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Temperleme Isıl İşlem Sıcaklıklarının AISI 1020 ve AISI 1040 Karbon Çeliklerin Mekanik Özellikleri Üzerine Etkileri

Nursel ALTAN ÖZBEK[*,a], Erdem SARAÇ[b]

[a,*] *Duzce University Cumayeri Vocational School of Higher Education, 81700, Düzce, Türkiye.*
[b] *Duzce University Institute of Science, Mechanical Engineering, 81620, Düzce, Türkiye.*

MAKALE BİLGİSİ

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ÖZ

Bu çalışmada, temperleme ısıl işlem sıcaklıklarının endüstride geniş bir kullanım alanına sahip olan AISI 1020 ve 1040 karbon çeliklerin mekanik özellikleri üzerine etkileri araştırılmıştır. Numuneler 850 °C'de su verme işleminin ardından 450, 550 ve 650 ° C olmak üzere üç farklı sıcaklıkta 1 saat süre ile temperlenmiştir. Numunelerin mekanik özelliklerini belirlemek için sertlik ölçümleri, çekme ve çentik darbe testleri yapılmıştır. Ayrıca numuneler mikroyapısal olarak da incelenmiştir. Sonuçlar, su verme işleminden sonra temperleme ısıl işlemi uygulandığında her iki numunenin sertlik, çekme dayanımı ve akma dayanımı değerlerinin düştüğünü ortaya koymaktadır. Temperleme sıcaklığı arttıkça, bu değerler düşme eğiliminde olmuştur. Ancak, temperleme ısıl işlemi ve artan temperleme sıcaklığı ile darbe değerleri artmıştır.

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Effects of Tempering Heat Treatment Temperatures on Mechanical Properties of AISI 1020 and AISI 1040 Carbon Steels

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ABSTRACT

In the present study, the effects of tempering heat treatment temperatures on the mechanical properties of AISI 1020 and 1040 carbon steel types, which have a wide range of use in industry, were investigated. The samples were quenched at 850 °C, and then they were tempered at three different temperatures; 450, 550, and 650 °C, for 1 hour. Hardness measurements of the samples were performed to determine their mechanical properties. Besides, the samples were subjected to tensile and charpy impact tests. The samples were examined microstructurally, as well. The results reveal that the hardness, tensile strength, and yield strength values of both samples decreased when tempering heat treatment was applied after quenching. As the tempering temperature increased, these values tended to decrease. However, the impact value increased with the tempering heat treatment and increasing tempering temperature

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1. INTRODUCTION *(GİRİŞ)*

Carbon steel is one of the most widely used materials in the industry, an iron-carbon alloy with up to 2.1% wt.% carbon in its composition. This steel can be divided into three categories based on its carbon content, namely low carbon steel, medium carbon steel, and high carbon steel. The mechanical properties of carbon steels are improved via heat treatment involving austenitizing followed by quenching and tempering, giving them a martensitic microstructure. In general, heat treatment is defined as controlled heating and cooling processes applied to steel to impart desired properties. Heat treatments

*****Sorumlu yazar**: nurselaltan@duzce.edu.tr

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applied to the steel are related to the transformation of its microstructure. The compositions and structures of the products the conversion affect the mechanical properties of the steel directly. Numerous thermal methods have been developed. The use of these methods depends on the type of steel and the expected properties such as hardness, strength, toughness, abrasion resistance. One of these heat treatment methods is tempering. In tempering, the material is heated to a temperature below the austenitization temperature. Tempering temperature varies according to the type of steel. At the end of the process, the hardness of the steel having a taut structure decreases, and the toughness increases due to the decrease in the tension level [1, 2].

Verma and Singh [3], conducted a study investigating the effects of heat treatment on the mechanical properties of AISI 1040 steel. For this purpose, after being kept at 900 °C for 120 minutes, tempering was applied to water-hardened AISI 1040 steel at 250, 450, and 650 °C, for 60, 90, and 120 minutes. Besides, the hardness measurements of the samples were performed. Also, tensile strength, yield strength, and elongation values were obtained by tensile testing. As a result, the highest hardness, tensile strength, and yield strength values were obtained at the lowest temperature of 250 °C in 60 minutes. These values decreased with increasing tempering temperature and holding time. To determine the effects of tempering on microstructural features and mechanical properties. Çaligulu et al. [4] cooled 38MnS6 and 41CrMo4 steel materials in oil after annealing them at 900 °C for 1 hour and then tempered these materials at 300 °C, 400 °C, and 500 °C. The results revealed that the transformation from martensitic to bainitic structure depended on the tempering temperature of the steels. It was also observed that hardness values decreased according to the tempering temperature. Rahman et al. [5] conducted a study to determine the effects of heat treatment on the hardness and microstructural properties of low carbon AISI 1020 steel. For this purpose, the samples were heated in a heat treatment furnace at 950 °C for 2 hours and then cooled in different environments (water, air, ash). The highest hardness increase (302%) was obtained by cooling in water and the lowest hardness increase (21%) by ash cooling. The austenite phase in ash cooling turned into ferrite and perlite. A small amount of ferrite and cementite phases occurred during air cooling. In water hardening, the austenite phase was converted to a stable martensite phase. Guler and Ozcan [6] examined the effects on the strength of high carbon steel materials by quenching. The materials were heated in the oven at 700, 750, 800, 850, and 900 °C, for 30 minutes, and then taken out of the oven and cooled in water. The results of tensile tests and hardness measurements revealed that the materials became brittle and quenched. Koksal et al. [7] a tempered variety of carbon steels (Ç1020, Ç1030, Ç1040, and Ç1050) at 100, 200, 400, and 600 °C after quenching and investigated the changes in their mechanical properties. F-Δl curves were obtained by applying the tensile test to the steels whose carbon contents were 0.20 - 0.50% by weight. Strength coefficients (K), deformation hardening exponent (n), yield (Re), and tensile strength (Rm) values were found by using curves.

The increase in carbon content increased yield and tensile strength values. It was found out that the strength coefficient (K) and deformation hardening base (n) decreased significantly with increasing quenching temperature. Especially, the yield and tensile strength of C1040 and C1050 steels significantly decreased. Lee et al. [8] investigated the mechanical properties and microstructural features of AISI 4340, under different tempering processes. The samples were first austenitized (annealed) at 850 °C for 30 minutes and then cooled in oil. They were then heated at 100, 200, 250, 300, 400, 500, and 650 °C for 2 and 48 hours, respectively, and subjected to a dynamic fracture test. Fractography of the specimens was also made to analyze their fracture and embrittlement mechanisms. The results showed that the mechanical and microstructural properties of the samples were significantly affected by temperature and duration of tempering. The hardness and strength of the tempered martensite decrease with increasing temperature and time. Saraç and Ozbek [9] investigated the effects of tempering heat treatment temperature on the mechanical properties of AISI 4140 steel after quenching. The samples were quenched and then tempered for 1 hour at four different temperatures: 300, 450, 550, and 650 °C. Hardness measurements of the samples were performed to determine their mechanical properties. Besides, samples were subjected to tensile and impact tests. The hardness reached its maximum at 300 °C, the lowest tempering temperature. The highest tensile strength and yield strength values were also obtained at this temperature. With increasing tempering temperature, the tensile and yield strength values of the samples decreased.

In the current study, the effects of tempering applied at different temperatures (450, 550, and 650 °C) on the mechanical properties of AISI 1020 and AISI 1040 carbon steel were investigated after quenching. The tensile and yield strength, elongation, and impact energy of the samples were investigated by performing the tensile and notch impact test. With the microstructure photographs of the samples, the effects of tempering temperatures were analyzed.

2. EXPERIMENTAL METHODS (*DENEYSEL YÖNTEMLER*)

The chemical components of the carbon steels used in the study as a result of spectral analysis are shown in Table 1. Steel samples were subjected to quenching at 880 °C. Then, the tempering process was applied at 450, 550, and 650 °C, for 1 hour. Hardness measurements of the samples were performed on the METKON DUROLINE-M device.

In the measurements, 1000 grams of the load was applied for 10 seconds. The samples were subjected to the 200 tons capacity Zwick Z2000H model servohydraulic pulling device tensile tests (Figure 1). Charpy impact tests were performed via Zwick-rkp 450 Model (Figure 2). For each measurement value, 3 samples were tested and their average values were taken.

Table 1. Chemical components of test samples *(Deney numunelernin kimyasal bileşimleri)*

Element (%)	C	Mn	Si	Cr	Ni	Mo	P	S
AISI 1020	0.22	0.52	0.15	0.01	0.01	0.05	0.01	0.01
AISI 1040	0.42	0.60	0.31	0.13	0.08	0.01	0.02	0.01

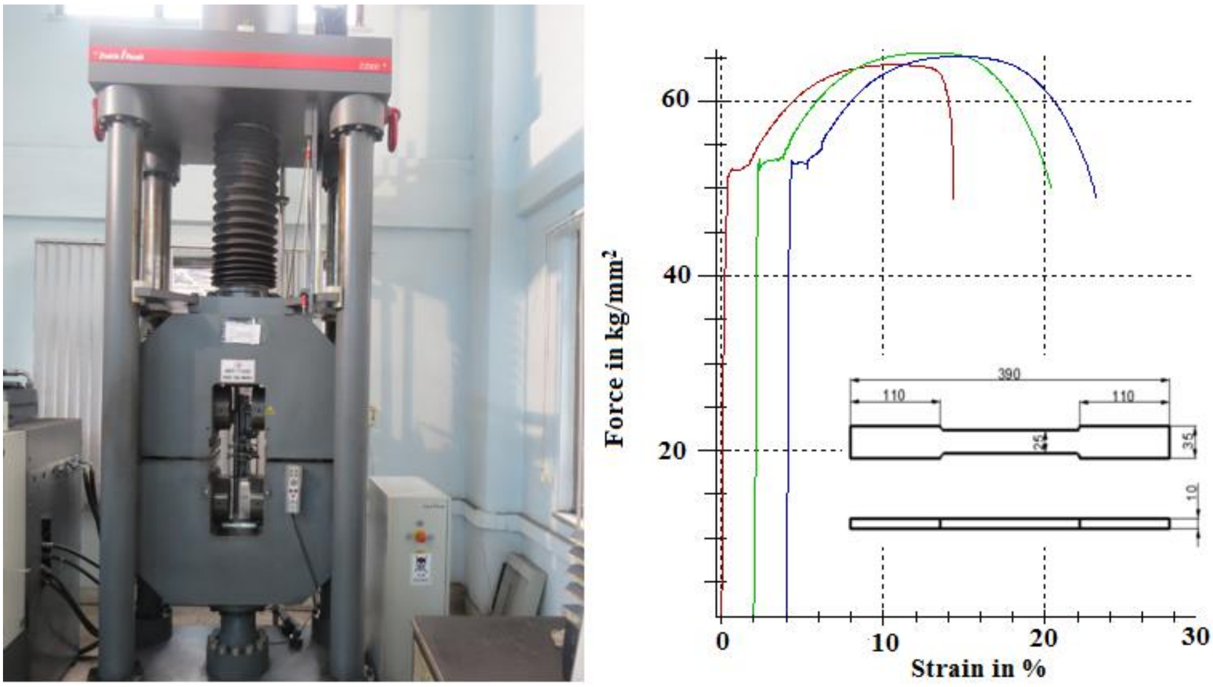

Figure 1. Tensile testing machine and test sample *(Çekme deney cihazı ve deney numunesi)*

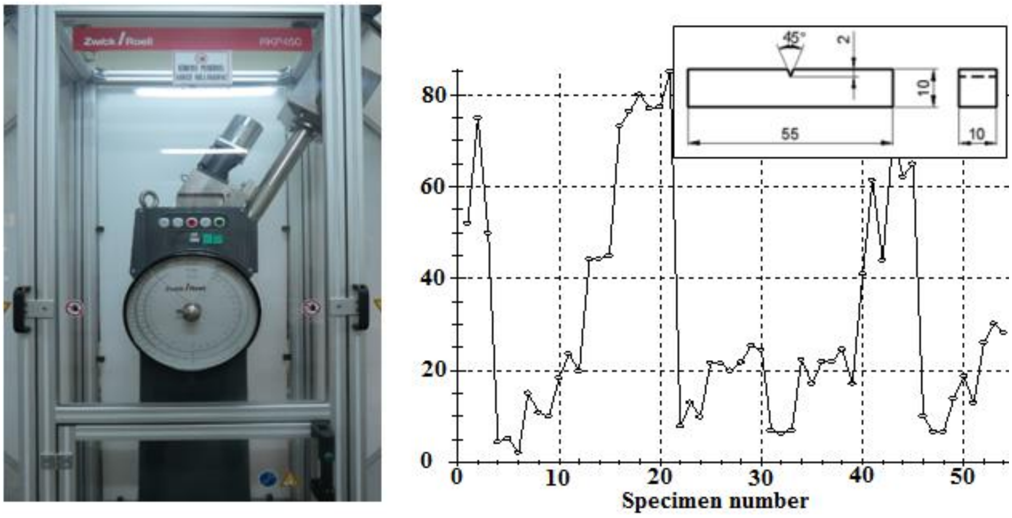

Figure 2. Charpy impact tester and test sample *(Çentik darbe deney cihazı ve deney numunesi)*

3. RESULTS AND DISCUSSION (*SONUÇLAR VE TARTIŞMA*)

3.1. Microstructure (*Mikroyapı*)

Figures 3 and 4 show microstructure photographs of AISI 1020 steel samples taken at 200X and 500X magnification. The photographs show bainite, residual austenite, ferrite, and martensite structures. After quenching, it was seen that the martensite structure is dense in the samples. This structure is very hard and fragile because of its high internal stresses. With the tempering heat treatment applied at 450 °C, it was seen that the martensite structure of these partially decreased. At 550 °C tempering temperature, it was seen that the martensite structure decreases and there is an increase in the bainite and pearlite structures. When tempered at 650 °C, it was seen that the martensite structure is very low, and the structure of bainite and perlite is very high.

Figures 5 and 6 show microstructure photographs of AISI 1040 steel samples taken at 200X and 500X magnification. While the martensite structure, which is denser after quenching, decreased after the tempering process, the ferrite and carbide increased. Besides, increasing tempering temperature leads to a decrease in martensite structure but an increase in ferrite and spheroidal carbides.

3.2. Hardness (*Sertlik*)

The hardness measurement results of the samples can be seen in Fig 7. Microhardness and macro hardness measurements were found to be compatible with each other. Between the two types of material, AISI 1040 material revealed higher hardness values under all heat treatment conditions. This is due to the differences in chemical compositions of the two steel types. In general, as the carbon content increases, the hardness of the steel increases [10]; whereas, the fracture toughness decreases. On the other hand, Cr in the chemical composition of AISI 1040 steel increases wear resistance, hardenability, resistance to oxidation, and corrosion in steel [10]. It is also considered to be the result of differences in Si levels between these two materials. Si dissolves in iron and tends to strengthen it [10].

For both types of material (AISI 1020 and AISI 1040), the highest hardness values were measured in the quenched samples. The hardness of the samples decreased with the increasing tempering temperature. While the AISI 1020 material had a microhardness level of 360.533 after quenching, the microhardness of the sample decreased by 25% with the tempering heat treatment applied at 450 °C, and by 40% with the tempering heat treatment applied at 650 °C.

For AISI 1040 material, the microhardness value was found to be 637.433 after quenching, but it decreased by 43% and 54% at 450 °C and 650 °C respectively. Similarly, when tempering was applied at 650 °C after quenching, macro hardness values of AISI 1040 and AISI 1020 materials decreased by 46% (from 56.766 HRC to 30.8 HRC) and 51% (from 38.333 HRC to 18.733 HRC) respectively. It can be concluded that increasing the tempering temperature results in lower work hardening capacity [11]. The martensite structure, which has a hard structure at low tempering temperature, decreased with the increasing tempering temperature, and the bainite and pearlite structure, which have a softer structure, increased.

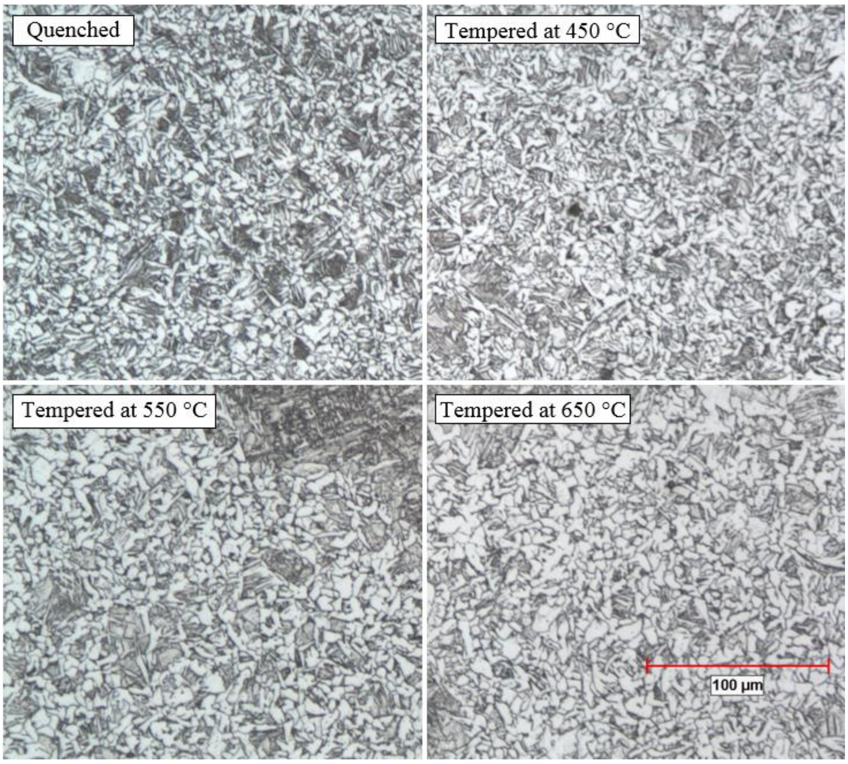

Figure 3. The microstructure of AISI 1020 steel (200X magnification) *(AISI 1020 çeliğinin mikroyapısı (200X büyütme))*

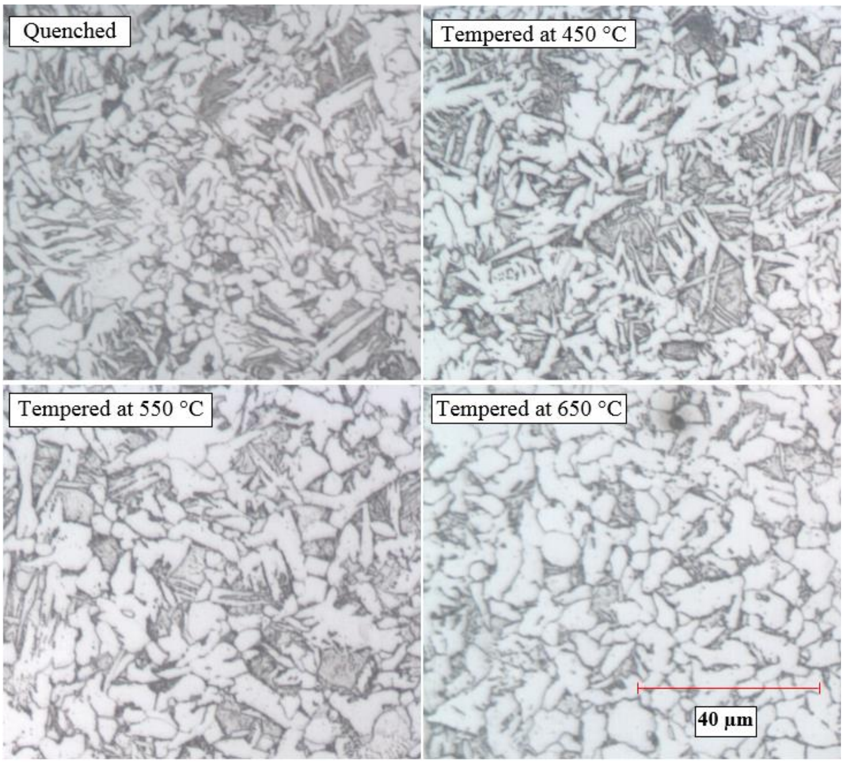

Figure 4. The microstructure of AISI 1020 steel (500X magnification) *(AISI 1020 çeliğinin mikroyapısı (500X büyütme))*

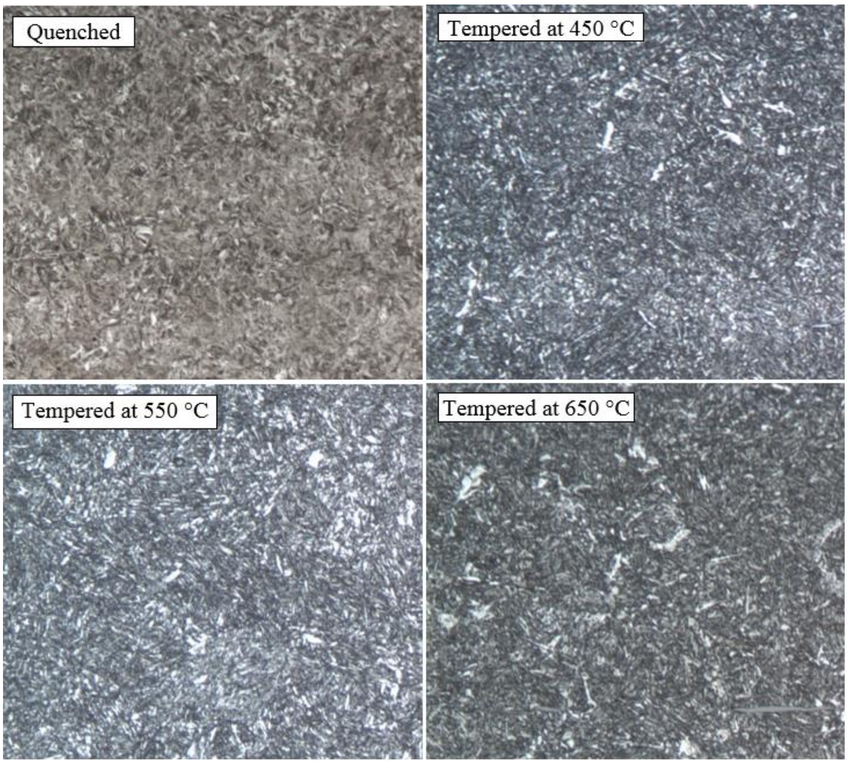

Figure 5. The microstructure of AISI 1040 steel (200X magnification) *(AISI 1040 çeliğinin mikroyapısı (200X büyütme))*

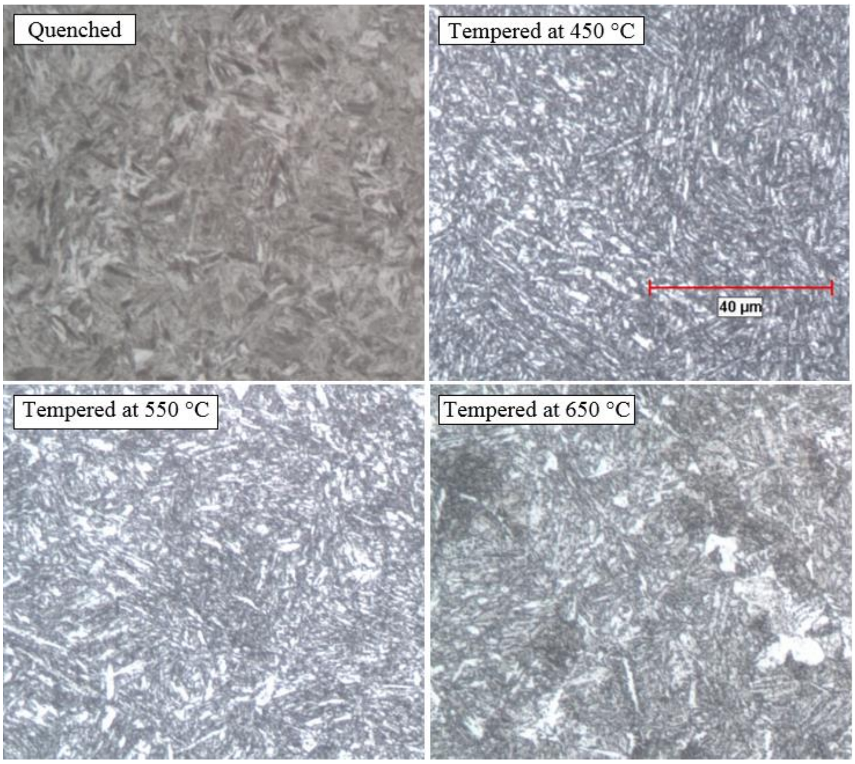

Figure 6. The microstructure of AISI 1040 steel (500X magnification) *(AISI 1040 çeliğinin mikroyapısı (500X büyütme))*

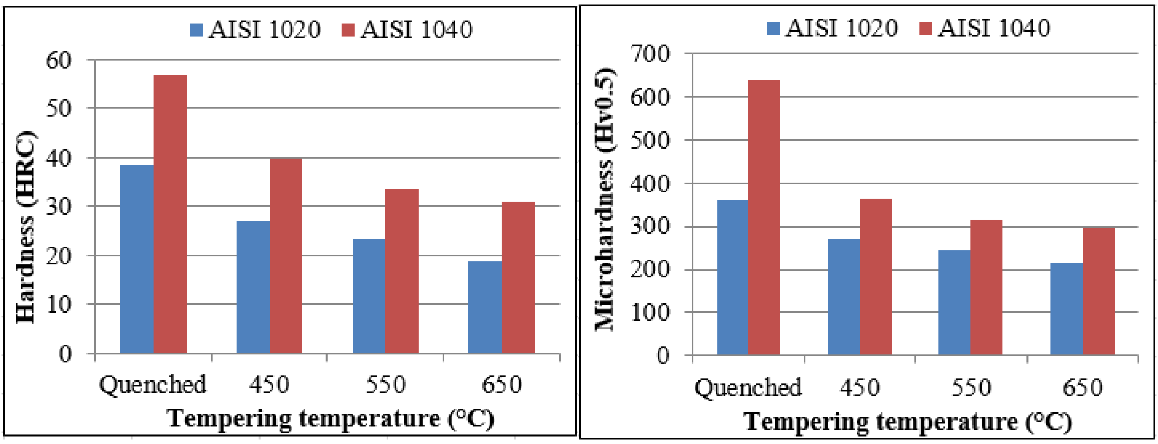

Figure 7. Hardness test results *(Sertlik deneyi sonuçları)*

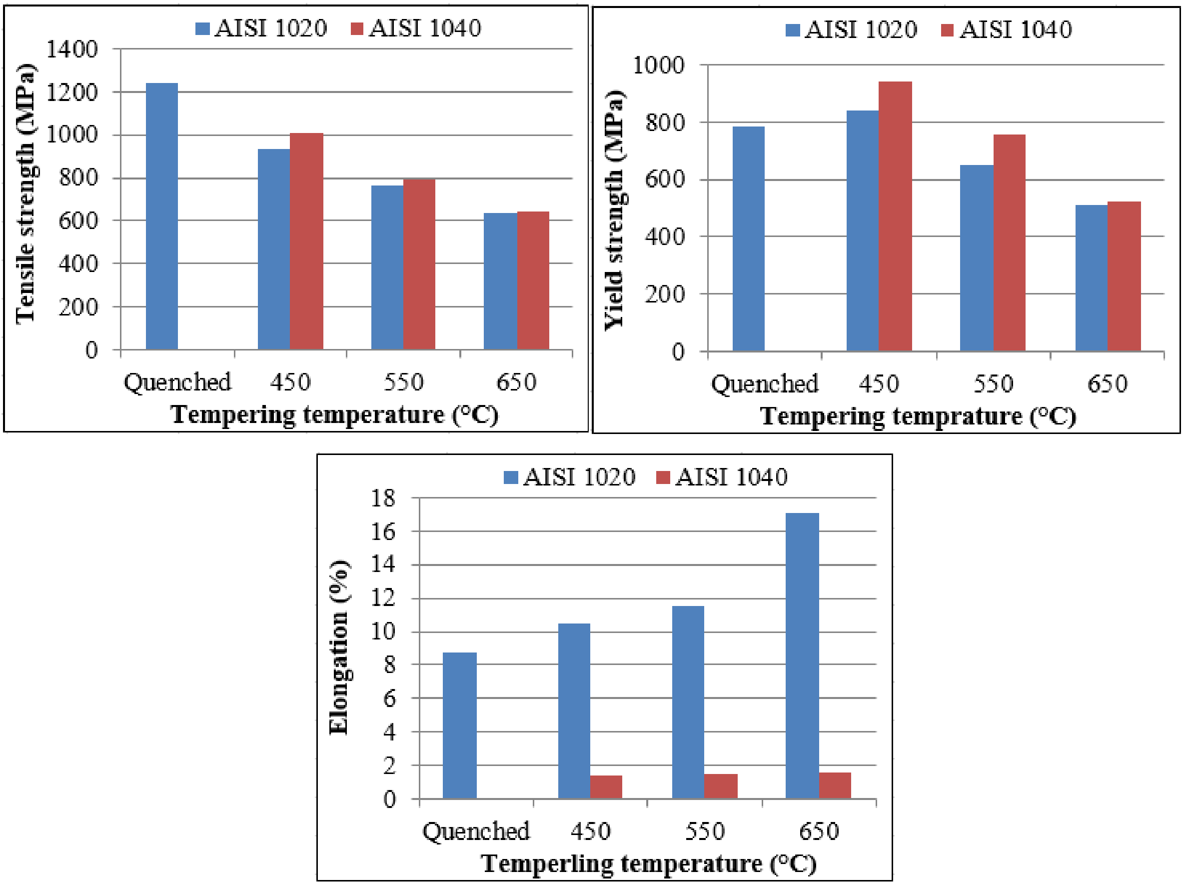

Figure 8. Tensile test results *(Çekme deneyi sonuçları)*

3.3. Tensile Test (*Çekme Deneyi*)

The results of the tensile test are presented in Fig. 8. While the tensile test was carried out as usual in the quenched sample of AISI 1020 material, the quenched sample of AISI 1040 material behaved in a brittle manner and was directly broken. For this reason, the yield and tensile strength could not be measured. This may be associated with the brittle material after the quenching process and the excess residual stresses. In general, yield strength and tensile strength values of AISI 1040 material are higher than AISI 1020 material. As mentioned earlier, this can be attributed to the greater presence of elements such as C, Cr, and Si in the chemical composition of AISI 1040 material. Thanks to these elements, AISI 1040 material has a higher hardenability and strength than AISI 1020 material. For this reason, the elongation at break values of AISI 1020 material were found to be higher.

As can be seen in Fig. 8, the yield strength and tensile strength decrease with increased tempering temperature. When the differences between yield strength and tensile strength are considered as a measure of the work hardening rate, it can be concluded that increasing tempering temperature results in lower work hardening capacity.

As shown in the elongation change graph, the elongation value of AISI 1040 steel is much lower than that of AISI 1020 steel under all heat treatment conditions. For both types of materials, elongation values increased with the tempering process and increasing tempering temperature. This implies that the ductility increases. As the tempering temperature increased, the material became more ductile, and thus, the hardness value decreased.

3.4. Charpy Impact Test (*Çentik Darbe Deneyi*)

There is a certain relationship between the impact energy and ductility of the materials. The impact energies of non-ductile materials are also low. Fig 9 shows the impact energy values of the samples. The impact energy of AISI 1040 material is much lower than that of AISI 1020 material. This difference between the two materials is 93%, 79%, 77%, and 75% respectively in the quenched samples, tempered at 450 °C, 550 °C, and 650 °C, respectively. This is attributed to the difference in the amount of C between the two steel types. Increasing the amount of C increases the iron carbide (cementite/Fe_3C) ratio. The strength increases since iron carbide is a hardening phase. However, ferrite-cementite interfaces are ideal interfaces for crack nucleation. Therefore, with the increase of iron carbide ratio, the strength increases but the fracture toughness and elongation decrease.

While the lowest impact energy value for both types of materials was found to be in the samples that were given water, the impact energy values increased significantly together with the tempering heat treatment. Impact energy values also increased with an increase in tempering temperature from 450 °C to 650 °C. The impact energy value of AISI 1020 material, which was 58.95 J after quenching, increased by 127% and reached 133.85 J when tempered at 450 °C. This value increased by 17.9% at the tempering temperature of 550 °C, and 21.6% at 650 °C. Similarly, in AISI 1040 material, when tempering heat treatment was applied at 450 °C, 550 °C, and 650 °C, the impact energy value increased by 603%, 30.7%, and 30.4%, respectively. What is crucial here is that the impact energy is very low in the quenched sample of the AISI 1040 material, and the impact energy shows a very high increase with the first tempering process.

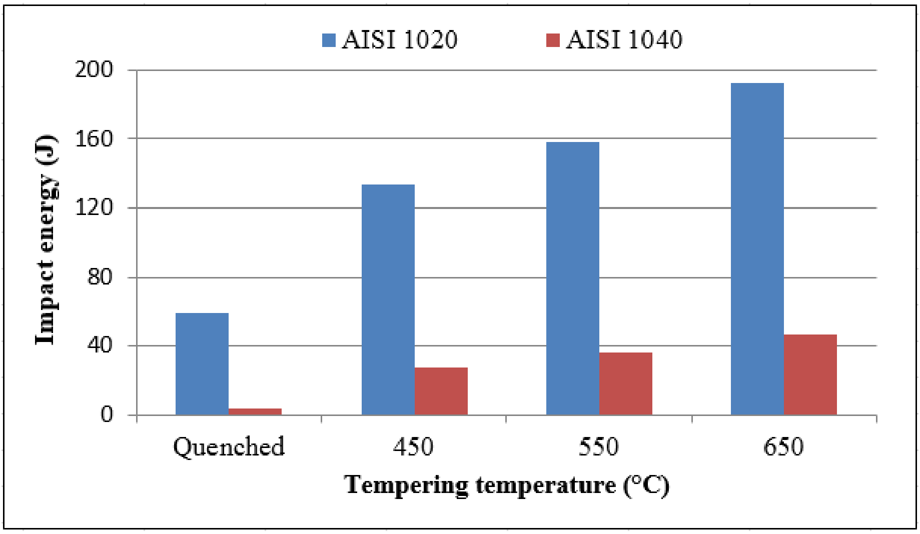

Figure 9. Impact test results *(Darbe debneyi sonuçları)*

4. CONCLUSIONS (*SONUÇLAR*)

In this study, after the quenching process of AISI 1020 and AISI 1040 steel types, the tempering process was applied at three different temperatures: 450, 550, and 650 °C, and the effects of the heat treatments on the mechanical properties of steels were investigated. The results obtained in the study are as follows:

- Compared to AISI 1020 steel, AISI 1040 steel has a higher hardenability. AISI 1040 steel showed higher hardness values in all heat treatment types.
- With the tempering process and increasing tempering temperature, there was a decrease in the hardness values of both types of materials.
- Compared to AISI 1020 steel, AISI 1040 steel has higher tensile strength and yield strength under all heat treatment conditions. With the tempering and the increasing tempering temperature, the tensile strength and yield

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- strength values decreased in both types of materials.
- The elongation value of AISI 1040 steel is lower under all heat treatment conditions. With the tempering process and increasing tempering temperature, the elongation values of the samples increased.
- Under all heat treatment conditions, the impact energy of AISI 1040 material is much lower than that of AISI 1020 material. With the tempering heat treatment, the impact energies of both materials increased. As the tempering temperature increased, the impact energies increased, too.

CONFLICT OF INTEREST STATEMENT *(ÇIKAR ÇATIŞMASI BİLDİRİMİ)*

The authors reported no potential conflict of interest.

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