Carbon Migration in Dissimilar Welds

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Introduction
Carbon migration is a concern in industries where dissimilar metal weld joints are common. The phenomenon occurs when welding base metals of different chromium contents, such as low alloy steels to stainless steels. After prolonged exposure to high temperatures, carbon from the low alloy steel migrates across the weld fusion line to the higher chromium weld deposit. The chromium combines with carbon readily forming $\text{M}_{23}\text{C}_6$ carbides. This results in a carbon-depleted zone in the low alloy steel and a carbon-enriched band on the weld metal side of the fusion line. Consequently the carbon-depleted layer has low creep strength often resulting in creep failure.

By using filler metals high in nickel and low in chromium, migration can be diminished or even eliminated. It is widely known that nickel impedes the diffusion of carbon in ferrous alloys and thus we can assume it can prevent carbon migration. A difference of chromium at the fusion line is also an important driving force. With fillers containing low levels of chromium, the effects of carbide formation are greatly reduced as less carbon is drawn from the parent steel.

Experiment
Filler Metal Selection:
In order to test the effects of the nickel-to-chromium ratio, three filler metals were selected for weldments on ASTM A53 pipe. They included 308L, Hastelloy X, and commercially pure nickel. The nickel and chromium content for each of the metals is shown below in Table 1.

<table>
<thead>
<tr>
<th>Metal</th>
<th>Nickel (%)</th>
<th>Chromium (%)</th>
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</thead>
<tbody>
<tr>
<td>ASTM A-53 Pipe</td>
<td>0.1</td>
<td>1.1</td>
</tr>
<tr>
<td>308L Filler</td>
<td>47.0</td>
<td>22.0</td>
</tr>
<tr>
<td>Hastelloy X Filler</td>
<td>99.2</td>
<td></td>
</tr>
<tr>
<td>Pure Nickel Filler</td>
<td></td>
<td></td>
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</tbody>
</table>

The three filler metals were chosen based on their balance of nickel and chromium content. 308L was selected for its relatively low nickel and relatively high chromium content. This combination is likely to produce significant carbon migration. Hastelloy X was selected for its high nickel and chromium content. This combination should be effective at preventing carbon migration. Pure nickel was selected for its extremely high nickel content and extremely low chromium content. This combination should be the most effective at preventing carbon migration.

Welding:
Manual stringer beads were made using Gas Tungsten Arc Welding (GTAW) with each filler metal on ASTM A53 steel pipe. The welds were air cooled to room temperature and sectioned transverse to the weld bead using a band saw.

Aging:
To simulate high temperature service, half of each weld was subjected to a post weld age at 1200°F for 96 hours. The remaining half of each weld was not aged.

Results
Both aged and un-aged parts of each weld were polished, etched and prepared for metallographic examination. The degree of carbon migration was determined by visually evaluating the level of carbon depletion in the base metal and the amount of chromium carbide formation in the weld metal.

Un-aged Samples:
None of the un-aged samples exhibited any evidence of carbon migration. No chromium carbide precipitation or carbon-depleted layers were observed on any samples. See Figures 1, 2 and 3. These results were expected since carbon migration is known to occur during prolonged times at high temperatures. Since these samples were not aged no carbon migration occurred.

Aged Samples:
• 308L Filler: The 308L filler metal was not effective at preventing carbon migration. The aged sample exhibited an extensive chromium carbide precipitation layer in the weld metal and a carbon-depleted zone in the base metal. See Figure 1.
• Hastelloy X Filler: The Hastelloy X filler metal was effective at preventing carbon migration. There seems to be very little to no evidence of a carbon-depleted layer or any chromium carbide precipitation. See Figure 2.
• Pure Nickel Filler: The pure nickel filler metal was very effective at preventing carbon migration. No evidence of a carbon-depleted layer or any chromium carbide precipitation was observed in the aged sample. See Figure 3.

Conclusions
1. The ratio of nickel to chromium in weld filler metals appears to be an important factor in preventing carbon migration.
2. A nickel to chromium ratio of approximately 0.5:1 in the 308L filler metal is susceptible to carbon migration and thus possible creep failures.
3. A nickel to chromium ratio of approximately 2:1 in the Hastelloy X filler metal is effective at preventing carbon migration and thus would protect against creep failures.
4. A nickel to chromium ratio of approximately infinity in the pure nickel filler metal is effective at preventing carbon migration and thus would protect against creep failures.
5. It can be concluded that there is a ideal ratio of nickel to chromium (somewhere between 0.5:1 and 2:1) that would be effective at preventing carbon migration.

Table 1 - Typical compositions (%) of key alloy elements for ASTM A-53 pipe, and three filler metals.

Figure 1 - Fusion line of weld made using 308L filler metal. In the aged sample, note the extensive chromium carbide precipitation (black band) drawn into the weld metal. Consequently this has left a lighter carbon-depleted zone in the base metal adjacent to the fusion line. The nickel to chromium ratio of 0.5:1 was not effective at preventing carbon migration across the fusion line.

Figure 2 - Fusion line of the weld made using Hastelloy X filler metal. There was no observable change in the appearance of the fusion line. No chromium carbide precipitation or carbon depletion zone was observed in either the aged or un-aged samples. The nickel to chromium ratio of 2:1 in Hastelloy X filler metal was effective at preventing carbon migration across the fusion line.

Figure 3 - Fusion line of the weld made using commercially pure nickel filler metal. There was no observable change in the appearance of the fusion line. No chromium carbide precipitation or carbon depletion zone was observed in either the aged or un-aged samples. The nickel to chromium ratio of nearly infinity in commercially pure filler metal was effective at preventing carbon migration across the fusion line.

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