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A Case Study of Heat Treatment on AISI 1020 Steel

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Abstract- Proper heat treatment of steels is one of the most important factors in determining how they will perform in service. Engineering materials, mostly steel, are heat treated under controlled sequence of heating and cooling to alter their physical and mechanical properties to meet desired engineering applications. In this study we have chosen AISI 1020 steel as for our research work and we have tried to find out the mechanical properties (hardness) and micro structural properties (martensite formation, carbon self-locking region) by means of appropriate heat treatment process (annealing, normalizing & hardening). Here the steel specimens were heat treated in a furnace at different temperature levels and soaking time; and then cooled in various media (air, ash, water). After that the hardness of the specimens were rechecked for the comparison with previous data and the microstructures of the specimens were examined using metallurgical microscope equipped with camera. These results showed that the hardness of AISI 1020 steel can be changed and improved by different heat treatments for a particular application. From the microstructures we have found that the annealed specimens with mainly ferrite structure give the lowest hardness value and highest ductility while hardened specimens which comprise martensite give the highest hardness value and lowest ductility. On the other hand, normalized specimens have given the moderate hardness and ductility comparing with hardened and annealed specimens.

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A Case Study of Heat Treatment on AISI 1020 Steel

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I. Introduction

In engineering similar metals are required to possess very strange combination of properties when they are subjected to different conditions of working. They may have to be subjected to, twisting, impact loading, as well as to withstand various stresses like tensile, compressive and shear in different places of their utility. Moreover for using them or their alloys as a tool material, they may require hardness, toughness, along with softer shank. In order to induce certain desirable properties in the metals, Heat treatment operations are applied to the material. For this purpose the metals may have to be heated to different temperatures, cooled and reheated in different media. The properties of metals can be improved, graded or altered practically by controlled heating and cooling *i.e.* by heat treatment [1].

Microscopic examination (microanalysis) is the study of the structured materials under a microscope at large magnification. The structure observed is called microstructure. A definite though only qualitative relationship exists between the structure of a metal observed in an optical microscope and certain properties of that metal. In many cases microanalysis shows that the variations in alloy properties are due to variations in chemical composition and conditions of treatment [1].

Polishing of specimen surface for microscopic study is done to prepare a smooth, deformation or distortion free surface for giving a clear two-dimensional view of the microstructures present. But, the polished surface of a uniform specimen appears bright without any detail under the metallurgical microscope. To make its structure apparent under the microscope it is necessary to impart unlike appearances to the constituents. This is accomplished by selectively corroding or etching the polished surface [1].

Transformation temperature is a function of chemical composition and heat treatment and quenching processes done on these alloys. In heat treatment process, the rate of quenching, exposure time and heat treatment temperature control the forward and reverse transformation temperatures of austenite to martensite and martensite to austenite [2].

Hardening is the heat treatment process which increases the hardness of a steel piece by heating it to a certain high temperature and then cooling it rapidly to room temperature. In this process a piece of steel is heated to a temperature of 30°C to 50°C above the upper critical temperature for hypo-eutectoid steels and by the same temperature above lower critical temperature for hyper-eutectoid steels. Depending upon its thickness, it is held at this temperature for a specified time and then cooled in a suitable cooling medium (quenching bath) like water, brine, oil or current of air from blower or compressor [3]. However, water is corrosive with steel, and the rapid cooling can sometimes cause distortion or cracking [4].

Annealing is that heat treatment process which softens an already hardened steel piece by heating it to a certain high temperature and then cooling it very slowly to room temperature. This process refines grain structures, softens the steel, improves its machinability

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and restores its ductility by reducing hardness. It also removes internal stresses [1].

The tensile strength and hardness of steel produced by annealing are less than that produced by normalizing [5].

Normalizing is a heat treatment process to make steel moderate hard from soften steel. The normalizing of steel is carried out by heating approximately 100'F above the upper critical temperature line and then cooling in air to room temperature. It does not soften the steel to the extent it is done by annealing and also it does not restore ductility as much as done by annealing [2].

II. Various Microstructures

Prediction of microstructure transformations is prerequisite for successful prediction of mechanical properties after a heat treatment and of generation of stresses and strains during a heat treatment. Phase transformation modeling is one of the main challenges in modeling of heat treatment [6]. During annealing, softening processes are under way in the microstructure and, in some cases, recovery and recrystallization take place as well. Naturally, the morphology of carbides changes as well [7].

a) Ferrite

It is α-iron (B.C.C.) having not more than 0.025% carbon in solid solution. It is major constituent in low carbon steels and wrought iron. Its hardness varies from 50 to 100 B.H.N. Its upper tensile strength is about 330 MN per m2 and percentage elongation about 40. It can be easily cold worked [1].

b) Cementite

It is iron carbide, with 6.67% carbon. Its upper tensile strength is about 45 MN per m2 and hardness about 650 B.H.N. It is white in color and is brittle. It occurs in steels which have been cooled slowly. It is magnetic below 250°C .In steels containing carbon less than 0.8% it is present as a component of another constituent, "pearlite". In steels containing more than 0.8% carbon it exists as a grain boundary film [1].

c) Pearlite

In its microstructure it consists of alternate laminations of ferrite and cementite. It contains about 0.8% carbon in iron. It is the strongest constituent of steel. Its hardness is about 180 B.H.N., ultimate tensile strength about 920 MN per m2 and percentage elongation about 5% [1].

d) Austenite

It is a solid solution of carbon in ý-iron (F.C.C.) containing a maximum of 2% carbon at 1130°C. It is tough and non-magnetic. It exists in plain carbon steels above upper critical temperature. Elements like chromium and manganese in steel preserve all or some of austenite down to 0°C. Austenite consists of polyhedral grains showing twins [1].

e) Martensite

In plain carbon steel it is obtained by quenching from above upper critical temperature. It is the hardest constituent obtained in given steel. It shows a fine needle-like microstructure. Its hardness is about 700 B.H.N. It is unstable and disappears on reheating the steel. It is magnetic and less tough than austenite. It is considered to be highly stressed α-iron supersaturated with carbon [1].

III. Methodology

Figure 3.1 : Muffle furnace (manual)

Figure 3.2 : Muffle furnace (automatic)

Figure 3.3 : Metallurgical Microscope

Figure 3.4 : Polishing Machine

a) *Material Composition*

The chemical composition of AISI 1020 steel

Table 1 : Material composition of AISI 1020 steel

C	Si	Mn	Cr	Ni	P	S	Fe
0.20	0.22	0.66	0.055	0.18	0.015	0.028	Balanced

b) Working Steps

The following steps were carried out in our experimental investigation:

- Samples of AISI 1020 steel were prepared for hardness test in Brinell Hardness Tester machine.
- After that the following specimens were heat treated in the furnace for reaching the austenization temperature (850-900°C) of the following specimens.
- Then the specific heat treatment operation like hardening, annealing and normalizing had been done.
- For specific heat treated specimen, the hardness test was done for assessing the change in hardness.
- Metallographic tests were carried out to observe the changes in microstructures after heat treatment.

IV. Result and Discussion

a) *For Annealing*

In this case the specimen was put in the furnace for 850°C and we kept it in this situation for approximately 35 minutes. After that it was cooled in a heap of ashes so that it was cooled down at a very slow rate.

The function of annealing is to restore ductility and also removes internal stresses but its Brinell Hardness Number is less than hardening because here carbon get more time to react with oxygen in the atmosphere for slow cooling rate.

b) *For Hardening*

In this case the specimen was put in the furnace for 850°C and we kept it in this situation for approximately 10 minutes. After that it was cooled in water so that it was cooled down very quickly.

The function of hardening is to increase the hardness of the specimen and so its Brinell hardness number is larger than annealing and normalizing because here carbon cannot get more time to react with oxygen (for quick cooling rate), so carbon is trapped with the specimen and formed martensite.

c) *For Normalizing*

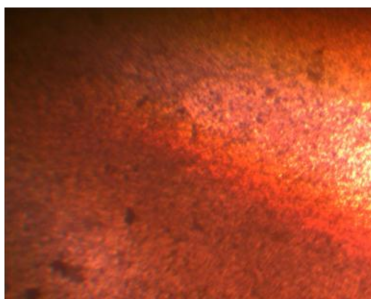
In this case the specimen was put in the furnace for 850°C and we kept it in this situation for approximately 45 minutes. After that it was cooled in room temperature.

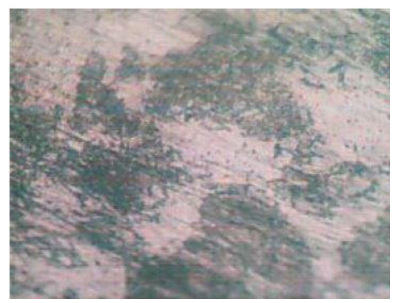
Normalizing does not soften the steel to the extent it is done by annealing and also it does not restore ductility as much as is done by annealing. Its Brinell Hardness Number is less than hardening but greater than annealing.

Table 2 : Effect of heat treatment on hardness

Heat treatment technique	Hardness number (B.H.N.)	
	Before heat treatment	After heat treatment
Annealing	109	127
Hardening (water quenched)	109	431
Normalizing	109	151

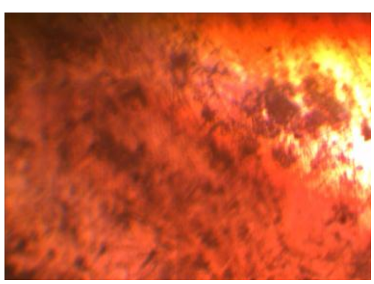
From the *Table 2* we can easily indicate that there is a significant change in hardness number of the hardened specimen comparing with normalizing and annealing. It is happened because of self-locking of carbon particles in the hardened specimen. In the microstructures of these specimens we have indicated the carbon-saturated region with arrow marks (*Figure 4.1, Figure 4.2, Figure 4.3*) and these help to find out the differences among the microstructures of annealed, normalized and hardened specimens comparatively. As slow cooling is done in annealing so it transforms austenite to soft pearlite and also mixed with ferrite or cementite and this cementite increases the brittleness of the steel. Normalizing converts soft steel to moderate hard steel. In this case cooling rate is faster than annealing and for this reason, when the specimen is cooled in room temperature then ferrite and cementite are formed but their quantity is less. So the specimen is enhanced with considerable ductility by reducing its brittleness. In hardening process austenite structure is directly formed into martensite structure for fast cooling. Actually the rapid cooling converts most of the austenite into martensite which is a hard constituent and more stable than austenite at ordinary temperatures.

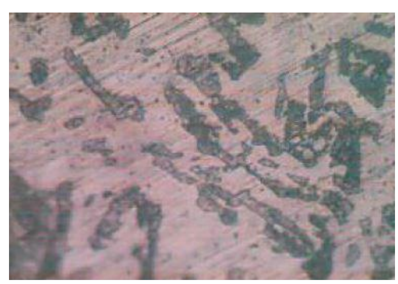




Experimental Actual

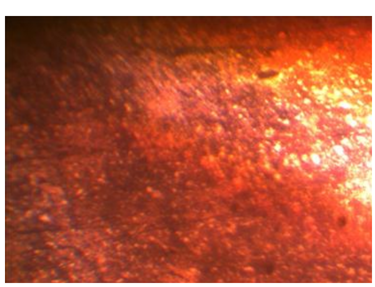
Figure 4.1 : Annealed AISI 1020 steel microstructure (100X)

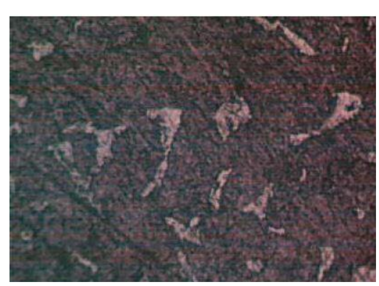




Experimental Actual

Figure 4.2 : Normalized AISI 1020 steel microstructure (100X)





Experimental Actual

Figure 4.3 : Hardened AISI 1020 steel microstructure (100X)

V. Conclusion

Here we have tried to show that the different means of cooling rate are responsible to provide significant change or effect on the microhardness of steels depending on the carbon content of steel. The microhardness increases with the increasing cooling rate and carbon content due to solid solution hardening and formation of the martensite phase. Thus heat treatment is used to obtain desired properties of steels such as improving the toughness, ductility or removing the residual stresses.

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