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Analysis of Mechanical Properties of mild steel Applying Various Heat treatment

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ABSTRACT

In this study mild steel is selected as specimen for testing various mechanical properties. The effects of heat treatment (annealing, hardening, and tempering) on the mechanical properties of selected specimen are analyzed. Annealing, hardening and tempering are the most important heat treatment processes often used to change mechanical properties of engineering materials .The purpose of heat treating is to analyze the mechanical properties of iron, usually ductility, hardness, Yield strength, tensile strength and impact resistance. The heat treatment develops hardness, softness, and improves the mechanical properties such as tensile strength, yield strength, ductility, corrosion resistance and creep rupture. These processes also help to improve machining effect, and make them versatile. Samples of malleable iron are examined after heating at 900^0C and quenched in oil. The mechanical behavior of the samples is investigated using universal tensile testing machine for tensile test, compression test and Rockwell hardness tester for hardness testing. Samples revealed that with increasing temper temperatures: (a) hardness first increases to a maximum and then gradually decreases; (b) yield strength first decreases, then increases, and then increases again; (c) ultimate strength first increases to a maximum and then steadily decreases; and (d) ductility (% elongation) gradually decreases till 600ºC, and then increases rather sharply. The mechanical properties can easily be modified by heat treating to suit a particular design purpose. In the present study, selected samples are heat-treated at different temperature above the austenitic region and quenched followed by tempering in order to investigate the effect of different tempering temperature on the mechanical properties of iron. The changes in mechanical behavior as compared with unquenched samples are explained in terms of changes in tensile strength. Tensile test specimens are produced from malleable iron which is subjected to various forms of heat treatment processes like annealing, hardening and tempering. Results showed that the mechanical properties of malleable iron can be changed and improved by various heat treatments for a particular application. Results showed that the mechanical properties can be changed and improved by various heat treatments for a particular application. It was also found that the annealed samples with mainly ferrite structure gave the lowest tensile strength and hardness value and highest ductility value while hardened sample which comprise marten site gave the highest tensile strength and hardness value and lowest ductility value.

Keywords: Heat treatment process, mild steel, Mechanical properties, Universal Testing Machine, Rockwell hardness tester.

1. Introduction

The subject of mechanical testing of materials is an important aspect of engineering practice. Today, more concern is being given to the interpretation of test results in terms of service performance, as well as giving reliable indications of the ability of the material to perform certain types of duty. Mechanical tests are also employed in investigational work in order to obtain data for use in design to ascertain whether the material meets the specifications for its intended use.Heat treatment is defined as an operation or combination of operations involving heating and cooling of a metal or alloy for this case involving the mild steel in the solid state in such ways as to produce certain microstructure and desired mechanical properties (hardness, toughness, yield strength, ultimate tensile strength, Young's modulus, percentage elongation and percentage reduction). Annealing, normalizing, 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 defined as a heat treatment that consists of heating to and holding at a suitable temperature followed by cooling at an appropriate rate, 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 In normalizing, 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 [1].

Steel is an alloy of iron with definite percentage of carbon ranges from 0.15-1.5% [2], plain carbon steels are those containing 0.1-0.25% [3]. Steel is mainly an alloy of iron and carbon, where other elements are present in quantities too small to affect the properties. The other alloying elements allowed in plain-carbon steel are manganese and silicon. Steel with low carbon content has the same properties as iron, soft but easily formed. As carbon content rises, the metal becomes harder and stronger but less ductile and more difficult to weld. There are two main reasons for the popular use of

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steel: (1) It is abundant in the earth's crust in form of Fe_2O_3 and little energy is required to convert it to Fe. (2) It can be made to exhibit great variety of microstructures and thus a wide range of mechanical properties. Although the number of steel specifications runs into thousands, plain carbon steel accounts for more than 90% of the total steel output. The reason for its importance is that it is a tough, ductile and cheap material with reasonable casting, working and machining properties, which is also amenable to simple heat treatments to produce a wide range of properties [1].The purpose of heat treating carbon steel is to change the mechanical properties of steel, usually ductility, hardness, Yield strength, tensile strength and impact resistance. The standard strengths of steels used in the structural design are prescribed from their yield strength. Most engineering calculations for structure are based on yield strength. The heat treatment develops hardness, softness, and improves the mechanical properties (such as tensile strength, yield strength, ductility, corrosion resistance and creep rupture. These processes also help to improve machining effect, and make them versatile. They are found in applications such as train railroads, beams for building support structures, reinforcing rods in concrete, ship construction, tubes for boilers in power generating plants, oil and gas pipelines, car radiators, cutting tools etc [3].The mild steel or called low carbon steel as the main component to through the process of the heat treatment where it containing several characteristic. The general range of mild steel is 0.05% to 0.35%. Mild steel is a very versatile and useful material. It can be machined and worked into complex shapes has low cost and good mechanical properties. It is forms the vast bulk of the steels employed for general structural fabrication, sheet metal and so on. Bolts and studs are supposed to be made from mild steel (up to 0.25% carbon) with characteristic toughness and ductility.

2. Materials and Methods

Sample of ASTM A-36 mild steel was purchased from a local market located in Khulna, Bangladesh. All specimens of mild steel of dimensions 8×8×8 mm was cut using power hacksaw. The chemical composition of the mild steel sample was determined as given in Tables 1. Standard tensile and impact specimens were made from ASTM A-36 mild steel sample using lathe machine. Samples were subjected to different heat treatment: annealing, normalizing, hardening, and tempering in accordance to ASM International Standards [4].Heat treated specimens were tested for mechanical properties. The heat treatment conditions are listed in Table 2. Four specimens were prepared for each heat treatment type.

Table 1: Chemical composition of mild steel

Iron family	C%	Si %	Mn %	S %	P%	Fe %	Cu%
Mild steel	0.29	0.28	0.10	0.10	0.04	98.14	0.2

3. Results and Discussions

2.1 Determination of mechanical properties

Mechanical properties (hardness, tensile strength, toughness, yield strength, elongation and percentage of elongation) of the treated and untreated samples are determined using standard methods. For hardness testing, oxide layers formed during heat treatment were removed by stage-wise grinding and then polished. Average Rockwell Hardness Number (B) readings were determined by taking two hardness readings at different positions on the samples, using a Standard Rockwell hardness tester and tensile test using universal testing machine. Impact energy was recorded using the Izod impact tester. For tensile properties, tensile specimens were loaded into a 2000-kg Mosanto Tensiometer hooked up to a data logger. Load-elongation data were recorded and converted into stress-strain graphs. Yield strength, ultimate (tensile) strength, Young's modulus and ductility (% elongation and reduction) are determined based on these graphs, in accordance with ASTM standard test procedures (ASTM A-36) [5,6,7].

Condition	Annealed	Normalized	Hardened	Tempered
Temperature, °C	910	910	910	450
Holding time, min	70	70	30	70
Cooling medium	Furnace	Air	Water	Air

2.2 Effect of Heat Treatment on Mechanical Properties

The effect of heat treatment (annealing, normalising, hardening, and tempering) on the mechanical properties (ultimate tensile strength, hardness, toughness, percentage elongation, and percentage reduction) of the treated and untreated samples is shown in Table 3. The untreated samples value of mechanical behavior was noted as follows: tensile strength 402.45 MPa, yield strength 220.03MPa, hardness 69.80 HRC, toughness J, percentage of elongation 23.16%, percentage of reduction 56.24% , young modulus 207.88Gpa, yield strength 217.31 N/mm^2 .

Table 3: Mechanical Properties of heat treated and untreated ASTM A -36 steel

Mechanical properties						
Heat Treatment	Tensile Strength (Mpa)	Hardness (HRC)	Percentage Elongation (%)	Percentage Reduction (%)	Yield Strength (MPa)	Young Modulus (GPa)
Untreated	402.45	69.80	23.16/15	56.24	220.03	207.88
Annealed	389.34	62.15	25.22	64.12	212.54	302.32
Normalised	452.13	120.36	22.70	63.23	242.26	288.12
Hardened	734.32	293.4	6.90	37.39	278.11	632.47
Tempered	421.76	100.01	23.20	69.01	232.78	293.63

Comparing the mechanical properties of annealed sample with the untreated sample, annealed sample showed that lower tensile strength (389.34MPa), yield strength 212.54 MPa and hardness (62.15HRC) and increase in reduction in area (25.22%), elongation (64.12%), modulus of elasticity (302.32GPa). The decrease in tensile strength and hardness can be associated with the formation of soft ferrite matrix in the microstructure of the annealed sample by cooling. The mechanical properties of the normalized specimen are found to be 452.13 MPa, 242.26MPa, 120.36HRC, 63.23 % and 22.70 % for tensile strength, yield strength, hardness, percentage reduction and percentage elongation, respectively. The increase in tensile strength and hardness as compared to annealed and untreated sample was due to proper austenising temperature at 910^{o}C and higher cooling rate, which resulted in decrease in elongation, which was lower than those obtained for untreated and annealed samples due to pearlitic matrix structure obtained during normalization of ASTM A-36steel.

The mechanical properties of the hardened sample revealed that it had the highest value of tensile strength 734.32 MPa, yield strength 278.11 MPa and highest hardness (293.4 HRC) were obtained. The specimen was austenised at 910^{o}C for 30 minutes and then water quenched. This treatment increased the tensile strength and hardness but there was massive reduction in elongation and reduction in area 6.90%, and 37.39%, respectively.

The mechanical properties of tempered sample showed that the tensile strength, yield strength, hardness, percentage reduction and percentage elongation were 421.76 MPa, 232.78 MPa, 100.01 HRC, 69.01 % and 23.20%, respectively. Comparing the mechanical properties of tempered sample with hardened sample, it was found that there was decrease in tensile strength and hardness at tempering temperature 450^{0}C while the percentage elongation and percentage reduction increased which can be associated to the graphitization of the precipitated carbides that resulted in the formation of ferrite at tempering temperature of 450^{o}C. This showed that tempering temperature improved the degree of tempering of the martensite, softening the matrix and decreased its resistance of plastic deformation. However, the test results showed that annealing treatment gave an elongation superior to any other heat treatment studied. The variability in ultimate tensile strength, percentage elongation, percentage reduction hardness and toughness of treated and untreated ASTM A-36steel are shown in Figures 1 to 5, respectively.

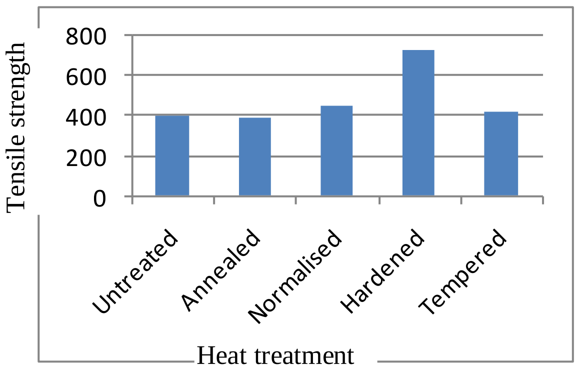

Fig. 1: Tensile Strength of treated and untreated samples of ASTM A-36steel

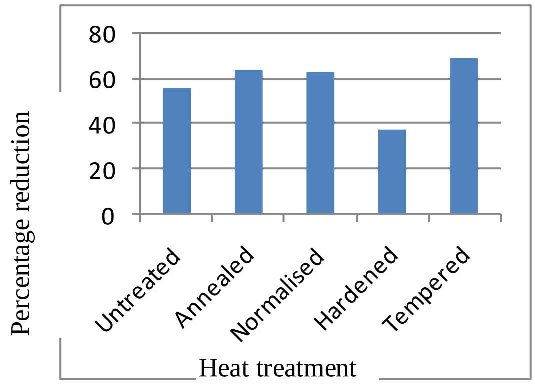

Fig. 2: Percentage reduction of treated and untreated samples of ASTM A-36steel

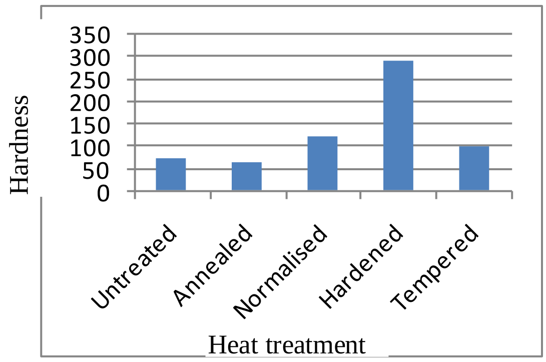

Fig. 3 Hardness of treated and untreated samples of ASTM A-36 steel

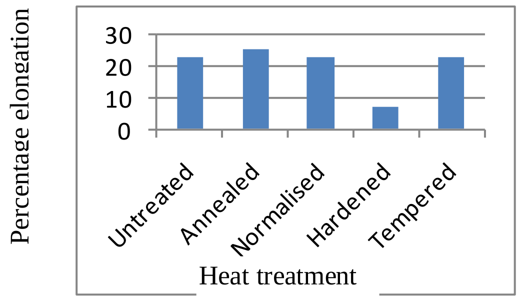

Fig. 4: Percentage elongation of treated and untreated samples of ASTM A-36steel

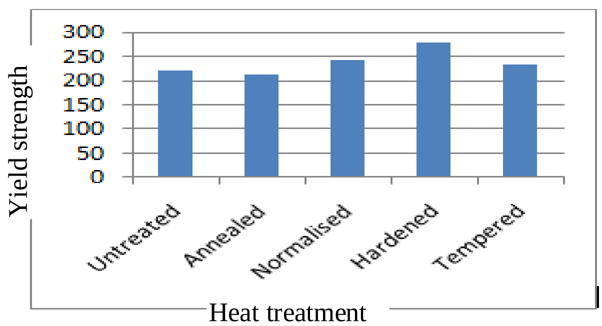

Fig. 5: Yield Strength of treated and untreated samples of ASTM A-36 steel

The value of tensile strength were observed to be in the order; hardened > normalized >tempered >untreated<annealed, possibly as a result of the

refinement of the primary phase after the subsequent cooling processes. The value of hardness was observed to be higher for the hardened steel specimen. The hardness of the steel increases with cooling rate and also with increasing pearlite percentage The reason being that martensite is one of the strengthening phases in steel. The increase in the hardness was due to the delay in the formation of peatrlite and martensite at a higher cooling rate. The yield strength value for the hardened specimen was also observed to be greater than that of normalized and annealed specimens, while the normalized specimen also has a greater value than that of tempered and annealed specimen. It was also observed from the graphs that for all the heat treated specimens, except for the hardened specimen, there were tremendous increase in the toughness of the material which indicates that hardened material, though have a very high tensile stress, but at the expense of its toughness, hence where toughness is a major concern. However if strength is also desired along with hardness, this should not be done. It is seen that annealing causes a tremendous increase in % elongation (ductility). It can be clearly seen comparing all the heat treatment processes, optimum Combination of Ultimate Tensile Strength, Yield Strength, % Elongation as well as hardness can be obtained through austempering only.

4. Conclusions

From the results obtained, it can be said that mechanical properties depends largely upon the various form of heat treatment operations and cooling rate. 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, annealed mild steel will give satisfactory results. According to the results of investigation on the effect of heat treatment on mechanical properties and microstructure of ASTM-A36 mild steel, the following conclusions were made: Tensile strength, yield strength and hardness of low carbon ASTM A-36 steel 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. This treatment is recommended as final treatment after manufacturing. The tempered samples gave an increase in tensile strength and hardness than untreated sample as a result of formation of tempered martensite and resultant ferrite structure that were obtained. Hardened sample had the highest tensile strength and hardness with lowest ductility and impact strength when compared to other heat treated samples. Hardening is strongly recommended when the strength and hardness are the prime desired properties in design. The mechanical properties of ASTM A-36steel can be altered through various heat treatments. The results obtained confirmed that improvement in mechanical properties that can be obtained by subjecting ASTM A-36 steel to different heat treatments investigated in this study.

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