EFFECT OF CRYOGENIC TEMPERING ON STEEL

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Abstract-In the field of mechanical engineering we are always looking to improve the mechanical properties of the material. By doing so we can improve the quality of the product we are making. In order to improve the properties of the material, heat treatment process is used such that mechanical properties such as strength, hardness, wear resistance, etc. is improved. But at the end of heat treatment we get material more brittle and difficult to use in practical. Tempering process is used to increase the ductility of material. Even though there will be some internal stresses in the material, In order to remove these internal stresses and to improve the wear resistance of the material, new treatment called CRYOGENIC TEMPERING is used. In this project we have discussed about the effect of cryogenic tempering on steel.

Key words: Cryogenic, Tempering, Steel, properties, micro structure analysis

1. INTRODUCTION

Zbigniew Zurecki studied the Cryoyogenic [1] Quenching of Steel Revisited through include SEM, EDS, Charpy impact and wear resistance measured using the standard pin-on-disk as well as a diamond stylus micro-scratching technique adopted from the field of thin-film technologies. Results confirm the cryotreatment enhanced precipitation in the subsequent tempering step of what turns out to be 100-250 nm alloy-depleted carbides, and moderate improvements in wear resistance and hardness, both scaling with the cryogenic treatment time and at the cost of reduced impact resistance.M. Pellizzari and A. Molinari [2] conducted Deep Cryogenic Treatment. Deep Cryogenic Treatment (DCT) was applied to two different cold work tool steels, X155CrMoV121 and X110CrMoV82, to improve their wear resistance. Several heat treatment cycles were investigated, by carrying out DCT both after quenching, after tempering and between quenching and tempering. Deep cryogenic treatment always reduces wear rate of the two steels, even if it does not influence significantly hardness. The effect is more pronounced when cryogenic cycle is carried out immediately after quenching. The influence of DCT on tempering curves was also investigated and the effect on retained autenite transformation was highlighted.

Kristoffer P. Kollmer [3] conducted Physical Testing, Microstructure analysis and concludes that Tensile strength increases ranged between 7% and 16% for cold tempered specimens. There was almost no change in impact strength between treated and untreated specimens. Reduction in grain size of treated specimens, Uniform distribution of carbon particles, Eliminate or diminish grain boundaries.Rahul H.Naravade,[4] conducted test on D6 tool steel. In this work, the effects of cryogenic treatment on the wear behavior of D6 tool steel were studied. The effects of cryogenic temperature, cryogenic time (kept at cryogenic temperature for 20 and 40 h) on the wear behavior of D6 tool steel were studied. Wear tests were performed using a pin-on-disk wear tester. The findings showed that the cryogenic treatment decreases the retained austenite and hence improves the wear resistance and hardness. Due to more homogenized carbide distribution as well as the elimination of the retained austenite, the deep cryogenic treatment demonstrated more improvement in wear resistance and hardness compared with the shallow cryogenic treatment.

Richard N. Wurzbach, and William DeFelice [5] shows the improvement in wear resistance of cryo treated materials with untreated materials through the examples of gears, bearings, engines, bronze impellers with surface roughness experiments. While improvements in the wear performance of blades and tooling are the most common and well documented use of cryogenic processing, extending the life of components that are not designed to wear in normal service has also been demonstrated for maintenance department. Meng, Fanju, etal [6] studied Role of Eta-carbide Precipitation's in the Wear Resistance Improvements of Fe-12-Cr-Mo-V-1.4C Tool Steel by Cryogenic Treatment and performed wear resistance test, micro structural analysis, x-ray diffraction analysis which concludes that improvement in wear resistance, alignment of carbon atoms and fine precipitation of eta-carbides. A.Bensely, A.Prabhakaran, D.Mohanlal, G.Nagarajan [7] studied the Enhancing the wear resistance of case carburized steel (En 353) by cryogenic treatment and concluded with the results of wear resistance has been improved by 85% for SCT over CHT and 372% for DCT OVER CHT and carbide precipitation is finer.

John Gayda and L.J Ebert [8] studied the effect of cryogenic cooling on the tensile properties of metal matrix composites. Tensile specimens machined from metal-matrix, oriented-fiber composites (aluminum alloy reinforced with high strength stainless steel wire) were heated t o 260°C and cooled in air t o produce a tensile residual stress state in the matrix. The results indicated cryogenic refrigeration extended the first stage (totally elastic) behavior of these materials. It was shown that the beneficial effects of the cryogenic treatment resulted from an alteration of the residual stress state brought about by plastic flow of the matrix. Finally, it was shown that these effects could be computed by rigorous analytical methods.

However there are reports from metallurgist who are skeptic about cryogenic treatment. The present project work deals with the effect of cryogenic tempering on wear resistance and stress of medium carbon steel.

2. MATERIALS AND METHODOLOGY

2.1 Experimental Procedure:

Experimental procedure consists of sampling, dry sliding wear test, microstructure analysis and analyzing stress through ANSYS

2.2. Sampling

After procuring the raw material, chemical analysis was done for the conformation of the material composition. A sample for 10mm diameter, 30mm long was polished using alumina paper. After conforming the material, the material procured is machined according to machine requirement and subjected to appropriate treatments as required for the tests.

In conventional heat treatment (CHT), the machined test samples has to undergo hardening at 1093 K for 30 min, then oil quenching at 313 K and tempering at 423 K for 90 min. For shallow cryogenic treatment, the samples were heat treated as for CHT, but without tempering. Then the samples were directly kept in a mechanical freezer at 193 K for 5 h and then exposed to room temperature and it is followed by tempering at 423 K for 90 min. The deep cryogenic treated samples were heat treated as for CHT, but without tempering, in which the materials are slowly brought down from room temperature to 77 K at 1.26 K/min, held at the same temperature for 24 h and subsequently brought back to room temperature at 0.63 K/min. Then the samples were subjected to tempering at 423 K for 90 min. Thus three sets of samples (i) CHT, (ii) SCT and (iii) DCT were taken for wear testing.

2.3. Dry sliding wear test

The amount of wear in any component will in general, depend upon a number of factors such as applied load, testing machine characteristics, sliding speed, sliding distance, environment and material properties. The measurement and evaluation of wear are difficult as it depends on several factors. However ASTM (American Standard for Testing and Materials) 99-95a describes a laboratory procedure for determining the wear of materials during sliding. In this test, materials are tested in Paris under nominally non-abrasive conditions. Two specimens are required for the test a pin with a flat tip and a flat tip and flat circular disk both are made of Steel of 0.45% carbon 353 in the present work. The size of the pin is 10 mm in diameter and 30 mm long whereas the disk is 160 mm in diameter and thickness of 10 mm. The case depth of 1 mm is given for both the test specimen. The pin is positioned perpendicular and forced against the revolving disk specimen with a required load. So the wear track on the disk is a circle, involving multiple wear passes on the same track. The variable speed motor in the machine causes the disk specimen to revolve about the disk center and the plane of the disk is held horizontally. Initially wear test was performed with lubrication (SAE 90) for 3 h but the wear loss was too small and could not be quantified even with a precision electronic weighing balance. Hence dry test was preferred for the study. The test was conducted for the samples of three different treatments namely CHT, SCT and DCT. The speed and load ranges were determined taking into account the capacity of the wear testing machine and the minimum amount of wear loss which could be measured using the weighing blance.Hence after each test only the mass loss of pin was considered as the wear. During the test the temperature of the pin and disk interface was very high, so an air blower was used. In order to ensure that the wear test is not performed continuously on the same track, which leads to the removal of carburized disks were utilized for testing. Hence tests were carried out for two different loads (20, 40 N), three sliding velocity and for three different treatment conditions (CHT, SCT and DCT). Wear results are obtained by conducting test for a selected sliding velocity and load. Each specimen was tested for duration of (5 min) before arriving at the weight loss. The wear rate of each pin was calculated from the weight loss during this test duration. The amount of wear is determined by weighing the specimen before and after the tests using a precision physical weighing balance with an accuracy of 0.001 g. Since the mass loss is measured, it is converted to volume are reported as wear rate of pin (mm^3/m) for the three different treatments. A comparison has been made to identify the effects of each treatment on wear improvement. The hardness test was carried out for the very same wear tested same wear tested samples and the results are given in Table.

Table 1 WEAR TEST FOR SAMPLE AT LOAD 20 N

VELOCITY	SAMPLE	WEAR		DIFFERENCE	WEAR RATE	WEAR RESISTANCE	% OF WEAR RESISTANCE		
		IW	FW				SCT-CHT	DCT-SCT	DCT-CHT
0.7855	CHT	1.3743	1.354	0.0203	$8.565X10^{-12}$	$3.083x10^{9}$			
	SCT	1.384	1.3727	0.0113	$4.768X10^{-12}$	$5.205x10^{9}$	68.89	470.16	862.9
	DCT	1.3921	1.3903	0.0018	$7.59X10^{-13}$	$2.967x10^{10}$			
1.571	CHT	1.354	1.3297	0.0243	$1.023X10^{-11}$	$5.15x10^{9}$			
	SCT	1.3727	1.3618	0.0109	$4.599X10^{-12}$	$1.079x10^{10}$	109.5	421.2	991.8
	DCT	1.3903	1.3884	0.0019	$8.017X10^{-13}$	$5.623x10^{10}$			
2.0946	CHT	1.3297	1.3235	0.0062	$2.616X10^{-12}$	$2.692x10^{10}$			
	SCT	1.3618	1.3582	0.0036	$1.519X10^{-12}$	$4.357x10^{10}$	61.8	104.3	230.7
	DCT	1.3884	1.3868	0.0016	$6.751X10^{-13}$	$8.903x10^{10}$			

Table 2 wear test for sample at load 40 n

VELOCITY	SAMPLE	WEAR		DIFFERENCE	WEAR RATE	WEAR RESISTANCE	% OF WEAR RESISTANCE		
		IW	FW				SCT-CHT	DCT-SCT	DCT-CHT
0.7855	CHT	1.3235	1.2945	0.029	$1.224 X 10^{-11}$	$4.316 x 10^{9}$	24.4	128.6	184.5
	SCT	1.3582	1.3363	0.0219	$9.241 X 10^{-12}$	$5.372 x 10^{9}$			
	DCT	1.3868	1.3781	0.0087	$3.67 X 10^{-12}$	$1.228 x 10^{10}$			
1.571	CHT	1.2945	1.2463	0.0482	$2.034 X 10^{-11}$	$5.193 x 10^{9}$	100.5	346.4	795.4
	SCT	1.3363	1.3137	0.0226	$9.536 X 10^{-12}$	$1.041 x 10^{10}$			
	DCT	1.3781	1.3735	0.0046	1.94X 10-12	$4.647 x 10^{10}$			
2.0946	CHT	1.2463	1.2041	0.0422	$1.781 X 10^{-11}$	$7.908 x 10^{9}$	129.3	376	991.7
	SCT	1.3137	1.2964	0.0173	$7.299 X 10^{-12}$	$1.813 x 10^{10}$			
	DCT	1.3735	1.3702	0.0033	$1.393 X 10^{-12}$	$8.633 x 10^{10}$			

2.4. GRAPHS:

2.4.1. WEAR RATE GRAPH

Table 3: wear rate vs sliding velocity

Sliding Velocity	WEAR RATE		
	CHT	SCT	DCT
0.7855	8.57E-12	4.77E-12	7.59E-13
1.571	1.03E-11	4.60E-12	8.02E-13
2.0946	2.62E-12	1.52E-12	6.75E-13

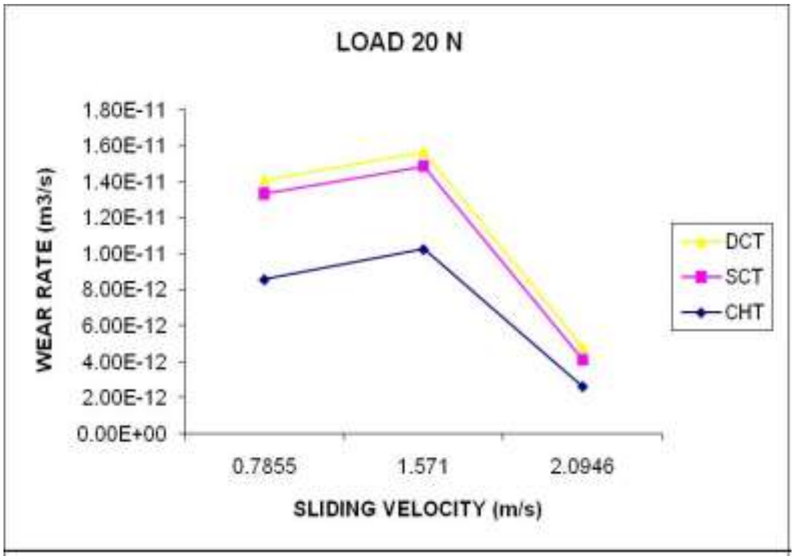

Figure 1 Wear Rate at 20 N for Three Different Treatments

Graph shows the CHT samples have the high wear rate compared to the SCT, DCT samples for the respective sliding velocities 0.7855 m/s, 1.571 m/s, 2.0946 m/s. values of the wear rate for the load of 20 N is shown in above table.

Table4 Wear Rate Vs Sliding Velocity

Sliding Velocity	WEAR RATE		
	CHT	SCT	DCT
0.7855	1.22E-11	9.24E-12	3.67E-12
1.571	2.03E-11	9.54E-12	1.94E-12
2.0946	1.78E-11	7.30E-12	1.39E-12

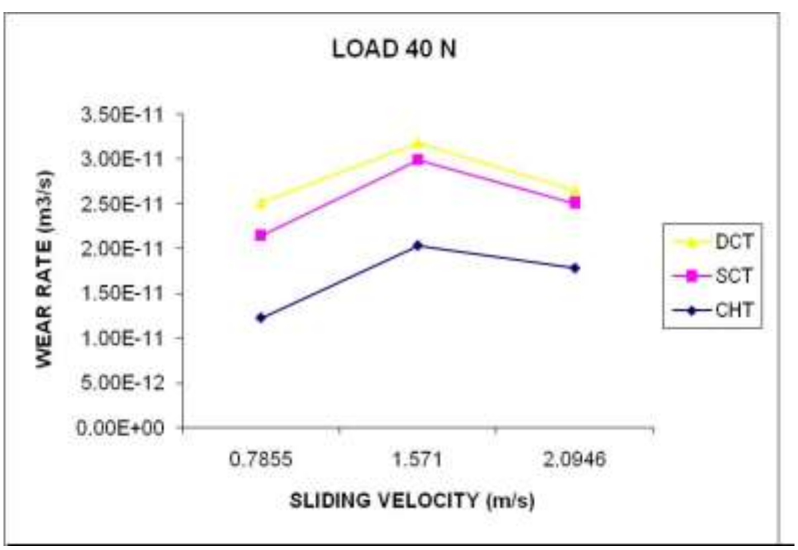

Figure 2 Wear Rate at 40 N for Three Different Treatments

Graph shows the CHT samples have the high wear rate compared to the SCT, DCT samples for the respective sliding velocities 0.7855 m/s, 1.571 m/s, 2.0946 m/s. values of the wear rate for the load of 40 N is shown in above table.

2.4.2. Wear resistance improvement charts:

Table 5.Wear Resistance Vs Sliding Velocity

Wear resistance	CHT	SCT	DCT
0.7855	3.08E+09	5.21E+09	2.98E+10
1.571	5.15E+09	1.08E+10	5.62E+10
2.0946	2.70E+10	4.36E+10	8.90E+10

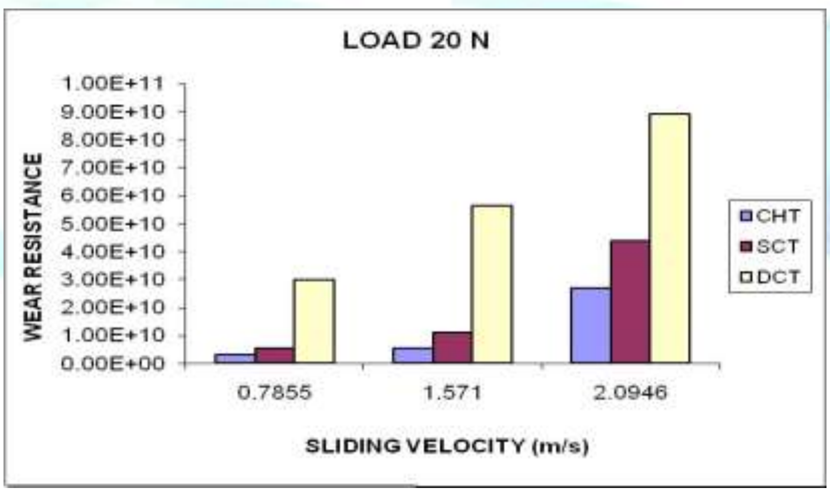

Figure 3 Wear Resistances at 20 N For Three Different Treatment

Wear resistance improvement chart shows that DCT samples have highest wear resistance comparing with CHT, SCT samples for the respective sliding velocities 0.7855 m/s, 1.571 m/s, 2.0946 m/s. values of the wear resistance for the load of 20 N is shown in above table.

Table 6: wear resistance vs sliding velocity

Wear resistance	CHT	SCT	DCT
0.7855	4.32E+09	5.37E+09	1.23E+10

1.571	5.19E+09	1.04E+10	4.65E+10
2.0946	7.91E+09	1.81E+10	8.63E+10

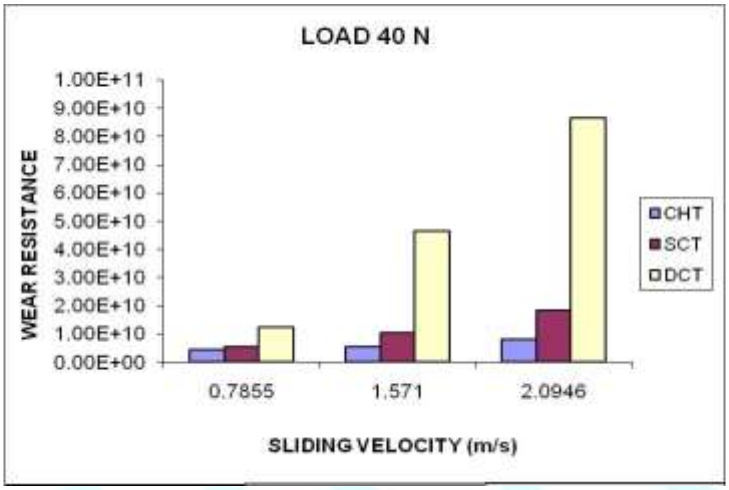

Figure 4 Wear Resistances at 40 N for Three Different Treatments

Wear resistance improvement chart shows that DCT samples have highest wear resistance comparing with CHT, SCT samples for the respective sliding velocities 0.7855 m/s, 1.571 m/s, 2.0946 m/s. values of the wear resistance for the load of 40 N is shown in above table.

3. RESULTS AND DISCUSSION

3.1.Microstructure Analysis:

In order to find out the mechanism for the wear resistance improvement micro structural evaluation was made using Metallurgical Microscope. The microstructure of CHT sample is shown in figure which shows the enormous amount of austenite is retained in the case of material, which is evident from the white patches of on the microstructure.

Figure 5 Microstructure of CHT sample at 15x

The microstructure of SCT sample is shown in figure which shows the formation of martensite by needle like structures and not a uniform carbide precipitation by block dots.

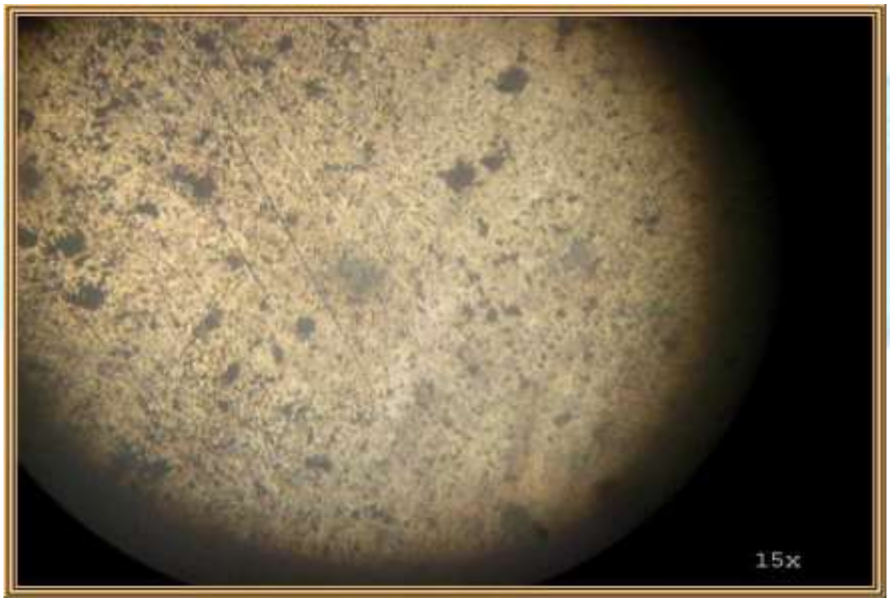

Figure 6 Microstructure of SCT sample at 15x

The microstructure of DCT sample is shown in figure which shows the martensite structure by needle like structures.

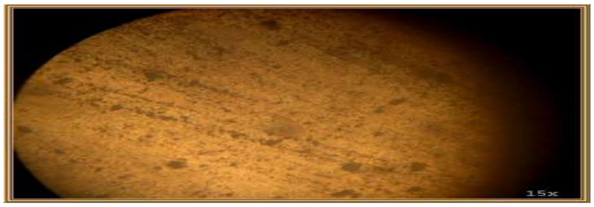

Figure 7 Microstructure of SCT Sample At 15x

3.2. Carbide Precipitation:

The block dots are called as carbides. Figure shows the microstructure of CHT sample at 100x which shows the non uniform carbide precipitation

Figure 8 Microstructure of CHT Sample At 100x

Figure shows the microstructure of SCT sample at 100x which shows the carbide precipitation is trying to be uniform but not get the correct uniformed structure

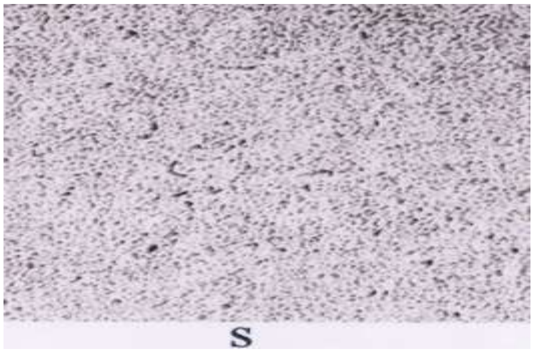

FIGURE 9 Microstructure of SCT sample at 100x

Figure shows the microstructure of DCT sample at 100x which shows the carbide precipitation is more uniform rather than CHT,SCT samples

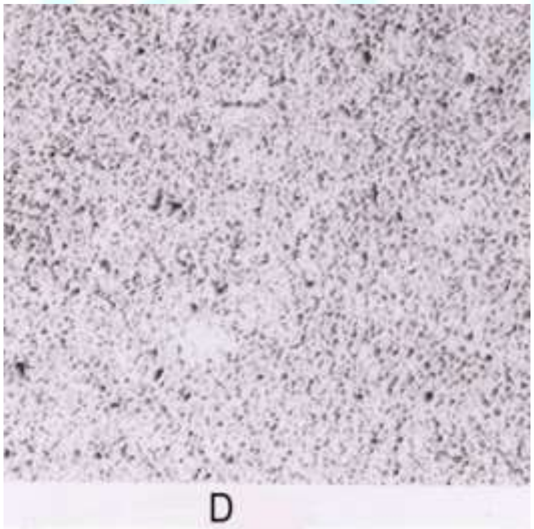

FIGURE 10 Microstructure of DCT sample at 15x

From the results of the microstrure, effect of converting retained austenite to martensite, DCT sample induced uniform precipitation and finer distribution of carbides, which are solely responsible for thr improved wear resistance and hardness.

4. CONCLUSION

From the wear resistance test results, it is proved that wear resistance of Deep Cryogenic treated materials and Shallow Cryogenic treated material is higher than that of Conventional heat treated materials. For the load of 20 N, the average values for % of wear resistance improvement for all the sliding velocities are,

SCT-CHT = 80%

DCT-SCT = 332%

DCT-CHT = 695%

For the load of 40 N, the average values for % of wear resistance improvement for all the sliding velocities are,

SCT-CHT = 85%

DCT-SCT = 284%

DCT-CHT = 657%

The improvement in wear resistance is attributed to the conversion of retained austenite to martensite brought in by cryogenic treatment. It is confirmed by the microstructure analysis which also shows the uniform carbide precipitation.

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