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EFFECT OF CRYOGENIC TREATMENT ON MICROSTRUCTURE OF T-15 TOOL STEEL

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ABSTRACT

Cryogenic treatment process uses sub-zero temperatures down to -184°C to modify the micro-structure and properties of material. This process is an extension of heat treatment which further improves the properties of material. This paper focuses on the effect of cryogenic treatment on High Speed Steel (T-15) tool material. Cryogenic treatment at -184°C is conducted in this research and its properties compared with untreated material. It has been found that as the temperature is decreased, microstructure of material is refined and more number of carbide precipitates appeared on the surface after the treatment. Interestingly to note that the retained austenite is completely converted into martensite after subjecting the T42 HSS specimen to cryogenic treatment. The micro structural changes results in improvement of properties of HSS, (T-15) tool material. The X-Ray diffraction pattern showed that the presence of retained austenite in CT HSS has been found to be very less as compared to UT HSS specimen. During cryogenic treatment contraction in lattice of martensite and austenite took place. Due to super saturation martensite with carbon and thermodynamic instability, the carbon atoms squeezed out of martensite, migrated to the neighbouring lattice defects and acted as nucleation sites for the growth of fine carbides.

KEYWORDS: Cryogenic treatment, wear resistance, HSS (T-15), microstructure.

INTRODUCTION

Cryogenic treatment, which is sometimes called cryogenic tempering, utilizes ultra-cold temperatures to modify the microstructure of metals and other materials. It has been widely adopted as a cost reduction and performance enhancing technology. It is also used as an enabling technology. It ultimately improves the performance of the metal, alloy and other materials. The cryogenic treatment process uses sub-zero temperatures down to -184 °C to modify the micro-structure of the material. This treatment promotes additional transformations in metals, alloys and other materials. People usually relate heat treatments with high temperatures, but thermal treatments can also involve cooling. Cryogenic process is extension of heat treatment which further improves the properties of material.

The basic CT process consists in a gradual cooling of the component until the defined temperature, holding it for a given time (freezing time) and then progressively leading it back to the room temperature. Depending upon the application of the temperature it may be classified as shallow cryogenic treatment (SCT), is to gradually cool the work piece at about – 84 °C and deep cryogenic treatment (DCT) is to cool the work piece at about -184 °C.

D. Das. A.K. Dutta et al. [1] explored the benefit of cryo-treatment process for achieving improvement in wear resistance of die/tool steel. They conducted a series of wear tests on AISI D2 steel samples subjected to cryo-treatment at -185 °C for different durations. The wear rates at different loads and sliding velocities, morphologies of the worn-out surfaces and the characteristics of the wear debris have been systematically examined to assess the possible critical duration of cryo-treatment to achieve the best wear resistance property. The wear experiments have been supplemented by detailed microstructural investigations with an emphasis to reveal the amount of retained austenite and the characteristics of the carbide particles apart from hardness evaluation.

Mahdi Koneshlou et al. [2] focuses their paper on the effects of low temperature (subzero) treatments on microstructure and mechanical properties of H13 hot work tool steel. SCT at -72 °C and DCT at -196 °C were applied and it was found that by applying the subzero treatments, the retained austenite was transformed to martensite. As the temperature was decreased more retained austenite was transformed to martensite and it also led to smaller and more uniform martensite laths distributed in the microstructure. The deep cryogenic treatment also resulted in precipitation of more uniform and very fine carbide particles. The microstructural modification resulted in a significant improvement on the mechanical properties of the H13 tool steel. Deep cryogenic process in case of carburized EN-19 alloy steel was conducted by R. Mohandoss [3]. Tensile strength of the material increased by 22.63 % in cryo-treatment and 7.94% increase in case carburized conditions respectively when compared to untreated material. But the material loses its ductility and becomes brittle which may not be suitable for handling impact loads.

The metallurgical investigation of cryogenic treated HSS tool was conducted by S. Sendooran et al. [4]. It showed that due to DCT the retained austenite structure was completely converted into martensite structure and hardness is improved by 17%. The process also promotes the precipitation of fine carbide particles in tool steels and steels with proper alloying metals. The fine carbides act as hard areas with a low coefficient of friction in the metal that greatly adds to the wear resistance of the metals. J.Y. Huang et al. [5] studied that cryogenic treatment has been claimed to improve wear resistance of certain steels and implemented in cutting tools, autos, barrels etc. Although it was confirmed that cryogenic treatment can improve the service life of tools. In their further studied they found that the microstructure of M2 tool steel changed before and after cryogenic treatment. Microstructure investigation indicates that cryogenic treatment can facilitate the formation of carbon clustering and increase the carbide density in the subsequent heat treatment, thus improving the wear resistance of steels.

Jagtar Singh et al. [6] found that as the temperature was decreased, more retained austenite was transformed to martensite and it also led to smaller and more uniform martensite laths distributed in the micro structure. Micro structural analysis is carried out by using optical emission microscope. Pin- On -Disc wear test was also applied and results showed that the wear resistance of the En45 spring steel was improved remarkably after cryogenic treatment. Cryogenic processing has been around for many years but is truly in its infancy when compared to heat-treating. For centuries the Swiss would take advantage of the extremely low temperatures of the Alps to improve the behavior of their steels [7]. Lakhwinder Pal Singh et al. [8] conducted studies to optimize cutting parameters using cryogenically treated high speed steel tool by Taguchi application. Three cutting parameters such as speed, feed rate and depth of cut are optimized with considerations of surface roughness. The microstructure has been found more refined and uniformly distributed after cryogenic treatment of HSS tool. Lakhwinder Pal Singh et al. [9] reported that CT HSS tools exhibit better performance based on tool wear, surface roughness of the work specimen, power consumption during operation than the UT HSS tools.

MATERIALS AND METHODS

Following methodology has been adopted to conduct the study

Chemical composition

The chemical composition of T-42 HSS is carried out at R & D Centre for Bi-Cycle and Sewing Machine, Ludhiana (India) presented in Table 1 for confirmation about the specification of the selected grade.

Table 1: Chemical composition of T-15 HSS in weight %

Carbon (C)	Chromium (Cr)	Molybdenum (Mo)	Tungsten (W)	Vanadium (V)	Cobalt (Co)
1.43	3.92	3.560	8.56	2.90	5.45

Cryogenic treatment

Cryogenic process is conducted using deep cryogenic processing. Deep cryogenic treatment is done using 12-24-12 cycle. The temperature of cryogenic chamber is ramp down from atmospheric temperature to -184°C in 12 hrs. The soaking period is 24 hrs. The temperature of cryogenic chamber is ramp up from -184°C to atmospheric temperature in another 12 hrs. In this way 12-24-12 cycle is complete, followed by tempering at 250°C for 3hour.

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X-Ray Diffractometer analysis and Microstructure testing.

The samples were studied for X-Ray Diffractometer (XRD) analysis, Microstructure and Optical Micrograph. XRD was conducted at IIT Ropar, Punjab, Microstructure test was conducted at R & D Centre for Bi-Cycle and Sewing Machne, Ludhiana, Punjab.

RESULTS AND DISCUSSION

The cryogenic treatment of HSS facilitates the formation of fine carbides in the structure. Microstructure is refined due to which it helps to increase the wear resistance.

X-Ray Diffractometer analysis, Scanning Electron Microscopy, Microstructure.

The samples were studied for X-Ray Diffractometer (XRD) analyses. Presence of austenite is inevitable in the UT HSS. The diffusion of carbon is sufficiently suppressed for hard martensite. The rate of cooling, cooling temperature and alloy composition will determine how much austenite will be 'retained' in the microstructure at room temperature. The presence of austenite has significant consequences in crucial metallurgical applications such as metal cutting. The X-Ray diffraction pattern (Fig. 1) showed that the presence of retained austenite in CT HSS has been found to be very less as compared to UT HSS specimen. During cryogenic treatment contraction in lattice of martensite and austenite took place. Due to super saturation martensite with carbon and thermodynamic instability, the carbon atoms squeezed out of martensite, migrated to the neighbouring lattice defects and acted as nucleation sites for the growth of fine carbides. After cryogenic treatment, fine precipitates of carbides were formed, with concurrent softening of martensite. The X-Ray diffraction pattern (Fig. 2) corresponding to CT HSS showed no traces of austenite.

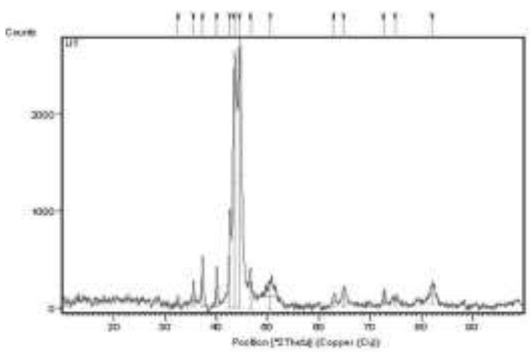

Fig. 1: XRD Graph for UT HSS

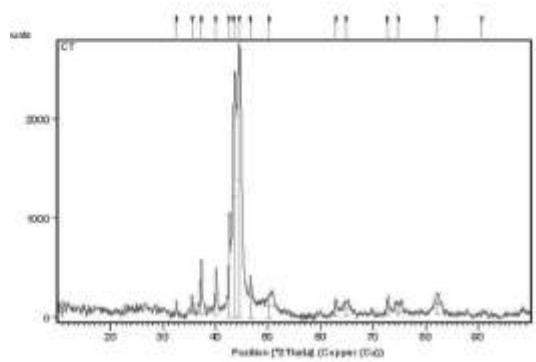

Fig. 2: XRD Graph for CT HSS

The microstructure analysis of the samples was carried out using metallurgical microscope at a magnification of 100X. There is a noticeable difference in the microstructure of UT and CT. Fig. 3 shows the microstructure of UT sample, which consists of grain boundaries and austenitic structure. Fig. 4 shows the microstructure of CT sample, there is refinement in the microstructure. Grains become refined in the structure and number of carbides precipitates increases after the treatment. Due to refinement of the structure the cryogenically treated samples shows better performance in terms of mechanical and wear properties of the material.

Fig. 3 Microstructure of Non-treated HSS T 15, S 400 tool at 100X

Fig. 4: Microstructure of Cryogenic-treated HSS T 15, S 400 tool at 100X

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Hardness Test

The Hardness of the test specimens was tested on Rockwell scale on Rockwell hardness tester at R & D Centre for Bi-Cycle and Sewing Machine, Ludhiana (India). It is observed that the hardness of UT and CT sample is 64 HRC and 67 HRC respectively. The CT sample has the higher hardness when compared with UT sample. These results indicate that hardness increases by cryogenic treatment. In the CT sample, the increase in hardness, attributed to more homogenized carbide distribution and higher carbide percentage.

CONCLUSIONS

1. The lower temperature (-184°C) leads to formation of a higher carbide concentration by the cryogenic treatment which results in increased wear resistance.
2. Microstructure shows that after the cryogenic treatment the microstructure of material is re- fined, retained austenite is completely converted in martensite and more number of secondary carbides precipitate on the surface. All these factors help to increase the wear resistance as well as other properties of material.
3. The CT sample has the higher hardness when compared to UT samples. This is due to precipi- tation of more no of carbides after the deep cryogenic treatment.

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