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Analysis of the mechanical characteristics of mild steel using different heat treatment

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Abstract

The specimen used in this study to test various mechanical properties is mild steel. Analyzed are the effects of heat treatment (annealing, hardening, and tempering) on a particular specimen's mechanical characteristics. The most significant heat treatment procedures frequently employed to alter the mechanical properties of engineering materials are annealing, hardening, and tempering. Heat treatment is used to examine the mechanical characteristics of iron, which are typically ductility, hardness, yield strength, tensile strength, and impact resistance. Heat treatment increases mechanical qualities like tensile strength, yield strength, ductility, corrosion resistance, and creep rupture in addition to developing hardness and softness. These procedures also increase the effectiveness of the machining and increase their adaptability. Utilizing universal tensile testing equipment for the tensile test, a compression test, and a Rockwell hardness tester for the hardness test, the mechanical behavior of the samples is examined. Heat treating makes it simple to alter the mechanical properties to meet a specific design objective. To examine the impact of various tempering temperatures on the mechanical properties of mild steel, selected samples are heated to various temperatures above the austenitic area, quenched, and then tempered. Tensile strength variations are used to describe the changes in mechanical behavior compared to unquenched samples. Mild steel is used to create tensile test specimens, which are then heated through a variety of processes, including annealing, hardening, and tempering. The results demonstrated that different heat treatments for a specific application can alter and enhance the mechanical properties of mild steel.

Additionally, it was discovered that the hardness and ductility values of the hardened samples, which contain martens ite, were higher than those of the annealed samples, which primarily had ferrite structure.

Keywords: Rockwell hardness tester; Mechanical properties; Heat treatment process; Mild steel; Universal Testing Machine

1. Introduction

Engineering practice heavily involves the study of mechanical testing of materials.Today; more attention is being paid to how test findings should be interpreted in terms of service performance as well as providing trustworthy Indicators of the material's capacity to carry out specific

Types of task Mechanical testing are also used in investigative work to gather data for design purposes to determine whether the material satisfies the requirements for its intended use [3]. When applied to mild steel in its solid state, heat treatment is defined as an action or series of actions that involves heating and cooling the material in order to produce the desired microstructure and mechanical properties (hardness, toughness, yield strength, ultimate tensile strength, Young's modulus, percentage elongation, and percentage reduction).The most significant heat treatments frequently employed to alter the microstructure and mechanical properties of engineering materials, notably steels, are

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annealing, normalizing, hardening, and tempering. It is used when elongations and a noticeable level of tensile strength are required in engineering materials. Annealing is defined as a heat treatment that entails heating to and holding at a suitable temperature followed by cooling at an appropriate rate. It is most frequently used to soften iron or steel materials and refines its grains because of ferrite-pearlite microstructure. The material is heated to the austenitic temperature range during normalizing, and then it is cooled with air. 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 [3]. Manganese and silicon are the other alloying ingredients permitted in simple carbon steel. Low carbon steel has the same soft, formable characteristics as iron. The metal becomes stronger and harder as the carbon content increases, but it also becomes less ductile and more challenging to weld[3].The widespread use of steel is due primarily to two factors: [1] It exists in large quantities as Fe_2O_3 in the earth's crust, and converting it to Fe requires little energy. [2] It can be produced to display a wide range of mechanical properties and a huge variety of microstructures. Despite the thousands of different steel requirements, simple carbon steel makes up more than 90% of all steel production. Its relevance can be attributed to the fact that it is a tough, ductile, and affordable material with reasonable casting, working, and machining qualities, as well as being responsive to straightforward heat treatments to generate a variety of features [1].Heat treating carbon steel is done to modify the material's mechanical characteristics, which typically include ductility, hardness, yield strength, tensile strength, and impact resistance. The yield strength of the steels used in structural design is utilized to determine the standard strengths [3]. The majority of structural engineering calculations are based on yield strength. The mechanical qualities (such as tensile strength, yield strength, ductility, corrosion resistance, and creep rupture) are enhanced by the heat treatment, which also generates hardness and softness. These procedures also increase the versatility of the machining process [3]. They are used in a variety of applications, including train tracks, building support beams, concrete reinforcing rods, shipbuilding, boiler tubes for power plants, oil and gas pipelines, automobile radiators, and cutting tools [15].The main component that goes through the process of heat treatment and has numerous characteristics is mild steel, also known as low carbon steel. Mild steel typically falls within the range of 0.05% to 0.35%. Mild steel is an extremely useful and adaptable substance. It is inexpensive, has good mechanical qualities, and can be fashioned into intricate designs. It makes up the vast majority of the steels used for sheet metal, general structural fabrication, and other applications. Bolts and studs are required to be constructed of mild steel, which has a typical toughness and ductility and contains up to 0.25% carbon.

2. Materials and Methods

An ASTM A-283C mild steel sample was acquired from a neighborhood shop in Khulna, Bangladesh. Using a power hacksaw, all mild steel specimens with dimensions of 8x8x8 mm were cut. The mild steel sample's chemical makeup was determined and is shown in the tables.

1. Using a lathe, standard tensile and impact specimens were created from ASTM A-283C mild steel samples. According to ASM International Standards, samples underwent several heat treatments, including annealing, normalizing, hardening, and tempering [5].Mechanical characteristics of heat-treated specimens were examined. Table 2 contains the conditions for the heat treatment. For each form of heat treatment, four specimens were created.

Table 1 Chemical composition of mild steel

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

3. Results and Discussions

3.1. Determination of mechanical properties

Utilizing accepted techniques, the treated and untreated samples' mechanical characteristics (hardness, tensile strength, toughness, yield strength, elongation, and percentage of elongation) are determined. The heat-treated oxide layers were removed for hardness testing by stage-by-stage grinding, followed by polishing. By obtaining two hardness readings on the samples at various locations using a Standard Rockwell hardness tester and a tensile test using a universal testing machine, average Rockwell Hardness Number (B) values were calculated. The Izod impact tester was used to measure impact energy. Tensile samples were put into a 2000-kg Mosanto Tensiometer that was connected to a data recorder to determine the material's tensile properties. Stress-strain graphs were created using load-elongation data. According to ASTM standard test protocols (ASTM A-283C), the following properties are obtained based on these graphs: yield strength, ultimate (tensile) strength, Young's modulus, and ductility (% elongation and reduction) [6,7,8].

Table 2 Determination of mechanical properties

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

3.2. Heat Treatment's Effect on Mechanical Properties

Table 3 displays the impact of heat treatment (annealing, normalizing, hardening, and tempering) on the mechanical parameters of the treated and untreated samples (ultimate tensile strength, hardness, toughness, % elongation, and percentage reduction). The mechanical behavior value of the untreated samples was observed as follows: elongation 23.16%, reduction 56.24%, young modulus 207.88Gpa, yield strength 217.31 N/mm2, tensile strength 402.45 MPa, yield strength 220.03 MPa, hardness 69.80 HRC, toughness J.

Table 3 Mechanical Properties of heat treated anduntreated ASTM A-283C steel

Mechanical properties						
Heat Treatment	**Tensile Strength (Mpa)**	**Hardness (HRC)**	**Percen tage Elongtion (%)**	**Percen tage Reduction (%)**	**Yield Strength (MPa)**	**YoungModul us (GPa)**
Untreated	405.55	68.21	23.16/15	56.24	220.03	207.88
Annealed	385.33	60.34	25.22	64.12	212.54	302.32
Normalized	445.23	118	22.70	63.23	242.26	288.12
Hardened	715.42	289	6.90	37.39	278.11	632.47
Tempered	411.34	99.78	23.20	69.01	232.78	293.63

When compared to the untreated sample, the mechanical parameters of the annealed sample revealed reduced tensile strength (389.34 MPa), yield strength 212.54 MPa, and hardness (62.15 HRC), as well as higher reduction in area (25.22%), elongation (64.12%), and elastic modulus (302.32GPa). The annealed sample's microstructure's cooling-induced creation of a soft ferrite matrix has been linked to a reduction in tensile strength and hardness. Tensile strength, yield strength, hardness, percentage reduction, and percentage elongation are found to be 452.13 MPa, 242.26 MPa, 120.36 HRC, 63.23%, and 22.70% for the normalized specimen's mechanical parameters, respectively. The proper austenising temperature of 910oC and faster cooling rate led to a decrease in elongation, which was lower than that obtained for untreated and annealed samples due to the pearlitic matrix structure obtained during normalization of ASTM A-283C steel. The increase in tensile strength and hardness as compared to annealed and untreated sample was caused by the increase in hardness and tensile strength. The hardened sample's mechanical characteristics showed that it had the maximum tensile strength (734.32 MPa), yield strength (278.11 MPa), and hardness (293.4 HRC). The specimen was quenched in water after being austenised at 910oC for 30 minutes. The tensile strength and hardness were both enhanced by this treatment; however the elongation and area were drastically reduced, by 6.90% and 37.39%, respectively.

Tensile strength, yield strength, hardness, percentage reduction, and percentage elongation of the tempered sample were 421.76 MPa, 232.78 MPa, 100.01 HRC, 69.01%, and 23.20%, respectively. Comparing the mechanical characteristics of the tempered and hardened samples, it was discovered that the tensile strength and hardness decreased at the tempering temperature of 4500C while the percentage elongation and reduction increased. This can be attributed to the graphitization of the precipitated carbides, which led to the formation of ferrite at the tempering temperature of 450oC. This demonstrated that increasing the temperature during tempering enhanced the martensite's degree of tempering, softened the matrix, and reduced the material's resistance to plastic deformation. The test findings, however, demonstrated that annealing treatment provided a greater elongation than any other heat treatment examined. Figures 1 to 5 illustrate, accordingly, the variation in ultimate tensile strength, percentage elongation, percentage reduction hardness, and toughness of treated and untreated ASTM A-283C steel.

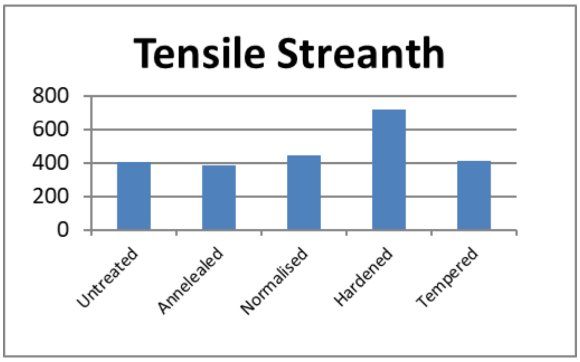

Figure 1 Tensile Strength of treated and untreated samplesof ASTM A-283C steel

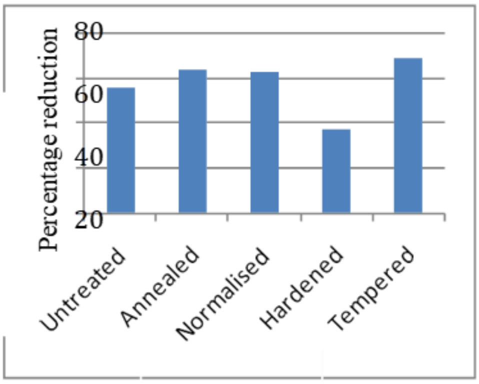

Figure 2 Percentage reduction of treated and untreatedsamples of ASTM A-283C steel

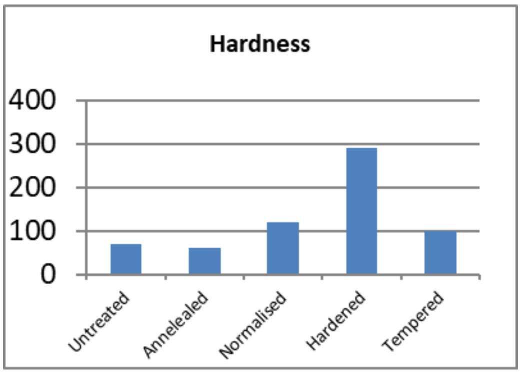

Figure 3 Hardness of treated and untreated samples ofASTM A-283C steel

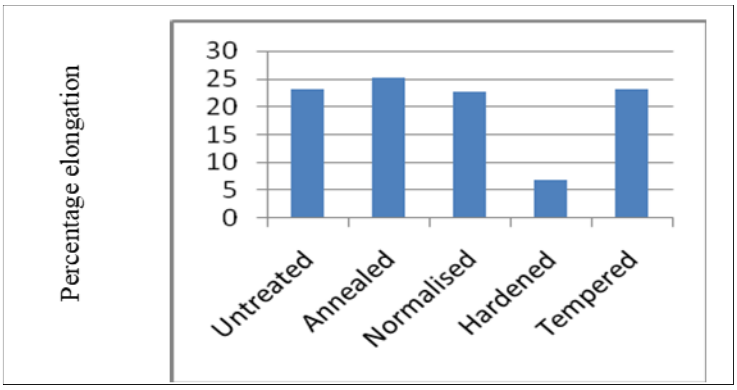

Figure 4 Percentage elongation of treated and untreatedsamples of ASTM A-283C steel

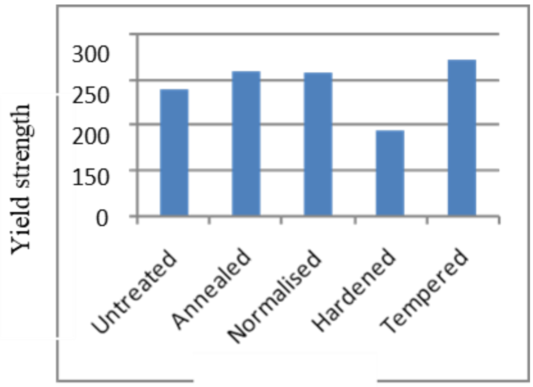

Figure 5 Yield strength of treated and untreatedsamples of ASTM A-283C steel

Tensile strength values were found to be in the following order: hardened > normalized > tempered > untreated > annealed, probably as a result of the primary phase's refining following the subsequent cooling operations. For the specimen of hardened steel, a greater hardness value was noted. The rate of cooling and the proportion of pearlite both increase the steel's hardness. The reason is that one of steel's strengthening stages, martensite, is. The development of peatrlite and martensite was delayed at a faster cooling rate, which contributed to the increase in hardness. The normalized specimen likewise has a greater value than the tempered and annealed specimens, and the yield strength value for the hardened specimen is higher than that of the normalized and annealed specimens. The graphs also showed that the toughness of the material significantly increased for all heat-treated specimens except for the hardened specimen, indicating that even though hardened material has a very high tensile stress, it does so at the expense of its toughness, which is why toughness is a major concern. However, this should not be done if strength is also sought in addition to hardness. It has been observed that annealing significantly increases elongation (ductility). When evaluating all heat treatment methods, it is evident that austempering is the only method that can produce the best combination of ultimate tensile strength, yield strength, percent elongation, and hardness.

4. Conclusions

According to the findings, mechanical properties are significantly influenced by the different types of heat treatment operations and cooling rate. Therefore, a suitable method of heat treatment should be used depending on the qualities and the applications that may be required for any design purpose. Mild steel that has been annealed will produce results that are satisfactory for high ductility and little toughness. The following conclusions were drawn from research on the impact of heat treatment on mechanical characteristics and microstructure of ASTM-A36 mild steel: Low carbon ASTM A-283C steel's tensile strength, yield strength, and hardness all rose with plastic deformation while ductility and impact strength dropped as a result of the strain hardening effect.

In comparison to annealed samples, normalization treatment has also produced materials with higher tensile strength and hardness. This procedure is advised as the last one to perform after manufacturing. Due to the production of tempered martensite and the resulting ferrite structure, the tempered samples had higher tensile strength and hardness than the untreated samples. When compared to other heat-treated samples, the hardened sample exhibited the lowest ductility and impact strength and the highest tensile strength. When strength and hardness are the primary desired features of a design, hardening is strongly advised. Through various heat treatments, ASTM A-283C steel's mechanical characteristics can be changed.

The findings supported the possibility of improving mechanical properties by applying various heat treatments to ASTM A-283C steel, which were the topic of this study.

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