# Improvement In The Corrosion Rate And Mechanical Properties Of Low Carbon Steel Through Deep Cryogenic Treatment.

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**Abstract-** Exploration of the benefit of cryotreatment for achieving improvement in corrosion rate of mild steel is a topic of current research interest. This study is concerned with the effect of deep cryogenic treatment at temperature of -193$^0$ C on the corrosion rate and mechanical properties. A series of corrosion rate tests have been carried out to cryotreated samples. The specimen were divided into two groups, the first group was subjected to conventional heat treatment process at a temperature of 950$^0$ C for about 1 hour and the other group was subjected to deep cryogenic treatment for about 36 hours at a temperature of -193$^0$ C, followed by tempering at 150$^0$ C for about 1 hour to both the groups. The results have shown that after DCT the corrosion rate and mechanical properties of the samples were all improved. The changes in microstructure due to (DCT) were clearly noticeable, the grain boundaries were no longer visible and the microstructure consists of baninite, martensite and retained austenite.

**Keywords:** Deep Cryogenic treatment, mild steel, corrosion resistance, Rockwell hardness, heat treatment.

## 1. Introduction

Cryogenic treatment is a supplementary heat treatment that is performed on some finished steel component as an effective method to improve their performance[1]. Two types of cryogenic treatments are generally applied, the shallow cryogenic treatment which is performed between (-60$^0$C) and (-90$^0$C), and the deep cryogenic treatment that is conducted at temperatures below (-196$^0$C)[2]. Cryogenic treatment is a proper operation (treatment) 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. [3] With deep-cryogenic treatment applied immediately after quenching, residual austenite is reduced, and spots for the nucleation of -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 [4].

Barron studied the effect of cryogenic treatment on the corrosion resistance different metal specimen and found out that the largest improvement was shown in the case of S-2 tool steel for which the corrosion rate was reduced by a factor 1.786 and the least improvement was shown in case of 4142 Cr-Mo alloy steel[5]. Previous research studies mainly focuses on the enhancement of the properties of High speed steel, tungsten carbide, aluminium, die steel and its micro structural changes. The objectives of this work are to investigate the effects of deep cryogenic treatment in conjunction with the heat treatment on the corrosion rate, hardness and tensile strength of the mild steel.

## 2. Experimental procedure

The investigations were made by using the specimen made from round bar having diameter 10mm. For the suitable heat treatment the knowledge of the upper and lower critical temperature is needed. The critical temperature can be found out with the help of Andrew's Equation.

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

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

The Chemical composition and critical temperature are listed in Table 1.The mechanical properties of the mild steel are shown in Table 2.


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**Table 1:-** Chemical composition of the Mild steel with its critical temperatures

| S.No. | Element | % |
|---|---|---|
| 1. | Carbon | 0.247 |
| 2. | Manganese | 0.54 |
| 3. | Silicon | 0.153 |
| 4. | Nickel | 0.073 |
| 5. | Chromium | 0.11 |
| 6. | Aluminium | 0.022 |
| 7. | Sulphur | 0.03 |
| 8. | Phosphorus | 0.038 |
| 9. | Copper | 0.091 |
| 10 | $Ac_1$ | $723^0$ C |
| 11 | $Ac_3$ | $814^0$ C |

**Table 2:** Mechanical Properties of the mild steel in original state

| | |
|---|---|
| Tensile Strength (MPa) | 610 |
| Elongation (%) | 15 |
| Yield Strength ( MPa) | 306.6 |
| Microhardness | 180 |
| an (J/cm$^2$) | 86 |

First of all the specimen were heat treated in a rotary furnace at a temperature of 950$^o$ C for about 1 hour followed by water quenching. After that the specimen are divided into two groups A & B. The group A specimen are further tempered at a temperature of 150 $^0$C for 1 hour. The Group B specimen were deep cryogenically treated at a temperature of -193 $^0$C having soaking period 36 hours under controlled conditions followed by tempering at a temperature of 150 $^0$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 hardness test, corrosion rate and tensile test to study the effect of deep cryogenic treatment over heat treatment. Microstructure analysis was also conducted.

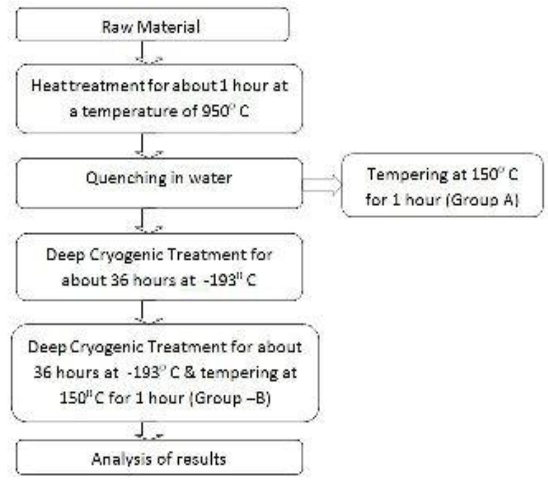


**Fig.1:-** Process Flow Chart

### *3.1 Hardness Test*

Rockwell hardness testing is a general method for measuring the bulk hardness of metallic and polymer materials. Although hardness testing does not give a direct measurement of any performance properties, hardness correlates with strength, wear resistance, and other properties. Hardness testing is widely used for material evaluation due to its simplicity and low cost relative to direct measurement of many properties. This method consists of indenting the test material with a diamond cone or hardened steel ball indenter. The indenter is forced into the test material under a preliminary minor load F usually 150kg. When equilibrium has been reached, an indicating device, which follows the movements of the indenter and so responds to changes in depth of penetration of the indenter, is set to a datum position.

### *3.2 Corrosion Test*

The corrosion test was performed on a round bar having diameter 10mm in a salt solution for seven days. For corrosion test weight loss is considered as a main factor. After each day the weight of specimen was measured by using electronic weighing machine and noted down. The test samples were cleaned properly before and after weighing to remove the scale formation.

### *3.3 Tensile Test*

The tests were performed on Universal testing machine setup. The tensile test has been performed on three different samples of both group A, B and mild steel samples. The tensile test was carried out according to American Society for testing Material (ASTM) A370-05.A rod tensile specimen of geometry and dimensions having dimensions as shown in Figure 2.

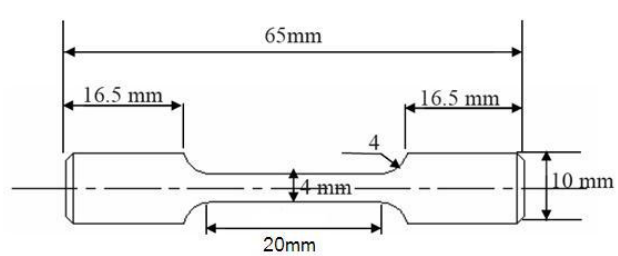


**Fig.2** Specimen for Tensile Test

### *3.4 Microstructue test*

Samples for microstructure examination were ground using different grades of wet emery papers (220, 400, 800 and 1200), then polished using two grades of diamond paste (1um and 0.3 um). Distilled water and alcohol were used to clean the samples in succession. Etching was carried out using Nital etching solution (2% HNO3 in alcohol), followed by washing them with water and soup to remove stains, then rinsed with alcohol and dried. The microstructure examination is performed with an optical microscope which has a photo digital system and computerized by special imaging software. The images were photographed with a magnification of (100X and 500X).

## *4. Result & Discussion*

### *4.1 Hardness Test*

Samples were tested from each group as well as from simple mild steel. The average hardness of the mild steel sample have an equivalent hardness of 4-5 HRC and the average hardness of the Group A obtained is 12-14 HRC. The maximum hardness was observed in case of cryogenic treated samples of value 24-25 HRC .From the result it is concluded that there is considerable increase in the hardness value of the cryogenic treated sample as compared to Heat Treated sample and Mild Steel. The Hardness values are tabulated in the Table 3.

**Table 3:-** Average Hardness value of the different samples

| S.No. | Specimen | Hardness (HRC) |
|---|---|---|
| 1. | Mild Steel | 4.5 |
| 2. | Heat Treated | 13 |
| 3. | Deep Cryogenic Treated | 24.5 |

### *4.2 Corrosion Rate Test*

The improvements in the Corrosion rate of the cryogenically treated samples of Group B were studied and it's comparison with Group A and Mild steel samples. The samples were subjected to a salt solution for seven days and found out that the corrosion rate of the deep cryogenic treated samples shown an improvement as compared to mild steel and heat treated samples. The values of corrosion rate for deep cryogenic treated, mild steel and heat treated samples are tabulated in the table 4, 5 and 6 respectively.

**Table: - 4** Corrosion rate for Deep Cryogenic Treated samples

| S.No. | Initial Wt (gm) | Wt After 7 days (gm) | Wt Loss (mg) | Corrosion Rate |
|---|---|---|---|---|
| 1 | 40.02 | 39.85 | 133 | 1.47 |
| 2 | 39.1 | 38.93 | 154 | 1.71 |
| 3 | 38.9 | 38.75 | 167 | 1.85 |

**Table: - 5** Corrosion rate for Mild Steel samples

| S.No. | Initial Wt (gm) | Wt After 7 days (gm) | Wt Loss (mg) | Corrosion Rate |
|---|---|---|---|---|
| 1 | 39.4 | 39.05 | 349 | 3.85 |
| 2 | 39.16 | 38.74 | 417 | 4.61 |
| 3 | 39.36 | 38.93 | 427 | 4.72 |

**Table: - 6** Corrosion rate for Heat Treated samples

| S.No. | Initial Wt (gm) | Wt After 7 days (gm) | Wt Loss (mg) | Corrosion Rate |
|---|---|---|---|---|
| 1 | 39.55 | 39.27 | 277 | 3.06 |
| 2 | 39.1 | 38.31 | 287 | 3.17 |
| 3 | 39.36 | 39.05 | 307 | 3.40 |

From the above values tabulated in the tables it was found out that corrosion rate in case of deep cryogenic treatment is 47.6% and 61.7 % less than that of heat treated and mild steel samples.

### *4.3 Tensile Test*

Tensile test has been performed on the different samples of Group A, Group B and mild steel samples. Average of these three values has been taken and considered as absorbed energy. It has been observed that the tensile strength of deep cryogenic treated samples is more than that of the Group A and mild steel samples respectively. The values are tabulated in table 7

**Table 7:-** Values for Tensile test

| S. No. | Specimen | Tensile Strength(MPa) |
|---|---|---|
| 1 | Mild Steel | 638.5 |
| 2 | Heat Treated Steel | 781 |
| 3 | Deep Cryogenic Treated | 982 |

The tensile strength of the Group B was more than 53.7% from untreated mild steel samples whereas it was 25.7% more than that of heat treated samples.

### *4.4 Microstructure test*

Figure 3, 4 and 5 represents the microstructure of mild steel, heat treated and deep cryogenic treated mild steel samples respectively. The microstructure of mild steel consists of ferrite and pearlite grain boundaries, microstructure of heat treated samples consists of bannite and martensite but the layer of the samples were slightly decarburised where as the microstructure of DCT samples consists of Baninite and martensite with clear grain boundaries.Some amount of austenite was also retained in both group A and B samples.

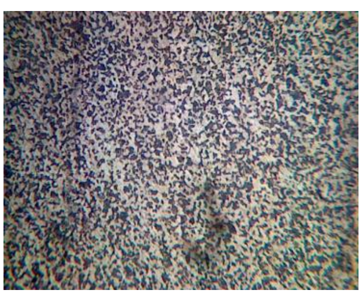

**Fig. 3 :-** Microstructure of Mild Steel (at 100X)

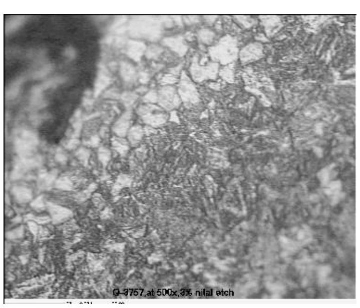

**Fig. 4 :-** Microstructure of Heat Treated Mild Steel (500X)

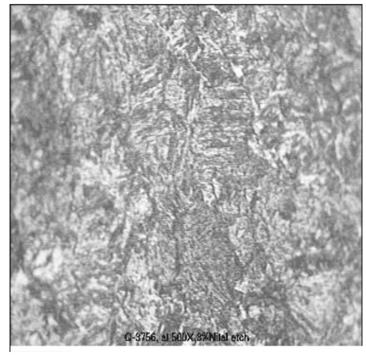

**Fig. 5 :-** Microstructure of Deep Cryogenic Treated Steel (500X)

## *5. Conclusion*

The present study carried out to determine the influence of deep cryogenic treatment on the corrosion rate and mechanical properties of heat treated mild steel samples. The following conclusions have been drawn:

1. The corrosion resistance is more in case of deep cryogenic treated mild steel samples as compared to untreated mild steel samples and intercritical heat treated samples.
2. The corrosion rate of deep cryogenic treated mild steel samples are 47.6% less than that of heat treated mild steel samples and 61.7 % less than that of mild steel specimen.
3. The hardness value of the deep cryogenic treated samples increased by 88.8 % when compared with heat treated samples.
4. The cryogenic treatment increases the tensile strength of the samples up to 53.7% when compared to untreated mild steel samples and 25.7 % as compared to heat treated mild steel specimen.
5. Finally, the net conclusion is that deep cryogenic treated mild steel samples are giving better result for the wear and mechanical properties like tensile strength and hardness.

The results indicate that the corrosion rate of the material is governed by a number of factors such as environmental conditions, hardness of the material, chemical composition and the type of treatment process.

## *References*

[1]. Nirmal S. Kalsi, Rakesh Sehgal, and Vishal S. Sharma , "Cryogenic Treatment of Tool Material: A Review" , *Materials and Manufacturing Processes*, 25: 1077–1100, 2010

[2]. Dr. Abbas A. Hussein, Murtadha Qasim Idan AL-kinani , "Effect of Cryogenic Treatment on the properties of low carbon A858steel Journal of Engineering.

[3]. Barron, "A Study on the Effect of Cryogenic Treatment on Tool Steel Properties", Louisiana Technical University Report, Agust 30, 1984.

[4]. S. Sendooran, P. Raja “Metallurgical Investigation On Cryogenic Treated HSS Tool”, International Journal of Engineering Science and Technology (IJEST)Vol.3No.5May2011

[5]. Barron, R.F., R.H. Thompson, “Effect of cryogenic treatment on corrosion resistance ”.