Analysis of Mechanical Properties of Medium Carbon Steel using various Heat Treatment Processes

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Abstract

This study aims to analyze the effect of different austenitizing temperatures on the resistance to impact load (or impact energy) and hardness of a medium carbon steel grade SAE 1040. Steel casting at a significant level is done using heat treatment methods, including the study of mechanisms for improving mechanical properties. Mechanical properties of steel at different temperatures for heat treatment are studied and the interaction between the temperature, hardness, and strength of the material is observed. Specimen were heated to temperatures of 700°C and 900°C to obtain austenite phase at different fractions. After austenitization of 90 minutes, specimen were quenched in water, cooled in air and furnace. Heat treatment at the temperature of 900°C for 90 minutes, then cooling in furnace resulted in the highest value of impact energy. Heat treatment at the temperature of 900°C for 90 minutes, then quenching in water resulted in highest hardness value. It was observed that the best combination mechanical properties were obtained by normalization at 900°C. From the results, it is evident that the heat treatment improves the mechanical properties of as-casted steel.

Keywords—Impact energy, hardness, Mechanical properties, water, air and furnace.

1 Introduction

VARIOUS materials are available for manufacturing machine parts. Carbon steel is in wide acceptance due to its mechanical properties (high strength and toughness, etc.) and plays an important role in the manufacturing crankshafts, couplings, gears, shafts, axles, cold-headed parts, screwdrivers, pliers, Train tracks, supporting columns, concrete reinforcement plates, shipbuilding, boiler tubes in power plants, oil and gas pipes, vehicle radiators, cutting equipment and many other engineering tools. Heat treatment with cooling rate controls the diffusion rate and microstructure by changing the molecular arrangement and size of grain at various phases of a material that enable metals and alloys more suitable for particular applications [1][2].

The material modification process, such as cryogenic heat treatment, positively modifies steel's properties to get the best out of service life, i.e. stress relieving or strengthening properties. In general, heat treatment is defined as (i) thermal treatment comprising of hardening process: hardening and then tempering, softening process: normalizing and annealing, (ii) thermo-chemical process comprises of nitriding, boronizing, carburizing, and (iii) thermo-mechanical processes consisting of mechanical activity during the heat treatment period. Although heat treatment is not a new technique, no effective use has been made of the fact that most researchers are looking at the process in general. The satisfactory results from these rich steel materials have still not been obtained for improvement/modification, especially consdiering that most steel products were made of recycling scrap materials.

Heat treatment is the term used for any method which changes the physical properties of a metal through heating the metal to a temperature that is in austenite range. Subsequently, the metal is cooled with appropriate cooling rate that creates grain size and types of grains which in turn actually controls the physical properties. Strength, ductility, hardness, toughness, and wear and corrosion resistance can be easily modified by heat treatment techniques including annealing, normalizing, hardening, tempering, case hardening, precipitation strengthening [1]. Annealing is the process of heating a metal to austenitization temperature for a particular time period and then cooling it down to room temperature in a furnace. On the other

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hand, normalizing is the process of heating a metal to austenitization temperature for a particular time period and then cooling it to room temperature in air. Another process, referred to as hardening, is heating a metal to austenitization temperature for a particular time period and then immediately quenched in water or oil. Tempering is the heat treatment technique in which hardened specimen is heated to a temperature below the lower austenitization temperature [1]. Steel becomes very hard but also brittle if it is heated till it becomes glowing red and then directly quenched in clean water. In fact, if the red hot steel slowly cools, it is easier to cut, form and file as it is relatively soft. The industrial thermal processing is highly complex and is based on a precise and sophisticated technology [1][2].

2 Literature Review

The American Society for Metals, the American Foundry Men's Association, and the Society of Automotive Engineers have adopted a brief glossary of terms for heat treatment. The water's cooling capability is considered as unity with the quenching severity parameter H [3]. The H parameters of different quenching media showing the ability to remove heat during the quenching process are thus contrasted with those of the water. The highest possible cooling capacity for most alloy steels is achieved with mineral oils, but these are relatively non-biodegradable, costly and toxic [4]. Consequently, in the past, comprehensive work has been done on replacing mineral oils with aqueous chemical and polymer alternatives. Specimen of medium carbon steel containing 0.36% carbon are heated for 1.5 hour at temperature of 850°C and then normalized in air and hardened in Palm oil and water. Specimen hardened in Water has higher tensile strength (894 MPa) and hardness (RHN 47). Whereas, Palm oil quenched has higher toughness value of 17 J [5]. Specimen of medium carbon steel (containing 0.34% carbon) are heated at 910°C for 1.5 hour and then cooled in furnace and air. For hardening, medium carbon steel is heated at 910°C for 40 minutes and quenched in water. Hardened specimen are then carried for tempering at a temperature of 450°C for 90 minutes.

Relative to other heat treated specimens, hardened sample has the lowest ductility and resistance to affect the highest hardness and tensile strength. Annealed specimen has higher values of toughness. Heat treatment for normalization leads to a higher hardness and tensile strength relative to the specimens annealed. The tempered specimen shows an improvement in tensile strength and hardness in the untreated sample. The untreated microstructure has been observed in ferrite and perlite. Annealed has graphite flakes in ferrite, normalizing has graphite flakes in perlite, hardened has graphite flakes in martensite, and final tempered has graphite flakes in martensite [6].

Medium carbon steel contains 0.51% carbon with 0.41% copper, or 0.54% carbon without copper. Annealing samples are heated at 200°C, 400°C, and 600°C holding each for 15 minutes and at 650°C for 1 hour. Afterwards, the samples are cooled in a furnace to 520°C. The furnace door is then opened for cooling until red heat is gone. The samples are then quenched in oil to room temperature. Tempering samples are then tempered one by one at 200 , 400°C and 600°C for 60 minutes.

Compared with the medium carbon steel with copper, the medium carbon steel without copper has the lower hardness and tensile strength. The hardness of both types of steel decreases as the tempering temperature increases. Medium carbon steel containing copper has a poor ductility relative to copper free medium carbon steel. Ductility of both grades of steel increases as the temperature of tempering process increases [6]. Medium carbon steel (containing 0.33% carbon) are austenitized at 900°C for one hour, and are then quenched in water at temperatures of 35°C, 50°C, 65°C, 80°C and 95°C. The Rockwell hardness testing machine is used for the measurement of hardness. The impact test is carried out using the balanced impact machine Hounsfield. The tensile test is conducted on the Hounsfield Tensometer.

Whereas hardness is a water-quenched steel's desired property, quenching at 65°C gives the best results. The toughness of water-quenched medium carbon steels can be greatly improved by only slightly decreasing the hardness and increasing the water temperature to 95°C. Water quenching can be used to achieve better mechanical properties for low carbon steel without the need for additional energy tempering or quenching in certain harmful and/or costly oils [7]. Water quenching has been used to harden the steel since centuries. It can be represented as rapid metal cooling from the temperature treatment solution, usually in the range of 845°C to 870°C for steels. Quenching is typically done to prevent precipitation of ferrite or pearlite, and facilitating the formation of martensite or bainite formation [8]. In the hardened conditions, steel should be 100% martensite to achieve maximum yield [9].

The severity of water makes the hardened steel brittle, and in some cases, also leads to the formation of internal cracks, thereby restricting their engineering application. The deficiencies of water-quenched steel have led to the development of hardening and tem-

C	Fe	Mn	P	S
0.37 - 0.44	98.6 - 99	0.60 - 0.90	0.040	0.05

TABLE 1: Chemical composition of SAE 1040 steel by wt. %.

pering of heat treatment, as all hardened steel is tempered. With tempering, it is possible to alter the properties of quenched steel to lessen the hardness and improve impact energy and ductility [9]. One way of minimizing dimensional distortion and cracking during quenching is to reduce the difference in temperature between different areas of a component (or sample). This frequently includes the application of aqueous polymer or oil alternatives to control heat transfer during quenching [8].
The study presented in this paper analyzes the effect of different austenitizing temperature of medium carbon steel of grade 1040. The toughness and hardness are analyzed for the enhancement of mechanical properties of medium carbon steel of grade 1040. Mechanical properties of steel are studied for heat treatment. Different temperatures and the interaction between temperature, hardness and strength of the material is observed.

3 Experimental Procedure

The material SAE 1040 was purchased from local market in Karachi, Pakistan. The chemical composition in weight percentage of medium carbon steel Grade SAE 1040 material used for investigation is shown in Table 1.

3.1 Test Specimen Preparation

Prior to heat treatment, specimen were prepared according to ASTM standards. The impact specimen were prepared according to ASTM E23-07a. Whereas, the hardness specimen were prepared according to ASTM E10-12.

3.2 Heat Treatment

The specimen were analyzed at different austenitizing temperatures of 900°C and 700°C. The sets of specimen were heated in Gas furnace at room temperature. The furnace took 13 minutes to reach 900°C. The total time specimen remained in the furnace was 90 minutes. Afterwards, the specimens were cooled in water, air and furnace. Another set of specimen were also heated in similar furnace. This time furnace took 5 minutes to reach 700°C and the total time specimen remained in the furnace was 90 minutes. The specimens were then cooled in water, air and furnace

((a)) Specimen before polishing

((b)) Specimen after polishing

Fig. 1: Hardness specimen before polishing and after polishing

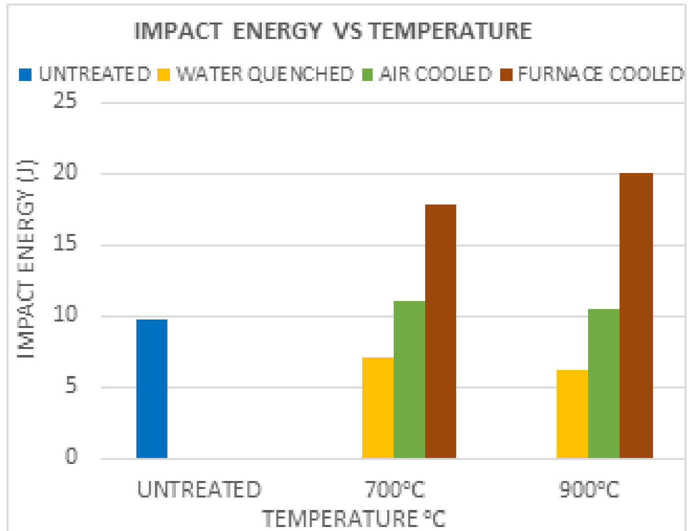

Fig. 2: Impact energy at 700°C and 900°C with different cooling conditions (after 90 min austenitization)

3.3 Mechanical Properties

Impact energy was tested with Izod impact tester. For hardness test, indention surface of specimen were polished using polishing machine, as shown in Figure 2. Hardness test was conducted with Brinell hardness testing machine with a scale HB/30 = Brinell hardness with a ball of 2.5 mm diameter, and with a test force of 187.5 N (19 kgf) applied for 15 second.

4 Experimental Results

This section discusses our experimental results in detail.

4.1 Impact Energy

The impact energy of untreated and heat-treated specimen results are illustrated in Figure 2 and Table 2. The specimen heated at 900°C for 90 minutes, followed by a furnace cooling, had the highest impact energy of 20 J. Figure 2 shows that the impact energy of the

Mechanical Properties	Untreated	Specimen austentized at 700°C			Specimen austentized at 900°C		
		Normalized	Hardened	Annealed	Normalized	Hardened	Annealed
Impact Energy (J)	9.7	11	7.1	17.86	10.5	6.2	20
Hardness (HB)	244	340	580	190	410.5	660	150.37

TABLE 2: Impact energy and hardness results (before and after heat treatment)

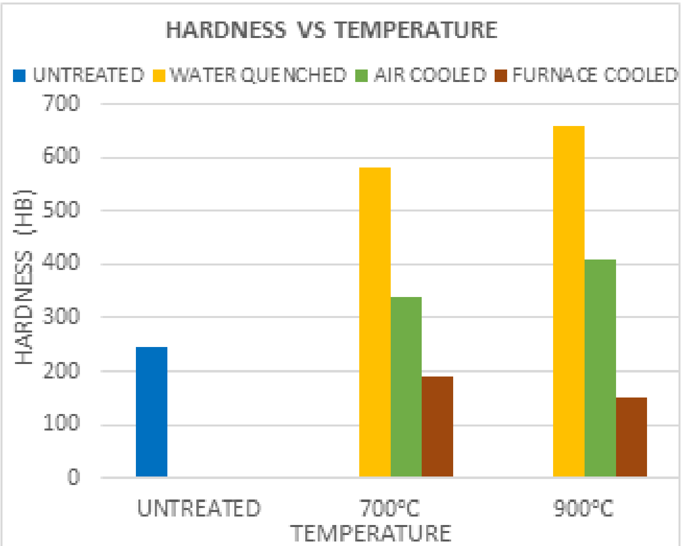

Fig. 3: Hardness value at 700°C and 900°C with different cooling conditions (after 90 min austenitization).)

specimens is dependent on the heat treatment temperature after 90 minutes austenitization. The furnace-cooled specimens' impact energy is higher than that of cooled at a fixed temperature in air and water. Moreover, furnace cooled specimens' impact energy increases after 900°C.

5 Analysis & Discussion

Quenching is the fast cooling rate used at austenitizing temperature which results in diffusion-free transformation of austenite into body-centered tetragonal crystal structure martensite and less pearlite, where carbon cannot have more time to react with oxygen. Therefore, carbon is trapped in the specimen and martensite is formed which in turn significantly increases the hardness of carbon steel, as martensite is one of the strengthening phases in steel.

Tbe water-quenched specimens from austenitization temperature of 700°C gave higher value of hardness (580 HB) and lower value of impact energy (7.1 Joule) when compared with untreated specimens. The specimens showed the highest value of hardness (660) and lowest value of impact energy (6.2 Joule) when quenched from 900°C after 90 minutes of austenitization.

Normalization is used to build a consistent fine-grained structure in a material and to protect it from excessive softening. It shapes the pearlitic matrix structure in a material because of the air cooling rate in normalization. The pearlitic structure is hard and strong, but not very tough. The specimens normalized at 700°C and 900°C have improved the impact energy and hardness as compared to untreated specimen.

Annealing is often applied for the softening of iron and steel products and refines the grains due to the presence of austentized microstructure of ferrite-pearlite and, in some cases, recovery and recrystallization also takes place. Furnace cooling enhances the specimen's impact energy and reduces the hardness. Annealing the specimen at 700°C results in higher impact energy (17.86 Joule) and lower hardness (190 HB) as compared to untreated specimen. Highest impact energy (20 Joule) and lowest hardness (150.3 HB) were obtained by furnace cooling after 90 minutes of austenitization at 900°C.

6 Conclusion

An analysis was carried out to improve the mechanical properties of SAE 1040 by monitoring the conditions of heat treatment. The specimen was tested according to ASTM standards after heat treatment. Based on the current study, following conclusions are drawn.

1) To improve the mechanical properties of steel, proper selection of the austenitizing temperature, holding time and cooling method is very important. Heat treatment at 900°C for 90 minutes, followed by furnace cooling, results in the highest value of impact energy. The combination in present condition are Izod impact energy: 20 J and hardness: 150.37 HB.
2) Heat treatment at the temperature of 900°C for 90 minutes, followed by water quenching, results in the highest value of hardness. The combination in present condition are Izod impact energy: 6.2 J and hardness: 660 HB.
3) The best combination mechanical properties were obtained by normalization at 900°C.
4) The fast cooling rate from higher temperature results in increasing the value of hardness and decreasing the value of impact energy.

Whereas, the slow cooling rate from higher temperature results in increasing the value of impact energy and decreasing hardness.

This study concluded from the overall results that the mechanical properties of casted steel f grade 1040 got improved by using the heat treatment processes.

References

[1] Verhoeven, J.D.“Steel metallurgy for the non-metallurgist.” ASM International, 2007.
[2] Totten, George E., “Steel Heat Treatment Handbook”, -2 Volume Set. CRC press, 2006.
[3] Krauss, George. ”Steels Heat Treatment and Processing Principles ASM International.” Materials Park, 1993.
[4] Grishin, S. A., and Yu N. Churyukin., ”Evaluation of the cooling capacity of quenching media based on water”, Metal Science and Heat Treatment, Vol. 28, No.10, pp. 744-745, 1986.
[5] Ndaliman, Mohammed Baba., ”An assessment of mechanical properties of medium carbon steel under different quenching media.” AU JT, Vol. 10, No. 2, pp. 100-104, 2006.
[6] Fadare, D. A., T. G. Fadara, and O. Y. Akanbi., ”Effect of heat treatment on mechanical properties and microstructure of NST 37-2 steel.”, 2011.
[7] Alabi, A. A., et al., ”Effect of Water Temperature on the Mechanical Properties of Water-Quenched medium carbon steel.” Journal for Energy Technologies and Policy, Vol. 2, No. 4, pp. 40-45, 2012.
[8] Bates, C. E., and G. E. Totten., ”Quench Severity Effects on the As-quenched Hardness of Selected Alloy-steels”, Heat Treatment of Metals, Vol. 19, No. 2, pp. 45-48, 1992.
[9] Htun, Min Shan, Si Thu Kyaw, and Kay Thi Lwin., ”Effect of heat treatment on microstructures and mechanical properties of spring steel”, Journal of metals, materials and minerals, Vol. 18, No.2, pp. 191-197, 2008.