The Effect of Heat Treatment on the Mechanical Properties of Stainless Steel Type 304

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Abstract: ***The stainless steel has a wide uses in engineering industry because of his geometric properties, such as resistance corrosion, high flexibility, appropriate hardness, and its ability to tolerate static and dynamic loads. And it is a very suitable in domestic uses and in manufacturing some of automotive parts and in many engineering applications. In this research a sample of stainless steel type 304 was selected, where heat treatment (Normalizing) was carried out for him, this process was carried out at (1150, 1100, 1150) C^0 respectively, after that tempering process was carried out at 350 so as to remove the internal stresses and to prevent carbides precipitation which occurs at a temperature of (450-800) C^0 for the stainless steel, also mechanical tests were carried out, which is tensile and hardness tests using Brinell method, in addition to that a fatigue and wear testing, also tear and shock testing using Sharbi method, in general the experimental results showed that the thermal treatment leads to improve the mechanical properties with the exception of the shock testing, and the best cases appeared at 1100 C^0.***

Keywords: Heat treatment, stainless steel, mechanical tests 304

1. Introduction

Heat treatments or thermal treatment is heating processes usually takes place on different metals and keep them at a constant temperature for an appropriate period of time depends on the thickness of the model to bring change to the internal structure followed by a change in the natural and mechanical properties of these metals. And it can thus hardening different metals. Where the carbon steel alloy as well as steel alloy and stainless steel gained a paramount importance, which consider to be one of the few engineering alloys that are thermally processed to take advantage of change of mechanical properties due the changes that occur in the internal structure which is made in the solid state, Heat treatments can be applied to stainless steel not only in order to increase the hardness, but also to improve the durability, flexibility and ductility, Mechanical properties depends on the microstructure which occur during the phase transitions and changes that occur during heat treatments [1], and the ratio of carbon have a large control in the mechanical properties and in heat treatment that can be used and heat treatments can be classified as follows [2].

1.1 Annealing

The microscopic structure of the stainless steel characterized by its high volume of crystals (Grain) for its original size due to the growth of these crystals (Grain Growth) which occurs as a result of heating upper than critical temperature that followed by very slow cooling therefore the material should left inside the furnace until it reaches the rooms temperature. This process does not lead to improve the mechanical properties for stainless steel due to deposition of carbides which occurs at a temperature (400-800 m) C^0 therefore been excluded in our research this.

1.2 Normalizing

Where the stainless steel is heated to a degree higher than the degree of the upper critical temperature heat and stay at this temperature for and appropriate period and then cooled directly with air cooling. This process leads to a decrease in the size of the crystals and increasing in the number of those crystals in comparison to the crystals gained by fermentation process, and this is due the effect of cooling rate on the grain size where, whenever cooling speed increased the number of the grain consequently increased because of its small size, which thus lead leads to increase grain boundaries and thereby increasing in the hardness.

1.3 Hardening

Where stainless steel is heated to a temperature higher than the upper critical temperature heat and cooled by water or oil or any convenient liquid, where the resulting a single phase solution consists of a complex Carbides such chromium carbide and iron carbide and manganese carbide, this can lead to form a supersaturated solution, which will the saturated excessive carbon atoms be dissolved in the solution due to the rapid cooling, which will make crystal structure have a centered body prism-shaped (BCT) [3].

1.4 Tempering

Where heating to lower than critical temperature is carried out and before austenite reformation to allow again redeployment. This paper deals with heat treatments for a equivalent type 304 stainless steel, which is carried out by heating it to temperature above upper critical temperature and stay at this temperature for specified period of time, and then cooling it by direct air, then process of tempering is carried out at 350 C^0 in order to remove internal stresses. Heat treatments aim is to change the mechanical and physical properties of metal, where soft stainless steel presence for example does not withstand stresses and does not resist the wear by friction. Processes of normalizing and tempering where used and annealing and hardness have been eliminated, that is because the alloying additions in steel lead to the deposition of steel carbides where the presence of chromium in this ratio cause the deposition of chromium carbide which increases the hardness and makes the steel brittle steel as the use of hardening leads to distortions emergence which will reduce the mechanical properties.

2. Research Problems

Problems of this researches lies in the following question: Can a heat treatment of stainless steel designed to improve the mechanical properties and get rid of the fragility resulting from the deposition of carbides together to retain the basic properties of stainless steel which is corrosion resistance.

3. Research Purpose

Research aim is to find a heat treatment to be their purpose to improve the mechanical properties of stainless steel type (304) without compromising the basic stainless steel properties, which is corrosion resistance as well as to know the heat treatment type required and the necessary degree to conduct such treatment and the proper ideal temperature needed to conduct such as this treatment.

3.1. The internal structure of stainless steel

The internal structure of stainless steel is thick due to the slow cooling rates, so the alloy containing carbon ration of (0.08) freezing starts up to 1510C^0 and be completed within 1498 C^0 so we resort to the thermal treatments in order to reduce the size of the granules. Which leads to improve mechanical properties? The best suitable heat treatments of Austenite stainless steel is slow heating to a temperature (50-100) C^0 above the upper critical temperature (A_3), the excessive overheating for long time within the field of the Austenite leads to a clear growth of formed Austenite granules figure (1). Leading to the formation of a bad structure therefore heating degree should not exceed the required degree [4].

When a certain alloy is suddenly cooled, this prevent transitions occurring in the internal structural, so often becomes possible to lock up the internal structure of the metal as it is at high temperature and keep them up the rooms temperature. The presence of alloying elements such as nickel and chrome manganese will help in the increase of temperature (T4) (critical temperature upper) and reduce the temperature (T3) (degree lower critical temperature),figure (2), which will contribute to increase the stability of the austenite developed [5] which leads to form so-called closed-loop Kama [6].

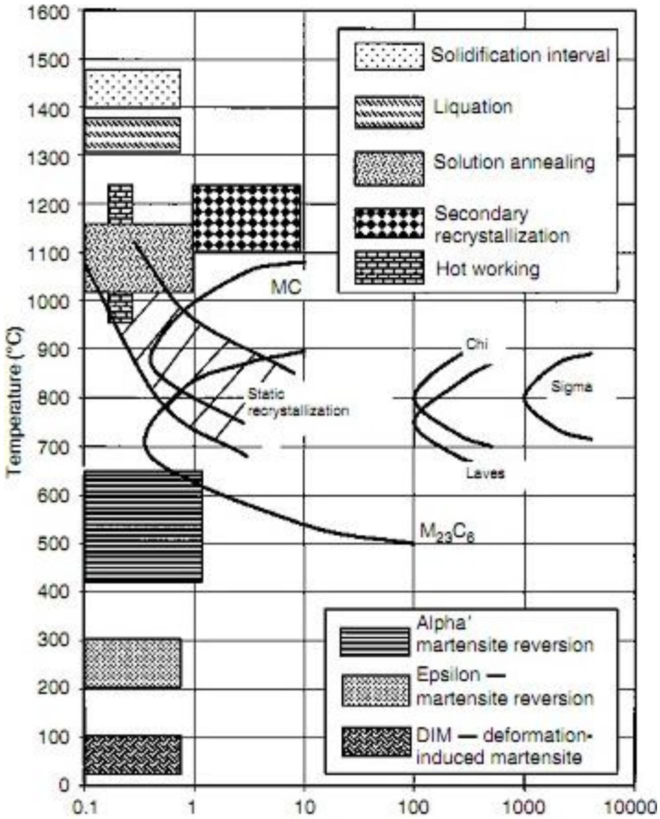

Figure 1: the major heat treatment the transformation that occurs in the Austenite stainless steel at the rooms temperature and liquid phase

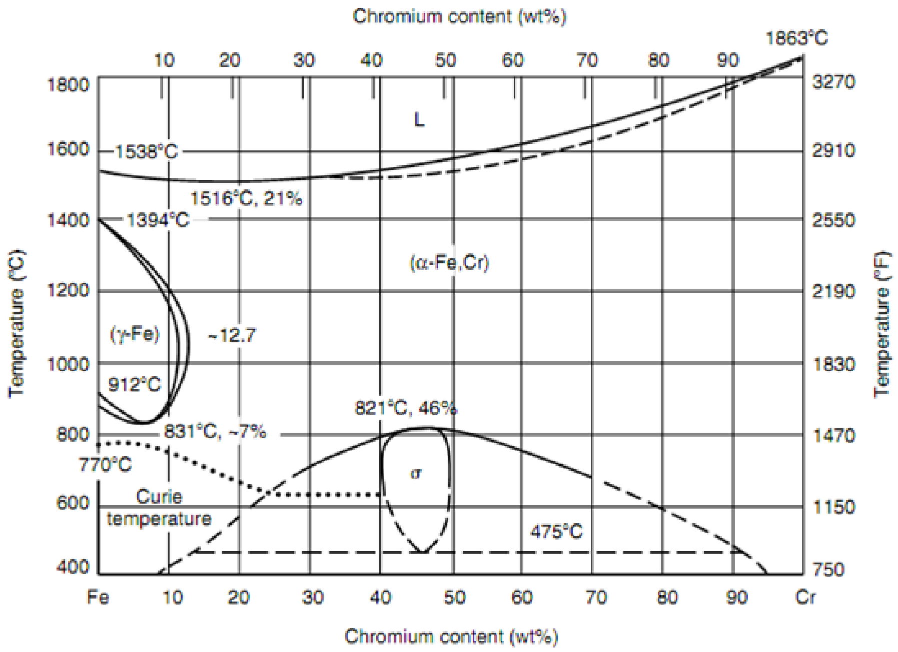

Figure (2) Kama closed loop forming in thermal equilibrium of chromium

3.2 Carbides Development

The chrome and presence of manganese helps the formation of carbides where these carbides are considered to be harder than iron carbide in the case of its formation, as if it was found with the presence of other elements it will consist a complicated carbides, as the presence of nickel in the iron contributes to deposit the Graphite independently which leads to a decrease in mechanical properties, but these few rate of carbon help to from Graphite independently figure (3).

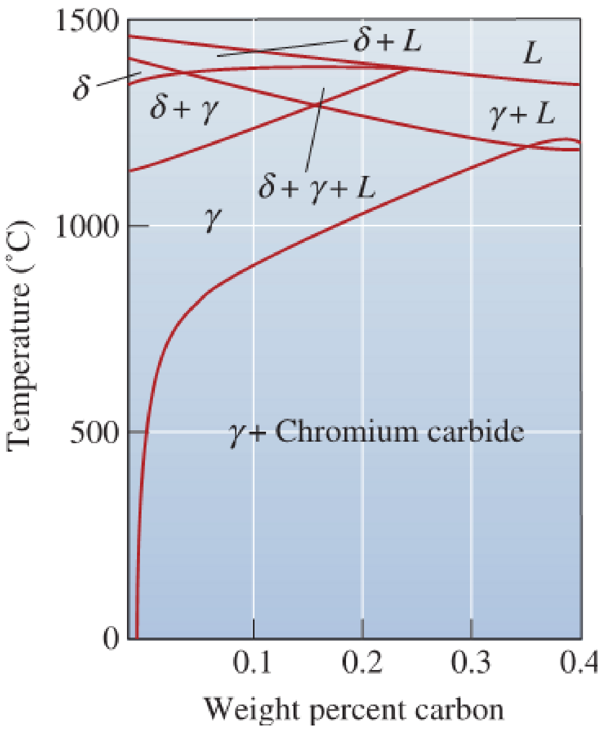

Figure 3: Carbide Development

3.3 Stainless Steel

Metal alloy containing a mixture of elements which the steel is the main ingredient as well as other elements such as carbon by no more than about 2.1% the rate of chromium not exceed 30%, in addition to some elements which represent about 8.5% such as nickel to improve its properties. Resistance to rust and corrosion gained due to the formation of coherent thin layer which is not visible from the chromium oxide stick to the surface of the metal and pure from corrosion, and this become protective sufficiently in high percentage whenever the rate of chromium is high in the steel**[7]**.

Stainless steel often classified in accordance to the microstructure to five classes which are, Austenitic stainless steel and Ferritic and Martensitic and Duplex stainless steel (Austenitic and Ferritic) in addition to tempered stainless steel by Precipitation method (Hard enable), also Austenitic stainless steel specified by dropping of thermal conductivity and increasing of the thermal expansion coefficient.

Stainless steel first time known by a Bareilly scientist in 1912 he managed to obtain an alloy contains (12-13)% chromium which not rust in atmosphere and other media, it was used for manufacturing tableware, and since then until now appeared many kinds, especially those that require a high resistance to corrosion du the harsh medium help to corrosion like the mediums exist in the chemical and petroleum industries.

The main function of Chrome when added to carbon steel is to increase the hardness, the increasing in the hardness refer basically to the chromes property as a hardwood carbides stabilizer (Cr_7C_3) or ($Cr_{23}C_6$) in addition to this, the protective layer that arise on the outer surface and which is very cohesive can be capable of non-interaction the material with the outer atmosphere which leads to form a protective layer to protect the alloy from corrosion [8].

4. The effect of Alloying Elements Presence

4.1 Manganese

If manganese is found by more than 1% it is considered alloys, whereas an increase in the proportion of manganese in stainless steel on the account of the carbon it will work to increase the ductility and shock resistance after normalizing and after heat treatment where it can reduce the viability of stainless steel for fragile break in the same time the manganese will stabilize carbides and be the same (Mn_3C) which will strengthens the ferrite and increase the depth of stainless steel hardening.

4.2 Nitrogen

The presence of nitrogen by more than (0.02%) leads to compound the fragile formation (Fe_3N) where it is difficult to prevent nitrogen from the penetration of the molten metal because of the recent exposure of the atmosphere at the outer molding.

4.3 Carbon

The rate of carbon affect directly on the mechanical properties of stainless steel as well as it controls the type of heat treatment process which is required to conduct on the stainless steel.

4.4 Phosphor

It forms the fragile phosphide (Fe_3p) which dissolves in the solution and so their presences increase the depth of hardening.

4.5 Chromium

Most of the chromium production goes to steel alloy manufacturing and to the electroplating, as the chromium helps to increase the hardness also it contribute to lower the temperature (A4)(degree of upper critical temperature), and raise the temperature (A3) (lower critical degree temperature). Chromium also increases the depth of hardening, and the most important disadvantages is, its impact in helping to grow the grains and this accompanied with decline in durability. Therefore it is necessary to take care during heating treatment process and avoid heating increase [9].

4.6 Nickel

Adding nickel lowers the damages caused by chromium which are grains growth, as well as nickels disadvantage is helping to form graphite which helps the chromium to reduce them, therefore the two elements should always be added together to obtain the high resistance against corrosion and obstruct the retardation of transformation during heating treatment [10].

5. Precedent Studies

5.1 Zia Hoy and his colleagues [11] studied the impact of the heating treatment on the microstructure and mechanical properties for the white cast iron and find out that the heating treatment leads to make changes in the microstructure also it leads to improve the mechanical properties of the white cast iron.

5.2 Tadian Saidi and his colleagues [12] studied the impact of heating treatment cycle on functions capability of the malleable iron, and find out that the heat treatment leads to improve the functions capability of the malleable iron.

5.3 Ihklas Ahmed Basher and Gyda Ibrahim Hassan [13] studied the impact of heating treatment the resistance of corrosion on mediocre carbon stainless steel when it exposed to sulfur well water, and they concluded that the best resistance to corrosion is for the stainless steel treated by annealing.

5.4 Nyvin Alwandayi [14] also studied the impact of the partial heat treatments on the mechanical properties of the solid high-carbon used in manufacturing active parts of the cold cutting templates, where effective heat treatment was conducted.

5.5 Waleed Esam Hana [15] studied the effect polymeric hardening mediums on some properties of stainless steel 316 type, where hardening heat treatments included, hardening and then tempering, hardening and deep-freezing, after all it was found that the thermal treatment leads to improve the mechanical properties and using polymer medium such as polyphones alcohol (PVA) helps to get positive results in comparison to conventional hardening mediums such as water, oil

5.6 Researchers Abdullas and Hussein [16] studied the effect of heat treatment on the rate of galvanic corrosion, where two processes conducted the annealing and normalizing and it was found a decreasing in size of the microstructure cells causes an increasing in the corrosions rate because of the corrosion galvanic cells increasing, in addition to that increasing in grain bounders with anodic nature which its area increases by the reduction of microstructure cells.

6. Practical part

Gravimetric analysis ratio; gravimetric analysis ration was carried out for the samples by (X-RAY) type (SPECTOR x SORT) in the specialist engineering industries institute of the Ministry of Industry and Minerals in Baghdad and the ratios was as shown in the table (1) below.

Table 1: the chemical composition of all components of the all-steel samples steel chemical elements analysis

Iron	Nitrogen	Nickel	Chromium	Silicon	Sulfur	Phosphorus	Manganese	Carbon	304
Balance	0.1	10	19	0.75	0.02	0.045	1.5	0.08	

6.1. Samples Preparation

This study was conducting by using stainless steel 304, special standard samples were prepared by experimenting the sample to tensile test and special standard samples by wear test and special samples by fatigue test, and all tensile, wear, hardening and fatigue test were carried out as it shown in figure (4).

Figure 4: Represents a portion of the samples that were used in the testing process

6.2. Microscopic test

Sample Microscopic test was conducted after mounting process were conducted and grinding and polishing the samples with the existence of alumina AL_2O_3 solution with accuracy of (0.6µ) and then cleaned with water and alcohol and dried down to move to the stage of the appearance (display) it was filmed with zoom power of (900X) to know the exact composition and the results were as in the attached figure (5) below.

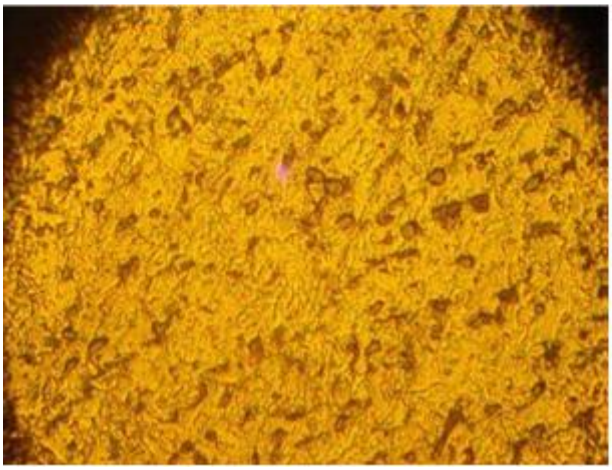

Figure 5: the microscopic structure of the samples before heat treatment

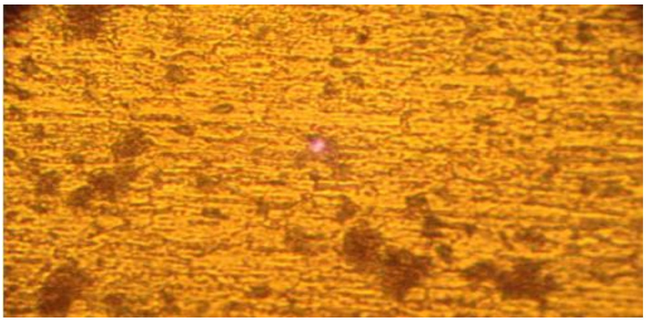

Figure 6: microscopic structure of the samples after heat treatment at 1050 C^0

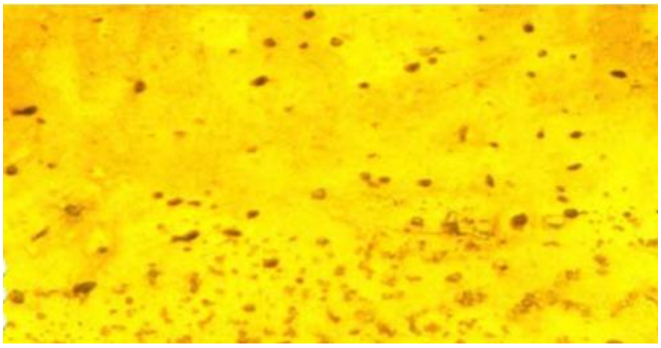

Figure 7: microscopic structure of the samples after a thermal treatment at 1100 C^0

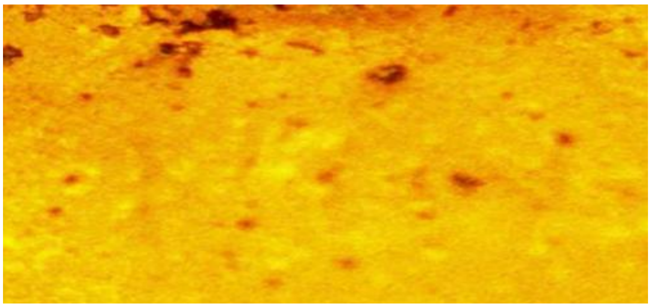

Figure 8: the microscopic structure of the samples after heat treatment at 1150 C^0

6.3. Thermal treatment

Thermal treatment was conducted at the Al Dour Technical Institute using a modern digital electric furnace made in Japanese in the Al Dour technical institute laboratory Figures (9),(10).

Figure 9: of the modern electric furnace where the heat treatment was conducted

6.4. Wear test

Wear test was carried out in Al Dour Technical Institute by using wear test device made in England

Figure 10

6.5. Fatigue Test

Fatigue test was carried out in minerals laboratory in Al Dour Technical Institute using fatigue test device as well as the same thing for tensile, pressure, hardness and shock.

7. Results and Discussion

The results shown as in table 2 below:

Table 2: Results

No.	*Type of heat treatment*	*Tensile Strength* N/mm^2	*Brinell hardness HB*	*Shock test Joule*	*Yield stress* N/mm^2	*Wear test*	*Fatigue Test D/cycle*
1	Sample without heat treatment	505	123	325 J	215	181	35000
2	Sample treated thermally at (1050) for 20 minutes and then tempering at (350) for 30 minutes	520	190	320 J	320	22	36200
3	Sample treated thermally at (1100) for 20 minutes and then tempering at (350) for 60 minutes	590	210	312J	375	25	38500
4	Sample treated thermally at (1150) for 20 minutes and then tempering at (350) for 30 minutes	510	212	217J	370	24	31190

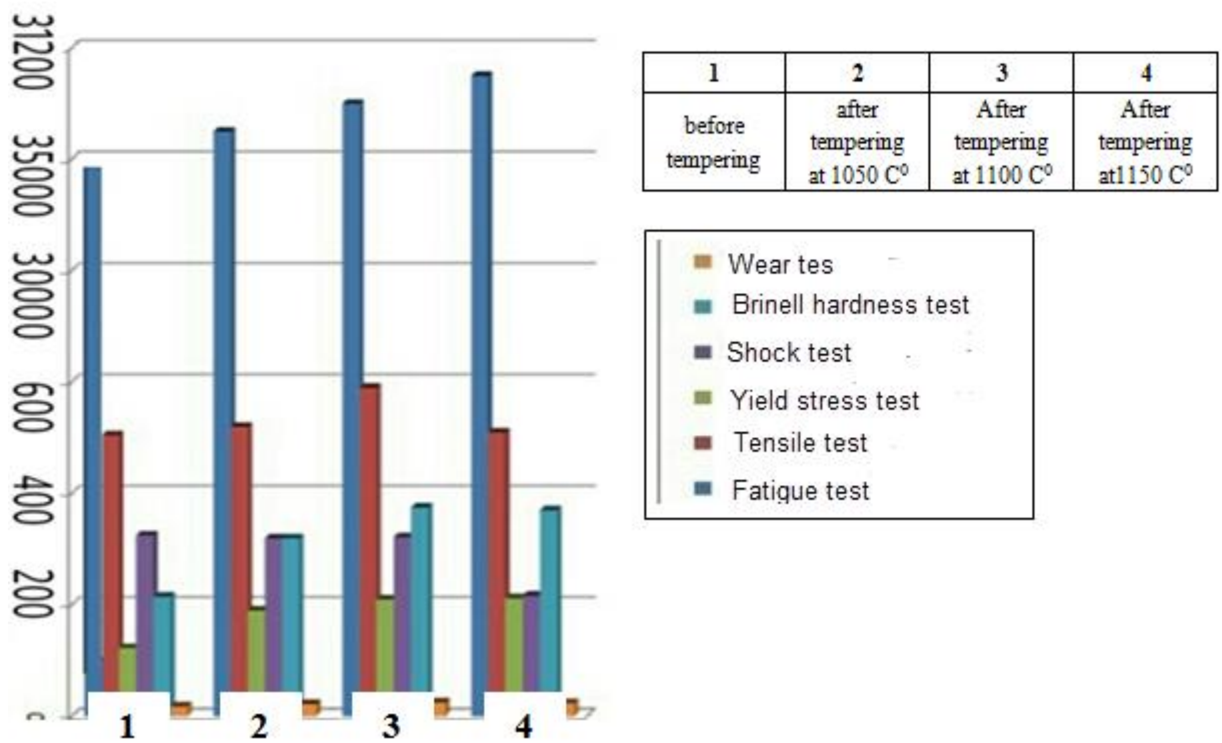

Figure 4: Results of mechanical tests

1) It was observe in all conducted mechanical properties and improvement, the improvement was marked in tensile test, where s the tensile test was increased in all heat treatments, in addition to yield stress, hardness also increased.
2) The only property that have not been improved is the test of wear and tear due to the deposition of some carbides in a non-homogeneous in the outer surface of the samples sections, which reduce the smooth coated outer layer of the surface causing and increasing in the friction due to the sort of rough layer which is somewhat incoherent
3) There has been no noticeable improvement in the test shock because it is also known that the hardness inversely proportional to material resistance shocks
4) The improvement in the mechanical properties can be attributed to a shift in the internal structure where the ferrite phase shift within coarse pearlite to ferrite within smooth pearlite in the alloy that has been treated thermally which was thermally treated and turning successive layers of complex rough carbides and consequently to soluble soft granules in a ground of austenite because of its stability and lack of full transformation to pearlite, and this was evident by observing the microstructure of the attached image.
5) Temperature degree of tempering effect on the mechanical properties of the steel, tempering carried out in low temperature (300-350) C̊ lead to increase the durability of stainless steel, without a noticeable decrease in its hardness. The higher the tempering degree the lower in steel hardness (as a result of the disintegration of the complex carbides) and maximum tensile resistance and limited flexibility, but increasing in ductility.
6) We cannot fail to mention that the shock resistance of the steel is less, if it was tempered in temperature degree of (300-350) C^0 and this phenomenon called brittle tempering, the reason of its appearance is due to the remained or austenite decomposition or to complex carbides deposition, therefore we should avoid tempering in this range of the temperatures degree, when there is a desire to increase the resistance of the stainless steel.

8. Conclusions

After conducting laboratory mechanical tests on all samples thermally treated and compare the results before and after thermal treatment it can be conclude the following:

1. Capability of tensile strength has been improved due reducing the size of the granules, which led to increased grain boundaries.
2. Increasing in fatigue life of the thermally treated alloy
3. The appearance of roughness on the surface treated thermally, which led in increasing the friction in addition to the deposition of carbides toward the surface which contributed emerging a coherent surface layer resulting in an increase in the rate of wear
4. Exciting excess in fatigue cycles because of the metaphase changes for the basis of the alloy.

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