

EXPERIMENTAL INVESTIGATION ON THE EFFECT OF CONTROLLED HEATING AND COOLING PROCESSES IN AISI 1040 STEEL

Mrs. ALAMURU SUNANDA^{1,*}, and Dr. MUNAGAPATI VENKATA JAGANNADHA RAJU²

Received: March 07, 2021; Revised: November 20, 2021; Accepted: August 03, 2022

Abstract

In this research, the changes in the Microstructure and mechanical characteristics of AISI 1040 were evaluated under various cooling and heating conditions. Controlled heating and cooling improve strength, hardness, wear resistance, softness and yield strength, and ductility. The primary application of the material is in the manufacturing of crankshafts, couplings, and railway wheels, tracks. To examine the effect of various heat treatment processes, AISI 1040 was heat treated in a furnace using various heat treatment techniques such as annealing, normalizing, and hardening at a temperature of 910°C, and tempering at 450°C. The structural behavior of AISI 1040 was examined with an optical microscope at various heat-treating conditions. Mechanical properties were studied through tensile and hardness tests. From the experimental analysis, the microstructure and mechanical characteristics of AISI 1040 can be changed and greatly enhanced by controlled heating and cooling. After experimental investigation, the changes in mechanical behavior and structure of AISI 1040 before and after heat treatment were compared. Results showed that the mechanical and microstructural characteristics of AISI 1040 were altered and improved by various heat treatment methods.

Keywords: Controlled heating, Controlled cooling, AISI 1040 steel, Enhancement of properties, Sand casting, Tensile test, Hardness test

Introduction

In order to meet the requirements of designers, the mechanical strength and fatigue life of structural components must be improved (Guarino and ponticelli, 2017). Steel is one of the principal engineering materials (Talabi *et al.*, 2014) and is easily obtainable.

Currently, in the automotive, aerospace, defense, and in other industries, the demand for

AISI 1040 is growing slowly (Sanusi and Akinlabi, 2018). This is due to their superior mechanical properties and high resistance to fatigue and wear (Liu *et al.*, 2018). Steel is commonly characterized as an alloy of iron and carbon with a carbon content ranging from a few hundred percent to about 2wt percent. Steels May exhibit a broad range of properties depending on the composition as well as

¹ Mechanical Engineering, Sreenidhi Institute of Science and Technology, Hyderabad, Telangana, India, E-mail: sunandasathish14@gmail.com

² Mechanical Engineering AU College of Engineering, Visakhapatnam, Andhra Pradesh, India, E-mail: rajumvj@gmail.com

* Corresponding Author



Figure 1. Sand casting samples

the phases and micro constituents present, which in turn depend on heat treatment. (Principles of Heat Treating of Steels, 2021).

The heat treatment method represents an important step in the manufacture of suitable materials. The material is heated in a furnace at a predefined temperature (910°C) during the heat treatment for a specified time during which it is cooled down in a specified manner. Heat treatment can assess material strength and chemical behavior (Sanusi and Akinlabi, 2018). Heat treatment can be used to regulate the metal's micro-structure to make it easier to manage or to offer better properties (Manchanda and Marang, 1992). Heat treatment is a method used to modify certain metal and alloy properties to make them more suitable for a particular form of use (Rahman *et al.*, 2016). The temperatures of metals are heated to, and after heat treatment, the cooling rate will dramatically change the properties of metals.

Heat treatment will dramatically change the properties of a metal (George *et al.*, 2014; Hasan, 2016). Parameters that affect the composition and the properties during heat treatment are the Type of alloy, heating condition, cooling condition, and time (Eurotherm by Schneider Electric, 2021). The intention of this research is to enhance the properties and structural behavior of AISI 1040 steel through the optimized heat-treatment process.

Materials and Methods

Material Specifications

In this present work, samples with 25mm diameter and 350mm length have been taken to conduct experimental work (Rahman *et al.*, 2016). These AISI 1040 steel rods were prepared using the sand-casting process in Indy engineering, one of the metal casting industries located in charlapally, Hyderabad. Later these samples were machined to standard dimensions for hardness, tensile test. In order to carry out the tensile test, the preparation was done with respect to ASTM A370-19, and for

Table 1. Chemical composition of AISI 1040 steel as received condition

Element	Composition %
C	0.415
Mn	0.607
P	0.027
S	0.006
Si	0.31
Cr	0.052
Ni	0.12
Fe	Bal

Table 2. Summary of the heat treatment process

Condition	Temp (°C)	Holding Time (min)	Cooling Medium
Annealed	910	70	Furnace
Normalized	910	70	Air
Hardened	910	30	Oil
Tempered	450	70	Air

hardness, the test procedure was carried out with respect to IS 1500-2019. The chemical composition of AISI 1040 in the received condition is shown in Table 1.

Specimen Preparation

In order to investigate the mechanical properties and microstructure of the steel, five samples of 25mm diameter and 350mm length were prepared using a sand-casting process (Nandhan, 2019). The prepared samples were shown in Figure 1. Out of these five samples, four samples were annealed, normalized, hardened, and tempered using a muffle furnace. One sample in as-cast condition was tested for chemical analysis using an optical emission spectrometer. Steel samples were heated to 910° C for annealing, normalizing, and hardening and 450°C for tempering. (Hasan, 2016). Later, samples were cooled using various media. The sample for annealing was cooled in the furnace, the sample for normalizing in the air and hardening sample in engine oil, tempering sample in the air. After these treatments, the tensile test, and hardness test was carried out by a universal testing machine, the Rockwell hardness testing machine. Samples for metallography were prepared and etched in 2% Nital Reagent, and the microstructures were revealed at a magnification of X100 under an Olympus metallurgical microscope. Ultrasonic testing was implemented in the samples to know the flaws in the interior of the casting. The Summary of heat treatment process shown in Table 2.

Mechanical properties testing

Using standard methods mechanical properties of various samples in as-cast condition and heat-treated conditions are determined. Hardness is

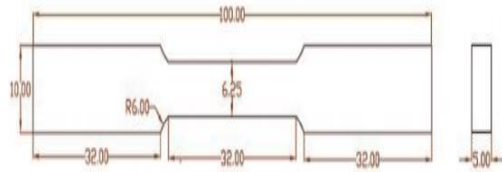


Figure 2. Tensile test specimen according to ASTM A370-19

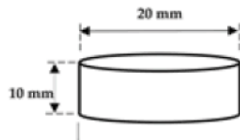


Figure 3. Hardness test specimen according to IS 1500-2019

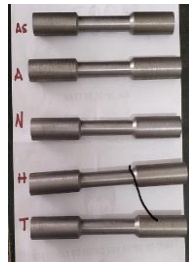


Figure 4. Specimen for tensile test



Figure 5. Specimens after tensile test



Figure 6. Hardness Samples



Figure 7. Rockwell hardness tester



Figure 8. Universal testing machine



Figure 9. Microscope for structure evaluation

measured using a Rockwell hardness testing machine that applies a specific load and measures the depth of the resulting impression on a surface. When the load is removed, the depth reading is taken. In the sample, two readings in different positions can be taken. The average of those two readings is the Rockwell hardness number (HRB). A tensile test is performed using a universal testing machine to determine the properties. The standard specimens for tensile and hardness were shown in Figures 2 and 3. The specimens before and after the tensile test were shown in Figures 4 and 5, and the hardness samples were shown in Figure 6.

Rockwell, universal machines were shown in Figures 7 and 8.

Microscopic evaluation

Proper specimen preparation is a very important aspect of conducting microstructure analysis. For easy handling first, the samples were sectioned. Later mounting can be done to protect the surface of the material. To make the surface of the material ready for polishing, a grinding operation was performed before polishing. Chemical etching is the most used method to enhance the structural features of the material. The microscope showed in Figure 9.

Table 3. Mechanical properties of as-cast and heat-treated 1040 samples

Heat treatment	Tensile Strength (MPa)	Hardness (HRB)	% Elongation	% Reduction	Youngs modulus
As cast	472.64	95	20.16	54.21	133.63
Annealed	419.26	87	22.46	63.14	482.45
Normalized	513.74	99	16.14	60.40	286.14
Hardened	611.72	107	7.12	42.12	324.42
Tempered	535.74	102	24.18	73.62	414.17

Table 4. Effect of controlled heating and cooling on structure

Heat treatment	Micro Examination
As cast	Pro eutectoid ferrite grains in the matrix of Pearlite with the prior-austenite grain boundaries.
Annealed	Coarse Ferrite and Pearlite.
Normalized	Fine Ferrite and Pearlite Structure
Hardened	Martensite, along with Retained Austenite
Tempered	Fine ferrite and pearlite

Results and Discussion

The results obtained from the tensile and hardness tests after experimentation are shown in Table 3.

From the results, the hardness of the annealed sample is less compared to the remaining samples. The hardness value is more for the hardened sample. The strength is also more for the hardened sample compared to the remaining samples. The strength is the least for the annealed sample. Below are Figures 10, 11, 12, 13, and 14. represents graphical data.

Heat treatment effect on the microstructure

The effect of heat treatment on the Microstructure of the as-cast sample and heat-treated samples are shown in Table 4.

The microstructure of various samples was shown in Figures 15, 16, 17, 18, and 19.

Nondestructive inspection technique

Ultrasonic testing is used to recognize flaws within the casting interior, such as cracks, and porosity based on the reflection of high-level frequency sound waves. The inspection process was implemented on all five samples. A cathode ray oscilloscope tracks the interval of time between the transmitted ray and the reflected ray. On the cathode ray oscilloscope screen, the sound wave travel path is plotted where it can also be determined. Ultrasonic sample inspection provided a sign confirming that no major defect indications were observed on all the samples. The ultrasonic inspection was shown in Figures 20 and 21.

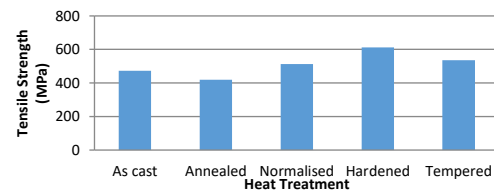
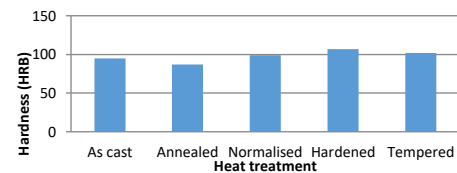
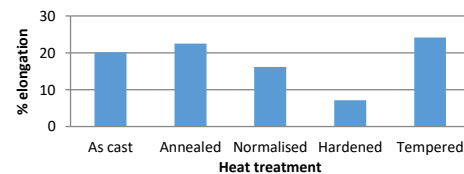
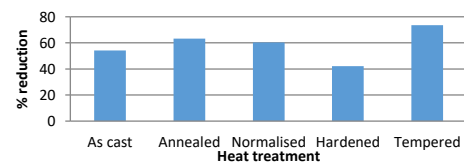
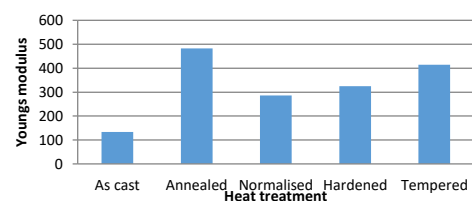
**Figure 10. Tensile Strength Vs Heat treatment****Figure 11. Hardness Vs Heat Treatment****Figure 12. % elongation Vs Heat treatment****Figure 13. % reduction Vs Heat treatment****Figure 14. Youngs Modulus Vs Heat treatment**



Figure 15. As cast structure (X100)

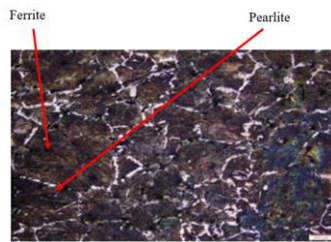


Figure 16. Annealed structure (X100)

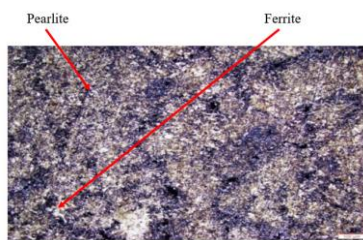


Figure 17. Normalized structure (X100)

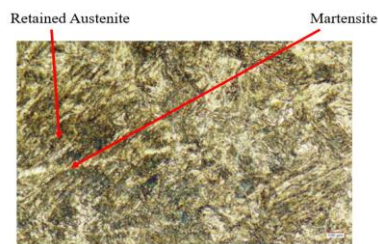


Figure 18. Hardened structure (X100)



Figure 19. Tempered Structure (X100)

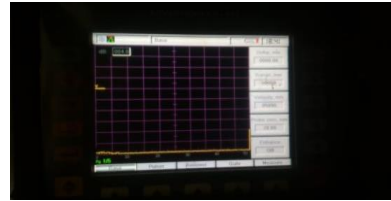


Figure 20. Ultrasonic inspection



Figure 21. Ultrasonic inspection

Conclusions

During this work, the effect of various heat treatment processes such as annealing, tempering, normalizing, and hardening to enhance mechanical properties and microstructure were investigated. Based on the results, the following conclusions were made. The annealed specimen shows lower hardness and strength compared to as-cast, hardened, normalized, and tempered specimens. The hardened specimen has more strength and hardness. Hardening is highly suggested when strength and hardness are the primary desired features of a design. In comparison to annealed samples, normalization samples have more tensile strength and hardness. In comparison to annealed samples, tempered samples have more tensile strength and hardness. Based on the study of microstructure as cast sample has Pro eutectoid ferrite grains in the matrix of Pearlite with the prior-austenite grain boundaries. compared to the annealed sample, tempered and normalized samples have Fine ferrite and Pearlite structure. From the results of the ultrasonic inspection, it was confirmed that no major defect indications were observed. From the results, it was confirmed that the improvement in properties and structural behavior could be obtained by subjecting 1040 steel to various heat treatments.

References

- Alloys Eurotherm by Schneider Electric. (2021). Retrieved 17 November 2021, from <https://www.eurotherm.com/us/metals-processing-applications-us/an-introduction-to-the-heat-treatment-of-metallic-alloys>.

- George, R.R.M., Ottoor, K., and T, G. (2018). The Effects of Heat Treatment on The Microstructure and Mechanical Properties of EN19 Steel Alloy. *International Journal of Materials Science and Engineering.*, 6(2):56-66.
- Guarino, S., and Ponticelli, G. (2017). High Power Diode Laser (HPDL) for Fatigue Life Improvement of Steel: Numerical Modelling. *Metals.*, 7(10):447. doi: 10.3390/met7100447
- Liu, X., Xiao, L., Wei, C., Xu, X., Luo, M., and Yan, W. (2018). Effect of multi-directional forging and annealing on abrasive wear behavior in a medium carbon low alloy steel. *Tribology International.*, 119:608-613. doi: 10.1016/j.triboint.2017.11.043
- Manchanda, V., and Marang, G. (1992). *Materials and metallurgy*. New Delhi: Khanna.
- MF, Hasan. (2016). Analysis of Mechanical Behavior and Microstructural Characteristics Change of ASTM A-36 Steel Applying Various Heat Treatment. *Journal Of Material Science and Engineering.*, 5(2). doi: 10.4172/2169-0022.1000227
- Nandhan, B. (2019). To study the effect of annealing, normalizing, and quenching on mechanical properties of shaft-like steel specimens. *International Journal of Engineering Science Invention Research and Development.*, 5(12).
- Principles of Heat Treating of Steels. (2021). Retrieved 16 November 2021, from <https://www.totalmateria.com/articles/Art159.htm>.
- Rahman, S., Karim, K., and Simanto, M. (2016). Effect of Heat Treatment on Low Carbon Steel: An Experimental Investigation. *Applied Mechanics And Materials.*, 860:7-12. doi: 10.4028/www.scientific.net/amm.860.7
- Sanusi, K., and Akinlabi, E. (2018). Experiment on Effect of heat treatment on mechanical and microstructure properties of AISI steel. *Materials Today: Proceedings.*, 5(9):17,996-18,001. doi: 10.1016/j.matpr.2018.06.132
- Talabi, S., Owolabi, O., Adebisi, J., and Yahaya, T. (2014). Effect of welding variables on mechanical properties of low carbon steel welded joint. *Advances In Production Engineering and Management.*, 9(4):181-186. doi: 10.14743/apem2014.4.186.