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Research Article

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Heat treatment of a low carbon steel (A case study of the mechanical properties)

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Abstract Low carbon steel is cheap and easily available, having all material properties that are acceptable for many applications. Heat treatment carried out on low carbon steel is to improve the properties such as ductility, toughness, machinability, refine grain structure, strength, hardness, tensile strength and to relive internal stress developed in the materials during cold or hot working. An AISI8620, American standard mild steel was subjected to different heat treatment operations. Low carbon steel with varying mechanical properties that can be utilized in different engineering applications was obtained.

Keywords Heat Treatment, Low Carbon Steel, Ductility, Hardness, Ultimate Yield Strength

1. Introduction

Steel have many practical applications in every aspect of life. As we know there is a little bit of steel in everybody life. Steel is favorable properties are the best among the goods. Steel is divided into low carbon steel, medium carbon steel and high carbon steel on the basis of the percentage of carbon content in the steel structure. Low carbon steel have carbon of 0.15% to 0.45%, medium carbon steel have carbon content of 0.45% to 0.8% and high carbon content have carbon content of 0.8% to 1.5%. Dead or mild steel have carbon content that is below 0.15% [1-2]. Steel with low carbon content have properties similar to iron. As the carbon content increases the hardness also increases, the metal becomes harder and stronger but less ductile and more difficult to weld. Higher carbon content lowers the melting point [3]. For a material to effective fit into any engineering applications there is the need to be heat treated. Heat treatment helps to change the mechanical properties of steel, usually ductility, brittleness, hardness, yield strength, or impact resistance. Electrical and thermal conductivity are slightly altered but young modulus is unaffected. Steel has a higher solid solubility for carbon in the austenite phase, which is why all heat treatment except spherodizing and process annealing, start by heating to an austenite phase [4-5]. The rate at which the steel is cooled through the eutectoid reaction affects the rate at which carbon diffuses out of austenite, which determine the new microstructure of the steel, hence, the new mechanical properties [6]. Fast cooling gives rise to a finer pearlite and cooling slowly gives rise to a coarser pearlite. Various heat treatment processes are employed to achieve different mechanical properties such as annealing, process annealing, diffusing annealing, normalizing, hardening, austempering, martempering, tempering, surface hardening, flame and induction hardening, nitriding, cyaniding, carbonitriding, carburizing, gas carburizing, liquid carburizing, and pack carburizing. The possible applications of low carbon steel are very wide. The need for heat treatment is to expand the field of usefulness. It can find applications in gear teeth, crane wheel, crane cable drum, machines worm steel, ball bearing, crankshaft, shackles of lock, hydraulic clutch on diesel engine for heavy vehicle, fittings overhead electric transmission lines, boiler mountings, railway wheels, support bracket for tractor etc [7]. This paper is set to improve the mechanical properties of low carbon steel and thus improve it area of applications.

2. Material and Methods

2.1. Material

The main material used in this research work is an AISI8620 low carbon steel obtained from hurlag technologies. It is an American specification of mild steel having the pearlite matrix (up to 70%) with relatively less amount of ferrite (30% - 40%). It has high hardness with moderate ductility and high strength. It can be said that it is a pearlite/ferrite matrix.

2.2. Methods

2.2.1. Sample Preparation

A low carbon steel rod of 120 mm in length was cut and machined into 12 equal specimens before subjecting them to different heat treatment operations.

Heat Treatment

Heat treatment is the process of heating and cooling a particular material at a particular temperature in other to improve its properties. The main reason of heat treating the low carbon steel used in this research is to create matrix microstructure and associated mechanical properties not readily obtained in the as-cast condition. The as-cast matrix microstructure of low carbon steel consists of ferrite or pearlite or combinations of both, depending on the cast section size and/or alloy composition. The principal objective of this research work is to carry out the heat treatment on low carbon steel and compare the mechanical properties with the as-received sample. The various heat treatment operation employed in this research work are:

Annealing

- The specimen was heated to a temperature of 900 °C.
- The specimen was held at this temperature for 2 h.
- Then the furnace was switched off and the specimen was allow to cool with the same rate as the temperature of the furnace decreases

The objective of keeping the specimen at 900 °C for 2 h is to homogenize the specimen. The temperature of 900 °C lies above Ac1 temperature. The specimen was removed from the furnace after 2 days when the furnace temperature had already reached the room temperature.

Normalizing

- The specimen was heated to a temperature of 900 °C
- The specimen was held at this temperature for 2 h
- Then the specimen was brought out and allowed to cool to room temperature

Quenching

This experiment was performed to harden the cast iron. The process involved putting the red hot cast iron directly into a liquid medium. The process include

- Heating the specimen to a temperature of 900 °C and was allowed to homogenize at this temperature for 2 h.
- After 2 h, the specimen was taken out and dropped into an oil bath.
- The specimen was removed from the oil bath after about an hour and cleaned properly.

Tempering

This was carried out on the specimen in other to induced softness into the matrix of the material. This was experimented at different temperature. The processes include

- Eight specimens were heated to a temperature of 900 °C for 2 h and then quenched in an oil bath.
- Two out of the eight specimens were heated to a temperature of 250 °C, but were held at that temperature for different time period of one and half hour and two hours respectively.
- Three specimens were heated to 450 °C and held at this temperature for one hour, one and half hour and two hours respective.
- Three specimens were heated to 650 °C and held at this temperature for one hour, one and half hour and two hours respective.

Austempering

This is the main essence of this research work. The objective is to develop a more efficient mechanical property in the material.

- The specimen was heated to the temperature of 900 °C and sufficient time was allowed at that temperature, so that the specimen got properly homogenized.
- A salt bath was prepared by taken 50 % of $NaNO_3$ and 50 % of KNO_3 salt mixture. The objective behind using these salts is to get a salt mixture that will remain in the molten state at a temperature of 350 °C.
- After the specimen got properly homogenized it was taken out of the furnace and put in another furnace where the container with salt mixture was kept at a temperature of 350 °C.
- At that temperature of 350 °C the specimen was held for 2 hours. This time the austenite gets converted to bainite. The objective behind choosing the temperature of 350 °C is that at this temperature
- The specimens were held at this temperature for 2 hours, the salt was taken out of the furnace.
- The specimen was quenched in an oil bath.

2.2.2. Study of Mechanical Properties

As the object of this research work is to compare the mechanical properties of various heat treated cast iron specimen. The specimens were taken for hardness test and tensile test.

Hardness test

The heated treated specimen hardness was measured by Rockwell hardness testing machine. The procedures are as follows

- The brass indenter was inserted in the machine, load adjusted to 100 Kg.
- The minor load of 10 Kg was first applied on the specimen
- The major load was applied and the depth of indentation was measured.

Ultimate Tensile Strength Test

The ultimate tensile strength of the heat treated specimens were determined using universal tensile testing machine to obtain the percentage elongation, ultimate tensile strength, and the yield strength

3. Result and Discussion

The result of the various test carried out on each of the specimens are shown in the tables below

Table 1: Hardness Value of the Heat Treated Steel

Specimen specification	Time (Hours)	Hardness
Quenched at 900 °C and Tempered at 250°C	1	45
	1½	39
	2	34
Quenched at 900 °C and Tempered at 450 °C	1	38
	1½	34
	2	29
Quenched at 900 °C and Tempered at 650 °C	1	31
	1½	27
	2	24
Austempered at 350 °C	1	29
	2	29
As-received	-	22

Table 2: Hardness and Tempering Temperature at Constant Tempering Time of 1Hr

Specimen specification	Hardness
Quenched at 900 °C and Tempered at 250 °C	43
Quenched at 900 °C and Tempered at 450 °C	36
Quenched at 900 °C and Tempered at 650 °C	33

Table 3: Hardness vs Tempering Temperature for Constant Tempering Time of 1½ Hr

Specimen specification	Hardness
Quenched at 900 °C and Tempered at 250 °C	39
Quenched at 900 °C and Tempered at 450 °C	34
Quenched at 900 °C and Tempered at 650 °C	28

Table 4 Hardness vs Tempering Temperature for Constant Tempering Time of 2Hrs

Specimen specification	Hardness
Quenched at 900 °C and Tempered at 250 °C	34
Quenched at 900 °C and Tempered at 450 °C	29
Quenched at 900 °C and Tempered at 650 °C	22

Table 5: Tensile Properties at Different Tempering Temperature for 1 Hr Tempering Time

Specimen specification	Time (Hours)	UTS (Mpa)	Yield strength(Mpa)	Elongation %
Quenched at 900 °C and Tempered at 250 °C	1	548	334	9.654
Quenched at 900 °C and Tempered at 450 °C	1	497	297	14.369
Quenched at 900 °C and Tempered at 650 °C	1	318	234	20.476

Table 6: Tensile Properties Different Tempering Temperature for 1½ Hr Tempering Time

Specimen specification	Time (Hours)	UTS (Mpa)	Yield strength (Mpa)	Elongation %
Quenched at 900 °C and Tempered at 250 °C	1 ½	543	331	12.269
Quenched at 900 °C and Tempered at 450 °C	1 ½	313	284	18.345
Quenched at 900 °C and Tempered at 650 °C	1 ½	487	238	24.856

Table 7: Tensile Properties Different Tempering Temperature for 2 Hrs Tempering Time

Specimen specification	Time (Hours)	UTS (Mpa)	Yield strength (Mpa)	Elongation %
Quenched at 900 °C and Tempered at 250 °C	2	412	267.5	22.821
Quenched at 900 °C and Tempered at 450 °C	2	382	254.6	27.514
Quenched at 900 °C and Tempered at 650 °C	2	251	198	27.729

From the different heat treatment given to the steel samples. It was observed that the higher the tempering temperature, the higher the ductility of the quenched specimens. The micrographic examination of the specimen shows a martensitic microstructure. From Table 1, it was observed that the specimen that was heated to 900℃ and tempered at 250 °C for 1 hour had the highest hardness value of 45 while the specimen that was treated at 900 °C and tempered at 650 °C for 2 hours had the lowest hardness value of 24. But there was an improvement in the hardness value of the heat treated steel compared with the hardness value of the as-received sample which was 22. The variation in the hardness value of the heat treated steel is as a result of the longer the tempering temperature the higher the ductility that is induced into the microstructure of the sample. The austempered steel at 350 °C has constant hardness value of 29 for different holding temperature.

Table 2 to Table 4 shows the variation in the hardness value as the tempering temperature increases. The Ultimate Tensile Strength (UTS) and yield strength was shown in Table 5. The UTS and the Yield strength decreases as the tempering temperature increases but the percentage elongation increases as the tempering temperature increases, this is because ductility is induced into the matrix of the heat treated steel as the tempering temperature increases. The same trend was also observed in Table 5 and Table 6.

4. Conclusion

From the results obtained in this research work, it can be concluded that the mechanical properties of the heat treated steel varies upon the different heat treatments. Ductility is better obtained by tempering at high temperature (650 $^{\circ}$C) for 2 hours. Higher hardness value can be achieved by tempering at 250 $^{\circ}$C for 1 hour. Annealing causes a great increase in the percentage elongation (ductility) of the heat treated steel while optimal combination of UTS, yield strength, percentage elongation and hardness value can be achieved through austempering.

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