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The Influence of Annealing and Normalizing Processes on the Mechanical Properties and Chemical Composition of Carbon Steel ASTM A285Gr.C

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Abstract*: *Paper Carbon steel ASTM A285 Grade C it's easy to use and has all the material properties that are suitable for many purposes. One of the most metallurgical processes is heat treatment. Heat treatment on carbon steel is to improve ductility, toughness, strength, hardness and tensile strength and to relieve internal stress developed in the material. This paper describes the effect of rising temperature change on the mechanical properties of specimens.

Two important processes of heat treatment are achieved in this paper; First heat treatment process is "Annealing" that involves heating specimens gradually in a furnace above several 723 °C and then soaking it in the furnace and then cooled inside the furnace. "Normalizing" is a second process that also involves heating the specimens gradually in a furnace above several 723 °C and soaking it in the furnace followed by cooled in the air. The specimen prepared according to ASTM (American Society for Testing and Material) standard. With increasing the temperature of the annealing process the strength of the specimens is decreased until it reached around 350 MPa at 1000 °C. Through the chemical composition of the specimen after the heat treatment process and compared with nominal compositions observed that the specimens loosed elements.

Keywords* : *ASTM; Carbon steel; Annealing; Normalizing; Mechanical properties.

I. INTRODUCTION

The heat treatment is defined as an operation or a combination of operations, involving the heating and cooling of a metal or an alloy in the solid state for the purpose of obtaining certain desirable condition or properties.

The different types of processes of heat treatment are similar because they all require metal heating and cooling; the difference in the heating temperature and the cooling levels used and the final result. The customary method of heat treating ferrous metals are annealing, normalizing, hardening and tempering [1].

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Annealing is a generic term that denotes a procedure consisting of heating and keeping at an appropriate temperature followed by cooling at a suitable rate, mainly for softening metallic materials. It is possible to anneal most nonferrous metals. Controlling heat treatment processes (Heating, Socking, and Cooling) is possible only when the proper equipment is available [2].

A. Carbon steel

Carbon steel is a malleable, iron-based metal containing carbon, with small amounts of manganese, silicon, phosphorus, and other elements [3]. Classification of ferrous metal is shown in figure 1.1.

B. Applications of Carbon steel

Carbon steel is used virtually, in manufacturing of every type of product, such as the shapes required for applications that contain the pressure and the shapes required for structural applications, boilers, pressure vessels, heat exchangers, and other applications. Carbon steel is used in which good strength and ductility is needed. Other important factors include price, provided in the market, and ease of manufacture[3].

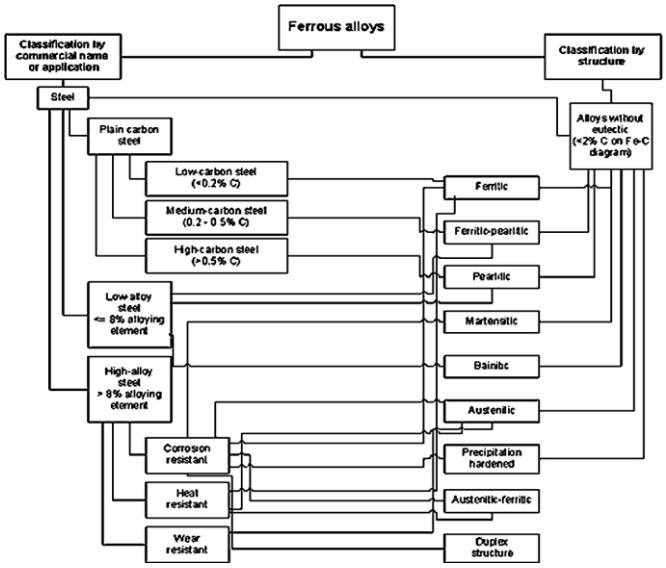

Fig. 1.1: Classification of ferrous metal [5]

C. Heat Treatment

Heat treatment is the process of metals being controlled by heating and cooling to change the physical and mechanical behavior of metals. Often it is used to increase a material's strength, ductility, and formability. Also, it can be used to improve the machining of metal that can be used in the machines [6].

D. Stages of heat treatment:

The success heat treatment process involves three basic steps: heating, soaking, and cooling. Figure 1.2 shows the steps of heat treatment

1. Stage 1: heating the metal slowly to ensure a uniform temperature.
2. Stage 2: soaking the metal at a given temperature.
3. Stage 3: cooling the metal to room temperature.

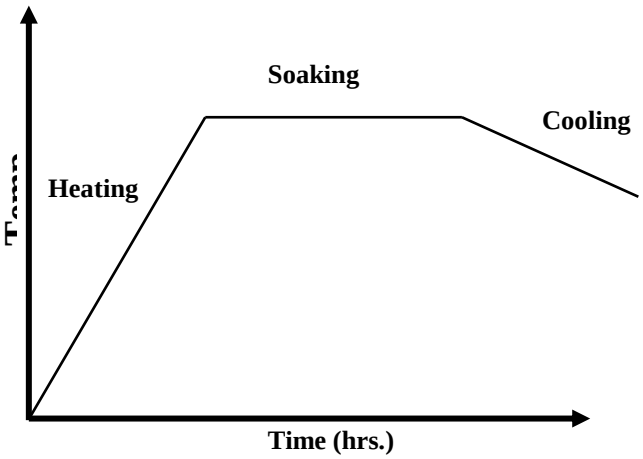

Fig. 1.2: The stages of heat treatment[7]

II. LITERATURE REVIEW:

There are several articles in the literature dealing with carbon steel heat treatment, including those listed below:

Fryad J. Mahmud, et al.[8] Studied the influence of the heat treatment process on the mechanical behaviors of steel type SG 255. The annealing process carried out at different temperatures (850, 900 and 950 ºC). The mechanical behavior of the specimen was verified by performing a tensile test of the specimen until the fracture. Compared to the results obtained from local factory. It has been shown that it is possible to achieve a higher elongation level around 34 % with a lower annealing temperature of 900 ºC and this leads to a decrease in production costs without reducing the value of the cylinder.

Al-Qawabah et al.[9], by using low carbon steel they to study the influence of different annealing temp. on the mechanical characteristics, microstructure, micro hardness, and impact toughness. In particular, they used several temperature annealing regimes; 820,860, 900 and 940 ˚C. The impact energy has been found to be increased as the temperature of the annealing increases; the average is 22.5 percent that has been reached at 820 ˚C. It was found that the micro hardness decreased as the annealing temp. increased except at 940 ˚C, the peak decrease was 31.6 percent, which was reached at 900 ˚C.

Pradip A. Dahiwade, et al. [10], studies the influence of steel hardness during hot rolling processes by Annealing and Normalizing. They observed that after normalization, the hardness of the steel specimen is higher than that found in annealing because the cooling rate is faster in normalizing rather than in annealing. In contrast, the uniform steel specimen microstructure includes finer grains relative to the structure of annealed steel.

Obiukwu Osita, et al.[11] They investigated the influence of various heat treatment procedures on mechanical properties of 0.35% carbon steel (annealing, normalizing, tempering). The results of the tests of tensile, impact and hardness revealed that the mechanical properties differ with each condition of heat treatment. Also researched was the microstructure of various heat-treated steels. It can be concluded from this research paper that the increase in fatigue strength is directly proportional to the increase in tensile strength.

Yassin Mustafa Ahmed et al.[12] And through different mechanical tests and chemical composition check the performance of base metal and welding line of the household LPG cylinder manufactured in the Kurdistan region. the manufacturing process of the LPG cylinder includes the annealing process by direct flame. The chemical composition examination of the LPG cylinder shows they lose elements after annealing process compared with the standards.

III. METHODOLOGY

A. Material Preparation:

The metal used in this study was investment carbon steel (ASTM A285Gr. C), square plates with dimensions (25*25*12) mm (Length, Width, Thickness). The chemical compositions of carbon steel (ASTM A285Gr. C) used in experimental work are shown in table I.

The mechanical properties of the specimen are presented in tables II. The base metal contains elongated grains of α (light etched) and transformed β (dark etched).

Table-I: Chemical Composition of carbon steel (ASTM A285Gr.C)

Element / Material	% C	%Mn	%Si	%P	%S	%Ni	%Cr	%Mo	%Fe
Nominal chemical composition	0.28	0.7-1.1	0.4	0.035	0.04	—	—	—	Balance
A285-Gr C	0.26	0.9	0.35	0.35	0.02	0.035	0.050	0.08	Balance

Table- II: Mechanical properties of carbon steel (ASTM A285Gr.C)[13]

Yield Strength (Mpa)	Ultimate Tensile Strength (MPa)	Elongation %
205	380-515	27

B. Heat treatment process:

The heat treatment process was conducted on a carbon steel plate (ASTM A285Gr. C) and has been carefully studied as part of a comprehensive heat treatment procedure. These studies highlight the relationships between the heat treatment process and mechanical properties. The heat treatment process includes annealing at different temperatures (860,890,920,950, and 1000 ^{o}C), and normalizing at (860, and 890 ^{o}C). The microstructure of carbon steel (ASTM A285Gr. C) is showing in figure 3.1.

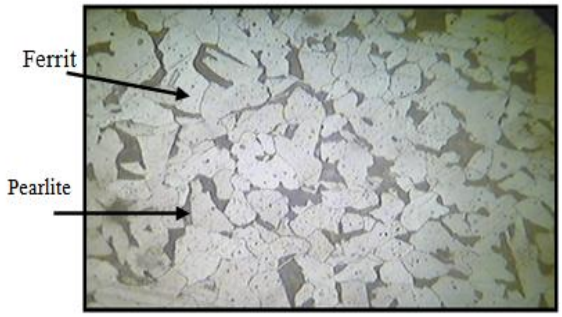

Fig.3.1:Microstructure of Carbon steel ASTM A285Gr.C

IV. RESULT AND DISCUSSION

The section below describes the results and the influence of the heat treatment process on carbon steel (ASTM A285Gr. C), and discuss their impact at mechanical properties.

A. Heat treatment processes:

The structures of the specimens are a brittle structure with fine grain size. The influence of the heat treatment process on the microstructure will result in the transformation of the structures into ductile with coarse grain, and with increasing the temperature of the heat treatment the structure will be more ductile and the size of the grain will be large. The results were shown in the figures below.

1. Influence of heat treatment process on composition elements of carbon steel:

After annealing process of carbon steel at 860 °C and chemical composition analyzing of the specimen and compared to the constituent elements of carbon steel before the annealing, it's obvious the specimen did not lose any elements after annealing process because the heat treatment was carried out inside the oven and that the heating of the specimen by indirect heating by convection.

Table-III: Chemical Composition of carbon steel (ASTM A285Gr.C)

Element / Material	% C	%Mn	%Si	%P	%S	%Ni	%Cr	%Mo	%Fe
Nominal chemical composition	0.26	0.9	0.35	0.03	0.02	0.035	0.050	0.08	Balance
A285-Gr C	0.24	0.88	0.29	0.021	0.0187	0.03	0.04	0.07	Balance

2. Annealing process:

The full annealing process consists of heating the suitable temperature with soaking time for 30 minutes, after that cooling process in the furnace. The annealing process is performed at different temperatures (860, 890, 920, 950, and 1000 ^{o}C). Figure 4.1 showed the microstructure of a specimen with 860 ^{o}C annealing temperature.

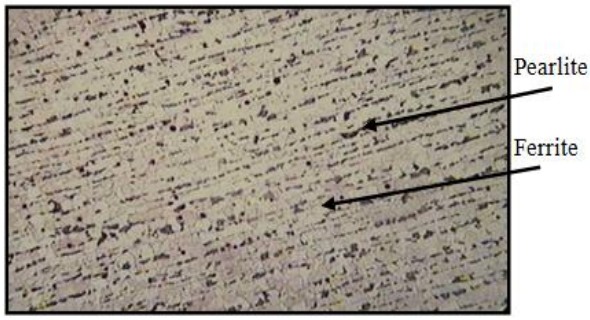

Fig. 4.1: Microstructure of Carbon steel ASTM A285Gr.C with annealing at 860 ^{o}C and 30min soaking time

As above figure 4.2, display the microstructure of a specimen with annealing temperatures 1000 ^{o}C after that turned off the oven and left it in the oven for two days.

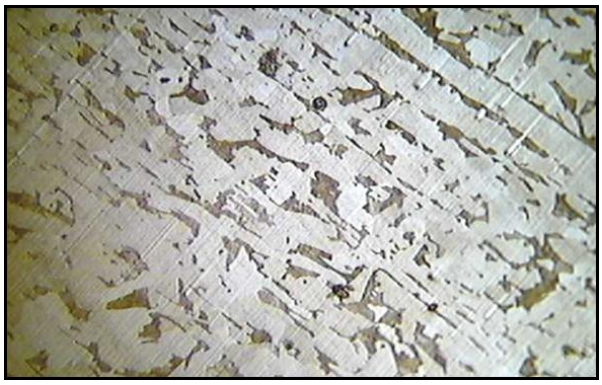

Fig. 4.2: Microstructure of specimen with annealing temperature 1000 ^{o}C

3. Normalizing process:

Normalizing is a heat treatment process that is used to make a metal more ductile and tough, and is a technique used to provide uniformity in grain size and composition in an alloy. The specimen heated before and after the transformation temperature above 20-80 C above the Acm, then kept for an appropriate period as full annealing, then cooling in the open air. The microstructure after the normalizing process is fine perlite + ferrite in specimen before transformation temperature and fine perlite + cementite in the specimen after transformation temperature. Hardness and tensile strength higher than compared to full annealing, with ductility and less impact resistance[7].

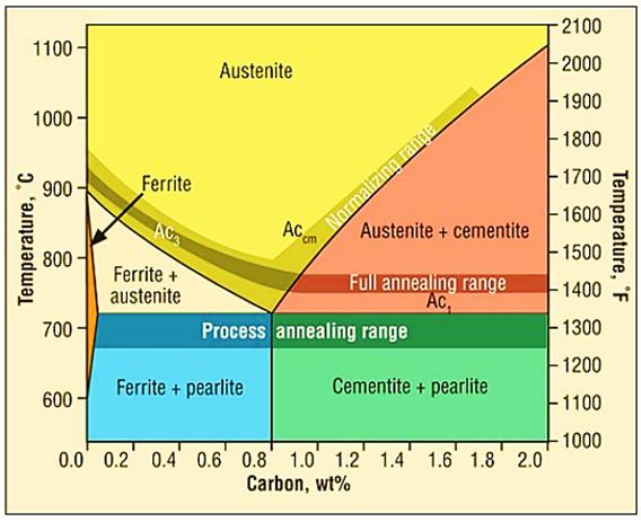

Fig. 4.6: Heat treatment process[7]

Figure 4.7 show the microstructure of the sample after the normalizing process at 860 °C and with soaking time for 30 minutes, after that cooling process in the open air.

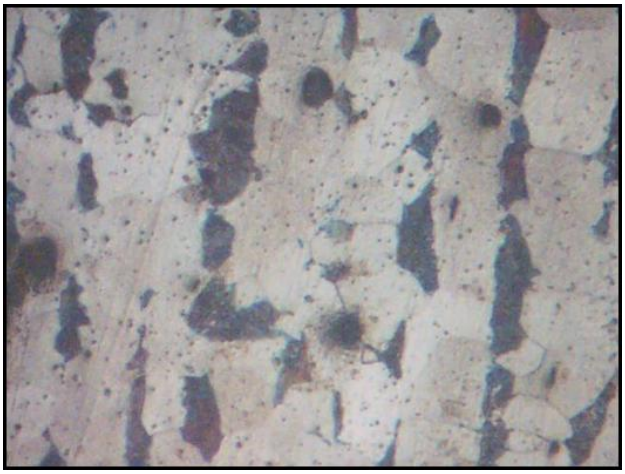

Fig. 4.7: Microstructure of specimen with normalizing temperature 860 ºC

B. Mechanical Test

1. Hardness test

Hardness is a material property that helps it to withstand p lastic deformation, typically by penetration. The term hardness, however, may also refer to bending, scratching, abrasion, or cutting resistance.

During the heat treatment process, the mechanical properties of specimen changes due to the chemical reactions and other unexpected changes may occur according to the nature of the metal of specimen.

The hardness across the specimen cross-section was measured using a Rockwell testing machine. The applied load during the tests was 1471N, and the time was 10 seconds. The values are presented in table 4.2 the hardness of specimen before heat treatment process in its initial condition was 33 HRC as shown in figure 4.9.

Fig. 4.9: Rockwell hardness machines

The results obtained from the hardness test are displayed in table 4.2

Table IV: Hardness test results

Specimen No.	Average HRC
Specimen No.1 control	53.5
Specimen No.2 annealing 860 ºC	48.78
Specimen No.3 annealing 890 ºC	47.5
Specimen No.4 annealing 920 ºC	45.58
Specimen No.5 annealing 950 ºC	43
Specimen No.6 annealing 1000 ºC	42.6
Specimen No.7 normalizing 860 ºC	56.8
Specimen No.8 normalizing 860 ºC	56.4
Specimen No.9 normalizing 890 ºC	58.2
Specimen No.10 Normalizing 890 ºC	58.4

2. Tensile test specimens

Figure 4.10 displaying the distribution load curve of a specimen without heat treatment. The result obtained from the tensile test that the value of the ultimate tensile strength is (466.92 MPa).

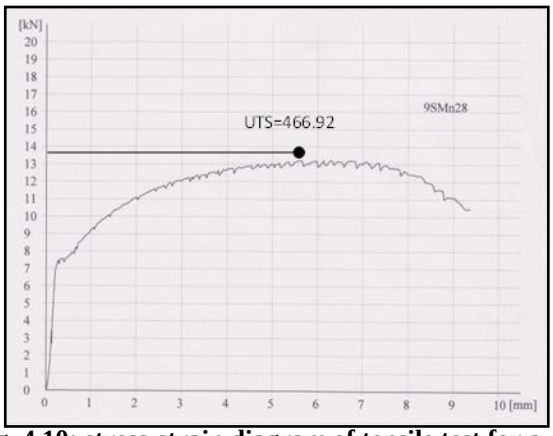

Fig. 4.10: stress-strain diagram of tensile test for a specimen ASTM A285Gr. C.

Figure 4.11 showed the Stress-Strain curve of a specimen with 860 ºC annealing temperature. The result obtained from the tensile test that the value of ultimate tensile strength is (414.86 MPa).

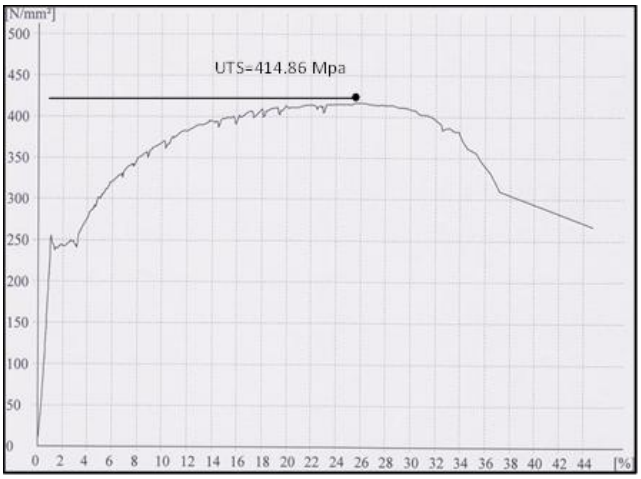

Fig. 4.11: stress-strain diagram of tensile test for a specimen, and annealed to 860 °C

Compare this result to the result of the specimen without heat treatment we observed that the value of (UTS) is reduced this is because of the annealing temperature and the material will be more ductile.

The Stress-Strain curve of a specimen with 890 ºC annealing temperature was showing in figure 4.12.

Fig. 4.12: stress-strain diagram of tensile test for a specimen, and annealed to 890C°

The result obtained from the tensile test that the value of ultimate tensile strength is 413.8 Mpa. From the figure above note that ultimate tensile strength reduced due to an increase in the temperature of the annealing process.

Figure 4.13, 4.14, and 4.15 showed the Stress-Strain curve of a specimen with 920 ºC, 950 ºC, and 1000 ºC. Annealing temperature. The result obtained from the tensile test that the value of ultimate tensile strength is (394.35 MPa), (390.11 MPa), and (352.26 MPa) respectively.

Fig. 4.13: stress-strain diagram of tensile test for a specimen, and annealed to 920 °C

Through observation of the ultimate tensile strength at 920 ºC, 950 ºC, and 1000 ºC still reduced with raised the temperature of annealing process.

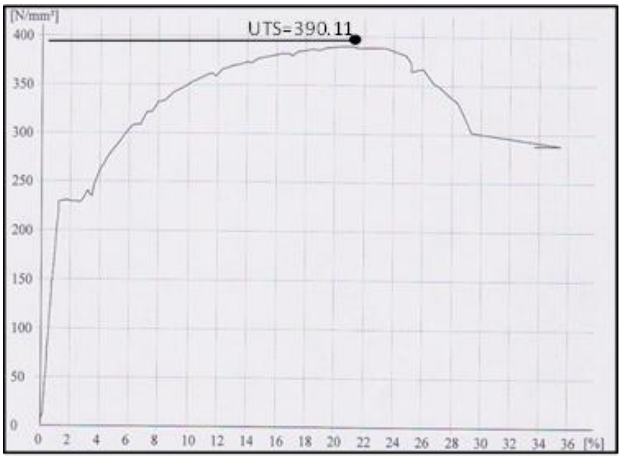

Fig. 4.14: stress-strain diagram of tensile test for a specimen, and annealed to 950°C

Fig. 4.15: stress-strain diagram of tensile test for a specimen, and annealed to 1000 °C

Figure 4.16 showed the Stress-Strain curve of a specimen with 860 ºC normalizing temperature. The result obtained from the tensile test that the value of ultimate tensile strength is (449.52 MPa).

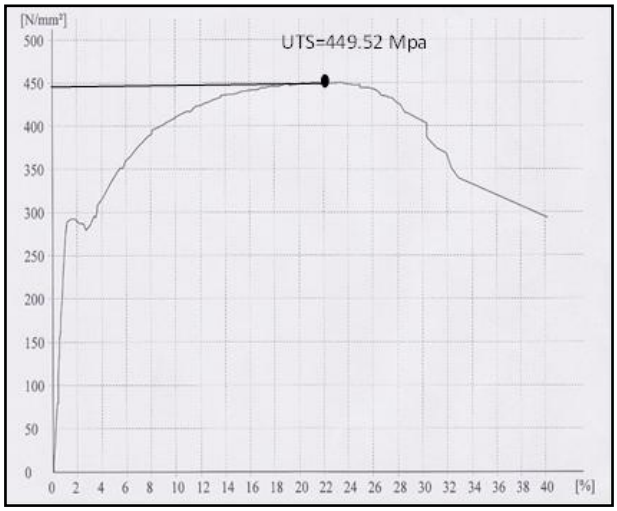

Fig. 4.16: stress-strain diagram of tensile test for a specimen, and normalized to 860 °C

V. CONCLUSIONS

The two types of heat treating processes are similar to each other because they are all involve heating and cooling of metals; and the difference between the two heat treatment processes is heating, temperature, and soaking time cooling rates and the final result. These types of heat treatment have a direct effect on the metal.

In the case of the hardness test, the value reduced this is due to the increase in annealing temperature because the material changed from brittle to ductile.

In the case of microstructure, the result is ferrite and pearlite, before heat treatment, it has a fine grain but by affecting of annealing temperature the material changed to ductile with coarse grain.

Concluding, after achieving two important processes (annealing and normalizing) conclude that:

1. The best annealing process for carbon steel ASTM 285 Gr. C at 860 ^{o}C with soaking time 30 minutes inside the furnace.
2. The annealing process inside the furnace does not lead to losing elements.

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