AN INVESTIGATION ON THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF QUENCHED AND TEMPERED SS440C MARTENSITIC STAINLESS STEEL

A.A. Salih*, M.Z. Omar, J. Syarif and Z. Sajuri
Department of Mechanical and Materials Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia
*Corresponding author’s E-mail: abeeralnami@yahoo.com
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ABSTRACT
440C steel is a high-carbon martensitic stainless steel with excellent mechanical properties. This paper describes the relative effect of various austenitizing temperature and tempering temperature on the microstructure and mechanical properties of 440C martensitic stainless steel. Solution treatment was carried out at 1150°C for 1 hr, followed by reheat at 1100°C and 30 minute holding. Then, tempered at various temperatures for 1 hr. In the As-quenched sample the microstructure contains undissolved carbide M7C3 with retained austenite in a matrix of un-tempered martensite while as the austenitizing temperature increase, the size of the austenite grain also increases with decrease in the mechanical properties. Hardness test found out that tempering at 500°C resulted in maximum hardness value of 564HV. However, the hardness of the as-quenched sample was 765HV. Tensile test at 500°C tempering temperature showed Y.S of 2100MPa and UTS of 2178MPa. As comparison, the as-quenched sample showed Y.S of 1300MPa and UTS 1507MPa. It is believed that secondary hardening phenomenon occurred while tempering and influence the value of hardness and tensile strength of the 440C steel.

Keywords: Tempering, Hardness, 440C, Tempered martensite.

1. INTRODUCTION
Martensitic stainless steel are commonly used in quenched and tempered condition. The heat treatment consists of annealing to obtain austenite and dissolve carbide, followed by cooling to transform the austenite into martensite and subsequent tempering of martensitic structure. The microstructure of martensitic stainless steel consists of martensite, undissolved carbide as well as retained austenite and the amount of carbide in the as-quenched microstructure influence on the properties of this material such as hardness, strength, toughness and wears (Rejaskhar et al., 2009; Firdus et al., 2009). 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. Its high hardness is due to a hard martensitic matrix and to the presence of a large concentration of primary carbide (William, 1997; William, 2010). The aim of the present study was to investigate the microstructure and properties of 440C in various condition of heat treatment.

2. EXPERIMENTAL PROCEDURE
2.1 Heat treatment and image analysis
The steel studied in this work is 440C martensitic stainless steel. The chemical composition for the material acquired using Arc-Spark spectrometers as shown in Table 1.

<table>
<thead>
<tr>
<th>Element</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Cr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition (wt%)</td>
<td>1.145</td>
<td>0.552</td>
<td>0.492</td>
<td>16.01</td>
</tr>
</tbody>
</table>

The heat treatment which is used in this work as shown in Figure 1. The solution treatment is performed at 1150°C for 60 minute and followed by oil quenched. High austenitizing was sufficient to transform the steel into austenite and to form martensite after quenched (William, 2010).

1 hr
30
60

Figure 1 Heat treatment cycle for SS440C Treatment

Followed by tempering 60 minute at various tempering temperature. Microscope examination was carried out by optical microscopy (OM) and scanning electron microscopy (SEM). As verification energy dispersive
(EDX) was conducted to confirm types of carbides that precipitate in the microstructure. Furthermore, the vickers hardness was conducted on heat treated sample with 5 Kg loading and 15 second loading time. Tensile test was conducted on heat treated also with applied 0.09mm/min stress-strain at RT in accordance to ASTM E8.

2.2 Grain size:
After preparation the samples, a metallograph is used to examine the microstructure at various magnification and acquire photomicrographs of the grain structure.
The ASTM grain size equation

\[ N = 2^{n-1} \]  

(1)

\[ \log (N) = (n-1) \log (2) \]  

(2)

To find the ASTM grain size n, we must take the log of both sides of the equation. Also, we need a photo micrograph at 20X to find both capital N and small n.

3. RESULTS AND DISCUSSION
3.1 Microscopic evaluation
Figure 2 are the optical and scanning electron micrographs of (a) as-quenched 440C samples. Figure 2 (a) shows same amount of RA within martensite structure. Figure 2 (b) shows the spheroidal carbides precipitate within the martensite structure. Energy dispersive EDX spot analysis confirmed that the spheroidal carbides are \( M_7C_3 \) carbides.

Figure 2(c) the shape of martensite plate still remained after 1100°C and large number of fine particles precipitation on the austenite grain boundary. Because the rapid growth at higher temperature has strong relation with dissolution behaviour of carbide which cause more and more plate martensite and retained austenite after quenching (Chang and Wu, 2009; Badheka et al., 2010).

EDX analysis showed that the precipitate carbide are \( M_7C_3 \) formed with addition of some alloying element that have strong affinity to carbon at high tempering temperature (Balan et al., 1998; Kargoz et al., 2008).

![Micrographs of heat treatment SS440C](image)

Figure 2  Micrographs of heat treatment SS440C (a) OM 1150°C (b) SEM 1500 °C and (c) SEM 1100 °C

![EDX analysis of the specimens after austenitizing at 1150°C for 60 min](image)

Figure 3  EDX analysis of the specimens after austenitizing at 1150°C for 60 min

Figure 4 (a- d) Shows the micrograph of the samples during tempering include tempered martensite, newly formed martensite and carbide precipitate (Fadhila et al., 2007; Sudsakan et al., 2010).
Figure 4 OM micrograph of specimens after tempering for 1 hr at (a) 400°C, (b) 500°C, (c) 600°C, (d) 700°C.

Figure 5 EDX analysis of the specimens after tempering at 600°C for 60 min

3.3 Austenitizing

Figure 6 shows the influence of hardness at various austenitizing temperature on the average values of Vickers hardness. In general, the high hardness is due to the homogenous distribution of plate martensite in the structure (Nasery et al., 2011). Besides that, increase the austenitizing temperature associate solution of Cr carbide M₇C₃ into matrix and thus loses pinning effect by carbide, helps grain growth of austenite and lead to the reduction of hardness with more increase in the temperature (Yaso et al., 2008; Amuda and Mridha, 2009).

Figure 6 Vickers hardness, Austenite grain size as a function of the Austenitizing temperature.

3.4 Tempering process

Figure 7 shows the influence of hardness at various tempering temperature on the average value of Vickers hardness. The hardness value of as-quenched sample was 765HV. For the as-tempered samples, it can be seen that average hardness gradually decreases with increase tempering temperature. The change in hardness suggests the process of precipitation and growth of carbides, as well as the recovery and recrystallization of the matrix (Fei et al., 2007; Salleh et al., 2009). The softening occurred when the M₇C₃ carbides start to coarsen and martensite less tetragonal (Yaso et al., 2008; Suleyman et al., 2009; Badheka et al., 2009). However, secondary
hardening phenomenon may have possibly occurred at 500°C tempering temperature, where the hardness value is highest.

Figure 7 Change of Vickers hardness with tempering temperature

3.5 Tensile test
The tensile test was carried out for the as-quenched and tempering temperature. Figure 8 show the tensile properties of as-quenched and tempered specimen of 440C martensitic stainless steel. It can be clearly seen that the UTS of the as-quenched specimen was 1507Mpa and Y.S of 1300Mpa. The decrease in the mechanical properties after as-quenched can be attributed to the high brittleness of the martensite structure in the as-quenched specimen. As a result, tempered process had the best combination in both microstructure and mechanical properties.

Figure 8 Tensile Properties

4. CONCLUSION
This study has demonstrated the microstructure and mechanical properties evolution of the SS440C after Austenitizing and tempering process following the conclusion were drawn.

1. The maximum hardness is resulting from austenitizing at 1100 °C.
2. Increase the hardness at tempering temperature in the range of 400-600 °C due to precipitation and growth of carbide when the austenite transformed to martensite during tempering.
3. Hardness test showed highest value at 500°C tempering temperature. It is thought to have occurred due to secondary hardening phenomenon.
4. The 500°C tempering temperature had the best combination of both microstructural and mechanical properties.
5. Softening occurred when the M₇C₃ carbide start to coarsen and martensite become less tetragonal.

REFERENCES
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