Effect of Austenitizing and Tempering Temperatures on the Mechanical Properties of Hot Forged AISI 4140 Steel

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Abstract

Parts that are produced from AISI 4140 steel using hot-forging process are widely used in industrial applications. Nevertheless, there are few studies reported in literature related to hot-forging of AISI 4140 steel.

In this study, following the hot-forging process, mechanical and micro-structural changes at different austenitizing and tempering temperatures have been analysed experimentally. Samples that are obtained from industrially produced parts have been austenitized at 900°C, 880°C and 860°C followed by quenching with oil then tempering at 640°C, 570°C and 480°C. Austenitization and tempering time has been selected as 140 and 200 minutes respectively for all samples. Hardness and tensile tests of the samples carried out along with metallographic microstructure analysis.

Following the Heat-Treatment process samples have been subjected to tensile test in acc. with TS EN ISO 6892-1 and hardness test acc. with TS EN ISO 6506 - 1 standards respectively. After the heat treatment of hot forged AISI 4140 steel, keeping the austenitization and tempering temperatures constant, the effect of these temperature on mechanical and microstructural properties has been investigated.

1. Introduction

Forging can be considered as a plastic forming method in order to give the metal a desired shape, reduce grain size and improve mechanical properties while maintaining a controlled plastic deformation under impact or pressure [1]. The main reason behind the forging materials are stronger than the castings materials is due to the fiber-structure that emerges during the forging operations. Emergence of the fiber-structure improves the mechanical properties of the parts. Forgings constitute the safety critical parts that are durable against impacts and strains which are used in vehicles (planes, cars, trains) agricultural machines and tools, construction machines, missiles and rockets, weapons industry, turbine motors and various machines. Forging process is classified according to different criterias [2].

Forging can be executed as hot-forging, warm-forging or cold-forging. Let Tm denotes the melting temperature of the material and T is the temperature that deformation is applied, forging can be classified as follows.

If T/Tm< 0.3, then cold forming;
If T/Tm = 0.3 - 0.5 then semi-hot forming;
If T/Tm > 0.6 then hot forming is performed. [3]

AISI 4140 steels have the widest range of use among the Cr-Mo containing quenched & tempered steels and are known as Chrome - Molybdenum Steel. They are utilized in manufacturing cars and planes, crankshafts, axle shafts, hubs, various shafts, gears, machine parts and elements with high strength and ductility [4]. Chemical analysis of AISI 4140 steel is shown in table 1 below [5].

<table>
<thead>
<tr>
<th>Elements</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Si</th>
<th>Cr</th>
<th>Mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Weights</td>
<td>0.38</td>
<td>0.75</td>
<td>0.035</td>
<td>0.04</td>
<td>0.15</td>
<td>0.80 - 1.10</td>
<td>0.15 - 0.25</td>
</tr>
</tbody>
</table>

Figure 1. Fiber-Structure after forging
2. Experimental Procedure

2.1. Method

In this study, AISI 4140 steel is annealed at 1250°C until its deformation temperature and forged with drop-hammer. Following this process, samples austenitized and tempered at different temperatures, then the characteristic results of this procedure is examined.

2.2. Material

This study investigates the chemical analysis of Ø80 AISI steel obtained from Asil Çelik I.C. Chemical analysis has been performed at quality lab of Omtaş I.C. with ARL 3460 spectrometer on the AISI 4140 steel obtained from Asil Çelik I.C. Chemical analysis results have been shown in Table 2.

<table>
<thead>
<tr>
<th>Material</th>
<th>% C</th>
<th>% Si</th>
<th>% Mn</th>
<th>% S</th>
<th>% P</th>
<th>% Cr</th>
<th>% Mo</th>
<th>% Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>AISI 4140</td>
<td>0.450</td>
<td>0.340</td>
<td>0.790</td>
<td>0.020</td>
<td>0.023</td>
<td>0.860</td>
<td>0.155</td>
<td>0.090</td>
</tr>
</tbody>
</table>

2.3. Production

2.3.3. Forging

AISI Steel has been cut by EXACTCUT TAC 155 circular saw with %1 sensitivity in order to obtain 12 samples, 240 mm in length. After tempering at 1250°C in induction furnace, samples have been forged with MPM6300 drop-hammer up to 60 mm in thickness.

2.3.2. Heat treatment

Samples have been austenitized continuously for 140 mins at 860°C, 880°C and 900°C temperatures in Sistem Teknik Furnace. Then they have been quenched in oil at 60-80°C for 14 mins. After washing the samples to remove oil on the surface for 6 mins, they have been put into tempering furnace at 480°C, 570°C and 480°C for 200 mins. Heat treatment process applied to the samples is summarized in Fig. 2 below.

Figure 2. Process flow chart

2.3.3. Preparation of test specimens

24 and 12 pieces of test specimens have been prepared at Omtaş I.C. for tensile strength and microstructural analysis examinations respectively.

3. Result and Discussion

AISI 4140 steel has been annealed at 1250°C and formed in the axis perpendicular to the deformation direction with hot-forging process. Heat-treatments at different temperatures have been performed after forging. In order to define the mechanical properties of the samples, hardness, tensile tests along with optical & SEM analysis carried out and the results given in subsequent sections.

3.3. Hardness test results

Hardness values of AISI 4140 steel samples which have been austenitized at 900°C, 880°C and 860°C followed by oil quenching, forging and tempering at 640°C, 570°C and 480°C are shown in Fig. 3.

As shown on Fig. 3 AISI 4140 steel which has been austenitized at 900°C for 140 mins, has the average hardness value of 401 HB. The hardness value descends to 358 HB after tempering at 480°C for 200 mins. As the tempering time remains constant and the temperature increases to 570°C, hardness value becomes 321 HB. When the tempering temperature ascends to 640°C average hardness value has been measured as 274 HB.

As shown on Fig 3 AISI 4140 steel which has been austenitized at 880°C for 140 mins, has the average hardness value of 418 HB. The hardness value descends to 362 HB after tempering at 480°C for 200 mins. As the tempering time remains constant and the temperature ascends to 570°C, hardness value becomes 323 HB. When the tempering temperature ascends to 640°C average hardness value has been measured as 286 HB.

As shown on Fig 3 AISI 4140 steel which has been austenitized at 860°C for 140 mins has the average hardness value of 458 HB. The hardness value descends to 395 HB after tempering at 480°C for 200 mins as the tempering time remains constant and the temperature ascends to 570°C, hardness value becomes 337 HB. When the tempering temperature ascends to 640°C average hardness value has been measured as 289 HB.

Table 2. Chemical composition of AISI 4140 steel
In case the duration of austenitizing and tempering along with the tempering temperatures kept constant for each specimen, the average hardness value decreases while austenitization temperature increases as shown on Fig. 3.

### 3.3. Tensile test results

Tensile strength values of AISI 4140 steel samples, austenitized at 900°C, 880°C and 860°C, quenched in oil and tempered at 640°C, 570°C and 480°C are shown in Fig. 4. As shown on Fig. 4, AISI 4140 steel which has been austenitized at 900°C for 140 mins after having been quenched in oil, has the average tensile strength value of 1386 MPa. The tensile strength value descends to 1201 MPa after tempering at 480°C for 200 mins. In the case of tempering time kept constant and the temperature ascends to 570°C, tensile strength value becomes 1066 MPa. When the tempering temperature ascends to 640°C average tensile strength value has been measured as 921 MPa.

As shown on Fig. 4, AISI 4140 steel which has been austenitized at 880°C for 140 mins followed by quenching in oil, has the average tensile strength value of 1432 MPa. The tensile strength value descends to 1260 MPa after tempering at 480°C for 200 mins. In the case of tempering time remains the same and the temperature ascends to 570°C, tensile strength value becomes 1082 MPa. When the tempering temperature ascends to 640°C average tensile strength value has been measured as 929 MPa.

As shown on Fig. 4, AISI 4140 steel which has been austenitized at 860°C for 140 mins after having been quenched in oil, has the average tensile strength value of 1543 MPa. The tensile strength value descends to 1358 MPa after tempering at 480°C for 200 mins. In the case of tempering time remains the same and the temperature ascends to 570°C, tensile strength value becomes 1119 MPa. When the tempering temperature ascends to 640°C average tensile strength value has been measured as 946 MPa.

### 3.3. Optical & SEM microstructures

As shown on Fig. 5, 6 and 7; following the austenitizing at 860°C and quenching in oil of the sample, acicular martensitic structure can be observed when the microstructures are examined in optical microscope and SEM.
As shown on Fig. 8, 9 and 10; following the austenitizing at 860, quenching in oil then tempering at 480°C of the sample, tempered martensitic microstructure is observed instead of acicular martensitic structure when the microstructures are examined in optical microscope and SEM.

4. Conclusion

Although hot forged AISI 4140 steel sample which has been austenitized at 860°C, quenched in oil then tempered at 480°C has slightly low tensile strength and hardness values compared to other samples, it has better microstructure. The sample which has been austenitized 860°C, quenched in oil then tempered at 480°C possesses the optimal microstructure and mechanical values.

References