1-1 INTRODUCTION

Cast Irons are basically iron – carbon alloys having carbon between 2.11 % and 6.67 % Eutectic reaction takes place during solidification. Alloys having carbon between 2.11 % and 4.3 % are called hypo – eutectic Cast Irons ; the alloy containing 4.3 % C is called eutectic Cast Iron ; and the alloys containing between 4.3 % and 6.67 % carbon are called hyper – eutectic Cast Irons . The castability is the best of an eutectic alloys . The industrial Cast Irons have carbon normally in the range of 2.11 % to 4.0 %, along with other elements like silicon , manganese , sulphur and phosphorus in substantial amounts . Higher carbon content make them more brittle . Cast Irons are brittle , and cannot be forged , rolled , drawn , etc. but can only be ' cast into desired shape and size by pouring the molten alloy of desired composition into a mould of desired shape and allowing it to solidify . As casting is the only and exclusively suitable process to shape these alloys , so called Cast Irons .

Cast Irons is made by remelting pig iron often along with substantial quantities of scrap iron and scrap steel , and taking various steps to remove undesirable contaminants such as phosphorus and sulphur .

The melting unit may be cupola , electric arc , and induction furnaces , reverberate furnace , etc. The common Cast Irons are brittle and have lower strength properties than steels . By proper alloying , good foundry control and appropriate treatment , the properties of Cast Iron may be varied over a wide range . Cast Irons are cheap and can be cast more readily than steels .

1-2 Iron and Carbon Diagram

The horizontal axis shows the percentage of carbon in iron (mass ratio), and the vertical axis shows the temperature. This graph shows the percentages of carbon in iron between 0 – 6.67%, which is practically important (and there are no iron alloys with higher carbon percentages than that as primary alloys), when the percentage of carbon is 6.67% or greater, it forms a cementite alloy, one of the types iron alloys.

The lines in the curve connect the points at which temperature is fixed, and the lines separate the iron phases from each other. Some important points are marked with lettering, and in some graphs the point I is denoted instead of J.

The line ABCD shows the boundary between the liquid state and the solid state, where the alloy is at higher temperatures than the liquid state. And the line AHIECF represents the boundary of the solid phase, and below this line the alloy solidifies. Between these two lines, the alloy is in a gelatinous state consisting of a liquid state, delta iron δ, gamma iron γ, and cementite (Fe3C) in different concentrations and quantities. When the alloy cools below the liquid line, primary crystallization begins from the molten.

Because of the allotropic property of iron, different phases are formed for it that differ according to the percentage of carbon in it. Iron forms different mixed crystals δ, γ and α with different percentages of carbon. The distribution of atoms is in different cell units and the tallest crystal cells are also different. Technical nomenclature for crystalline mixtures are: δ ferrite for δ crystal mixture, austenite for γ crystal mixture, and ferrite for α
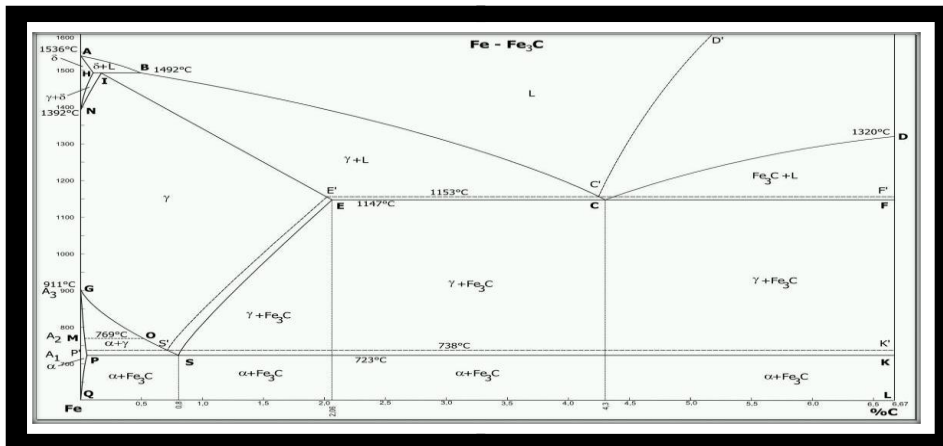
Figure 1-1: Iron and Carbon

The high amount of carbon in Cast Iron exceeds the solubility of this element in ferrite and/or austenite. The excess of carbon promotes the precipitation of a carbon rich phase during solidification, which remains during cooling to room temperature and this phase can be a carbide or graphite. Therefore, the final structure of Cast Irons is composed of a metallic matrix and carbide or graphite, depending on the chemical composition and on the solidification rate. According to the microstructure, Cast Irons are classified as white, gray, ductile and mottled irons and

Cast Irons are heterogeneous alloys, which solidify with a eutectic phase. They contain Fe, C and Si as the major alloying elements and often incorporate Cr, Ni, Mn, Mo, Cu and other elements to enhance specific chemical and mechanical properties and.

Cast Iron structures are formed during crystallization, cooling and heat treatment of these materials. During crystallization process, the final type, content, distribution and geometry of Cast Iron phases are decided. On the other hand, the appearance of casting fracture depends on the type of high-carbon phases, i.e. graphite and cementite. Thus, conventionally, based on the appearance of Cast Iron fracture, grey and white Cast Irons, or mottled Cast Iron are distinguished, and on this division, the classification of Cast Iron grades correctly produced is based. The irons are referred to as "white" irons

Due to the appearance of the fracture surface of these irons compared to grey Cast Irons .

Cast Iron is a group of iron–carbon alloys with a carbon content more than 2%. Its usefulness derives from its relatively low melting temperature. The alloy constituents affect its colour when fractured: white Cast Iron has carbide impurities which allow cracks to pass straight through, grey Cast Iron has graphite flakes which deflect a passing crack and initiate countless new cracks as the material breaks, and ductile Cast Iron has spherical graphite "nodules" which stop the crack from further progressing.

Cast Iron, an alloy of iron that contains 2 to 4 percent carbon, along with varying amounts of silicon and manganese and traces of impurities such as sulfur and phosphorus. It is made by reducing iron ore in a blast furnace. The liquid iron is cast, or poured and hardened, into crude ingots called pigs, and the pigs are subsequently remelted along with scrap and alloying elements in cupola furnaces and recast into molds for producing a variety of products.

1-3 Types of the Cost Iron:-

Most Cast Iron is either so-called gray iron or white iron, the colors shown by fracture. Gray iron contains more silicon and is less hard and more machinable than is white iron. Both are brittle, but a malleable Cast Iron produced by a prolonged heat treatment was developed in France in the 18th century, and a Cast Iron that is ductile as cast was invented in the United States and Britain in 1948. Such ductile irons now constitute a major family of metals that are widely used for gears, dies, automobile crankshafts, and many other machine parts.

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Figure 1-2: Examples of Cost Iron

Carbon (C), ranging from 1.8 to 4 wt%, and silicon (Si), 1–3 wt%, are the main alloying elements of Cast Iron. Iron alloys with lower carbon content are known as steel.

Cast Iron tends to be brittle, except for malleable Cast Irons. With its relatively low melting point, good fluidity, castability, excellent machinability, resistance to deformation and wear resistance, Cast Irons have become an engineering material with a wide range of applications and are used in pipes, machines and automotive industry parts, such as cylinder heads, cylinder blocks and gearbox cases. It is resistant to damage by oxidation but is difficult to weld.

The earliest cast-iron artefacts date to the 5th century BC, and were discovered by archaeologists in what is now Jiangsu in China. Cast Iron was used in ancient China for warfare, agriculture, and architecture. During the 15th century, Cast Iron became utilized for cannon in Burgundy, France, and in England during the Reformation. The amounts of Cast Iron used for cannon required large scale production. The first cast-iron bridge was built during the 1770s by Abraham Darby III, and is known as The Iron

Bridge in Shropshire, England. Cast Iron was also used in the construction of buildings.

Pair of English firedogs, 1576. These, with firebacks, were common early uses of Cast Iron, as little strength in the metal was needed.

Grey Cast Iron is characterized by its graphitic microstructure, which causes fractures of the material to have a grey appearance. It is the most commonly used Cast Iron and the most widely used cast material based on weight. Most Cast Irons have a chemical composition of 2.5–4.0% carbon, 1–3% silicon, and the remainder iron. Grey Cast Iron has less tensile strength and shock resistance than steel, but its compressive strength is comparable to low- and medium-carbon steel. These mechanical properties are controlled by the size and shape of the graphite flakes present in the microstructure and can be characterized according to the guidelines given by the ASTM.

Grey is the most versatile and widely used Cast Iron. The presence of carbon leads to formation of graphite flakes that does not allow cracks to pass through, when the material breaks. Instead, as the material breaks the graphite initiates numerous new cracks. The fractured Cast Iron is greyish in colour, which also gives it the name. The graphite flakes

make the grey Cast Iron exhibit low shock resistance. They also lack elasticity and have low tensile strength.

However, the graphite lakes gives the Cast Iron excellent machinability, damping features as well as good lubricating properties making them useful in many industrial applications. The graphite microstructure of the Cast Iron has a matrix that consists of ferrite, pearlite or a combination of two. The molten grey iron has greater fluidity and they expand well during the solidification or freezing of Cast Iron. This has made them useful in industries like agriculture, automobile, textile mills, etc.

1-3-1 White Cast Iron

White Cast Iron displays white fractured surfaces due to the presence of an iron carbide precipitate called cementite. With a lower silicon content (graphitizing agent) and faster cooling rate, the carbon in white Cast Iron precipitates out of the melt as the metastable phase cementite, Fe_3C, rather than graphite. The cementite which precipitates from the melt forms as relatively large particles. As the iron carbide precipitates out, it withdraws carbon from the original melt, moving the mixture toward one that is closer to eutectic, and the remaining phase is the lower iron-

Carbon austenite (which on cooling might transform to martensite). These eutectic carbides are much too large to provide the benefit of what is called precipitation hardening (as in some steels, where much smaller cementite precipitates might inhibit [plastic deformation] by impeding the movement of dislocations through the pure iron ferrite matrix).

Rather, they increase the bulk hardness of the Cast Iron simply by virtue of their own very high hardness and their substantial volume fraction, such that the bulk hardness can be

approximated by a rule of mixtures. In any case, they offer hardness at the expense of toughness. Since carbide makes up a large fraction of the material, white Cast Iron could reasonably be classified as a cermet. White iron is too brittle for use in many structural components, but with good hardness and abrasion resistance and relatively low cost, it finds use in such applications as the wear surfaces (impeller and volute) of slurry pumps, shell liners and lifter bars in ball mills and autogenous grinding mills, balls and rings in coal pulverisers, and the teeth of a backhoe's digging bucket (although cast mediumcarbon martensitic steel is more common for this application).

It is difficult to cool thick castings fast enough to solidify the melt as white Cast Iron all the way through. However, rapid cooling can be used to solidify a shell of white Cast Iron, after which the remainder cools more slowly to form a core of grey Cast Iron. The resulting casting, called a *chilled casting*, has the benefits of a hard surface with a somewhat tougher interior.

High-chromium white iron alloys allow massive castings (for example, a 10-tonne impeller) to be sand cast, as the chromium reduces cooling rate required to produce carbides through the greater thicknesses of material. Chromium also produces carbides with impressive abrasion resistance.[*citation needed*] These high-chromium alloys attribute their superior hardness to the presence of chromium carbides. The main form of these carbides are the eutectic or primary M_7C_3 carbides, where "M" represents iron or chromium and can vary depending on the alloy's composition. The eutectic carbides form as bundles of hollow hexagonal rods and grow perpendicular to the hexagonal basal plane. The hardness of these carbides are within the range of 1500-1800HV.

When the white Cast Iron is fractured, white coloured cracks are seen throughout because of the presence of carbide impurities. White Cast Iron is hard but brittle. It has lower silicon content and low melting point. The carbon present in the white Cast Iron precipitates and forms large particles that increase the hardness of the Cast Iron. It is abrasive resistant as

well as cost-effective making them useful in various applications like lifter bars and shell liners in grinding mills, wear surfaces of pumps, balls and rings of coal pulverisers, etc.

1-3-2 Malleable Cast Iron

Malleable iron starts as a white iron casting that is then heat treated for a day or two at about 950 °C (1,740 °F) and then cooled over a day or two. As a result, the carbon in iron carbide transforms into graphite and ferrite plus carbon (austenite). The slow process allows the surface tension to form the graphite into spheroidal particles rather than flakes. Due to their lower aspect ratio, the spheroids are relatively short and far from one another, and have a lower cross section vis-a-vis a propagating crack or phonon. They also have blunt boundaries, as opposed to flakes, which alleviates the stress concentration problems found in grey Cast Iron. In general, the properties of malleable Cast Iron are more like those of mild steel. There is a limit to how large a part can be cast in malleable iron, as it is made from white Cast Iron.

Malleable Cast Iron is basically white iron that undergoes heat treatment to convert the carbide into graphite. The resultant Cast Iron has properties that vary from both grey and white Cast Iron. In case of malleable Cast Iron, the graphite structure is formed into irregularly shaped spheroidal particles rather than flakes that are usually present in gray Cast Iron. This make the malleable Cast Iron behave like low-carbon steel. There is considerable shrinkage that results in reduced production of Cast Iron as well increased costs. Malleable Cast Iron can be identified easily by the blunt boundaries.

1-3-3 Ductile Cast Iron

Developed in 1948, *nodular* or *ductile Cast Iron* has its graphite in the form of very tiny nodules with the graphite in the form of concentric layers forming the nodules. As a result, the properties of ductile Cast Iron are that of a spongy steel without the stress concentration effects that flakes of graphite would produce. The carbon percentage present is 3-4% and percentage of silicon is 1.8-2.8%.Tiny amounts of 0.02 to 0.1% magnesium, and only 0.02

to 0.04% cerium added to these alloys slow the growth of graphite precipitates by bonding to the edges of the graphite planes. Along with careful control of other elements and timing, this allows the carbon to separate as spheroidal particles as the material solidifies. The properties are similar to malleable iron, but parts can be cast with larger sections.   Ductile Cast Iron is yet another type of ferrous alloy that is used as an engineering material in many applications. To produce ductile iron, small amount of magnesium is added to the molten iron, which alters the graphite structure that is formed. The magnesium reacts with oxygen and sulphur in the molten iron leading to nodule shaped graphite that has earned them the name-nodular Cast Iron. Like malleable iron, ductile iron is flexible and exhibits a linear stress strain relation. It can be casted in varied sizes and into varying thickness.

1-3-4 Main usage of Cast Irons

The exceptional wear resistance of results primarily from high volume fraction of hard Crrich carbides, although the toughness of the matrix also contributes to the wear resistance. For abrasion resistance, nearly all HCWCI alloys used are hypoeutectic alloys containing 10 - 30 *wt. %*Cr and 2 - 3.5 *wt. %*C. High chromium irons in the compositional range of 12 - 30 *wt. %*Cr are extensively used for components that manipulate, mechanically process aggregates and raw materials

Such components include ore crushers (a) and (b), rollers (c), ball mill liners (d) and (e), and pulverising equipment (f) .
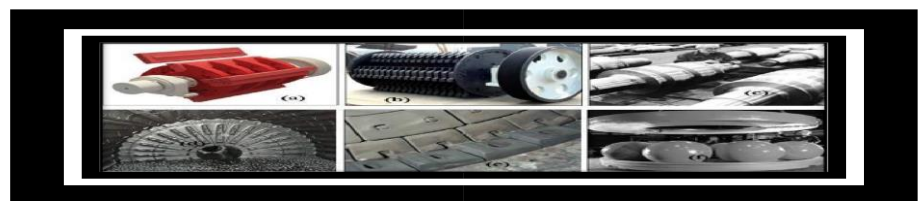

FIGURE 1-3. Illustrations of the cast wear-resistant components made from HCWCI alloys

In wear applications that do not involve corrosion, for example, rollers and tables in coal pulverising or in dry ball mills, the most popular alloys are based on chromium levels of 18 - 22 wt. %Cr. In wet wear applications where combined abrasion and corrosion resistance is needed, for example slurry pumping (FIGURE 2) in extraction processes,

C. R. L. D. Y. H. B. a. D. K. Tang X. H., "Variations in Microstructure of High Chromium Cast Irons and Resulted Changes in Resistance to Wear, Corrosion and Corrosive Wear," Wear, vol . grades containing 25 - 30 wt. %Cr are preferred . The high chromium Cast Irons containing 30 - 40 wt. %Cr with lower carbon levels at

1.5 - 2.4 wt. %C have ferritic matrix structures. Ferrite (δ-Fe) is normally undesirable in abrasion resistant high chromium Cast Irons since it is softer than austenite and does not work-harden significantly during wear service. However, there are ferritic chromium Cast Irons which have been developed for combined corrosion and abrasion resistance, and in particular for heat-resistant components .

FIGURE 1Slurry pumping components consisting of HCWCI

The microstructure of as-cast hypoeutectic composition of HCWCI alloy contains hard eutectic carbides of the form $(Cr,Fe)_7C_3$ supported in an austenitic matrix. The extent to which the matrix is fully austenitic depends on homogeneity and cooling rate. For example, localised carbon and chromium depletion during carbide formation can result in the

transformation of austenite (γ-Fe) to martensite (α-Fe) at the eutectic carbide edges . The hypoeutectic irons solidify as primary austenite dendrites with a network of interdendritic eutectic M_7C_3 carbides. Depending on the thickness and composition, notably Cr/C ratio and the levels of hardenability elements, the primary austenite may remain stable on cooling of the castings or it may fully or partially transform to pearlite .

Abrasion and corrosion resistance can normally be improved by destabilization and tempering heat treatments. After air hardening, i.e. force air quench (FAQ) from destabilization temperatures, the microstructure of a HCWCI consists of eutectic carbides, which are normally not affected by heat treatment, and precipitated secondary carbides in a martensitic matrix plus a small amount of retained austenite. Any retained austenite is transformed to martensite and/or bainite during subsequent tempering treatments. The type of secondary carbide formed during destabilisation depends on the composition and destabilisation temperature .

A vast effort has been devoted to the research of the Fe-Cr-C ternary system in an effort to establish all parameters of this system . Although the high chromium white iron class of alloys covers both hypo- and hyper-eutectic alloys, this review will concentrate on the hypoeutectic grades commonly used as cast components. This review explores the relationship between the microstructure of high chromium white irons and the properties relevant to service in material applications (handling).

1-4 Use the Cast Iron

1.   Grey Cast Iron: Engine cylinder blocks, flywheels, gearbox cases, machine-tool bases.

2.   White Cast Iron: Bearing surfaces.

3.   Ductile Cast Iron: Gears, Camshafts, crankshafts, piston ring.

4.   Many types of sanitary fittings like sewer pipes, manholes, water pipes, cisterns are manufacturing using Cast Iron.

5.   Column base and metal columns can be made using Cast Iron

6.   Casting mold used for making lamp posts, metal staircases, gates, etc.

7.   Carriage wheels and rail chairs are made from Cast Iron.

8.   Various types of agriculture equipment and implements can be made from it.

9.   Various machinery parts can be made from Cast Iron.

10.   It is used in making automotive parts.

11.   It is used in making pots pans and utensils.

12.   It is used in making anchors for ships.

1-5 Effects of alloying elements

In majority of the Cast Irons, it is the interaction among alloying elements (including C and Si) which has the greatest effect on properties. This influence is exerted mostly by effects on the amount and shape of graphitic C present in the casting. As an example, in low alloy Cast Irons, depth of chill or the tendency of the iron to be white as-cast depends greatly on the CE, the Si in the composition, and the state of inoculation. The addition of other elements can only modify the basic tendency established by the C-Si relationship.

On the other hand, abrasion resistant white Cast Irons are specifically alloyed with Cr to produce fully carbidic Cast Irons. One of the benefits of Cr is that it causes carbide, rather than graphite, to be the stable C rich eutectic phase upon solidification. At higher Cr contents (greater or equal to 10 %) M_7C_3 becomes the stable C rich phase of the eutectic reaction. In general, only small amounts of alloying elements are needed to improve depth of chill, hardness, and strength. High alloy contents are needed for the most significant improvements in abrasion resistance, corrosion resistance, or elevated temperature properties.

Alloying elements such as Ni, Cr, and Mo are used, singly or in combination, to provide specific improvements in properties compared to unalloyed Cast Irons. Since the use of such elements means higher cost, the improvement in service performance is to be adequate to justify the increased cost.

1-5-1 Effect of carbon

In chilled irons, the depth of chill decreases, and the hardness of the chilled zone increases, with increasing C content. C also increases the hardness of white Cast Irons. Low C white Cast Irons (2.50 % C) have a hardness of about 375 HB (Brinnel hardness), while white Cast Irons with fairly high total C (more than 3.50 %) have a hardness as high as 600 HB. In unalloyed white Cast Irons, high total C is essential for high hardness and maximum wear resistance. Carbon decreases the transverse breaking strength and increases the brittleness. Carbon also increases the tendency for graphite to form during solidification, especially when the Si content is also high. As a result, it is very important to keep the Si content low in high C white Cast Irons. The usual range of C content for unalloyed or low alloy white Cast Irons is around 2.2% to 3.6 %. For high Cr white Cast Irons, the normal range is from about 2.2 % to the C content of the eutectic composition, which is around 3.5 % for a 15 % Cr Cast Iron and around 2.7 % for a 27 % Cr Cast Iron The C content of gray and ductile alloy Cast Irons is generally somewhat higher than that of a white Cast Iron of similar alloy content. In addition, the Si content is usually higher, so that graphite is formed during solidification

1-5-2 Effects of silicon

Silicon is present in all Cast Irons. In alloy Cast Irons, Si is the main reason that determines the C content of the eutectic. Increasing the Si content lowers the C content of the eutectic and promotes the formation of graphite upon solidification. Hence, the Si content is the prime reason for controlling the depth of chill in unalloyed or low Cr chilled and white Cast Irons.

In high alloy white Cast Irons, Si has a negative effect on hardenability. It tends to promote pearlite formation in martensitic irons. However, when sufficient amounts of pearlitic suppressing elements such as Mo, Ni, Cr, and manganese (Mn) are present, increasing the Si contest raises the Ms Temperature of the alloy, thus tending to increase both the amount of martensite and the final hardness.

The Si silicon content of chilled and white Cast Irons is usually between 0.3 % and 2.2 %. In martensitic Ni-Cr white Cast Irons, the desired Si content is generally 0.4 % to 0.9 %.Si additions of 3.5 % to 7 % improve high temperature properties by raising the eutectoid transformation temperature.

Elevated levels of Si also reduce the rates of scaling and growth by forming a tight, adhering oxide scale. This occurs at Si contents above 3.5 % in ferritic Cast Irons and above 5 % in 36 % Ni austenitic Cast Irons. Additions of 14 % to 17 % (frequently accompanied by additions of about 5 % Cr and 1 % Mo) yield Cast Iron that is very resistant to corrosive acids, although resistance varies somewhat with acid concentration. High Si Cast Irons (14 % to 17 %) are difficult to cast and are virtually not machinable. High Si Cast Irons have particularly low resistance to mechanical and thermal shock at room temperature or moderately elevated temperature. However, above around 260 deg C, the shock resistance exceeds that of ordinary gray Cast Iron.

1-5-3 Effect of Sulfur

Most commercial gray irons contain between 0.06 and cementite , in order to end up with a pearlitic gray iron of high strength . of silicon . The higher the sulfur content , the greater will be the amount of 0.12 percent sulfur . The effect of sulfur on the form of carbon is the reverse combined carbon , thus tending to produce a hard , brittle white iron . Aside from producing combined carbon , sulfur tends to react with iron to form iron sulfide (FeS) . This low - melting compound , present as thin inter dendritic layers , increases the possibility of cracking at elevated tempera tures (red - short) . High sulfur tends to reduce fluidity and

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often is respon sible for the presence of blowholes (trapped air) in castings . Fortunately , manganese has a greater affinity for sulfur than iron , forming manganese sulfide (MnS) . The manganese sulfide particles appear as small , widely dispersed inclusions which do not impair the properties of the casting . It is common commercial practice to use a manganese content of two to three times the sulfur content .

1-5-4Effect of Manganese

Manganese is a carbide stabilizer , tending to increase the amount of combined carbon , but it is much less potent than sulfide , its effect is to reduce the proportion of combined carbon by re sulfur . If manganese is present in the correct amount to form manganese moving the effect of sulfur . Excess manganese has little effect on solidifi cation and only weakly retards primary graphitization . On eutectoid graphi tization , however , manganese is strongly carbide - stabilizing .

1-5-5 Effect of Phosphorus

Phosphorus (P) is a mild graphitizer in unalloyed Cast Irons. It mildly reduces chill depth in chilled Cast Irons. In alloyed Cast Irons, the effects of P are somewhat obscure. There is some evidence that it reduces the toughness of martensitic white Cast Irons. The effect, if any, on abrasion resistance has not been conclusively proved. In heavy section castings made from Mo containing Cast Irons, high P content is considered detrimental since it neutralizes part of the deep hardening effect of the Mo. It is considered desirable to keep the P content of alloy Cast Irons below around 0.3 %, and some specifications call for less than 0.1 %. In Cast Irons for high temperature or chemical service, it is normal to keep the P content below 0.15

1-5-6 Effect of Copper

Copper in moderate amounts can be used to suppress pearlite formation in both low and high Cr martensitic white Cast Irons. The effect of Cu is relatively mild compared to that of Ni.

Because of the limited solubility of Cu in austenite, Cu additions probably are usually limited to around 2.5 % or less. This limitation means that Cu cannot completely replace Ni in Ni-Hard irons.

When added to chilled Cast Iron without Cr, Cu contracts the zone of transition from white to gray iron, thus reducing the ratio of the mottled portion to the clear chilled portion.

Copper is most effective in suppressing pearlite when it is used in conjunction with around 0.5 % to 2.0 % Mo. The hardenability of this combination is generally good, which indicates that there is a synergistic effect when Cu and Mo are added together to Cast Iron. Combined additions are particularly effective in the martensitic high Cr Cast Irons. Here, Cu content is usually held to 1.2% or less with larger amount tends to induce austenite retention. Copper is used in amounts of around 3 % to 10 % in some high Ni gray and ductile Cast Irons which are normally specified for corrosion or high temperature service. Here, Cu enhances corrosion resistance, particularly resistance to oxidation or scaling.

1-5-7 Effect of Molybdenum

Molybdenum in chilled and white Cast Irons is distributed between the eutectic carbides and the matrix. In graphitic irons, its main functions are to promote deep hardening and to improve high temperature strength and corrosion resistance. In chilled Cast Irons, Mo additions mildly increase depth of chill. It is, however, around one-third as effective as Cr. The primary purpose of small additions (0.25 % to 0.75 %) of Mo to chilled Cast Iron is to improve the resistance of the chilled face to spalling, pitting, chipping, and heat checking.

Molybdenum hardens and toughens the pearlitic matrix. Where a martensitic white Cast Iron is preferred for superior abrasion resistance, additions of 0.5 % to 3.0 % Mo effectively suppress pearlite and other high temperature transformation products. Mo is even more effective when used in combination with Cu, Cr, Ni, or both Cr and Ni. Mo has an advantage over Ni, Cu, and Mn in that it increases depth of hardening without appreciably over-

stabilizing austenite, thus preventing the retention of undesirably large amounts of austenite in the final structure. When studying the influence of different amounts of Mo on the hardenability of high Cr white Cast Irons, It can be seen that the hardenability (measured as the critical diameter for air hardening) increases as the ratio of Cr to C increases.

The pearlite suppressing properties of Mo have been used to advantage in Cast Irons of high Cr content. White Cast Irons with 12 % to 18 % Cr are used for abrasion resistant castings. The addition of 1 % to 4 % Mo is effective in suppressing pearlite formation, even when the castings are slowly cooled in heavy sections. Mo can replace some of the Ni in the Ni-Cr type of martensitic white Cast Irons. In heavy section castings in which 4.5 % Ni is generally used, the addition of 1 % Mo permits a reduction of Ni content to around 3 %. In light section castings of this type, where 3 % Ni is normally used, the addition of 1 % Mo permits a reduction of Ni to

1.5%.Molybdenum, in quantities of around 1 % to 4 %, is effective in enhancing corrosion resistance, especially in the presence of chlorides. In quantities of 0.5 % to 2 %, Mo improves high temperature strength and creep resistance in gray and ductile Cast Irons with ferritic or austenitic matrices.

1-5-8 Effect of Vanadium

Vanadium (V) is a strong carbide stabilizer and increases the depth of the chill. The magnitude of the increase of depth of chill depends on the amount of V, the composition of the Cast Iron, section size, and the conditions of casting. The powerful chilling effect of V in thin sections can be balanced by additions of Ni or Cu, by a large increase in C or Si, or both. In addition to its carbide stabilizing influence, V in amounts of 0.10 % to 0.50 % refines the structure of the chill and minimizes coarse columnar grain structure. Because of its strong carbide forming tendency, V is rarely used in gray or ductile Cast Irons for corrosion or high temperature service.

1-6 Heat treatment of gray Cast Iron

1-6-1 Annealing

The heat treatment most frequently applied to gray iron , with the possible exception of stress relieving , is annealing . The annealing of gray iron consists of heating the iron to a temperature high enough to soften it and / or to minimize or eliminate massive eutectic carbides , thereby improving its machinability . This heat treatment reduces mechanical properties substantially . It reduces the grade level approximately to the next lower grade : for example , the properties of a class 40 gray iron will be diminished to those of a class 30 gray iron . The degree of reduction of properties depends on the annealing temperature , the time at temperature , and the alloy composition of the iron Gray iron is commonly subjected to one of three annealing treatments , each of which involves heating to a different temperature range . These treatments are ferritizing annealing , medium (or full) annealing , and graphitizing annealing Ferritizing Annealing . For an unalloyed or low - alloy Cast Iron of normal composition , when the only result desired is the conversion of pearlitic carbide to ferrite and graphite for improved machinability , it is generally unnecessary to heat the casting to a temperature above the transformation range . Up to approximately 595 ° C (1100 ° F) , the effect of short times at temperature on the structure of gray iron is insignificant . For most gray irons , a ferritizing annealing temperature between 700 and 760 ° C (1300 and 1400 ° F) is recommended Medium (full) annealing . It is usually performed at temperatures between 790 and 900 ° C (1450 and 1650 ° F) . This treatment is used when a ferritizing anneal would be ineffective because of the high alloy content of a particular iron . It is recommended , however , to test the efficacy of temperatures below 760 ° C (1400 ° F) before a higher annealing temperature is adopted as part of a standard procedure

Holding times comparable to those used in ferritizing annealing are usually employed . When the high temperatures of medium annealing are used , however , the casting must be cooled slowly through the transformation range , from about 790 to 675 ° C (1450 to 1250 ° F) Graphitizing Annealing . If the microstructure of gray iron contains massive carbide particles , higher annealing temperatures are necessary . Graphitizing annealing may simply serve to convert massive carbide to pearlite and graphite , although in some applications it may be desired to carry out a ferritizing annealing treatment to provide maximum machinability The production of free carbide that must later be removed by annealing is , except with pipe and permanent mold castings , almost always an accident resulting from inadequate inoculation or the presence of excess carbide formers , which inhibit normal graphitization ; thus , the annealing process is not considered part of the normal production cycle To break down massive carbide with reasonable speed , temperatures of at least 870 ° C (1600 ° F) are required . With each additional 55 ° C (100 ° F) increment in holding temperature , the rate of carbide decomposition doubles . Consequently , it is general practice to employ holding temperatures of 900 to 955 ° C (1650 to .1750 ° F)

1-6-2 Normalizing

Gray iron is normalized by being heated to a temperature above the transformation range , held at this temperature for a period of about 1 hour per inch of maximum section thickness , and cooled in still air to room temperature . Normalizing may be used to enhance mechanical properties , such as hardness and tensile strength , or to restore as - cast properties that have been modified by another heating process , such as graphitizing or the preheating and postheating associated with repair welding The temperature range for normalizing gray iron is approximately 885 to 925 ° C (1625 to 1700 ° F) . Austenitizing temperature has a marked effect on microstructure and on mechanical properties such as hardness and tensile strength The tensile strength and hardness of a normalized gray iron casting depend on the following parameters Combined carbon content Pearlite spacing (distance between cementite plates) Graphite morphology The graphite morphology does

not change to any significant extent during normalization , and its effect on hardness and tensile strength is omitted in this discussion on normalizing Combined carbon content is determined by the normalizing (austenitizing) temperature and the chemical composition of the casting . Higher normalizing temperatures increase the carbon solubility in austenite (that is , the cementite volume in the resultant pearlite) . A higher cementite volume , in turn , increases both the hardness and the tensile strength . The alloy composition of a gray iron casting also influences carbon solubility in austenite .

Some elements increase carbon solubility , some decrease it , and others have no effect on it . The carbon content of the matrix is determined by the combined effects of the alloying elements The other parameter affecting hardness and tensile strength in a normalized gray iron casting is the pearlite spacing , Pearlite spacing is determined by the cooling rate of the casting after austenitization and the alloy composition . Fast cooling results in small pearlite spacing , higher hardness , and higher tensile strength . Too high a cooling rate may cause partial or martensitic transformation . The addition of alloying elements may change hardness and tensile strength significantly

1-6-3 Hardening (Quench and Temper)

 It is important to carefully select and control the process parameters when performing these operations so as to avoid problems such as distortion , warpage , overheating (" burning ") or quench cracking . The lower - critical temperature for Cast Irons determined by sample analysis

In practice, castings to be hardened are austenitized at a temperature of 10-38°C (50100°F) above the upper-critical temperature for one hour per 25 mm (1 inch). Heating should be gradual so as not to induce thermal stresses. After soaking, the parts are quenched. Typically, a severe quench is unnecessary. Oil or polymer quenching can also be used. Tempering follows and can be performed over a wide range, from 120-595°C (250-

1100°F), to develop proper mechanical properties. Tempering time is typically *shorter than for steels.*

2-1 Introduction

Heat treatments can be done by heating the metal toacertain temperature then keepling The are carried out to chane the properties of metal such as hardness, ductility, remove in internal stresses from the operation, and remove the effects of cold forming processes. This chapter contains all steps of heat treatments, preparation af specimens, and all teste neccessary to the specimens

Heat treatment processes are carried out to change the properties of the metal, including:

And increase the hardness. And increase ductility and toughness. Increasing the metal's susceptibility to forming and operating processes. And remove the internal stresses resulting from the operation. And remove the effects of cold forming processes. Although there are a variety of methods of heat treatment of steel (gray Cast Iron) as follows:

1_ Annealing: The sample was placed in the oven for half an hour at a temperature of 900 °C, and then slowly cooled inside the oven.

2_ Normalization: The sample was placed in the oven for half an hour at a temperature of 900°C, and then cooled with air.

3_Hardening: The sample was placed in the oven for half an hour at a temperature of 900°C, and the type of cooling was quenched with oil for 1/2

hour and Tempering :The specimen was entered to the oven for half of an hour at temperature 400 and then stoped the oven and stayed 2 hours after that cooled in air

2-2Preparation of specimens

Agray cost iron as abar was obtained and tested the chemical composition in the مكان الفحص it is cut in to eighy specimens, and then cleaning operation

A gray Cast Iron flange was obtained and cut into four samples by turning, and then cleaning operations were carried out for the samples with a grinding paper by the **polishing device.as shown in figure1:**

Figure1: grinding machine

2-2-1 Microstructure test

Microscopic examination of the structure Was taking a form of gray Cast Iron (2.5_4.0%) and carbon (3_1%) silicon was softening scribbling paper with different degrees of distribution (200,400,600,800) using the device Softening was then refined samples using

alumina solution granule size (3μm0.) after that was shown samples by solution (Alnayatl) and then washed with water and then dried by a hot-air drying device. It was then examined the microscopic structure of gray Cast Iron by optical microscope.as figure2: shown in

Figure 2-1: a light microscope

2-2-2 Hardness testing

The Brinell Hardness Test method is the most commonly used hardness measurement technique in the industry. In the Brinell Hardness Testing, the hardness of a metal is

Figure 2-2: The hardness machine

determined by measuring the pe rmanent indentation size produced by an indenter. Harder materials will generate shallow indentations while the softer materials will produce deeper indentations. This test method was first proposed by Swedish engineer Johan August Brinell in 1900 and according to his name, the test is popular as Brinell Hardness Test.as shown in figure3:

The hardness was tested using Brinell hardness using a Brinell device. The hardness number was calculated by taking the average of two readings for each sample and using a load of 31N, penetration time of 10s, and diameter 2.5mm. And calculates the Brinell hardness number on it:

BHN =

where BHN = Hardness of the Brinell

P = pregnancy on the indentation tool (kg) .

D = Diameter steel ball (mm) .

d = measurement Diameter at the edge of the impression (mm).

As shown in the figure, and that the hardness value is measured by the effect of the tool on the sample surface from the calculation surface area.as shown in figure4:
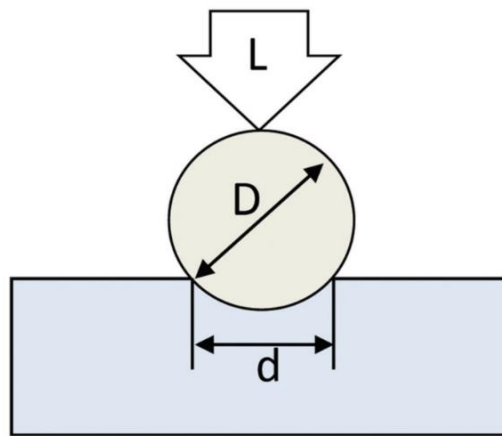

Figure2-3: shows the diameter of ahierarchical effect.

2-2-3 Corrosion testing

The corrosion properties of the base and heat treated samples were measured using the Tafel test Using saline solution at room temperature as shown in figure 5:

Figure 2-4 : Corrosion machine (Tafel)

According to the ASTM standard, Pt, SCE, and sample were used as scale, reference, and working electrodes, respectively. Effective dynamic polarization curves were generated. Using Tafel plots, the corrosion potential and corrosion current density (Icorr) were

$$\text{Corrosion rate(mpy)} = \frac{0.13 \, I_{\text{corr}} \, (Ew)}{\rho}$$

estimated by the anodic and cathodic branches. The test was performed with step-up voltage at a scan rate equal to 0.4 mV w -1 of the initial potential which is 250 megavolts less than the open circuit potential. Scan continued up to 250m open circuit potential. The measured wear rate can be obtained as follows:

Mpy= corrosion rate

Icorr = current density (µA . cm−2),

Ew = Equivalent weight (g/eq)

P = Corrosion density (g/ cm−3)

(mpy) (mils per year), respectively. The constant 0.13 represents the metric and time conversion factor.

2-2-4 Wear testing

Use the wear test in the wear tester from Disk On-Pin . Pin Type And in dry conditions, after preparing samples in the same way as for microscopy samples preparation, but without showing, the length of the samples were (15.35cm) and diameters (5cm).

The values   of the variables that were adopted in this test are:

1. Slipping time = 30s

2. Slip distance = 330m

3. Rotational speed = 350rpm

4. Load applied = 25N

Figure 2-5: wear machine.

3.1 Introduction:

This chapter contains all results of the specimens before and after heat treatments. The microstructure, Brinell hardness, Tafel test, and wear test will disscused.

3-2 Chemical Composition:

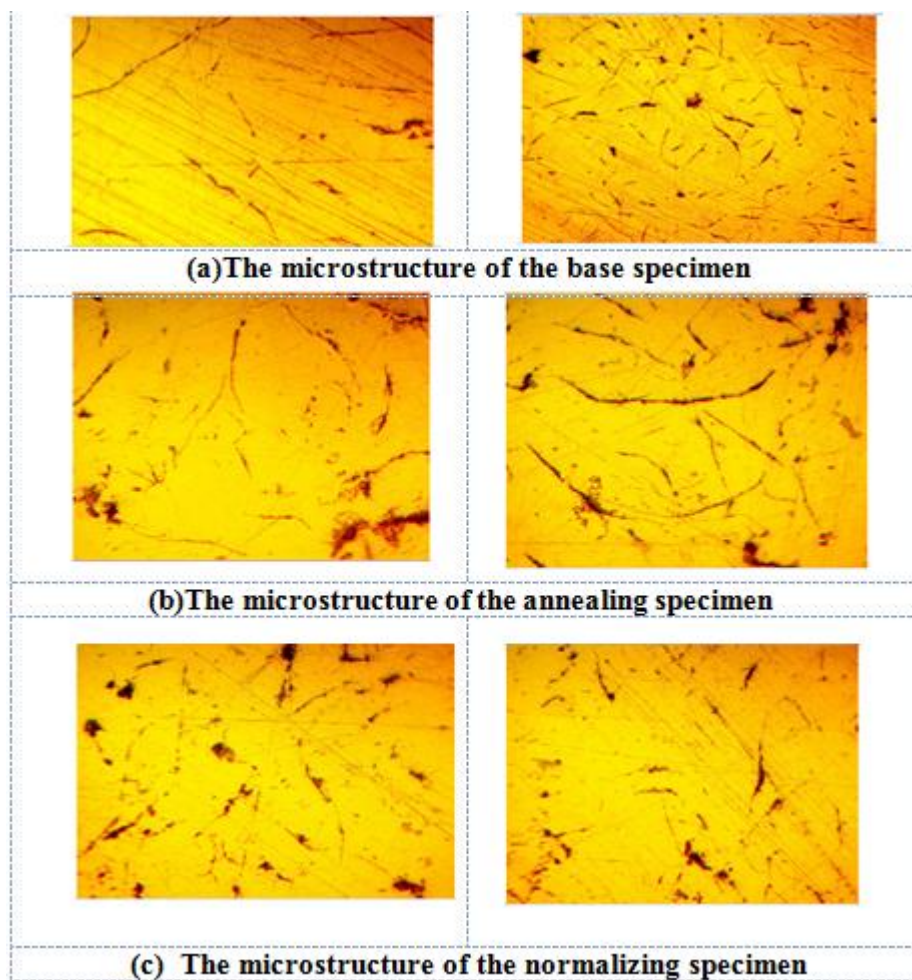The chemical composition of gray Cast Iron was presented in Table (3-1):

element	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Cu	Fe
weight%	2.7	2.07	0.562	0.12	0.12	0.102	0.0318	0.0467	0.00079	0.112	Bal

3-2 The Microstructure:

Figure (3-1) represents the microstructure of the specimens by using two magnification 20X and 60X by optical microscope. The base specimen contained long graphite flakes in the ground of ferrite. After the annealing treatment there was very low cooling rate which gave sufficient time for the carbon atoms to diffuse. The diffusion of carbon atoms promotes the decomposition process of carbon on the graphite flakes which in turn affect the matrix resulted structure. The matrix of ferrite and graphite flakes , this matched with[10].In heat treatments of gray Cast Iron we are not able to change the shape and distribution of graphite(although the graphitization degree is partially being changed) we can influence the basic metal matrix[11].

After normalizing treatment including heating the specimen to 900℃ in order to get an austenite phase then cooling in air. The cooling rate is enough to prevent the diffusion of carbon atoms. That leads the decomposition process of carbon on graphite flakes is less than that occur in annealing process. This will result in more perlite on the account of ferrite as shown in Figure (3-1-c),this similar to [10].

The microstructure of the third heat treatment of hardening and tempering represents in Figure(3-1-d). After quenching in oil the microstructure of gray Cast Iron was martinsite which is a supersaturated solid solution of carbon in BCT(Body Centre Tetragonal). Because of the drastic coolers and entrapment of carbon in iron the martinsite is very hard ,very brittle and is of little use in industry. Another heating cycle is needed to precipitate carbon out of martinsite as Fe3C by a process of tempering .The tempering process have been conducted at 450℃ then specimens cooled in air. The microstructure was tempered martinsite and flakes of graphite in different shape by comparing with the base specimen. This is matched with [10].

(a)The microstructure of the base specimen

(b)The microstructure of the annealing specimen

(c) The microstructure of the normalizing specimen

(d)The microstructure of the quenching and tempering specimen

Figure (3-1): The microstructure of specimen before and after heat treatments
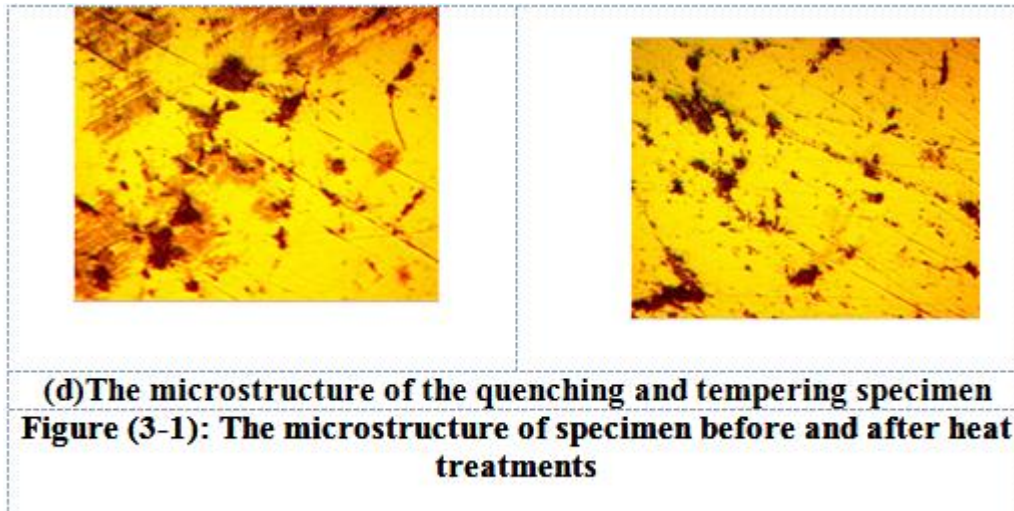
3-3 Brinell hardness:

Figure (3-2) represents the hardness of all specimen. The hardness of specimen after normalizing process had the maximum hardness as 222.5 HB because the perlite matrix after cooling in air and refinement of the grain structure. The hardness of the specimen after hardening and tempering less than the normalizing specimen as 207.5HB depending on the tempering temperature and the carbon content as in [12]. Hardness of the annealing specimen was the lowest value as 175HB but the base specimen had 190 HB larger than the annealing specimen. The decomposition of hard cementite of perlite to spheroidised cementite and ferrite in the process of annealing heat treatment may equally have accounted for the relative reduction in hardness characteristics of the annealed and tempered specimens relative to the normalized specimen. The increasing of hardness is very useful in the modification of brake rotor wear resistance since the rotor subjected to almost continuous contacting by the brake pads[10].
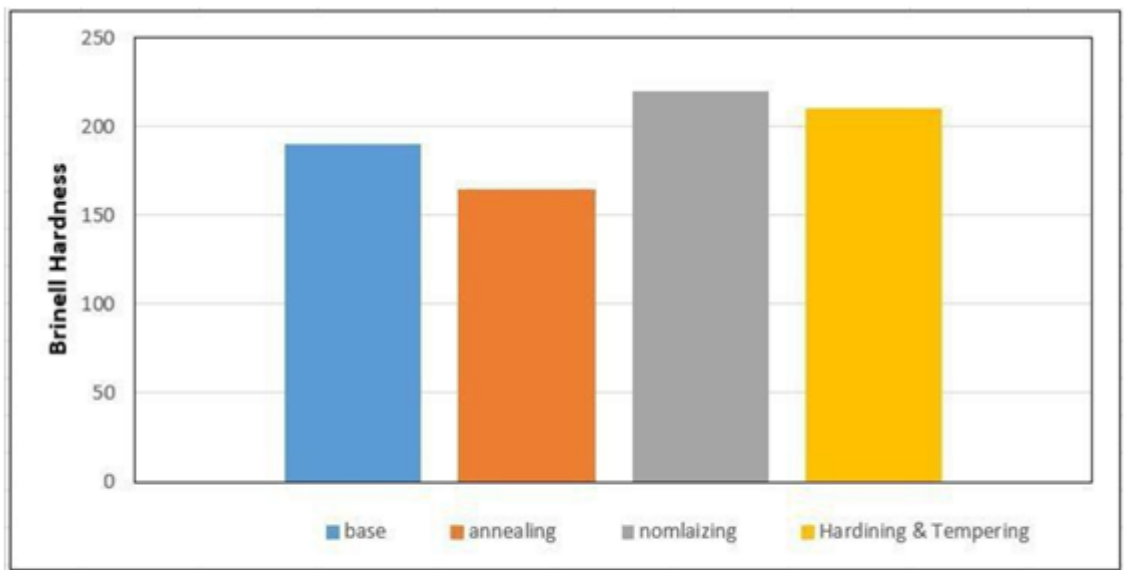
Figure (3-2): Brinell Hardness of the specimens before and after heat treatments.

3-4 Corrosion test:

Tafel test of all specimen demonstrate in Figure(3-3). The annealing specimens had the highest value of current of corrosion 36.67μA but the lowest value of the hardening and tempering specimen as 2.34 μA. Thus the value of corrosion rate of the hardening and tempering process was the smallest value as 0.0095MPY because the temper martensite was more passive to salt solution. The normalizing specimen had corrosion rate as 0.116MPY because the properties of perlite phase. The base specimen had corrosion rate as 0.104MPY because the long graphite flakes . The annealing specimen had 0.148 MPY as in Figure(3-3).
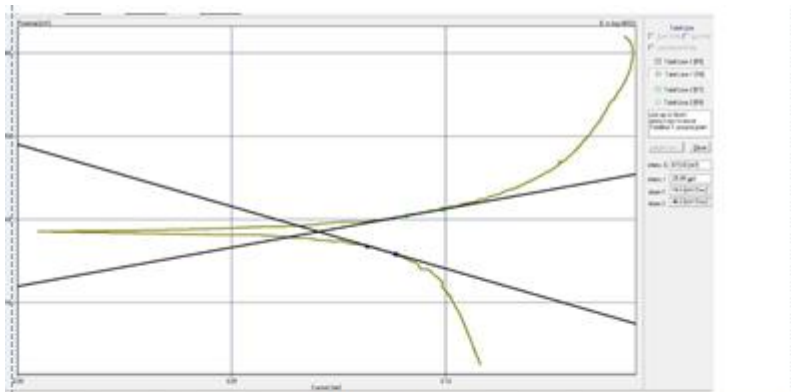
(a)Base specimen
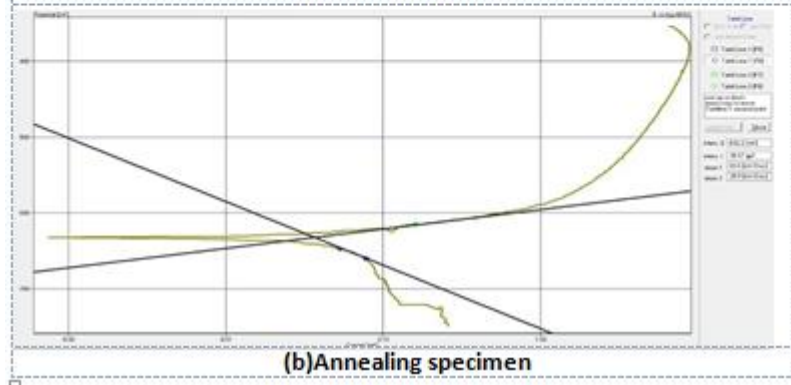
(b)Annealing specimen
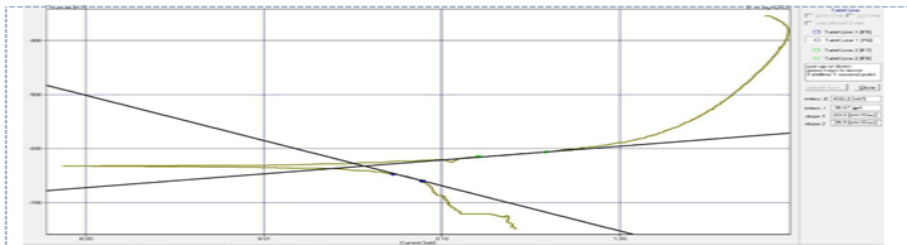
(c) Normalizing specimen
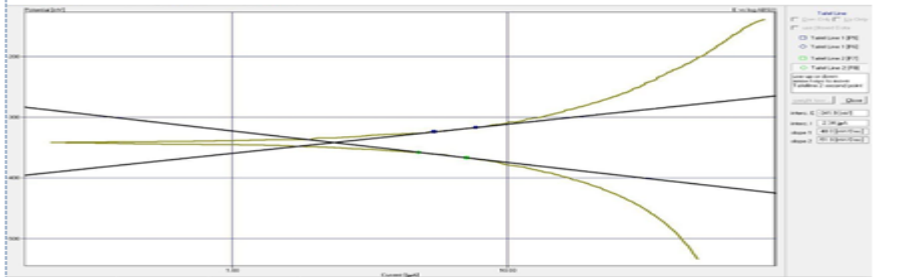
(d)Hardening and tempering
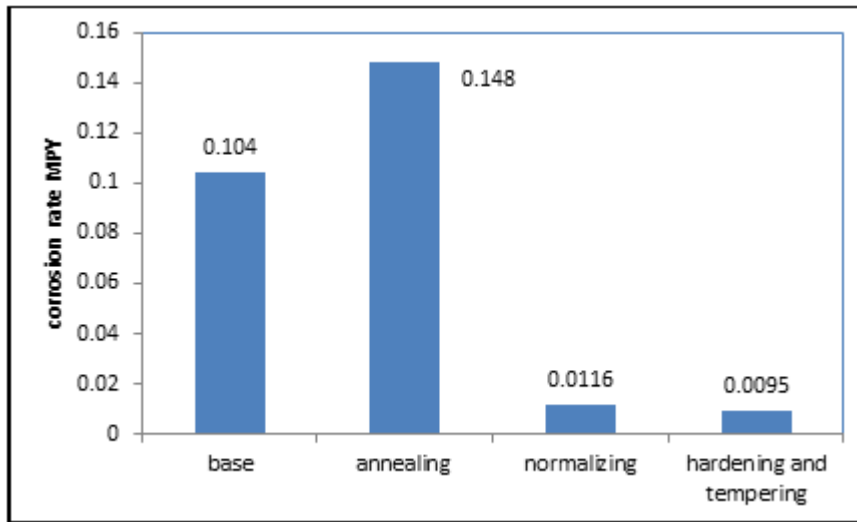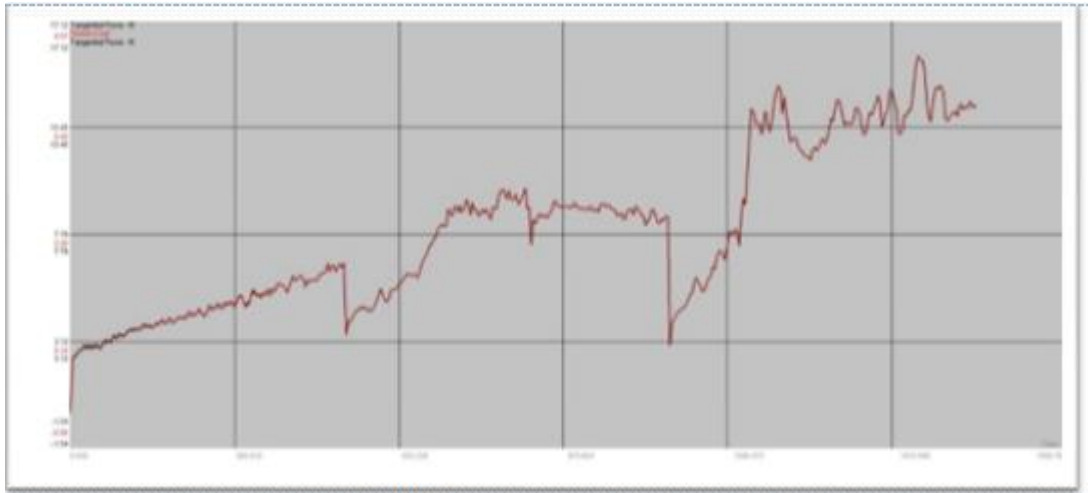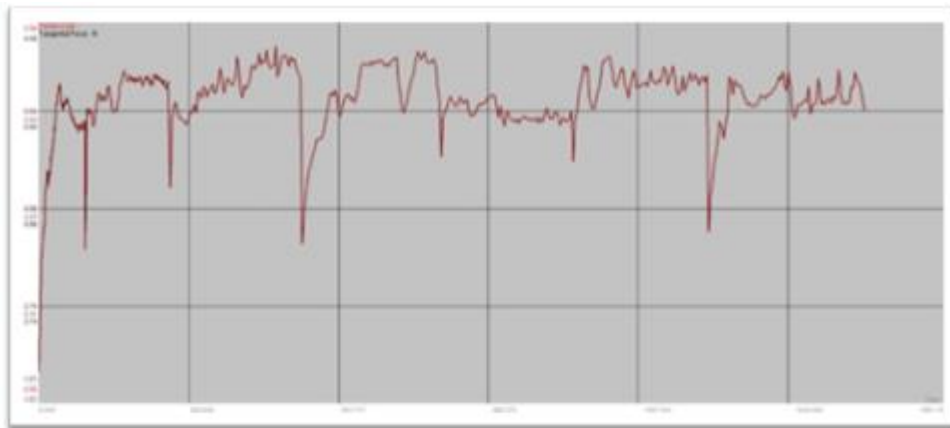**Figure(3-3): Tafel test of specimens before and after heat treatments**

Figure (3-4): The corrosion rate of the specimens before and after heat treatments
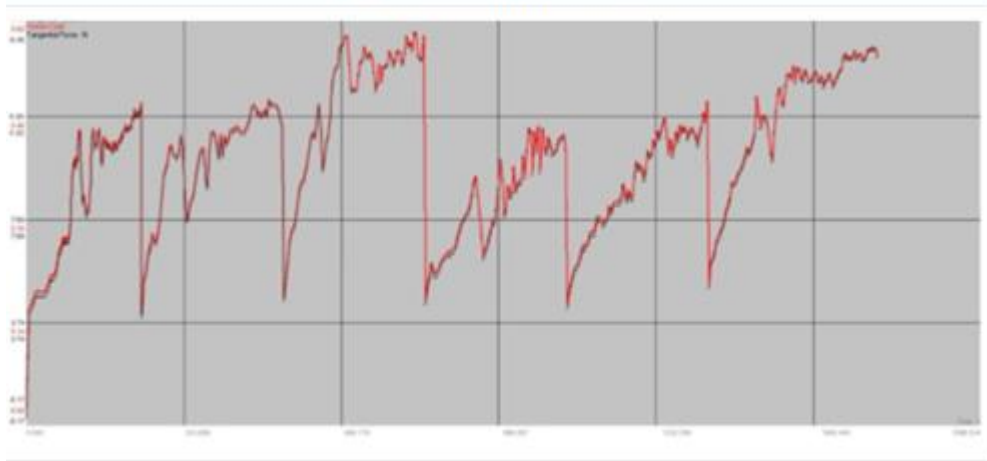
3-5 Wear Test:

Figure (3-5) represents the wear test of all specimens by drawing the relation between the friction coefficient and sliding distance. Figure (3-6) represent the weight loss with time for all specimens . The base specimen lost small weight didn't exceed 0.005 after 30 min because the gray Cast Iron had good property of lubrication[13]. Flakes of graphite were responsible of good lubrication thus the wear resistance was very good. The normalizing specimen, which having the great value of Brinell hardness, had lowest value of weight loss as 0.0008 after half of hour. The annealing specimen lost highest value of weight after 5 min as 0.0432 but after that 10 min decreased the weight loss to 0.0057 because the properties of ferrite matrix and the graphite flakes. After 15 min increased the value of weight loss to 0.0176. The hardening and tempering specimen had low value of weight loss not exceed 0.0017 after 15 min but increased to 0.0144 after 30 min. The improvement in hardness that accompanied with a noticeable development in ductility can gives a supporting for the using of normalizing treatments in the manufacturing of an automotive brake rotor where an impact resistance is large due to a modified ductility that accompanied with a high hardness and ultimate tensile strength[10].
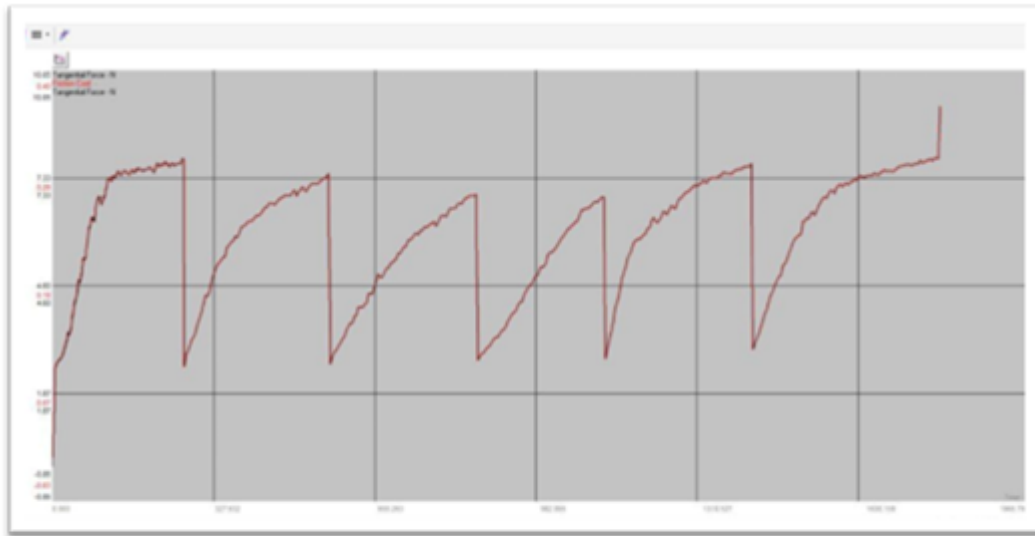
(a)Base specimen

(b) Annealing specimen

(c) Normalizing specimen

(d) Hardening and tempering specimen

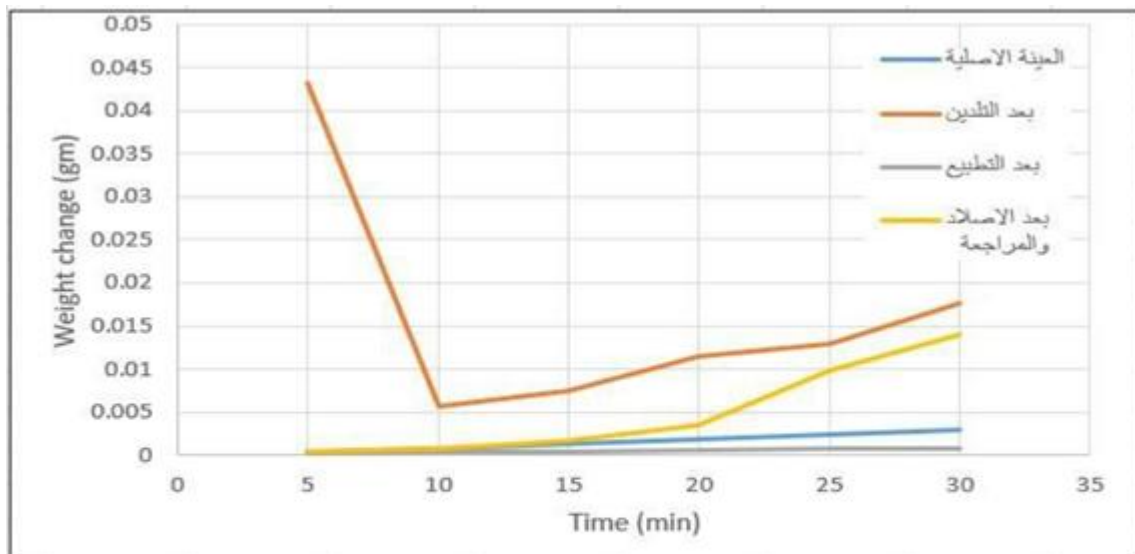**Figure (3-5): The wear test of the specimens before and after heat treatments**

Figure (3-6): The weight loss of the specimens before and after heat treatments

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