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A Review on Effect of Cryogenic Treatment on Tool Steel

Neha S. Dixit[1], Vaibhav V. Khond[2], Prashant K Kavale[3]

[1]*Mechanical Engineering Department,*
[2]*Mechanical Engineering Department,*
[3]*Mechanical Engineering Department,*

Abstract*— Cryogenic treatment is used nowadays commonly in manufacturing various tools and instrument like forging dies. It is the type of material processing technology. Cryogenic treatment not only affects the surface of the component but it affects whole structure of component.Cryogenic treatment has been recognised that they can reduce the retained austenite and improve the performance of materials by improving its martensite structure also increase the formation of very small carbides, improving the general mechanical properties of the steels. This paper reviews cryogenic treatments involved in treating tool steel, effect of process parameters and their effect on properties.

***Keywords*— Cryogenic treatment, Tool steel, Austenite, Wear resistance, Fracture toughness**

I. INTRODUCTION

All metals may not possess desired properties in their final product. Manufactures are always interest in materials that are lighter and stronger to give highest productivity. Therefore selection of materials for cutting tools should be careful selection. Cutting tools must have following properties like:

- High resistance to brittle fracture
- Performance at elevated temperatures during high speed cutting operations
- Easily fabricated and Cost effective
- Resistance to thermal and mechanical shock

Tradition materials such as high speed steel continue to undergo improvement inproperties by modification in the compositions and processing techniques. As a result of thesetechnological advances the high speed steel is still surviving the competition from ceramicsand carbides. Surface treatments will change the surface of tool material also. Surface treatments commonly divided into two major categories i.e.

- Treatments that covers the surface
- Treatments that alters the surface

Cryogenic treatment is an inexpensive permanent treatment which follows the conventionalheat treatment cycle. It is found over research that the life span of the cutting tool is increased along withthe hardness and toughness by the cryogenic treatment.[1]

When the material is subjected to hest treatment the atomic structure may change due to movement to dislocations, increases or decreases in solubility of atoms, increase in grain size, formation of new grains, formation of new different phase and change in crystal structure etc.[2] Objectives of Heat Treatments are as follows:

- To increase wear resistance
- To increase strength and hardness
- To increase ductility and toughness
- To obtain fine grain size
- To improve machinability
- To remove internal stresses induced by non-uniform cooling from high temperature during casting and welding
- To improve machinability
- To improve cutting properties of tool
- To improve surface properties

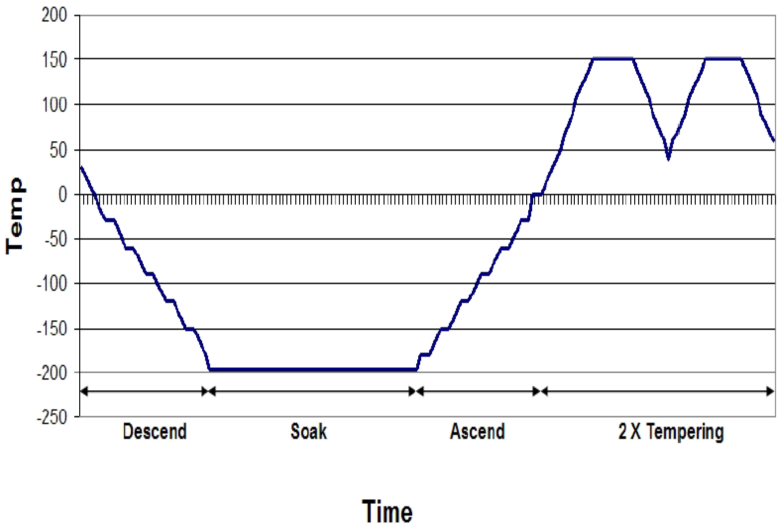

Fig.1DCT Cycle [3]

II. CRYOGENIC TREATMENT

A. *Basic of Cryogenic Treatment*

Cryogenic word is made of two Greek words i.e.: Kryo: which means very cold, frost and Genics: which means to produce. The cryogenic processing is modification of a material or component using cryogenic temperatures. Cryogenic processing makes changes to the crystal structure ofmaterials. In this technology product or specimen gets frozen at ultra-low temperature of -193^{0}C. Then that product or specimen is held at temperatures around -193^{0}C for 12-48 hours followed by gradual ascend and tempering.

This process consists of controlled cooling of conventionally hardened materials to a specified temperature followed by controlled heating of the materials back to the ambient temperature for subsequent tempering process.

Cryogenic treatment has been classified into shallow cryogenic treatment (SCT) anddeep cryogenic treatment (DCT) depending upon the temperatures:

- SCT: 193K for 5 h and then exposed to RT (room temperature)
- DCT: material is brought down to 77K at 1.26 K/min, held there for 24 h and brought back to RT at 0.63 K/min.

.Two different types of cryogenic solutions used for the cryogenic treatment of materials:

1. Liquid Nitrogen (-196^{0}C)
2. Liquid Helium (-269^{0}C)

Liquid nitrogen is generally used as it is cheaper than liquid helium and can be available easily.

B. *Process of Cryogenic Heat Treatment*

Fig. 2 Process flow of Cryogenic Treatment

- Austenization: In this process specimen is heated from room temperature to its austenizing temperature around 1100^{0}C, at slow rate ranging from 0.5 to 1.5^{0}C.
- Cooling: In this direct cooling of specimen from austenizing temperature to -196^{0}C at the rate 1.5 to 2^{0}C. It is also known as quenching.
- Soaking: For 24 to 36 hours soaking is done.
- Heating: From -196^{0}C to room temperature at rate of 0.5 to 1^{0}C/min
- Tempering: Tempering is important with ferrous metals. The cryogenic temperature will convert almost all retained austenite into primary martensite, which is brittle. To reduce the brittleness it is tempered back using the same tempering process as is used in a quench and temper cycle in heat treatment. Tempering temp is from 422K (149^{0}C) on up to 866K (593^{0}C), depending on the metal and required hardness. [1] [11] [12]

III. LITERATURE SURVEY

M. Perz, C. Rodriguez, F. J. Belzunce studied the specimens which were subjected to different quenched and tempered treatments i.e. TT1, TT2, TT3 and TT4. TT1 treatment contains the gas quenching and triple tempering, TT2 treatment contains gas quenching, cryogenic treatment (-196^0C during 12 hours) and triple tempering, TT3 treatment contains oil quenching and triple tempering while TT$ treatment contains oil quenching, cryogenic treatment (-196^0C) during 12 hour and triple tempering. The studied material was an H13 steel, typically that material used to make hot forging dies. After treatment the observed that fractures toughness effectively increases. TT2 and TT4 give respectively 22.5% and 24% increment related to their corresponding treatments without cryogenic phase, TT1 and TT3. They also observed that quenching media affects the toughness of steel due to effect of cooling rate. Oil quenching has higher toughness than the gas quenching. Quenched and tempered H13 steel has a martensitic microstructure with well dispersed and finely distributed carbides. Using Scanning Electron Microscopy (SEM) it is observed that cryogenics generate high internal stress state that activates the carbide nucleation in the first phases of tempering. This results in finer and evenly distributed precipitation which also gives rise to martensite with less carbon. [3]

Macros Perez, Fransisco Javier Belzunce carried out the deep cryogenic treatments on H13 steel. The discussed the effect of deep cryogenic treatments in the mechanical properties of an AISI H13 steel. Two different quenching media i.e. gas and oil and effects of cryogenic stages were studied. They concluded that tensile mechanical properties and hardness of an H13 steel were barely changed. Cryogenic treatment improved the fracture toughness of H13 steel. The quenching media also affected the fracture toughness of steel due to effect of cooling rate. They observed that toughness is increased due to the homogeneously dispersed carbide precipitation from cryogenic treatment. They states in conclusion that oil quenching also produced a higher residual stress state and lower retained austenite content at the end of the quenching phase compared to air or gas quenching because of the higher severity of the former medium.[4]

D. Das, K. K. Ray, A. K. Dutta studied the effect of the temperature of the treatment on the wear behaviour of AISI D2 steel.Specimens were studied under the conventional treatment, cold treatment, shallow cryogenic treatment and deep cryogenic treatment in separate batches. Conventional treatment consists of hardening and tempering while cold shallow cryogenic and deep cryogenic treatment consist additional step of controlled sub zero treatment with the lowest quenching temperature under 198, 148 and 77K respectively, was incorporated into the curing and quenching treatments. They concluded that, all types of sub-zero treatments improve the wear resistance of die steel. The obtained hardness of AISI D2 steel fir convention and deep cryogenic treatments are 759 and 791 VHN, respectively and typical values of their specific wear rate are $1.03*10^{-6}$ and $8.26*10^{-9}$ $mm^3N^{-1}mm^{-1}$. Also, obtained results lead to the conclusion that lowers the temperature of sub zero treatment higher is the improvement in wear resistance. [5]

Mahdi Koneshlou, KavehMeshinchiAsl, FarzadKhomamizadeh studied the effect of cryogenic treatment in microstructure, mechanical and wear behaviours of AISI H13 hot work tool steel. They concluded that deep cryogenic treatment may help to achieve more durable tool steel parts. Due to sub zero treatments, retained austenite was transformed to martensite.Cryogenic treatment at very low temperature and holding sample for more time resuts into in the precipitation of more uniform and vary fine carbide particles.. Cryogenic treatment results into improving the wear properties of H13 tool steel. [6]

S. T. Dhande, V. A. Kane, M. M. Dhobe, and C. L. Gogte studied the influence of soaking periods in cryogenic treatment of tungsten carbide. Based on results obtained they concluded that cryogenic treatment significant reduction in weight loss f WC-CO tools at 8 hour soaking period by 67%. They observed that due to refinement of the structure, formation of stable structure and proper alignment of particles which improves the wear characteristics. [7]

IV. EFFECTS OF CRYOGENIC TREATMENT

Cryogenic treatment results in significant amount of retained austenite which has some damagingeffects on mechanical properties of tool steels such as machinability, wear, hardness and mostimportant of all on dimensional stability of tool steels. Cryogenic treatment increases the fracture toughness which will be the positive effect for tool steel to make forging dies. When specimen is treated under treatment TT4 i.e. oil quenching, cryogenic treatment at -196^0C during 12 hour and triple tempering higher fracture toughness is observed. SEM analysis focused on the starting zone of fracture growth from fatigue pre-crack is reported as shown in fig.

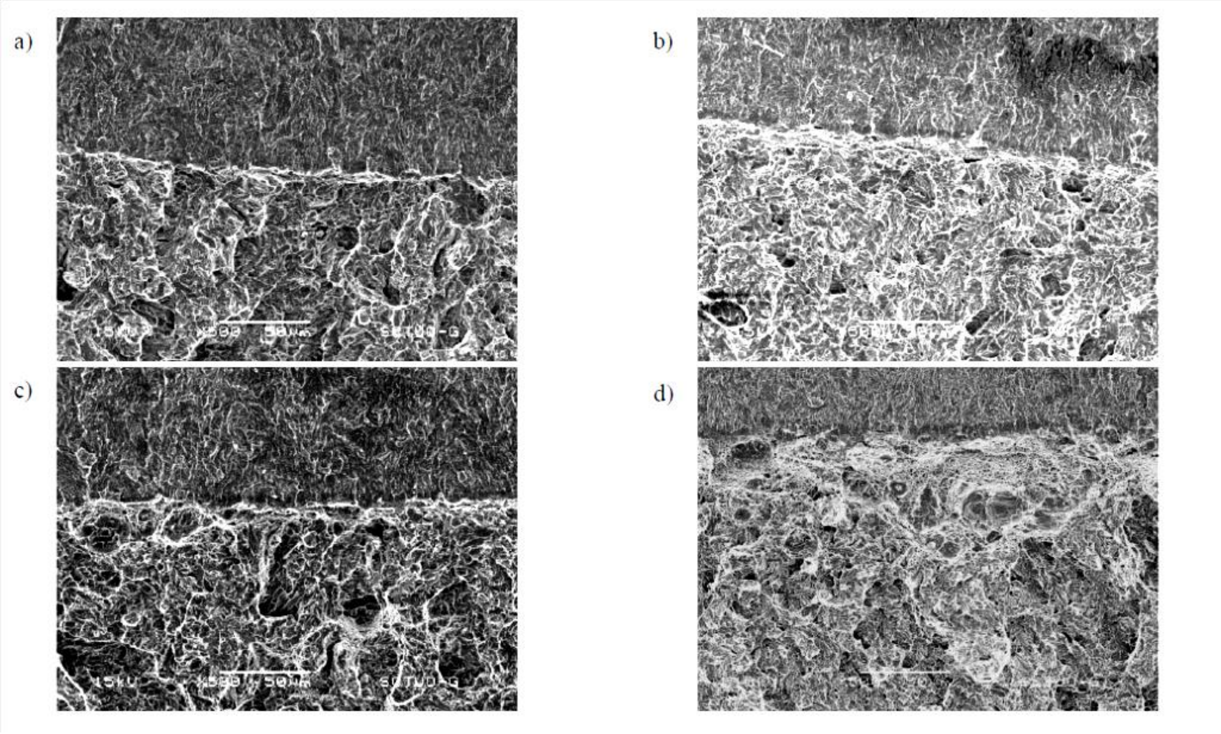

Fig. 3 General view at 500x of the crack growth from the pre-crack a) TT1, b) TT2, c) TT3 and d)TT4 [4]

From the fracture pattern it is observed that existence of ductile micro mechanisms i.e. nucleation, growth and coalescence of micro activities just at the beginning of the crack growth. The initial crack blunted, generating a plastic zone in the crack front before the complete breakage of the specimen. [4]

Due to cryogenic treatments, there is modification in carbide distribution pattern, due to this there is positive effect on hardness, mechanical strength, fracture toughness and structure homogeneity. The maintenance at -196^{0}C gives rise to a fine modulated structure with carbon enriched regions and structural defects. This structure leads to a finer and more homogeneous carbide precipitation during the tempering phase and to an increase in the volume fraction of nanocarbides. [8][9][10]

Cryogenic treatment results in precipitation of very fine and more uniform distribution of carbide particles in microstructure after tempering. Increase in volume percentage of carbides is probably due to transforming of retained austenite to martensite which leads to more precipitation of carbides during tempering. The carbides also appear to be more spherical in deep cryogenically treated sample.

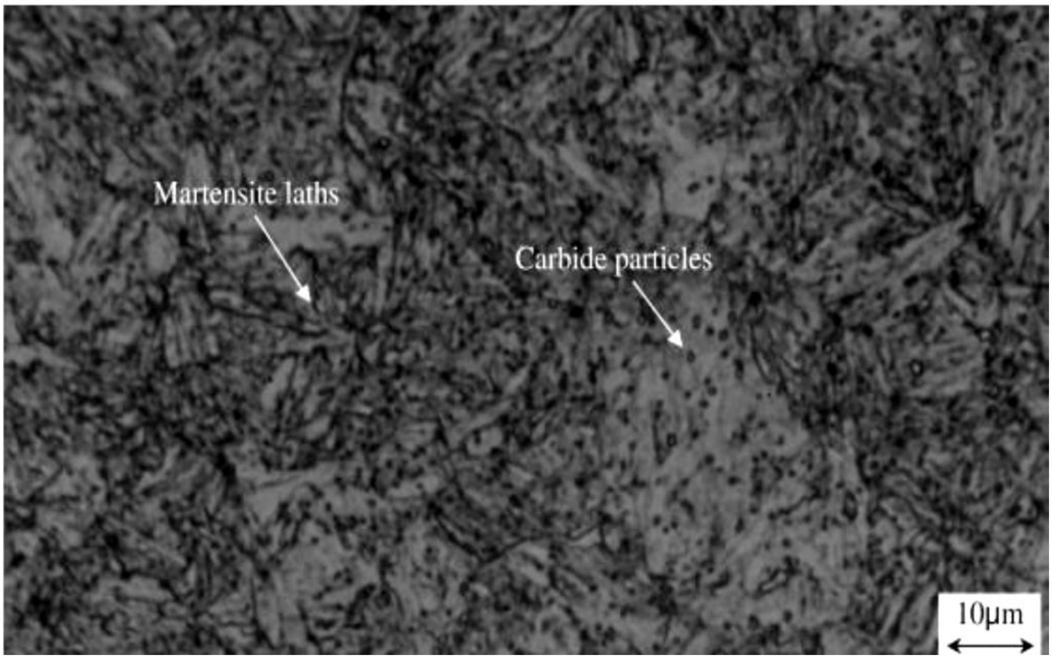

*Fig.4*SEM images showing *microstructure of the alloy andled to transformation of retained austenite to martensite carbides distribution [6]*

Dur to application of cryogenic treatment, formation of finer martensite laths in microstructure initiates nucleation sites for precipitation of fine carbide particles which results in the enhancement of mechanical properties. The most important effect of tempering deep cryogenically treated samples was improving wear properties of alloy better distribution of martensite laths along with more uniform and finer distribution of carbides results in increase in wear properties. Due to smaller and more uniform distribution of carbides there is prevention of growth formation of cracks due to strengthening of microstructure.

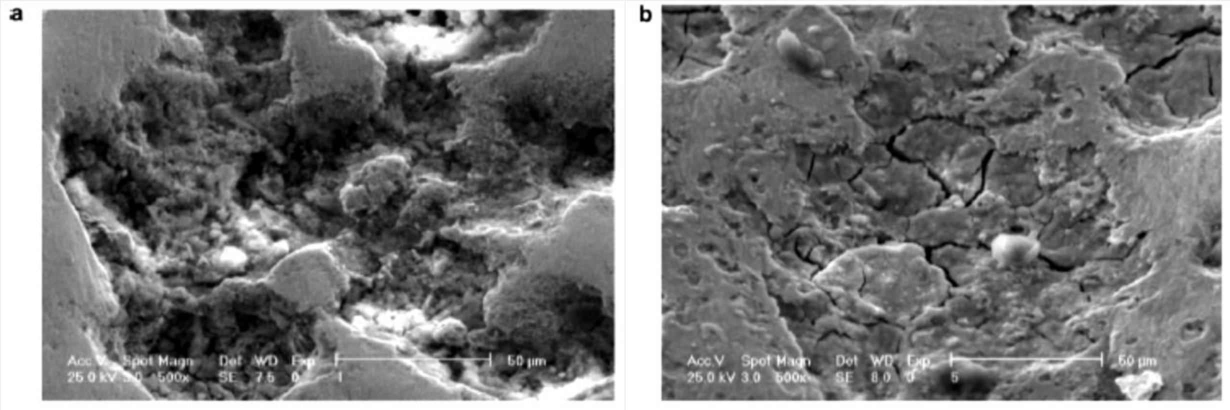

Fig.5 SEM images showing worn surface alloy (a) and (b) after 100 hours. [6]

From images we can say that cracks grow faster in the alloy without any sub-zero treatments. After deep cryogenic treatment, although cracks are formed, the crack propagation rate is much slower compared to non-cryogenically treated sample.

V. CONCLUSION

From literature survey and previous work done by the researchers, following summaries have been made from literature surveys:

- Cryogenic treatment increases the hardness, strength, wear resistance, fracture toughness, dimensional stability and also improve fine grain size of tool steel.
- Due to cryogenic treatment retained austenite is converted into the martensite. This conversion of retain austenite into martensite in tool steel improve the properties of tool life.
- Refinement of carbides is more in case of cryogenically treated HSS tools in comparison to that of untreated tools.
- Wear properties of tool steel is improved as the effect of tempering the deep cryogenic treatment.
- Deep cryogenic treatment dependent on the parameters like, austenite temperature, soaking temperature, soaking period, rate of cooling, tempering temperature, tempering period, quenching media.

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