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Investigation of Heat Treatment on Mechanical Properties of Medium Carbon Steel

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ABSTRACT

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The effect of various heat treatment operations (annealing, normalizing and hardening) on mechanical properties of medium carbon steel was investigated. The samples were prepared and heat-treated at 770 ºC subsequently was cooled by different quenching media. The mechanical properties of the treated and untreated samples were determined using standard methods. Results showed that the mechanical properties of carbon steel can be changed and improved by various heat treatments. It was also found that the annealed samples has the lowest tensile strength and hardness value and highest ductility, while hardened samples has the highest tensile strength and hardness value and lowest ductility value.

Keywords : heat treatment, medium carbon steel, AISI 1040 steel, quenching media, mechanical properties

I. INTRODUCTION

Heat Treatment is the controlled heating and cooling of metals to alter their physical and mechanical properties without changing the product shape [1]. 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. In general, the procedure of heat treatment process consists of three stages. First stage is heating the material. Second, hold the temperature for a period of time and third, cool down the metal to room temperature. Annealing is a heat treatment process that changes the physical and sometimes also the chemical properties of a material to increase ductility and reduce the hardness. The application of annealing heat treatment is that the resulting metal is soft, can be cut and shaped easily. Normalizing is defined as a heat treatment process where a material is heated to a predecided elevated temperature, hold at that temperature for a certain period of time, and then allowed to cool freely in the air to reach room temperature. Normalized steels are harder and stronger than annealed steels. Hardening is a heat treatment process in which steel is rapidly cooled from austenitising temperature. As a result of hardening, the hardness, tensile strength and wear resistance of steel are improved. Hardening treatment generally consists of heating to hardening temperature, holding at that temperature, followed by rapid cooling such as quenching in oil or water or salt baths.

Steels are alloys of iron and carbon plus other alloying elements. Steel is commonly used in building construction, infrastructure such as bridge, tools equipment, machinery, ship, vehicle components and weapon [2]. Carbon Steel is divided into three subgroups depending on the amount of carbon in the metal: Low carbon steels/mild steels (up to 0.3% carbon), medium carbon steels (0.3–0.6% carbon), and high carbon steels (more than 0.6% carbon). Medium carbon steels are similar to low carbon steels except they contain carbon from 0.30% to 0.60% and manganese from 0.60% to 1.65%. These steels are mainly used for making shafts, axles, gears, crankshafts, couplings, and forgings.

II. LITERATURE REVIEW

M. M. Blaoui et al [3] researched that the influence of austenitization temperature, cooling rate, holding time and heating rate during the heat treatment on microstructure and mechanical properties (tensile strength, yield strength, elongation and hardness) of the C45 steel. The specimens are cooled in different mediums (water, oil, air). The results revealed that microstructure and mechanical behavior of the C45 steel depends on cooling rate, austenitization temperature, holding time and heating rate.

D. A. Fadare et al [4] investigated that the effect of heat treatment (annealing, normalizing, hardening, and tempering) on the microstructure and mechanical properties of NST 37-2 steel. The steel samples were heat treated in an electric furnace at different temperature levels and holding times; and then cooled in different media. The mechanical properties of the treated and untreated samples were determined using standard methods and the microstructure of the samples was examined. Results showed that the mechanical properties of NST 37-2 steel 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 and toughness value while hardened sample which comprise martensite gave the highest tensile strength and hardness value and lowest ductility and toughness value.

J. K. Odusote et al [5] studied the effect of quenching media on the mechanical properties of medium carbon steel. Samples of steel were examined after heating between 900°C - 980°C and soaked for 45 minutes in a muffle furnace before quenching in palm oil and water separately. The mechanical behavior of the samples was investigated and the microstructure of the quenched samples was studied. Results showed that the tensile strength and hardness values of the quenched samples were relatively higher than those of the as-cast samples. Quenching in water resulted in higher tensile strength and hardness possibly due to formation of martensitic structure after quenching.

The hardness and microstructure of AISI1020, AISI 1040 and AISI 1060 steels were investigated under different treatment by Adnan Çalik [6]. The samples were heated and treated at 1250°K for 4 h and subsequently were cooled by three different methods. The hardness of the samples was investigated and the microstructure of the treated samples was studied. Experimental results have shown that the microstructure of these steels can be changed and significantly improved by varying the cooling rate. Thus heat treatment (heating and cooling) is used to obtain desired properties of steels such as improving the toughness, ductility or removing the residual stresses.

P. Senthilkumar [7] investigated the effect of quenching media on the mechanical properties of 7075 aluminium alloy. The Al7075 alloy has been subjected to solutionizing heat treatment at a temperature of 475°C for 2 hours followed by quenching in water and oil. Tensile strength, impact strength and hardness were carried out on the untreated and heat treated specimens. The experimental results show that the highest tensile strength, impact strength and hardness was found in samples quenched in oil.

Heider Yasser Thamir Alyasiri [8] conducted his research on AISI 1018 low carbon steel samples where prepared for tensile and hardness test. The samples of low carbon steel were heated to austenite zone then cooled in different mediums with different cooling rates. Mechanical tests show increase in hardness, yield strength, tensile strength, modulus of elasticity, and yield/tensile ratio as cooling rate is increase. Ductility has inverse proportionality to cooling rate.

Rajesh Jha et.al [9] conducted a study on the effect of heat treatment on mechanical properties of mild steel (ASTM A36). Heat treatment was carried out in a furnace at a temperature of 800°C, after heating at such temperature quenching was carried out using brine solution. Various mechanical properties such as tensile strength, yield strength, modulus of elasticity, bulk modulus, shear modulus, poisson's ratio, elongation percentage & hardness are analyzed to investigate the effect of heat treatment on the mild steel. It was revealed that heat treatment produces significant effect on properties of mild steel.

Ch. Tirumala Prasad et al [10] investigated the hardness of 1040 steel using various cooling methods. The samples were prepared and heat-treated at 750 ºC and 850 ºC subsequently was cooled by three different methods. The results of this investigation showed that the hardness depends on the heating time, heating temperature and method of cooling.

III. MATERIALS AND METHODS

Material used

AISI 1040 medium carbon steel specimens were machined by using lathe machine to the standard dimensions for tensile and hardness test. Table-1 shows the chemical composition of AISI 1040 steel.

Table-1: Chemical composition of AISI 1040 steel

Chemical composition of AISI 1040 steel	
Element	**Content (%)**
Carbon	0.37 - 0.44
Manganese	0.6 - 0.9
Phosphorus	0.04 max
Sulphur	0.05 max
Iron	Balance

Heat Treatment

Steel specimen is prepared for tensile test and cylindrical specimens are prepared for hardness. Three sets out of four sets are subjected to three types of heat treatment namely annealing, normalising and hardening and one set is left without heat treatment. All the three sets to be subjected to heat treatment are first heated to 770°C for 70minutes. One set to be hardened is quenched in water, second set to be normalised is cooled in air, while the set to be annealing is cooled in the furnace slowly after switching off the furnace.

Mechanical Testing of Specimen

Mechanical properties (tensile strength, percentage of elongation and hardness) of the treated and untreated samples are determined using standard methods.

IV. RESULTS AND DISCUSSION

The effect of heat treatment on the mechanical properties of the treated and untreated samples is shown in table-2.

Table-2: Mechanical test results

S.No	Heat Treatment	Tensile Strength (Mpa)	Percentage Elongation (%)	Hardness (BHN)
1	Untreated	618.1	24.7	203
2	Annealed	589.4	26.4	178
3	Normalised	723.9	18.1	348
4	Hardened	802.3	14.8	562

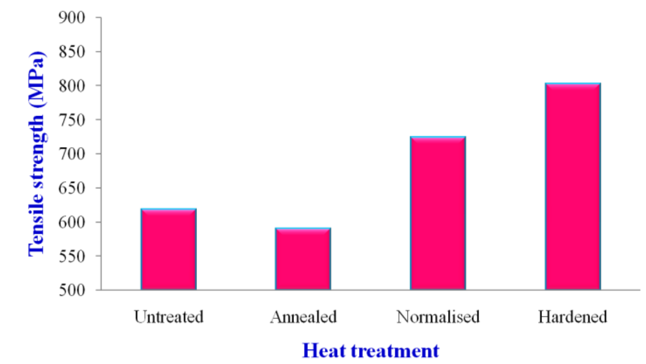

Figure-1: Tensile strength of treated and untreated samples

Figure-1 shows the effect of heat treatment on the tensile strength of medium carbon steel. The tensile 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 untreated and annealed specimen. This enhancement may be due to the fact that the cooling process is influenced by the cooling rate used for these treatments. The cooling rate is depending on the thickness of the steel [11]. Hardening cooling rate compared to normalizing is faster, because in hardening cooling process is done by water cooling and in normalizing this is done by air cooling. Water is one of the most efficient quenching media where maximum tensile strength is acquired. More rapid the cooling, finer grains are formed which results in a specimen to have higher tensile strength [12]. O.O. Agboola et al [13] reported that that soaking time has the largest influence on the tensile strength of the heat-treated medium carbon steel. The mechanical properties of medium carbon steel were investigated under different heat treatment by P. Senthilkumar [14]. The samples were heated to 900°C and left for 45 minutes inside the furnace as a soaking time, then cooled by three types of cooling media (air, oil and water). The result reported that the tensile strength of the water quenched specimen is higher as compared to untreated, oil and air quenched specimen.

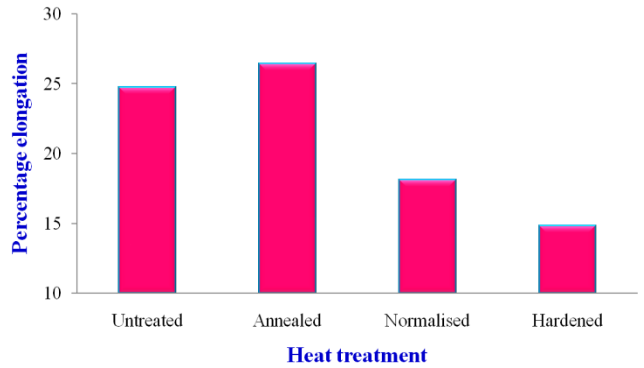

Figure-2: Percentage elongation of treated and untreated samples

Figure-2 shows the percentage elongation of the as-received and the heat treated specimen. The annealed specimens have the highest percentage elongation followed by the untreated specimen while the hardened specimen have the least percentage elongation. A material's strength and its ductility (elongation) are related. As strength increases, ductility decreases, and vice versa [2]. This statement can clearly be seen from table-2, where annealed specimen with high elongation values show lower tensile strength values. Hasan MF [15] investigated the mechanical properties and microstructure characteristics change of ASTM A-36 steel after different heat treatments. Samples were heated at 910⁰C in furnace. Various heat treatment processes namely annealing, normalizing, hardening and tempering here conducted. Based on the results, the percentage elongation value for the annealed specimen was observed to be greater than that of tempered, received, normalized and hardened specimens.

Hardness

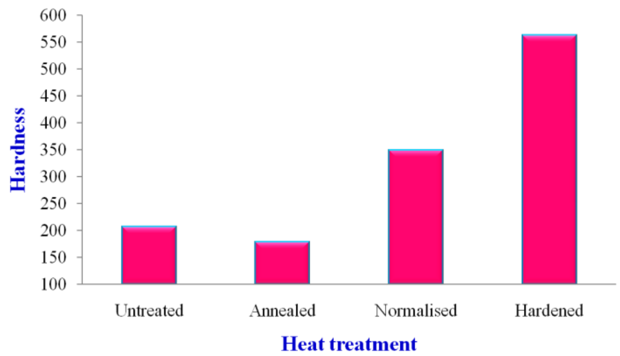

Figure-3: Hardness of treated and untreated samples

It is clear from the values given in Table-2 and from Figure- 3, that the hardness of the hardened samples is greater than those of other types of samples. The value of the hardness were also observed to be in the order; hardened > normalized > untreated > annealed. Annealing has the lowest rate of cooling, while hardening experiences the highest rate of cooling. Hardening leads to the highest hardness values, as expected. It happens because of self-locking of carbon particles in the hardened specimen. The hardness of the steel was mainly influenced by the grain development. The thickness also playing a main role in controlling the growth of the grain [11]. O.O. Agboola et al [13] reported that the ranking of the importance of the process parameters on the hardness of the medium carbon steel was soaking time > temperature > quenchant. Bhrigu nandan [16] focused on the effect of heat treatment processes on the mechanical properties of steel. The results showed that the hardness value for the hardened specimen was observed to be greater than that of normalized, untreated and annealed specimens, while the untreated specimen also has a greater value than that of annealed specimen, which has the least value.

III. CONCLUSION

From the results of investigation on the effect of heat treatment on mechanical properties of medium carbon steel, the following conclusions were made:

- Annealed sample had the lowest tensile strength and hardness with highest ductility when compared to other heat treated and untreated samples.
- Hardened sample had the highest tensile strength and hardness with lowest ductility when compared to other heat treated and untreated samples.

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