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An Experimental Study of the Effect of Heat Treatment using Water and Air on the Hardness of Carbon Steel

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Abstract
Heat treatment processes are widely used in manufacturing to achieve high levels of improving the mechanical properties of metal materials, including hardening, which is multiple stages starting from high hardening of the metal until it is almost brittle and even soft, it is also used in annealing metals that industrial processes have hardened to adapt the metals to the purposes used for them in various industries. In this paper, practical experiments, such as heat treatment, are conducted on five samples of carbon steel, as it is one of the important materials in many industries. This experiment aims to demonstrate the extent of the effect of cooling media on the microstructure and the hardness that these samples reached after the operations performed on them. These samples were exposed to a temperature of 850°C in an electric furnace, then cooled in air, and also cooled in water. After cooling in water, they were exposed to different temperatures, which are 200°C, 400°C, and 600°C, then polished in several stages after that, then washed with acetone. Then they were exposed under an electron microscope to show the change that occurred in the microstructure of these samples. Then Vickers Hardness Test was conducted to show the hardness of these samples. The results showed that the samples that were immersed in water had a much higher hardness than those that were left to cool in the air, and the samples that were heated in the second stage from 200°C to 600°C had a lower hardness and increased plasticity of the metal as the temperature increased.

Keywords: Carbon steel, heat treatment, hardness, microstructure, cooling media

1. Introduction

Steel is an iron material that contains some very low amounts of carbon and some different alloying elements. This diversity of compositions allows creating thousands of compositions that contain specific properties to meet a large number of needs required in industries. About 26 different elements are used in several groups and in various proportions to produce carbon structural steel as well as low alloys [1].
Iron and carbon alloys have gained great importance as they are among the few engineering alloys that can be treated by heat treatment to benefit from the change in their mechanical properties due to the

changes that occur in the internal structure, that take place in the solid state. Heat treatment processes can be applied to steel not only with the aim of increasing its hardness but also to improve its durability, flexibility and ability to withstand shocks.

Heat treatment is defined as controlled heating and cooling associated with a specific metal and in specific ways to achieve certain mechanical properties, including hardening, annealing, normalizing, and tempering. Hardening is considered one of the most important heat treatments that are used in many industries. This is attributed to changing the fine structure that leads to a change in mechanical properties, which is used in the design of many materials, especially steel.

Annealing is one of the important heat treatments that is most often associated with steel or iron materials that can be hammered

It is used when there are clear and thoughtful requirements during the design of materials. Usually, steel is strengthened and tempered to achieve certain mechanical properties and enhance these properties, especially to achieve high quality and also its resistance to corrosion.

In the annealing process, the steel compound is heated until it reaches high temperatures in order to enhance the austenite phase, where it is kept at the temperatures it has reached until the ideal standard of carbon dissolves. After this stage, it is cooled in specific amidst such as oil or water at a controlled rate.

Also, the steel must be in a 100% hardened state to obtain high production quality. In this case, the steel is very brittle, since the use of quenched steel is very little in design applications. Through annealing, the properties of annealed steel can be modified by reducing its hardness and increasing its durability [2].

Various heat treatment processes play an important role in improving the microstructure of engineering materials, including steel. These processes include Hardening, Annealing, Tempering, and Normalization. [3].

According to the Alloy Steel Research Committee (ASRC), it was found that the content of carbon steel does not exceed 0.5% silicon and 0.5% manganese, and the remaining types of steel are considered alloy steel. The primary elements added to steel are nickel, lead, molybdenum, silicon, vanadium, manganese, chromium, cobalt, and niobium [5].

2. Vickers Hardness Testing

Hardness is considered one of the most important common mechanical properties to measure a material's strength, condition, and performance characteristics. Hardness measurement is a common method for controlling the mechanical properties of a material. Hardness is not considered a specific value only, but rather it is considered one of the complex values that have a close relationship with the primary mechanical properties of the material [6].

The Vickers hardness test is considered one of the commonly used methods for characterizing and determining the mechanical properties of materials, as it has a great advantage in determining the hardness of all materials [7].

The hardness of materials is determined by Vickers test with the following equation:

$HV = O1891\ P\ (N)/D^2\ (mm^2)$ (1)

Where:

D: Represents the average diagonal distance (d1 and d2) of the indentation mark.

P: The force applied to the indenter [8].

3. Vickers Test Advantages

1. Vickers test equipment is widely available in research laboratories.
2. Sample preparation is relatively easy and not complicated.
3. It is considered one of the easy and cheap tests.
4. Vickers test can be classified as a non-destructive test [9].
   For this reason, the Vickers test was chosen to conduct the hardness tests in this experiment.

4. Experiment

In the heat treatment experiment, five pieces of carbon steel were cut, each piece containing 0.5% carbon. After that, the pieces were placed for about half an hour in an oven at a temperature of 850Co, and they were cooled in different ways.

Fig 1: The Five Specimens

The five specimens which were heated in the furnace about half an hour at 850o Co were cooled as the following:

1. The first specimen was cooled in the air.
2. The second specimen was quenched in water.
3. The third specimen was quenched in the water then it was heated again to 200C^{o}.
4. The fourth specimen was quenched in the water then it was heated to 400^{o} C^{o}.
5. The fifth specimen was quenched in the water then it was heated again to 600C^{o}.

Fig 2: The Specimens in the Furnace

After heating and cooling the samples each in a different way, the samples were polished in multiple steps to obtain a flat surface. They were then washed with acetone, dried, and then placed in Nittal for five seconds.

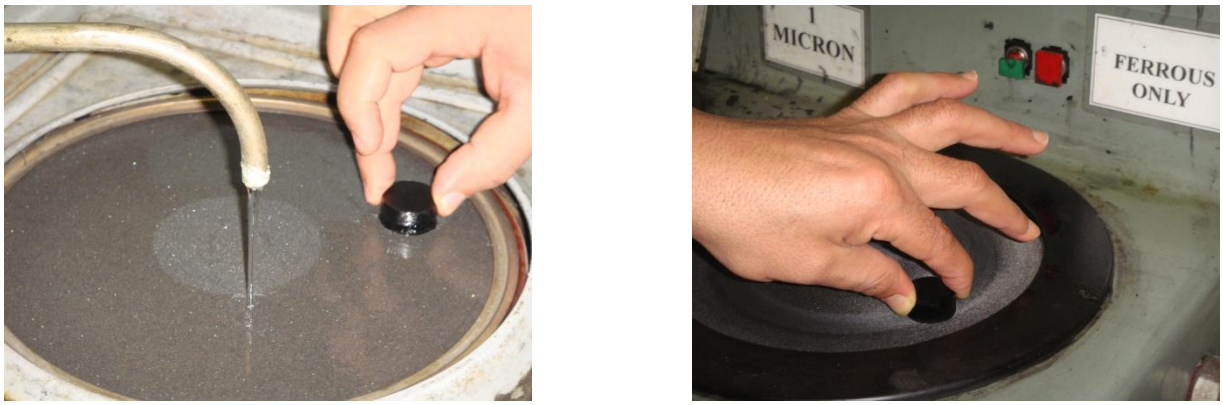


Fig 3: The Specimen is polished

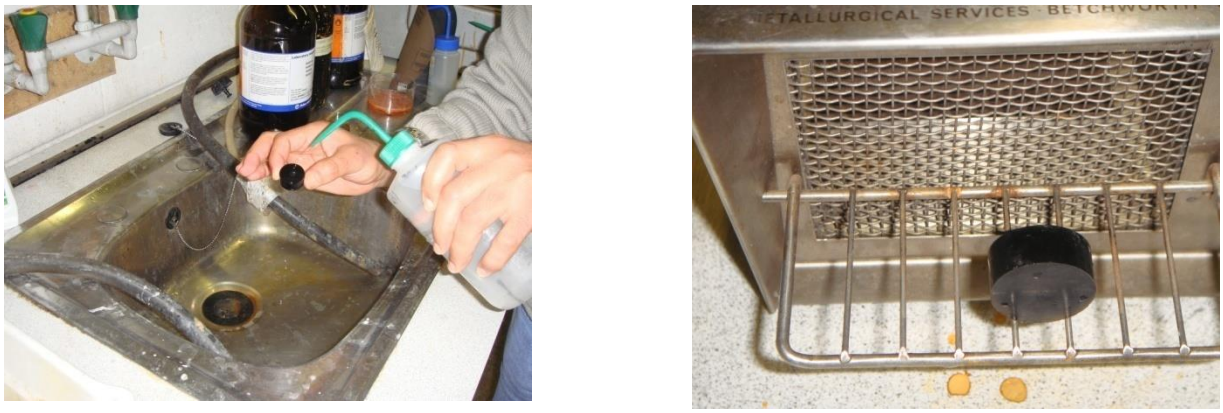
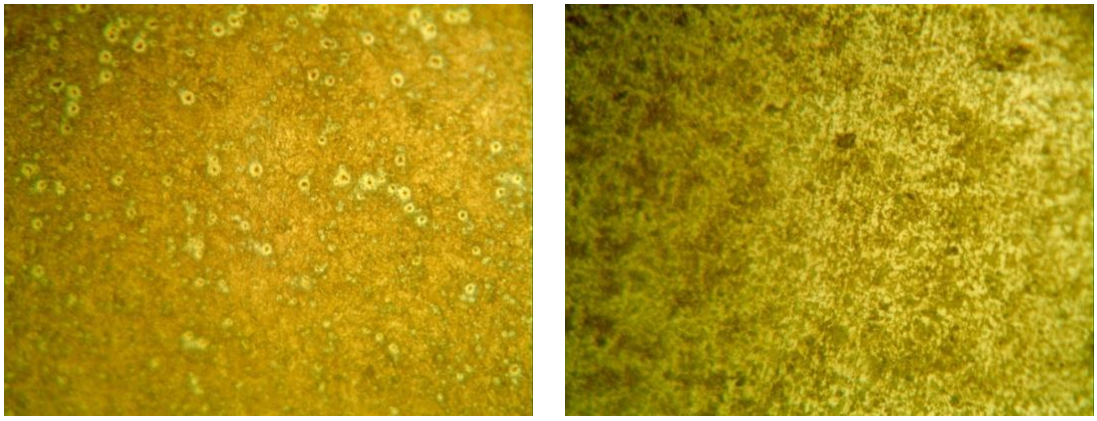


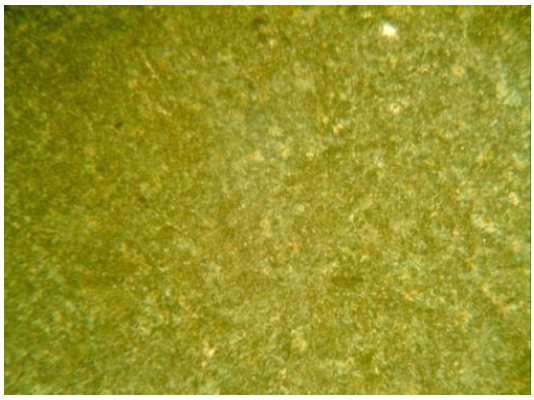
Fig 4: The Specimen is washed with the Acetone and Remained to Dry

The following figures illustrate the microstructure of the specimens which was done by using a microscope.

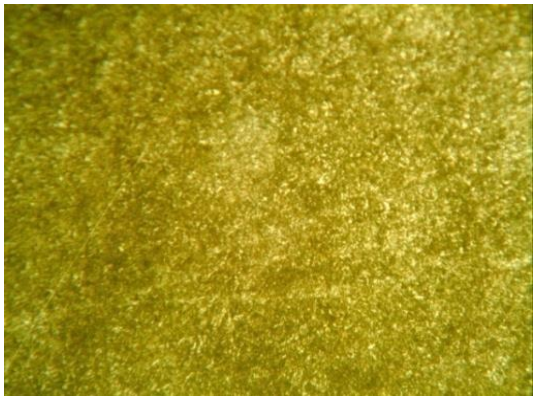


Heated to 850C^{o}- Air cooled Heated to 850C^{o} then water quenched

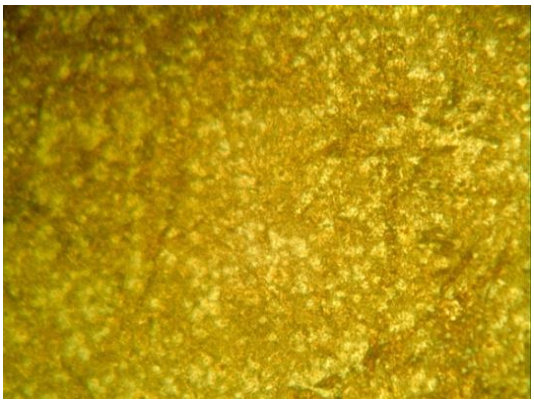
Fig 5: Specimens Which Were Heated to 850C^{o} Then the First Air Cooled, and the Second Water Quenched



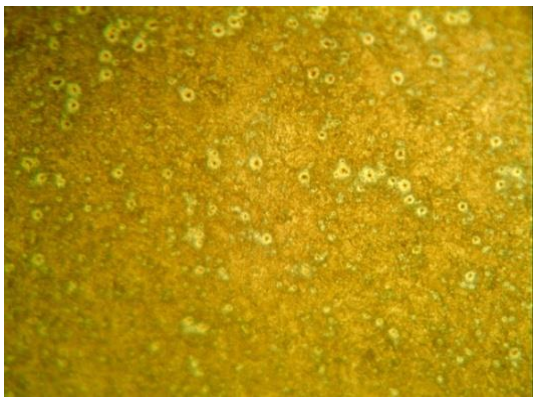
Water quenched-reheated to 200C°- Air cooled



Water Quenched-Reheated to 400C° Air Cooled



Water Quenched-Reheated to 600C° Air Cooled



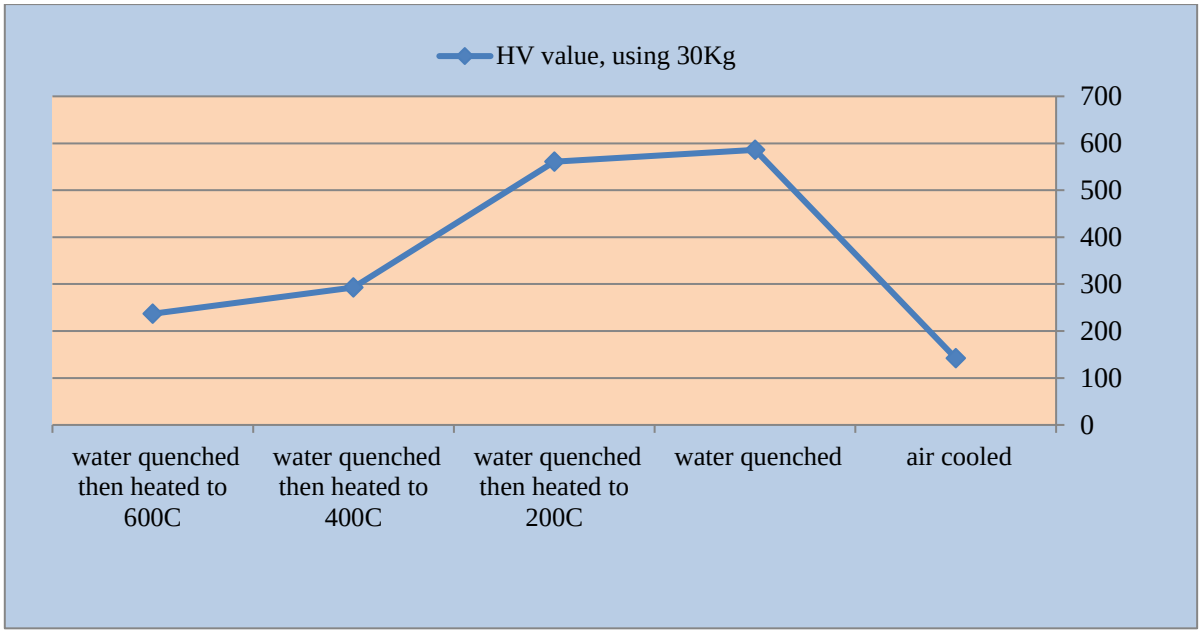
Heated to 850C°- Air Cooled

Fig 6: Specimens Which Were Heated to 850C° Then Water Quenched Than Heated to 200 C°, 400 C°, and 600C° Then Were Air Cooled

In this experiment the Vickers Hardness Test was applied for all the specimens to test their hardness, and the table below is showing the result of the hardness test.

Table 1: Shows the Result of the Hardness Test for Every Specimen

Specimen	Diagonal (d1)	Diagonal (d2)	Average	HV Value, using 30Kg
Air Cooled	6.3	6.2	6.25	142
Water Quenched	3.25	2.9	3.08	586
Water Quenched then Heated to 200C°	3.38	2.93	315	561
Water Quenched then Heated to 400C°	462	509	485	293
Water Quenched then Heated to 600C°	5.95	2.78	4.365	237



Graph 1: Shows the Result of the Hardness Test for Specimen which were Cooled in Air, Water Quenched, Water Quenched then Heated to 200C°, Water Quenched then Heated to 400C°, Water Quenched then Heated to 600C°

5. Conclusion

From the chart above it is observed that the effect of the heat treatment on the hardness of the carbon steel depend on the temperature and on the cooling rate, firstly from the chart the hardness of the specimens which was cooled in the air is quite low, secondly the hardness of the specimen which was quenched in the water it was at the highest peak, thirdly, it is observed that the curve of the hardness was going down of the specimens which were tempered.

From the pictures of the of the specimens above it clearly noticed that the impact of the heat treatment on the carbon steel depend on the degree of the temperature and the rate cooling, also from the experiment it is noticed that the microstructure of all the specimens has been changed.

The variety of the demands for producing products in different situation of hardness, this led to use the heat treatment in different fields in manufacturing. Since the demands of customers are increased, those cause to use the heat treatment in variety fields to change the properties of the structure of materials depending on the purpose which is needed. Heat treatment has improved the structures of products also it enhanced the quality of products.

6. References

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