

INFLUENCE OF DEEP-CRYOGENIC TREATMENT ON THE WEAR BEHAVIOR AND MECHANICAL PROPERTIES OF MILD STEEL

Mandeep Singh¹, Harpreet Singh²

¹Assistant Professor, Mechanical Engineering, Lovely Professional University, Phagwara, India

²Assistant Professor, Mechanical Engineering, C.T. Group of Institution, Jalandhar, Punjab

Abstract

Deep Cryogenic Treatment (DCT) is now extensively used as supplementary process for the achievement of specific goals in many engineering applications like manufacturing of high precision & accurate parts, press tools, welding tips, improving wear resistance etc. In the present study DCT was applied to inter critically heat treated low carbon steel to improve their mechanical properties and wear behaviour. The specimen was held for duration of 28 hours in cryogenic processor at a temperature of -193°C followed by tempering at a temperature of 150°C for 1 hour. A comparative study between intercritical heat treated and deep cryogenic treated specimen have been carried out to show the wear behaviour at different load and speed. Also hardness test and microstructure test have been performed. The experimental results have shown an increase in wear resistance for deep cryogenic treated samples as well as for intercritical heat treated samples.

Keywords— wear, mild steel, deep cryogenic treatment, micro hardness, impact, other manufacturing processes.

-----***-----

1. INTRODUCTION

Steel is widely used in the various engineering application such as automotive, agricultural, constructional purposes etc. Steel generally contains 0.02–2.1% carbon content and depending upon the need of industry steel is selected for different processes. After that there are different types of heat treatment processes which used for improving its various mechanical properties by altering the microstructure of steel. Properties of heat treated specifically depend on three different phases such as heating temperature, soaking period and cooling rate.

Over the past few decades, extensive interest has been shown in the effect of low-temperature treatment on the performance of tool steels [1, 2, 3]. Low-temperature treatment is generally classified as either “cold treatment” at temperatures down to about -80°C (dry ice) or “Deep Cryogenic treatment” at liquid nitrogen temperature of -196°C [5]. Cryogenic treatment is not a substitute for heat treatment, as often mistaken for, but it is a supplementary process to conventional heat treatment before tempering [2, 5]. Cryogenic treatment is an optimal method for reducing percent of retained austenite. Cryogenic treatment consists of heating steel up to austenite temperature, cooling it in quench environment and then immediately putting it in sub-zero centigrade degree and then tempering heat treatment. Increasing resistance to wear, reduction of internal stresses, consistency of dimensions and deposition of micro carbides in the field can be regarded as the most important privileges of using cryogenic heat treatment. The less the temperature of cryogenic environment, improvement in properties is performed with more rapidity. [4] With deep-cryogenic treatment applied immediately after quenching, residual austenite is reduced, and

spots for the nucleation of ϵ -carbides created during tempering are created in martensite. Cryogenic treatments can produce not only transformation of retained austenite to martensite, but also can produce metallurgical changes within the martensite. This offers many benefits where ductility and wear resistance are desirable in hardened steels [6]

Previous research studies mainly focuses on the enhancement of the properties of high speed steel, tungsten carbide, aluminum, die steel and its micro structural changes. The objective of this work was to investigate the effects of deep cryogenic treatment in conjunction with the intercritical heat treatment on the wear behavior, hardness and microstructure changes in low carbon steel.

2. EXPERIMENTAL PROCEDURE

The investigations were made by using the specimen made from the flat having dimensions 50mm wide & 12 mm thick. For the suitable heat treatment, knowledge of the upper and lower critical temperature is needed. The critical temperature can be found out with the help of Andrew’s Equation

$$Ac_1 = 723 - 10.7\text{Mn} - 16.9\text{Ni} + 29.1\text{Si} + 16.9\text{Cr} + 290\text{As} + 6.38\text{W}$$

$$Ac_3 = 910 - 203\sqrt{\text{C}} - 15.2\text{Ni} + 44.7\text{Si} + 104\text{V} + 31.5\text{Mo} + 13.1\text{W}$$

First of all the specimen were intercritical heat treated in a rotary furnace at a temperature of 815°C for about 40 minutes followed by water quenching. After that the specimen were

divided into two groups A & B. The group A specimen were further tempered at a temperature of 150 °C for 1 hour. The Group B specimen were deep cryogenically treated at a temperature of -193 °C having soaking period 28 hours under controlled conditions followed by tempering at a temperature of 150 °C for about 1 hour. Treatment process of the specimen are shown in Fig.1. The samples of the group A & B were then subjected to microhardness test, wear test and microstructure test to study the effect of deep cryogenic treatment over intercritical heat treatment.

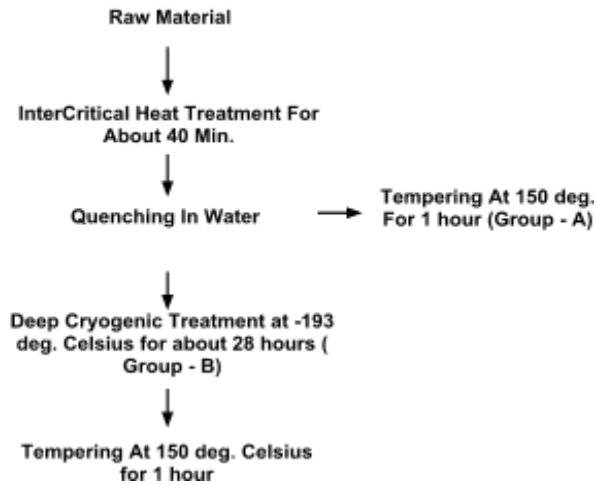


Fig.1:- Process Flow Chart

2.1 Vickers Hardness Test

The micro hardness measurement was done on the samples of group A, B and low carbon steel. The samples were prepared as per the standards. The vickers test has two distinct force ranges, micro (10g to 1000 g) and macro (1 kg to 100 kg), to cover all testing requirements. The Vickers ranges use a 136° pyramidal diamond indenter that forms a square indent [7]. The test was performed under ASTM E384 Standard. The micro hardness values were taken average value of the different specimen. The vickers hardness number is a function of the test force divided by the surface area of the indent. The average of the two diagonals is used in the following formula to calculate the Vickers hardness.

$$HV = \text{Constant} \times \text{test force} / \text{indent diagonal squared}$$

2.2 Wear Test

The wear test was performed on a machine called Pin on Disc machine. The samples were mounted perpendicularly on a stationary vice such that its one of the face is forced to press against the abrasive that is fixed on the revolving disc. When the disc rotates for a particular period of time, the sample can loaded at the top to press against the disc with the help of a lever mechanism. The samples for wear test were of rectangular shape having dimension 40mmx2.5mmx12mm. The test were

repeated by altering the load & speed of the rotating disc but keeping the time constant (5 min/per sample) .The wear rate is calculated by measuring the equivalent amount weight loss by weighing the sample before and after the test using electronic weighing machine. Formula used to find out the wear resistance and wear rate of the samples are as follow:-

- Wear Volume = weight loss / density.
- Wear Rate = wear volume / sliding distance.
- Wear resistance = 1 / wear rate

2.3 Microstructure Test

The tests were performed on metallurgical microscope epiphot 200 having magnification 50 – 1000X. The microstructure has been performed on different samples of group A, B and low carbon steel. The test method ASM VOL 9, IS 1501: 2000 was followed. The samples were first polished by using emery paper of grit 120, 200,600,800 and 1000 and up to 1µm, followed by polishing using diamond paste on rotating linen disc and finished with polishing on velvet cloth using white kerosene as coolant. These samples were etched with 2% natal and dried in air. The etched samples were studied using image analyser.

3. RESULT & DISCUSSION

3.1 Microhardness Test

Samples were tested from group A, B as well as from mild steel. The maximum micro hardness was observed in case of cryogenic treated samples as compared to intercritical heat treated specimen and untreated low carbon steel. The result in table 3 indicates that microhardness of the various specimens. The increase in microhardness may be attributed to the complete transformation of austenite to martensite. This observation is unlike that of Bensely et al. [9] who indicated no or negligible variation in hardness due to cryotreatment. However, the observed increase in hardness is in agreement with some other observations [8, 10, 11].

Table 3:- Average microhardness value of the different samples

S.No	Specimen	Microhardness(HV1)
1.	Mild Steel	180-183
2.	Intercritical Heat Treated	350-353
3.	Deep Cryogenic Treated	384-387

3.2 Wear Test

The improvement in the wear resistance of the cryogenically treated samples of group B were studied with varying load as well as with varying speed and it's comparison with group A and low carbon steel samples.

3.2.1 Variation in the WR with Varying Load at Different Speed: -

Fig. 3 shows the variation of wear resistance at varying load of 30 N, 40N and 50N at speed of 350 rpm of different group samples. The wear resistance of the group A and group B samples was 65% and 97% more than that of the low carbon steel samples at a load of 30N. Similarly at a load of 40N and 50N, the wear resistance of group A and group B was 60% and 88%, 50% and 78% respectively more when compared with low carbon steel samples respectively. The substantial improvement in wear resistance of deep cryogenically treated specimens is because of the fine carbides, which are dispersed more uniformly than earlier in addition to the transformation of the retained austenite into martensite [10]. The presence of dual phase microstructure also may be reason for increase in wear resistance.

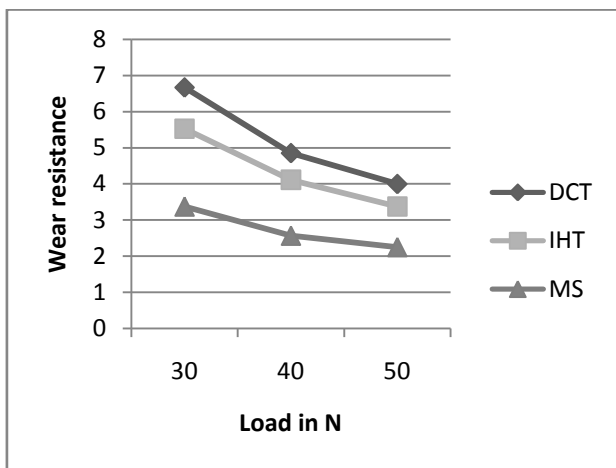


Fig: - 3 Variation of wear resistance with varying load at constant speed of 350 rpm

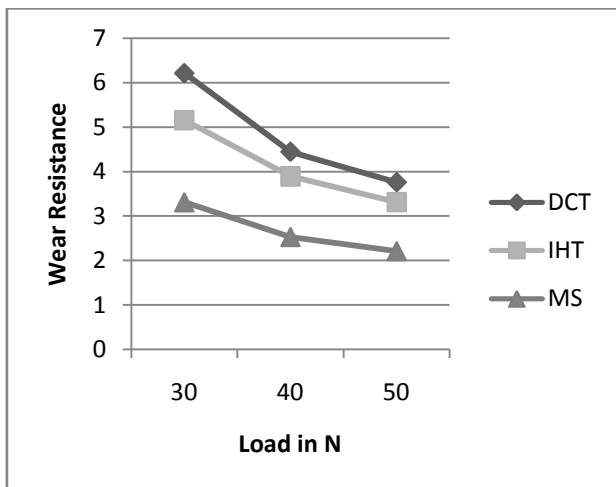


Fig: - 4 Variation of wear resistance with varying load at constant speed of 450 rpm

Fig. 4 shows the variation of wear resistance at varying load of 30N, 40N and 50N at a speed of 450 rpm of different group samples. At a load of 30N wear resistance of the group A and group B sample was 57% and 88% more than that of untreated mild steel samples. Similarly there was a decrease in wear resistance at a load of 40N and 50 of Group A, Group B and untreated low carbon steel specimen as compared to load of 30 N. The improvement in the wear resistance of Group A and B with respect to low carbon steel start decreases as the load increases.

Fig. 5 shows the comparison of wear resistance of the Group A, Group B and untreated low carbon steel sample at varying load but constant speed of 550 rpm. At a load of 30N the wear resistance of Group A and Group B was 56% and 80% respectively more than that of low carbon steel specimen. For load 40N the wear resistance of Group A and B was 46 % and 72 % more than that of low carbon steel specimen. The wear resistance of Group A and B is respectively 44% and 66% more than that of low carbon steel for an applied load of 50N.

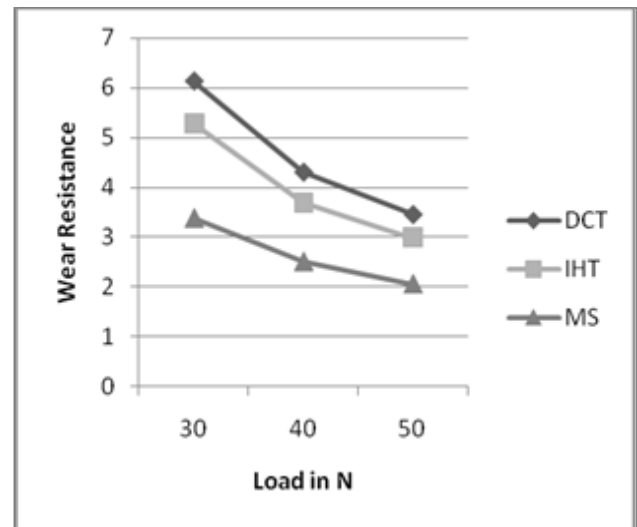


Fig: - 5 Variation of wear resistance with varying load at constant speed of 550 rpm.

3.3 Microstructure Test

Microstructure test had been performed on the different samples of group A, group B and low carbon steel samples. The micro structural examination was carried out to study the changes for each group of the samples that influence the wear resistance when they are subjected to cryogenic treatment and heat-treatment process. Fig.6 shows the microstructure of DCT steel having microstructure of martensite and bainite which may be due to isothermal cooling of heat treated steel. Fig. 7 shows the microstructure of intercritical heat treated specimen who's having microstructure bainite and martensite, but its surface was decomposed to 0.120mm, also the percentage of bainite is more than that of martensite which would be reasons for low

wear resistance of intercritical heat treated specimen. Fig 8 shows the microstructure of untreated low carbon steel that have microstructure of ferrite and pearlite.

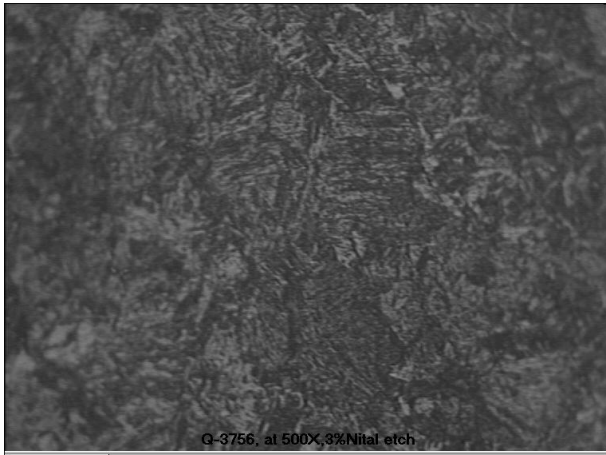


Fig.6- Microstructure of DCT sample

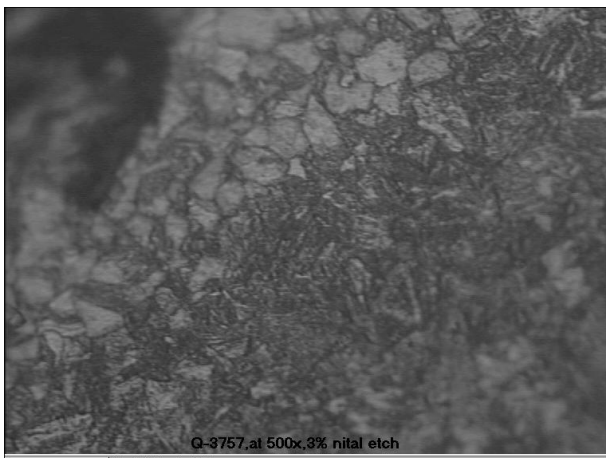


Fig.7 – Microstructure of Intercritical heat treated sample.

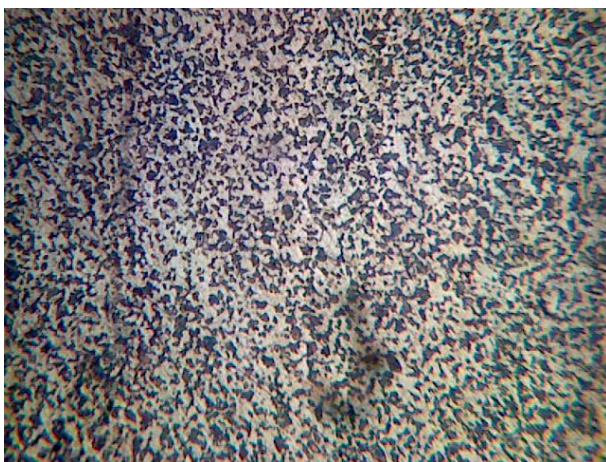


Fig.8 – Microstructure of low carbon steel.

4. CONCLUSIONS

The present study carried out to determine the influence of deep cryogenic treatment on the wear behavior and mechanical properties of intercritical heat treated low carbon steel samples. The following conclusions have been drawn:

- The deep cryogenic treatment was effective in improving the wear behaviour of low carbon steel.
- The wear resistance is more in case of deep cryogenic treated steel samples as compared to untreated low carbon steel samples and intercritical heat treated samples.
- The hardness value has a direct effect on the wear resistance of different samples that is why deep cryogenic treated samples was having more wear resistance as compared to intercritical heat treated and untreated low carbon steel samples..
- The wear resistance of deep cryogenic treated specimen is 21% , 97 % more as compared to Intercritical heat treated sample and untreated low carbon steel sample at a of load 3 kg and rpm 350 respectively.
- The microstructure of the deep cryogenic samples consists of martensite and bainite, which may be reason for increased wear properties and hardness.
- Finally, the net conclusion was that deep cryogenic treatment effects the mechanical and wear properties of low carbon steel samples.

The results indicate that the abrasive wear of the material is governed by a number of factors such as conditions during wear, hardness of the material and the type of treatment process.

REFERENCES

- [1]. Popandopulo, N.; Zhukova, L.T. “Transformation in high speed steels during cold treatment”, Met. Sci. Heat Treatment 1980 22,(10)708–710.
- [2]. Mohan Lal, D.; Renganarayanan, S.; Kalanidhi, A. “Cryogenic treatment to augment wear resistance of tool and die steels”, Cryogenics 2001, 41, 149–155.
- [3]. Molinari, A.; Pellizzari, M.; Gialanella, S.; Straffelini, G.; Stiasny, K.H. “Effect of deep cryogenic treatment on the mechanical properties of tool steels”, J. Mater. Process. Technol. 2001, 118, 350–355.
- [4]. Barron, “A Study on the Effect of Cryogenic Treatment on Tool Steel Properties”, Louisiana Technical University Report, August, 30, 1984.
- [5]. Barron, R.F. “Cryogenic treatment on metals to improve wear resistance. Cryogenics”, 1982, 22, 409–414.
- [6]. S. Sendooran, P. Raja “Metallurgical Investigation On Cryogenic Treated HSS Tool”, International Journal of Engineering Science and Technology (IJEST) Vol.3 No.5, May 2011.

- [7]. E.L. Tobolski & A. Fee, "Macroindentation Hardness Testing," ASM Handbook, Volume 8: Mechanical Testing and Evaluation, ASM International, 2000, 203-211, ISBN 0-87170-389-0.
- [8]. Mohan Lal, D.; Renganarayanan, S.; Kalanidhi, "A. Cryogenic treatment to argument wear resistance of tool and die steels". Cryogenics 2001, 41, 149–155.
- [9]. Bensely, A.; Prabhakaran, A.; Mohan Lal, D.; Nagarajan, G., "Enhancing the wear resistance of case carburized steel (En 353) by cryogenic treatment". Cryogenics 2005, 45, 747–754.
- [10]. Meng, F.; Tagashira, K.; Azuma, R.; Sohma, H. "Role of etacarbide precipitations in the wear resistance improvements of Fe-12Cr-Mo-V-1.4C tool steel by cryogenic treatment". ISIJ International 1994, 34, 205–210.
- [11]. Yun, D.; Xiaoping, L. Hongshen, X. "Deep cryogenic treatment of high-speed steel and its mechanism". Heat Treatment of Metals 1998, 3, 55–59.
- [12]. P Sekhar Babu; P Rajendran; K Narayana Rao; "Cryogenic Treatment of D2 Tool Steels to Augment Wear Resistance", International Journal of Material Science ISSN 0973-4589 Volume 4, Number 1 (2009), pp. 9–16.