IMPROVEMENT OF MECHANICAL PROPERTIES OF ALLOY STEEL TYPE (40X) BY USING HEAT TREATMENTS

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Abstract

Heat treatment is a process or several processes contained heating and cooling a solid metal or alloy is such way as to obtain desired conditions or properties , or recovery the properties was existed in metal or alloy which exposed to certain operational process . The objective of this study is to investigate effect of heat treatment on mechanical properties of low-chromium alloying steel (1.1%Cr) with (0.4%) carbon and these properties are : tensile strength , hardness , elongation , and reduction in area . The heat treatments included full annealing which consist of heating steel to(870?C) and cooling in furnace, hardening which done by heating to(870?C) and quenching in oil , and tempering in (300?C and 600?C) . The mechanical properties was measured before and after heat treatment as illustrated in the diagrams between heat treatment mechanical properties .The important of this research is that it used a material was used only in militarism fields and calculated its properties to compared them with another steels types for using in civil fields .

Keywords:- heat treatment , mechanical properties , Alloy steel Type (40X) .

تحسين الخواص الميكانيكية للفولاذ السبائكي نوع (40 X) بإستخدام المعاملات الحرارية

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الخلاصة.

المعاملة الحرارية هي عملية أو مجموعة عمليات تتضمن تسخين وتبريد المعدن أو السبيكة في الحالة الصلبة بطريقة تضمن الحصول على الخواص أو الظروف المرغوب بها ، أو إستعادة الخواص التي كانت موجودة في المعدن أو السبيكة المتعرضين لعملية تشغيلية معينة . أن الهدف من هذه الدراسة هو البحث في تأثير المعاملات الحرارية للفولاذ السبائكي واطئ الكروم نوع (40X) المحتوي على نسبة كروم (1.1%) مع نسبة كاربون (0.4%) وقد شملت هذه الخواص كل من : مقاومة الشد ،الصلادة ، الإستطالة ، والتقلص في المقطع . تضمنت المعاملات الحرارية كل من التخمير التام والذي يتضمن التسخين لدرجة حرارة (870?C) ثم التبريد داخل الفرن ، الإصلاد حيث تسخن العينات إلى درجة (870?C) يعقبها الإخماد في الزيت ، والمراجعة في درجات حرارة (300?C) و (600?C) . تم قياس الخواص الميكانيكية قبل وبعد المعاملة الحرارية وكما موضح في المخططات البيانية بين المعاملة الحرارية والخواص الميكانيكية . تكمن أهمية البحث الحالي إلى كونه يتطرق إلى مادة كانت تستخدم حتى في المجالات العسكرية فقط وعدم التطرق إلى خواصها في المصادر العلمية لذلك تم إختبار الخواص الميكانيكية لهذه المادة في سبيل مقارنتها بخواص أنواع الفولاذ الأُخرى من أجل إمكانية إستخدامها في المجالات المدنية .

الكلمات الدالة : المعاملة الحرارية ، الخواص الميكانيكية ، الفولاذ السبائكي نوع (40X) .

Introduction .

An alloy steel may be defined as one whose characteristic properties are due to some element other than carbon . Although all plain-carbon steels contain moderate amounts of manganese (up to about 0.9%) and silicon (up to about 0.3%) , they are not considered alloy steels because the principal function of the manganese and silicon is to act as deoxidizers . They combine with oxygen and sulfur to reduce the harmful effect of those elements · Alloying elements are added to steels for many purposes , some of the most important are : increase hardenability , improve strength at ordinary temperature , improve mechanical properties at either high or low temperature , improve toughness at any minimum hardness or strength , increase wear resistance , increase corrosion resistance , and improve magnetic properties [Avner,1983].

Heat Treatments .

We can defined heat treatment as a heating and cooling a solid metals or alloy in such way to obtain desired conditions or properties and to get a good improvement in these properties . There are many types of heat treatments which can explained as :

Full Annealing.

The heat treatment consist of heating steel to a temperature between (850 ?C - 870?C) for transform all steel structure to austenite phase , and then slow cooling in furnace [Higgins,1993] . the target from this process in alloy steel is to refine grain size of steel , where chromium cause growth of grain size which will cause brittleness of steel at elevated temperature . also full annealing tends to improve machinability and normalized crystal structure as well as removed segregation and internal stresses [Totten,2006].

Hardening .

This treatment used for all types of tools and parts which required high hardness and impact strength . the hardening temperature to medium carbon steel with alloying elements is between (850 ?C - 870?C) and then quenching in water or oil to obtain desired structure and properties [Avner,1983] .

Tempering .

Due to quenching from high temperature there will be a defect and stresses in steel structure such as growth of austenite grain size after quenching which formed coarse grains of martensite leads to decrease toughness and increase brittleness , as well as increased thermal stresses [Higgins,1993] . so that , tempering process is done to improve properties after quenching . the rang temperature of tempering at high temperature between (500?C-600?C) and at low temperature rang between (180?C-200?C) [DeGarmo,2008].

Normalizing .

Normalizing resembles the full annealing of castings in that maximum temperature attained is similar . it is in method of cooling that processes differ . in normalizing the steel is removed from the furnace and allowed to cool in still air [Totten,2006].

Recrystallization .

The plastic deformation of any metal produces internal stresses and alters the electrical conductivity as well as the magnetic permeability of the material . however , heating of a plastically deformed metal will effect a relief of the internal stresses and recovery of electrical conductivity and magnetic permeability [Kim,2006].

Chromium Steel .

The (Fe-Cr-C) system is the basis of a number of the most widely used wear resistant materials having application in mining , mineral processing , cement works , agricultural sectors and rolling mill rolls [Tagashira,2000]. There are three types of chromium steel , ferritic , martensitic , and pearlitic .

The pearlitic type which the subject of this study contain (1-1.5) percent chromium and (0.35 - 1) percent carbon . this type of steel used for axle shafts , connecting rods , and gears ; while those types of steel containing more than one percent of carbon are extremely hard and useful for the manufacturing of ball bearing , drawing dies , and parts for grinding machines [Hongsug,2001]. The main function of chromium when added in small amount to the carbon steel is to increase hardness and in the same time will raise strength with some loss in ductility . the chromium tends to form hard carbides with carbon such as M_2C , M_7C_3 , and $M_{23}C_6$ which will raise the hardness of steel , in addition, the chromium lower the A_4 temperature and raise A_3 temperature [Tagashira,2000] .

Experimental Part.

The experimental part includes four steps :

1- Chemical Composition Test . this test done by *X*-Ray Fluorescent to know the composition of this type of steel , and the **table (1)** show the composition of low chromium steel .

2- Preparation of Specimens. Which consist of :

a-Specimens of hardness test, which have a disk shape with (25*mm*) diameter and (10*mm*) thickness, as shown in **figure (1-a)**.

b- Specimens of tensile test, as shown in **figure (1-b)** these specimens have a circular section with a 150mm length and 18mm diameter as (*ASTM*) standards.

3- Heat Treatments . this study used a three types of heat treatments as follows:

1- Full Annealing . heating specimen to temperature (870?C) and soaking in this temperature one hour and then slow cooling in furnace.

2- Hardening in Oil . heating specimen to temperature (870?C) and soaking in this temperature one hour , then quenching in oil.

3- Tempering .this treatment take place in two temperatures:

a- heating to (300?C) and soaking one hour, and then cooling in air.

b- heating to (600?C) and soaking one hour, and then quenching in oil.

figure(2-a) show the microstructure of low chromium steel before heat treatment , and the **figure (2-b)** the microstructure after tempering at (600?C) .

4- Mechanical Tests : mechanical testes included:

1- Hardness Test :in this test we used "Brinell method" to measure hardness , this test made with a ball of (10*mm*) diameter loaded into specimens , and the hardness number represent the diameter of impression after remove the load , which left on surface by the ball . Brinell hardness number (*HB*) IS calculated from the following formula :

$$HB = \frac{P}{\left(\frac{\pi \times D}{2}\right)\left(D - \sqrt{D^2 - d^2}\right)}$$

where :

HB = Brinell hardness number (N/m^2)

P = test load (N)

D = diameter of ball (mm)

d = diameter of impression (mm)

2 - Tensile Test :this test used for measure the following properties :

a - Tensile Strength .

tensile strength can be obtain from the following formula :

$$\sigma = P/A$$

where :
σ = tensile strength (N/m^2)
P = test load (N)
A = cross section area of specimen (m^2)

b- Elongation .
this property is determined by fitting part of specimen after fracture together and measuring the distance between the original gauge marks . the elongation can be obtained from this formula:

$$Elongation\,(\%) = \frac{L_f - L_O}{L_O}$$

where:
L_f =final gauge length (mm)
L_o = original gauge length (mm)

c- Reduction in Area (%) .
this also determined from the broken halves of the tensile specimen by measuring the minimum cross-section area and using the following formula :

$$R.A(\%) = \frac{A_O - A_f}{A_o}$$

Where :
A_o = Original cross-section area.
A_f = Final cross-section area.

Results & Discussion .

From the results obtained by mechanical tests which consist of tensile strength , hardness , and elongation and established in diagrams before and after heat treatments on low-chromium steel , observed that :

From the **figure (3)** which represent the effect of heat treatments on Brinell hardness observed that low-chromium steel have relatively high hardness and this due to the stable carbides formed by chromium which be higher hardness than Fe_3C . the hardness of low-chromium steel changed when carryout of heat treatment , according to the effect of this treatment , since its hardness decrease when treated with full annealing because of the microstructure of steel is pearlite in ferrite matrix , and this structure have a good elasticity as well as the this heat treatment refining the grain size of steel which cause lower of hardness value.
The hardness extremely increase after done hardening in oil , since , due to quenching from high temperature the martensite phase will form , and this phase have a high hardness which leads to brittleness . on the other hand , when achieve tempering at (300?C) , the hardness will decrease so largely due to form tempered martensite (Troostite) , which have fine grain size . but when used tempering at high temperature (600?C) , the hardness will increase again because of forming a large amounts of carbides generated from added chromium and these carbides leads to raise hardness, and steel structure known as (Sorbite).

The **figure(4)** shown the effect of heat treatments on tensile strength of low-chromium steel. tensile strength of this type of steel have a high value before heat treatment due to large grain size of steel , but when performs fall annealing on steel the tensile strength . But , when hardening in oil is done, the tensile strength is raise so largely due to form of martensite phase , from the other hand , when treated steel by tempering at (300?C) ,the tensile strength will decrease so largely because of martensite formation (Sorbite) which have a small grain size . this type of martensite consist from ferritic matrix distributed on it carbides grain .

in edition , this property will extremely increased when treated steel with tempering at (600?C) due to the substitution diffusion speed ,where this carbides raises the yield strength and in the end will raise strength .

The elongation committed reversely with tensile strength , where if the elongation increase the tensile strength will decrease and vise versa .the principal factor determined the elongation value is materials grain size in addition to this factor there are several factors have an effects on elongation such as thermal stresses ,type of alloying elements defects. pearlitic steel have relatively high elongation and this show in **figure (5)** , this elongation comes from steel structure which consist of pearlite and ferrite , and both phases are ductile .

elongation sever intense reduction which come from the change in it's internal structure , since the structure transformed to martensite and some residual ferrite with generated thermal stresses and growth martensite grains to coarse grains , all this due to increase brittleness and lower elongation . but , when treated steel with full annealing .

the elongation will increase so large and this due to the refine grain size to steel structure which contain pearlite in ferrite matrix ,and this structure is ductile , so that, the elongation will rise . however, the elongation raise twice about what in hardening when treated with tempering at(300?C) , where the structure transforming to ferrite matrix distributed on it carbides grains which give a high elongation , also stresses will remove from steel . but , when raise tempering temperature to(600?C) , the elongation value will decrease because of increase carbides formation into steel structure which leads to lower elongation .

The **figure (6)** show the effect of heat treatment on reduction in area of specimens , where the specimens have a good reduction percentage of reduction in area because of it have good ductility . this percentage of reduction in area can be improved when done full annealing due to increase ductility of material which comes from the structure of steel(pearlite + ferrite) . however , the reduction in area will decrease when treated material by hardening in oil , because of martensite formation which be a hard and brittle phase .

the hardness and brittleness of martensite can be minimized by tempering at (300?C) , where the brittle martensite will transform to tempered phase (Troostite) which have a better ductility resulting good reduction in area , and when rise temperature of tempering to(600?C) reduction in area will decrease due to increase carbides formation .

Conclusions .

From the obtained results we get :

1- Improving hardness and tensile strength after hardening in oil with reducing the elongation and reduction in area because forming martensite phase .

2- After full annealing the elongation will increased conjugate with reducing the value of hardness , tensile strength ,and reduction in area due to the refine grain size of steel .

3- Improving elongation and reduction in area after tempering at(300?C) with lowing the hardness and tensile strength because forming the phase of tempered martensite (Troostite) .

4- After tempering at(600?C) the hardness and tensile strength will increase conjugate with reducing the elongation and reduction in area because forming Sorbite phase .

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Table (1): Composition of Low - Chromium Steel

Metal	C	Cr	Mn	Si	Mo	S	P
Percentage(%)	0.4	1.1	0.54	0.23	0.04	0.016	0.012

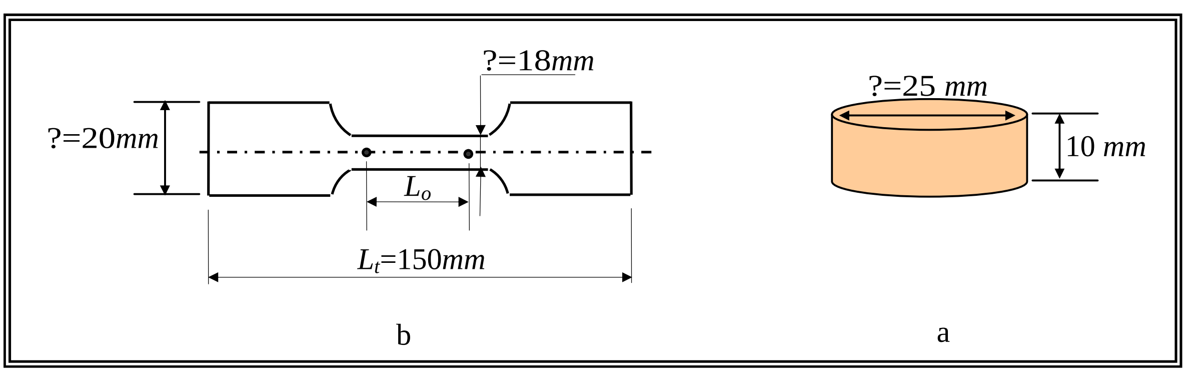

Figure (1): a- Specimen of hardness test b- Specimen of tensile test

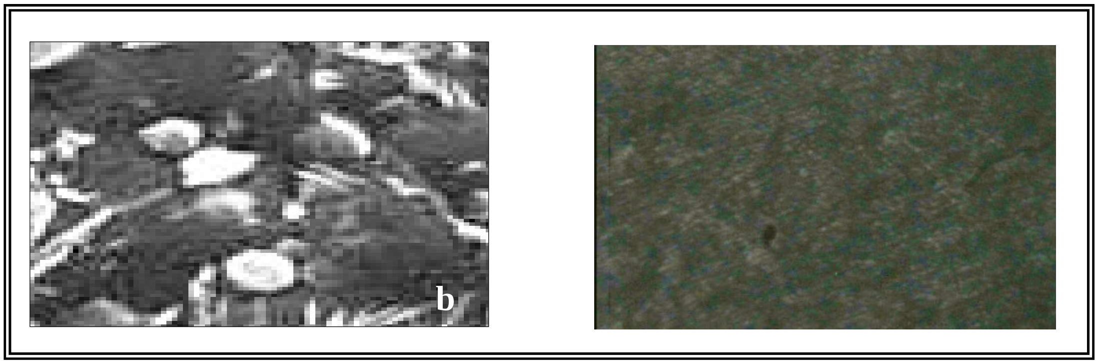

Figure (2): a- microstructure of low chromium steel before heat treatment
b- microstructure after tempering at(600?C)

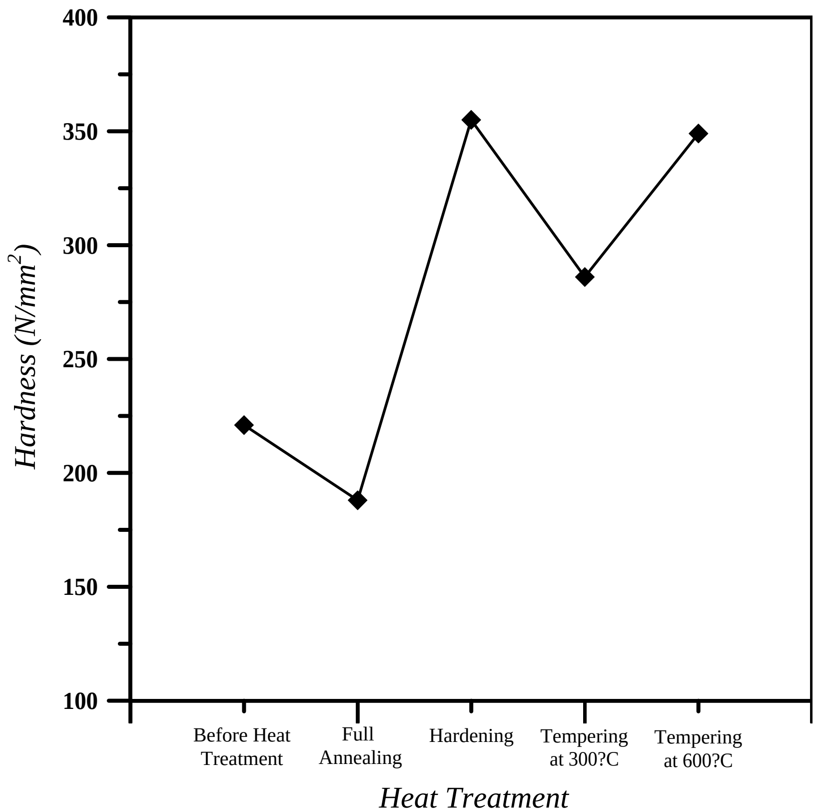

Figure (3): Hardness

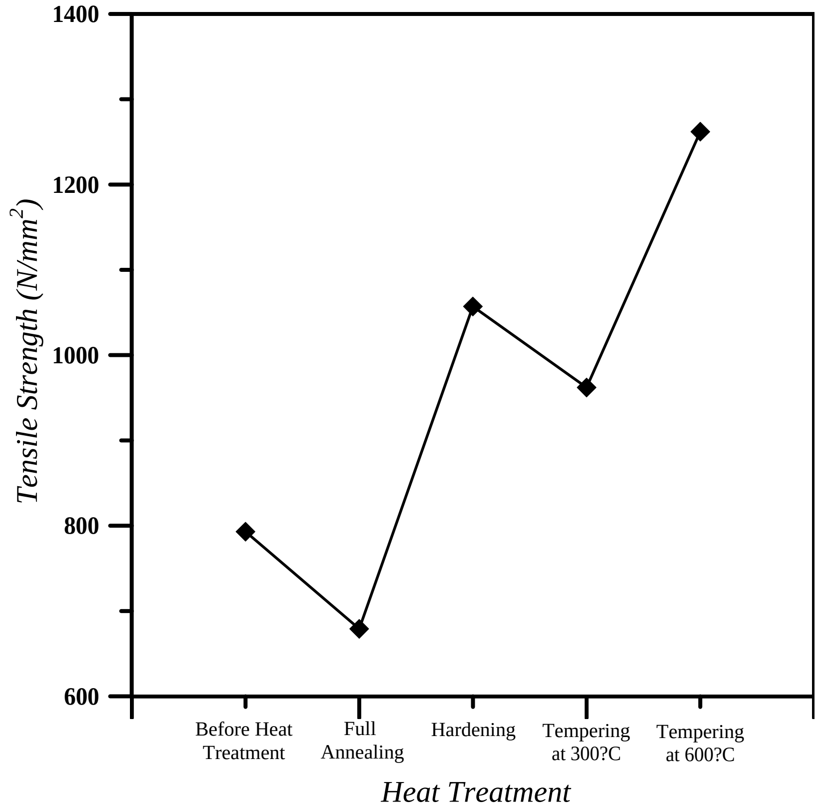

Figure (4): Tensile Strength

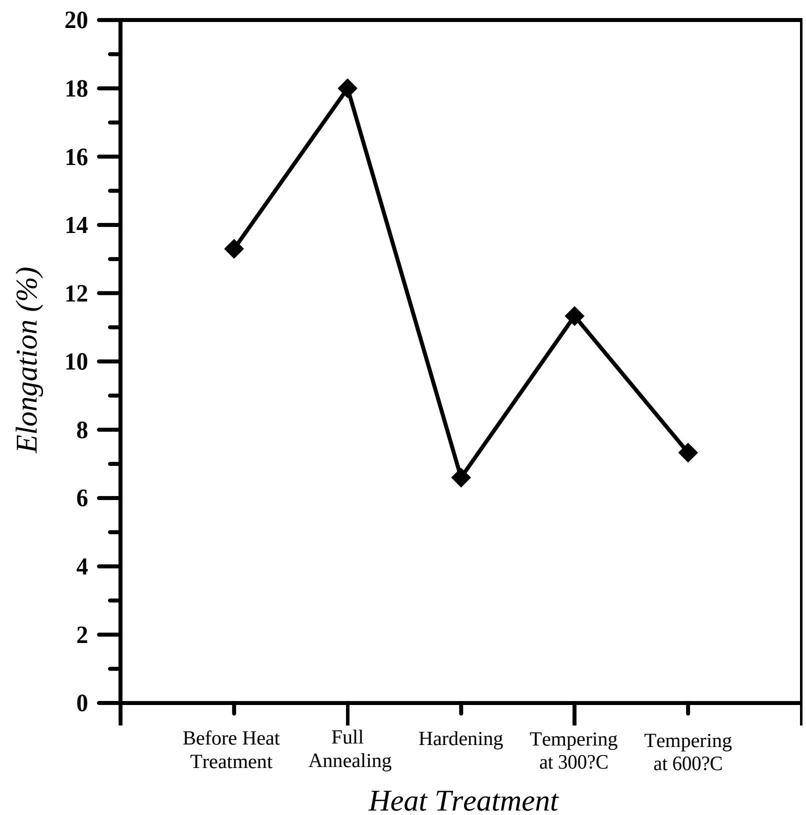

Figure (5): Elongation

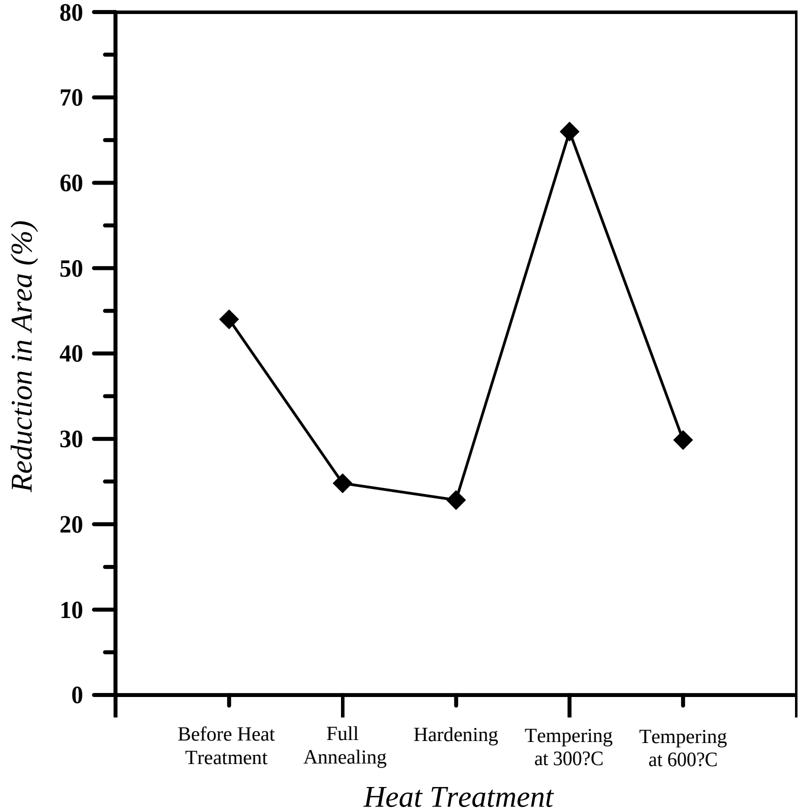

Figure (6): Reduction in Area