ENHANCING THE MECHANICAL PROPERTIES OF VARIOUS MATERIALS BY CRYOGENIC TREATMENT

A Project report

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properties of various materials by cryogenic treatment

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ABSTRACT

This project deals with the effects of cryogenic treatment on EN8 steel, Mild steel and Aluminum responsible for enhancing the mechanical properties. Cryogenic treatment of metal parts consists of cooling down these parts at predetermined rate up to a given cryogenic temperature maintaining the parts at that lowest temperature for a given duration of time and then allowing these parts to warm up at a given warming up rate.

The Reason for mechanical properties improvement is the conversion of austensite into martensite. The degree of undercooling decides the potential to transform retained austensite into martensite. The other reason is also due to the precipitation of finely dispersed carbides in the martensite.

This project in the ultimate analysis presents the details of cryogenic treatment, testing methods and the result that show the enhancement of mechanical properties in cryogenically treated parts. The test has shown that the cryogenic treatment has improved the various mechanical properties. The various tests performed are tensile test, hardness test, wear test. In the process of ascertaining these findings it was brought out in this exercise that under cryogenic treatment the parts perform better than untreated tools. This makes it useful in increasing the accuracy and reducing the overall manufacturing lead-time, which in turn will increase the productivity and profit.

ஆய்வுச் சுருக்கம்

இந்த ஆய்வு EN8 ஸ்டீல், மைல்டு ஸ்டீல் மற்றும் அலுமினியத்தை மீக்குளிர்வியல் சோதனைக்கு உட்படுத்தும் போது அதில் உள்ள மெக்கானிக்கல் ப்ராபர்டீஸில் எற்படும் மாற்றங்களை பற்றி விவரிக்கிறது. மீக்குளிர்வியல் சோதனையில் உலோக பொருட்களை சோதனைக்கு உட்படுத்தும் போது, முன்பே தீர்மானிக்கபட்ட வெப்பநிலைக்கு கொண்டு வரப்படுகிறது.

உலோக பொருட்களில் உள்ள மெக்கானிக்கல் ப்ராபர்டீஸை மாற்றுவதற்கு காரணம் என்னவென்றால் அதில் உள்ள ஆஸ்டன்சைட்களை மார்டன்சைட்டுகளாக மாற்றுவதாகும். மீதமுள்ள உலோக பொருட்களின் ஆஸ்டன்சைட்களை அதன் பயன்பாட்டிற்கு பயன்படுத்துவதற்கு முன் அதனை மீக்குளிரிவியல் முறைக்கு உட்டுபடுத்த வேண்டும். இதனை மாற்ற மற்றொரு காரணம் என்னவென்றால் அதில் உள்ள விரவிய கார்பன் துகள்களை ப்ரிசிபிடேஷன் முறையை உபயோகப்படுத்துவது.

இந்த ஆய்வு எதை பற்றி விவரிக்கிறது என்றால் அதில் உள்ள மீக்குளிரிவியல் சோதனை, சோதனை முறை, மற்றும் உபயோகபடுத்தப்படும் பொருட்களின் மெக்கானிக்கல் ப்ராபர்டீஸில் ஏற்படும் மேம்பாடுகள் ஆகியவை ஆகும். இந்த ஆய்வில் பயன்படுத்தப்பட்ட உலோகப் பொருட்களை பல்வேறு சோதனை முறைக்கு உட்படுத்தப்படுகிறது. அவை யாதெனில் வலிமை தன்மை, கடினதன்மை மற்றும் தேய்மான தன்மை போன்றவை ஆகும். இந்த ஆய்விலிருந்து பெறப்பட்ட முடிவு யாதெனில் சோதனைக்கு உட்படுத்தாத பொருட்களை காட்டிலும் சோதனைக்கு உட்படுத்திய பொருட்கள் மிகவும் நேர்த்தியானது. இதன் மூலம் அடையபடும் மற்ற பயன்கள் யாதெனில் பொருட்களின் துல்லியம், உற்பத்தி திறன் மற்றும் லாபம் ஆகியவை அதிகரித்துள்ளது, அதே சமயம் அதனை தயாரிப்பதற்கான நேரம் குறைந்துள்ளது.

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LIST OF SYMBOLS AND ABBREVATIONS

SCT	-	shallow cryogenic treatment
DCT	-	deep cryogenic treatment
LN2	-	liquid nitrogen
ASTM	-	American standards for testing of materials
RHT	-	Rockwell hardness test
EN8	-	English number
Wt	-	weight

Chapter 1

Introduction

CHAPTER 1

INTRODUCTION

Owing to globalization, industry must avoid compromising quality in order to compete in the market. Presently, the growth of the automobile industry is increasing tremendously. Research efforts are widespread with a view to improving the life and performance of components in automotive, aircraft, racing engine etc applications by various treatments. Over the past few decades, research interest has been in the effect of cryogenic treatment on the performance of steels. Supplementing cryogenic treatment to conventional treatment processes may help the manufacturer to achieve high durable component. Cryogenic treatment is an inexpensive one-time treatment that influences the core properties of the component, unlike purely surface treatments. In the present research work, improving the mechanical properties of steel components by cryogenic treatment is considered. They are highly stressed, expensive components. These components undergo frequent fatigue failures and wear failures due to overloading, poor heat treatment, and improper material characteristics. And hence the cryogenic treatment is performed on these components. Cryogenic treatment is generally classified as shallow cryogenic treatment. Sometimes referred as subzero treatment (193K) or deep cryogenic treatment (DCT) (77K) based on the treatment temperature. Normally, SCT or subzero treatment are widely used for high precision parts in order to have high dimensional stability. However, DCT may also be employed due to the increased benefits reported in terms of wear resistance and compressive residual stress compared with SCT.

their desired metallurgical and structural properties. In our case, this is a temperature at -196°C. These ultra cold temperatures are achieved using computer controls, a well-insulated treatment chamber and liquid nitrogen (LN_2). The value of cryogenic treatment of steel and other materials has been debated for many years; even serious metallurgical professionals have serious reservations about its value. A typical treatment consists of a slow cool-down rate (2.5 °C/min equivalent to 4.5 °F/min) from ambient temperature to the temperature of liquid nitrogen. When the material reaches approximately 80 K (–315 °F), it is soaked.

These ultra-cold temperatures, below -310°F, will greatly increase the strength and wear life of all types of vehicle components, castings and cutting tools. In addition, other benefits include reduced maintenance, repairs and replacement of tools and components, reduced vibrations, rapid and more uniform heat dissipation, and improved conductivity. Cryogenics International's process is like an insurance policy for your tools and components. In today's competitive marketplace, the necessity for sophisticated deep cryogenic treating has become a reality. In addition to stress relief, today's companies are finding that controlled deep cryogenic treatment dramatically increases the useful life of components, perishable tooling and wear parts. Cryogenics International is located in Scottsdale, Arizona. In 1988, Cryogenics International (CI) was granted a U.S. patent for its revolutionary new computerized deep cryogenic treatment systems. Cryogenics International now makes dramatic cost savings and increased productivity available to many people and industries around the world.

1.1MECHANISM OF CRYOGENICS

There are three mechanisms related to cryogenic treatment of steels. The conversion of retained austenite (RA) to martensite is one. This mechanism is important and brings several benefits, including a contribution to increased wear resistance. Additionally, it provides for a more homogeneous grain structure, free of (e.g. better heat dissipation). This is because the imperfections act as points of diffusion, effectively "blocking" or de-grading the thermal properties of the metal at those points.

A second mechanism, even more important to increased wear resistance, is the precipitation of eta-carbides in carbon steels. This has been documented by a team of Japanese researchers in a technical paper presented at ISIJ.

In order to understand its significance, it is important to realize that the introduction of carbon to iron is what fundamentally makes steel. Carbon,(C) a non-metal, is chemically dissolved into iron (Fe). Chemically, the largest amount of carbon that can be dissolved into iron is somewhere around 7%. "High carbon" steels - those that are recognized for their high wear resistance properties - they are often thinking about Tool Steels that may have somewhere between 0.7% and 1.2% Carbon content. A little bit of carbon goes a long way in enhancing the wear resistance of steels.

Carbon - diamond is the hardest element. By chemically blending it with iron (Fe), it effectively protects the iron molecules by providing a tough, highly wear resistant molecularly bonded partner.

On the down side, the more carbon that you add, the less ductile that the metal becomes. You could also say that it becomes more brittle or that it loses toughness (in a machine tool sense). So it is always a balancing act of having high carbon for high wear resistance versus not too much whereas the steel fails due its reduced ductility/ increased brittleness.

Carbon is critical to wear resistance in steels. When carbon steels (and cast irons, etc.) undergo a cryogenic treatment, free carbon atoms are able to locate themselves within the chemical lattice of the iron / carbon (Fe-C) matrix in a place where they are more atomically attracted. This modification to the carbon improve wear resistance of carbon steels, cast irons, etc. In general terms, the more carbon, the better the effect.

It occurs because of the result of TTT (Time Temperature Transformation) process. When steels are brought to a very low temperature (e.g. -300 F) for extended periods, heat is removed. As a result, molecular activity is reduced -- or molecular movement is minimized (at theoretical absolute zero, which is about -460 F, there is no molecular movement.) So as heat comes back into the steel, e.g. as it gradually warms up, kinetic activity (molecular motion) increases and carbon atoms actually "tweak" themselves into a more ideal position within the chemical matrix. In a simply stated version, free carbon atoms are attracted to open spots within the iron matrix. This mechanism, ever so slight, can have big implications on increased wear resistance. It is the mechanism that the Japanese team documented and in my view is the one that is most critical to improving wear resistance in carbon steels.

Finally, the third mechanism is residual stress relief. Einstein observed that matter is at its most relaxed state when it has the least amount of kinetic energy (or molecular activity). With a proper cryogenic treatment, any metal will be relaxed and residual stresses relieved. It is perhaps the least recognized benefit of cryogenic treatment. Parts that "walk" or "creep" during machining are the result of residual stresses in the metal that have been machined away that were keeping the part in a certain plane. So more and more people are cryogenically stress relieving metal parts to reduce the creep and walk factors that causes parts to go out of round or flat and fail critical tolerances. This is most successfully done after rough-cut and before final machining. Again, this can benefit any metal and is unrelated to the other mechanisms cited above.

Chapter 2

Literature survey

CHAPTER 2

LITERATURE SURVEY

Following are the overview of the relevant work done related to cryogenic treatment .It gives the description of literature reviewed from various research papers published in international and national journals, proceedings of various conferences and books.

D.Mohanlal, S.Renganarayana, A.Kalanidhi et al. (2001) has defined that cryogenic treatment is an inexpensive one time permanent treatment affecting the entire section of the component unlike coatings. The treatment is an add-on process over conventional heat treatment in which samples are cooled down to prescribed temperature level. Hence it improves the wear resistance of treated samples then that of untreated ones.

K.Matsunga, T.Ishikawa, S.Kajii, T.Hogami et al. (2001) has investigated the properties of the most promising material Si-Ti-C-O and have experimented the enhancing properties of this material by cryogenics and also concludes that the thermal conductivity became low thereby acting as a shock resistant insulating wall in various fields.

Z.Zhang, P.Klien et al. (2004), highligts the use of liquid nitrogen in cryogenics. The storage of lightweight pressure vessels for transportation of liquefied gases has been increasingly used for ground and air vehicles. So with respect to friction and wear properties the liquid nitrogen is used and the properties are found out. After the reduction in testing temperature. It had also contributed to the reduction in shear stresses during sliding.

B.Subramaniam, K.Kato, K.Adachi, B.Basu et al. (2005) explains the friction and wear properties of different solid lubricant coatings used in the bearings of high speed cryogenic turbo pumps of liquid rocket engines which were experimented in liquid nitrogen immersed conditions. He found that the solid lubricant coatings were showing promising results as in liquid nitrogen the properties have a decreasing trend with increase in sliding speed.

A.Bensley, A.Prabhakaran, D.Mohanlal, G.Nagarjan et al. (2005) presents an analysis with the pin on disk wear test and carried out for three different load conditions and seven sliding speeds for the samples which has undergone three different treatments namely conventional heat treatment, shallow cryogenic treatment and deep cryogenic treatment. He found that the wear resistance has been considerably increased due to shallow cryogenic treatment and deep cryogenic treatment and includes much more improvement compared to conventional treatment. The wear resistance is much better in deep cryogenic treatment.

A.Y.L.Yong, K.H.W.Seah, M.Rahman et al. (2006) describes a study on the effects of cryogenic treatment of tungsten carbide. The main aim of this study is to analyze the differences in tool performance between cryogenically treated and untreated tools. He showed in his study that under certain conditions cryogenic treatment is detrimental to tool life and performance. It was also shown that cryogenically treated tools perform better than untreated tools.

Chris Y. Yuan, Hong C. Zhang, Gregory Mckenna, Carol Korzeniwski, Jianzhi Li et al. (2006) presents the results from a study of cryogenic decomposition as potential alternative recycling method for obsolete printed circuit board scraps. In this method liquid nitrogen is used to form a environment as low as 77k for PCB treatment. Then theses scraps wee investigated, analyzed and demonstrated that energy absorbed during the impact test for the cryogenically treated boards is insignificantly different from those without the treatment.

A.Bensley, D.Senthilkumar, D.Mohanlal, G.Nagarajan, A.Rajadurai et al. (2006), reviews his research work that improving the mechanical properties of crown wheel and pinion components. Both the crown and pinion are made from chromium nickel stresses components of automobile. The results confirm that the tensile behavior is reduced after cryogenic treatment for 815M17 when compared with conventional heat treatment.

J.C.Burton, P.Taborek, J.E.Rutledge et al. (2006) uses a sliding block cryotribometer designed to measure friction at cryogenic temperatures and. An optical cryostat and high-speed video was used. The purpose of measurements described here is to provide a survey of friction behavior over a wide range of temperature for materials of engineering importance. He concludes that PTFE coatings on stainless steel could be recycled to cryogenic temperatures many times and survive intact with no degradation of their properties.

Steven T.Downey II, Nicholas Bembridge, Peter N.Kalu, Herbert M.Miller, Gregory S. Rohrer, Ke Han et al. (2007) investigates the grain boundary character distribution of 316LN satinless steel exposed to both elevated and cryogenic temperature. The results were analyzed on significant changes in the overall brain boundary character. The results of this study shows that the grain boundary character distribution of this steel is similar to other poly crystals and not affected by typical thermal treatments in processing or cryogenic temperatures.

Birgit Kannbieber, Wolfgang Malzer, Marcel Pagels, Lars Luhl, Gundolf Weseloh et al. (2007) demonstrates the use of the microprobe in combination with a cold nitrogen gas stream for the cryogenic fixation of specimens. This paper demonstrates the capabilities of 3D micro- XRF under cryogenic conditions for investigations of biological specimens. This shows that with cryogenic fixation the specimen is stable in the order of several hours.

Chapter 3

Methodology

CHAPTER 3

METHODOLOGY

Cryogenic treatment is the process of treating metal parts at very low temperature at about -196°C. This process can be achieved b slowly cooling the metal specimens in the chamber containing liquid nitrogen (LN2) for a period of time (24 hrs) and allowing them to warm-up to the room temperature. Due to this treatment the soft retained austensite is transformed into hard martensite. There is also a precipitation of carbides in the martensite and decreases the residual stresses in tool steel. Therefore the tool life of tool steels increases.

3.1 PREPARATION OF SPECIMENS

Extensive experiment was done to determine the mechanical properties of treated and untreated metal specimens. The specimens were cut according to the ASTM standards of standard metric. And the dimensions are the following. (14)

Table 3.1 Specimens

TEST	NAME OF THE SPECIMEN	NO: OF SPECIMEN	DIMENSION
Tensile test	EN8 Steel	2	180 mm
	Mild steel	2	180 mm
	Aluminum	2	180 mm
Hardness test	EN8 steel	2	15 mm
	Mild steel	2	15 mm
	Aluminum	2	15 mm
Wear test	EN8 steel	2	30 mm
	Mild steel	2	30 mm
	Aluminum	2	30 mm

The surface of the specimen is smoothened with the emery sheets. And the grades used for smoothening the specimens are 200 and 400. This is done in order to get a good surface finish.

3.2 TREATMENT IN MUFFLE FURNACE

The EN8 steel and mild steel were kept in the muffle furnace for continuous heat treatment. A muffle furnace is a continuous heat treatment passage of material throughout the specimens, the production cycle of which includes a treatment of predetermined duration at a temperature which may be about 910°C, in which furnace is heated by a flame producing burner without the combustion gases directly contacting the specimens to be treated. This furnace comprises an inlet zone provided casing provided around the muffle, a heating zone provided inside a heat-insulated chamber provided with at least one means for circulating combustion gases around the heating zone of the muffle, and an outlet zone provided with at least one means for controlling the cooling rate of the treated specimen. For the heat treatment of refractory or carbon-containing products, impregnated with a carbon-containing material such as pitch, the pyrolysis of which produces combustible vapors, the heating zone is divided into three sections by means of an additional partition- a zone for exuding and removing volatile materials from the pitch; a zone for pyrolyzing and carbonizing the pitch and a final firing zone.(12)

This process is employed to relieve internal stresses.No microstructural changes occur during the process.In this sense it differs from other subcritical treatments in which the structural improvement takes place.Internal stresses are those stresses which can exist within a body in the absence of external forces.These are also known as residual stresses or locked in stresses.Internal stresses under certain conditions can have adverse effects.For example steels with residual stresses under corosive environment fail by stress-corrsion cracing whereas in general failure by stress-corrosion cracking occurs under the combined action of corrosion and externally applied stresses, these stresses also enhance the tendency of steels towards warpage and dimensional instability. Fatigue strength is reduced considerably when resiual tensile stresses are present in the steel.The problems associated with internal stresses are more difficult in brittle materials than in ductile materials.

The process of stress relieving consists of heating steel uniformly to a temperature below the lower critical temperature, holding at this temperature for a sufficient time,followed by uniform cooling will itself result in the development of internal stresses.hence the very purpose of stress relieving will be lost.The extent to which stresses can be relieved depend on the temperature employed and holding time.

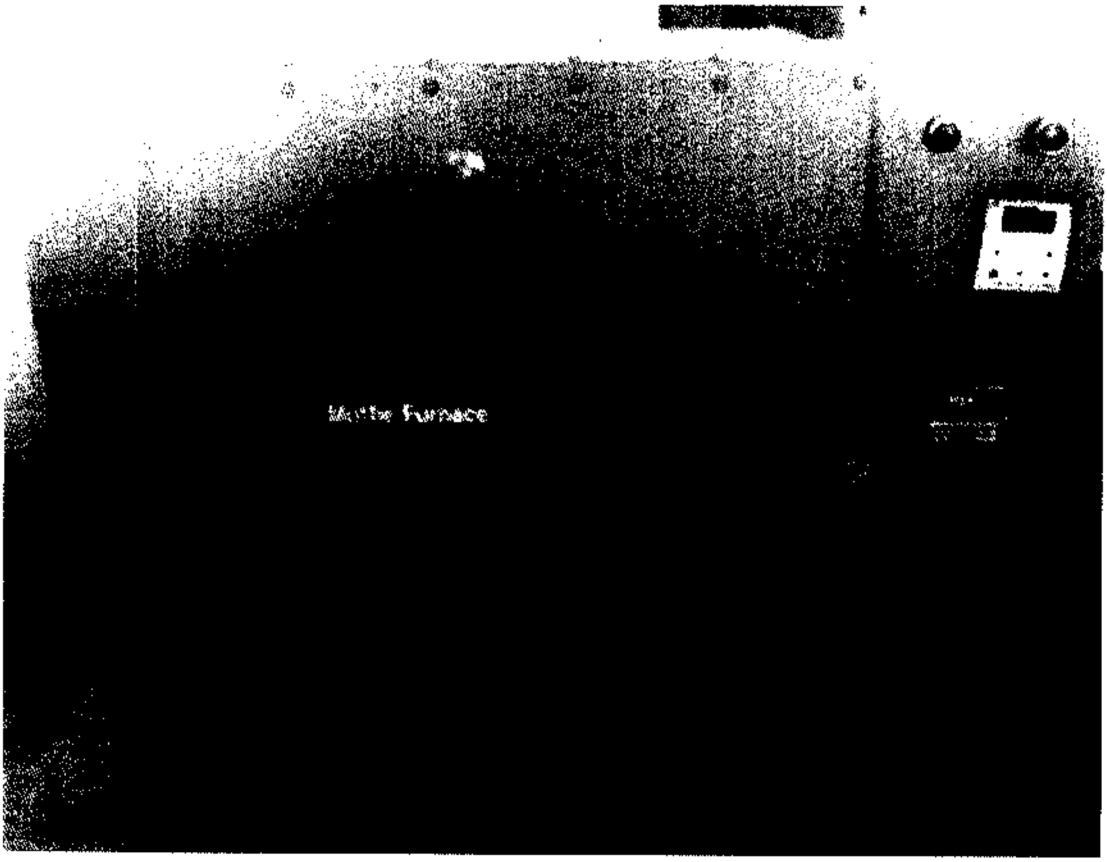

Figure 3.1 muffel furnace

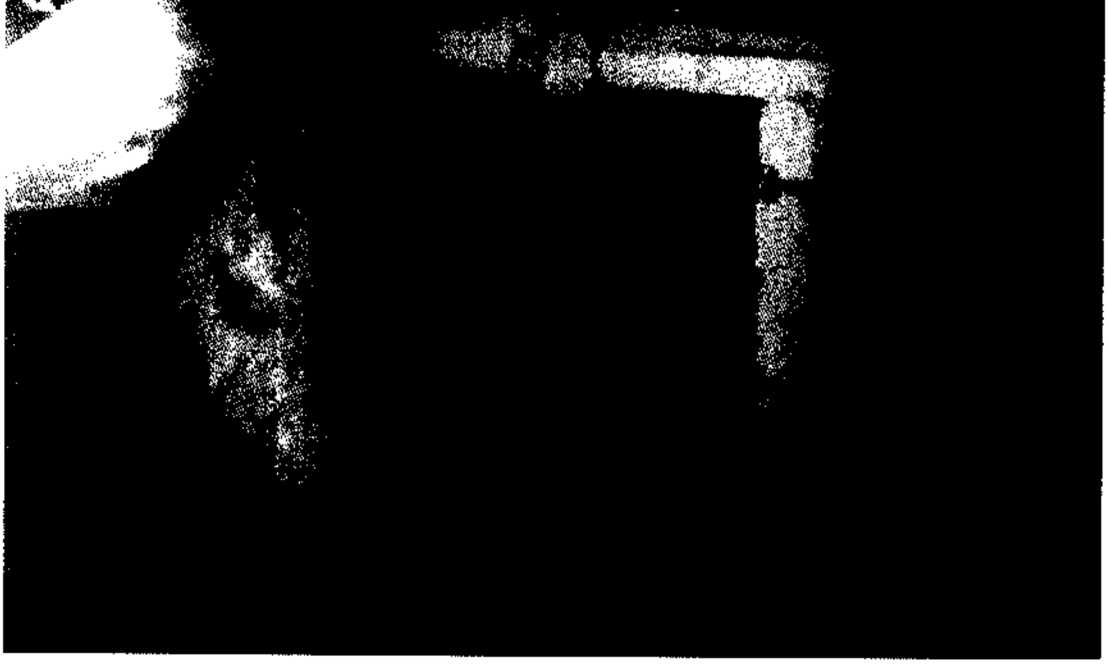

Figure 3.2 Furnace chamber

3.3 CRYOGENIC QUENCHING

In Cryogenic quenching the metal specimens are immersed at very low temperatures of about -196°C. This process can be achieved by slowly cooling the metal specimens in the chamber containing liquid nitrogen (LN2) gas for a period of time (12 hrs) and allowing them to warm-up slowly up to the room temperature.

After the specimens are quenched in the liquid nitrogen for 12 hours where in the hardening of the specimens occur. Hardness is a function of the Carbon content of the steel. Hardening of steel requires a change in structure from the body-centered cubic structure found at room temperature to the face-centered cubic structure found in the Austenitic region. The steel is heated to Austenitic region. When suddenly quenched, the Marten site is formed. This is a very strong and brittle structure. When soft structure. When the cooling rate is extremely slow then it would be mostly Pearlite, which is extremely soft. Harden ability, which is a measure of the depth of full hardness achieved, is related to the type and amount of alloying elements. Different alloys, which have the same amount of Carbon content, will achieve the same amount of maximum hardness; however, the depth of full hardness will vary with the different alloys. The reason to alloy steels is not to increase their strength, but increase their harden ability - the ease with which full hardness can be achieved throughout the material.

Usually when hot steel is quenched, most of the cooling happens at the surface, as does the hardening. This propagates into the depth of the material. Alloying helps in the hardening and by determining the right alloys one can achieve the desired properties for the particular application. Such alloying also helps in reducing the need for a rapid quench cooling - thereby eliminates distortions and potential cracking. In addition, thick sections can be hardened fully.

Cryogenics or deep freezing is done to make sure there is no retained Austenite during quenching. The amount of Marten site formed at quenching is a function of the lowest temperature encountered. At any given temperature of quenching there is a certain amount of Marten site and the balance is untransformed Austenite. This untransformed Austenite is very brittle and can cause loss of strength or hardness, dimensional instability, or cracking. Quenches are usually done to room temperature. Most medium carbon steels and low alloy steels undergo transformation to 100% Marten site at room temperature. However, high carbon and high alloy steels have retained Austenite at room temperature. To eliminate retained Austenite, the quench temperature has to be lowered. This is the reason to use cryogenic quenching. The components used for cryogenic quenching are:

Liquid nitrogen – the liquid nitrogen (LN2) gas is used as the coolant and the lowest temperature that can be achieved by soaking the specimens was -196°C.

Process chamber – insulated chamber that could hold liquid nitrogen and specimens for an adequate duration without refilling.

Liquid nitrogen container – container liquid nitrogen used to supply a jet of evaporated nitrogen gas into the chamber through a fine flow control valve.

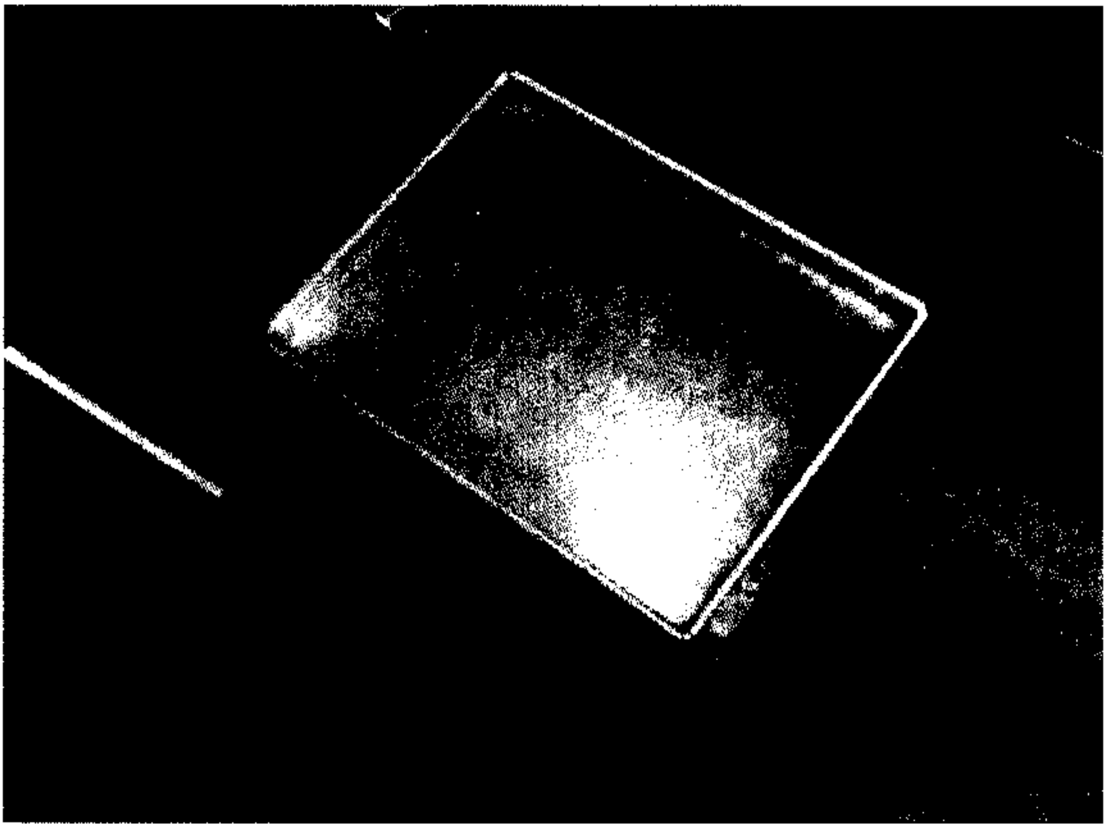

Figure 3.3 Cryogenic apparatus

3.3.1 Liquid nitrogen

Addition of highly ionized salts to water decreases the viscosity of water and reduces the duration of vapor blanket stage. Both these parameters help in quenching bath. However, by increasing the degree of agitation, the cooling rate may be increased further. In this way the possibility of formation of soft spots arising from the presence of steam pockets is reduced to a great extent. Aqueous solutions of salts such a sodium chloride, liquid nitrogen and calcium chloride are referred to as brine solutions whereas solution of sodium hydroxide is referred to as caustic solution. Such solution are of great use especially for shallow harden able grades of steel. Though the cooling rates are high in these solutions, distortion is less severe than in water quenching. Just as in the case of water these solutions too are commonly used at room temperature. Special attention should be paid to the periodical checking of handling equipments and to solution, which in turn raises the labor cost. (12)

Figure 3.4 Liquid nitrogen container

The specimens are left in the atmospheric air for cooling after the cryogenic quenching process. Tempering refers to heating steel above a critical temperature, then cooling it rapidly to freeze it in a very hard state followed by re warming it to an intermediate temperature to give hardness suitable for the job intended. (13)

Heating the metal above a critical temperature (usually red hot and non-magnetic) causes this steel carbide to mix uniformly with the steel in a non-crystalline form (called austenite). Slow cooling at this point (e.g. buried in wood ash or lime) results in a soft-layered crystalline structure and is referred to as annealing. Rapid cooling in water or oil results in a very hard crystalline structure (called martensite). The creation of either extreme requires, however, heating to the critical temperature first to form austenite. In the as quenched martenstic condition the steel is too brittle for most applications .The formation of marten site also forms high residual stresses in the steel. Therefore hardening is almost followed by tempering or drawing which consists of heating the steel to some temperature below the critical temperature. The purpose of tempering is to relieve the residual stresses and to improve the ductility and toughness of the steel. This increase in ductility is usually attained at the sacrifice of the hardness of growth. The tempering is a dividing line between applications that require high hardness and that requiring high toughness .If the principal property is hardness or wear resistance, the part is tempered below 400°F, if the primary requirement is toughness the part is tempered above 800°F. (13)

A study of the constitution and structure of all steels and irons must first start with the iron-carbon equilibrium diagram. Many of the basic features of this system influence the behavior of even the most complex alloy steels. For example, the phases found in the simple binary Fe-C system persist in complex steels, but it is necessary to examine the effects alloying elements have on the formation and properties of these phases. The iron-carbon diagram provides a valuable foundation on which to build knowledge of both plain carbon and alloy steels in their immense variety. It should first be pointed out that the normal equilibrium diagram really represents the metastable equilibrium between iron and iron carbide (cementite). Cementite is metastable, and the true equilibrium should be between iron and graphite. Although graphite occurs extensively in cast irons (2-4 wt % C), it is usually difficult to obtain this equilibrium phase in steels (0.03-1.5 wt %C). Therefore, the metastable equilibrium between iron and iron carbide should be considered, because it is relevant to the behavior of most steels in practice.

There are several temperatures or critical points in the diagram, which are important, both from the basic and from the practical point of view.

Firstly, there is the A_1, temperature at which the eutectoid reaction occurs (P-S-K), which is 723°C in the binary diagram.

Secondly, there is the A_3, temperature when α-iron transforms to γ-iron. For pure iron this occurs at 910°C, but the transformation temperature is progressively lowered along the line GS by the addition of carbon.

The third point is A_4 at which γ-iron transforms to δ-iron, 1390°C in pure iron, hut this is raised as carbon is added. The A_2, point is the Curie point when iron changes from the Ferro- to the paramagnetic condition. This temperature is 769°C for pure iron, but no change in crystal structure is involved. The A_1, A_3 and A_4 points are easily detected by thermal analysis or dilatometer during cooling or heating cycles, and some hysteresis is observed. Consequently, three values for each point can be obtained. Ac for heating, Ar for cooling and Ae (equilibrium}, but it should be cooling, as well as to the presence of alloying elements.

The great difference in carbon solubility between γ- and α-iron leads normally to the rejection of carbon as iron carbide at the boundaries of the γ phase field. The transformation of γ to α - iron occurs via a eutectoid reaction, which plays a dominant role in heat treatment.

The three phases, ferrite, cementite and pearlite are thus the principle constituents of the infrastructure of plain carbon steels, provided they have been subjected to relatively slow cooling rates to avoid the formation of metastable phases.

The austenite- ferrite transformation

Under equilibrium conditions, pro-eutectoid ferrite will form in iron-carbon alloys containing up to 0.8 % carbon. The reaction occurs at 910°C in pure iron, but takes place between 910°C and 723°C in iron-carbon alloys.
However, by quenching from the austenitic state to temperatures below the eutectoid temperature Ae_1, ferrite can be formed down to temperatures as low as 600°C. There are pronounced morphological changes as the transformation temperature is lowered, which it should be emphasized apply in general to hypo-and hyper-eutectoid phases, although in each case there will be variations due to the precise crystallography of the phases involved. For example, the same principles apply to the formation of cementite from austenite, but it is not difficult to distinguish ferrite from cementite morphologically.

The initial development of grain boundary allotriomorphs is very similar to that of ferrite, and the growth of side plates or Widmanstaten cementite follows the same pattern. The cementite plates are more rigorously crystallographic in form, despite the fact that the orientation relationship with austenite is a more complex one. As in the case of ferrite, most of the side plates originate from grain boundary allotriomorphs, but in the cementite reaction more side plates nucleate at twin boundaries in austenite.

The austenite-pearlite reaction

Pearlite is probably the most familiar micro structural feature in the whole science of metallography. Pearlite is a very common constituent of a wide variety of steels, where it provides a substantial contribution to strength.

These structures have much in common with the cellular precipitation reactions. Both types of reaction occur by nucleation and growth, and are, therefore, diffusion controlled. Pearlite nuclei occur on austenite grain boundaries, but it is clear that they can also be associated with both pro-eutectoid ferrite and cementite. In commercial steels, pearlite nodules can nucleate on inclusions.

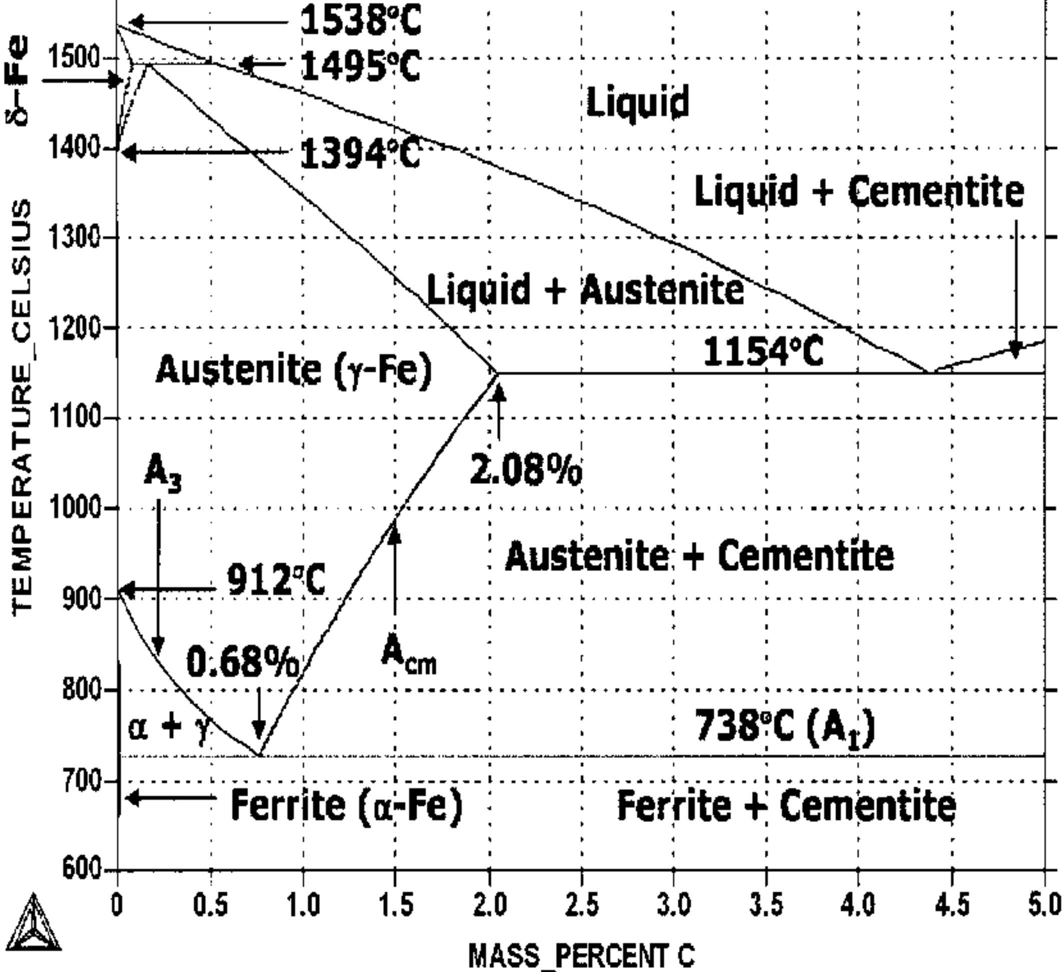

Figure 3.5 Fe-C phase diagram

Chapter 4

Testing methods

CHAPTER 4

TESTING METHODS

The effect of cryogenic treatment in the steels specimen can be analyzed by conducting the various tests on both treated and untreated specimens. After the specimens were prepared according to the above steps the tensile, hardness and wear tests were carried out.

4.1 TENSILE TEST

Tensile test is one of the most widely performed tests. Various properties of the material hat can be determined are yield stress, upper and lower yield points, tensile strength, elongation and reduction in area. Here universal testing machine is used for performing the tensile test. Figure shows dimensions of the specimen for tensile test. The specimen is subjected to tensile load till fracture occurs. Results of such a tensile test can be represented in the form of engineering stress strain curve. Tensile strength also known as ultimate tensile strength is defined as the maximum stress, which a material can withstand it, is obtained by dividing maximum load by original cross sectional area of tensile specimen. Tensile strength also provides a fair good idea about hardness and fatigue strength of the material.(12)

Technical specifications

Measuring cap (KN)	-	1000
Measuring range	-	0-1000
Least count	-	0.1
Load range in KN	-	20 to 1000
Resolution of piston movement	-	0.1
Max tensile clearance at Fully descended piston position	-	50 to 850
Max clearance for compression Test (mm)	-	0-850
Distance between columns (mm)	-	750
Piston stroke	-	250
Max straining speed at no Load (mm/min)	-	80

TENSILE TEST OF EN8 STEEL

Tensile strength of untreated EN8 steel = 444.30N/mm2

Tensile strength of treated EN8 steel = 544.88N/mm2

% Of improvement = 22.63 %

TENSILE TEST OF MILD STEEL

Tensile strength of untreated mild steel	=	481.22N/mm2
Tensile strength of treated mild steel	=	488.86N/mm2
% Of improvement	=	1.58 %

TENSILE TEST OF ALUMINIUM

Tensile strength of untreated aluminum	=	227.88N/mm2
Tensile strength of treated aluminum	=	227.88N/mm2
% Of improvement	=	0 %

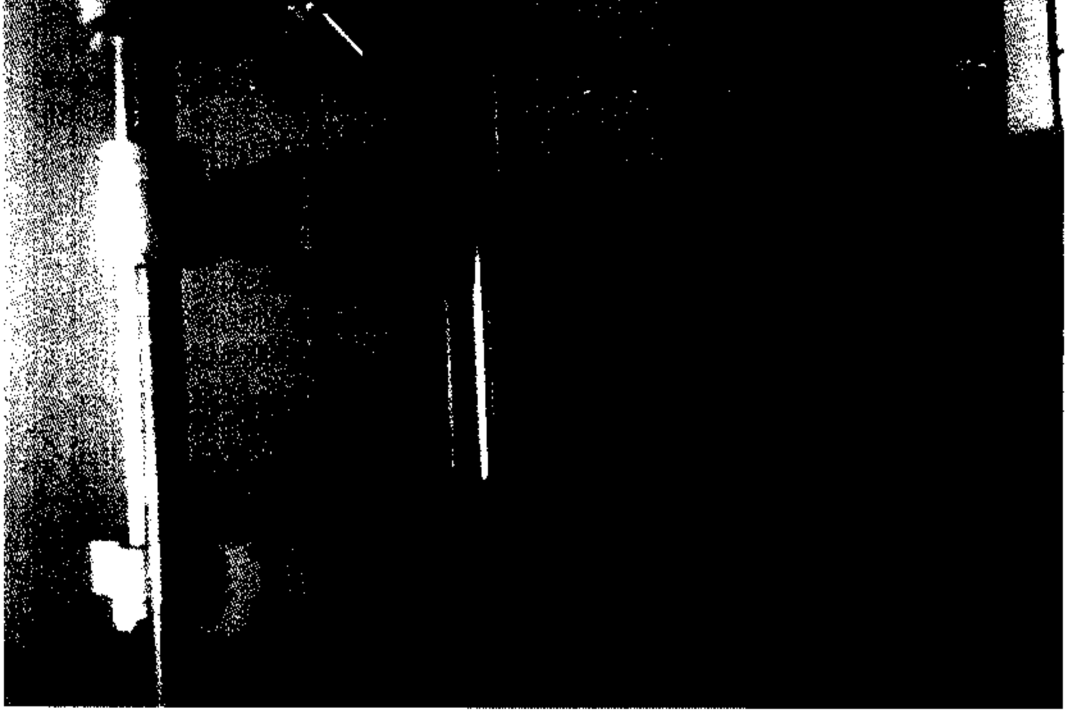

Figure 4.1 Universal testing machine

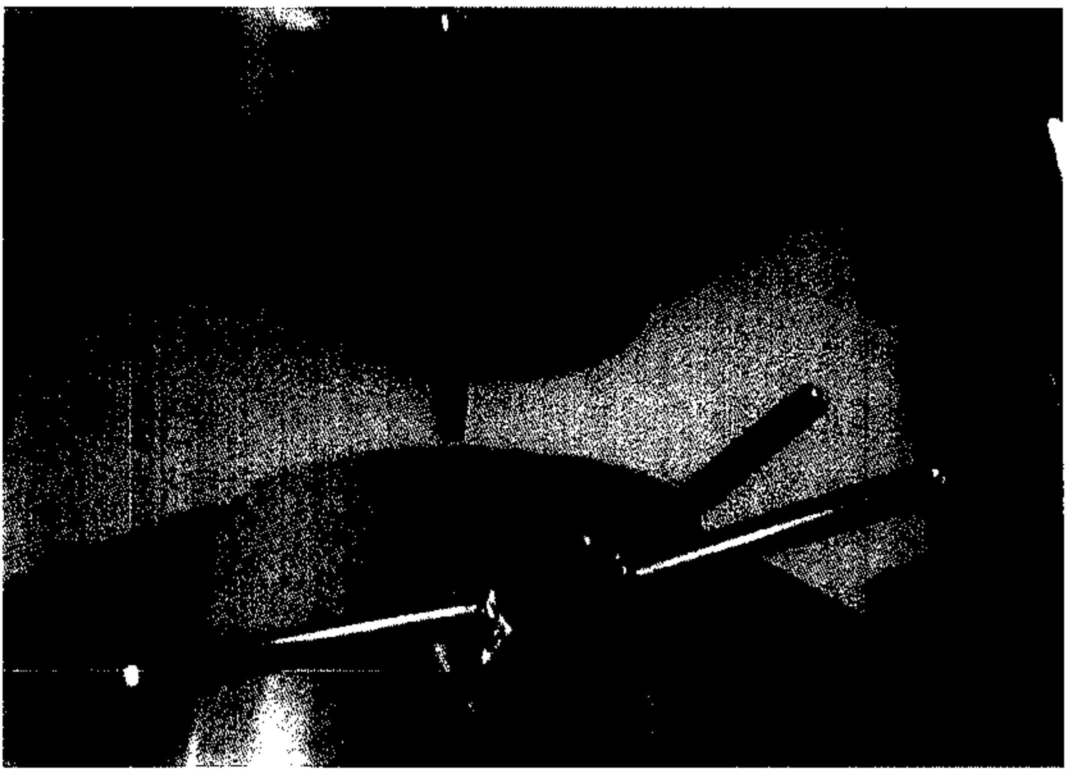

Figure 4.2 Ram holding the specimen

This test differs from both the Brinell and Vicker's hardness test in the sense that here the depth of penetration and not the surface area is used as the parameter for arriving at the hardness value. It works on the principle that the depth of penetration varies with the hardness of material. The higher the hardness the smaller will be the depth of penetration and vice versa. The readings on the dial gauge are calibrated with respect to the depth of penetration. Thus no calculation is required. However the test is very popular in day-to-day industrial practice. There are two basic reasons for this. Firstly this is a fast process and secondly very small indentation is made on the surface. (13)

In Rockwell hardness test in order to determine the hardness of a material a 120° diamond cone also known as Brale indenter or 1/16" and 1/8" diameter steel balls are generally used as indenter. Loads of 60,100 and 150 Kgs are generally used. Depending on the combination of load and indenter various scales are incorporated I the same dial of Rockwell hardness tester. It is very important to write the symbol while denoting Rockwell hardness number. A minor load serves a number of purposes like it takes care of scratches on the surfaces or coarse surface finish and reduces tendency towards ridging or sinking in.

4.2.1 ROCKWELL HARDNESS TEST

4.2.1.1 Steps in Rockwell hardness test

- This hardness test uses a direct –reading instrument based on the principles of different depth measurement.
- The test is carried out by slowly raising the specimen against the indenter until a fixed minor load has been applied.
- This is indicated on the dial gauge.

- After the dial pointer comes to rest, the major load is removed and with the minor load still acting the Rockwell hardness number is read on the dial gauge.
- A shallow impression on a hard material will result in a high number while e deep impression on a soft material will result in a low number. (13)

4.2.1.2 Applications of Rockwell hardness test

Finished parts, such as bearings, bearing races, valves, nuts, bolts, gears, pulleys, rolls, pins, pivots, stops, cutting tools such as saws, knives, chisels, scissors, forming tools, small castings and forgings, sheet metal, large–diameter wire, electrical contacts, plastic sheet or parts, case hardened parts, cemented carbides. (13)

4.2.1.3 Advantages of Rockwell hardness test

- The Rockwell hardness test is rapid and simple in operation.
- Since the loads and indenters are smaller than those used in the brinell hardness test.
- This test can be used in thinner specimens.
- The hardest as well as the softest materials can be tested. (13)

4.2.1.4 Data

Table 4.1 RHT of EN8 steel

Material	Load kg	Penetrator used	Scale used	Rockwell hardness number
Untreated EN8 steel	150	Diamond cone	C	86 92 93
Treated EN8 steel	150	Diamond cone	C	95 92 95

The percentage of improvement in hardness of EN8 steel is 4.05 %

Table 4.2 RHT of MS

Material	Load kg	Penetrator used	Scale used	Rockwell hardness number

Mild steel				65 68
Treated Mild steel	150	Diamond cone	C	74 71 70

The percentage of improvement in hardness of Mild steel is 11.39 %

Table 4.3 RHT of Aluminum

Material	Load kg	Penetrator used	Scale used	Rockwell hardness number
Untreated aluminum	100	1/16 "steel ball 1.5875 mm	B	8 6 7
Treated aluminum	100	1/16 "steel ball 1.5875 mm	B	12 13 13

The percentage of improvement in hardness of aluminum is 80.95 %

Figure 4.3 Hardness testing machine

Figure 4.4 Diamond cone

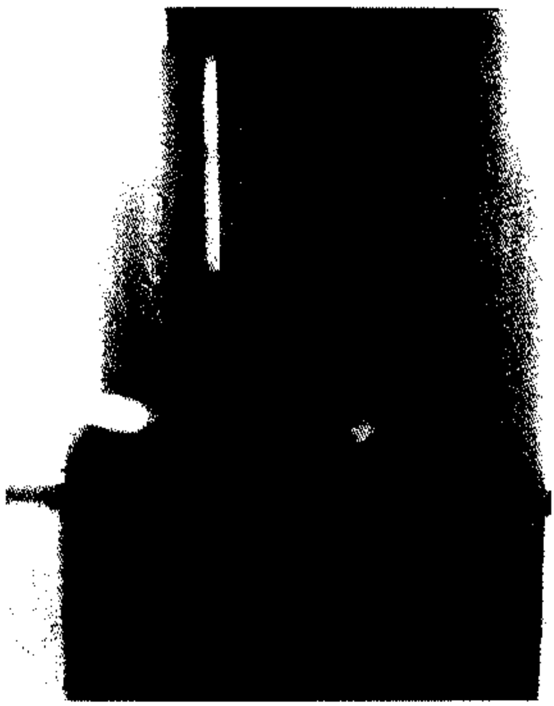

Figure 4.5 stainless steel cone

Figure 4.6 Screw rod

Figure 4.7 Hand lever

4.3 WEAR TEST

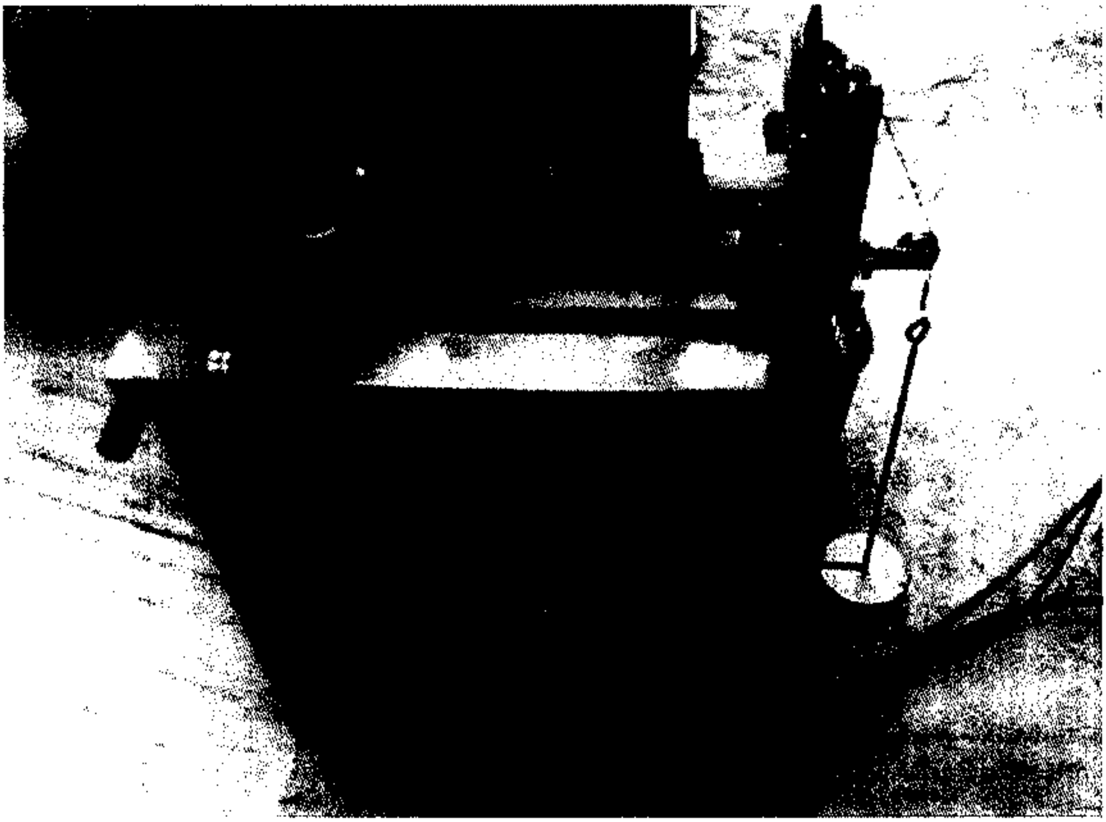

Figure 4.8 Pin on disk

The pin on disk tester represents a substantial advance in terms of simplicity and convenience of operation, ease of specimen clamping and accuracy of measurements, both of wear and frictional force. The machine is designed to apply loads up to 200N and is intended both for dry and lubricated test conditions.

It also facilitates study of friction and wear characteristics in sliding contacts under desired conditions. Sliding occurs between the stationary pin and a rotating disc. Normal load, Rotational speed and wear track diameter can be varied to suit the test conditions. Tangential frictional force and wear are monitored with electronic sensors and recorded on PC. These parameters are available as functions of acquisition system, sensor, and cables.

4.3.1 Specifications

Sample pin size	-	3-12 mm dia
Sample disk size	-	dia 165*8 thick
Wear track diameter	-	50-140 mm
Sliding speed range	-	0.5-2000 m/s
Disc rotation speed	-	150-2000 rpm
Sensor	-	proximity sensor
Normal load	-	1,2,5 kg
Dead weight	-	5-200 N
Frictional force least count	-	0.1
Accuracy	-	0.1+/- 2% of measured Frictional force
Wear range	-	+/- 2
Least count	-	1 micron
Accuracy	-	1+/- 1% of measured Wear
Lubrication system discharge	-	0.5 max L/min
Capacity	-	2 L
Environmental chamber	-	closed chamber
Test duration	-	0-99.59 hours
Electrical	-	230/1/50 VAC
Power	-	2 KVA

4.3.2 Operation procedure

- Thoroughly clean specimen; remove burs formed in the circumference using emery paper.
- Place the specimen pin between the jaws and adjust the height of the pin with respect to the wear disc using height adjustment block after ensuring that the loading arm is parallel to the plane of the wear disc. Tighten the clamping screws on the adjustable jaw to clamp the specimen pin firmly. Swivel the height adjustment block away from loading arm.
- Set required track radius by moving the sliding plate over graduated scale on base plate. Tighten the slider clamping screws and ensure assembly is clamped firmly. Place test weight in the loading pan.

The amount of wear generated depends upon the applied load, sliding speed, sliding distance, material properties and environment. For getting reliable and repeatable wear data, contact between the wear disc and the specimen pin is to be 100 % and virgin material of specimen pin is to be exposed to the wear disc. Because of surface roughness, foreign materials present at the specimen pin surface, initially wear rate is not uniform.

4.3.3 Parameter Specifications (5)

Track diameter	=	0.1 m
Velocity	=	3.61 m/s
Sliding distance	=	1500 m
Load	=	70 Kgs

4.3.4 Data

WEAR OF UNTREATED EN8 STEEL

From the experiment:

33.2 N	=	2 mins
35.6 N	=	4 mins
37.5 N	=	6 mins
Frictional force	=	35.43 N
Initial weight	=	16.7617 gm
Final weight	=	16.7555 gm
Wear	=	56 mg

WEAR OF TRATED EN8 STEEL

From the experiment:

28.2 N	=	2 mins
27.1 N	=	4 mins
25.3 N	=	6 mins
Frictional force	=	26.86 N
Initial weight	=	16.7653 gm
Final weight	=	16.7226 gm
Wear	=	42 mg

Reduction in wear	=	**14 mg**
The percentage of reduction in wear of EN8 steel	=	**25 %**

WEAR TEST OF MILD STEEL

WEAR OF UNTREATED MILD STEEL

From the experiment:

33.0 N	=	2 mins
35.8 N	=	4 mins
37.1 N	=	6 mins
Frictional force	=	35.3 N
Initial weight	=	17.9976 gm
Final weight	=	17.9911 gm
Wear	=	65 mg

WEAR OF TREATED MILD STEEL

From the experiment:

28.2 N	=	2 mins
27.2 N	=	4 mins
27.4 N	=	6 mins
Frictional force	=	27.6 N
Initial weight	=	17.8716 gm
Final weight	=	17.8575 gm
Wear	=	14.1 mg
Reduction in wear	**=**	**50.9 mg**
The percentage of reduction in wear of mild steel	**=**	**21.69 %**

WEAR TEST OF ALUMINUM

From the experiment:

26.1 N	=	2 mins
24.5 N	=	4 mins
14.1 N	=	6 mins
Frictional force	=	21.56 N
Initial weight	=	5.8522 gm
Final weight	=	5.8316 gm
Wear	=	20.6 mg

WEAR OF TREATED ALUMINUM

From the experiment:

30.2 N	=	2 mins
26.7 N	=	4 mins
24.6 N	=	6 mins
Frictional force	=	27.16 N
Initial weight	=	5.8417 gm
Final weight	=	5.7207 gm
Wear	=	12.1 mg

Reduction in wear	=	**8.5 mg**
The percentage of reduction in wear of aluminum	=	**58.73 %**

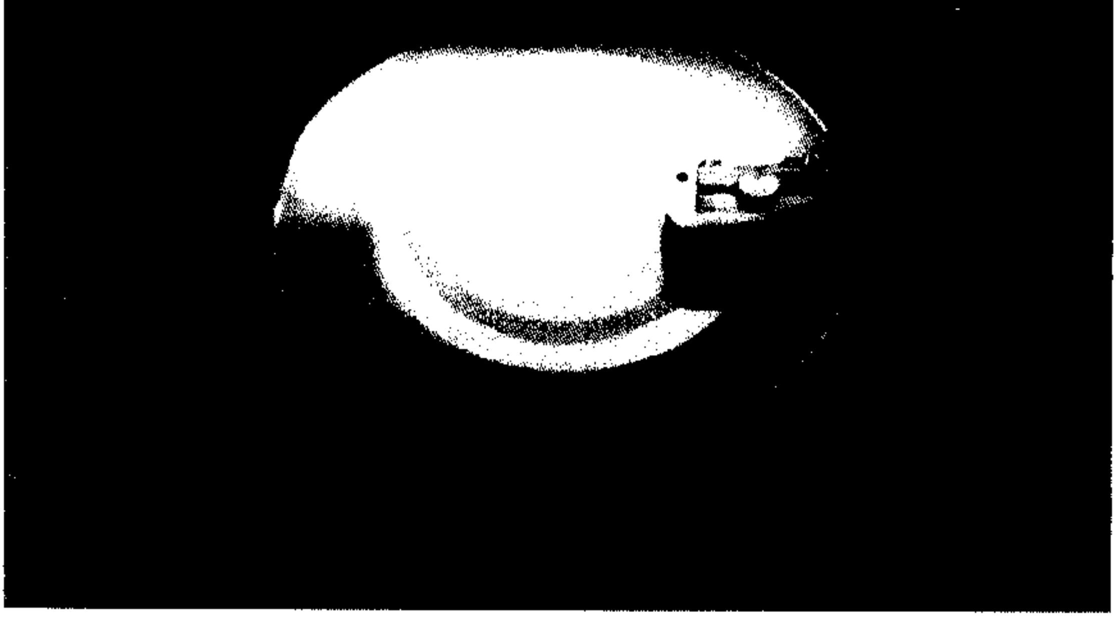

Figure 4.9 Specimen holder

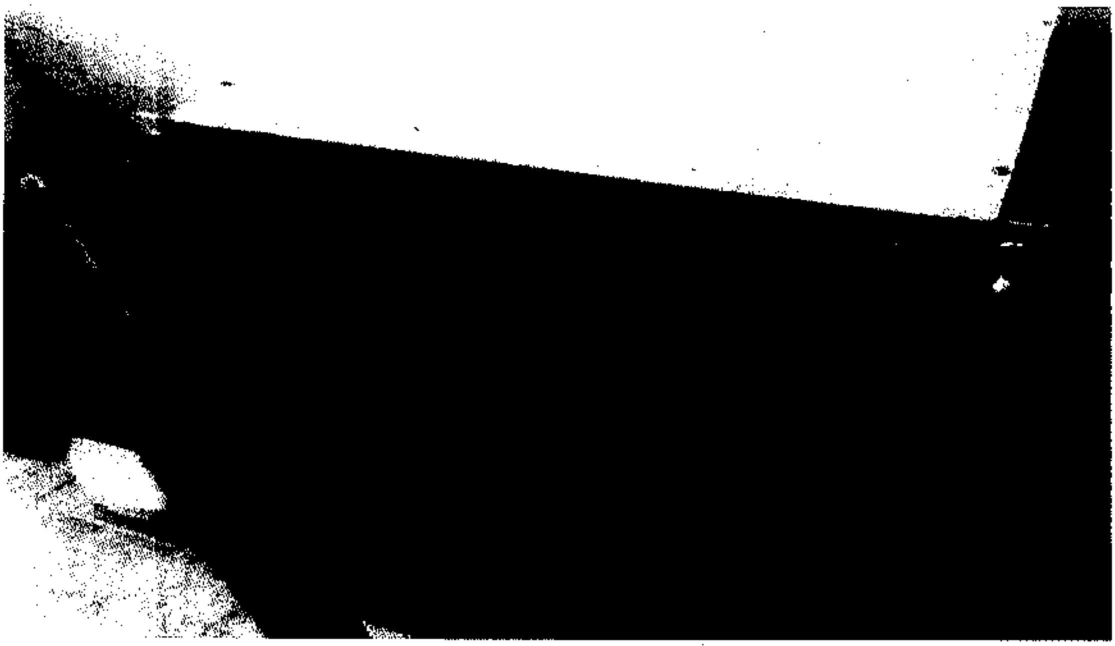

Figure 4.10 Controller

Chapter 5

Results and discussions

CHAPTER 5

RESULTS AND DISCUSSIONS

Heat treatment of steel involves the transformation from its softer more malleable annealed state to a harder more durable state. This is done, as it has been for centuries, by heating the steel and then rapidly cooling it. The result is a harder and more wear resistant object. The metallurgical reason for this is that as the steel is heated, it forms an austenite crystal structure or matrix. Rapidly cooling or quenching the steel (traditionally at room temperature) triggers some of the austenite structure to change into a different matrix called marten site. It's the marten site structure that gives tempered steel its hardness and wear resistance for applications from cutting tools to punch dies.

The goal of heat treatment then is to transform as much of the austenite as possible into marten site. However, some of the austenite is retained even after tempering. Through experiments it was found that if the quench was lower than the traditional room temperature, less austenite was retained. Cryogenic treatment is an extension of the well-known heat and quench cycle. It is specifically about controlled thermal cycling of materials from +300[degrees] F to -300[degrees]F generally approxiamately a 15 to 30 hour period of time.

Longer wearing components, generally extends life of tools and parts. Extended product life, reduce stress, reduced distortion, enhanced performance, reduced heat retention and increased horsepower. Process can be applied to items that are new/used or sharp/ dull: remanufacturing or re sharpening and best of all, sharpening or redressing.

In this project it has been proved that cryogenic treatment imparts more wear resistance when compared to the untreated specimens. The wear loss is very minimal in the wear test. The improvement in the wear resistance and hardness is attributed to the conversion of retained austenite to marten site brought in by cryogenic treatment.

The tensile strength is the value most frequently recorded and cited from the results of tension test. However its value of little significance with regard to the strength of a metal .For ductile metals the tensile strength should be regarded as a measure of the maximum load that a metal can withstand under the very restrictive conditions of uni axial loading. However because of the long practice of using the tensile strength to describe the strength of materials it has become a familiar property and as such is a useful identification of a material in the same sense that the chemical composition serves to identify a metal or alloy. Furthermore tensile strength is easy to determine and is a reproducible property. For brittle materials the tensile strength is a valid design criterion.

The benefits of cryogenics are that it increases the resistance to wear and longer life in most plastics, metals. It also has lower electrical resistance, higher signal to noise ratios in some electronics, improved vibrational characteristics, more rapid and even heat dissipation. These benefits add up to higher efficiency and lower production costs.()

With the following graphs we can interpret that in untreated specimens the breaking point is achieved soon but in treated specimens the breaking point is achieved little late comparatively. However aluminum shows no change.

In the below figure the untreated EN8 steel shows the breaking point at around 170N/mm2. But in treated EN8 steel the breaking point is achieved at around 150N/mm2. This phenomenon is due to the cryogenic treatment of the metal specimen. Because of this there is transformation of austensite into martensite and the retained austensite is precipitated as carbides thereby increasing the hardness. This enables the specimen to break a little later than the untreated specimens.

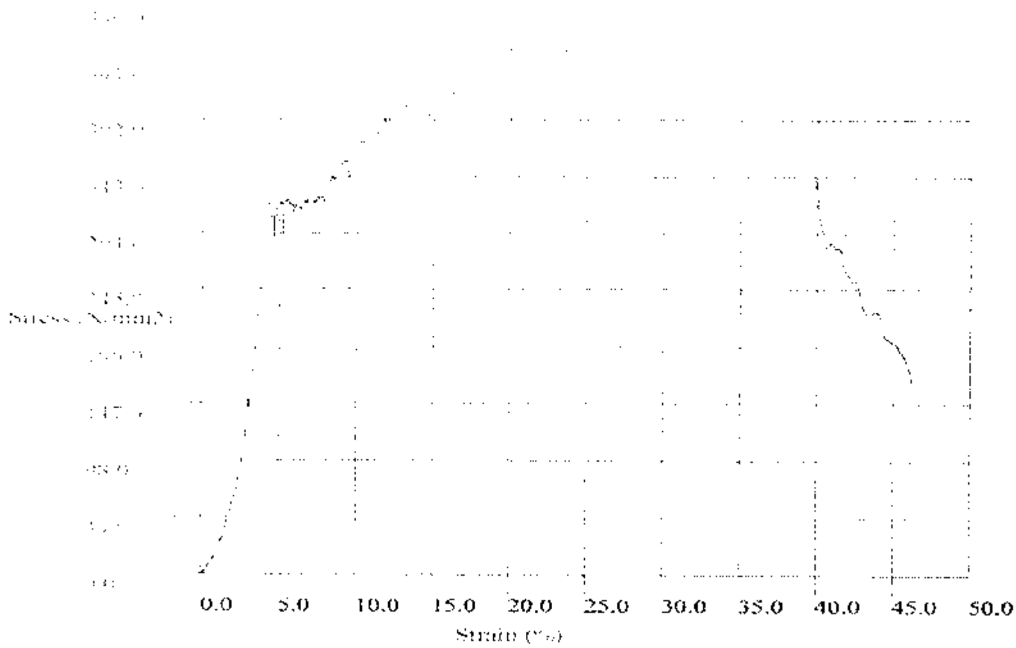

Figure 5.1 Untreated EN8 Steel

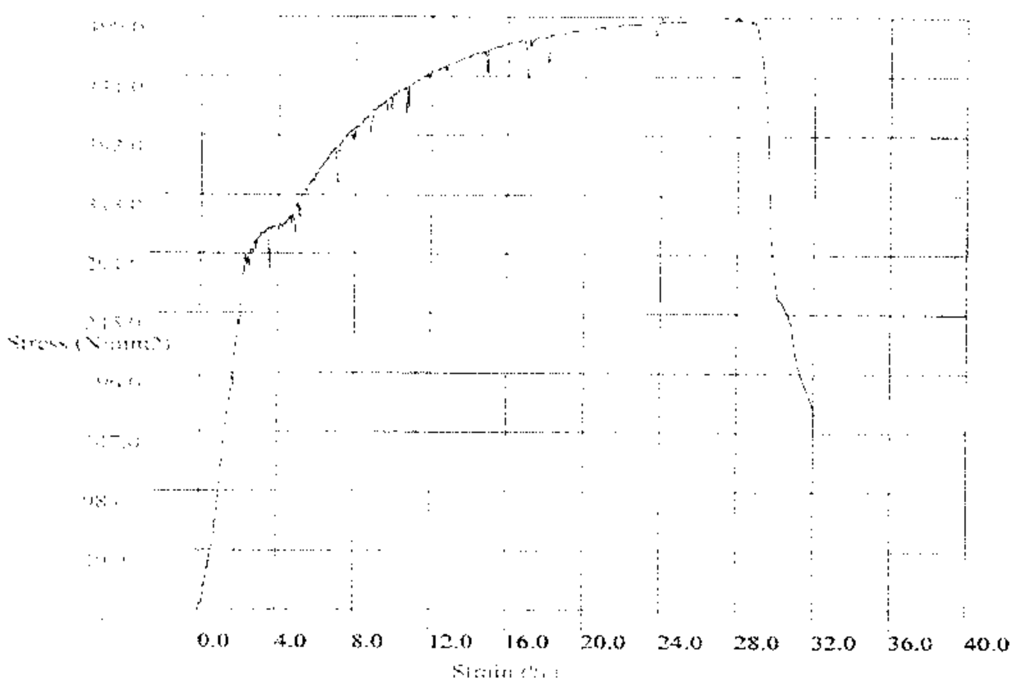

Figure 5.2 Treated EN8 steel

the treated ones. This enables cryogenically treated specimen to be used in a wide range of applications.

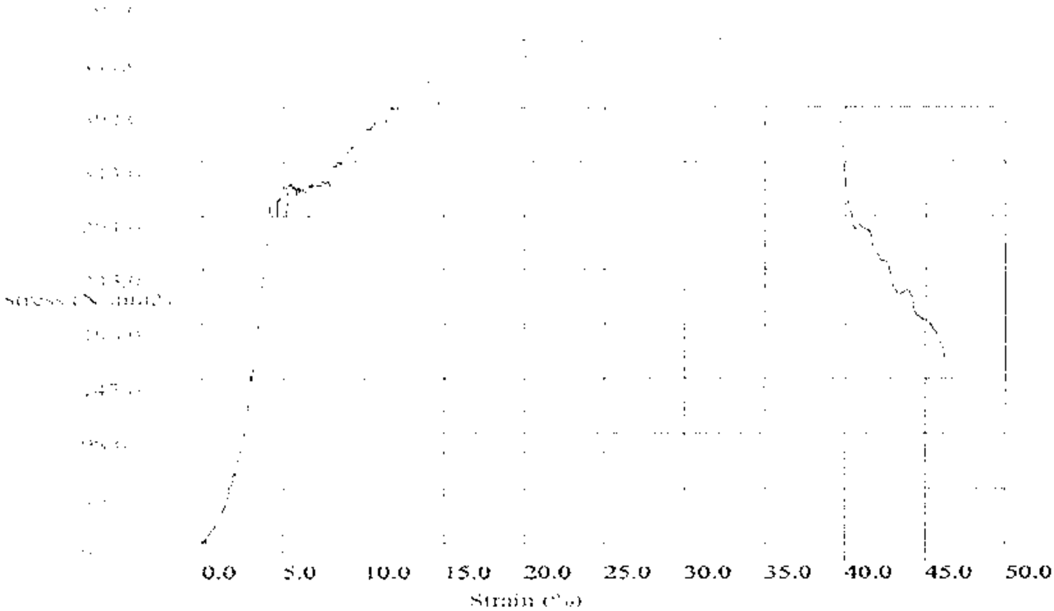

Figure 5.3 Untreated Mild Steel

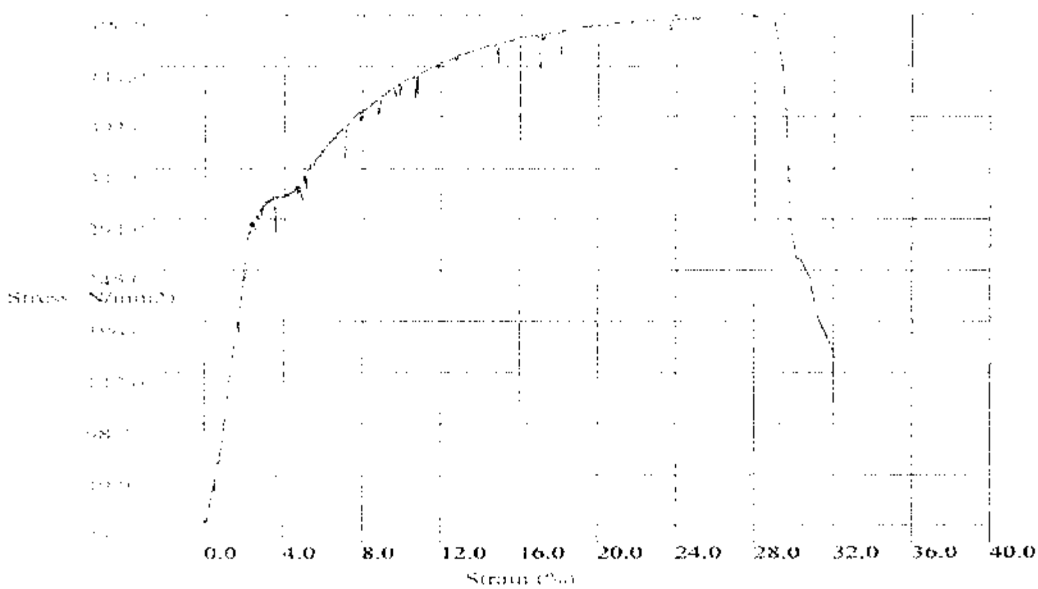

Figure 5.4 treated mild steel

In this following graph, unlike EN8 and mild steel aluminum shows no difference in the breaking point of untreated and treated specimen because the tensile strength does not differ. Hence cryogenically treated aluminum has no effect due to the cryogenic treatment.

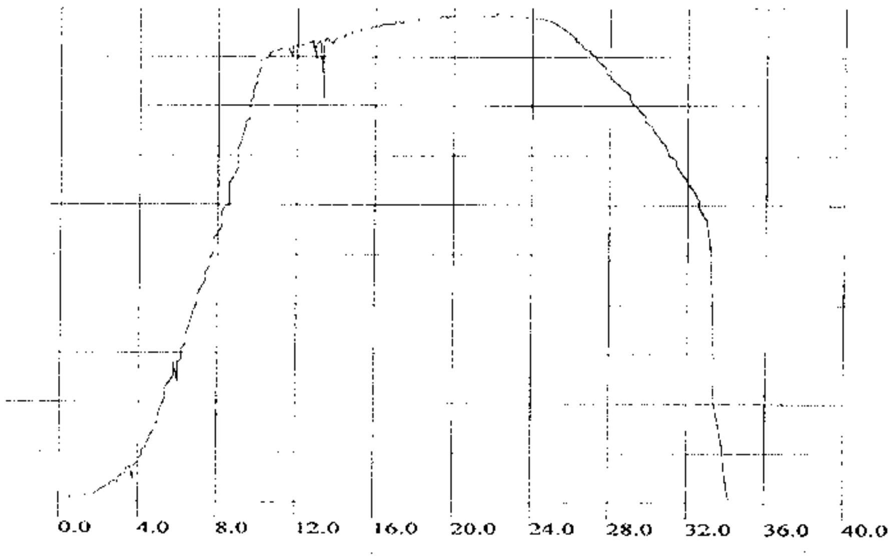

Figure 5.5 Untreated Aluminum

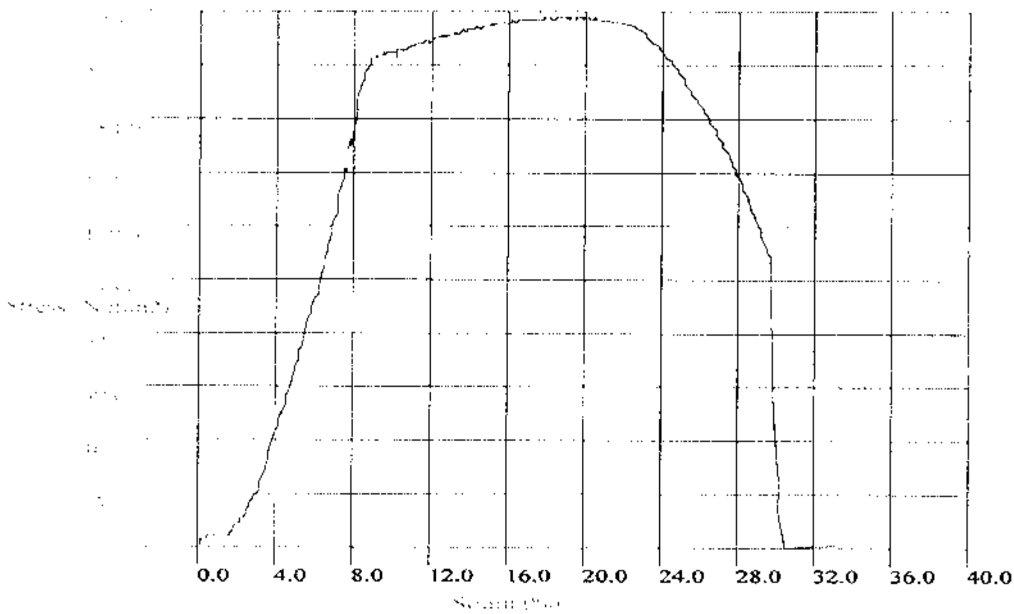

Figure 5.6 Treated Aluminum

Chapter 6

Applications

CHAPTER 6

APPLICATIONS

Cryogenic treatment is a widely proved and accepted method. It is because of its huge benefits in any field. The maintenance of this method is less and can be used and applied with ease. And thus it has found its applications in the fields like Machining. In machining it is used in lathes, drill bits, cutting and milling tools. As a cutting tool cryogenics enhances the wear resistance, which thereby decreases the frequent change of tools thereby making it more economic.

It is also widely used in pulp and paper industry, wherein saws, chippers, millers and cutters are used. In oil and gas industry it is widely accepted. As in drilling, compression, pumps, pumps jack gears, valves and fittings hardness plays a vital role. And it has been proved in this project that cryogenic increases hardness. This same phenomenon is also for mining, drill bits, drilling steel, slashed teeth and face cutters. In food processing cryogenic acts as a good storage media, which prevents food from getting spoiled. Grinders, knives and extruding dies, textiles, scissors, needles, shears and cutting tools, wood fabricating, saws, drill bits, routing bits and planes are also used extensively because of the cryogenic treatment. In dental and surgical instruments cryogenics gives good strength, hardness and wear resistance as proved in this project. Thus these are the areas where cryogenics is applied and used successfully. (16)

Chapter 7

Conclusion

CHAPTER 7

CONCLUSION

The main concern in this project is to highlight the features of cryogenics and the way it increases the various mechanical properties of the specimens the specimens used are EN8 steel, mild steel and aluminum .The enhancing properties are determined by conducting tensile test, hardness test and wear test. These tests reveal the property of cryogenic treatment. The known fact about cryogenic treatment is that it gives superior strength and improves the life span of cutting tools. It also enhances the hardness and wear resistance of steel. The treated tools perform better than untreated tools.

In the various tests treated and untreated specimens were used and analyzed. Treated specimens in this project are the ones that are immersed in the cryogenic medium known as Liquid nitrogen. It has been concluded from the journals that due to cryogenic treatment the internal structure of steel changes that is transformation of austensite into martensite and precipitation of carbides take place. This enables the specimen to increase in these characteristics.

The results obtained in tensile test shows an imrovement in tensile strength. EN8 steel shows an increase in tensile strength by 22.63 %. In mild steel it tensile strength.

The hardness of the various materials is also increased by cryogenic treatment. From the result the hardness of EN8 steel increases by 4.05 % and in mild steel by 11.39 %. The hardness of aluminum shows a drastic increase of 80.95 %.

Wear resistance is a vital characteristic of cryogenics, which shows a good result in this project. The percentage of reduction in wear of EN8 steel is 25 % and in mild steel it is 21.69 %. For aluminum the percentage of reduction for wear in 58.73 %.

With these results it is concluded that the tensile strength, hardness and wear resistance of the specimens are increased by cryogenics, which is of great help in various fields of science and engineering.

Chapter 8

Scope of future work

CHAPTER 8

SCOPE OF FUTURE WORK

Cryogenics is a very wide field in which many researchers are into work. After the results obtained from this project cryogenic searches for more future work .the future work of this project is that the problem parameter can be optimized. The various problem parameters are cooling grade, cooling temperature, tempering temperature and soaking time. These parameters can be optimized effectively to get a maximum increase in wear resistance and hardness in different metals. These can thereby fetch industrial applications in a much larger scale.

Another future scope of this project work is the study on microstructure phase changes. This study includes the transformation of austensite intomartensite , the precipitation of retained austensite into carbides and the formation of eta carides. All this enhances the mechanical properties of metals in a large scale and there can be a definite increase in the improvement of mechanical properties.

Liquid helium can also be used instead of liquid nitrogen in the future work. There can be a thorough examining, analyzing and interpretation of results in the improvement of mechanical properties by cryogenic treatment in liquid helium medium. The various properties of liquid helium can be studied and the use of it at the

The various characteristics at this medium and temperature level can also be studied. Hence cryogenics fetch for more future works.

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