

JOURNAL OF SCIENCE



SAKARYA UNIVERSITY

Sakarya University Journal of Science

ISSN 1301-4048 | e-ISSN 2147-835X | Period Bimonthly | Founded: 1997 | Publisher Sakarya University |
<http://www.saujs.sakarya.edu.tr/en/>

Title: Effect of Different Heat Treatments on Mechanical Properties of AISI Steels

Authors: Seil EKŐI

Received: 2019-10-04 12:29:41

Accepted: 2020-02-24 12:10:22

Article Type: Research Article

Volume: 24

Issue: 3

Month: June

Year: 2020

Pages: 472-479

How to cite

Seil EKŐI; (2020), Effect of Different Heat Treatments on Mechanical Properties of AISI Steels. Sakarya University Journal of Science, 24(3), 472-479, DOI:

<https://doi.org/10.16984/saufenbilder.629371>

Access link

<http://www.saujs.sakarya.edu.tr/en/issue/52472/629371>

New submission to SAUJS

<http://dergipark.org.tr/en/journal/1115/submission/step/manuscript/new>



Effect of Different Heat Treatments on Mechanical Properties of AISI Steels

Seçil EKŞİ*¹

Abstract

Heat treatment has great importance on the mechanical properties of materials. This paper reports experiments on effects of heat treatment on the mechanical and microstructures behavior of AISI 1040 and AISI 1060 steel. To analyze the effect of different heat treatments, AISI 1040 specimens were prepared through quenching, quenching and tempering, normalizing and spheroidizing. To understand effect of tempering time/temperature and annealing time on AISI 1060 steel specimens were prepared through annealing and tempering. Tensile test and hardness test were performed on steel specimens. The mechanical properties of steel specimens were correlated with the microstructure of steels.

Keywords: heat treatment 1, mechanical properties 2, microstructures 3, hardness 4

1. INTRODUCTION

Today, steel materials with the developing technology are used widely from health to space technologies. Heat treatment of steel is becoming more and more important in its widespread use from transportation to communication, from construction to agriculture and consequently improving its mechanical and metallographic properties.

Mechanical properties of steels are depend on different physicochemical applications in steel production. It is a function of the microstructure and chemical structure formed as a result of the

processes. In order to obtain a certain condition in terms of internal structure and properties, temperature and the appropriate sequence and time is called heat treatment. In general, heat treatments can be grouped into two main groups: Annealing and hardening: Approach of the internal structure of the stable balance with annealing (cooling is done slowly). In hardening austenitic steel a semi-stable internal structure (martensite) is formed.

Many different heat treatment process can be applied to steels in order to increase tool life and reduce machining costs operations. The aim of these heat treatments is to soften the structure and increase tool life, reduce cutting forces. These

* Corresponding Author: eksi@sakarya.edu.tr

¹ Sakarya University, Mechanical Engineering Department, Sakarya, Turkey. ORCID ID: 0000-0002-1404-718X

treatments generally decrease the mechanical properties of steels.

There are many studies on heat treatment of steels [1-13]. Zhang et al. investigated the effect of tempering temperature on the microstructure properties of stainless steel. They reported that main factors affecting the strength and toughness were austenitization and large-size precipitates when the tempering temperature was above 540 °C [1]. Sanij et al. investigated the effect of double quenching and tempering with conventional quenching and tempering heat treatment processes on microstructure and mechanical behavior of hot rolled AISI 4140 steel. They showed that impact toughness of double quenching and tempering heat treated specimens is much higher than that of the conventional quenching and tempering condition [4]. Saastamoinen et al. studied on effects of chemical composition and mechanical properties on direct-quenched and tempered high-strength structural steel [5]. Jiang et al. studied on heat treatment parameters of quenched and tempered steel. They investigated microstructure and mechanical properties of a heat treated steel. They reported that the tempering temperature is a very effective factor and the quenching temperature the secondary effective factor on mechanical properties of steel [11].

In this study, tensile, hardness and microstructures properties of AISI 1040 and 1060 steels are investigated experimentally. Also, effects of the tempering time/temperature on the hardness of steels were studied.

2. EXPERIMENTAL STUDY

AISI 1040 steel and AISI 1060 steel were used in experiments. Steel specimen were prepared for tensile testing, hardness measurement and microstructure imaging.

2.1. Preparation of Specimen

Tensile specimens were prepared according to the ASTM E-8 standard. View of geometry of tensile

test specimen and tensile/hardness/microstructure specimens were given in Figure 1. Three specimens were prepared for each configuration.

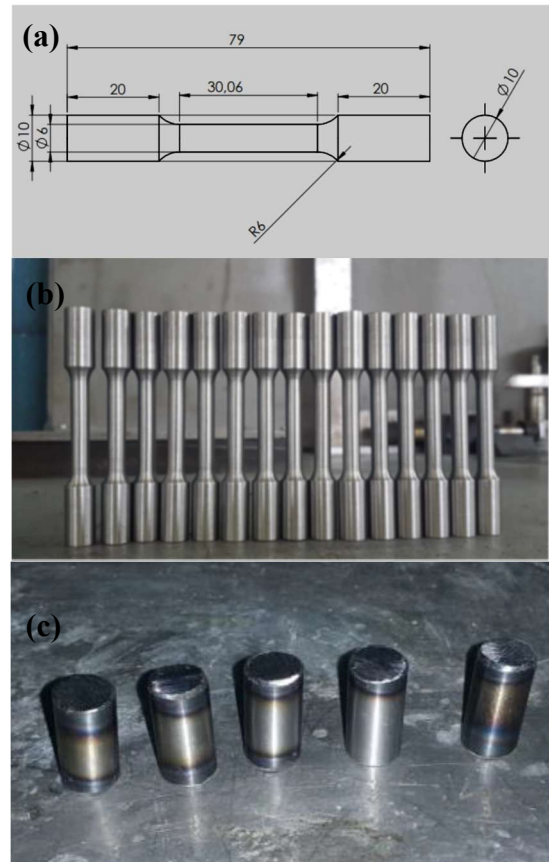


Figure 1. a) Geometric properties of tensile specimen, b) Tensile test specimen, c) Hardness and microstructure test specimen

2.2. Heat Treatment

Heat treatment process was carried out with Protherm furnace with 1200°C capacity. Heat treatment plan of AISI 1040 steel specimens was given in Table 1.

Table 1. Plan of heat treatment

Heat treatment	Non-treated	Quenching	Quenching+tempering	Normalizing	Spheroidizing
Process	As received	Annealing at 900°C for 1 hour	Annealing at 900°C for 1 hour	Annealing at 950°C for 1 hour	Annealing at 700°C
		Quenching in water	Quenching in water Tempering 400°C for 1 hour	Cool in air	Cool in furnace

Heat treatment plan of AISI 1060 steel specimens was given in Table 2.

Table 2. Plan of heat treatment

Group no	Annealing temperature [°C]	Annealing time [hour]	Tempering temperature [°C]	Tempering time [hour]
1	-	-	-	-
2	900	1	300	1
		1	400	1
		1	500	1
		1	600	1
3	900	1	500	2
		1	500	4
		1	500	6
4	900	2	500	1
		4	500	1
		6	500	1

2.3. Tensile test

The tensile testing of the steels specimen was carried out by using Zwick universal testing machine with 3000 kg capacity until the specimen broke. Tensile speed was 3 MPa/s. View of tensile test machine was given Figure 2.

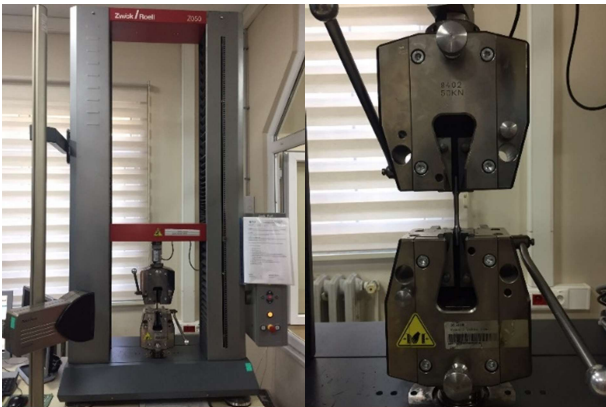


Figure 2. Tensile test machine

2.4. Hardness Measurements

Hardness measurement was carried out by LEICA VMHT MOT micro hardness device.

2.5. Microstructure Analyses

The polished specimens were etched with nital and microstructures were examined respectively.

Microstructure analyses were performed with Olympus optical microscope.

3. EXPERIMENTAL RESULTS

3.1. Experimental results of AISI 1040 steel

3.1.1. Microstructures

The microstructures of the non-treated specimen are shown in Figure 3.

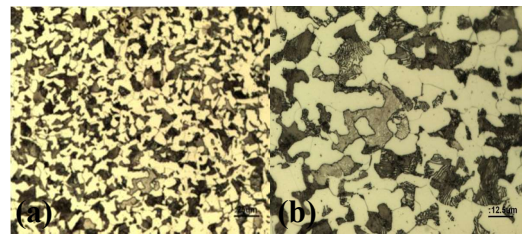


Figure 3. Microstructure of non-treated specimen a) 20X, b) 50X

The structure was consist of ferrite grains and perlite grains (ferrite phase and cementite phase composition).

The microstructures of the quenching specimen under the microscope are given in Figure 4.

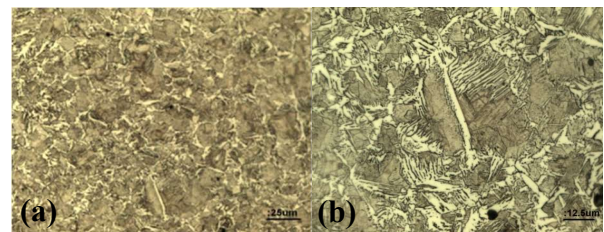


Figure 4. Microstructure of quenching specimen a) 20X, b) 50X

The structure is martensite. White areas show residual austenite. It is very hard and fragile due to high internal stresses. It cannot be used in this way, tempering must be applied.

The microstructures of the quenching + tempering specimen under the microscope are given in Figure 5.

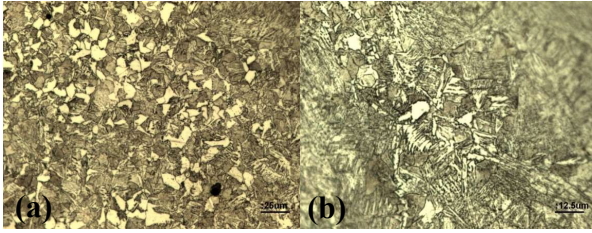


Figure 5. Microstructure of quenching + tempering specimen a) 20X, b) 50X

It is in austenite structure at 900°C and then it is brought to 400°C and the residual austenite is seen besides ferrite and perlite phases.

The microstructures of the spheroidizing specimen under the microscope are given in Figure 6.

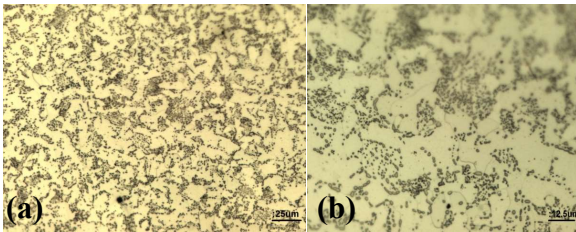


Figure 6. Microstructure of spheroidizing specimen a) 20X, b) 50X

Due to the annealing at 700 degrees, microstructure of steel has a ferrite and cementite phase. Since the steel specimen was cooled in a furnace for a long time, it was seen that the cementite particles turned into a spherical structure after annealing process. The microstructures of the normalization specimen under the microscope are given in Figure 7.

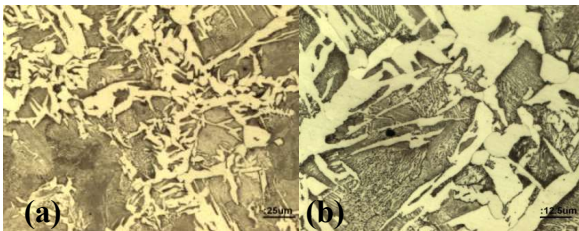


Figure 7. Microstructure of normalizing specimen a) 20X, b) 50X

Microstructure of the normalized specimen is also made up fine grained ferrite and pearlite.

3.1.2. Hardness results

The hardness of each heat treated specimens were measured 3 times in three different area of specimen and average values is given in Table 3.

Table 3. Hardness results

Heat Treatment	Hardness (HV)
Non-treated	224
Quenching	276
Quenching+ Tempering	258
Spheroidizing	163
Normalization	192

According to these results, the specimen with the highest Vickers hardness value is the non-treated specimen with 258 HV value, and the least specimen is the spheroidizing specimen with 163 HV value. The specimen with the highest hardness value from the heat treated specimens is the quenching specimen. The reason for this is that the quenching process is a type of heat treatment performed to make the steel materials more durable. The cooling rate required for this process depends on the specimen size, the tendency to harden and the quenching medium. However, the cooling rate should not be higher than necessary in order to prevent distortion, cracking and even breakage of the part. As mentioned earlier, a higher cooling rate than necessary causes cracks or distortions within the part, resulting in abnormal transformation stresses, and thus deforms by exhibiting lower strength due to internal stresses.

3.1.3. Tensile test results

Stress-strain curves obtained from tension tests are given Figure 8.

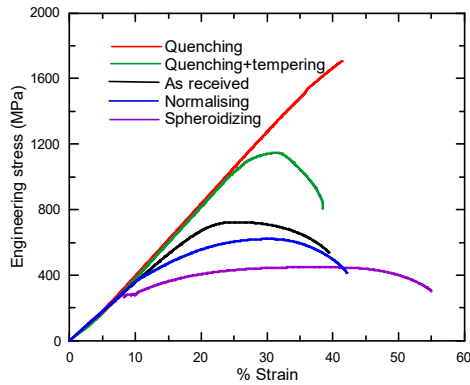


Figure 8. Stress-strain curves of tensile specimens

The highest strength was obtained in the quenched specimen. Although tensile strength is around 1700 MPa, it does not have much ductility due to its brittle fracture. The quenched specimen was brittle fractured. Tensile strength is 1100 MPa in tempered specimen after the quenched. The ductility and toughness values are high. Quenched and tempered specimen showed normal ductile breakage. After the normalization heat treatment of specimen, tensile strength increased up to 600 MPa and ductility values increased further. The specimen subjected to normalization heat treatment showed ductile fracture between spheroidizing and quenching + tempering. Tensile strength decreased and elongation values increased in spheroidizing process specimen greatly. The specimen subjected to spheroidizing heat treatment was broken with high ductility. There are many studies in the literature that support these results [2-5]. The strength of materials decreased after full annealing heat treatment due to a decrease in dislocation density [3]. Double quenching and tempering process provided significant improvement of 23% in impact toughness as compared to the conventional quenching and tempering condition [4].

The damage images of the specimens after the experiment are shown in the Figure 9.

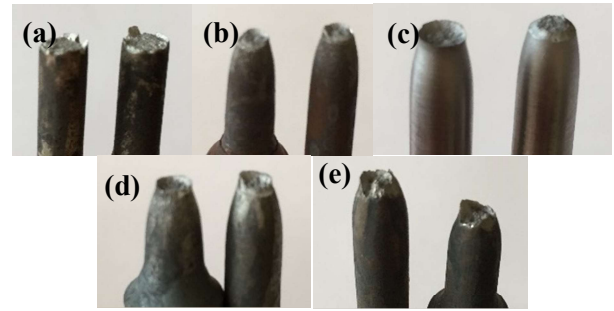


Figure 9. Specimens views after the tension tests a) quenching, b) quenching +tempering, c) as received, d) normalizing, e) spheroidizing

3.2. Experimental results of AISI 1060 steel

The effects of time and temperature parameters on the microstructure and hardness of tempering processes on AISI 1060 were given in this part. Test plan had given in Table 2. 3 different groups of experiments were planned.

Table 4. The hardness values of the specimens which were tempered at 500°C for 1 hour

Annealing time (h) at 900°C	Hardness (HV)
2	390
4	388
6	376

3.2.1. Hardness results

The hardness values of the specimens which were annealed at 900°C for 2, 4, 6 hours and tempered at 500°C for 1 hour are given in Table 4. Views of microstructure was given Figure 10.

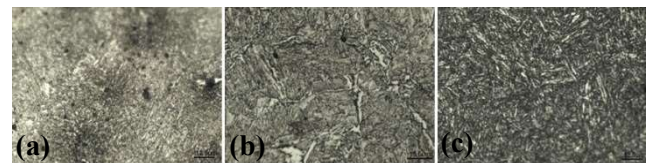


Figure 10. Views of the specimens which were annealed at 900°C for 2 (a), 4 (b), 6 (c) hours and tempered at 500°C for 1 hour

Hardness values decreased slightly with increasing annealing time.

The hardness values of the specimens which were annealed at 900°C for 1 hour and tempered at 500°C for 2, 4, 6 hours are given in Table 5. Views of microstructure was given Figure 11.

Table 5. The hardness values of the specimens which were annealed at 900°C for 1 hour

Tempering time (h) at 500°C	Hardness (HV)
2	354
4	350
6	295

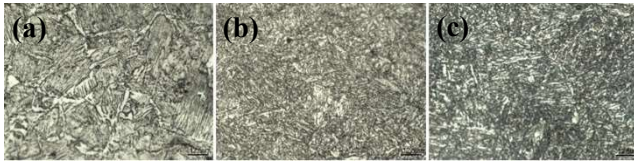


Figure 11. Views of the specimens which were annealed at 900°C for 1 hour and tempered at 500°C for 2 (a), 4 (b), 6 (c) hours

It was observed that hardness values decreased with increasing time of tempering process at same temperature.

The hardness values of the specimens which were annealed at 900°C for 1 hour and tempered at 25°C, 300°C, 400°C, 500°C, 600°C for 1 hour are given in Table 6. Views of microstructure was given Figure 12.

Table 6. The hardness values of the specimens which were annealed at 900°C for 1 hour and tempered for 1 hour

Tempering temperature (°C)	Hardness (HV)
25	728
300	669
400	527
500	480
600	483

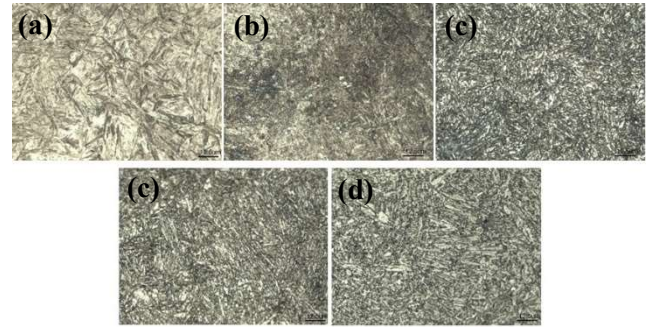


Figure 12. Views of the specimens which were annealed at 900°C for 1 hour and tempered at 25°C, 300°C, 400°C, 500°C, 600°C for 1 hour

When the microstructures were examined, it was observed that the martensitic structures formed during annealing decreased.

After 1 hour annealing at 900 °C and tempering at 500 °C for 2, 4 and 6 hours it was observed that hardness decreased with increasing tempering temperatures. Long-tempered steels have been found to have less hardness values than non-treated steels. It has been observed that the martensitic structures in the microstructures are further reduced. After 2, 4, 6 hours annealing at 900 °C and 1 hour tempering at 500 °C, hardness was examined and it was seen that there was no effective change with the duration of annealing process. Hardness values were close to each other. A significant decrease in hardness values was observed with increasing tempering temperature. Thereafter, effect of the tempering temperature after quenching process on the hardness value is very important. Similar studies have been conducted in the literature. It supported this in the studies conducted in the literature. Increasing in tempering temperature decrease the mechanical properties of materials [1,6-9]. Tempering time and annealing time have little effect on hardness.

4. CONCLUSION

In this study, effects of heat treatment on the mechanical and microstructures behavior of AISI 1040 and AISI 1060 steel were investigated experimentally. When the above results were

taken into consideration, this study primarily yielded the following conclusions:

- Hardness of 1040 steel specimens was increased only in the quenched specimen according to the non-treated state and a decrease was observed in the others.
- Highest strength and toughness values were achieved in quenched and quenched + tempered samples, respectively.
- The effect of tempering time of 1060 steel on the hardness values was found to be very small. The main important parameter was found to be tempering temperature.
- It has been found that the effect of the annealing time and tempering time in the austenite zone on the hardness is very low.

REFERENCES

- [1] Y. Zhang, D. Zhan, X. Qi , Z. Jiang, “Effect of tempering temperature on the microstructure and properties of ultrahigh-strength stainless steel,” *Journal of Materials Science and Technology*, vol.35, pp. 1240–1249, 2019.
- [2] S. Ebner, C. Suppan, R. Schnitzer, C. Hofer, “Microstructure and mechanical properties of a low C steel subjected to bainitic or quenching and partitioning heat treatments,” *Materials Science & Engineering A*, vol. 735, pp. 1–9, 2018.
- [3] D. Kong, C. Dong, X. Ni, L. Zhang , J. Yao, C. Man, X. Cheng, K. Xiao, X. Li, “Mechanical properties and corrosion behavior of selective laser melted 316L stainless steel after different heat treatment processes,” *Journal of Materials Science & Technology*, vol. 35, pp. 1499–1507, 2019.
- [4] M.H. K. Sanij, S.S. G. Banadkouki, A.R. Mashreghi, M. Moshrefifar, “The effect of single and double quenching and tempering heat treatments on the microstructure and mechanical properties of AISI 4140 steel,” *Materials and Design*, vol. 42, pp. 339–346, 2012.
- [5] A. Saastamoinen, A. Kaijalainen, T. T. Nyo, P. Suikkanen, D. Porter , J. Kömi, “Direct-quenched and tempered low-C high-strength structural steel: The role of chemical composition on microstructure and mechanical properties,” *Materials Science & Engineering A*, vol. 760, pp. 346–358, 2019.
- [6] L. Xu, L. Chen, W. Sun, “Effects of soaking and tempering temperature on microstructure and mechanical properties of 65Si2MnWE spring steel,” *Vacuum*, vol. 154, pp. 322–332, 2018.
- [7] K. Chen, Z. Jiang , F. Liu, J. Yu, Y. Li, W. Gong, C. Chen, “Effect of quenching and tempering temperature on microstructure and tensile properties of microalloyed ultra-high strength suspension spring steel,” *Materials Science and Engineering: A*, vol. 766, pp.1–11 2019.
- [8] A. Saastamoinen, A. Kaijalainen , J. Heikkal, D. Porter , P. Suikkanen, “The effect of tempering temperature on microstructure, mechanical properties and bendability of direct-quenched low-alloy strip steel,” *Materials Science and Engineering: A*, vol. 730, pp. 284–294, 2018.
- [9] F. Liu, X. Lin, M. Song, H. Yang, K. Song, P. Guo, W. Huang, “Effect of tempering temperature on microstructure and mechanical properties of laser solid formed 300M steel,” *Journal of Alloys and Compounds*, vol. 689, pp. 225–232, 2016.
- [10] S. Wang, H. Yu, H. Gu, T. Zhou, L. Wang, “Effect of trace ferrite on mechanical properties of a tempered HSLA steel.” *Materials Science and Engineering: A*, vol. 744, pp. 299–304, 2019.

- [11] B. Jiang, M. Wu, M. Zhang, F. Zhao, Z. Zhao, Y. Liu, “Microstructural characterization, strengthening and toughening mechanisms of a quenched and tempered steel: Effect of heat treatment parameters,” *Materials Science and Engineering: A*, vol. 707, pp. 306–314, 2017.