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Wear Resistance Enhancement of AISI D3 Tool Steels by Cryogenic Treatment: A Review

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Abstract - **The aim of this study is to reveal the enhancement of wear resistance of AISI D3 Tool Steel by Cryogenic Treatment. Cryogenic Treatment is often referred as Cryotreatment, is an add-on process to the conventional heat treatment. In the experimentation process, samples of AISI D3 tool steel were taken in batches out of which some samples were treated with conventional heat treatment (QT) whereas other were cryogenically treated (QCT) at 77 K for a period of 24 hrs. Dry sliding wear test were carried out on Pin on Disk machine. The input parameters are Load (N), and sliding velocity (V). Trials were performed in combination of above said parameters. Later on SEM was been carried on the worked samples so as to compare the microstructural changes between the conventional heat treated samples and cryogenically treated samples.**
Keywords: **Cryogenic, Cryogenic Treatment, Tool Steels**

I. INTRODUCTION

Cryogenic treatment is a post heat treatment process carried on various tool steels. The mass of products tool steels refers to variety of carbon and alloy steels that are particularly well-suited to be made into tools. Their suitability comes from their distinctive hardness, resistance to abrasion, their ability to hold a cutting edge, and their resistance to deformation at elevated temperatures (red-hardness). Various applications of Tool steels includes there use in cutting tools, punches, and other industrial tooling. Different tool steels are developed to resist wear at temperatures of forming and cutting applications.

Tool steels can be broadly divided into six categories like cold work, shock resisting, hot work, high speed, water hardening, plastic mold and special- purpose tool steels. Among the above listed tool steels, cold work steels are the most important category, as they are used for many types of tools, dies and other applications where high wear resistance and low cost are needed.

Tool steel is generally used in a heat treated state. Conventional heat treatment gives hardness as well as toughness, wear resistance and ductility to steel. But even after performing the conventional heat treatment properly, it cannot remove all of the retained austenite (large, unstable particles of carbon carbide) from steel. The retained austenite as it is a soft phase in steels could reduce the product life and in working tools. It can be transformed into martensite, but this new martensite is very brittle and differs from the tempered one, which is used in tools. Also this martensite causes micro cracks and reduces the product life. (A. D. Wale, *et. al*, 2013).

Regarding the problems mentioned above, the controlled transformation of retained austenite into martensite is essential for many components. In order to obtain this transformation cryogenic treatment is used. Most recent evidence shows that the wear resistance is further enhanced by virtue of cryogenic treatment at liquid nitrogen temperature. Most researchers believed that there are two mechanisms to improve the mechanical properties of the work that has been treated cryogenically. The first mechanism is attributed to the transformation of retained austenite to martensite. The second is to initiate the nucleation sites for precipitating a large number of fine carbides in to matrix of marten site. (Fanju Meng *et al*, 1994; Chai Hung Sun, 2006).

Cryogenic treatment is additional process to the conventional heat treatment of tool/die steel. It consist of controlled cooling of conventionally hardened steel specimens to selected cryogenic temperature (-50^{o} C to -196^{o} C) and holding there for selected period of time (i.e. 8 h to 75 h) followed by heating it back to the ambient temperature at a predetermined rate of subsequent tempering treatment. Various benefits of cryogenic treatment includes improved wear resistance, hardness, toughness, resistance to fatigue cracking, microstructure of metal (retained austenite to martensite). The greatest improvements in properties is obtained by selecting proper heat treatment process sequence, soaking time, hardening, tempering temperature and cooling rate.

II. LITERATURE SURVEY

Until the end of 1960's attempt made to perform CT with the results of cracking components. The cryogenic treatment system developed by Ed Busch in the late 1960s and later improved by Peter Paulin with a temperature feedback control on cooling and heating rates allows to perform effective and crackles. CT until very low temperatures subsequently, the research about CT has been validated during the 1980s by the development, computerized temperature control systems have been developed to get crackless cryogenic treated components to achieve maximum benefits.(P.I. Patil *et al*, 2012)

The increase in wear resistance of tool steels by CT with increasing holding time has been reported earlier. (Mohan Lal D *et al*, 2001; Collins *et al*, 1997; Yun *et al*, 1998). However, the results reveal, for the first time, that there exist a critical holding time in the CT of D2 steel for obtaining the best combination of desired microstructural and wear property of die/tool steels. Further they observed that the large number of SC's and their finer sizes are the key factors for the improvement in wear resistance in cryotreated specimens and in delineating the critical time of holding.

Baron and Mulharn (Barron *et al*, 1979) have studied the effect of soaking time on wear resistance of AISI-T8 steel. They observed drastic change during first few hours and then gradual small increase.

Mo-Cr HSS by cryoprocessing for 2 and 16 hr as soaking period and showed that the wear resistance is more in case of steel treated for 16 hr. (Jinyong *et al*, 2007). In two different studies it is shown that the soaking period is important to the final properties of the tool steels and soaking period of 20 hr is enough as the atoms in the material require time to diffuse to new location. (Barron *et al*, 1996; Dobbins *et al*, *1995)*. On the contrary, Kamody DJ in his patent asserts that the soaking period has no role in deciding the final condition of material being processed and a soaking period of 10 min was recommended to allow the material to achieve thermal equilibrium before it is removed and reheated. (Kamody DJ, 1993).

III. EXPERIMENTATION

AISI D3 Tool steel material is selected for studying enhancement of wear resistance of cryotreated tool steel as compared to conventional heat treated tool steels.

The chemical composition of the investigated AISI D3 Tool steel and its standard specifications are presented in table given below for the confirmation about the characteristics of the selected grade. Specimen Pins of diameter 10 mm and height 30-35 mm dimensions were subjected to conventional heat treatment and cryogenic heat treatment in separate batches. The details of the cryogenic processing in between hardening and tempering treatment are illustrated in Fig. 1. Cryogenic process was carried at 77 K, keeping soaking time as 24 h.

Microstructural examinations have been carried out using Scanning Electron Microscopy (SEM). The size, population density and interparticle spacing of small secondary carbides have been studied.

Amount of primary carbides (PCs, d_m>5μm) and secondary carbides (PCs, $d_m \leq 5$μm)

TABLE I NOMINAL COMPOSITION OF INVESTIGATED STEEL

Element	Actual % Wt	AISI Specification of D3 Tool Steel
C	2.12	2.10 – 2.30
Mn	0.31	0.20 – 0.40
Cr	11.60	11.50 – 12.50
Ni	0.07	0.50
V	0.21	0.20 – 1.00
Si	0.39	0.10 – 0.40

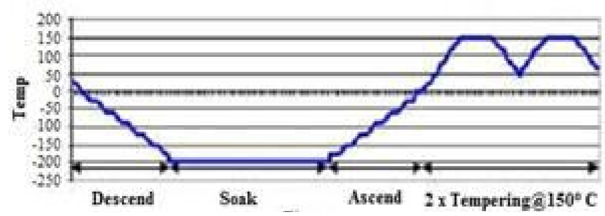

Fig.1 Deep cryogenic treatment followed between hardening and tempering

Dry Sliding wear test of pin specimens (Dia. 10 mm, Height 30-35 mm) against Alumina disc haven been done using a pin-on-disc machine following ASTM standard G99-05. Wear test have been carried out under varying normal load. F_N (24.52 – 98.1) uses various combinations of Sliding velocity and Speed of revolution keeping the sliding distance as constant. Average steady-state wear rate has been estimated considering at least three test results performed under identical conditions. Worn surfaces of specimens are examined under SEM to identity the wear mechanism.

IV. RESULT AND DISCUSSION

From the above graphs it is evident that there is increase in wear resistance of AISI D3 material after performing cryogenic treatment.

Figure 2 shows the variation of wear resistance with the variation in load conditions at a constant sliding velocity of 1m/s. Here it can be cleared observed that, there is increase in wear resistance due to cryogenic treatment.

The maximum increase in wear resistance obtained is 18.54% when the load is 49.6 N. whereas the minimum increase in wear resistance is 14.04% when the load is 24.5 N. It can also be observed that there is a variation in increase of wear resistance along with the variation in load. The average increase in the wear resistance obtained in graph 1 is 15.95%.

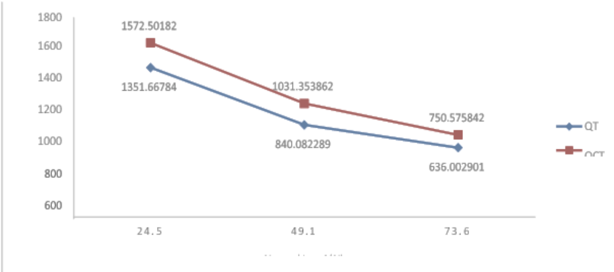

Fig. 2 Graph Showing variation of wear resistance along with variation of load at sliding velocity 1.0 m/s

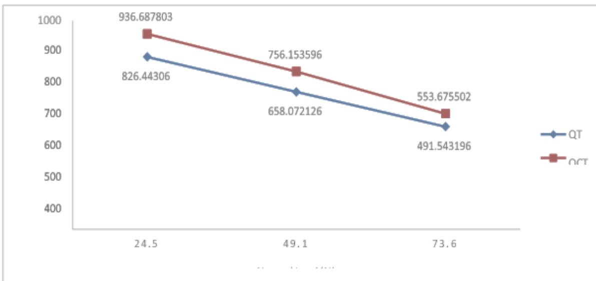

Fig. 3 Graph showing variation of wear resistance along with variation of load at sliding velocity 1.5 m/s

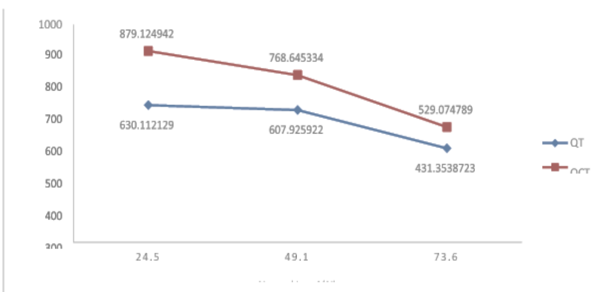

Fig. 4 Graph showing variation of wear resistance along with variation of load at sliding velocity 2.0 m/s

Figure 3 indicates the variation of wear resistance with the change in load conditions at a constant velocity of 1.5 m/s. Here it can be cleared observed that, the maximum increase in wear resistance is about 12.97 % at 49.1 N load. Whereas the minimum increase in wear resistance is 11.22% when the load is 73.6 N. Also the average increase for velocity 1.5 m/s and various load 24.5 N, 49.1 N and 73.6 N is about 11.98%. Figure 4 indicates the variation of wear resistance with the change in load conditions at a constant velocity of 2.0 m/s. Here it can be cleared observed that, the maximum increase in wear resistance is about 28.32 % when the load is 24.5 N. whereas the minimum increase in wear resistance is 18.47 % when the load is 73.6 N. Also it can be observed that the average increase in is around 22.56%.

V. CONCLUSION

It can be concluded from the result that, there is considerable increase in the wear resistance after performing cryogenic treatment. It is already being understood that, the increase in wear resistance after cryogenic treatment varies from few percent to few hundred percentage. Therefore depending upon the load conditions it should be decided whether the cryogenic treatment should be necessarily carried out or not.

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