INTRODUCTION

The dissimilar welding is advantageous for Oil & Gas industries to develop complex equipment. The technique allows us to combine the best properties of the materials chosen. It is very used to manufacture pipelines high strength low alloy steel (HSLs) pipe with Ni-based inner cladding. However, the mixture of different materials may cause solidification cracks [1]. Thus, an appropriate selection of materials is required to avoid defects. In this context, the CALPHAD method was successfully used to select materials for dissimilar welding joint a HSLS pipe with Alloy 625 inner cladding. The Scheil model was used to simulate the solidification of a high-strength low alloy (HSLA) steel when diluted with Ni-based alloys, in order to select the Ni-based alloy most indicated to application.

EXPERIMENTAL PROCEDURE

The present study investigated the metallurgical compatibility of a HSLA when mixed with Ni-based alloys, in order to select materials for dissimilar welding of cladded pipes used to manufacture pipelines. The HSLA assessed was the welding steel consumable AWS ER100S-G that was designed to achieve at least 100 ksi or 689 MPa. Two Ni-Cr-Mo alloys were investigated, the traditional Alloy 625 and the Alloy 686. Both alloys represent the family of corrosion resistant Ni-based alloys commonly recommended for several oxidizing and reduction environments, mainly the Alloy 686 which has an exception corrosion resistant to pitting corrosion. The chemical composition of the 100S-G steel, Alloy 625 and Alloy 686 are shown in Table 1.

Table 1. Chemical composition of the materials used.

<table>
<thead>
<tr>
<th>Chemical composition</th>
<th>Alloy/Elem.</th>
<th>C</th>
<th>Co</th>
<th>Cr</th>
<th>Cu</th>
<th>Fe</th>
<th>Mo</th>
<th>Ni</th>
<th>P</th>
<th>S</th>
<th>Si</th>
<th>Ti</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>100S-G steel</td>
<td>0.04</td>
<td>0.12</td>
<td>0.11</td>
<td>Ball. 1.3</td>
<td>0.38</td>
<td>0.82</td>
<td>-</td>
<td>0.055</td>
<td>0.014</td>
<td>0.042</td>
<td>0.13</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Alloy 625</td>
<td>0.1</td>
<td>0.06</td>
<td>21.67</td>
<td>0.09</td>
<td>8.81</td>
<td>Ball. 3.73</td>
<td>0.002</td>
<td>0.015</td>
<td>-</td>
<td>0.02</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alloy 686</td>
<td>0.01</td>
<td>0.05</td>
<td>20.66</td>
<td>0.38</td>
<td>0.24</td>
<td>16.40</td>
<td>Ball. 0.02</td>
<td>0.015</td>
<td>-</td>
<td>0.06</td>
<td>3.98</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To assess the metallurgical compatibility it was supposed six dilution levels between the HSLA and each Ni-based alloy: 0% (pure HSLA), 5%, 10%, 15%, 20%, 30%, 40% and 50%. Each mixture condition was simulated using the classical solidification model of Scheil-Gulliver [4]. The model was implemented in ThermoCalc 2017b software, which is based on the CALPHAD method. It used the database TCFX8, once even the higher mixture condition with the Ni-based alloys kept the Iron as the major element.

RESULTS AND DISCUSSION

The results obtained for each dilution condition was combined and assessed based on the evolution of initial solidification temperature (T_s), final solidification temperature (T_f) and solidification temperature range (ΔT). The simulated results of the mixture condition for Alloy 625 and Alloy 686 are shown in Figure 1.

Figure 1. Simulated results of the 100S-G steel when diluted with the Ni-based alloys: a) Alloy 625 and b) Alloy 686.

The results predicted a large ΔT for mixture conditions with Alloy 625, while narrow ΔT for mixture conditions with Alloy 686 was predicted. Due to the microsegregation, low melting point phases like Laves phase were responsible for this behavior [3,4]. This feature increases the cracking susceptibility since the remaining metal liquid experiences a high strain at the final of solidification [1]. These results were confirmed in welding experiments (Figure 2).

Figure 2. Scheil simulation and microstructure for the HSLA cladded with a) the Alloy 625 and b) the Alloy 686. The results highlighted the solidification cracking observed due to microsegregation and nucleation of low melting phases like Laves phase.

CONCLUSIONS

- The simulated results based on CALPHAD method successful pointed out the Alloy 686 as the most recommended for the dissimilar welding with AWS ER100S-G steel (HSLA);
- The welding experiments confirmed a high cracking susceptibility for the Alloy 625 mixture conditions and an opposite tendency for the Alloy 686 mixture conditions.

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REFERENCES