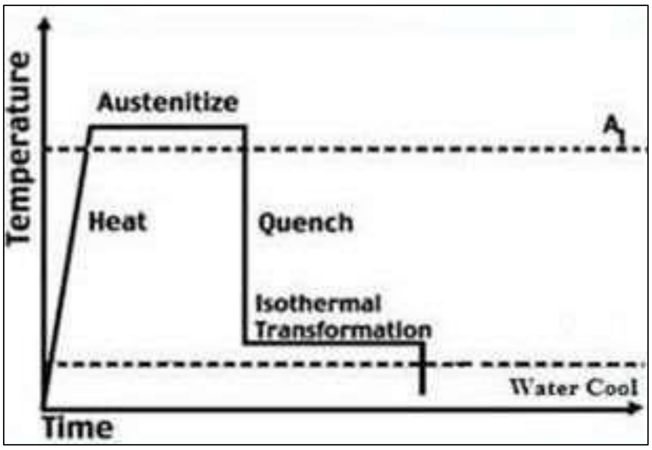


Fig. 1: Austempering Procedure

The steps involves for performing austempering process are labeled below-

1. The required number of specimen was heated to the austenitization temperature of 950C in laboratory atmosphere in muffle furnace for 60min so that's specimen got properly homogenized.
2. After the specimen was properly homogenized at 950C, cooling medium of air and water were applied so that both specimen and furnace were cooled to the Austempering temperature of 360C.
3. Now the specimen held in the furnace at austempering temperature for 15, 30, 45 min as given in table. During this soaking period, the austenite gets changed into required microstructures. The idea behind selecting the austempering temperature of 360 C is that heat treatment with in this temperature will give lower bainitic ferrite which is a circular in structure so that properties developed in the material are admirable.
4. Then the specimen is taken out and cools in water to room temperature. During the transfer of the work piece to room temperature, due to slight oxidation of the surface scale, formation takes place. Hardness value will vary and the specimen cannot be gripped properly on the machine surface if the scale is not removed from the surface. To keep away from this complication the face of the specimens were advanced to take away the scale from the surface. After the scale elimination, the sample is prepared for further experiment.

Table 1: The Austempering Window

Austenitizing Temperature	Tempering Temperature	Soaking Period (min)
950ºC	360ºC	20
		40
		60

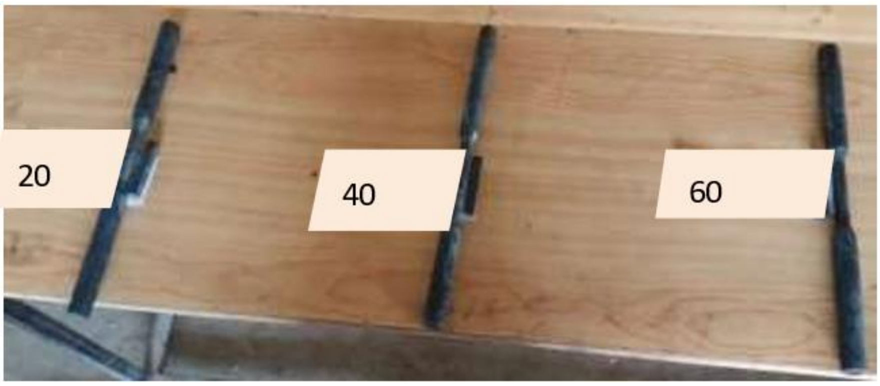


Fig. 2: Specimen after Austempering

2.2 MARTEMPERING:- In the martempering process, steel is heated above the upper critical temperature and then quenched it at temperature of 150 300 C, To turn the temperature to be consistent all over the chapter, the work piece is held above the martensite start temperature in the martempering process. The steel is cooled in air at room temperature after this process. Austenitization, quenching and cooling are included in martempering process. To avoid the formation of ferrite, pearlite or bainite, quenching rate should be fast.

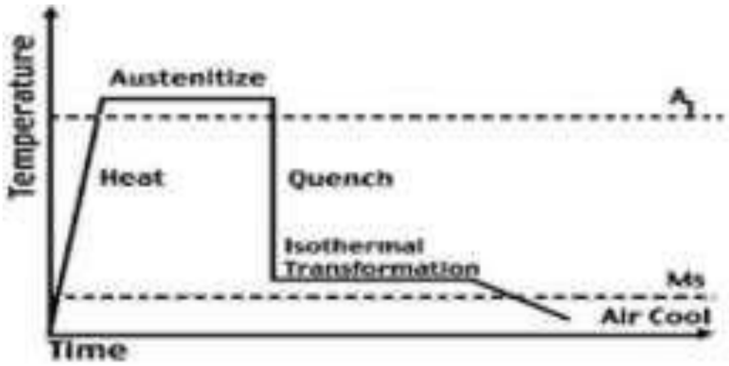


Fig. 3: Martempering Procedure

Steps include in Martempering process are-

1. The specimen was heated to the austenitization temperature of 950 Cfor60minsothat, it can properly be homogenized.
2. After the specimens were properly homogenized a cooling medium of air and water were applied so that work piece and furnace both were cooled to a tempering temperature of 160 C.
3. At the tempering temperature of 160 C the specimen were held for 15, 30 and 45 min as given in the table. In this time, the austenite gets changed into required microstructure. The idea behind choosing this temperature is to produce hard martensitic microstructure.
4. At last, the specimen is cooled in air to room temperature. After removing scale from the surface, the specimen ready for further testing.

Table 2: The Martempering window

Austenitization Temperature	Tempering Temperature	Soaking Period (min)
950°C	160°C	20
		40
		60

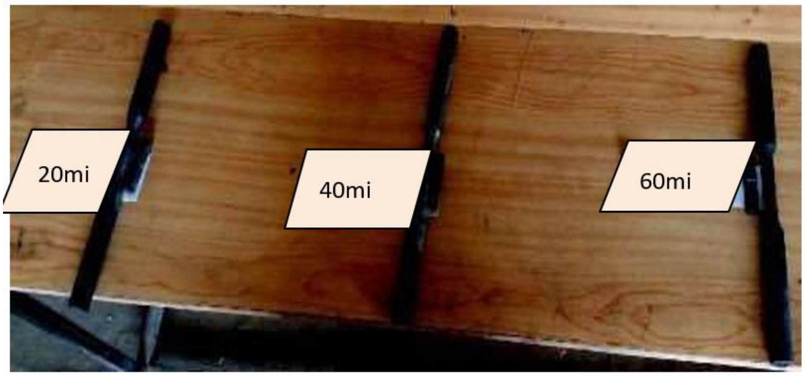


Fig. 4: Specimen after Martempering

2.3 MECHANICALTESTING:- The material properties were exposed by different mechanical testing when force is applied statically or dynamically.

2.3.1 TENSILETEST:- The tensile test is one types of destructive test. The ultimate tensile strength and ductility of the material is found out with the help of tensile test. The test is performed only for the gauge length not for whole length of the material. The tensile test is performed on universal testing machine (UTM) model AMT40 sample were polished by different grades of papers to remove scale from the surface of the specimen before testing. Turning and taper turning operation on lathe machine also used for making the specimen for tensile test

2.3.2 IMPACTTEST (CHARPY'TEST):- The specimen is put as simply supported beam in Charpy test. The impact load is applied to the center behind the notch with the help of hammer. A standard V-shape notch with include angle of 45ocut in the specimen. The notch is situated on the tension side of the specimen during the impact load to complete the three point bending. To increase the stress concentration and yield stress due to elastic and plastic actions provided by V-notch. In the presence of a sharp notch, these two effects break the specimen due to brittle fracture more readily. The amount of energy required for rupture of the work piece decreases by sharpness of V-notch.

2.3.3 HARDNESSTEST:- Vickers hardness testing machine is used for hardness test, model no. NM 250 with square based diamond pyramid indenter having 136 angles between the opposite faces. The Vickers hardness test is similar to Brinell hardness test in that the hardness is obtained from the relationship between the applied load and the surface area of the indentation or by calculation. The impression produced by the test will be a square shape. According to the thickness and hardness of the specimen, the load is selected. The ratio of load applied to the surface area of the indentation in kg/mm2 is called Vickers hardness number. The test is performed for smaller cross chapter, very hard materials. The Vickers hardness number is determined from special table in accordance with measured value of diagonal.

2.3.4 MICROSTRUCTURE EXAMINATION:- Metallurgical scope was used for microstructure examination, model 33K 9HP. A source of light, condensing lens and diaphragm contained in a metallurgical scope. By using a plane mirror placed at 75of the incident rays, the light is focused on the surface of the specimen vertically. The objective lens and the eyepiece which are corrected for chromatic and spherical deviation contained in metallurgical scope. The magnification of eyepiece lens can be vary up to 5*, 10*, 15*. The magnification of objective lens can be vary up to 10*, 50*, and 100*. The microscope is fitted with the adjustment screws for moved up and down. It contains a low volt illuminating bulb (6-8v) with a transformer and switch.

3. RESULTS AND DISCUSSIONS

3.1 TENSILESTRENGTH:

The tensile test result for the austempered and martempered samples are listed below in table 3.1and 3.2

Table 3: Tensile test result of Austempered samples

S. No	Austempering Window		le Strength MPa
	Temperature (ºC)	Time (min)	
1	360	20	750.46
2	360	40	732.65
3	360	60	719.74

Table 4: Tensile test result of martempered samples

S. No	Martempering Window		le Strength MPa
	Temperature (ºC)	Time (min)	
1	160	20	905.98
2	160	40	887.73
3	160	60	879.65

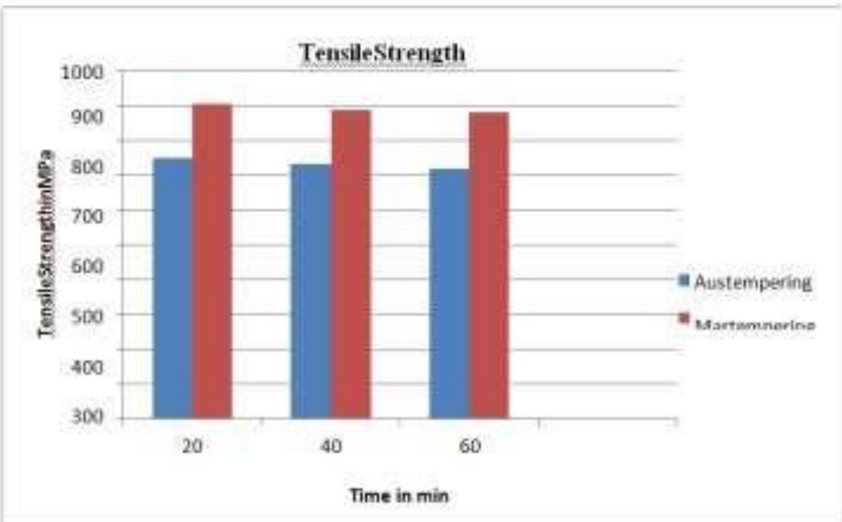


Fig. 5: Effect of Austempering and Martempering time on Tensile strength of EN31steel

From the figures in case of austempering process the value of tensile strength decreases with increasing austempering time because the amount of retained austenite increases with time. The maximum value of tensile strength is obtained at 360 C for 20 min soaking time. In case of martemering process maximum value of tensile strength is achieved in the entire samples because of formation of martensite from austenite. As the soaking time increases the value of tensile strength decreases because moderate bainite increase sand reduced the extent of martensite and retained austenite. The maximum value of tensile strength is obtained for 20 min soaking time.

3.2 ELONGATION:

The variation of ductility with time is shown in table 3.3 and 3.4

Table 5: Ductility of Austempered sample

S. No	Austempering Window		Elongation (%)
	Temperature (ºC)	Time (min)	
1	360	20	22.11
2	360	40	24.60
3	360	60	26.33

Table 6: Ductility of Martempered samples

S. No	Martempering Window		Elongation (%)
	Temperature (ºC)	Time (min)	
1	**160**	**20**	**12.54**
2	**160**	**40**	**16.32**
3	**160**	**60**	**19.11**

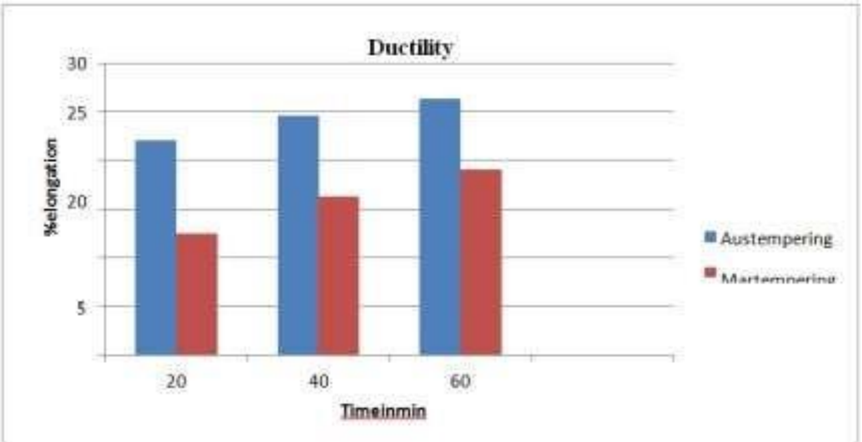


Fig. 6: Variation of Ductility with time

From figure In case of austempering process the ductility is found to be increased up to 40 min due to increasing the amount of retained austainite with austempering time and less martensite on subsequent cooling to room temperature. Beyond 40 min the ductility is decreased because the retained austenite decomposes into the bainite ferrite and carbide. In case of martempering the ductility is found to be increases with time because of formation of pearlite in the microstructure. Pearlite is formed in the microstructure because of slow air cooling.

3.3 IMPACTTEST:-

The variation of toughness with austempering and martempering time for EN31steelis shown in table 7 and 8

Table 7: Toughness of Austempered samples

S. No	Austempering Window		Toughness (Joule)
	Temperature (oC)	Time (Min)	
1	**360**	**20**	**147.17**
2	**360**	**40**	**158.62**
3	**360**	**60**	**169.44**

Table 8: Toughness of Martempered samples

S. No	Martempering Window		Toughness (Joule)
	Temperature (oC)	Time (Min)	
1	**160**	**20**	**121.61**
2	**160**	**40**	**157.34**
3	**160**	**60**	**168.67**

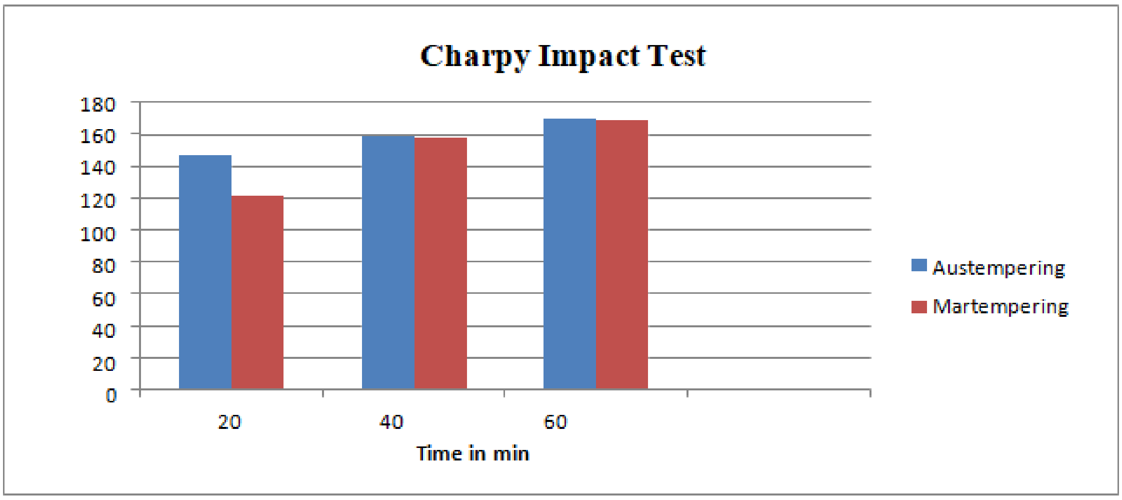


Fig. 7: Impact toughness for heat treated samples

According to figure in case of austempering the value of impact toughness is increasing with Austempering time because the percentage of bainite increases and the austenite and martensite volume decreases with time. The maximum value of toughness is obtained at 360 C for 60 min soaking time. Whereas in case of martempering process as the soaking time increases the value of toughness is increases because of increment in amount of bainite and reduced the extent of martensite and retained austenite. The maximum value of toughness in case of Martempering process is obtained at 160 C for 60min soaking time.

3.4 VICKERS HARDNESS TEST:-

The hardness test results for austempering samples and martempering samples are shown in table 9 and 10

Table 9: Hardness values for Austempering samples

S. No	Austempering Window		Hardness (HV)
	Temperature (oC)	Time (Min)	
1	360	20	1406.9
2	360	40	821.3
3	360	60	789.4

Table 10: Hardness value for Martempering samples

S. No	Martempering Window		Hardness (HV)
	Temperature(oC)	Time (Min)	
1	160	20	1109.4
2	160	40	1546.7
3	160	60	1784.1

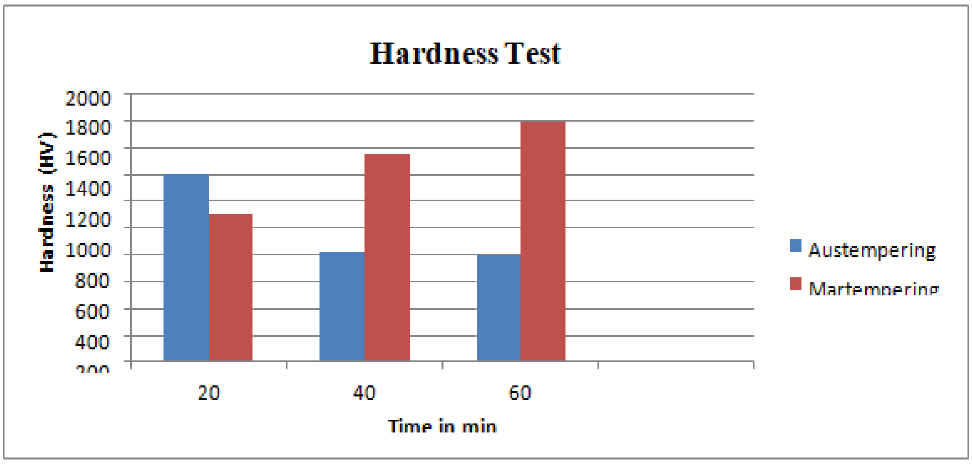


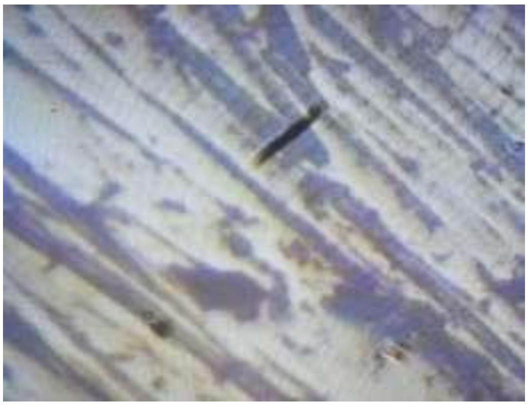
Fig. 8: Vickers Hardness Number for Heat Treated Samples

From the figure it is clear that the value of hardness is decreases as the Austempering time increases because of higher bainite volume fraction at higher austempering time. The maximum value of hardness is obtained at 360 C for 20min soaking period. The Martempered samples are hardest among the entire specimen because the austenite increases hence the value of hardness is also increases. The maximum value of hardness in case of martempering process is obtained at 160 C for 60 min time.

3.5 MICROSTRUCTURAL OBSERVATIONS:-

The microstructure of Austempered and Martempered samples was studied under the metallurgical microscope with100* magnification.

3.5.1 AUSTEMPERING:



A-Austempering with 20 min soaking period

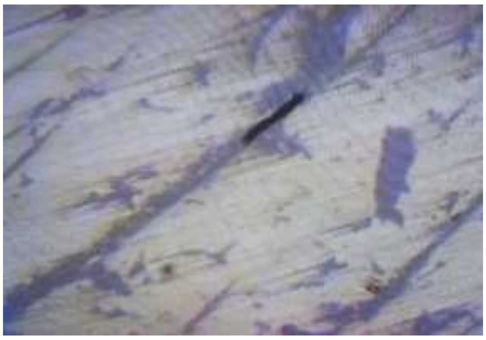
B-Austempering with 40 min soaking period

C-Austempering with 60 min soaking period

Fig. 9: Microstructure of Austempered Samples (100×magnifications)

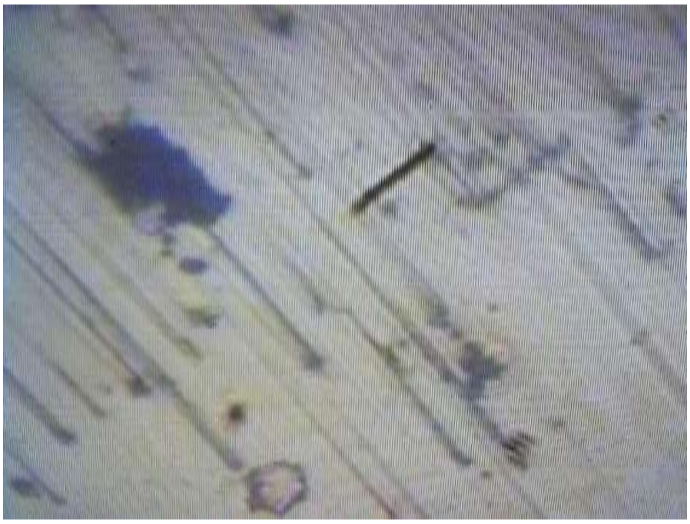
After heat treatment, microstructure contains martensite+bainite and retained austenite. The dark needle- shaped structure is bainite. The dark brown region is martensite and white/gray areas are retained austenite. Austempered specimen with 20 min soaking time shows the good density of carbides. Specimen with 40 min soaking time has less carbide compare to 20min soaking time. The specimen austempered with 60 min soaking time has a good number of carbide but only in selected areas.

3.5.2 MARTEMPERING :-



A-Martempering with 20 min soaking time

B-Martempering with 40min soaking time



C-Martempering with 60 min soaking time
Fig. 10: Microstructure of Martempered Samples (100×magnifications)

After martempering process, the microstructure contains martensite, bainite and pearlite. The dark needled- shaped structure is bainite. Brown region is martensite and lamellar structure is pearlite. Martempered specimen with 20 min soaking time shows the good density of martensite and pearlite. As the time increases moderate bainite increases and reduced the extent of martensite and retainedaustenite.

4. CONCLUSION

EN31 steel was subjected to various heat treatment processes for enhancing the material properties. From the present study, the following conclusions are drawn.

- ❖ The specimen austempered for 20 min has a higher value of tensile strength and for 60 min time has the least value of tensile strength, because of retained austenite present in the microstructure.
- ❖ The specimen austempered for 40min has a higher value of ductility, and 60 min has the least amount of ductility, because of bainite ferrite and carbide formation.
- ❖ The specimen martempered for 20 min has a higher value of tensile strength and 40 min has the least value, whereas maximum value of ductility is obtained at 60min because of martensite formation.
- ❖ Austempering conducted for 60 min has a higher value of impact toughness, and 20 min has the least value whereas the samples martempered for 60 min has the higher value in entire heat treated samples because of bainitic structure in the samples.
- ❖ The maximum value of hardness is obtained for 20 min soaking period in case of austempering because the martensite formation cannot be prevented.
- ❖ The maximum value of hardness is obtained at 60 min soaking time in entire heat treated samples in case of martempering process because of martensite formation.

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