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A REVIEW ON "EFFECT OF DEEP CRYOGENIC AND SHALLOW CRYOGENIC HEAT TREATMENT"ON MICRO HARDNESS AND WEAR RESISTANCE OF DIFFERENT STEELS"

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Abstract-Cryogenic treatment (CT) is the process of submitting the materials to deep cryogenic temperatures (below 120K) following predetermined time-temperature curves in order to enhance some of their the mechanical ,physical or structural properties.Various mechanical components such as ball bearings, bushes, tools, cam and follower that undergo sliding or rolling contact are subjecedt to some degree of wear. So wear is a serious problem while studying the failure of components. Different approaches have been applied by various researchers to control wear by different thermal coating methods and cryogenic heat treatments. It was found that after cryogenic heat treatment there is an increase in hardness, increase in wear resistance, reduced residual stresses, toughness due to transformation of retained austenite to martensite, and by eta-carbide formation. This paper aims at the study of various approaches used in Cryogenic Heat treatment processes and their effects on properties of different types of steels.

Keywords: Cryogenic heat treatment, deep cryogenic, shallow cryogenic, wear, micro hardness.

1. INTRODUCTION

The word Cryogenics is derived from the Greek words 'Kryos" (meaning cold) and "Genes" (meaning born). The cryogenic processing is modification of a material or component using cryogenic temperatures. Cryogenic temperatures are defined by the Cryogenic Society of America as being temperatures below 120K (-244°F, -153°C). Cryogenic processing makes changes to the crystal structure of materials. The major results of these changes are to enhance the abrasion resistance and fatigue resistance of the materials[15].

In Ferrous metals, cryogenic processing converts retained austenite to martensite and promotes the precipitation of very fine carbides. Fine carbon carbides and resultant tight lattice structures are precipitated from cryogenic treatment. These particles are responsible for the exceptional wear characteristics imparted by the process, due to a denser molecular structure; reducing friction, heat, and wear. Cryogenic Processing is not a coating. It affects the entire volume of the material. It works synergistically with coatings. Furthermore, the cost of cryogenic treatment is said to be less than the cost of coating, which is currently a popular method for improving tool life. Cryogenic Processing has a great effect on High Speed Steel cutting tools. The normal result is that the tools will last considerably longer, typically 2 to 3 times longer. Cryogenic processing establishes a very stable piece of metal that remains distortion free [17].

Figure-[1.3] Multistage cryogenic processor[20]

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2. TYPES OF CRYOGENIC HEAT TREATMENT:

2.1 Shallow Cryogenic Treatment (SCT):

It is a type of cryogenic treatment in which the material is cooled at a temperature range of -80°c to enhance the properties of material.The effect of this treatment is very significant. At this temperature the transformation of the retained austenite into martensite starts[8].

2.2 Deep Cryogenic Treatment (DCT):

Similar to shallow cryogenic treatment, deep cryogenic treatment is also a supplementary process to conventional heat treatment[8]. In deep cryogenic heat treatment, the samples are slowly cooled to -196 °C, held-down for many hours and gradually warmed to room temperature[47].

2.3 Wear and its types:

Wear is related to interactions between surfaces and specifically the removal and deformation of material on a surface as a result of mechanical action of the opposite surface[50].

- Adhesive wear
- Abrasive wear

2.3.1 Adhesive Wear:

Adhesive wear can be found between surfaces during frictional contact and generally refers to unwanted displacement and attachment of wear debris and material compounds from one surface to another[50].

2.3.2 Abrasive wear:

Abrasive wear occurs when a hard rough surface slides across a softer surface. ASTM International (formerly American Society for Testing and Materials) defines it as the loss of material due to hard particles or hard protuberances that are forced against and move along a solid surface[50].

3. PROCESS OF CRYOGENIC HEAT TREATMENT:

Cryogenic treatments basically consist in submitting the materials to deep cryogenic temperatures (below 120K) following predetermined time-temperature curves in order to enhance some of their physical or structural properties.

According to the previous definition, it must be noticed that the subzero processes (at about -80 ºC) that are used in many traditional heat treating facilities to reduce the austenite content in some tool steels cannot be considered cryogenic treatments[5].

3.1.Cryogenic temperatures

Cryogenics, the term is used today as a synonym for the low temperature state. It is not well defined at what point on the temperature scale refrigeration ends and cryogenics begins; although, the workers at the national institute of standards and technology at boulder, Colorado have chosen to consider the field of cryogenics as that involving temperatures below -150°C (i.e.123°K).This is the logical dividing line since the normal boiling points of the so called permanent gases(as helium, hydrogen neon nitrogen, oxygen and normal air)lie below -150°C while Freon refrigerants like hydrogen sulphide and other common refrigerants have their boiling points above -150°C.At such cryogenic temperatures, many materials behave in ways unfamiliar under ordinary conditions. Mercury solidifies, rubber becomes as brittle as glass, specific heats of gases and solids decrease in a way that confirms the predictions of quantum theory. The electric resistance of many, metals and metalloids decrease abruptly to zero at temperatures of few Kelvin. If an electric current is introduced into a ring of metal that has been cooled to the super conductive state; it will continue to travel around the ring and may be detected many hours later. The ability of super conductive materials to retain current has led to experiments for constructing computer memory modules that would operate at these low temperatures[8].

Figure-1.6. Helium at 150 Degree Celsius[8]

3.2.Methods to Produce Low Temperatures

- By compressing the gas, the gas is cooled releasing heat and later allowed to expand producing ultra low temperatures.

Cryogenic temperatures are achieved either by rapid evaporation of volatile liquids or by expansion of gases confines initially at pressures of 150-200 atmospheres. The expansion may be simple, that is, through a valve to a region of low pressure, or it may occur in the cylinder of reciprocating engine, with the gas driving the piston of the engine. The second method is more efficient but it is also more difficult to apply[8].

- Magnetism produces low temperatures. When a material is magnetized it becomes warm and cold when demagnetized in controlled atmosphere thus producing low temperatures.

Dewar flask Cryogenic refrigerator: The evaporation of liquid helium at reduced pressures produces temperatures as low as 0.7 Kelvin (that is, -272.44°C or -458.4°F).Still lower temperatures can be attained by adiabatic demagnetization; the principle of which is that when a magnetic field is established around a paramagnetic substance, the field aligns the ionic magnets and later when the field is removed, the tiny ionic magnets resume their random alignments, reducing the thermal energy of the whole sample in the process where finally, the temperature falls to a level as low as 0.002 Kelvin. Repetition of such a process produced temperatures as low as 0.00001 Kelvin[8].

For storing liquids at cryogenic temperatures, Dewar flasks have proved useful. A typical Dewar flask comprises two flasks one within the other separated by evacuated space. The walls involved are silver painted to reduce the heat passage across vacuum. Substances colder than liquid air cannot be handled in open Dewar flasks[8].

3.3. Cryogenic processing effects[2]:

- Homogenizes the Crystal Structure
- Grain Structure refinement
- Improved structural compactness
- Prevents concentrated Heat Built-up
- Increases Resistance to Deformation
- Reduces Deformation significantly
- Retained austenite is converted to a fine martensite matrix
- Mechanical Properties like micro-hardness,tensile strength etc. are the same across any cross-section.
- Significant improvement in dimensional stability
- Relieves residual Stresses
- Several fold improvement in hot hardness
- Significant improvement in material toughness
- Increases wear resistance
- Increases corrosion resistance
- Good dimensionality
- High strength
- Good quality
- Lower stress corrosion
- This process is eco friendly in nature
- There is no waste deposition

4. REVIEW OF EXISTING LITERATURE:

M. Pellizzari et al.[30] had applied Deep Cryogenic Treatment (DCT) 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 austenite transformation was highlighted. By means of DSC(differential scanning calorimetry) and dilatometry, tempering transformations were investigated, confirming that DCT mainly enhances destabilization of martensite, by activating carbon clustering and transition carbide precipitation.

P Sekhar Babu et al.[27] studied that cryogenic treatment is said to improve wear resistance of tool and die steels and implemented at many places for that purpose. Although it has been confirmed that cryogenic treatment improves wear resistance and tool life, the process has not been standardised with inconsistent results varying from researcher to researcher.The authors have studied the improvement in wear resistance of M1, EN19 and H13 tool steels after cryogenic treatment. The materials were tested for improvement in abrasive wear resistance after cryogenic treatment at different temperatures below 0°C. All the samples were first heat treated as per standard norms and re tempered after cryogenic treatment. The samples were treated at 0° C, -20° C, - 40° C, -80° C and -190° C. It was observed that the wear resistance improved for all the samples from 315% to 382% depending on the material .

R. Kelkar et al.[22] elucidate the effect of cryogenic treatment on mechanical properties of M2 tool steel and correlate this with microstructural changes, resulting from different heat treatments. Five different combinations of tempering and cryogenic treatment after austenitizing and quenching were used. It was concluded that a higher dislocation density and carbon clustering resulting from the cryogenic treatment are responsible for the property enhancement of the steel. Carbon atoms initially cluster near dislocations to lower the overall energy of the system and subsequent heating leads to the precipitation of fine carbides. The higher dislocation density in cryotreated samples can be attributed to the strain induced by conversion of retained austenite to martensite & differential contraction of matrix relative to carbide phases during cooling.

Kamran Amini et al.[32] studied that 1/2304 steel is a kind of steel which is used very much for manufacturing cold rolling. In these parts, percent of residual Austenite has considerable effects on the life of roll, because in working conditions due to exerted stresses, there is possibility for transformation of residual Austenite to martensite. In this manner, the obtained martensite can cause the roll to be broken. The results of the performed tests in this research indicate that it is possible to reduce the amount of residual Austenite in the structure with cryogenic heat treatment.

Irappa Sogalad et al.[26] studied the influence of cryogenic treatment of pin on load bearing ability of interference fitted assemblies. En8 steel was used to prepare the pin and bush. The pins were soaked in liquid nitrogen (cryogenic temperature) and ice for different time periods. The bushes were heated and then assembled without applying the external pressure. The assemblies were tested for their strength. A comparative study on results of experimental and Lame's approach has been carried out. The results reveal that assemblies with cryogenically treated pin exhibits higher load bearing ability. The degree of increase in load bearing ability with increase in soaking time at cryogenic temperature is small. The variation in load bearing ability obtained through experimental investigation is in agreement with that of Lame's approach. The cryogenic treatment of tool steels increases the hardness and wear resistance. This increase is due to transformation of retained austenite to martensite at cryogenic temperature.

Barron et al.[35] investigated that the cryogenic treatment of steels facilitates the formation of fine eta carbides in the martensite structure. The iron or substitutional atoms expand and contract. Further, the carbon atoms shift slightly due to lattice deformation as a result of cryogenic treatment thus, enhances the wear resistance.

Huang et al.[33] studied the change in microstructure of tool steel before and after cryogenic treatment. Cryogenic treatment can facilitate the formation of carbon clustering and increase the carbide density in the subsequent heat treatment. This result in increase in wear resistance of tool steels.

Mohanlal et al.[38] reported that cryogenic treatment is an inexpensive one time permanent treatment affecting the entire section of the component unlike surface coatings and improves wear resistance and tool life.

R. F. Barron et al.[36] studied that cryogenic treatment produces metallurgical changes in the microstructure of steel. These changes are the principal reasons for the dramatic improvement in wear resistance. As greater amounts of retained austenite are transformed, and the amount of martensite is increased, the material obtains a more uniform hardness. The studies have shown that hardness is not increased appreciably in the material being treated but the consistency of the hardness is greatly improved. The surface energy of martensite is higher than that of austenite due to the differences in their atomic structures. (Austenite has a Face-Centered-Cubic crystalline structure and martensite has a Body-Centered-Tetragonal crystalline structure). In adhesive wear situations, the martensite is less likely to 'tear' out than is austenite. The probability of wear particles forming in steel in which the austenite has been transformed to martensite is less than for steel containing some retained austenite.

Harold et al.[11] applied a cryogenic treatment (-306° F) to tungsten carbide and compared with untreated carbide to determine if tool wear could be reduced during turning tests with medium density fiberboard (MDF). Both the tool force data and observation of the cutting edges indicate that tool wear was reduced. The cryogenic treatment appeared to have an effect upon the cobalt binder by changing phase or crystal structure so that more cobalt binder was retained during cutting.

P Sekhar Babu et al.[14] studied that cryogenic treatment is said to improve wear resistance of tool and die steels and implemented at many places for that purpose. Although it has been confirmed that cryogenic treatment improves wear resistance and tool life, the process has not been standardised with inconsistent results varying from researcher to researcher. In this work the authors have studied the improvement in wear resistance of M1, EN19 and H13 tool steels after cryogenic treatment. The materials were tested for improvement in abrasive wear resistance after cryogenic treatment at different temperatures below 0°C. All the samples were first heat treated as per standard norms and re tempered after cryogenic treatment. The samples were treated at 0° C, -20° C, - 40° C, -80° C and -190° C. It was observed that the wear resistance improved for all the samples from 315% to 382% depending on the material.

A study by the IIT Research Institute published in November 1995 for the Instrumented Factory for Gears sponsored by the US Army ManTech was conducted to study the effects of the carburizing process and cryogenics treatments in modifying the microstructure of the material.The results of the tests as presented at the INFAC Industry briefing, June 13, 2000 were that the deep cryogenic treatment gave 50% extra pitting resistance, 5% more load carrying capacity, and a 40°F to 60°F higher tempering temperature.

R. Kelkar et al.[29] studied that the effects of cryogenic treatment on the microstructure except for the obvious conversion of retained austenite to martensite are very significant. Two other microstructural effects result from cryogenic treatment. First there is an increase in the dislocation density resulting from the residual austenite conversion to martensite. Secondly, carbon atom clustering occurs leading to fine carbide precipitation after some weeks at room temperature.

T. Yugandhar et al.[28] reported that cryogenic treatment improves the mechanical properties like hardness,wear resistance, toughness, and resistance to fatigue cracking. The possible reasons for this improvement are as follows. According to one theory of this treatment, transformation of retained austenite is complete – a conclusion verified by X-ray diffraction measurements. Another theory is based on the strengthening of steels by the precipitation of submicroscopic carbides. An added benefit is said to be a reduction in internal stresses in the martensite developed during carbide precipitation, which in turn reduces tendencies to micro-crack.

5. CONCLUSION

To enhance the performance of these materials different types of cryogenic heat treatments have been adopted by different researchers and concluded that:

1.Microstructure of the cryogenically treated material is very fine, stable, continuous & stress free. The hardness and wear resistance of multi-cryogenically treated samples is also quite high as compared to the untreated samples.

2. The increase in wear resistance has been attributed to the transformation of soft retained austenite into the harder martensite and the formation of fine carbide particles, in the metal structure.

3. During wear, the frictional force in multi-cryogenically treated samples is also less as compared to untreated samples.

4. Dimensional accuracy and surface finish also substantially improved mainly due to significant reduction of wear.

5. Cryogenic treatment affects the entire section of the component unlike coatings.

6. Materials which are non ferrous like brass and gunmetal, do not have martensite formation and also do not have carbides precipitation, but the non ferrous materials improve a lot on cryogenic treatment due to residual stress relief. This phenomenon of residual stress relief applies to all materials whether ferrous or non ferrous.

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