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Effect of Heat Treatment on Mechanical Properties and Microstructure of Ingot $30CrMoV_9$ Steel

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ABSTRACT

Engineering industry, mostly steel are heats treated under controlled sequence of heating and cooling to alter their physical and mechanical properties to meet desired engineering applications. In this study, the effect of heat treatment (Isothermal annealing process, full annealing and normalizing) on the microstructure, fracture section and some selected mechanical properties of ingot $30CrMoV_9$ steel such as ultimate tensile strength, tensile yield strength, percentage reduction, percentage elongation, toughness and hardness. Sample of steel was purchased from local market and the spectrometry analysis was carried out. The steel samples were heat treated in an electric furnace at different temperature levels, holding times and then cooled in different media. The mechanical properties of the treated and untreated ingot samples were determined using standard methods. Results showed that the mechanical properties of ingot $30CrMoV_9$ steel can be changed and improved by various heat treatments for a particular application. It was also found that the full annealed samples with mainly ferrite structure gave the lowest tensile strength and hardness value and highest ductility and toughness value. While normalizing sample which comprise martensite gave the highest tensile strength and hardness value and lowest ductility and toughness value.

Introduction

Heat treatment operation is a means of controlled heating and cooling of materials in order to effect changes in their mechanical properties (hardness, toughness, yield strength, ultimate tensile strength, Young's modulus, percentage elongation and percentage reduction). Heat treatment is also used to increase the strength of materials by altering some certain manufacturability objectives especially after the materials might have undergo major stresses like forging and welding [1]. Annealing, normalising, hardening and tempering are the most important heat treatments often used to modify the microstructure and mechanical properties of engineering materials particularly steels. Annealing is the type of heat treatment most frequently applied in order to soften iron or steel materials and refines its grains due to ferrite-pearlite microstructure; it is used where elongations and appreciable level of tensile strength are required in engineering materials [2].

In normalising, the material is heated to the austenitic temperature range and this is followed by air cooling. This treatment is usually carried out to obtain a mainly pearlite matrix, which results into strength and hardness higher than in as received condition. It is also used to remove undesirable free carbide present in the as-received sample [3].

It was however known that mechanical properties of steel were strongly connected to their microstructure obtained after heat treatments which are performed to achieve good hardened and tensile strength with sufficient ductility [4]. The material modification process, modify the behavior of the steels in a beneficial manner to maximize service life i.e stress relieving or strength properties e.g cryogenic treatment or some other desirable properties [5].

Steels are normally hardened and tempered to improve their mechanical properties, particularly their strength and wear resistance. In hardening, the steel or its alloy is heated to a temperature high enough to promote the formation of austenite, held at that temperature until the desired amount of carbon has been dissolved and then quench in oil or water at a suitable rate. Also, in the harden condition, the steel should have 100% zmartensite to attain maximum yield strength, but it is very brittle too and thus, as quenched steels are used for very few engineering applications [6]. The aims of this research were study the effect of heat treatment on mechanical properties of steel ingot type 30 $CrMoV_9$.

Materials and Method

Sample of ingot 30Cr MoV_9 steel bar with 25 mm diameter and 75mm long was purchased from a local market located in Baghdad. The chemical composition of the steel sample was determined as given in Tables 1. Standard tensile and impact specimens were made from ingot type 30Cr MoV_9 steel sample using lathe machine. Samples were subjected to different heat treatment: full annealing, normalising, hardening, and tempering in accordance to ASM International Standards [7]. The heat treatment conditions are listed in Table 2. Four specimens were prepared for each heat treatment type.

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Table 1. The actual and standard chemical composition of ($30CrMoV_9$) steel.

Element wt%	C	Si	Mo	Mn	S	P	Cr	Mo	Ni	V	Cu	Al	Fe
Standard	0.2-0.34	≤ 0.4	0.1-0.25	0.40-0.70	0.03	0.035	2.30-2.70	0.023	-	0.10-0.20	-	0.009	Bal
Actual	0.59	1.82	0.18	0.86	0.015	0.025	0.19	0.17	0.25	0.15	0.25	0.006	Bal

Experiments

After careful preparation of the tensile specimen samples from the $30CrMoV_9$ steel, it was taken to the furnace for the heat treatment operations. To commence the operation, the furnace was initially calibrated to determine the furnace operating temperature based on the pre-set furnace temperature. To determine this, the furnace was set to an initial temperature of 200°C and the furnace was switched on. This temperature was maintained with the aid of thermostat that was used to control the furnace temperature. On attaining this temperature, a thermocouple was now introduced into the furnace chamber to measure and compare the temperature of the chamber which was adjusted until it give same output temperatures. The various forms of the heated processes were stated below.

Heat Treatment Processes

Isothermal annealing process

The specimens to be hardened were placed inside the furnace and heated to a temperature of 850°C. At this temperature, there is transformation of the steel to austenite. The samples were retained at this temperature for a period of 30 minute during which the transformation must have been completed, and cooled inside furnace to 670°C, and hold at this temperature at 30 minute after that removed the sample from the furnace and rapid cooling in air to room temperature.

Full Annealing process

A full annealing was carried out on the specimen in corbolite furnace by heating the metal slowly at 875°C. It is held at this temperature for sufficient time (one hour) for all the material to transform into austenite. It is then cooled slowly inside the furnace to room temperature. The grain structure has coarse pearlite with ferrite or cementite.

Normalizing process

Each samples of the steel to be normalized were placed in the furnace and heated to temperature of 875°C. The samples were retained at this temperature for the period of one hour for full transformation to austenite. They were later removed from the furnace and left in air for cooling.

Material Testing

Tensile test

After the successful heat treatment operation, the various heat treated samples were taken for the tensile test. The test was performed on Standard Universal Testing Machine type Hoyotou TN 10M, made in controlab company, Franc. Each of the specimens was inserted one after the other into the machine jaws and having fastened the specimen properly at both ends, tensile test upto the fracture limit was carried out.

Microstructure Examination

Microstructure examination of the treated and untreated samples was carried out. Each sample was carefully grounded progressively on emery paper in decreasing coarseness. The grinding surface of the samples were polished using Al_20_3 carried on a micro clothe. The crystalline structure of the specimens were made visible by etching using solution containing 2% Nitric acids and 98% methylated spirit on the polished surfaces. Microscopic examination of the etched surface of various specimens was undertaken using a metallurgical microscope (Universal Camera Microscope) with an inbuilt camera through which the resulting microstructure of the samples were all photographically recorded with magnification of 500.

Fracture Section Examination

The examination of topography fracture section of the treated and untreated samples was carried out by using scan electron microscope (SEM) to determine the brittle and ductile fracture.

Hardness Examination

Rockwell Hardness (HRC) was carried out by using (Indentc machine, production by England) which is depend on ISO 650-1/2 /2005. All specimens' were prepared with dimensions 10mm× 10mm × 6mm (length, width and thickness).

Impact Test:

Charpy impact test was applied to toughness test by using machine test model JBS-300 china manufacturing which depends on ASTM23. All specimens' were prepared with dimensions 10mm×10mm with V-notch 45°, and 2mm depth.

Results and Discussion

Effect of Heat Treatment on Mechanical Properties

The effect of heat treatment (normalizing, full annealing and Isothermal annealing) on the mechanical properties (ultimate Tensile Strength, yield stress, percentage elongation, percentage reduction, hardness and toughness) of the treated and untreated(as forged), samples is shown in Table 2. The tensile strength of the untreated (as forged), specimen was 500 N/mm^2 and hardness value of 394 HV, elongation 3%, reduction 5%, yield strength 460N/mm2 and toughness of 50J were obtained. Increase in hardness result from carbide formation (Cr_7C_3) as shown in X-Ray result in Fig. 3. Comparing the mechanical properties of full annealed sample with the untreated sample (as forged), full annealed sample showed higher ultimate tensile strength ($780N/mm^2$), yield strength $492N/mm^2$ and hardness (140 HN) and increase in reduction in area (65%), elongation (65%) and toughness (102J), because decay the carbide type(Cr_7C_3) to Fe_3C (lower hardness) with homogeneous distribution, as shown in Fig. 4 (X-Ray result), these results were a good agreements with results of [7,8 and 9].

The decrease in tensile strength and hardness can be associated with the formation of soft ferrite matrix in the microstructure of the full annealed sample by cooling. The mechanical properties of the normalized specimen were found to be ultimate tensile strength 362 N/mm^2, yield strength $210N/mm^2$, hardness 323 HV, toughness 65J, reduction in area 18% and elongation 18%. The increase in tensile strength and hardness as compared to full annealed and untreated sample was due to austenising temperature at 875°C and higher cooling rate. The mechanical properties of the Isothermal annealing specimen were found to be ultimate tensile strength 603 N/mm^2, yield strength $390N/mm^2$, hardness 160 HV, toughness 100J, reduction in area 60% and elongation 60%.

Effect of Heat Treatment on Microstructure

Figure 2-A, shown the microstructure of untreated specimen (as forged) showed a combination of ferrite (white) and pearlite (black), and show the grain flow with forged direction.

Table 2. Mechanical Properties of heat treated and untreated $30CrMoV_9$ steel

Specimen	ultimate Tensile Strength $(N/(mm)^2)$	Yield Stress $N/(mm)^2$ 0.2%	E%	R%	Toughness (J)	Hardness HV)(
As forged	500	460	3	5	50	394
Normalizing	362	210	18	18	65	323
Full annealing	780	492	65	65	102	140
Isothermal annealing	603	390	60	60	100	160

Figure 2-B, shows the microstructure of the normalized $30CrMoV_9$ steel. The normalized sample showed that the shape and size of the original austenite grains were influenced to a remarkable extent. The sample revealed a pearlitic matrix in which shorter graphite flakes than in annealed sample existed. It was observed that there was many short graphite flakes surrounded with patches of uniformly distributed pearlite structure.

Figure 2-C, shown the microstructure of the full annealed sample can be seen the ferrite grains had undergone complete recrystallization and these constituted the major portion of the microstructure of annealed. At 875 ^oC the deformed structure was fully homogenized and during the slow cooling from austenizing range to room temperature the final microstructure consisted of fine ferrite grains in which the pearlite was more uniformly distributed.

Figure 2-D, shown the microstructure of Isothermal annealing is a highly recrystalised ferrite grains (white dotted areas) with some secondary graphite site was observed. This micrograph revealed that the microstructure of specimen consisted of a number of appreciable carbide particles precipitated out from the matrix with solid inclusion, which indicated that the precipitate carbide particles decomposed by a process of solution in ferrite matrix. These results were good agreements with results of [10, 11]

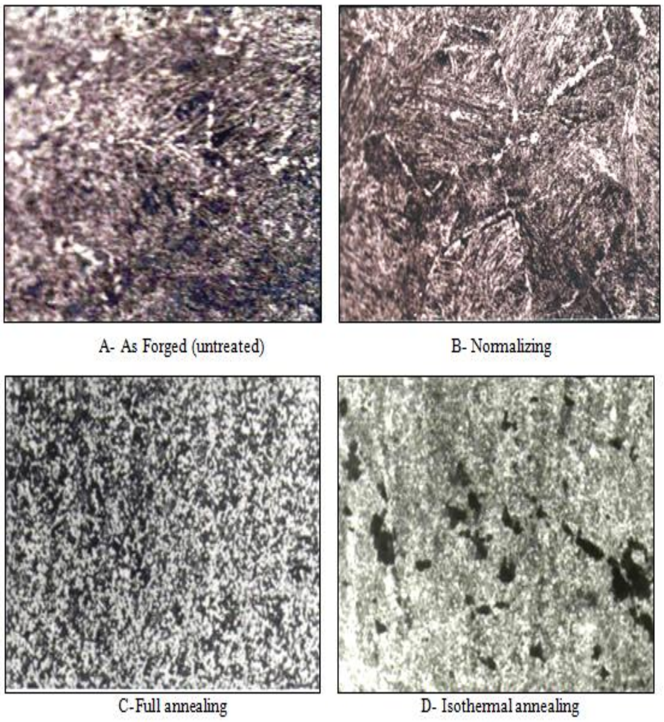

Figure 1. Microstructure of treated and untreated steel type $30CrMoV_9$ (X500).

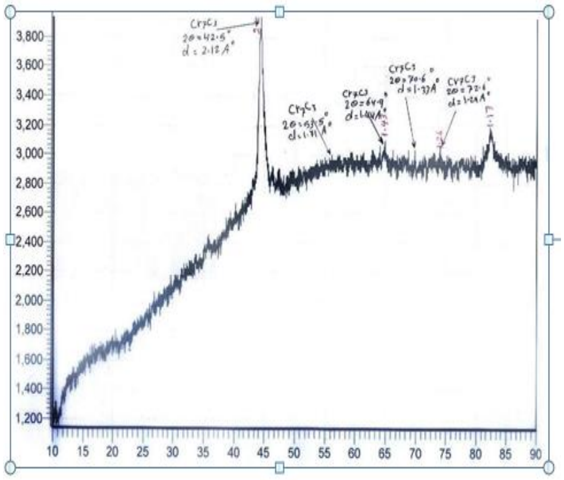

Figure 2. Result of X-Ray for ingot as received (untreated) for 30 Cr Mo V_9 Steel.

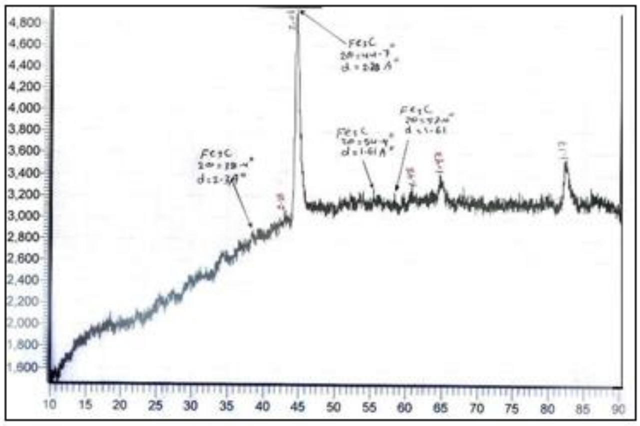

Figure 3. Result of X-Ray for ingot was full annealing treated for 30 Cr Mo V_9 Steel.

3- The effect of Treatment on Fracture Section

Figure 5; shows the SEM examination of the fracture section of treated and untreated ingot steel type $30CrMoV_9$. The Fracture topography was brittle fracture by appearance of fiber as shown in Figure 5-A and B, as forged untreated specimen and normalizing heat treatment due to high hardness. While Figure 3-C and D, were shown the ductile fracture by appearance of dimples result from softening due to lower hardness. These results were a good agreements with results of [12].

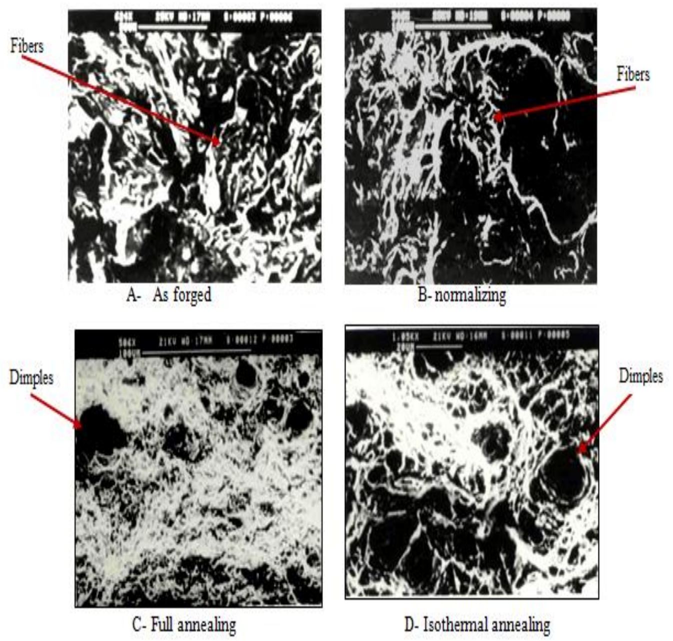

Figure 4. Fracture topography of treated and untreated steel type $30CrMoV_9$ (X 1050).

Conclusions

- From the results obtained of investigation on the effect of heat treatment on mechanical properties and microstructure of steel ingot type 30CrMoV9, it can be inferred that mechanical properties depends largely upon the various form of heat treatment operations and cooling rate.
- The tensile strength, yield strength and hardness were increased with plastic deformation while ductility and impact strength decreased due to strain hardening effect.
- Normalization treatment had also resulted in higher tensile strength and hardness than annealed samples. Hardened sample had the highest tensile strength and hardness with lowest ductility and impact strength when compared to other heat treated samples.

Hence depending upon the properties and the applications that may be required for any design purpose, a suitable form of heat treatment should be adopted. For high ductile and minimum toughness, full annealing the steel 30CrMoV9 ingot will give satisfactory results.

- The topography fracture section of materials was functions of brittle and ductile fracture were affected by heat treatment operation.

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