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Department of Mechanical Engineering

Production

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Hardening of Medium Carbon Steal

(Case Study)

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الآية

بسم الله الرحمن الرحيم

قال تعالى:(.........وَمَا أُوتِيتُم مِّن الْعِلْمِ إِلاَّ قَلِيلاً{85})

الإسراء

Dedication

We dedicate this thesis to:
Our parents: words are just not expressive enough,
They introduced us to the joy of reading from birth
enabling such a study to take place today,
Our brothers, sisters and our best friends, without them none of
our success will be possible.
Our gratefulness to Dr/ Jaffer Abdulhameed for supporting,
trusting in our selves ,funding, and guide us through the project to
the current success, believing in our skills, so God bless you …,

Acknowledgement

All praise and thanks to Allah who provide us with the ability to
complete this work. We are thankful to our families who are always
supportive and helpful throughout our studies.
We would like to express our special appreciation and gratitude to our advisors Dr. Jaffarabdulhameed, for being such a source of inspiration and motivation to us.
his patience and advises on our research and writing this thesis have been invaluable.

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ABSTRACT

The research lowered the corrosion of a crank made of medium carbon steel by increasing surface hardness. Two samples were taken from the crank and the hardness value was 227.26 BHN.

The samples was inter in the heat treatment furnace and heated to 850°C then cool the sample in the water, the hardness value of the two samples became 355.12 BHR, increasing in the hardness value is 127.86 BHN.

المستخلص

يتلخص البحث في تقليل التأكل لعمود مصنوع من الصلب متوسط الكربون عن طريق زيادة الصلادة السطحية, تم أخذ عينتان من العمود وتم قراءة الصلادة عن طريق مقياس برنيل للصلادة 227.26.

تم ادخال العينات فرن المعالجة الحرارية وتم ضبط الفرن على درجة حرارة 850 درجة مئوية ثم تم تبريد سريع في الماء. وأصبحت الصلادة المتوسطة للعينتان 355.12 بمقياس برنيل للصلادة , اي زادت صلادة بمقدار 127.86بمقياس برنيل للصلادة.

CHAPTER ONE

Introduction

1.1 Introduction

As designer, engineer, or material user you may specify material in your professional career, but steel probably will be your most used engineering material. Sometimes, you will want a steel to be soft and formable; sometimes, you will want the hardest steel available; and sometimes you will want high strength and toughness. Heat treatment of steels allows you to have these options.

For the following few thousand years, the quality of iron produced would depend as much on the ore available as on the production methods. By 17th century, iron's properties were well understood, but increasing urbanization in Europe demanded a more versatile structural metal.

The ability to make steels hard enough to be the tools that shape all other materials is probably the most important gift from nature, this called heat treatment of steels.

An understanding of the compositional and structural factors controlling the hardening of iron or steel was not achieved until the 18th century. It was pointed out in discussing the nature of metals that steels can be hardened through time and temperature induced transformation of the crystal. A number of engineering alloys can be hardened and strengthened by transformation hardening, but steels are unique in the degree of strengthening that can be achieved.

1.2 Problem Statement

The research problem is study the corrosion of medium carbon steel.

1.3 Project aim

The objective of the research is increasing the surface hardening of medium carbon steel.

1.4 Project scope

Surface hardening for crank made of medium carbon steel. The carbon content is 0.32 wt%.

Chapter Two

Theoretical framework and previous studies

Introduction

Steel is the world's most important engineering and construction material. It is used in every aspect of our lives; in cars and construction products, refrigerators and washing machines, cargo ships and surgical scalpels. It can be recycled over and over again without loss of property.

2.1 Steel:

Different types of steel are produced according to the properties required for their application and various grading system are used to distinguish steels based on these properties. [1]

Steel can be broadly categorized into four groups passed on their chemical composition:

1- Carbon Steel
2- Alloys Steel
3- Stainless Steel
4- Tool Steel

2.1.1 Carbon steel:

We previously defined a carbon steel as an alloy of iron, with carbon as the major strengthening element. The carbon strengthens by solid solution strengthening, and if the carbon level is high enough, the alloy can be quenched hardening. [1]

2.1.1.1 Types of carbon steel:

i. Mild or low carbon steel:

Approximately 0.05-0.30%carboncontent, low carbon steel has a relatively low tensile strength but it is cheap and malleable, surface hardness can be increased through carburizing.

ii. Medium carbon steel:

Approximately 0.30-0.60%carbon content, Balances ductility and strength and has good wear resistance.

iii. High carbon steel:

Approximately 0.60-0.99% carbon content,high carbon steel can be very strong.

iv. Ultra-high carbon steel:

Approximately 1.0-2.0% carbon content, ultra-high carbon steel can be tempered to great hardness. [1]

v. Cast iron:

Approximately above to 2% carbon content, also cast iron can contains with some elements as: silicon 1.0-3.0%, manganese 0.5-1.0%, sulphur up to 0.1%, phosphorus up to 1.0%.

There are four types of cast iron:

1_Gray cast iron.

2_White cast iron.

3_Malleable cast iron.

4_Ductile cast iron.

2.1.1.2 Equilibrium diagram for iron and carbon:

An equilibrium phase diagram is a graph showing phase relationships that occur in a metal alloy as it slowly cools from molten state.

The carbon can be in solid solution in iron with a body-centered cubic crystal structure, it can be in solid solution in facecentered cubic iron, or it can be present in the form of a compound with the composition of cementite.

Figure (2.1) shows the presence of the phases in equilibrium diagram at different temperatures and carbon content.The microstructure of carbon steels at the room temperature usually is a combination of these phases.

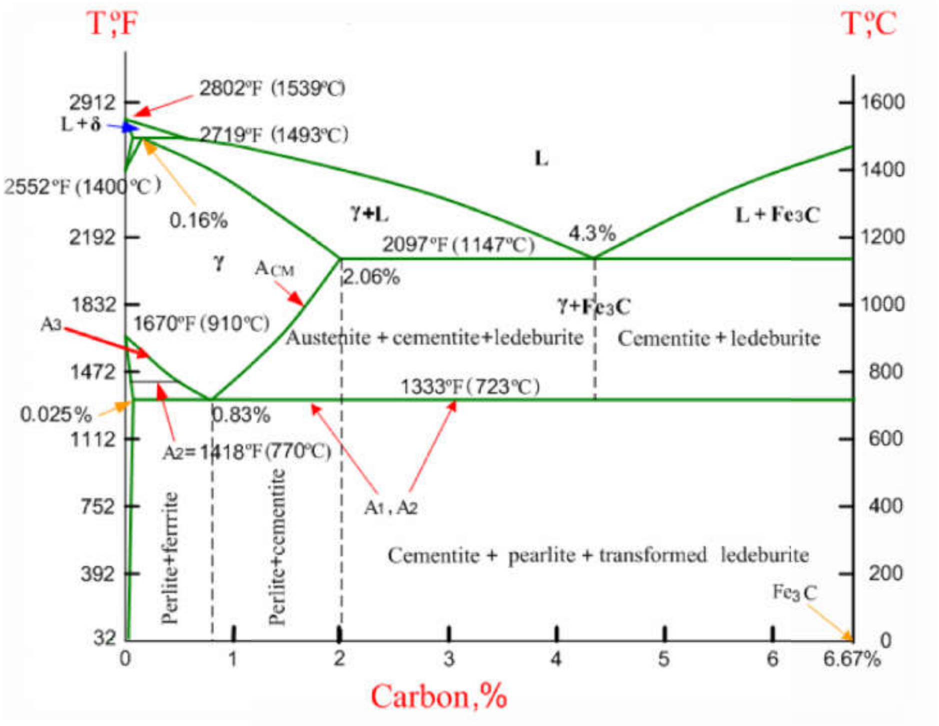

Figure (2.1) Equilibrium diagram of iron and carbon

The phase diagram shows that the structure should consist of a combination of ferrite and cementite. However, cementite is largely present in lamellar form, alternate layers of ferrite and cementite. This microstructure is called pearlite. [1]

2.1.1.3 Phases of iron and carbon:

The phases of iron and carbon are:

i. Ferrite:

A solid solution, it's stable at room temperature and capable of containing up to only 0.008 percent carbon at 70 degrees F. Magnetic ferrite is sometimes called alpha iron, not to be confused with the silver-rich alpha phase in the silver-copper phase diagram.

ii. Cementite:

This iron-carbon crystalline compound is also called iron carbide. Cementite contains 6.67 to 6.69 percent carbon and can combine with ferrite to form pearlite.

iii. Austenite

Also known as gamma iron, austenite is the FCC form of steel and is capable of dissolving almost 2.0 percent carbon. While austenite is never stable in carbon steel at less than 727 degrees F, additional alloys can make it stable at room temperature. Nonmagnetic and easily work-hardened, austenite is both strong and ductile.

iv. Pearlite

When thin, alternating layers of cementite and ferrite combine, you have pearlite, and it's what austenite transforms to when it's cooled slowly. Pearlite is always 0.77 percent carbon, and it usually makes steel more ductile.

v. Bainite:

Hard with low ductility, bainite is a combination of fine carbon needle in a ferrite matrix. It results when austenite is cooled at a rate lower than what's needed to form martensite.

vi. Martensite:

Martensite results when austenite is quickly cooled to the temperature at which it forms a body-centered tetragonal crystalline structure. If the carbon can't precipitate out of this shear type of structure, which is true for most common steels, it becomes trapped in the body-centered tetragonal lattice martenite.

This quenched structure is hard, brittle, and basically useless for most commercial steel applications. Tempering will gain back some ductility without costing too much in strength, making it valuable for various tool and die applications. In fact, martensite is what makes it possible to harden steel.

That should give you an idea of how a couple of critical graphic tools are used by metallurgists to predict how steels will react to heating and cooling at various rates. Next time, we'll pick up with hardening and carbon content, steel classifications, and then move to welding metallurgy. [1]

2.1.2 Alloy Steels:

We have defined alloy steels as a group of mill products that meet certain composition limits. Most of the common alloy elements used in alloy steels tended to increase harden-ability. They do so altering transformation temperatures and by reducing the severity of the quench required to get transformation to hardened structure.

Add alloying elements to steel besides improving harden-ability, Sometimes they improve corrosion characteristics, physical properties or machine-ability. [1]

2.1.2.1 Examples for alloys steel are:

i. **Nickel:**

Nickel increases the strength of ferrite, therefore increasing the strength of the steel. It is used in low alloy steels to increase toughness and harden-ability. Nickel also tends to help reduce distortion and cracking during the quenching phase of heat treatment.

ii. **Molybdenum:**

Molybdenum increases the hardness penetration of steel, slows the critical quenching speed, and increases high temperature tensile strength.

iii. **Vanadium:**

Vanadium helps control grain growth during heat treatment. By inhibiting grain growth it helps increase the toughness and strength of the steel.

iv. Tungsten:

Used in small amounts, tungsten combines with the free carbides in steel during heat treatment, to produce high wear resistance with little or no loss of toughness. High amounts combined with chromium gives steel a property known as red hardness. This means that the steel will not lose its working hardness at high temperatures. An example of this would be tools designed to cut hard materials at high speeds, where the friction between the tool and the material would generate high temperatures.

v. Copper:

The addition of copper in amounts of 0.2 to 0.5 percent primarily improves steels resistance to atmospheric corrosion. It should be noted that with respect to knife steels, copper has a detrimental effect to surface quality and to hot-working due to migration into the grain boundaries of the steel.

vi. Niobium:

In low carbon alloy steels Niobium lowers the transition temperature and aids in a finegrain structure. Niobium retards tempering and can decrease the harden-ability of steelbecause it forms very stable carbides. This can mean a reduction in the amount of carbondissolved into the austenite during heat treating.

vii. Boron:

Boron can significantly increase the harden-ability of steel without loss of ductility. Itseffectiveness is most noticeable at lower carbon levels. The addition of boron is usuallyin very small amounts ranging from 0.0005 to 0.003 percent.

viii. Titanium:

This element, when used in conjunction with Boron, increases the effectiveness of theBoron in the harden-ability of steel.

Figure (2.2) show TTT diagrams that the heat treated has to quench the steel very rapidly to get it to harden (<1s) the effect of the nickel, chromium, and molybdenum combination is to lessen the quenching requirements. An oil quench probably can meet the 10-s requirement indicated on the TTT diagram curve for the 4340 steel. There are good and bad effects of adding alloying element.

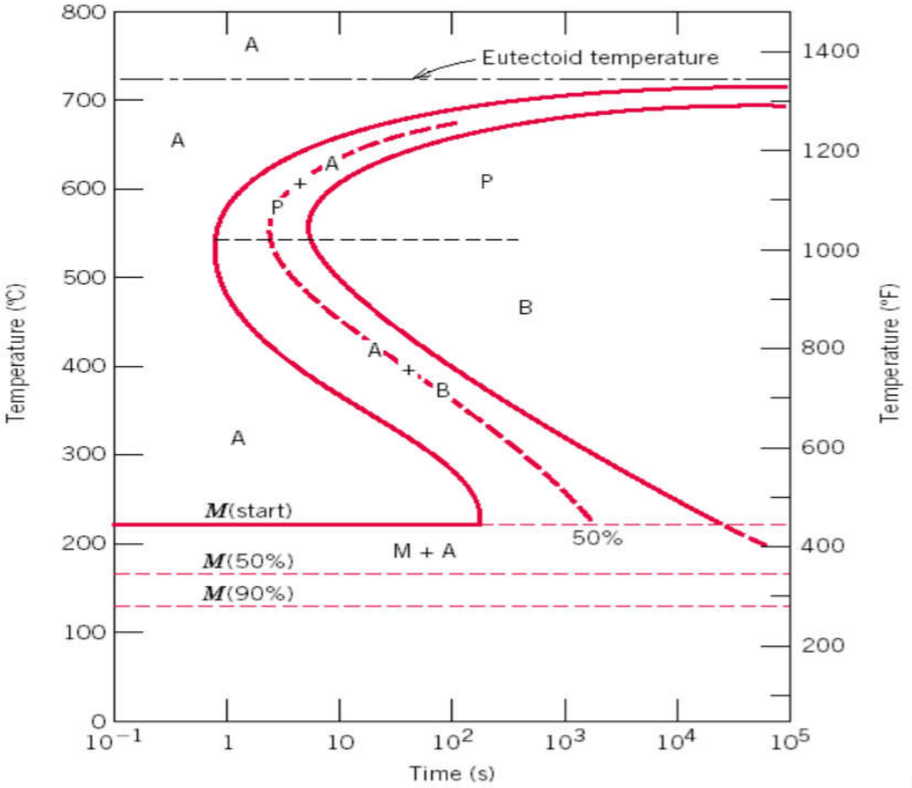

Figure (2.2) show TTT diagrams for steel.

Table (2.1): alloys steel

Elements	Typical ranges in alloy steel%	Principle effects
Aluminium	<2	Aids nitriding, restricts grain growth, oxygen in steel melting
Sulphur and phosphorus	<0.5	Adds machinability
Chromium	0.3-4	Increases resistance to corrosion and oxidation, increases harden-ability and high temperature strength
Nickel	0.3-5	Promotes an austenitic structure, increases harden-ability and toughness
Copper	0.2-0.5	Promotes tenacious oxide film to aid atmospheric corrosion resistance
Manganese	0.3-2	Increases harden-ability, lowers hardening temperature promoter an austenitic
Silicon	0.2-2.5	Removes oxygen in steelmaking, improve toughness, increases hardenability
Molybdenum	0.1-0.5	Promotes grain refinement, increases hardenability and high temperature strength
Vanadium	0.1-0.3	Promotes grain refinement, increases hardenability
Boron	0.0005-0.003	Added in small amounts to increases hardenability
Lead	<0.3	Added only to aid machinability
Nitrogen	<0.1	Acts like carbon in strengthening

2.1.3 Stainless Steels:

Stainless steels generally contain between 10-20% chromium as the main alloying element and are valued for high corrosion resistance. With over 11% chromium, steel is about 200 times more resistance to corrosion than mild steel. These steels can be divided into three groups based on their crystalline structure.

2.1.4 Tool Steels:

Tool steels contain tungsten, molybdenum, cobalt and vanadium in varying quantities to increase heat resistance and durability, making them ideal for cutting and drilling equipment. [1]

2.2 Heat treatment of steel:

The more common steel heat treatments arranges into three major categories that indicate the basic reason for heat treating steels:

2.2.1 Hardening:

Steel sometimes are hardened just to produce dimensional invariance. Gage blocks and other inspection gages need to be very hard (60-65 HRC) if they are to resist wear and scratches that could make dimensions change. Some stainless steel needs to be hardened to obtain their maximum corrosion resistance.

Quench hardening keeps the chromium in solution in the host iron and it is this chromium in solid solution that imparts the “stainless” characteristics. sometimes, steel are hardened improve a physical property such as coefficient of thermal expansion or some magnetic property steel used for permanent magnets usually are hardened to make the magnetism last longer. In summary there are many reasons for hardened steel: examples are everywhere. The important point to remember is that steels are unique in the degree of hardened and strengthening that is possible through heat treatment.

According to American Iron and Steel Institute the standard condition of hardening medium carbon steel are:

- Heat to 820°C - 850°C (1508°F - 1562°F)
- Hold until the temperature is uniform
- Soak for 10 - 15 minutes per 25mm of section
- Quench in water or brine

2.2.2 Normalizing:

A heat treatment process consisting of austenitizing at temperatures of 30–80˚C above the A_{C3} transformation temperature followed by slow cooling (usually in air). The aim of which is to obtain a fine-grained, uniformly distributed, ferrite–pearlite structure.

Normalizing is applied mainly to unalloyed and low-alloy hypo-eutectoid steels.For hypereutectoid steels the austenitizing temperature is 30°C–80˚C above the A_{C1} or A_{Cm} transformation temperature (Cooling rate 60°C-70˚C).

2.2.3 Annealing:

Annealing is a heat treatment that alters the physical and sometimes chemical properties of a material to increase its ductility and reduce its hardness, making it more workable. It involves heating a material to above its re-crystallization temperature, maintaining a suitable temperature, and then cooling.

In annealing, atoms migrate in the crystal lattice and the number of dislocations decreases, leading to the change in ductility and hardness.

In the cases of copper, steel, silver, and brass, this process is performed by heating the material (generally until glowing) for a while and then slowly letting it cool to room temperature in still air. Copper, silver and brass can be cooled slowly in air, or quickly by quenching in water, unlike ferrous metals, such as steel, which must be cooled slowly to anneal. In this fashion, the metal is softened and prepared for further work-such as shaping, stamping, or forming.

2.2.4 Tempering:

Tempering is a process of heat treating, which is used to increase the toughness of iron-based alloys. Tempering is usually performed after hardening, to reduce some of the excess hardness, and is done by heating the metal to some temperature below the critical point for a certain period of time, then allowing it to cool in still air. The exact temperature determines the amount of hardness removed, and depends on both the specific composition of the alloy and on the desired properties in the finished product. For instance, very hard tools are often tempered at low temperatures, while springs are tempered to much higher temperatures. [1]

2.3 The surface hardening of steel:

Surface hardening is a process by which steel is given a hard, wear resistant surface while retaining a ductile but tougher interior.

Surface hardening is usually done for the following reasons:

- To improve wear resistance
- To improve resistance to high control stresses
- To improve fracture toughness
- To improve fatigue resistance
- To components that usually require surface hardening as gears, bearing, valves, cam, shaft.....etc. [2]

Surface hardening techniques can be classified into two major categories:

1. Processes that change the surface chemical composition include case hardening or thermo chemical processes.
2. Processes that do not change the surface chemical composition include selective surface hardening or local thermal surface hardening.

2.3.1 Case hardening:

Case hardening methods include:

2.3.1.1 Carburising Processes:

Carburising is a hardening process in which carbon is introduced into the surface layer of the steel.

- The steel is heated in contact with a substance that has a high carbon content.
- The steel is held at a temperature above the UCT (850°C –950°C) for a suitable period of time
- Then quenched rapidly to produce a hardened surface layer or “case” over a softer and tougher core.
- The steel is then tempered to the desired hardness.

There are three carburising processes:

2.3.1.1.1 Pack carburising:

In pack carburising, the steel piece is packed in a steel container and completely surrounded with charcoal,The charcoal is treated with $BaCO_3$, which promotes the formation of CO,CO reacts with the low carbon steel surface to form atomic C,which diffuses into the steel.

Quenching is difficult in pack carburising. Usually the part is allowed to cool slowly and then hardened and tempered may be specified, depending on the service requirements of the product The carburising process does not harden the steel, it only increases the carbon content to a desired depth below the surface.

2.3.1.1.2Gas carburising:

Carburising is done with carbonaceous gases, such as: methane, ethane, natural gas or propane at around 930°C, The advantage of gas carburising is that the steel can be quenched directly from the carburising temperature.

2.3.1.1.3Liquid Carburising:

Carburising is done in liquid salts, which contain cyanide compounds such as NaCNShorter carburising time compared to pack and gas carburising. Environmental hazards of the salts used.

Quenching normally is accomplished by rapidly removing the part from the furnace (after it has soaked for sufficient time to reach the required temperature) and immersing it in agitated oil or water.

Some steel s can be hardened just by removing the part from the furnace and letting it cool by convection in room temperature air. The ease with which steel will transform to hardened structure on quenching is called harden-ability, and it can significantly in steels when alloy additions are made. [2]

The quenching requirements for particular steel can determined by studying diagram that show phase changes under non-equilibrium conditions. Figure (2.3) show isothermal transformation (IT) diagram.

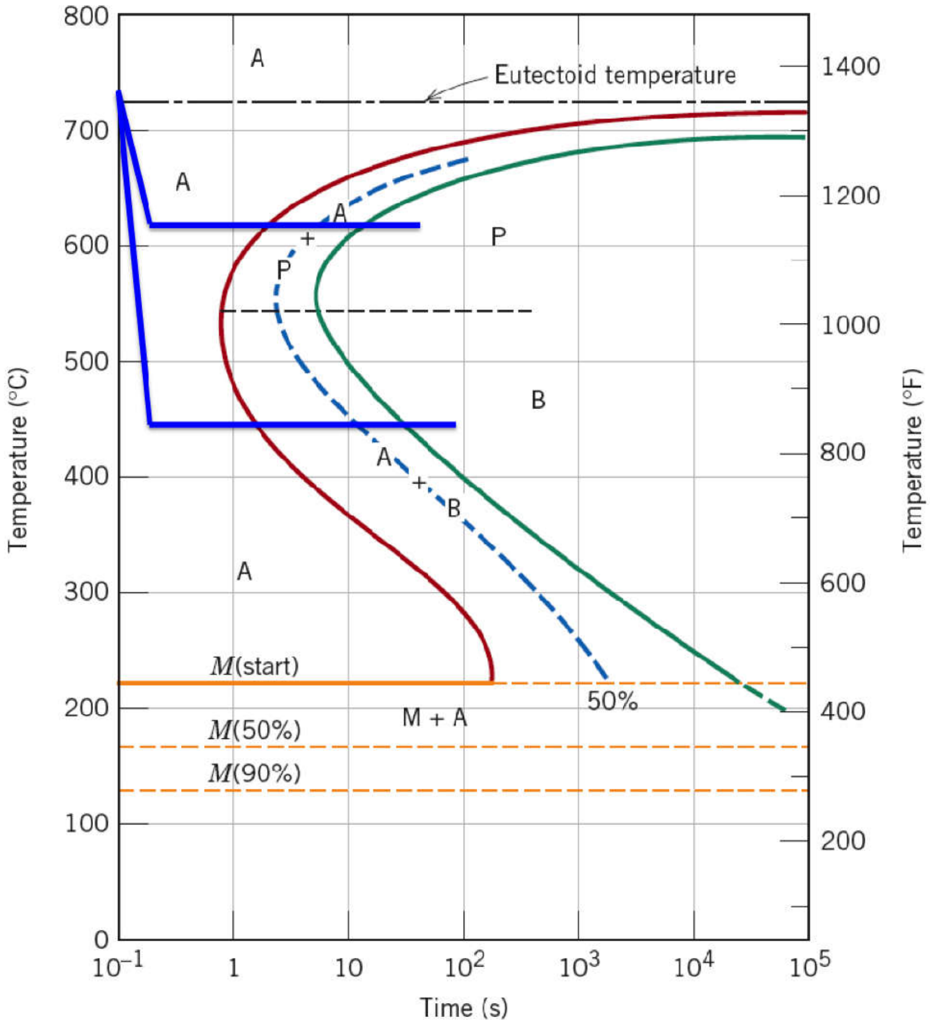

Figure (2.3) isothermal transformation experiments

2.3.1.2 Nitriding:

In nitriding, the steel piece is heated in a furnace between 500 – 600°C and at the same time is exposed to ammonia gas (NH_3).

The heat from the furnace causes the ammonia to decompose into hydrogen (H_2) and nitrogen (N_2).

ix. Heat treatment:

Prior to being nitrided, the work-pieces are heat-treated to produce the required properties in the core. Since greater scope is possible in the heat-treatment than is feasible in that associated with case-hardening, nitralloy steels often have higher carbon contents, allowing high core-strengths to be develop. The normal sequence of operation will be:

1_ Oil- quenching from 850°C to 900°C, followed by tempering at between 600°C and 700°C.

2_ Rough machining, followed by a stabilising anneal at 550°C for 5 hours, to remove internal stresses.

3_ Finish machining followed by nitriding.

Any areas of the surface which are required soft are protected by coating with solder or pure or pure tin, by nickel plating, or by painting with a mixture of whiting and sodium silicate.

x. Advantages and disadvantages of nitride:

Advantages of nitride over case-hardening are:

1- Since no quenching is required after nitride, cracking or distortion is unlikely, and components can be machine-finished before treatment.

2- An extremely high surface hardness of up to 1150 VPN is attainable with the aluminium type steels.

3- Resistance to corrosion is good, if the nitride surface is left unpolished.

4- Hardness is retained up to 500C, whereas a case-hardened component being to soften at about 200C.

5- The process is clean and simple to operate.

6- It is cheap if large numbers of components are treated.

xi. Disadvantages of nitride as compared with case-hardened are:

1- The initial outlay for nitride plant is higher than that associated with solid or liquid medium carburising, so nitride is only economical when large numbers of components are to be treated.

2- If a nitride component is accidentally overheated, the loss of surface hardness is permanent, unless the component can be nitride again.

A case-hardened component would need only to be heat-treated, assuming that it has not been so grossly overheated as to decarburise it.

Nitrogen reacts with elements in the steel to form nitrides in the outer layer of the steel providing high hardness and wear resistance.

Nitriding times range between 1–100 hours depending on steel composition and depth of hardening desired.Since nitriding does not involve austentizing the steel and subsequent quenching to form martensite, it can be carried out at comparatively low temperatures and thus produce less distortion and deformation**.** [2]

2.3.1.3 Carbonitriding:

This process involves both the diffusion of C and N into the steel surface. Nitriding is performed in a gas atmosphere furnace using a carburising gas such as propane or methane (source of C) mixed with several vol% of ammonia (NH3) (source of N).

Carbonitriding is performed at temperatures above the UCT (700°C – 800°C).Quenching is done in a gas which is not as severe as water quench(the result is less distortion on the material to be treated).

2.3.1.4 Cyaniding:

This process also involves both the diffusion of C and N into the surface layers of the steel.

In cyaniding, the steel is heated in a liquid bath of cyanide – carbonate – chloride salts and then quenched in brine, water or oil.

2.3.2 Selective Surface Hardening

These processes are also called localised heat treatment because only the surface is austenitised and quenched to produce martensite.

The basic requirement for these processes is that the steel must have sufficient carbon and harden-ability to achieve the required hardness at the surface (medium carbon steels are usually suited for these processes).

Selective hardening is applied because of one or more of the following reasons:

1. Parts to be heat-treated are so large as to make conventional furnace heating and quenching impractical and uneconomical - examples are large gears, large rolls, and die

2. Only a small segment, section, or area of the part needs to be heat-treated. Typical examples are ends of valve stems and push rods, and the wearing surfaces of cams and levers.
3. Better dimensional accuracy of a heat-treated part.
4. Overall cost savings by using inexpensive steels to have the wear properties of alloyed steels. [2]

Selective surface hardening are classified according to the heating source into:

2.3.2.1 Flame hardening:

In this process, the work-piece is of uniform composition throughout and the surface hardening occurs because the surface layers receive extra-heat treatment as compared with the core material.

The surface is heated to a temperature above its upper critical temperature, by means of a travelling oxyacetylene torch (Figure 2. 4), and is immediately quenched by a jet of water issuing from a supply built into the troch-assembly.

Symmetrical components such as gears and spindles, can be conveniently treated by being spun between centres so that the whole circumference is thus treated.

Only steel with a sufficiently high carbon – at least 4% can be hardened effectively in this way. Alloy steel containing up 4% nickel and 1% chromium respond well to such treatment. Before being hardened, the components are generally normalised, so that the final structure consists of a martensitic case some 4mm deep, and a tough ferritepearlite core. Core and are usually separated by a layer of bainite, which helps to prevent that hard case from cracking away from the core material. Should a final tempering process be necessary, this can also be carried, out by flame-heating, though furnace treatment is also possible since such low-temperature treatment will have no effect on the core particularly if it has been normalised.

Flame hardening can produce case depth of up to 0.8mm with a case hardness of 55-65 HRC.

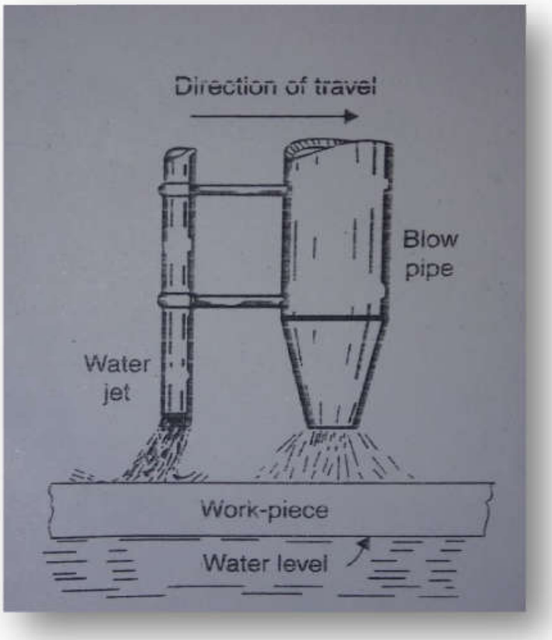

Figure (2.4) Flame-hardening

2.3.2.2 Induction hardening:

This process is similar in principle to flame-hardening, except that the component is usually held stationary whilst the whole circumference is heated simultaneously by means of an induction-coil. This coil carries a high-frequency current, which induces eddy currents in the surface of the component, thus raising its temperature. The depth to which heating occurs varies inversely as the square root of the frequency, so that the higher the frequency used, the shallower the depth of heating. Typical frequencies used are: 3000Hz for depths of 3-6mm or 9600Hz for depths of 2-3mm.

As soon as the surface of the component has reached the necessary temperature, the current is switched off and the surface simultaneously quenched by pressure jets of water, which pass through holes in the induction-block Figure (2.5)

The process lends itself to mechanisation, so that selected regions of a symmetrical component can be hardened, whilst other are left soft.

As in flame-hardening, the induction process makes use of the existing carbon content – which consequently must be at least 0.4% whilst in case hardening. [2]

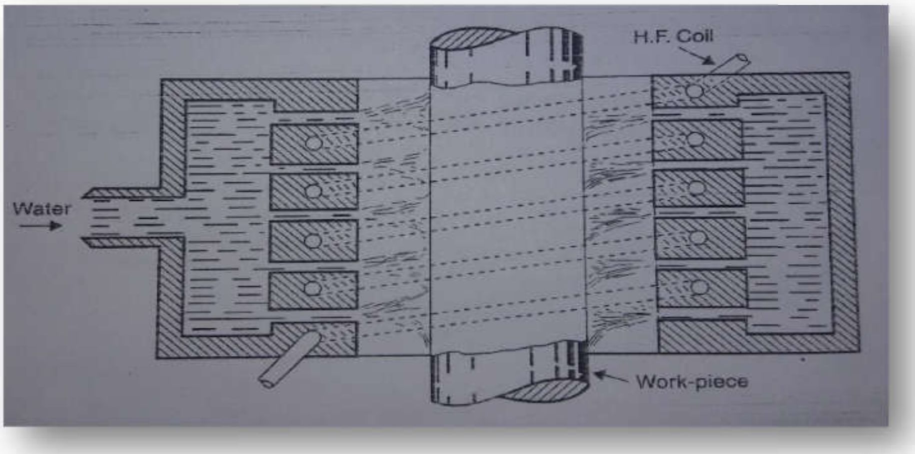

Figure (2.5) The principles of induction-hardening.

2.3.2.3Laser hardening:

Laser surface heat treatment is widely used to harden localized areas of steel and cast iron machine components.

This process is sometimes referred to as laser transformation hardening to differentiate it from laser surface melting phenomena. There is no chemistry change produced by laser transformation hardening, and the process, like induction and flame hardening, provides an effective technique to harden ferrous materials selectively. Other methods of laser surface treatments include surface melting and surface alloying.

Laser surface melting results in a refinement of the structure due to the rapid quenching from the melt, surface alloying elements are added to the melt pool to change the composition of the surface.

Laser transformation hardening produces thin surface zones that are heated and cooled very rapidly, resulting in very fine martensitic microstructures, even in steels with relatively low harden-ability. High hardness and good wear resistance with less distortion resultfrom thisprocess.

The laser method differs from induction and flame heating in that the laser can be located at some distance from the workpieces.

Also, the laser light is reflected by mirrors to the focusing lens, which controls the width of the heated spot or track. [2]

2.3.2.4Electron beam hardening:

Electron beam hardening is one of the most modern surface hardening technologies, with some special characteristics in comparison to other heat treatment technologies. Electron beam hardening is similar to other surface heat treatment processes in that the materials to be hardened is heated to the austenitization temperature, held at that temperature for a short period, and then quenched.

Maternsitic transformation occurs that generally differ neither thermodynamically nor kinetically from the transformation occurring under conventional conditions. Electron beam hardening belongs as laser beam hardening, to the process group known as short cycle heat treatments. When compared to all other conventional volume and surface layer heat treatment processes, the temperature time cycle are characterized by significantly higher austenitizing temperatures, as well as considerably higher heating and cooling rates (103 to 104 K/s) and short times (0.1 to 3 to 5 s). [2]

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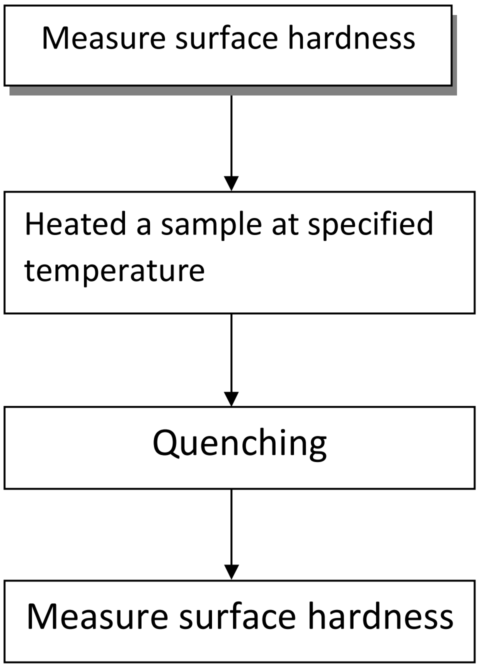
CHAPTER THREE

Methodology

3.1 Methodology Flow Chart:



3.2 Hardening:

Hardening is process in which steel is heated to a temperature above the critical point, held at this temperature and quenched in water, oil or molten salt baths.

As earlier mentioned that if a piece of steel is heated above its upper critical temperature and plunged into water to cool it an extremely hard, needle-shaped structure known as marten-site is formed. In other words, sudden quenching of steel greatly increases its hardness.

The hardening process is based on a very important metallurgical reaction of decomposition of eutectoid.

This reaction is dependent upon the following factors:-

1. Adequate carbon content to produce hardening.
2. Austenite decomposition to produce marten-site structures.
3. Heating rate and time.
4. Quenching medium.
5. Quenching rate.
6. Size of the part.
7. Surface conditions.

- The rapidly with which the heat is absorbed by the quenching bath has a considerable effect on the hardness of the metal. Clear, cold water is very often used, while the addition of salt still increase degree of hardness.oil, however, gives the best balance between hardness toughness and distortion for standard steels.
- In order to increase the cooling rate the parts may be moved around the quenching bath, either by hand, or by passing them through the tank in basket attached to mechanical conveyer. Large parts may be lowered into the tank by a crane and kept moving while cooling. It is often cheaper and more efficient, however, to circulate the cooling liquid around the hot part.
- The heating rate and heating time depend on the composition of the steel, its structure, residual stresses, the form and size of the part to be hardened, the more the intricate and large the part being hardened, the slower it should be heated to avoid stresses due to temperature differences between the internal and external layers of the metal, warping, and even cracking. The practically attainable heating rate depends upon the thermal capacity of the furnace, the bulk of the changed parts, their arrangement in the furnace, and other factors. The heating rate is usually reduced, not by reducing

the furnace temperature but by preheating the articles.

- The heating time for carbon tool steels and medium-alloy structural steels should be from 25 to 30% more than for carbon structural steels. The heating time for high-alloy structural and tool steels should be from 50 to 100% higher.

- When steel is exposed to an oxidizing atmosphere, because of thepresence of water vapor or oxygen in the furnace, a layer of iron oxide called (scale) is formed. Thin layer of scale has very little effect on cooling rate, but that a thick layer of oxide (0.005 in. deep) retort the actual cooling rate.

3.3 Measure of hardness:

Harden is not an intrinsic material property dictated by precise definitions in terms of fundamental units of mass, length and time. A hardness property value is the result of a defined measurement procedure.

The usual method to achieve a harden value is to measure the depth or area of an indentation left by an indenter of a specific shape, with a specific force applied for a specific time. There are three principal standard test methods for expressing the relationship between hardness and the size of the impression, these being Brinell, Vickers, and Rockwell. For practical and calibration reasons, each of these methods is divided into a range of scales, defined by a combination of applied load and indenter geometry.

3.3.1 Brinell hardness test:

Most commonly it is used to test materials that have a structure that is too coarse or that have a surface that is too rough to be tested using another test method.

Brinell testing often use a very high test load and a 10mm diameter indenter so that the resulting indentation averages out most surface and sub-surface inconsistencies.

The Brinell method applies a predetermined test load (F) to a carbide ball of fixed diameter (D) which is held for a predetermined time period and then removed. The resulting impression is measured with a specially designed Brinell microscope or optical system across at least two diameters – usually at right angles to each other and these results are averaged (d). Although the calculation below can be used to generate the

Brinell number, most often a chart is then used to convert the averaged diameter measurement to a Brinell hardness number.

Common test forces range from 500kgf often used for non-ferrous materials to 3000kgf usually used for steels and cast iron. There are other Brinell scales with load as low as 1kgf and 1mm diameter indenters but these are infrequently used.

$$B.H.N = \frac{2P}{\pi D(D-\sqrt{(D^2-d^2)})} \qquad (3.1)$$

B.H.N = brinell harden number

P = load

D = Ball diameter

d = impression diameter

3.3.2 Rockwell hardness test

The Rockwell test is generally easier to perform, and more accurate than other types of hardness testing methods. The Rockwell test method is used on all metals, except in condition where the test metal structure or surface conditions would introduce too much variations; where the indentations would be too large for the application; or where the sample size or sample shape prohibits its use.

The Rockwell method measures the permanent depth of indentation produced by a force/load on an indenter. First, a preliminary test force (commonly referred to as preload or minor load) is applied to a sample using a diamond or ball indenter. This preload breaks through the surface to reduce the effects of surface finish. After holding the preliminary test force for a specified dwell time, the baseline depth of indentation is measured.

After the preload, an additional load, call the major load, is added to reach the total required test load. This force is held for a predetermined amount of time (dwell time) to allow for elastic recovery. This major load is then released, returning to the preliminary load. After holding the preliminary test force for a specified dwell time, the final depth of indentation is measured. The Rockwell hardness value is derived from the difference in the baseline and final depth measurements. This distance is converted to a hardness number.

The preliminary test force is removed and the indenter is removed from the test specimen.

When selecting a Rockwell scale, a general guide is to select the scale that specifies the largest load and the largest indenter possible without exceeding defined operation conditions and accounting for conditions that may influence the test result. These conditions include test specimens that are below the minimum thickness for the depth of indentation; a test impression that falls too close to the edge of the specimen or another impression; or testing on cylindrical specimens.

Additionally, the test axis should be within 2-degress of perpendicular to ensure precise loading; there should be no deflection of the test sample or tester during the loading application from conditions such as dirt under the test specimen or on the elevating screw. It is important to keep the surface finish clean and decarburization from heat treatment should be removed.

3.2.3 Vickers hardness test:

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100kgf. The full load is normally applied for 10 to 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated. The area of the sloping surface of the indentation is calculated. The Vickers hardness is the quotient obtained by dividing the kgf load by the square mm area of indentation.

$$HV = 1.854\frac{F}{\mathrm{d}^2} \qquad \text{———————} \quad (3.2)$$

HV = Vickers Hardness

F = Load in kgf

d = Arithmetic of two diagonals

When the mean diagonal of the indentation has been determined the Vickers hardness may be calculated from the formula, but is more convenient to use conversion tables. The Vickers hardness should be reported like 800 HV/10, which means a Vickers hardness of 800, was obtained using a 10 kgf force. Several different loading settings give practically identical hardness numbers on uniform material, which is much better than the arbitrary changing of scale with the other hardness testing methods. The advantages of the Vickers hardness test are that extremely accurate readings can be taken, and just one type of indenter is used for all types of metals and surface treatments. Although thoroughly adaptable and very precise for testing the softest and hardest of materials, under varying loads, the Vickers machine is a floor standing unit that is more expensive than the Brinell or Rockwell machines.

3.4 Practical of Hardening:

3.4.1Tools:

1. Two sample of medium carbon steel.
2. Heat treatment furnace.
3. Water cooled tub.
4. Two combinatory.
5. Equilibrium diagram for iron and carbon.

3.4.2 Methods:

Brinell hardness was measured for two pieces and then placed in the heat treatment furnace.

The furnace was operated and adjusted at 850 ° C, when the furnace reaches the specified temperature automatically separates, the furnace take about 1 hour and 20 minutes to reach for specified temperature.

Let the pieces inside the furnace for enough time to equal the temperature in all part of piece then open the furnace and take the two pieces and cool them quickly in water and measure brinell hardness.

Figure (3.1) Furnace

CHAPTER FOUR

Results

4.1Brinell hardness:-

The typical test uses a 10 mm (0.39 in) diameter steel ball as an indenter with a 3,000kg . For softer materials, a smaller force is used; for harder materials, a tungsten carbide ball is substituted for the steel ball. The indentation is measured and hardness calculated as:

$$BHN = \frac{2P}{\pi D(D - \sqrt{(D^2 - d^2}))} \qquad \text{———————} \quad (4.1)$$

Where:-

BHN = Brinell hardness number (kg/mm^2)

P = applied load in kilogram-force (kg)

D = diameter of indenter (mm)

d = diameter of indentation (mm)

We measured the hardness of the work before the heat treatment and the hardness as shown below:-

Table (4.1) brinell value before hardness

The weight(g)	**d (mm)**	**D(mm)**	BHN_1
750	2	10	236.44
1000	2.4	10	217.92

First work piece:-

$$BHN = \frac{2P}{\pi D(D-\sqrt{(D^2-d^2)})} \qquad (4.2)$$

<u>In 750 g:-</u>

P=750g D=10mm d=2mm

$$BHN = \frac{2\times750}{\pi\times(10-\sqrt{(10^2-2^2)})} = \underline{\underline{236.6}}$$

In 1000g:

P=1000g D=10mm d=2.4mm

$$BHN = \frac{2\times1000}{\pi\times(10-\sqrt{(10^2-2.4^2)})} = \underline{\underline{217.92}}$$

Average of first workpiece hardness

$$= \frac{236.6+217.92}{2} = \underline{\underline{227.26}}$$

Table (4.2):Brinell value after hardness

Weight(g)	d_1**(mm)**	d_2**(mm)**	**D(mm)**	BHN_1	BHN_2
750	1.5	1.4	10	398.08	383.87
1000	2	1.9	10	303.3	335.23

d_1 ≡Diameter of indentation for first piece.

d_2 ≡Diameter of indentation for second piece.

D≡ diameter of indenter =10mm

diameter of indenter (mm)

First work piece:-

In 750 g:-

$$BHN = \frac{2\times750}{\pi\times10(10-\sqrt{(10^2-1.5^2)})} = \underline{\underline{398.08}}$$

In 1000g:-

$$BHN = \frac{2\times1000}{\pi\times10(10-\sqrt{(10^2-2^2)})} = \underline{\underline{303.3}}$$

Average first work piece hardness:-

$$= \frac{BHN_1+BHN_2}{2} = \frac{398.08+303.3}{2} = \underline{\underline{350.69}}$$

Second work piece: -

In 750g:-

$$BHN = \frac{2\times750}{\pi\times10(10-\sqrt{(10^2-1.4^2)})} = \underline{\underline{383.87}}$$

In 1000g:-

$$BHN = \frac{2\times1000}{\pi\times10(10-\sqrt{(10^2-1.9^2)})} = \underline{\underline{335.23}}$$

Average second work piece hardness:-

$$= \frac{BHN_1+BHN_2}{2} = \frac{383.87+335.23}{2} = \underline{\underline{359.55}}$$

Average first and second work piece hardness:-

$$= \frac{BHN_1+BHN_2}{2} = \frac{350.69+359.55}{2} = \underline{\underline{355.12}}$$

The hardness of the work piece was tested and measured as we found 227.26 BHN and then the heat treatment of the work piece was done and the hardness was measured, as we found 355.12 BHN

Here we see an increase in hardness of 127.86 BHN.

CHAPTER FIVE

CONCLUSION & RECOMMENDATION

5.1 Results:

The hardness of the work piece before heat treatment was found 227.26 BHN and then the heat treatment of the work piece was done and the hardness become 355.12 BHN

Here we see an increase in hardness of 127.86 BHN.

5.2Conclusion:

The surface hardening of medium carbon steel increaseby heated the sample above the lower critical temperature.the phases of medium carbon steel is austenite and make quick quenching in the water, the phase of medium carbon steel changed to martensite which have good hardness.

5.3 Recommendations:

As the future of study surface hardening of medium carbon steel we recommend for the following:

1. The surface hardening heat treatment increase the surface hardness, so you can make tampered heat treatment to improve internal stress.
2. Use complete lab contain with all measuring device of hardness and heat treatment.

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