Investigation of the Effect of Heat Treatment Parameters on Mechanical Properties of AISI 4140 Alloy Steel by Quenching in Water

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Abstract: ***In this study, the changes in the mechanical properties of AISI 4140 alloy steel, which was hardened by quenching in water, and then tempered by different temperatures, as a result of tempering at different temperatures were investigated experimentally. In this study, tensile and impact test specimens were prepared. These specimens were collected in 2 groups. While the first group of these samples was subjected to hardening by quenching only, the samples in the other group were also subjected to tempering processes after quenching. As a result of the heat treatments, these samples were subjected to tensile tests according to TS 138 EN 10002-1/2004 and to impact tests according to TS EN 10045-1/1999. As a result of the experiments, the changes in the mechanical properties of the samples, which were hardened by quenching, were investigated at different tempering temperatures.***

Keywords: Steel, Quenching, Tempering, Tensile Test, Impact Test

1. Introduction

The most important feature of AISI 4140 alloy steel is that it forms a hard martensitic structure after quenching due to the Cr and Mo alloying elements it contains, allowing mechanical properties such as strength, ductility and toughness to be provided together. For all these reasons, AISI 4140 alloy steel is always common steel. (Avner, 1986; Choo et al., 2000). The biggest disadvantage is the embrittlement that may occur during tempering at the specific temperature values of the machine elements (Oliveira et al., 2000). In order to prevent this negative effect, it is very important to choose the appropriate temper temperature (Charre, 2004; Buytoz, 2004). Depending on the applied austenitization process and the temper conditions after it, the wear properties of the materials change along with different metallurgical properties. Therefore, it is necessary to determine the properties of AISI 4140 alloy steel after tempering.

For the steel to harden, the cooling rate must be above the critical cooling rate of the material. If the austenitic steel is cooled to room temperature at different cooling rates, they gain different structures. These structures are shown in Figure 1.When the steel is cooled very slowly in the furnace, it turns into a structure containing ferrite and pearlite in close proportions. The microstructure of the steel cooled in water completely turns into martensite. Because of the rapid cooling, the return of the austenite to perlite is completely prevented. The austenite is cooled in such a way that it does not go below a minimum velocity, depending on the composition of the steel. Super cooled austenite undergoes different transformations in terms of cooling properties. These transformations are shown in Figure 2 and Figure 3. These transformations are: Transformation in perlite stage, Transformation at the level of Bainite, Transformation in the martensite grade

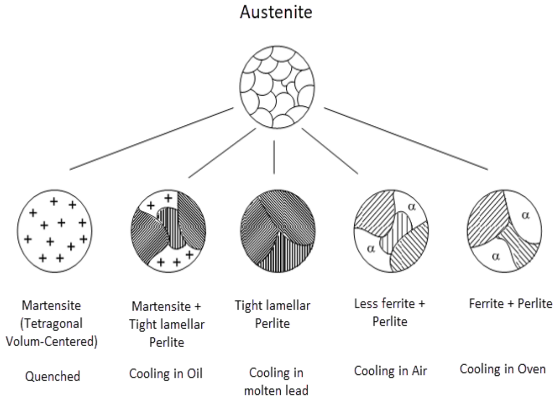

Figure 1: Structures achieved at various cooling rates (Materials Handbook)

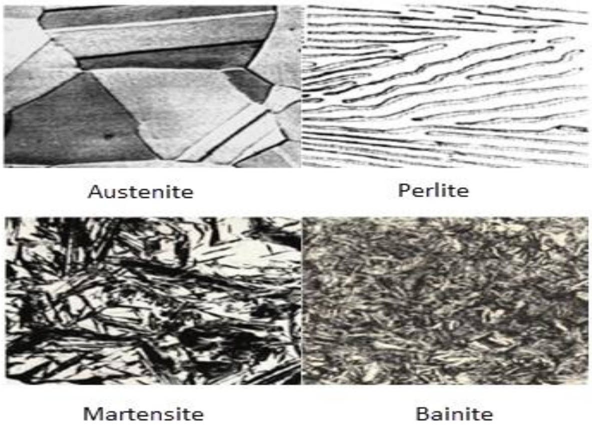

Figure 2: Microstructures of the quenched steel (Materials Handbook)

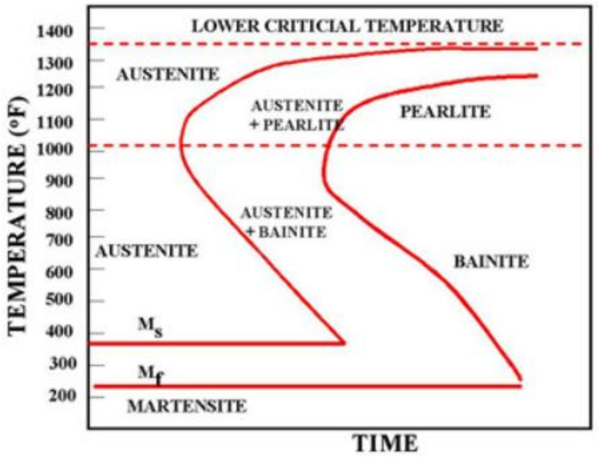

Figure 3: TTT Diagrams for Hardened Steel (Adolf Martens 1850-1914)

When the part at the austenitization temperature is immersed in water, the cooling is initially slow due to the insulation effect of the vapor film formed on the part surface. When the temperature drops below 600°C, the vapor film ruptures with the help of atomic mobility, and the vapor starts to rise in bubbles. The cooling rate reaches its highest value around 400-500°C. For this reason, 5-10% NaCl or NaOH is added to the water, the formation point of the vapor film is pulled to higher temperatures and the film formation is prevented. At the same time, in this cooling environment, the hardening depth of the part increases while the risk of cracking decreases.

2. Experimental Study

Twenty of the prepared samples were subjected to hardening process. The temperature required for the hardening process was determined as 840°C from the iron carbon balance diagram. After the samples were placed in the furnace, the furnace was started to be operated. The furnace reached its curing temperature 2 hours after it was started (Figure 4).

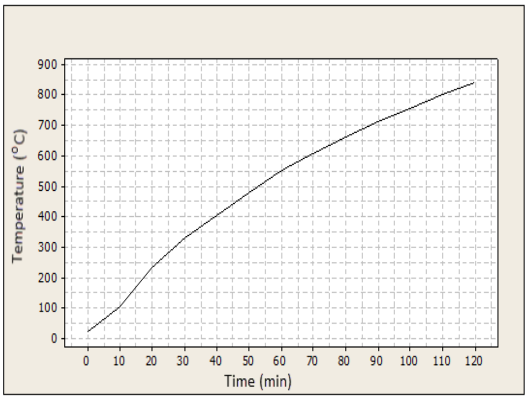

Figure 4: Oven heating graphics

When the oven temperature reached 840°C, the samples were kept in the oven for 25 minutes. After this waiting time, 10 of the samples were left to cool in water and 10 of them in oil. The samples, 2 of which were hardened in water and 2 of which were hardened in oil, were separated for testing. The remaining 16 test specimens were each reserved for the tempering process. (In this article, samples cooled in water were examined.)

The hardened samples were subjected to tempering process in 4 different temperature categories. These; The temperatures are 150°C, 300°C, 450°C and 600°C. Two test samples, each cooled in water and oil, were used for each test temperature. When the heat treatment furnace reached these temperatures, it was left to cool in air for 2 hours.

Tensile test specimens were prepared according to TS 138 EN 10002-1/2004 standards. Continuously increasing tensile force was applied to the test specimen in one axis, at a constant speed and constant temperature, until it ruptured. As a result of the experiment, tensile strength, yield strength, % elongation and % reduction in area were recorded.

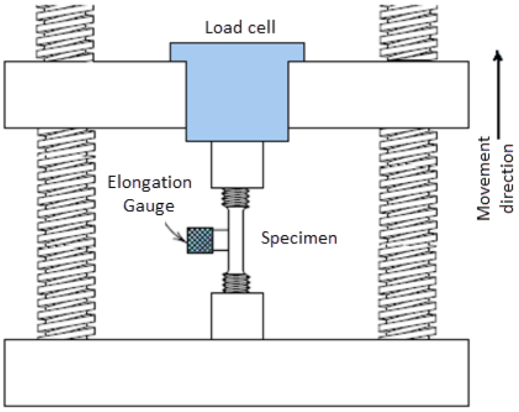

Figure 5: Tensile test device used in the experiment (DARTEC M9000 model universal test device)

Impact test is applied to determine the mechanical properties of metals under brittle fracture conditions. Charpy and Izod tests were used to measure impact energy.Charpy notch impact test Mitaş Enerji A.Ş. was also made according to TS EN 10045-1/1999.

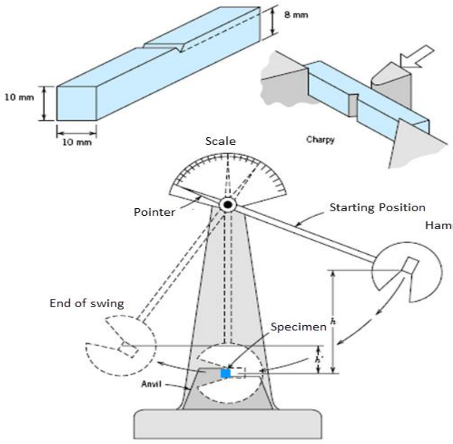

Figure 6: Charpy notch impact test specimen and test machine principal diagram (Callister, 2009)

3. Effect of Heat Treatment Parameters on Mechanical Properties

In the material, which was cooled very quickly from the hardening temperature, the carbon atoms did not find time to leave their cages due to the very rapid cooling. With this, the cage system is distorted and a great stress is placed on the material. As a result, a martensitic structure was formed in the material. After the tempering process, the carbon atoms left their cages and a pearlite structure called tempered martensite was formed.

The increase in tempering temperature caused coarsening of the microstructure. While the stresses loaded on the material are removed by tempering at low temperatures, the cementite phase is formed with the increase in temperature and the ferrite grains become coarser. This coarsening in the microstructure caused a decrease in the tensile and yield strengths, and an increase in the elongation at break and narrowing of the section.

When the martensitic structure was tempered at 600°C, recrystallization occurred and ferrite grains containing spherical cementite were formed and grown at the grain boundaries. As a result, while the tensile and yield strengths decreased, the impact strength increased. The hardening process was carried out in the quenching medium. Cracks were detected on the samples during hardening in the water environment. Studies show that such a situation is encountered in water hardening of AISI 4140 alloy steels (ASM Handbook).

Four different tempering processes were carried out at 150°C, 300°C, 450°C and 600°C temperatures. The mechanical properties of AISI 4140 alloy steel as a result of the tempering process are shown in Table 1.

Table 1: Mechanical properties of water-hardened AISI 4140 alloysteel according to different tempering temperatures

	Tempering Temperatures for Quenched Specimens			
Mechanical Properties	150°C	300°C	450°C	600°C
Hardness (HRC)	55	48	38	26
Tensile Strength (N/mm²)	1017	1781	1320	974
Yield Strength (N/mm²)	-	564	1275	880
Percent Elongation	-	6	10,5	14,5
Percentage Reduction in Area	-	31,2	38,5	50,2
Impact Resistance (Joule)	7,16	9,64	35,5	92

The hardness of the tempered steel showed an inverse trend with the increase in tempering temperature (Figure 7).

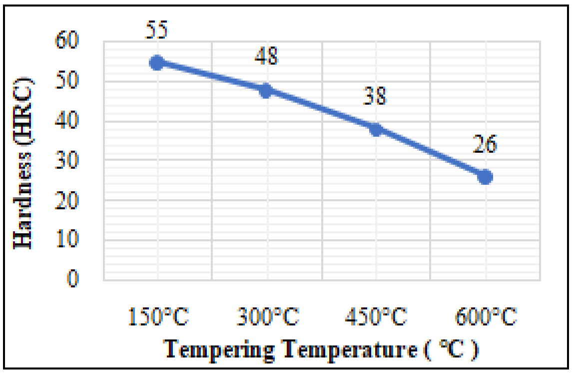

Figure 7: The change in the Hardness of the tempered steel

It was observed that the change in the tensile strength of the tempered steel first increased and then decreased again with increasing temperature (Figure 8).

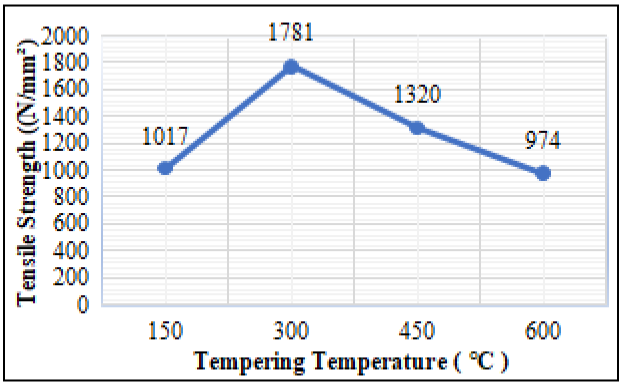

Figure 8: The change in the tensile strength of the tempered steel

It has been observed that the change in the yield strength of the tempered steel, like the tensile strength, first rises and then decreases with increasing temperature (Figure 9).

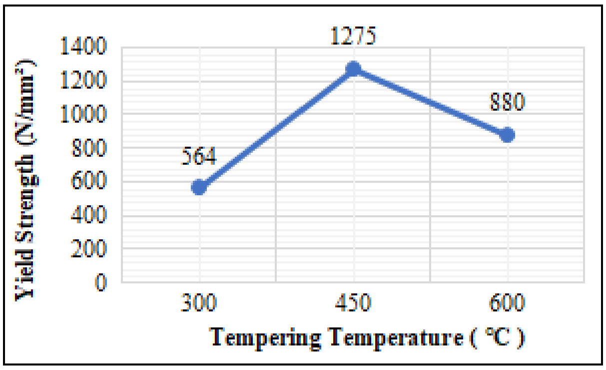

Figure 9: The change in the yield strength of the tempered steel

The change in percent elongation and percentage reduction in area increased with increasing tempering temperature (Figure 10 and Figure 11).

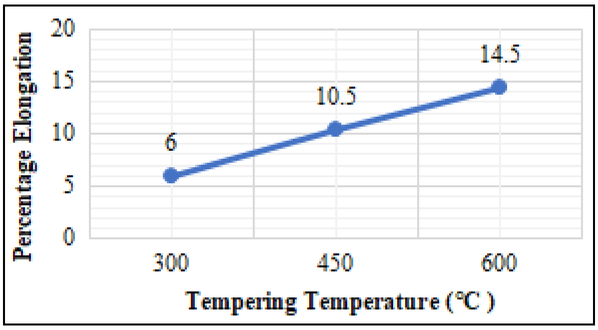

Figure 10: The change in percent elongation of the tempered steel

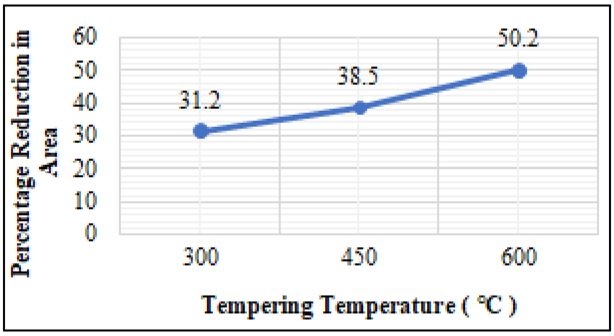

Figure 11: The change in percentage reduction in area of the tempered steel

And also, a rapid increase was observed in the impact strength values with increasing temperature (Figure 12).

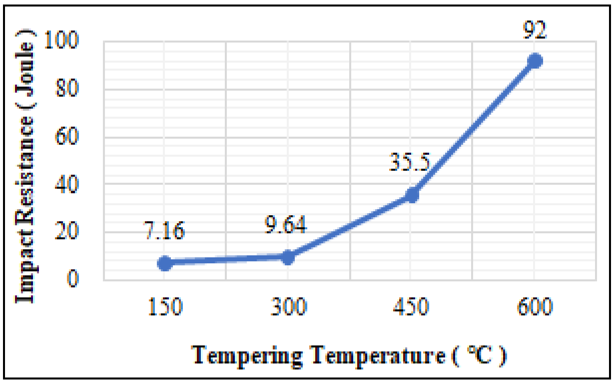

Figure 12: The change in impact resistance of the tempered steel

4. Conclusions

In water, the formation of carbide is prevented as the material cools very quickly.

The aim of this study is to determine whether the materials are brittle when ready for use, whether the material breaks brittle due to the notch effect, and whether the materials have aging tendencies.

In this study, a rapid increase in impact strength was observed at tempering above 300°C.Percentage Elongation and percentage reduction in area increased in directly proportion to the increase in tempering temperature. The hardness decreased with the increase in temperature. The highest elongation at break and reduction in cross section values were achieved as a result of the tempering process at 600°C. These values are 16% for percentage elongation at break and 58% for percentage reduction in area. But the hardness values, decreased from 51 HRC to 28 HRC that we can consider linear with the increase in tempering temperature.

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