Quenching & Partitioning In Stainless Steels

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Abstract: In the modern age, stainless steel (SS) can be used for the variety of applications because of its unique properties-resistance to corrosion and high strength. Typically, most of the steels are quenched to obtain martensite for high strength. In line with philosophy, when the SS is worked for high strength, by way of quenching, it loses ductility and hence the formability. Thus, the loss of formability limits its applications where we need material to bend at most but not to break. Recently, a new concept, known as quenching and partitioning (Q & P) is followed to realise both high strengths as well as ductility in the same material. In the two-step Q&P process, SS is heated first to single phase zone of austenite and quenched to a temperature just below the start of martensitic transformation (Ms) where a considerable amount of soft austenite retained along with hard martensite. In the second step, the temperature of quenched SS is raised above Ms so that trapped carbon atoms in the BCT martensite can move and make austenite richer in quantity. This enriched austenite with carbon is stable at room temperature.

Keywords: Martensite, Quenching and Partitioning, Ductility, Formability, Austenite.

I. Introduction

Good ductility at room temperature and superplasticity at elevated temperatures are the main features of the Q&P heat treated steels. This hardening process also increases the ductile nature of the material.

Carbon partitioning between martensite and retained austenite is usually ignored in quenched steels, because the temperature usually is too low for substantial amounts of carbon diffusion to occur after quenching, and because a different mechanism ordinarily eliminates carbon supersaturation in martensite, viz. carbide precipitation during tempering. Consequently, while carbon-enriched retained austenite has identified in martensitic steels for some time, the thermodynamics of carbon partitioning between martensite and retained austenite has been scarcely considered.

The concept of heat treatment of martensite, different from conventional quenching and tempering, is described. This involves quenching to below the martensite-start temperature and directly ageing, either at or above, the initial quench temperature. If competing reactions, principally carbide precipitation, are suppressed by appropriate alloying, the carbon partitions from the supersaturated martensite phase to the untransformed austenite phase, thereby increasing the stability of the residual austenite upon subsequent cooling to room temperature. This novel treatment has been termed ‘quenching and partitioning (D.V.Edmonds 2006).

II. Importance of Suppressing Carbide Precipitation

The absence of carbide formation is a fundamental element of the constrained par equilibrium model since the existence of a metastable equilibrium between ferrite and austenite is precluded if the more stable ferrite plus iron carbide equilibrium can be achieved. Any carbide formation effectively “consumes” carbon, since these carbon atoms are no longer available to enrich the austenite. For Q&P processing, however, any transition carbide precipitation diminishes the potential for carbon enrichment of austenite, and it is necessary to develop a better understanding of the onset of transition carbide formation, including composition and processing effects.

Since the chemical potential of carbon is much higher in as-quenched martensite than in the retained austenite, it is reasonable to conclude that carbide nucleation would be more likely in bcc ferrite than in austenite.
III. Indentations And Equations

Although it is considered that some heat treatment processes may have been done, or do currently follow the Q&P temperature/time profile, the intentional use of a heat treatment process to bring about the multiphase Q&P microstructures and associated mechanical properties that have been achieved in recent years is thought to be a new development. (Edmonds, 2006). A number of studies have now been published examining Q&P over carbon ranges from low-carbon TRIP steels to medium-carbon bar steels; although it is well to bear in mind that it is the carbon concentration of the quenched austenite which is essential, which in the case of austenite carbon enrichment is not the same as that of the bulk steel. (Gerdemann & J. G. Speer, 2004)

IV. Mechanical Properties of Q&P

One of the characteristics of dual/multi-phase structures is that they commonly exhibit continuous yielding behaviour. In this respect, Q&P steels do not disappoint. The difference in properties achieved by relatively small changes in the heat treatment procedure is noteworthy. This characteristic of the Q&P process led De Moor (who also studied the tensile properties of Q&P steel) to state that, ‘a variety of properties can be obtained even with a single chemical composition by adapting the heat treatment parameters’ (De Moor, 2009).

Mechanical properties in conjunction with technological properties, such as weldability, formability, and machinability, and their optimum combinations, are widely discussed in some mechanical engineering disciplines. In this manner, requirements arise for developing steels which could offer high strength and good formability, and which could be used for making parts with high resistance to failure and with a long life. Their properties are dictated by their treatment, as well as their alloying, mainly by the silicon content. Silicon fundamentally affects microstructure evolution during Q&P processing and, as a result, mechanical properties

V. The material used for the Experiment

In this experiment we used a stainless steel grade of 440C containing C% - 0.96, Mn% - 0.4, Si% - 0.82, Cr% - 16.43, Ni% - 0.19, Mo% - 0.47, V% - 0.106, Cu% - 0.039

440C is stainless steel and has the highest carbon content from 400 stainless steel series. It is usually heat treated to reach a hardness of 58-60 HRC. 440C can be oil quenched to achieve maximum hardness. It can be hardened to approximately Rockwell hardness no of 58, making it one of the hardest stainless steels. Because of its toughness and relatively low cost. These properties make this grade suitable for applications such as valve components and ball bearings. Grade 440A and 440C stainless steels have similar properties except for a slightly lower percentage of carbon in grade 440A.

All three forms of grade 440 sheets of steel are commonly used. However, grade 440C is more readily available than the other standard grades. Grade 440F, a free-machining type of grade 440 series, is also available with a high carbon content similar to that of grade 440C. Martensitic steel grades are high-hardness steels, usually fabricated using techniques that require hardening and tempering treatments.

These grades have a corrosion resistance lower than that of other austenitic grades. The applications of martensitic steels are limited by the loss of strength caused by over-tempering at high temperatures and loss of ductility at temperatures below zero.

VI. Hardness Before Q&P

The hardness of the stainless steel 440C material has been tested by using Brinell harness machine. In this testing, the 3000kgf is used to make an indent with the titanium coated ball. The diameters of the indent are measured using Brinell microscope. The hardness values have been determined from the mean indent diameter values. BHN for stainless steel 440C is 241.18.

\[
BHN = \frac{2P}{\pi D \left( D - \sqrt{D^2 - d^2} \right)}
\]

where:

- \( BHN \) = Brinell Hardness Number (kgf/mm²)
- \( P \) = applied load in kilogram-force (kgf)
- \( D \) = diameter of indenter (mm)
- \( d \) = diameter of indentation (mm)
VII. Hardness Of The Experimental Component After Heat Treatment
The component used in this experiment when it is heated to quench at different temperatures for a variety of time periods has been tested for their hardness and are tabulated below.

Table 1. The hardness of the 440C Stainless Steel After Heat Treatment

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>5</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>300</th>
<th>3000</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>228.76</td>
<td>228.76</td>
<td>351.81</td>
<td>414.63</td>
<td>351.81</td>
<td>301.95</td>
</tr>
<tr>
<td>350</td>
<td>414.63</td>
<td>228.76</td>
<td>400.82</td>
<td>414.63</td>
<td>228.76</td>
<td>228.76</td>
</tr>
<tr>
<td>400</td>
<td>228.76</td>
<td>196.54</td>
<td>228.76</td>
<td>241.18</td>
<td>201.44</td>
<td>414.63</td>
</tr>
</tbody>
</table>

VIII. Tensile Test Of The Experimental Component Before And After Heat Treatment

(1) Table 2-Tensile Testing Before Heat Treatment

<table>
<thead>
<tr>
<th>Ultimate Tensile Strength (N/mm²)</th>
<th>440C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elongation (%)</td>
<td>7.240</td>
</tr>
<tr>
<td>Yield Stress (N/mm²)</td>
<td>512</td>
</tr>
</tbody>
</table>

(2) Table 3-440C Tensile Testing After Heat Treatment

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>350°C</th>
<th>400°C</th>
<th>450°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate tensile strength (N/mm²)</td>
<td>734.667</td>
<td>1363.908</td>
<td>1311.241</td>
</tr>
<tr>
<td>Elongation %</td>
<td>17.6</td>
<td>17.6</td>
<td>20.40</td>
</tr>
<tr>
<td>Yield stress N/mm²</td>
<td>733.33</td>
<td>846.793</td>
<td>901.884</td>
</tr>
</tbody>
</table>
IX. Conclusion

For 440C partitioned at 350 °C for 3000sec hardness value increases by 60 and the tensile strength gets decreased by 39N/mm² before heat treatment.

At 400 °C for 3000sec hardness value gets decreased by 20 and tensile strength increases 600N/mm² by initial value.

At 450 °C for 3000sec hardness value gets increased by 173 and tensile strength increases 550N/mm² by initial value.

For this grade of Stainless steel if the material is partitioned at 450 °C for 3000sec having improved hardness and ductility.

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References


