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Influence of Cryogenic Processing on Microstructure and Properties of En8 Steel

Mansi M Lakhani, Niyati Raut

Abstract— En8 steel is most commonly used steel in applications like gears, bolts, pins, studs, etc. These applications of En8 material requires it to be readily machinable and at the same time posses sufficiently high amount of hardness and strength. Conventional heat treatment process that is used to enhance the mechanical properties of En8 steel consists of quenching and tempering. Cryogenic processing consists of quenching the material, then treating it at temperature as low as –193°C., followed by tempering of material. The existing literature confirms that cryogenic processing results in enhancement of mechanical properties of tool steel. Current study deals with finding out how effective is cryogenic processing for enhancing the harndess and impact strength of En8 material as compared to conventional heat treatment process.

Index Terms—Cryogenics, cryogenic processing, hardness, impact strength, martensite, mechanical properties, microstructure, retained austenite.

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1 INTRODUCTION

EN8 is an unalloyed En8 steel grade that contains between 0.36 and 0.44 percent carbon. En8 steel has good tensile strength and is often used in applications such as shafts, gears, pins, studs, bolts, keys, etc. En8 steel is readily machinable. Further, the mechanical properties of En8 material are enhanced by quenching and tempering or by surface treatments. Such wide area of applications of En8 steel generates the need to find various methods to improve different properties of steel.

Heat treatment of En8 steel significantly changes the mechanical properties, such as ductility, hardness and strength. Heat treatment of steel slightly affects other properties such as its ability to conduct heat and electricity as well. A variety of methods exist for treating steel with heat Most commonly used heat treatment process for enhancing properties of En8 steel is quenching and tempering. This method involves heating the material to the austenite phase and then quenching in oil or water. If quenched faster than the critical cooling rate the maximum amount of martensite will result based on the percent carbon in iron. While martensite has a high hardness value it is also very brittle and difficult to use in a practical way. Quenching also causes the build up of residual stress within the material. Hence tempering is followed by quenching. Tempering is used to reduce this residual stress which can enhance the ductility and toughness of martensite. Tempering involves re-heating the material and allowing carbon atoms trapped by iron to diffuse throughout the crystal structure. Longer tempering times result in softer more ductile steel.

There is a large volume expansion when martensite forms from austenite. As the martensite plates form during quenching, they surround and isolate small pools of austenite, which deforms to accommodate the lower density martensite. However, for the remaining pools of austenite to transform, surrounding martensite must deform. Because of the strong martensite resists the transformation, either the existing martensite cracks or the austenite remains trapped in the structure as retained austenite. Retained austenite causes significant changes in mechanical properties, such as internal stresses that weaken the part.

One of the potential solutions for above problem is cryogenic processing of the material. Treating the material at very low temperature is reffered to as cryogenic processing or cryogenic treatment. Cryogenic treatment after quenching results into conversion of reatined austenite to martensite, thereby reducing drawbacks of retained austenite.[1]

Cryogenic treatment can be classified as shallow cryogenic treatment and deep cryogenic treatment. Difference between shallow and deep cryogenic treatment is majorly in its optimal temperature of treatment and holding time. Optimal treating temperature for shallow cryogenic treatment is around -80°C and that for deep cryogenic treatment is around -190°C. Holding time for shallow cryogenic is generally between 5 hours to 8 hours, whereas in deep cryogenic treatment holding time may vary from 16 hours to 48 hours [2].

Deep cryogenic treatment is found more effective when compared to shallow cryogenic treatment [3]. The reason being, in deep cryogenic treatment the ramp down and ramp up rate of the is more even and in controlled manner resulting in more enhanced properties as compared to shallow cryogenic treatment. On the other hand, shallow cryogenic treatment consumes less time.

Another significant factor is that, tempering followed by cryogenic processing is mandatory. Untempered cryogenic processes material results in surface cracks [4].

Extensive amount of research with regards cryogenic treatment is been done on various tool steels and different cutting tool materials to evaluate the effect of cryogenic treatment on performance of various cutting tool materials. Previous research has shown that cryogenic treatment on various cutting tool materials results in improving tool life specifically due to enhanced wear resistance properties in materials such

- *Mansi M Lakhani is currently pursuing master's degree program in Manufacturing Systems Engineering from University of Mumbai, India, PH-8879655314. E-mail: mansilakhani09@gmail.com*
- *Niyati Raut is Assistant Professor, University of Mumbai, India, PH-9769225116. E-mail: shubhangi.nr@rediffmail.com*

as high speed steel, tungsten carbide, die steel, etc.[5] Literature also shows improvement of tool life with drastic difference in application such as HSS single point cutting tool, HSS drill, Cemented carbide inserts.[6], [7], [8]

2. MATERIAL AND METHODS

In the study, one set of En8 material is subjected to conventional hardening treatment followed by tempering and second set is subjected to cryogenic processing. After treatment, the materials are tested for hardness, impact strength and microstructure.

The En8 material is confirmed by carrying out chemical testing. The chemical test was perfomed using optical emission spectrometer. The test standards followed for chemical analysis was ASTM E 415:2015. The chemical test results are as shown in table 1.

Table 1. Chemical Tests Results

Content	C	Mn	Si	P	S
Required value %	0.35 - 0.45	0.6 – 1.00	0.050 – 0.35	0.060 max	0.060 max
Results %	0.36	0.75	0.21	0.024	0.024

Above composition confirms to En 8 steel.
Two sets of specimens for hardness, izod impact test and microstructure were made and following two types of treatments were perfomed on both sets of specimens:

1. Conventional heat treatment process
2. Cryogenic processing

2.1 Conventional heat treatment process

Hardening process hardnes the steel and tempering increases the toughness. The conventional hardening and tempering process was carried out on the specimens. Hardening process consists of heating the specimen to austenising temperature, typically with in the range of 815 to 870 °C, followed by oil quenching [2].

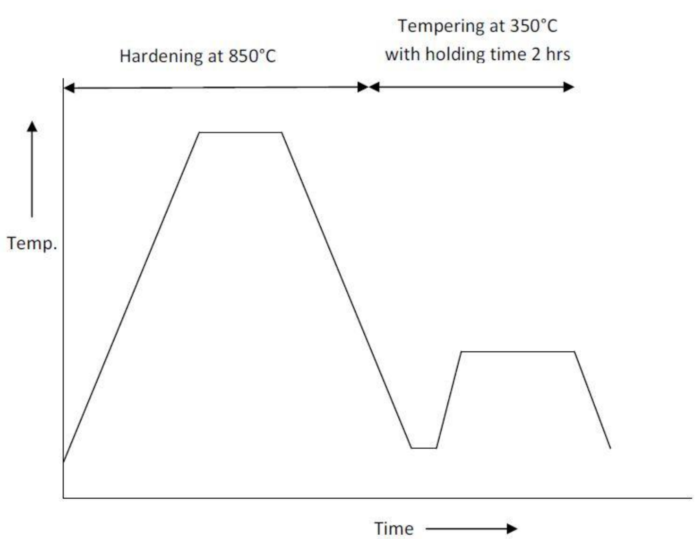

Fig. 1. Conventional Heat Treatment Process

Tempering of steel is a process in which previously hardened steel is heated to a temperature below the lower critical temperature and cooled at a suitable rate, to increase ductility and toughness. Steels are tempered by reheating after hardening to obtain specific values of mechanical properties and also to relieve quenching stresses and to ensure dimensional stability. Generally, tempering is done between range of 175 and 705 °C and for times from 30 min to 4 hours.

In this study, the oil queching was done after autenizing at 850°C. Quenching was followed by tempering at a temperature of 350°C for 2 hours [9] as shown in fig. 1.

2.2 Cryogenic Processing

Cryogenic processing of material is only done after hardening of material and post cryogenic treatment tempering is mandotory. In this study, the process followed was austenizing to 850°C, followed by oil quenching uptil room temperature. After oil quenching the material was brought down to temperature of -193°C with the ramp down rate of 0.5°C/min. Once the cryogenic temperature was achieved, the specimen was help at that temperature with the holding time of 24 hours. After that, the material was brought to rom temperature with ramp up rate of 0.5°C/min. Double tempering was performed post cryogenic treatment at 150°C for 1 hour. Cryogenic processing is represented in fig.2

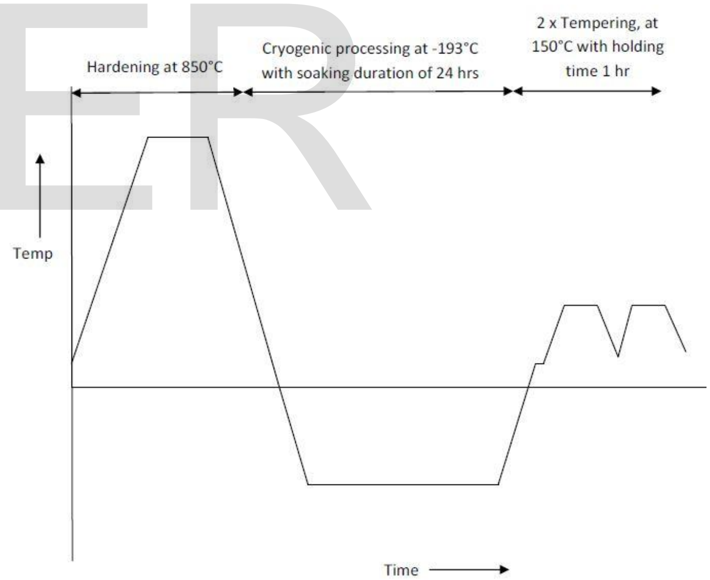

Fig. 2. Cryogenic processing

2.3 Hardness test

Brinell hardness test was performed on specimens M1 and M2. The standard test method followed while performing the test was ISO 6506 (Part-1):2005. 2.5 mm diameter ball intendor was used for the test. The load applied was 185.5 Kgf [10]. The brinel hardness value was found by using following relation:

$$BHN = \frac{2P}{\pi D\left(D - \sqrt{\left(D^2 - d^2\right)}\right)}$$

Where, P = Applied load in Kgf
D = Diameter of intender in mm
D = Diameter of intendation in mm

2.4 Impact Test

The izod impact test with single v-notch specimen was carried out using test method IS 1598(1977). Test specimens for M1 and M2 were prepared referring to same standards [11], as shown in fig.5 (dimensions are in mm)

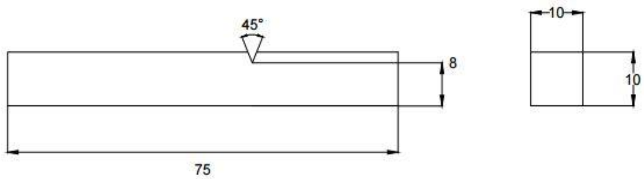

Fig. 3. Izod Impact Test specimen

2.5 Microstructure

The sample M1 and M2 were cut across cross section, polished by differerntgardes of silicon carbide papers and lapped with the aid of diamond paste on lapping machine. Later on, samples were etched with 2% natal solution. After sample preparation, the microstructure of the specimen M1 ans M2 were observed under trinocular metallurgical microscope. The test method followed for microexamination was ASM Vol.9 : 2004, ASTM E112 :13. [12], [13].

3 RESULTS AND DISCUSSION

3.1 Hardness

Hardeness test result of M1 and M2 material were evaluated and were as shown in table 3.

Table 2. Hardness Test Results

Spcimen	Hardness (BHN)
M1	243, 247, 247
M2	272, 278, 278

3.3 Impact strength

Izod impact test results for both materials are as shown in table 5. It is observed from the readings that deep cryogenic treatment have significant effect on impact strength of En8 materia. The impact strength of the material is found to be increased by 75%

Table 4. Izod Impact Test Results

Specimen	Izod Impact strength (Joules)
M1	24
M2	94

3.4 Microstucture

The microstructure as observed undertrinocular metallurgical microscopeshows that microstructure of the covnetionally treated material reveals tempered martenisite and more than 50% of retained austenite. Specimen that was cryogenic processed reveals tempered martensite and 5 – 10 % of reatianed austenite.

Also, percipatiated fine carbides have been observed in cryogenic processed specimen of En8. Fig 4 and fig. 5 shows microstructure of conventionally treated and cryogenic processed respectively with maginification of 100X

Fig. 4. Microstructure of covnetionally treated specimen

Fig. 5. Microstructure of cryogenic processed specimen

3.5 Significance of cryogenic processing with regards application of En8 steel.

En8 material is used in application such as general purpose axle, shafts, gears, spindle, pins, bolts, studs, etc. Such application of En 8 material requires improved properties of hardness, wear resistance, tensile strength, elongation and impact strength. Deep cryogenic treatment results in improvement of hardness which in turn would increase wear resisitance of the material, which have signicant importance in application of bolts, pins, etc. Also, deep cryogenic treatment results in significant improvement in impact strength with neglible change in tensile strength. Improved impact strength results in improved toughness of the material which is important in application such as shafts, general pupose axle, spindle etc.

En8 material is economically avaible and is easy to machine, hence deep cryogenic treatment of the En 8 material with above existing advantages gives an advantage of improved mechanical properties.

4 CONCLUSION

Curent study was carried out to evaluate the influence of cryogenic processing on En8 steel as compared to conventional heat treatment process. Following are conclusions drawn from the study:

1. Cryogenic processing of the material post hardening

treatment results in reduction in retained austenite from the matrix of martensite as confirmed from micro examination of the specimen.

2. Microstructure of the cryogenic processed material also reveals presences of fine carbide percipatates.
3. Due to above changes in micro struicture of the cryogenic processed material as compared to convetional heat treatment, the harndess and impact strength of the material has improved significantly.

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