Effect of Different Heat Treatment on the SS440C Martensitic Stainless Steel

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Abstract: Martensitic stainless steel are widely using for their good mechanical properties and moderate corrosion resistance. Oil quenching and tempering process offer enormous advantage to the martensite production because the treatment result can reveal optimum combination of toughness and ductility. The material used in this study was SS440C martensitic stainless steel. Quench and temper process was used as a major heat treatment method. The microstructure after quenched process consist of martensite structure with small amount of retained austenite. The optimum mechanical properties were found after tempering in martensite structure. But with more increase in the tempering temperature the mechanical properties are gradually decrease. In the present study, effect of heating temperature on microstructure and hardness had been investigated.

Key words: Tempered process, Martensite, M7C3 Carbide, volume fraction of martensite.

INTRODUCTION

The martensitic reaction in steels normally occurs athermally, i.e during cooling in a temperature range which can be precisely defined for particular steel. The reaction begins at a martensitic start temperature, \( M_s \). High carbon content (1wt %) in this steel depressed the martensite start,\( M_s \), temperature and hence may increased the amount of retained austenite. This, in return will lower the hardness value of the steel samples (Salleh et al., 2009). Martensite is a metastable and single phase structure that may be produced in steel by diffusionless and almost instantaneous transformation of austenite (William, 1997). Therefore, quenched steel are normally tempered to improve their impact properties and to increase their microstructure stability and normally done by reheat the quenched steel between room temperature and lower critical point. Martensitic type 440C with 16%Cr and 1 %C that has the highest hardness of any corrosion resistance steel. Its high hardness is due to a hard martensitic matrix and to the presence of a large concentration of primary carbide (William et al., 2010). The scope of this present study covers the microstructure and properties change after Austenitizing and tempering process of SS440C.

Experimental:

Materials:
The material used in this work was SS440C martensitic stainless steel with alloying element such as carbon and chromium to increase the hardness and strength. Chemical composition for the material was acquired using Arc-Spark Spectrometers Testing as shown in Table 1.

Heat Treatment:
SS440C martensitic stainless steel that can be heat treated to provide a wide range of hardness value. The first procedure for heat treated involves austenitizing process by heating the sample at 1150°C for 60 min, follow heating again at 1100°C for 30 min, quenched the sample produced martensitic structure. Higher austenitizing temperature was sufficient to transform the steel into austenite and to form martensite phase upon quenching (William, et al; 2010). The second procedure involves tempering process. To exam the tempered martensite and ferrite phase the tempering temperature was chosen varied between (400-700)°C for 1 hr (Lee et al., 1999).

Image Analysis:
The microstructure examination was carried out using optical microscopy (OM) and scanning electron microscopy (SEM) after etching with Villella’s regent. The identificated of carbide was carried out by EDX analysis. The Vickers hardness test was performed with a load 5 Kg choose from different area.

Vickers tester
The Vickers hardness test method consists of indenting the test material with a diamonds indenter, in the form of a right pyramid with a square base and an angle of 136° between opposite faces subjected to a load of 5
Kg. The full load is normally applied for 15 sec. The two diagonals of the indentation left in the surface of the material after removal the load are measured using a microscopy and their average calculated.

Table 1: Chemical composition of the SS440C martensitic stainless steel.

<table>
<thead>
<tr>
<th>Composition</th>
<th>Wt%</th>
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<tbody>
<tr>
<td>C</td>
<td>1.145</td>
</tr>
<tr>
<td>Si</td>
<td>0.552</td>
</tr>
<tr>
<td>Mn</td>
<td>0.492</td>
</tr>
<tr>
<td>Cr</td>
<td>16.01</td>
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</tbody>
</table>

RESULT AND DISCUSSION

Microscopic Evaluation:

The Optical micrograph of the SS440C austenitized at different temperature is shown in Fig. 1 (a)-(c). The microstructure of SS440C martensitic stainless steel in the austenitized condition includes martensite structure, retained austenite and undissolved carbide. After quenching, the martensite structure is the most common phase in the microstructure with undissolved carbide in high carbon steel (Hoceycombe, 1981; George, 2005). EDX analysis confirmed that the undissolved carbide were M₇C₃ as shown in Table 2.

Table 2: EDX analysis result of the carbide as shown in Fig. 1 C.

<table>
<thead>
<tr>
<th>Composition</th>
<th>at%</th>
</tr>
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<tbody>
<tr>
<td>C</td>
<td>31.87</td>
</tr>
<tr>
<td>Cr</td>
<td>13.84</td>
</tr>
<tr>
<td>Mn</td>
<td>0.78</td>
</tr>
<tr>
<td>Fe</td>
<td>53.11</td>
</tr>
<tr>
<td>Mo</td>
<td>0.41</td>
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Fig. 1: Micrographs of heat treatment SS440C (a) 1150°C (b) 1100°C (C) SEM 1150°C.

Fig. 1 (b) shows the micrograph for Austenitizing at 1100°C. The shape of martensite plate still remained and large number of fine particles precipitation on the austenite grain boundary. Because the rapid growth at high temperature has strong relation with dissolution of behaviour carbide. Therefore, large amount of carbon and alloying element enter into the matrix which cause more and more plate martensite and retained austenite after quenching (Wu et al., 2009).
Fig. 2 (a)-(d). Show OM micrograph for the specimens that were tempered at 400, 500, 600, and 700°C for 1 h. The microstructure for martensitic stainless steel during tempering includes tempered martensite, newly formed martensite and carbide precipitate (Sudsakan et al., 2010).

![OM micrograph](image)

Fig. 2: OM micrograph of specimens after tempering for 1 hr at (a) 400°C, (b) 500°C, (c) 600°C, (d) 700°C.

However, precipitate carbide can formed with addition of some of alloying element that have strong affinity to carbon at high tempering temperature (Karagoz et al., 2008; Balan et al., 1998). This is because the steel contains strong carbide forming element such as molybdenum, vanadium, and chromium. It become possible to recover the strength. The recovery strength occurs due to carbide precipitate in extremely fine but dense during tempering at elevated temperature and time (Bhadeshia, 2001). EDX confirmed the precipitate carbide was M₇C₃ within martensite structure.

Table 3: EDX analysis of the sample after tempering at 600°C for 60 min.

<table>
<thead>
<tr>
<th>Composition</th>
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<tbody>
<tr>
<td>C</td>
<td>29.73</td>
</tr>
<tr>
<td>Cr</td>
<td>25.44</td>
</tr>
<tr>
<td>Mn</td>
<td>0.94</td>
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<tr>
<td>Fe</td>
<td>35.73</td>
</tr>
<tr>
<td>Mo</td>
<td>0.44</td>
</tr>
<tr>
<td>V</td>
<td>0.47</td>
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**Austenitizing Temperature and Quenching Hardness:**

Fig. 3. shows the relation between austenitizing temperature and quenching hardness. The quenching hardness increase with austenitizing temperature, reaching a maximum of 765HV at 1100°C. Due to increase of austenitizing temperature associate with Cr carbide (M₇C₃) and loss pinning effect by carbide, helps grain growth of austenite and lead to reduction of hardness with more increase in the temperature (Yaso et al., 2008).

![Graph](image)

Fig. 3: Vickers hardness, Austenite grain size, and Carbide size as a function of the Austenitizing temperature.
Tempering Process:
The optimum hardness were observed when austenitizing at 1100°C for 30 min. This cycle was selected for the tempered process. In Fig. 4 the hardness value and tempered at various temperature are shown. The hardness decrease and increase again during tempering in the range 400-600°C. This is due to precipitation of carbide when the austenite transformed to martensite during tempering (Sudsakorn et al., 2010). It can be seen in Fig. 4 that hardness decreased again when the tempering temperature increase more than 600°C. This softening occurred when the M7C3 carbide start to coarsen and martensite become less tetragonal (Suleyman et al., 2009; Yaso et al., 2008).

Fig. 4: Change of Vickers hardness with tempering temperature.

Conclusion:
The investigation on the microstructure and mechanical properties of the as-quenched and tempered 440C steel led to the following conclusion:
1. The microstructure after heat treatment condition consists of martensite structure, retained austenite and undissolved carbide.
2. After tempering process the hardness decrease and increase again. This is because precipitate carbide when the austenite transformed to martensite during tempering.
3. The weaker in the properties occurs after 600°C tempering temperature because the carbide start coarsens and martensite become less tetragonal.

REFERENCES
George, K., 2005. Steel, processing, structure and performance. ASM international.