CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

In this literature review, the aim, scope, main arguments, prominent theories, practical application and the knowledge gaps of the cryogenic treatment pertaining to the various steels are discussed in relation to the following fields.

1. Cryogenic Treatment
2. Wear Behaviour and Hardness
3. Transformation of Retained Austenite
4. Precipitation of Carbides
5. Tensile and Fatigue Behaviour
6. Residual Stress
7. Toughness
8. Damping Capacity
9. Optimization of Cryogenic Treatment

2.2 CRYOGENIC TREATMENT

Wear is responsible for catastrophic failure of some machine components. This process occurs between hard particles and the working surface. Methods to enhance the life of the component are based on application of wear resistant materials or formation of hard, wear-resistant surface material. The wear rate of steels depends on their chemical constituents and conventional heat treatment as outlined by Suchanek and Kuklik (2009). Susheel Kaila (2010) pointed out that cryogenics is an exciting, important and inexpensive method to increase the life of the steel component. It improves abrasive wear resistance, erosion and corrosion resistance and stabilizes the strength characteristics of the steels. Two kinds of treatments namely shallow cryogenic treatment (SCT) and deep cryogenic treatment (DCT) are adopted by the researchers. The shallow cryogenic treatment is otherwise termed as sub-zero treatment or cold treatment. By Shallow Cryogenic Treatment the conventionally quench hardened steels are directly put in a freezer kept at -80ºC and soaked for 5 hours to attain thermal equilibrium. By Deep Cryogenic Treatment, the conventionally quench hardened steels are slowly cooled from room temperature to -196ºC at 1.24 ºC/ minute, soaked at -196ºC for 24 hours and finally heated back to room temperature at 0.62 ºC/ minute. This technique has been proved to be efficient in improving the mechanical and physical properties of materials such as alloys, metals, composites and plastics. During the last decade, cryogenic treatment techniques have been developed and are now broadly used by industry to improve the mechanical properties of steel components.

Hasim et al (2002) pointed out that the cryogenic treatment of materials are gaining importance in recent days because of their potential to produce steel components that find enormous application in industries, nuclear power plants, fertilizer plants, medical, aerospace and avionics. This is due to the fact that materials treated under cryogenic environments attain superior properties that call for operation under severe environments as indicated by Charles and Arunachalam (2006). It is a one time homogenous process that provides significant extension in the performance and productive life of steel components namely brake rotors, gears, engines, machine parts, machine tools and gun barrels.

Maria Arockia Jaswin et al (2010) investigates the wear resistance improvement in En 52 and 21-4N valve steels through shallow and deep cryogenic treatment using a reciprocatory friction and wear monitor as per the ASTM standard: G-133. The shallow cryogenic treatment is carried out at -80ºC and the deep cryogenic treatment is carried out at -196ºC. It has been observed that the wear resistance of En 52 and 21-4N has improved by 81.15% and 13.49% respectively, due to shallow cryogenic treatment, 86.54% and 22.08% respectively, due to deep cryogenic treatment, when compared to the conventional heat treatment. The microstructural study suggests that the improvement in wear resistance and hardness is attributed to the conversion of retained austenite into martensite, along with precipitation and distribution of the carbides brought in by the cryogenic treatment.

Barron Randall (1974) and Harish et al (2009) studied that deep cryogenic treatment of SAE 52100 bearing steel enhances wear resistance. Dong et al (1998) studied the effect of DCT with respect to the microstructure of T1 high speed steels. It is proved that deep cryogenic treatment can enhance wear resistance by the precipitation of nano-sized eta-carbides in the primary martensite. Mahdi Koneshlou et al (2011) studied the effects of shallow cryogenic treatments on microstructure and mechanical properties of H13 hot work tool steel. Shallow cryogenic treatment at -72 ºC and deep cryogenic treatment at -196 ºC are applied and it is found that by applying the shallow cryogenic treatment, the retained austenite is transformed to martensite. As the temperature is decreased more retained austenite is transformed to martensite. The deep cryogenic treatment at a very low temperature and long sample holding times also appear to result in the precipitation of more uniform and very fine carbide particles. However tempering of the deep cryogenically treated samples improve the wear properties of the H13 tool steel. Stratton (2007) put forward the following material processing route for the cryogenic treatment of steels to attain maximum wear resistance.

1. Heat to austenitizing temperature that will decrease retained austenite for the steel being treated
2. Hold for the recommended duration for the steel
3. Quench at a rate sufficient to give fully martensitic structure
4. Condition at 60°C for a maximum of 1 hour and immediately go to step 5
5. Cool to liquid nitrogen temperature (-196°C) at a rate slow enough to prevent cracking, preferably in a nitrogen atmosphere to avoid condensation
6. Hold at liquid nitrogen temperature for a minimum of 24 hours, preferably in a nitrogen atmosphere to avoid condensation
7. Reheat to room temperature at a rate slow enough to prevent cracking, preferably in nitrogen atmosphere to avoid condensation
8. Temper at the temperature recommended for the steel being treated

Surberg et al (2009) investigated the effect of deep cryogenic treatment on properties of AISI D2 tool steel. This tool steel AISI D2 is usually processed by vacuum hardening followed by multiple tempering cycles. Deep cryogenic treatment between the hardening and tempering process reduces processing time and improve the final properties. Blocks of AISI D2 are vacuum hardened from different austenitizing temperatures. The hardened blocks are then subjected to various combinations of single and multiple tempering steps (520 ºC and 540 ºC) and deep cryogenic treatments (-90ºC, -120ºC and -150ºC). The results show that for all austenitizing temperatures a single deep cold treatment followed by a single tempering cycle is sufficient to reduce the retained austenite below 1%. To achieve better structure of the steel to get the most desired properties, it is recommended researchers to execute cryogenic treatment after completion of quenching and before tempering in conventional heat-treatment cycle.

2.3 WEAR BEHAVIOUR AND HARDNESS

The wear of steel components used on machinery, which is operating in a wide range of industrial circumstances can cause sudden breakdowns, serious inefficiencies, and significant financial losses. These losses can be reduced by means of cryogenic treatment on steels. The frequently referred scientific literature results from Barron (1974) are given in Table 2.1. However, wear is not a simple one to measure in the laboratory, where testing parameters significantly affect the results. The actual wear experienced by a component may be quite different in practice. It has been found that a few machine elements, such as slitting blades used in paper cutting, have lasted six times longer after deep cryogenic treatment. Results from field trials on stamping dies, milling cutters and punches have also shown noteworthy improvements, given in Table 2.1. The improvement in wear for various tool steels after deep cryogenic treatment is as shown in Figure 2.1. Yong et al (2006) conducted the preliminary test to determine the influence of deep cryogenic treatment on end mills, zone punches, lathe tools and concluded that an increase in tool life from 50% to more than 200% were observed for the tools which had been soaked in liquid nitrogen for 12 hours.

Table 2.1 Field Trial of Wear Improvements in Deep Cryo Treated Tools (Barron (1974))

Tool Type	Tool Material (AISI no.)	Improvement in Wear Rate (%)
Stamping die	D-2	1000
Punch	M-7	600
End mill	M-42	450
Drills	C-2	300
Milling cutters	M-7	250
Drill	M-42	200
Punch	M-2	100

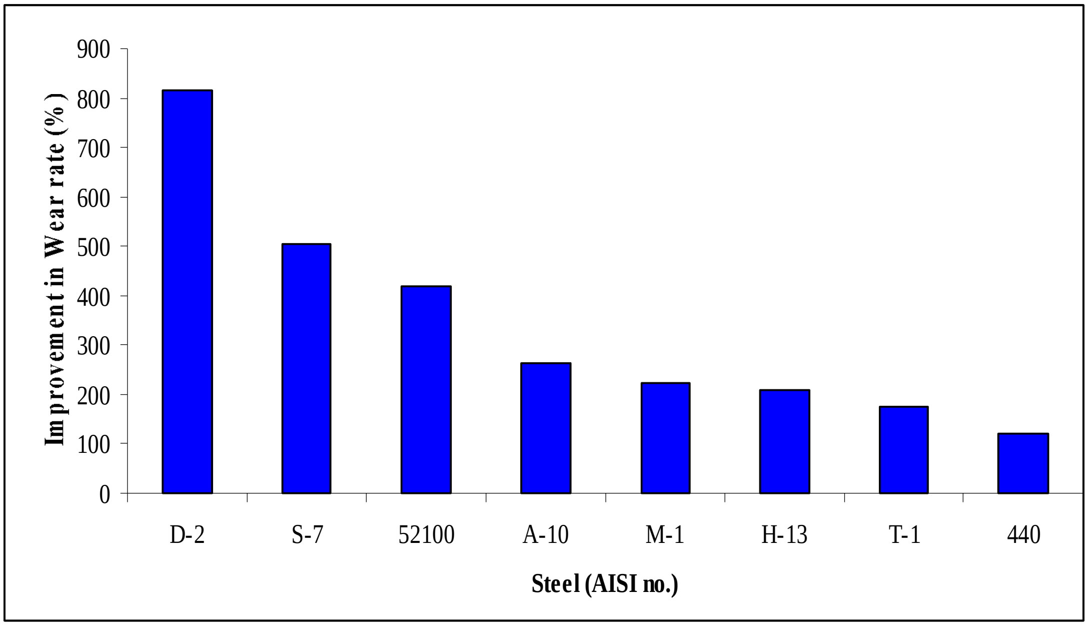

Figure 2.1 Improvement in Wear Rate due to Deep Cryogenic Treatment (Barron (1974))

Dhokey and Nirbhavne (2009) reported the wear rate of D-3 tool steel after deep cryogenic treatment and concluded that the reduction over conventional heat treatment was 93% for DCT. It is seen that combined effect of heat treatment and deep cryogenic treatment can assist in improving wear resistance in single tempering, whereas wear resistance deteriorate in subsequent double / triple tempering. The improvement of wear resistance in single tempering is due to the fine carbides nucleated during deep cryogenic treatment. But the coarsening of carbides is clearly observed in double and triple tempered samples. This contributes to the deterioration of wear resistance of D-3 steel. Barron and Mulhern (1980) carried out the experiments on carbon steel (C1045) to determine the effect of deep cryogenic treatment on the abrasive wear resistance. It is reported that there is an increase in the wear resistance by a factor of 1.4 for the C1045 steel. This is achieved by soaking the steels in liquid nitrogen temperature at -196°C for 24 hours.

Bensely et al (2005) studied the wear resistance of case carburized En353 steel after shallow and deep cryogenic treatments. The shallow cryogenic treatment samples are treated at -80ºC for 5 hours and the deep cryogenic treatment samples are treated at -196ºC for 24 hours. It is concluded that the improvement over conventional heat treatment was 85% and 372% for SCT and DCT respectively. In addition to the well-known effect of converting retained austenite to martensite, DCT induces precipitation and finer distribution for carbides which are solely responsible for the improved wear resistance**.**

Hao-huai Liu et al (2007) conducted the wear test and optical microscopy in order to find the effect of deep cryogenic treatment on abrasion resistant and micro structure of 3 Cr 13 Mo L1 V1.5 high chrome cast iron subjected to sub critical treatment. The results proved that the deep cryogenic treatment can remove the retained austenite but cannot convert the retained austenite to martensite completely. The abrasion resistance of high chromium cast iron are developed after cryogenic treatment. This development is owing to the precipitation of carbides, the transformation of retained austenite into martensite, and a refined microstructure resulting from deep cryogenic treatment. Flavio J da Silva et al, (2006) studied the influence of deep cryogenic treatment on M2 HSS high speed steel tool sample. The deep cryogenic treatment transforms the 25% volume of retained austenite in the as-quenched sample. This transformation is responsible for the enhancement of performance in the HSS twist drills.

Fanju Meng et al ((1994) investigated the wear resistance and microstructure of Fe-12Cr-Mo-V-1.4C tool steel with and without cryogenic treatment. It has been proved that deep cryogenic treated samples show enhancement from 110% to 600% through sliding wear test. It is correlated that the enhancement in wear resistance after deep cryogenic treatment can be attributed to the carbide precipitates. Joseph Vimal et al (2008) studied the effect of deep cryogenic treatment on En 31 steels done at different stages of heat treatment. It is observed that through deep cryogenic treatment the wear can be decreased by a maximum of 75% depending on the service conditions. It is concluded that the cryogenic treatment should be done before tempering and immediately after quench hardening to obtain maximum benefits.

According to Archard law of wear, the wear rate is inversely proportional to bulk hardness of the treated samples. The wear rate decreases with increasing bulk hardness. However, the decrease in wear rate is not linear with the increase in bulk hardness. Das et al (2010) investigated the correlation of wear behaviour and hardness of AISI D2 steel. The shallow cryogenic treatment in comparison to conventional heat treatment enhances the bulk hardness by just 3.8% but reduces the wear rate by 35.8% at normal load of 78.5 N. Similarly the difference of bulk hardness between shallow cryogenically treated and deep cryogenically treated samples is marginal

(4.2%). In many instances the mechanical properties of the interface layer that forms between the sliding surfaces during wear is entirely different from bulk material. Under these situations, distinct interrelation cannot be expected between the wear rate and the original hardness of the base material. Even in the wear conditions that do not result into such layer formation, the base material at the contact surface and subsurface usually undergo considerable modification due to wear by the combined effect of frictional shear stress and thermal effect. The addition or modification of small amount of second phase particles may not have considerable effect on hardness of the materials, but can substantially affect their wear rate by alteration of plastic deformation and/ or thermal softening in the course of wear. This was discussed in the literatures (Rabinowicz (1995), Blau (2005) , Rigney and Gleser (1978), Dautzenberg and Zaat (1973)). Therefore the wear rate of materials, more often than not, depends on the response of a material to the dynamic changes induced during wear rather than the original microstructure and mechanical properties of materials.

2.4 MECHANISM OF CRYOGENIC TREATMENT

Most researchers and scientists believe that the shallow and deep cryogenic treatment improves hardness and wear resistance of steels. The possible transformations induced by shallow cryogenic treatment are

- The transformation of retained austenite into martensite, which is responsible for the increase in hardness
- The precipitation of very fine carbides due to low temperature conditioning of martensite

The mechanisms of deep cryogenic treatment are

- The transformation of retained austenite into martensite

- The carbon redistribution (segregation and clustering) responsible for low temperature conditioning of martensite can occur only during long soaking

Since the transformation of retained austenite into martensite is athermal (ie. Time independent), it can occur during both kind of treatments namely shallow cryogenic treatment (-80º C for 5 hours) and deep cryogenic treatment ((-196º C for 24 hours). On the other side, the carbon redistribution (segregation and clustering), can occur in soaking duration of 24 hours. It is plausible that it can be observed only during deep cryogenic treatment and not in shallow cryogenic treatment. This is the major reason for the development of wear resistance in deep cryogenic treated samples.

2.4.1 Transformation of Retained Austenite

Investigators claims that the cryogenic treatment promotes the complete transformation of retained austenite into martensite at cryogenic temperatures, promoting improved wear resistance. The cryogenic treatment can be seen as an extension of quench cycle which continues the process of martensite formation. When materials are cooled to shallow cryogenic temperatures, large amount of retained austenite is decayed until it reaches -80 °C for certain steels. This treatment modifies the material microstructure and develops the hardness.

Vanvlack (1998) explained that the percentage of tempered martensite increases as the initial quenching temperature drops toward -73°C when in all practical purposes it reaches 100 percent. It is also concluded that the transformation of austenite to martensite is dependent only on temperature and the time required for transformation and the time is so short as to be negligible. The conversion of retained austenite to martensite is an athermal process.

Hong-Shan Yang et al (2006) investigated the effect of deep croyogenic treatment on the matrix structure and abrasion resistance of high chromium cast iron subjected to destabilization heat treatment. The deep cryogenic treatment promotes the transformation of retained austenite into martensite along with the secondary carbides precipitation. The deep cryogenic treated alloys produce higher hardness and wear resistance to the alloys when compared to the conventionally treated samples only if retained austenite present in hardened steel.

Akhbarizadeh et al (2009) studied the effects of cryogenic treatment on wear behaviour in D6 tool steel. Two cryogenic treatments were used: -63°C as shallow cryogenic temperature and -185°C as deep cryogenic temperature. The effects of shallow and deep cryogenic temperature, cryogenic time (kept at cryogenic temperature for 20 and 40 hours respectively) and stabilization (kept at room temperature for 1 week) on the wear behaviour of D6 tool steel were studied. Wear tests were performed using a pin on disk wear tester to which two different loads (120 and 180N) and three different velocities (0.05, 0.1 and 0.2 m/s) were applied. The findings showed that the shallow cryogenic treatment decreases the retained austenite and hence improves the hardness. Due to more homogenous carbide distribution along with the elimination of the retained austenite, the deep cryogenic treatment demonstrated a higher improvement in wear resistance and hardness compared with the shallow cryogenic treatment. By increasing the soaking time at cryogenic temperatures, more retained austenite was transformed into martensite along with the carbide precipitations thus improving the hardness and wear resistance

Sasikumar et al (2003) analyzed the premature failure of a tie bar made of AISI 4140 steel in a 150 tonne plastic injection-molding machine. A manufacturer of plastic injection molding machines reported a failure in the bottom tie bar in one of their 150 tonne molding machine within three months of service (in continuous operation). These tie rods in the injection molding machine are designed for a service period of more than five years. The photograph of the failure tie rod is shown in Figure 2.2. The high stress concentration has been introduced by a combination of improper molding parameters resulting in uneven tensions in the four tie bars and aggravated by the presence of some material defects. The material defects observed are inclusions, presence of some retained austenite and fine cracks. This retained austenite should be alleviated to improve the life of the component.

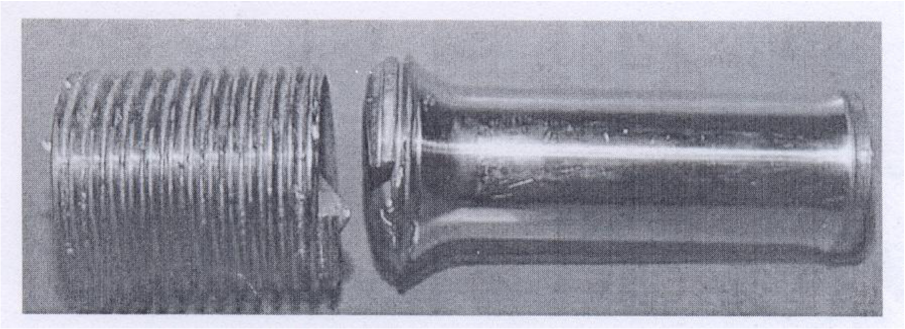

Figure 2.2 Photograph of Failed Tie Bar Made of 4140 steel

2.4.2 Precipitation of Carbides

Researchers claim that the cryogenic treatment facilitates the formation of fine carbides in the martensite, thus enhancing the wear resistance.

Amini et al (2010) investigated the effect of shallow and deep cryogenic treatments on the wear behavior of 80CrMo12. 5 tool steel was studied using two different temperatures: -80 ºC as the shallow cryogenic temperature and -196 ºC as the deep cryogenic temperature. For deep cryogenic treatment, samples were cooled to -196ºC with the cooling rate of 1ºC/min, held for 24 hour and heated up to room temperature with the heating rate of 1ºC/min. The cryogenic treatments increase the wear resistance and hardness. Shallow cryogenic treatment (SCT) decreases the retained austenite by 6% for the SCT sample. Deep cryogenic treatment eliminates the retained austenite and increases the carbide percentage. This increase was about 2% and the carbide distribution becomes more homogenous. This leads to an increase in the wear resistance of the samples.

Yuan-zhi Zhu et al (2008) investigated the mechanical properties of Fe-Cr-Mo-Ni-C-Co alloy which was quenched in liquid nitrogen and held for a period of 24 hours. Hardness tester, optical microscope, X ray diffraction, scanning electron microscope was used to investigate the mechanical properties and microstructure of the alloy. The results show that the hardness increases by 1−2 (HRC) and the compressive strength decreases slightly after cryogenic treatment. The increase in hardness is attributed to the transformation from austenite to martensite. The decrease in compressive strength is caused by residual stress. The large amount of carbide in the alloy and the obvious difference in thermal expansion coefficient between the carbide and the matrix at the deep cryogenic temperatures lead to this residual stress.

Firouzdor et al (2008) investigated the influence of deep cryogenic treatment on wear resistance and tool life of M2 HS drills in high-speed dry drilling configuration of carbon steels. Cryogenic treatment is generally classified as Shallow cryogenic treatment at -80ºC and Deep cryogenic treatment at -196ºC. The cooling and heating rates must be kept constant at about 0.5 ºC/min. The experimental results indicated 77% and 126% improvement in cryogenic treated and cryogenic-and temper-treated drill lives respectively. A low-temperature tempering (200°C) after cryogenic treatment is also found to be highly beneficial. It has been deduced that fine carbide precipitation during deep cryogenic treatment is the main reason for wear resistance improvement as a result of decreasing thermodynamically potential for dissolution in the work piece material and dispersion hardening effect. Transformation of retained austenite into martensite played an effective role to enhance the hardness value. Cryogenic treatment could not only facilitate the carbide formation but also increase the carbide population in martensite matrix and also make carbide distribution more homogenous. Cryogenic treatment affects the entire cross section of the component unlike coatings. Therefore, similar lives can be expected after each regrinding.

2.5 TENSILE AND FATIGUE BEHAVIOUR

Hossein Nedjad et al (2004) found the effect of conventional and shallow cryogenic treating or on the aging behaviour and tensile properties of Fe-10.5t%, Ni-5.8 wt%, Mo-3 wt% Mn. This alloy is aged at 753K. Tensile properties of the samples were determined after shallow cryogenic treating with dry ice (233K) for 43.2ks. It is concluded that shallow cryogenic treating doesn’t give remarkable enhancement on the tensile properties of alloy. Baldissera (2010) investigated the effect of deep cryogenic treatment on static mechanical properties of both hardened and solubilized AISI 302 stainless steel. No significant changes are detected on ultimate tensile strength and on yield stress. Slight but significant improvements are measured on the Rockwell-B hardness of the solubilized material after cryotreating at 88 K.

Zhirafar et al (2007) investigated the effect of cryogenic treatment on the mechanical properties and microstructure of AISI 4340 steel. It is shown that in general, hardness and fatigue strength of cryogenically treated samples are a slightly higher whereas the toughness of the cryogenically treated samples is lower when compared to that of the conventionally treated steel. Neutron diffraction shows the transformation of retained austenite to martensite while carbide formation occurs simultaneously during tempering. This is the key factor in improving hardness and fatigue resistance of the cryogenically treated samples. Moreover, Johan Singh et al (2003) investigated the influence of cryogenic treatment on the axial fatigue performance of fillet welded cruciform joints of AISI 304L stainless steel, which failed in the weld metal. It has been observed that after the deep cryogenic treatment, the fatigue life improved almost by a factor of two. During the treatment, significant microstructural changes that occurred accounted for the improved fatigue performance. Strain induced martensitic transformation is observed. During this transformation, the weld metals tend to expand inducing compressive residual stress in the weld metal.

2.6 RESIDUAL STRESS

Residual stresses are the stresses that remain within a part after the original cause of the stresses (external forces, heat gradient) has been removed. Kalpakjian (1985) points out that the residual stresses remain along a cross section of the component, even without the external cause. Samant and Dahotre (2008) describe that these internal stresses become evenly balanced by themselves. They exist in a free body that has no external forces or constraints acting on its boundary.

Before the engineer or metallurgist commits to measuring residual stress in some component or work piece, one must be sure that the reason for the measurement is clearly understood. According to the Handbook of Residual stress and deformation of steel (Ruud, 2002), the major reasons for residual stress are:

1. Failures that are suspected as being caused by fatigue, stress corrosion, corrosion fatigue or hydrogen embrittlement.
2. Assessment for the continued serviceability of a component, for example, life assessment which is usually focused on a concern for in-service failure.

3. Distortion occurring during processing of a component.
4. Distortion of components during storage or in service.

Residual stresses are caused by means of load or thermal gradients or both. These stresses are developed during different processes like non uniform plastic deformation during cold working, shot peening, surface hammering, grinding, welding, phase transformations, and high thermal gradients. Over the past few years, much interest has been shown in the properties and improvement of compressive residual stress. Knowledge of residual stress in steels is important in the component design field. It not only leads to improve fatigue resistance but also improves the dimensional stability. It can also lead to improve the contemporary drop in resistance against stress corrosion cracking. In polycrystalline and/ or multiphase materials, residual stresses can be classified as micro stresses and macro stresses. Almer et al (1998) states that the micro stresses are formed due to incompatibilities between grains or between phases and the macrostresses are formed by differential plastic deformation over a large scale relative to microstructure. Prevey (1996) explains that the macroscopic stresses or macro stresses are extended over large distances relative to the grain size. Macrostresses vary within the body of the component over a range larger than the grain size of the material. These stresses are of general interest in design and failure analysis. Macrostresses are tensor quantities. These stresses are determined for a given location and direction by measuring the strain in that direction at a single point. Microscopic stresses or microstresses are treated as scalar properties of the material. These microstresses are related to the degree of cold working or hardness, and the result of imperfections in the crystal lattice. Microstresses arise from variations in strain between the "crystallites" bound by dislocation tangles within the grains. They are acting over distances less than the dimensions of the crystals. Hoffmann et al (1997) point out that the micro stresses vary from point to point within the crystals.

They are producing a range of lattice spacing and broadening of the diffraction peak. These micro- residual stresses are generated during diffusionless martensitic transformation by dislocations and by solute carbon atoms remaining in their octahedral sites without diffusion.

Cryogenic treatment not only enhances the wear resistance of certain steels but also improves the compressive residual stress, dimensional stability and fatigue life. Due to increase in compressive residual stress the heat-treated parts withstand external stress during service without failure as pointed out by James G Bralla (1999). This leads to the improvement in design of heat treatment. Tamas Reti et al (2002) found that the amount of retained austenite present in steel plays a significant influence on the magnitude of the residual stresses and dimensional stability. They also pointed out that the effect of retained austenite on component performance is still a controversial issue. Some of the key factors influencing the retained austenite transformation include grain size, quenching temperature, hardening temperature, chemical composition, quenching cooling rates, and stress relieving or tempering. Retained austenite causes a decrease in tensile and yield strength in steels and reduces the maximum achievable surface compressive stress relative to the amount of this phase. Tempering in the range of 200 ºC results in a decomposition of the retained austenite to ferrite and cementite as explained in ASM Heat Treater’s Guide (1995). It might not always be the most effective way to reduce the amount of retained austenite, because of the marked decrease of hardness, mechanical strength and wear resistance. The contemporary loss in hardness due to the tempering of primary martensite partially hides the positive effect of retained austenite transformation. Alexandru and Bulancea (2002) have pointed out that cryogenic treatments have been proposed as a useful method to transform retained austenite prior to tempering and to overcome the problems related to austenite stabilization. The transformation of retained austenite into martensite influences the residual stress, which will have an effect on the performance of the material. However, Preciado et al (2006) stated that because of rather low amount of austenite (less than 15%) retained by conventional quenching in the microstructure of alloy steels, it appears that the cryogenic cooling would not cause additional microstructure improvements compared to ordinary quenching. So, cryogenic treatment is necessary to transform retained austenite into martensite, which is denser, smaller and distributed more uniformly than austenite. Besides, cryogenic treatment induces the precipitation of very fine carbides of dimension less than 1 micro meter, which occupies the micro voids so that it contributes to the increase of both coherence and density within the metal as pointed out by Alexandru and Bulancea (2002).

2.7 TOUGHNESS

Molinari et al (2001) studied that carbide precipitation occurs with a higher activation energy thus leading to a higher nucleation rate which in turn leads to finer dimensions and a more homogenous distribution. A new phenomenon referred as tempered martensite detwinning occurs in AISI M2 steel, which shows a reduction of twins after soaking at -196°C for 35h. Deep cryogenic treatment reduces the wear rate of the hot work tool steel. This result is interpreted on the basis of increased toughness, because in the presence of delamination, the ability of materials to oppose crack propagation can really increase the mechanical stability on the wear surface and load bearing capacity. Therefore, even if the deep cryogenic treatment does not influence hardness, it increases both toughness and wear resistance. This effect can have an important effect on the performances of the tools and for the hot forming of steels, where wear resistance and toughness are frequently the key properties.

Collins and Dormer (1997) observed that the deep cryogenic treatment improves the toughness of D2 cold work tool steel. In addition to the well-known effect of transforming retained austenite to martensite, with the consequent increase in hardness, deep cryogenic treatment has an effect on martnesite. It causes crystallographic and microstructural changes which, on reheating, result in the precipitation of finer distribution of carbides, with consequent increases in both toughness and wear resistance. CHI Hong-Xia et al (2010) investigated the effect of cryogenic treatment on the properties of Cr-8 type cold work die steel. The results show that cryogenic treatment increases hardness by decreasing retained austenite but the degree depends on the austenitizing temperature. When quenching at lower austenitizing temperature, the steel can obtain higher toughness by cryogenic treatment substituting conventional heat treatment process. Zurecki (2005) studied the influence of wear resistance cryogenically treated A2 steel. It is proved that there is a moderate improvement in wear resistance at the cost of impact toughness. Franjo Cajner et al (2009) compared the advantages of deep-cryogenic treatment over conventional heat treatment of high speed steels for the purpose of obtaining better properties as quoted in an increasing number of scientific articles. This article deals with the most important improvements of high speed steel properties achieved by using deep-cryogenic treatment. The effect of deep-cryogenic treatment on impact and fracture toughness, erosion wear resistance, and the material microstructure has been tested on samples made of PM S390 MC high speed steel. A set of test samples is heat treated by conventional methods (hardened and three times high temperature tempered), and the other set in deep cryogenic treatment methods. From the results, it can be concluded that the application of deep-cryogenic treatment results in significantly higher wear resistance of high speed steels, but no significant improvement in toughness has been observed.

2.8 CORROSION RESISTANCE

Baldissera and Delprete (2010) studied the effects of DCT on fatigue and corrosion resistance of AISI 302 austenitic stainless steel. AISI 302 austenitic stainless steel was experimentally investigated for both hardened and solubilized conditions. In both cases, no changes were detected after the DCT on the corrosion resistance and on the capability to reform oxide protective layer. Despite some effects on the fatigue data dispersion, no significant improvements are given by the DCT on the fatigue behaviour of the hardened material. The most interesting results were obtained on the solubilized material, where the DCT proved to be an effective method to improve both the fatigue limit and the fatigue life.

Fu-Zhen xuan et al (2008) investigated the 30Cr2Ni4MoV rotor steel with deep cryogenic treatments on corrosion resistance in high temperature water. For deep cryogenic treated specimen, no apparent improvement is observed on the hardness and corrosion resistance due to the limited carbon precipitate and austenite transformation. The carbon content in this steel is 0.28%C. It is realized that precipitation of fine carbides will reduce the internal stress in the martensite and thus minimize the susceptibility of micro cracking. In fact, the lower content of carbon of 30Cr2Ni4MoV limits the carbon precipitation. Hence, the corrosion resistance of 30Cr2Ni4MoV steel is not significantly improved by deep cryogenic treatment.

2.9 DAMPING CAPACITY

High damping steel materials have the potential to greatly reduce vibration and noise in many types of mechanical Systems. Damping capacity is a measure of a materials ability to dissipate strain energy during mechanical vibration under cyclic loading or wave propagation as put forward by

Lavernia et al (1995). The material absorbs up to 50-30% elastic energy per oscillation cycle as pointed out by Chudakov et al (2007). Utepov (2008) stated that the quenching leads to an improvement in the damping properties of steel, which is connected with the presence of a martensitic component in the structure. Hardening of martensite markedly raises the damping capacity of steel as pointed out by Favstov et al (2003). The damping capacity of steel is closely associated with the interfacial internal friction. The interfacial slip contributes strongly to the damping capacity. The weaker interface bonding leads to higher the damping capacity including the quality inverse factor. Lot of research has been done on the influence of cryogenic treatment on the wear resistance of steels. However, the scientific literatures related to damping behavior of cryogenically treated steel is limited. Therefore the study on damping behaviour is considered in the present research work.

2.10 OPTIMIZATION OF CRYOGENIC TREATMENT

Schiradelly and Diekman (2001) have applied Taguchi Design of Experiment (DOE) to identify and to optimize the critical parameters of cryogenic treatment for a martensitic stainless steel. By the analysis of variance (ANOVA) with the wear test results, it has been concluded that the significant parameter is the soaking temperature (72% in contribution). Oppenkowski et al (2010) identified the significance of conventional factors such as the austenitizing and tempering temperatures and of the factors relating to deep cryogenic treatment such as the cooling rate, holding time, and heating rate for powder metallurgical cold-work steel X153CrVMo12 using Taguchi technique. In addition, the optimum factor levels for different mechanical properties and the wear rate have been identified. The following conclusions are drawn from the results:

1. The most important factors influencing the properties of tool steels are the austenitizing and tempering temperatures

during conventional heat treatment. Of the factors relating to deep cryogenic treatment apart from the soaking temperature, only the soaking time and the heating rate have a significant effect on material properties. The cooling rate is only significant in interactions with the heating rate or the soaking time

2. When applying DCT to develop mechanical properties such as the elongation at fracture, deformation work and bending strength, a low austenitizing temperature in combination with a high tempering temperature is beneficial. The opposite combination, high austenitizing and low tempering temperatures, increases both the Vicker's hardness and the wear behavior
3. The wear rate is nearly constant for soaking times of up to 24 hours. For a longer soaking time of 36 h, the wear rate reaches a minimum and increases again on further holding

The soaking time shows a strong influence on the increase of hardness induced by the pre-tempering DCT. The microstructural mechanism involves the entire process of cooling and warming phases and so further enhancements could be possible with a prolonged DCT exposure which was pointed out by Baldissera and Delprete (2009).

The important conclusions of the review study made by Nirmal S. Kalsi et al (2010) are given as follows.

1. Deep cryogenic treatment has positive influence on the performance of steels. This could be a good alternative for improving performance, depending on the enhancement of the application. Optimization of the parameters involved in the whole treatment cycle must, however, precede the application

2. Complete process must be done as follows:

   Austenitization, quenching, cryogenic treatment and tempering, must be followed immediately one after the other in a cycle. The number of tempering cycles may be more than one depending on the properties of the material desired
3. It is clear that minimum possible soaking temperature is always beneficial to improve the properties of steel
4. Long soaking periods from 24 hours to 36 hours depending on the properties of the material, with lowest possible soaking temperature in cryogenic treatment, are preferred in order to achieve maximum wear resistance. Treatment at lowest temperature is sufficient to enhance fatigue load resistance due to more compressive stress generated, still further investigations are needed as little work has been found for fatigue load applications
5. Contribution of cryogenic treatment to improve the wear resistance is due to martensite, eta -carbide formation and homogeneous distribution of produced carbides rather than only removal of retained austenite
6. Much useful work has been reported by the researchers, but due to skepticism about the process, change in mechanism is still unpredictable. Parameters like austenitization temperature, quenching, cooling temperature, soaking duration, warming-up cycle, and tempering cycle needs further investigations to optimize the process for various materials

Based on the literature review, it is found that cryogenic treatment has the potential to enhance the mechanical properties of steel. Increasing the wear resistance upon shallow and especially deep cryogenic treatment is justified by the transformation of retained austenite to martensite along with the fine carbide precipitations. Lot of research has been done on the effect of cryogenic treatment on tool and high speed steels. However, few researches have been done on the effect of cryogenic treatment on medium carbon steels. The aim of the study is to find the effect of cryogenic treatment on wear resistance and some behaviour of En 19 steel.

In recent years, researchers have also tried to evaluate the process to optimize the cryogenic treatment parameters as pointed out by Nirmal S Kalsi et al (2010). The scientific literature available in this area is also limited. Hence, it is of great value to optimize the parameters used in the deep cryogenic treatment process with respect to En 19 steel. The popularity of the En 19 steel makes this study even more interesting. The best combination of the parameters affecting the deep cryogenic treatment in order to reduce the wear loss of En 19 steel was also found out in this study. The present research work fills the knowledge gaps on the influence of cryogenic treatment on En 19 steel.