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Influence of Heat Treatment on Mechanical Properties of Medium Carbon Steel

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ABSTRACT: The mechanical properties of medium carbon steel were investigated under different heat treatment. One set of the machined test samples were kept aside to be tested in the as-received condition (untreated specimens). The remaining machined specimens of the steel were heated to 900°C and soaked for 45 minutes using a muffle furnace. The first group of hot samples was cooled by air to room temperature through the normalizing process, but the second group was rapidly cooled by two types of the quenching media (engine oil and water). Tensile strength, hardness and impact strength were carried out on the untreated and heat treated specimens. Results indicated that the tensile strength and hardness of the quenched material is higher than the parent material (untreated specimens). The tensile strength and hardness of the water quenched material is higher than the other quenched materials. But the impact strength of the water quenched material is lower than the other heat treated and untreated materials.

KEYWORDS: Medium Carbon Steel, AISI4140, Heat treatment, Quenching media, Mechanical properties.

I. INTRODUCTION

Steel is basically an alloy of iron and carbon with a small percentage of other metals such as nickel, chromium, cobalt, molybdenum, tungsten etc. The steel material is a versatile engineering material with diverse applications in civil engineering constructions, mechanical equipment, automobile manufacturing etc, due to its wide range of attractive properties, ease of fabrication and relatively low manufacturing cost and for the fact that it is second only to concrete in annual production tonnage. Steel applications can be divided into seven primary market sectors. The figure -1 (pie-chart) shows how steel was used in the world [1]. In 2019, total world crude steel production was 1869.9 million tonnes.

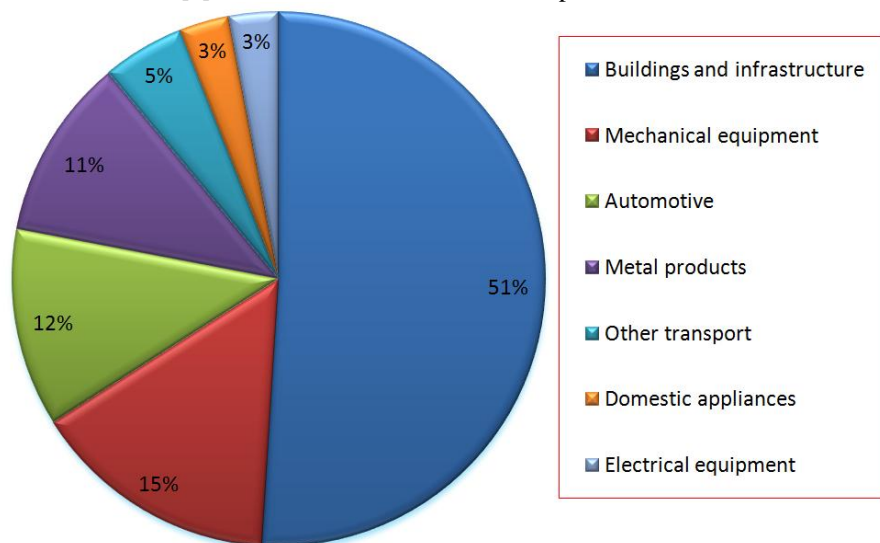


Figure-1: Use of steel in the world.

Steels can be broadly classified as plain carbon, low alloy, stainless and tool steels depending on their chemical compositions. The plain carbon steels can further be categorized into three groups depending on their carbon content as follows: the low carbon/mild steels-containing up to 0.3% carbon; the medium carbon steels between 0.3-0.6% carbon; and the high carbon steels which contain between 0.6-1.5% carbons.

Heat treatment is the controlled heating and cooling of metals to alter their physical and mechanical properties without changing the product shape. It is a process utilized to change certain characteristics of metals and alloys in order to make them more suitable for a particular kind of application. Steel can be subjected to variety of conventional heat treatments like annealing, normalizing, hardening and tempering. Normalizing heat treatment is a process applied to ferrous materials. The objective of the normalizing heat treatment is to enhance the mechanical properties of the material. The metal is heated in a furnace for normalizing heat treatment process. The temperature of the furnace is kept between 750°C - 980 °C and then allowed to cool in air. Quenching involves the rapid cooling of a metal to adjust the mechanical properties of its original state. In quenching process, a metal is heated to a temperature greater than that of normal conditions, typically somewhere above its recrystallization temperature but below its melting temperature. Held at this temperature for a considerable time to ensure thorough penetration of heat at this temperature well inside the component and then allowed to cool separately by quenching in a suitable medium like water, oil etc.

Application of AISI4140 steel

AISI4140 steel material can be used for as wide variety of applications where greater toughness and wear resistance is needed over lower carbon grades. Typical applications for 4140 steel uses include components, adapters, arbors, strippers, holder blocks, mold bases, ejectors, back up and support tooling, fixtures, jigs, molds, cams, drill collars, axle shafts, bolts, crankshafts, stubs, couplings, reamer bodies, axles, shafting, piston rods, rams, hydraulic machinery shafts, gears, sprockets, gear racks, chain links, spindles, tool bodies, tool holders, tie rods, connection rods, chuck bodies, collets, conveyor pins & rolls, ejector pins, forks, gears, guide rods, hydraulic shafts & parts, lathe spindles, logging parts, milling spindles, motor shafts, nuts, pinch bars, pinions, pump shafts, boring bars, tracks, slides, wear strips or parts, forming dies, brake dies, trim dies, bolsters, machinery parts and components, etc.

II. LITERATURE REVIEW

The mechanical properties of medium carbon steel (AISI C1035) were investigated under two different quenching media (water and palm oil) by M. B. Ndaliman [2]. The investigations centered on unheat - treated, normalized; water and palm oil quenched, and tempered conditions. The tempering temperature is 200°C. It was reported that the water quenched steel produced its best properties in strength and hardness, while palm oil quenched steel has its best property in impact strength.

Dr Eng. Frydman [3] investigated the properties of boron steel (B27) after different heat treatments. In this work steel was studied in state as delivered, after normalization, after hardening, after hardening and tempering at different temperatures (200°C to 700°C). He reported that the tensile strength and impact strength are improved after heat treatment.

T. Senthilkumar et al [4] focused on the effect of heat treatment processes on the mechanical properties of medium carbon steel. It is reported that the ultimate tensile strength and 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 annealed specimen, which has the least value.

C.J. Scheuer et.al [5] conducted a study on the effects of heat treatment conditions on microstructure and mechanical properties of AISI420 steel. The samples were heated to 1050°C and left for 0.5 hour inside the furnace as a soaking time, then cooled by three types of cooling media (air, oil and water). The result reported that the hardness of the water quenched specimen is higher as compared to oil and air quenched specimen.

M. Dauda et al [6] conducted his research on 0.509Wt%C medium carbon steel samples where prepared for tensile, hardness and impact test. One set of the machined test samples were kept aside to be tested in the as-received condition. The remaining samples were taken into the muffle furnace and heated to 880°C then quenched in water, engine oil, cotton seed oil, palm kernel oil, and olive oil. The results showed that the clear improvement of tensile strength and yield strength with highest values by quenching of engine oil, but with lowest value of the percentage elongation. The impact energy test reveal that the as-received sample absorbed the highest amount of energy before fracture while sample quenched in water absorbs the least energy. Water quenched sample has the highest hardness value.

Hasan MF [7] carried out his investigation on ASTM A-36 mild steel. Samples were heated at 910°C in furnace. Various heat treatment processes namely annealing, normalizing, hardening and tempering here conducted. Tensile and hardness tests were carried as per ASTM standards. The results show that hardened sample had the highest tensile strength and hardness with lowest ductility when compared to other heat treated samples.

Sattar Hantosh A. Alfatlawi [8] studied the effect of heat treatment on the machinability, tensile strength, hardness, ductility and microstructure of carbon steel. In this research, the heat treatments were performed by three types



of processes: normalizing, quenching and tempering, where the samples were heated to 900°C and held for 1 hour inside the furnace at that temperature. The first group of hot samples was cooled by air to room temperature through the normalizing process, but the second group was rapidly cooled by two types of the quenching media (cold water and polymer solution). It was concluded that the clear improvement of tensile strength and hardness with highest values by quenching of cold water, but with lowest value of ductility.

III. MATERIALS AND METHODS

Materials

Materials used in this study are medium carbon steel (AISI4140), while air, SAE 40 engine oil and water as cooling media.

Heat Treatment Process

One set of the machined test samples (for tensile, hardness and impact) were kept aside to be tested in the as-received condition. Three sets out of four sets are heated to 900°C and left for 45 minutes inside the muffle furnace as a soaking time, then cooled by three types of cooling media (air, oil and water). The cooling by still air is named normalizing process but the cooling by oil and water is termed quenching process.

Mechanical test

The heat treated and untreated specimens are further subjected to mechanical tests like, tensile, impact (charpy), and hardness.

IV. RESULTS AND DISCUSSION

The effect of heat treatment on the mechanical properties of the heat treated and untreated samples is shown in Table-1.

Table-1: Mechanical Properties of heat treated and untreated medium carbon Steel

Specimen	Tensile Strength (N/mm ²)	Impact strength (J)	Rockwell Hardness Value HRC
Normalized	719.8	16	39.5
Oil Quenched	1273.7	9	66.8
Water Quenched	1339.6	6	70.4
As-received	523.2	20	30.8

Tensile Strength

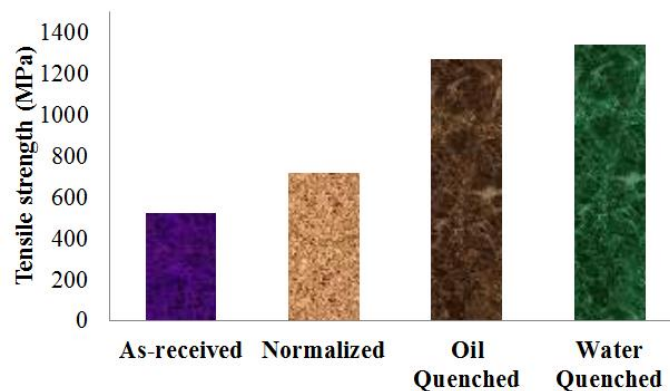


Figure-2: Tensile strength for untreated and heat treated samples

Figure-2 refers to the tensile strength for untreated and heat treated samples. It is observed that the best value of tensile strength was 1339.6N/mm² with the quenching by water. The quenching by engine oil achieved the second value of tensile strength (1273.7N/mm²), but the results reduced for other values of tensile strength for normalizing and unheated samples, the values were 719.8N/mm² and 523.2N/mm² respectively. Also the result of the tensile strength



with quenching by water was the best result compared to other processes. In water quenching, the amount of martensite formed is very high, hence tensile strength achieved is high. Jamiu Kolawole Odusote et al [9] investigated the mechanical properties of medium carbon steel heating between 900°C-980°C and quenched in both water and oil. He reported that the tensile strengths of the heat-treated samples were higher than that of the untreated steel sample, with the water quenched sample showing a higher strength. Njoku RE et al [10] had conducted his research on medium carbon steel. Based on the results, the tensile strength value for the water quenched specimen was also observed to be greater than that of oil quenched, normalized and received specimens, while the normalized specimen also has a greater value than that of received specimen, which has the least value. This leads to the fact that the water quenching gives the best result of the tensile strength.

Impact Strength

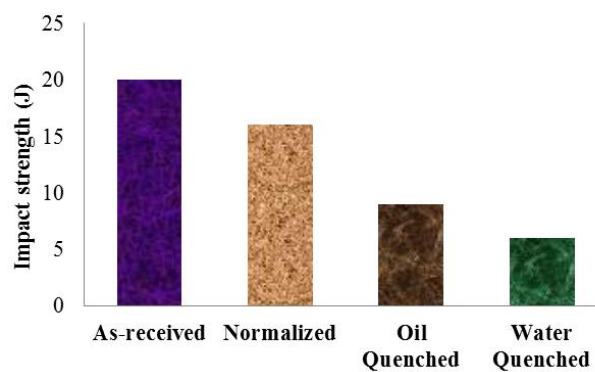


Figure-3: Impact strength for untreated and heat treated samples

Impact strength is the resistance of the material to withstand an impact or a sudden load that is applied and is measured in terms of energy which in our case, joules. Figure-3 refers to the impact strength for untreated and heat treated samples. The impact strength of the untreated (received) specimen was higher than those of the heat-treated materials. Results revealed that the normalized material possesses impact strength higher than the quenched materials. The least value of impact strength is obtained on water quenched steel. This strength is an indication of the level of toughness of the material. In water quenching, the amount of martensite formed is very high. The impact resistance decreases due to the increased quantity of martensite formation. Gurumurthy B.M et al [11] experimentally investigate the effects of normalizing, and hardening on the hardness, microstructure and toughness of AISI 4340 steel. They are reported that the toughness of the as-bought specimen is higher as compared to normalised and water quenched specimen. The effect of quenching media (palm kernel oil, cotton seed oil, neem seed oil, palm oil, SAE40 engine oil and water) on mechanical properties and microstructure of medium carbon steel were investigated by Joseph Babalola Agboola [12]. They are reported that as-received sample absorbed the highest amount of energy (183 J) before fracture while sample quenched in water absorbs least energy (28 J).

Hardness

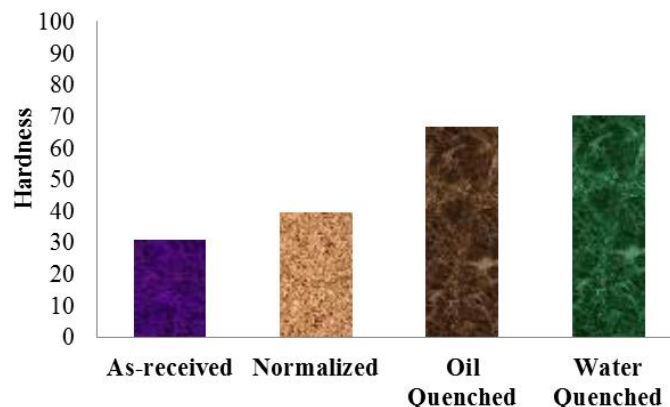


Figure-4: Hardness test results

The hardness measurements presented in figure-4 show that the hardness values of the heat-treated specimens are generally higher than that of unheat-treated steel. The water quenched samples had higher hardness compared to oil quenched samples. The value of the hardness were also observed to be in the order; hardened > normalized > untreated. This heat treatment results in the formation of martensite after quenching. Martensite is a harder phase, and its presence increases the hardness of steel. During quenching the steel changes its structure from an initial unhardened structure to a stronger final structure. N.Prithiviraj et al [13] investigated the effect of different quenching medium (air, oil and water) on the hardness of EN8. Based on the results, they are concluded that the hardness of the quenched materials was improved over the raw materials. Finally the water quenched material has the best mechanical properties in hardness when compared to the other quenched materials. Jamiu Kolawole Odusote et al [9] did experiments of effects of various quenching media (water and oil) on mechanical properties of medium carbon steel. They are reported that water quenched samples had higher vickers hardness number compared to oil quenched samples.

V. CONCLUSIONS

From the results of this study, the following points can be concluded;

- The tensile strength and hardness values of medium carbon steel (AISI4140 steel) increased after heat treatment.
- Medium carbon steel with Quenching in water has height values of tensile strength and hardness.
- The impact strength of the as-received specimen (untreated specimen) is higher than the other three.

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