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Subject: Experimental Hastelloy-N Filler Metals

Eight experimental alloys were submitted to the Welding and Brazing Laboratory for a cursory investigation of their applicability as filler metals for joining Hastelloy N. The alloys were analyzed and their chemical compositions are given in Table 1. It should be noted that their analyses are similar to each other and to the nominal Hastelloy-N composition. The major difference between the various alloys is indicated in the last column, "Others."

Because of our previous experience with filler metal from heat No. 7320, we have included this analysis in this investigation. The base metal chosen is MSRE grade, heat No. 5065. (Its analysis is given in Table 1.) It is 1 1/2-in.-thick plate and it was cut into 1/2-in.-wide strips. The gas-tungsten arc (GTA) process was employed, and the experimental alloys were used as filler metals in bead-on-plate welds. The slices were laid on their sides (the sawed surface up) and bead-on-plate welds made on the 1/2-in.-thick by 1 1/2-in.-wide base metal. The welding was done manually, using the GTA process with cold wire feed. All of the welds were made under identical parameters. We intended to employ two passes; however, due to excessive cracking in the first pass of alloy No. 185, no additional work was done with this alloy. Figure 1 (Y-95033) is a photograph of the weld made with alloy No. 185. Cracks are easily discernible in this picture.

Alloys Nos. 231 and 236 both contained crater cracks as a result of welding. In addition, alloy No. 236 contained weld metal cracks. Figures 2 (Y-95032, Y-95035) and 3 (Y-95031, Y-95036) contain photographs of welds made with alloys Nos. 231 and 236, respectively. The crater cracks are evident in both figures.

The remaining welds were all acceptable. This includes a weld made with filler metal from heat No. 7320, a heat which will live in infamy. Figure 4 (Y-95030) contains a photograph of the weld deposits made with heat No. 7320. Each of the weld-metal deposits are noteworthy for various reasons;
Table 1. Chemical Analysis of Experimental Hastelloy-N Filler Metals

<table>
<thead>
<tr>
<th>Alloy Identification</th>
<th>Ni</th>
<th>Mo</th>
<th>Cr</th>
<th>Fe</th>
<th>Mn</th>
<th>C</th>
<th>Si</th>
<th>Others</th>
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<tbody>
<tr>
<td>185</td>
<td>Bal</td>
<td>11</td>
<td>5.9</td>
<td>3.8</td>
<td>0.46</td>
<td>0.05</td>
<td>0.10</td>
<td>0.91 Ti</td>
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<tr>
<td>188</td>
<td>Bal</td>
<td>13</td>
<td>7.3</td>
<td>4.5</td>
<td>0.49</td>
<td>0.05</td>
<td>0.15</td>
<td>0.95 Al</td>
</tr>
<tr>
<td>231</td>
<td>Bal</td>
<td>12</td>
<td>7.0</td>
<td>4.2</td>
<td>0.03</td>
<td>0.05</td>
<td>0.12</td>
<td>1.3 Hf</td>
</tr>
<tr>
<td>232</td>
<td>Bal</td>
<td>13</td>
<td>8.0</td>
<td>4.5</td>
<td>&lt;0.02</td>
<td>0.05</td>
<td>0.12</td>
<td>1.2 Hf</td>
</tr>
<tr>
<td>236</td>
<td>Bal</td>
<td>10</td>
<td>6.5</td>
<td>4.2</td>
<td>0.54</td>
<td>0.05</td>
<td>0.13</td>
<td>1.0 Al</td>
</tr>
<tr>
<td>237</td>
<td>Bal</td>
<td>12</td>
<td>6.7</td>
<td>4.3</td>
<td>0.49</td>
<td>0.05</td>
<td>0.13</td>
<td>1.03 Nb</td>
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<tr>
<td>68688</td>
<td>Bal</td>
<td>13.8</td>
<td>5.0</td>
<td>0.50</td>
<td>0.078</td>
<td>0.40</td>
<td>0.02 Ti</td>
<td>OK</td>
</tr>
<tr>
<td>68689</td>
<td>Bal</td>
<td>14.0</td>
<td>7.6</td>
<td>4.88</td>
<td>0.47</td>
<td>0.078</td>
<td>0.50</td>
<td>0.45 Ti</td>
</tr>
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<td>7320</td>
<td>Bal</td>
<td>12.4</td>
<td>7.8</td>
<td>0.25</td>
<td>0.14</td>
<td>0.066</td>
<td>0.02</td>
<td>0.56 Ti</td>
</tr>
<tr>
<td>5065</td>
<td>Bal</td>
<td>16.5</td>
<td>7.2</td>
<td>3.9</td>
<td>0.55</td>
<td>0.065</td>
<td>0.60</td>
<td>0.01 Al</td>
</tr>
</tbody>
</table>

weld deposits from alloys Nos. 188 and 68689 were "dirty." Each contains excessive amounts of foreign material which "floated" to the surface and originated in the filler wire. These two filler metals both contained great amounts of highly oxidizable elements, aluminum and titanium plus silicon, respectively. Figures 5a (Y-95028) and 5b (Y-95029), respectively, contain photographs of welds from alloys Nos. 188 and 68689. Weld beads from alloy No. 68688 also contained some "dirt." This is evident in Fig. 6 (Y-95034). Alloy No. 68688 is high in silicon, a strong deoxidizer. Welds made from alloy No. 237 produced quite clean weld beads; however, alloy No. 232 was the cleanest and is outstanding in this respect. Figures 7 (Y-95026) and 8 (Y-95027) contain photographs from welds made with alloys Nos. 237 and 232, respectively.

I have metallographically examined the welds reported above. Figure 9 is representative of those weldments that did not contain cracks. These are welds made with filler alloys Nos. 188, 232, 237, 68688, 68689, and 7320. The microstructure of the individual alloys may vary due to differences in precipitates and their distribution; however, the base metal and fusion line heat-affected zones are quite similar. Figure 9a (Y-95014) is a photomicrograph of weld metal from alloy No. 188. The cast structure is evident as are
the grain boundaries of the weld metal. No cracks are seen. Figure 9b (Y-95913) is typical of the base metal (heat No. 5065) employed in this study. This base metal is Hastelloy N (Ni-16 Mo-7 Cr-4 Fe, wt %) and does contain the precipitates that are common in this alloy. The liquation of the precipitates that has been reported previously on numerous occasions is particularly evident in this study. Figure 9c (Y-95912) represents the type of structure seen in all of these welds. It should be noted, however, that no cracks are present and the heat-affected zone is sound and quite acceptable.

The weld made with filler alloy No. 185 was the most crack-sensitive, and this is evident in the photograph shown in Fig. 1 and in the macrograph in Fig. 10 (Y-95902). Cracking in this weld metal occurred in the first pass and was both longitudinal and transverse. The cracking, although severe, was contained almost wholly within the weld metal. Figures 11a (Y-95904) and 11b (Y-95903) are photomicrographs of representative transverse and longitudinal cracks, respectively. It can be seen, particularly in Fig. 11b, that the cracks were arrested at the heat-affected zone.

Alloy No. 236 produced primarily transverse cracks. These can be seen in Fig. 12 (Y-95907). Cracking occurred in the weld metal of the second pass and in the craters of both weld passes. Figure 13 (Y-95905, Y-95906) typifies the cracks seen in weldments made with alloy No. 236.

The alloy that produced the most heat-affected-zone cracks (and, of those that cracked, the least weld-metal cracks) was No. 231. Figures 14a (Y-95910) and 14b (Y-95909) show that the most severe cracking occurred in the heat-affected zone, and the weld metal showed only minor cracking tendencies. It is possible that the yttrium liquated the grain boundaries and resulted in their cracking.

Based on the cursory weldability study described above, my first choice as a filler metal would be alloy No. 232 and, second, No. 237. The presence of the approximately 0.5% Mn may be responsible for the slight amount of dross noted on weld No. 237. I would definitely shy away from those alloys that produced cracks in this study. These are alloys Nos. 185, 231, and 236. It should be noted that filler metal from heat No. 7320 is included in the "acceptable" group; however, one must bear in mind that the exploratory study employed a bead-on-plate technique on an unrestrained base metal. If sufficient filler metal had been available to prepare complete weldments on fully restrained base metal, it is obvious that more alloys would have fallen into the "unacceptable" category.
Fig. 1. Photograph of Bead-On-Plate Weld Made with Filler Metal From Alloy No. 185. Note hairline cracks in weld metal and in the crater (weld stop). Due to severe cracking, only one pass was employed in this alloy evaluation.
Fig. 2. Photographs of Weld Metal Deposited from Alloy No. 231. Note the dross in the weld bead (a) and the crater cracks (b).
Fig. 3. Photographs of Weld Metal Deposited from Alloy No. 236. The crater-crack produced in this weldment is evident in (b). Cracks are also present in the bead seen in (a).
Fig. 4. Weld Beads Deposited With Filler Metal From Heat No. 7320. No cracks and very little dross was produced.

(a) Y-95028

(b) Y-95029

Fig. 5. Weld Metal Deposited from Alloys Nos. 188 (a) and 68689 (b). These two filler metals produced the most dross containing weld deposits; however, they did not contain any cracks.
Fig. 6. Weld Metal Deposited from Alloy No. 68688.

Fig. 7. Weld Metal Deposited from Alloy No. 237. This was rated as the second cleanest weld metal.

Fig. 8. Weld Metal Deposited from Alloy No. 232. This filler alloy was judged the most clean. It also was in the "acceptable" group of filler metals (those that did not produce cracks) and, on the basis of this cursory investigation, is considered the best alloy of those studied.
Fig. 9. Photomicrographs Representative of Weldments That Did Not Contain Any Cracks. (a) is a photomicrograph of weld metal deposited from alloy No. 188. The only difference between the weld metals will be in the amount and distribution of the second phase. (b) is a photomicrograph of the unaffected base metal (heat No. 5065). (c) is a photomicrograph of an area of the heat-affected zone from the weld made with alloy No. 188. The great quantities of the precipitate common to Hastelloy N can be seen. The liquation of this precipitate and the resultant lamellar structure after it has solidified is evident.
Fig. 10. Photomacrographs of the Cracks, All of Which are Contained Within the Weld Metal, Produced by Filler Alloy No. 185. The upper macrograph shows the greatest number of traverse cracks. The lower illustrates the degree of longitudinal cracking encountered with this alloy.
Fig. 12. Photomacrographs of the Weld Metal Produced from Alloy No. 236. The cracks produced in this weld are predominantly transverse and are contained within the weld metal.
Fig. 14. Photomicrographs of the Heat-Affected Zone From the Welds Made with Alloy No. 231. This filler metal, out of all studied, resulted in the most heat-affected-zone cracks. The severity of the cracking is particularly evident in (a).