Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 7 Issue 05, May-2018

Cryogenic Treatment on Alloy Steels- A Review

Prabaharan.T
Senior Professor,
Department of Mechanical Engineering,
Mepco Schlenk Engineering college,
Sivakasi, Tamil Nadu, India

Karthik Pandiyan.G
Assistant Professor,
Department of Mechanical Engineering,
Sri Vidya College of Engineering and Technology,
Virudhunagar, Tamil Nadu, India

Abstract **- This paper studies the effect of cryogenic treatment on High Speed Steel(HSS) tool steels. Cryogenic treatment (CT) is the heat treatment process, it converts the austenite into martensite by which the materials to improve mechanical and physical properties to achieve increase in hardness, increase in wear resistance, reduced residual stresses, increase in fatigue Resistance, increased dimensional stability, increased thermal conductivity, toughness and homogeneous crystal structure on materials. The CT on cutting materials is the process of treating the cutting metal to the sub-zero temperature to improve the physical and the mechanical properties of the cutting tool. Many researchers have proposed various techniques to improve the lifetime of the cutting material. The motivation behind this paper is to compare the various techniques that are used in the treatment of the cutting tools and the selection of the best technique from the existing or by the modification to them. This paper aims to review about cryogenic treatment involved in various steels for the past few decades.**

Keywords - Austenite to Martensite; Cryogenic Treatment; Cutting Tool; Hardness; Life Time; Wear Resistance

I. INTRODUCTION

The cutting of the metal in the process of manufacturing of any material is an indivisible part. The cutting tool is also an important material that plays a major role in the manufacturing. The lifetime of this cutting tool is a major factor that has to be considered. Many techniques are used in the existing process to increase the lifetime of the cutting tool but this extends the lifetime of the tool up to certain extend. The cutting tool that is selected has to be used for cutting various materials under various conditions. In the conventional cutting process, the excessive heat is produced during the chip formation process; this increases the temperature of cutting tool and accelerates tool wear. To reduce the heat that is generated the cutting fluid is used. This is used to the cool the cutting tool and to lubricate the process thus by increasing the lifetime of the tool. Many techniques were suggested in alternate to the conventional heat treatment process in steels.

In Conventional heat treatment, the material is subjected to heat. The atomic structure microstructure may change due to movement or dislocations, increases or decrease in solubility of atoms, increase in grain size, formation of new grains, formation of new different phase and change in crystal structure etc. Conventional heat treatment include annealing, normalizing, quenching, tempering etc., These process are used to increase the hardness of the material by converting the austenite to martensite structure to improve hardness which increases the wear resistance of the material. The main problem in conventional heat treatment is that all the austenite is not converted into martensite. Figure 1 shows the representation of the conventional heat treatment process.

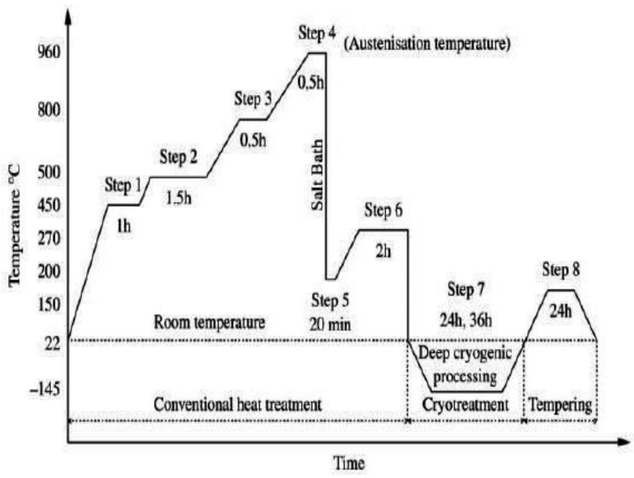

Fig 1 Schematic presentation of the heat treatment

In conventional high speed machining processes excessive heat is generated during the chip formation process, which increases the temperature of cutting tool and accelerates tool wear. In Conventional process of machining, cutting fluid is used to cool and lubricate cutting process. It does not facilitate longer tool life, higher cutting speed, better work surface, less built up edge, easier chip breaking and lower production cost. To rectify this problem cryogenic treatment of metals is carried on to achieve tool life productivity. In Cryogenic temperatures, tool materials get harder and stronger. Cryogenic cooling reduces the tool face temperature, enhances its hardness. The lubrication effect reduces friction and tool wear. Cryogenic machining eliminates the built up edge problem on tools because cold temperature.

Cryogenic treatment (CT) is supplement for the conventional heat treatment process in which materials are subjected to very low temperatures, sub-zero temperatures to enhance mechanical properties and to achieve improved wear resistance, reduced residual stress, increase in

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 7 Issue 05, May-2018

hardness, dimensional stability, fatigue resistance, toughness by transformation of austenite in to martensite. Cryogenic treatment is a onetime permanent process.

Cryogenic treatment is divided into two types

1. Deep cryogenic treatment (DCT) (-196ºc).
2. Shallow cryogenic treatment (SCT) (-80ºc).

Deep cryogenic treatment (DCT) is a onetime permanent process, in which the material is slowly cooled down to the cryogenic temperature and held at that temperature for a specified period of time and is heated back to room temperature. The main advantage of DCT is to enhance the wear resistance.

Shallow cryogenic treatment (SCT) (-80°C) is performed on carburized specimen in order to improvethe Mechanical properties like tensile, hardness, wear. This is due to transformation of some amount of retained austenite to martensite.

A. Cryogenic Treatment Process

Cryogenic treatment involves the following sequence:

1. Slow cooling to predetermined low temperature
2. Soaking for predetermined amount of time
3. Slow heating to room temperature
4. Tempering

Cryogenic heat treating is a process where the material is cooled to approximately −185 °C(−301 °F), usually using liquid nitrogen. In Cryogenic treatment the material is subjected to deep freeze temperatures as low as -185°C (-301°F), but usually -75°C (-103°F) is sufficient. The transformation of retained austenite into martensite improves the tensile strength and hardness of the material.

The wear resistance and toughness of the alloy steels have been improved by the cryogenic treatment. Cryogenic processing is alternate process to the conventional heat treatment process in steels. The cryogenic freezing treatment increases the life of tools, equipment, parts and materials by boosting tensile strength, toughness and stability. Due to cryogenic treatment of materials microstructure and properties (hardness, toughness and the content of retained austenite) are found to be improved. Cryogenic treatment has been identified to enhance the properties of Tools steels and improvement in tool life.

B. Cryogenic Machining Approach

From the papers reviewed, the cryogenic properties of workpiece materials and tool materials were studied. From this studies concluded that it is not desirable to cool the work piece for three reasons.

1. Metals tend to increase in hardness and strength at cryogenic temperature
2. Exposing the work piece to low temperatures may increase the abrasion to the cutting tool.
3. Dimensional accuracy and distortion reduction in grain size and structure.

At cryogenic temperatures, the tool will get harder and stronger. Impact testing shows that the tool materials do not noticeably change in brittleness, nor do they fracture more easily and the cutting tools, or work piece materials, to be cooled.

The cryogenic machining approach has following concepts.

1. Cryogenic fluid is applied directly to, and only to, the very tip of the cutting tool, where the material is being cut and heat is being generated.
2. The work piece will maintain constant temperature and not subjected to dimensional inaccuracy and geometrical distortion due to the flow rate of the cryogenic treatment on tool material.

II. LITERATURE SURVEY

Das, D.et al [5] examined the micro structure of the AISI D2 steel to achieve wear, hardness by treating the sample deep cryogenically at 77K for different soaking durations from 0 – 132 hours. The soaking time of the sample is varied. Then the samples are tested to find the wear resistance of the samples. The samples which are treated for 36h produces the best wear resistance. The results are obtained are based on the microstructural features, hardness values etc. The obtained results from the figure shows that there is increase in the soaking time of the tool increases the wear resistance of the tool.

Patil N et al [16]compared the cryogenic treated tool with the untreated tool. The HSS is used as the cutting tool. For the cryogenic process the liquid nitrogen is passed through a heat exchanger. The cooled gas obtained as the output is diffused inside the chamber by the fan. The samples and the nitrogen do not have the contact. This showed an increase in life of the cryogenically treated tool by 19.2% than the untreated tool. The figure 2 shows the comparisons of the life of the treated HSS and the untreated HSS.

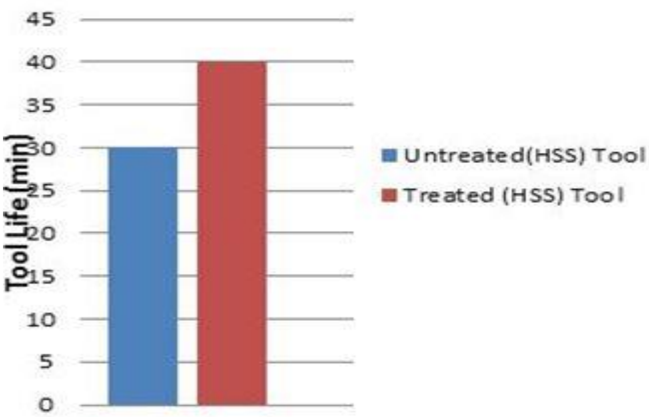

Fig 2 Comparison of Tool Life

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 7 Issue 05, May-2018

Lal, D et al[13] analyse the cryogenic treatment on standard rod and there is some increase of lifetime of the tool. The standard bar/rod is taken as the tool and the samples required number of samples are taken. Some of the samples were quenched, tempered and then cryogenically treated. Some of the samples were directly treated cryogenically and some were coated with TiN and then treated cryogenically. Then the wear resistance of the samples were identified. The observed results shows that the samples that are quenched, tempered and cryogenically treated has the higher resistance and the samples that are coated with TiN has the lower resistance. The TiN coating in combination with cryo-treatment provides 45% increase in the life of the tool.

Suchmann, P et al [18] conducted experiment on H11 hot working on tool steel. Deep Cryogenic Treatment (DCT) on the H11 hot working on tool steel to achieve wear and microstructure was studied. The specimens of the X37CrMoV5-1 steel are used as the specimen. For each schedule two specimens were prepared. The specimens used are heated and double tempered, and cryogenically treatment for 6 hours, 12 hours and 20 hours and tempered. The first specimen is used for the testing of wear resistance and the second specimen is used microstructural observations under the Transmission Electron Microscopy (TEM). The wear resistance, tensile test and the TEM observations were made for each specimen. The result showed that there is increase in the wear resistance at high temperature. Final results exhibit that cryogenic treatment of the X37CrMoV5-1 (H11) steel improves the resistance to wear at high temperatures.

Table I. Samples with their Treating Schedule

S.No	Specimen Designation	Heat Treating Schedule
1	(H+2T)	Heating to 1030°C, quenching in oil, double tempering (610°C)
2	(H+6C+2T)	Heating to 1030 °C, quenching in oil, deep freezing at -160°C for 6h, double tempering (610°C)
3	(H+12C+2T)	Heating to 1030°C, quenching in oil, deep freezing at -160°C for 12h, double tempering (610°C)
4	(H+20C+2T)	Heating to 1030°C, quenching in oil, deep freezing at -160°C for 20h, double tempering (610°C)

Akhbarizadeh, A. et al [1], investigated the grain size of the austenite after the deep cryogenic treatment for the D6 tool steel is identified. The wear resistance of the steel is identified by the pin-on-disk wear machine. The three samples of D6 tool steel rod with some composition of the materials are taken. To compare the effect of the wear behaviour, the samples were deep cryogenically treated. The samples were austenized in 975ºC for different times such as 10, 20 and 50 minutes. Then the samples were cooled to -63ºC followed by the nitrogen soaking for 10 hours. The samples were then heated to room temperature at the rate of 15-20 ºC/hr. The cryogenically treated and non-cryogenically treated samples were compared. The wear resistance of the sample were measured using the XRD. The deep cryogenic treatment improves the wear rate of the D6 steel tool than the non-cryogenically treated samples.

Gill, S. et al [7], observed the result of the cryogenic treatment on the M2 HSS tool. The samples of the tools were taken and are shallow and deeply treated cryogenically. This shows that there is significant increase in the lifetime of the tool when it is deeply treated. There is an increase of 50% in the lifetime when it is deeply treated and there is 35% increase in the lifetime when it is shallow cryogenic treated. Also the sample which is deeply cryogenically treated tool of M2 HSS is more consistent in the manufacturing process than the shallow cryogenically treated and the sample which is traditionally heated.

Chaudhari, Bet al [4], conducted experiment on tool steels to achieve the wear resistance and the hardness value of the tool has increase due to the cryoprocessing. The increase in the wear resistance is due to the effect of the conversion of the austenite to martensite and the precipitation of η-carbides in the steel. For the carbide cutting tool that is used the improvement in the wear resistance is due to the effect of the increased number of of η phase particles and also increase in the bounding strength of binders used. The wear rate of the AISI M2 HSS is decreased when it is treated cryogenically when compared with the conventional methods. The deep cryogenic treatment increases the wear rate than the shallow cryogenic treatment.

Khandekar, S. et al [12], an experiment has madeand the performance of dry machining to the machining with the conventional and nano cutting fluidswas analyzed. The 1% of the Al2O3 nano particle that is added to the conventional cutting fluid enhances the wettability characteristics of the tool than the conventional fluid and the pure water. The decrease in the crater and flank wear has enhanced the thermal properties, wettability and the lubricating characteristics of the nano cutting fluid. This causes the cutting force to be reduced to 50% and 30% when machining with the nano cutting fluids to the dry machining and machining with the conventional cutting fluid. This also reduced the Ra value of the machined value to 54.5% and 28.5% when nano cutting fluid is used compared to dry machining and machining with conventional cutting fluid.

Dhananchezian, M.,et al[6],analyse that cryogenic machining on AISI 1045 steel and aluminium 6061-T6 alloy was used as the samples. They carried out tests on orthogonal cutting of the sample tools under the dry and cryogenic conditions. The results obtained shows that the cutting temperature is reduced to 19 to 40% by the cryogenic cooling depending upon the level of parameters for process and the material used. The cutting force has also been increased by 15% to 10% by the cryogenic cooling for the machining of AISI 1045 steel and Aluminium 6061 – T6 alloy. The thickness of the chip has reduced up to 25% by the cryogenic machining with the liquid nitrogen jet than dry machining and the shear angle also increased up to 30%. The AISI 1045 steel and Aluminium 6061 – T6 taken as the sample has produced better result using the cryogenic machining than the dry machining.

Yildiz, Y et al [21],Electric Discharge Machining (EDM) method taken into an account for achieving the surface roughness. Be-Cu alloy is used as the work piece. The work piece is cryogenically treated to 88K and is again cooled to 172K. The effect of the treatment is measured using the Electric Discharge Machining (EDM).

There is about 20 to 30% increase in the material removal rate by the cold and the cryogenic treatment. There variations in the electrode wear rate, surface roughness and the average white layer thickness found to be marginal.

Venses, G., et al[20], the optimization of the deep cryogenic treatment process parameters for the improvement of wear resistance of 100Cr6 bearing steel using Taguchi technique was analysed. The parameters considered for optimization are cooling rate, soaking temperature, soaking time and tempering temperature with the target of achieving increased wear resistance. The experiment uses the 100Cr6 Bearing steel material soaked at temperatures of approximately -130°C,-150°C and -185°C for a period of 16,24, 36 and 48 hrs.The samples were tempered at 150°C, 200°C and 250°C. The optimum parameters for 100Cr6 bearing steel to be the attained at the cooling rate of 1.5ºC/min, soaking temperature of -150ºC, soaking period of 48hrs and tempering temperature of 150ºC, based on the Taguchi technique, achieved the maximum wear resistance and minimum wear loss.

Uygur, I et al [19], conduced experiment on cryogenic Treated alloy of AISI D3 Steel was studied. The alloy AISI D3 is a high-carbon, high-chromium steel used for various applications which are having high resistance to wear, pressure and abrasion. The uncoated AISI D3 steel used conventionally heat treated are compared with 24 h cryogenically treated samples and 36 hours cryogenically treated and 2 hours tempered at 150 °C. Due to uniform carbide distribution a higher carbide percentage are obtained, and the corrosion behaviour enhanced at 36hours of cryogenic treated samples, the corrosion resistance has been improved in the carbide percentage by 3% with uniform carbide distribution. Cryogenic treatment causes the formation of martensite, which can improve the mechanical properties and also reduce the good resistance to corrosion. In steels, martensite is more susceptible to corrosion than austenite. The results exhibits better performance as more corrosion resistance on treatment conditions in 3.5% NaCl which corrosion resistance are attained at cryogenically treated samples at 36 hours with 2 hours tempered samples than 24 hours treated samples.

Kaushal, A. et al [11], studied the cryogenic treatment on AISI-D2 Tool steel. The samples were cryogenically treated at -196ºc for 24 hours. After the cryogenic treatment on the AISI-D2 steel materials, the carbon bonding of the carbon atoms are very close to iron atoms. Thus they give strong Bonding characteristics to the steel. The material structure gets changed from austenite to martensite and achieves hardness from 810 h.vto 827 h.v

Liu, S.T et al [14] studied micro structure of The cryogenic treatment on Die steel. First of all the microstructure was analysed after quenching process or quenching tempering process. Then carbides content of retained austenite, surface hardness, mechanical properties and wear resistance ability of die steels are studied. Cryogenic treatment increased the hardness up to 10 - 14 HRC. The results exhibits that the cryogenic treatment reduces the volume of microstructure austenite to martensite to improve the size stability and wear resistance ability. Thus this improves the life of the die steels.

Idayan, A et al [9], compared the cryogenically treated tools with conventional heat treatment. cryogenic treatment on AISI440C bearing steel is compared to the conventional heat treatment and effect of cryogenic treatment on the mechanical Properties of AISI 440C Bearing Steel was studied. Cryogenically treated samples show improved properties then heat treated samples and hardness of the sample is improved by 7% when subjected to deep cryogenic treatment and by 4% when subjected to Shallow Cryogenic Treatment compared to heat treated samples. Final results show that deep cryogenic treatment having the higher reduction in austenite structure with higher hardness than Shallow Cryogenic Treatment.

Baldissera, P et al [2], studied and compared the DCT with tempered hardening. The cryogenic treatment on 18NiCrMo5 carburized steel was studied and focuses on the comparison between deep cryogenic treatment and tempering performed by conventional hardening. There is increase in hardness from +0.6 HRC to +2.4 HRC for all the cryo treated carburized steel and there is enhancement of the tensile strength up to 11%. The result shows the hardness of the 18NiCrMo5 steel has been increased by the deep cryogenic treatment. The hardness enhancement is greater than that of hardening steels and the final tempering. The pre-tempering on deep cryogenic treatment increases the hardness up to 2.4 HRC. The final result shows that the hardness of 18NiCrMo5 carburized steel increases with increases hardness by cryogenic treatment.

He Y et al [8], studied the strengthening and toughening of the 2800-Mpa grade maraging steel. Cryogenic treatment on 2800-MPa grade maraging steel is made to achieve strength and toughness at 200 K. This transforms into a low-carbon martensite structure without retaining austenite. A complete transformation to martensite structure steel is achieved by increase of hardness. The strength of the material is 2700 MPa due to the removal of the retained austenite by Cryogenic treatment before aging. The hardness increased fracture toughness remained at a high level, greater than 30 MPa. The final results shows that the strength of the material is 2700MPa and toughness is 30MPa due to cryogenic treatment.

Zhirafar et al [22], cryogenic treatment on AISI 4340 steel was studied and focused on the mechanical properties of steels. Cryogenic treatment samples are compared with conventional hardening samples. First, all conventional hardened materials are austenized followed by oil quenching. Then tempering was carried out at temperatures of 200, 300, and 450ºC respectively. Cryogenic treatment of sample material followed by slow cooling by oil-quenched at a temperature of −196ºC and holding at this low temperature for 24 hours in the room temperature. Due to cryogenic treatment of steels the austenite structure is converted into martensite structure. The austenite percentage decreased from 5.7 to 4.2% due to cryogenic treatment. This achieved higher level of hardness compared to the conventional heat treatment. Finally, the result shows that the cryogenic treated samples produced an increase in hardness by 2.4% and reduction on the toughness to 14.3%.

III. CONCLUSION

The lifetime of the cutting tool is an important factor that has to be considered during the manufacturing process. The review of the selected papers shows that the hardness of the cutting material has been increased by using the cryogenic treatment and improves the mechanical properties of the materials such as wear resistance, hardness, stability etc.,

The conclusion of the effect of cryogenic treatment on tool steel from the in depth review of literature as follows:

- Hardness of the Cryogenic treated alloy steel materials is increased than conventionally heat treated alloy steel materials due to the transformation of austenite structure to into martensite structure.
- Tool life of cryogenically-treated tool steels and die steels is improved as compared to the conventional heated treated alloy tool steels.
- Deep cryogenic treatment is mostly preferred than shallow cryogenic treatment because of lower deep freezing temperatures which improved wear resistances, increased hardness, dimensional stability and precipitation of ultrafine carbides.
- Cryogenic treatment of tool steel achieve increase in wear resistance of tool steel and tool life as compared to conventionally treatment of tool steel for different applications like turning, drilling and milling.
- Cryogenic treatment on tool steel is soaking temperature and its optimum value is around -175 ºC to -196 ºC.
- Cryogenic treatment provides improvement of tensile toughness and fracture toughness of tool steel.

Cryogenic treated case carburized or hardened tempered alloy steel provides improvement of mechanical properties like impact strength, wear resistance, dimensional stability and corrosion resistance.

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