Study of Austenitic Stainless Steel Welded With Low Alloy Steel Filler Metal

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INTRODUCTION

The purpose of this study is to determine the mechanical properties and the corrosion resistance of austenitic stainless steel welded with low alloy steel filler metal. It was reported to the Malfunction Investigation Staff (MIS) that uncoated low alloy steel filler metal had been inadvertently used to weld an austenitic stainless steel manifold. It is the conventional practice to weld the austenitic stainless steels with austenitic stainless filler metal, usually of the same or similar composition. For example, AISI* type 316 stainless steel is often welded with 316L filler metal ("L" denotes low carbon, 0.03% maximum carbon content).

Since the as-welded composition of the discrepant welds was not immediately available, it was approximated by calculation. It was determined from these calculations that the use of the low alloy steel filler metal would dilute the chromium content from 18% to 8% and the nickel from 12% to 7%. A search of the literature revealed no data on the impact strength and tensile properties of alloys containing 8% to 12% chromium and 7% to 12% nickel. Information on the most closely related industrial alloys, the 400-series stainless steels (which contain 12% chromium and less than 5% nickel), warns that these steels have limited ductility in the as-welded condition particularly at cryogenic temperatures. The manifold and many of the austenitic stainless steel weldments used in cryogenic systems and other ground support equipment (GSE) at Kennedy Space Center (KSC) are of necessity used in the as-welded condition, i.e., without further postweld heat treatment.

It was recognized that the discrepant welds contained a considerable amount of nickel, which would probably prevent the degree of low temperature embrittlement exhibited by the 400-series alloys. However, the lack of data on the impact properties of the discrepant weld compositions plus their lowered chromium content (which could significantly reduce corrosion resistance), were of concern.

It was later possible to obtain a segment of the discrepant welded manifold. Tensile and subsize (dictated by wall thickness) impact specimens were

*American Iron and Steel Institute
prepared from the weldments. Specimens were prepared for corrosion resistance
tests at the corrosion site at KSC. However, a weld development program was
initiated to provide impact, tensile strength, and corrosion test data from
standard size test specimens machined from weldments of austenitic stainless
steel plate joined with low-alloy steel filler metal. The chemical composi-
tion of the weld chemistry was varied to cover the expected variations of weld
chemistry likely to be produced by the inadvertent use of the discrepant fil-
ler metal.

EVALUATION OF THE MANIFOLD WELDMENTS

The discrepant manifold had been fabricated in 1976 utilizing tubular
pipe segments from manifolds manufactured and used earlier in the Apollo/
Saturn program, and a tee casting purchased in 1976. The test manifold con-
tained 12 girth (circumferential) welds (see Figure 1).

The manifold was hydrotested at the Development Testing Laboratory. The
3-inch diameter schedule 40-pipe section burst at 9,000 psig hydraulic pres-
sure, equivalent to a tensile strength of 75,000 psi. The failure did not
originate at a weld. This strength level is considered satisfactory for an-
nealed type 316L stainless steel pipe.

Samples for the pipe, the tee casting and the 12 weldments were analyzed
chemically for alloy makeup. Figure 2 shows a typical sample. The results,
as determined by the atomic absorption technique, are listed in Table 1.

The lower than normal chromium, nickel, and molybdenum analyses for some
of the weldments were: W-4, W-7, W-8, W-9, and W-10 (identified in Figure 1). The analyses indicated a reduction of these elements through dilution of the
316 stainless steel parent metal by the low alloy filler metal, as predicted
by the previously mentioned calculations. Visual examination of the manifold
showed that the surface finish of each of these welds was bright and clean,
indicating the possibility that they had been recently fabricated. The other
weldments (W-1, W-2, W-3, W-5, W-6, W-11, and W-12 in Figure 1) had higher
chromium, nickel, and molybdenum analyses, nominal for 316 stainless steel.
FIGURE 1
Manifold (3" pipe welded to tee casting) showing location of welds
FIGURE 2
Photomacrograph of manifold pipe to tee weldment.

Scribe mark indicates line of filing samples analyzed for chromium, molybdenum and nickel by semi-quantitative techniques. Magnification: 10X
### TABLE 1

Chemical Composition (%) of Manifold Weldments
Analysis of Filings as Determined by Semi-quantitative Techniques

<table>
<thead>
<tr>
<th>Description</th>
<th>Percentage Composition</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Molybdenum</td>
<td>Chromium</td>
</tr>
<tr>
<td>W-1</td>
<td>2.1</td>
<td>19.7</td>
</tr>
<tr>
<td>W-2</td>
<td>1.2</td>
<td>16.5</td>
</tr>
<tr>
<td>W-3</td>
<td>2.0</td>
<td>18.4</td>
</tr>
<tr>
<td>W-4 (new)</td>
<td>1.5</td>
<td>8.3</td>
</tr>
<tr>
<td>W-5</td>
<td>1.6</td>
<td>17.5</td>
</tr>
<tr>
<td>W-6</td>
<td>1.4</td>
<td>18.5</td>
</tr>
<tr>
<td>W-7 (new)</td>
<td>1.2</td>
<td>9.7</td>
</tr>
<tr>
<td>W-8 (new)</td>
<td>0.9</td>
<td>9.8</td>
</tr>
<tr>
<td>W-9 (new)</td>
<td>1.0</td>
<td>7.3</td>
</tr>
<tr>
<td>W-10 (new)</td>
<td>1.0</td>
<td>12.7</td>
</tr>
<tr>
<td>W-11</td>
<td>1.6</td>
<td>18.3</td>
</tr>
<tr>
<td>W-12</td>
<td>1.5</td>
<td>19.6</td>
</tr>
<tr>
<td>3&quot; Pipe PM</td>
<td>1.3</td>
<td>16.7</td>
</tr>
<tr>
<td>Tee Casting PM</td>
<td>1.3</td>
<td>18.8</td>
</tr>
<tr>
<td>BS160a</td>
<td>2.5</td>
<td>19.4</td>
</tr>
<tr>
<td>BS160a*</td>
<td>2.8</td>
<td>19.7</td>
</tr>
<tr>
<td>Low alloy weld wire*</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Type 316*</td>
<td>3.0</td>
<td>18.0</td>
</tr>
<tr>
<td>Type 410*</td>
<td>0.7</td>
<td>12.7</td>
</tr>
<tr>
<td>Type 420*</td>
<td>0.1</td>
<td>13.1</td>
</tr>
<tr>
<td>Type 430*</td>
<td>0.1</td>
<td>16.0</td>
</tr>
</tbody>
</table>

*Typical or nominal
The appearance of the higher alloy weldments was dull compared to the aforementioned weldments, indicating they had been welded earlier. These welds had a different weave pattern, indicating a different welding technique or operator.

On the basis of the chemical composition and appearance, it is assumed that weldments W-1, W-2, and W-3 were welded during the original fabrication of an older manifold. Similarly, weldments W-5 and W-6 joined a 45° bend to a length of the 3-inch diameter pipe in an older manifold. These two segments were recently joined at weldment W-4 to form a larger segment welded to one branch of the tee at weldment W-7. Also, weldments W-11 and W-12 are assumed to be older welds of an original manifold segment. The line containing these welds was joined to the tee casting at weldment W-10. Weldments W-9 and W-8 appear to be recent welds, adding the 90° elbow and an end fitting to complete the manifold. On the basis of this hypothesis, weldments W-4, W-7, W-8, W-9, and W-10 are referred to as "new" and the other seven welds as "old" in the remainder of this report.

Tensile and impact test specimens were machined from manifold weldments W-4 (new) and W-11 (old). The tensile tests were performed at room temperature. The impact tests were performed at room temperature and at minus 100°F. The minus 100°F was achieved by conditioning the samples in a bath maintained at minus 100°F. The results are presented in Tables 2 and 3.

The limited tensile test data indicated that both the new and old weldments were satisfactory. Failure occurred in the parent metal.

It was felt that impact test data derived from standard (10 mm x 10 mm) Charpy Vee specimens were essential for a significant evaluation of the impact properties of the discrepant stainless steel weldments. Since full-size impact specimens could not be obtained from the manifold, a welding plan was formulated using 1/2-inch (12.7-mm) thick annealed type 316L stainless steel plate, welded according to a procedure similar to the one used for welding the original manifold (pipe to tee to pipe) weldments. The welding plan is included in Appendix A.
### TABLE 2

**Modified Charpy Vee Impact Tests of Manifold Weldments**

Subsize specimens used were 5 mm x 5 mm

<table>
<thead>
<tr>
<th>Room Temperature Tests</th>
<th>AIE*** ft.-lbs.</th>
<th>Tests at -100°F**</th>
<th>AIE*** ft.-lbs.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sample No.</strong></td>
<td><strong>PM No.</strong></td>
<td><strong>Sample No.</strong></td>
<td><strong>W No.</strong></td>
</tr>
<tr>
<td>PM*1</td>
<td>33</td>
<td>PM 6</td>
<td>32</td>
</tr>
<tr>
<td>PM 2</td>
<td>32</td>
<td>PM 7</td>
<td>29</td>
</tr>
<tr>
<td>PM 3</td>
<td>30</td>
<td>PM 8</td>
<td>30</td>
</tr>
<tr>
<td>PM 4</td>
<td>31</td>
<td>PM 9</td>
<td>31</td>
</tr>
<tr>
<td>PM 5</td>
<td>31</td>
<td>PM 10</td>
<td>29</td>
</tr>
<tr>
<td>Average PM</td>
<td>31</td>
<td></td>
<td>30</td>
</tr>
<tr>
<td>W 4-1</td>
<td>16</td>
<td>W 4-6</td>
<td>12</td>
</tr>
<tr>
<td>W 4-2</td>
<td>17</td>
<td>W 4-7</td>
<td>10</td>
</tr>
<tr>
<td>W 4-3</td>
<td>12</td>
<td>W 4-8</td>
<td>11</td>
</tr>
<tr>
<td>W 4-4</td>
<td>13</td>
<td>W 4-9</td>
<td>11</td>
</tr>
<tr>
<td>W 4-5</td>
<td>17</td>
<td>W 4-10</td>
<td>16</td>
</tr>
<tr>
<td>Average W 4</td>
<td>15</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>W 11-1</td>
<td>27</td>
<td>W 11-6</td>
<td>25</td>
</tr>
<tr>
<td>W 11-2</td>
<td>25</td>
<td>W 11-7</td>
<td>25</td>
</tr>
<tr>
<td>W 11-3</td>
<td>26</td>
<td>W 11-8</td>
<td>29</td>
</tr>
<tr>
<td>W 11-4</td>
<td>29</td>
<td>W 11-9</td>
<td>29</td>
</tr>
<tr>
<td>W 11-5</td>
<td>30</td>
<td>W 11-10</td>
<td>27</td>
</tr>
<tr>
<td>Average W 11</td>
<td>27</td>
<td></td>
<td>27</td>
</tr>
</tbody>
</table>

*PM = parent metal

**Specimens cooled to -100°F**

***AIE = absorbed impact energy
<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Tensile Strength (psi)</th>
<th>% Elong. in 2 in.</th>
<th>Location of Fracture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ultimate</td>
<td>0.2% Yield</td>
<td></td>
</tr>
<tr>
<td>Parent Metal 1</td>
<td>97,800</td>
<td>76,760</td>
<td>46 Middle of gage length</td>
</tr>
<tr>
<td>Parent Metal 2</td>
<td>95,900</td>
<td>78,550</td>
<td>57 Middle of gage length</td>
</tr>
<tr>
<td>Parent Metal 3</td>
<td>97,800</td>
<td>79,900</td>
<td>39 Middle of gage length</td>
</tr>
<tr>
<td>Average</td>
<td>96,100</td>
<td>78,400</td>
<td>47 Middle of gage length</td>
</tr>
<tr>
<td>Weld 4A</td>
<td>105,700</td>
<td>85,500</td>
<td>20 Weld</td>
</tr>
<tr>
<td>Weld 4B</td>
<td>94,900</td>
<td>68,800</td>
<td>20 Heat-affected zone (PM)</td>
</tr>
<tr>
<td>Weld 4C</td>
<td>96,300</td>
<td>71,000</td>
<td>21 Heat-affected zone (PM)</td>
</tr>
<tr>
<td>Average</td>
<td>97,000</td>
<td>75,100</td>
<td>20</td>
</tr>
<tr>
<td>Weld 11A</td>
<td>88,500</td>
<td>73,000</td>
<td>20 Weld</td>
</tr>
<tr>
<td>Weld 11B</td>
<td>87,500</td>
<td>73,000</td>
<td>20 &quot;</td>
</tr>
<tr>
<td>Weld 11C</td>
<td>94,500</td>
<td>75,600</td>
<td>28 Heat-affected zone (PM)</td>
</tr>
<tr>
<td>Average</td>
<td>90,200</td>
<td>73,900</td>
<td>23</td>
</tr>
</tbody>
</table>

*3" Schedule-30 pipe: average wall thickness--0.190 inch
Specimens machined 3/4" wide in 2" gage length; welds machined flush
WELDING PROGRAM

The program was planned to report on the following conditions:

A. Worst condition--Low alloy filler metal would be used for all but the
   initial or root pass. (The root pass would be made with 316L weld
   filler metal. It is the usual practice to incorporate a 316L insert
   in stainless steel pipe welding. The use of the 316L filler metal
   for the first pass is in lieu of the insert.)

B. Intermediate condition--The initial passes, 1, 2, and 3, were to be
   316L filler metal. The final two passes on each side were to be the
   low alloy steel filler metal.

C. Best condition--The 316L plate was to be welded with 316L filler
   metal on all passes.

The AISI type 316L stainless steel plate was machined into panels accord-
   ing to the joint design and configuration shown in Phase I and Figure 1 of
   Appendix A. These panels were welded according to the schedules listed in
   Phase II of Appendix A. Welding process data sheets for conditions A, B, and
   C welded panels are in Appendix B. All welds were radiographically inspected
   and found acceptable according to KSC specification, Z-0003B.

Samples of weld metal from panels A, B, and C were analyzed by emission
   spectrographic and combustion techniques (see Table 4). The variation in
   chemical composition of chromium, molybdenum, and nickel of these weld metals
   closely approximates the composition of the old and new manifold weldments.

Sections from each panel were prepared for macro- and micro-examination.
   All welds were sound, with complete penetration.

   One face-guided bend and one side bend test specimen were machined from
   each of the three panels A, B, and C. The bend tests were performed satisfac-
   torily. No defects were found after 180° bends to the prescribed radius for
   the 1/2-inch plate.

   Ten standard Charpy Vee impact specimens were machined from the parent
   metal plate and weldments A, B, and C. Five tests from each group were con-
   ducted at room temperature and five tests at minus 100°F. The test results
   are listed in Table 5.
### TABLE 4

Chemical Composition (%) of 1/2 Inch Plate Weldments
Analysis as determined by emission spectrographic and combustion techniques

<table>
<thead>
<tr>
<th>Description</th>
<th>Chromium</th>
<th>Nickel</th>
<th>Molybdenum</th>
<th>Manganese</th>
<th>Silicon</th>
<th>Carbon</th>
<th>Sulfur</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate</td>
<td>18.45</td>
<td>10.92</td>
<td>2.02</td>
<td>0.89</td>
<td>0.22</td>
<td>0.024</td>
<td>0.022</td>
</tr>
<tr>
<td>Weld A (top)</td>
<td>11.76</td>
<td>6.51</td>
<td>1.65</td>
<td>0.90</td>
<td>0.27</td>
<td>0.024</td>
<td>0.021</td>
</tr>
<tr>
<td>Weld A (bottom)</td>
<td>9.20</td>
<td>5.50</td>
<td>0.73</td>
<td>0.92</td>
<td>0.35</td>
<td>0.024</td>
<td>0.023</td>
</tr>
<tr>
<td>Weld B (top)</td>
<td>10.05</td>
<td>6.69</td>
<td>1.07</td>
<td>1.14</td>
<td>0.41</td>
<td>0.021</td>
<td>0.021</td>
</tr>
<tr>
<td>Weld B (bottom)</td>
<td>10.89</td>
<td>6.53</td>
<td>0.93</td>
<td>0.90</td>
<td>0.37</td>
<td>0.020</td>
<td>0.022</td>
</tr>
<tr>
<td>Weld C (all)</td>
<td>18.77</td>
<td>11.29</td>
<td>2.02</td>
<td>1.40</td>
<td>0.41</td>
<td>0.034</td>
<td>0.023</td>
</tr>
</tbody>
</table>
TABLE 5
Standard Charpy Vee Impact Tests of 1/2 Inch Plate Weldments

<table>
<thead>
<tr>
<th>Room Temperature Tests</th>
<th>AIE***</th>
<th>Tests at -100°F**</th>
<th>AIE***</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample No.</td>
<td>ft.-lbs.</td>
<td>Sample No.</td>
<td>ft.-lbs.</td>
</tr>
<tr>
<td>PM*1</td>
<td>88</td>
<td>PM 6</td>
<td>74</td>
</tr>
<tr>
<td>PM 2</td>
<td>89</td>
<td>PM 7</td>
<td>76</td>
</tr>
<tr>
<td>PM 3</td>
<td>88</td>
<td>PM 8</td>
<td>72</td>
</tr>
<tr>
<td>PM 4</td>
<td>90</td>
<td>PM 9</td>
<td>72</td>
</tr>
<tr>
<td>PM 5</td>
<td>91</td>
<td>PM 10</td>
<td>73</td>
</tr>
<tr>
<td>Average PM</td>
<td>89</td>
<td></td>
<td>73</td>
</tr>
<tr>
<td>Weld A 1</td>
<td>60</td>
<td>Weld A 6</td>
<td>57</td>
</tr>
<tr>
<td>Weld A 2</td>
<td>77</td>
<td>Weld A 7</td>
<td>45</td>
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<tr>
<td>Weld A 3</td>
<td>88</td>
<td>Weld A 8</td>
<td>58</td>
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<tr>
<td>Weld A 4</td>
<td>78</td>
<td>Weld A 9</td>
<td>48</td>
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<tr>
<td>Weld A 5</td>
<td>88</td>
<td>Weld A 10</td>
<td>41</td>
</tr>
<tr>
<td>Average Weld A</td>
<td>78</td>
<td></td>
<td>50</td>
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<tr>
<td>Weld B 1</td>
<td>77</td>
<td>Weld B 6</td>
<td>53</td>
</tr>
<tr>
<td>Weld B 2</td>
<td>90</td>
<td>Weld B 7</td>
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<tr>
<td>Weld B 3</td>
<td>89</td>
<td>Weld B 8</td>
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<td>Weld B 4</td>
<td>91</td>
<td>Weld B 9</td>
<td>51</td>
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<tr>
<td>Weld B 5</td>
<td>75</td>
<td>Weld B 10</td>
<td>60</td>
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<tr>
<td>Average Weld B</td>
<td>84</td>
<td></td>
<td>54</td>
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<tr>
<td>Weld C 1</td>
<td>88</td>
<td>Weld C 6</td>
<td>73</td>
</tr>
<tr>
<td>Weld C 2</td>
<td>89</td>
<td>Weld C 7</td>
<td>74</td>
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<tr>
<td>Weld C 3</td>
<td>88</td>
<td>Weld C 8</td>
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<tr>
<td>Weld C 4</td>
<td>88</td>
<td>Weld C 9</td>
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<tr>
<td>Weld C 5</td>
<td>89</td>
<td>Weld C 10</td>
<td>73</td>
</tr>
<tr>
<td>Average Weld C</td>
<td>88</td>
<td></td>
<td>71</td>
</tr>
</tbody>
</table>

* = parent metal
** Specimens cooled to -100°F
***AIE = absorbed impact energy
The standard Charpy Vee impact specimens all failed, by design, at the center of the weld. These specimens reflect the effect of the difference in chemical composition on the mechanical properties of the material. The specimens machined from Panel A, the worst condition weldment, had an average impact toughness of 78 ft. lb. at room temperature and 50 ft. lb. at minus 100°F. The lowest single value was 41 ft. lb. at minus 100°F, which is considered an acceptable toughness level for a sound structural material. The ductile failure characteristics of the impact specimens are shown in Figures 3 and 4.

Five tensile test specimens were machined from each panel and tested. All the tensile specimens failed in the parent metal. The test values for ultimate and 0.2%-yield tensile strength were essentially the same for panels A, B, and C (see Table 6). The low alloy steel weldment A had 50% elongation, compared to 60% for the all 316L weldment, C.

The tensile properties and the impact toughness of the 316L stainless steel plate welded with low alloy steel filler metal are satisfactory, compared with 316L stainless steel plate welded with 316 filler metal. No significant difference in the test properties was found.

Corrosion

Accelerated corrosion due to the reduction in chromium content was anticipated. Samples of the welded plate panels A, B, and C, and test specimens from the discrepant weld, W-7, were exposed to the marine environment at a corrosion test site at Launch Complex-39.

Figure 5 shows the extent of corrosion after 8 months' exposure of a tensile specimen A-3, from the 316L plate welded with low alloy filler metal, and weldment W-7, one of the newer test manifold welds containing low chromium and nickel. It was noted that the corrosion was heavier in the last weld passes (the first weld pass was 316L).
FIGURE 3
Fracture Surfaces
Fracture surfaces of Charpy Vee impact specimens of stainless steel plate weldments. Magnification: 7.5X
FIGURE 4
Ductile Weld Structure

Scanning electron photomicrographs of the fracture surfaces of Charpy impact specimens showing that the cast weld structure is ductile for sample A (the lower alloy weld) as well as the 316L weld sample C.
### TABLE 6
Tensile Tests of Three Weldments of 316L Stainless Steel 1/2 Inch Plate Welds machined flush with plate (t=.495" to .515")

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Tensile Strength (psi)</th>
<th>% Elong.</th>
<th>Location of Fracture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ultimate</td>
<td>0.2% Yield</td>
<td>in 2 in.</td>
</tr>
<tr>
<td>Weld A 1</td>
<td>85,800</td>
<td>45,200</td>
<td>47.5</td>
</tr>
<tr>
<td>&quot; A 2</td>
<td>86,600</td>
<td>43,800</td>
<td>50.2</td>
</tr>
<tr>
<td>&quot; A 3</td>
<td>84,600</td>
<td>43,900</td>
<td>55.0</td>
</tr>
<tr>
<td>&quot; A 4</td>
<td>85,500</td>
<td>44,700</td>
<td>54.0</td>
</tr>
<tr>
<td>&quot; A 5</td>
<td>85,200</td>
<td>44,700</td>
<td>51.5</td>
</tr>
<tr>
<td>Average A *</td>
<td>85,500</td>
<td>44,400</td>
<td>51.5</td>
</tr>
<tr>
<td>Weld B 1</td>
<td>85,500</td>
<td>46,000</td>
<td>52.5</td>
</tr>
<tr>
<td>&quot; B 2</td>
<td>85,600</td>
<td>45,700</td>
<td>54.0</td>
</tr>
<tr>
<td>&quot; B 3</td>
<td>85,300</td>
<td>45,600</td>
<td>55.0</td>
</tr>
<tr>
<td>&quot; B 4</td>
<td>85,400</td>
<td>45,000</td>
<td>54.0</td>
</tr>
<tr>
<td>&quot; B 5</td>
<td>86,000</td>
<td>45,800</td>
<td>50.0</td>
</tr>
<tr>
<td>Average B **</td>
<td>85,600</td>
<td>45,600</td>
<td>53.1</td>
</tr>
<tr>
<td>Weld C 1</td>
<td>84,300</td>
<td>47,000</td>
<td>62.5</td>
</tr>
<tr>
<td>&quot; C 2</td>
<td>84,000</td>
<td>45,900</td>
<td>57.5</td>
</tr>
<tr>
<td>&quot; C 3</td>
<td>84,300</td>
<td>45,300</td>
<td>61.0</td>
</tr>
<tr>
<td>&quot; C 4</td>
<td>85,600</td>
<td>44,600</td>
<td>60.0</td>
</tr>
<tr>
<td>&quot; C 5</td>
<td>84,500</td>
<td>45,500</td>
<td>59.0</td>
</tr>
<tr>
<td>Average C ***</td>
<td>84,500</td>
<td>45,600</td>
<td>60.0</td>
</tr>
</tbody>
</table>

* A First pass 316 SS; all other 7 passes low carbon steel filler metal
** B Passes 1-4 316 SS; passes 5-8 low carbon steel filler metal
*** C All Weld passes 316 SS
FIGURE 5
Specimen Corrosion

Samples photographed after 8 months exposure at a corrosion site at LC-39, near the Atlantic Ocean. Scale is centimeter.
Corrosion Protection

A section of the welded panel "A" was machined flush with the plate surface, chemically cleaned, and then painted with "Aerocoat AR-7" (a nitrile-based paint containing aluminum and used at KSC for protecting stainless steels from corrosion). After six months' exposure at the corrosion site, no significant corrosion damage was noted. After an additional six months' exposure, no further change was observed. This type of protection will be reevaluated after longer exposure.

SUMMARY

No significant reduction in tensile properties or loss of impact toughness was experienced as a result of welding 316L stainless steel with low alloy steel filler metal.

Accelerated corrosion due to the lower chromium content was experienced. However, nitrile-based paint containing aluminum powder applied to a cleaned bright surface weld has provided corrosion protection for at least 18 months.
APPENDIX A

Welding Test Plan
For the Metallurgical Evaluation of Stainless Steel
Using Carbon Steel Filler Metal

Phase I
Prepare six, 1/2"-thick 316 stainless steel plates, 9" to 10" long (long direction original manufacturer) by 24", joint machined as in Figure A-1.

Phase II
Three panels are to be welded to the same welding schedule with variations in filler metal as shown below and in Figures A-2 and A-3.

A. The first pass on each of the three panels is to be welded with Type 316 filler metal. This procedure has been adopted to replace the use of the stainless insert used on pipe welds (see View A, Figure A-3).
B. The weldment shall be cleaned with a stainless steel wire brush to remove surface oxides and contaminants after each pass.
C. Radiograph and turn over the panel. Grind root of first pass to clean, bright metal. Remove defects.
D. Weld passes 3, 4, and 5.
E. Turn panel again and weld passes 6 and 7. Weld again if necessary to produce a smooth reinforcement.

These types of weld filler metal (1/16"-diameter uncoated) are to be used:
A. Panel A: First pass to be welded with 316; all other passes to be welded with carbon steel alloy filler metal
B. Panel B: Passes 1, 2, 3, and 4 to be welded with 316 or 316L filler metal
   Passes 5, 6, and 7 to be welded with carbon steel low alloy filler metal (also pass 8, if required)
C. Panel C: All passes to be welded with 316L filler metal

Radiograph all welds; identify and locate all flaws according to KSC specification, Z-0003A.
Phase III
Machine one face guided bend, one side bend, five tensile, and ten Charpy Vee impact specimens in accordance with Figures A-4, A-5, A-6, and A-7.

Phase IV
Perform bend tests. Test five tensile specimens and five impact specimens from each panel at room temperature.

Phase V
Test five impact specimens from each panel cooled to minus 40°F (and held at this condition for 20 minutes). Specimens should be tested within 10 seconds after removal from Dewar flask.

Phase VI
Metallurgical evaluation consisting of macro- and micro-examination will be made on the welding passes, parent metal, and heat-affected zones. Chemical analysis will be performed on the individual passes at the Microchemical Analysis Laboratory.

Phase VII
Four joints are being prepared in a schedule-40, 3"-diameter 316 pipe. This pipe will be welded in the conditions required to supplement the data derived from this program.

Phase VIII
Specimens will be prepared for corrosion resistance testing. This program will be formulated after completing Phase VI.

Phase IX
Publish report.

Ray A. Dyke, Jr.
November 4, 1976
FIGURE A-1
Recommended Joint Preparation
1/2" Plate Welds
Suggested Sequence:

1. Weld land.
2. Wire brush with stainless steel brush.*
3. Weld second pass 1/16" diameter wire.
4. Turn over and grind or machine out first pass with mill or shaper, flush with land.
5. Weld 3rd, 4th, and 5th pass.
6. Turn plate over; weld 6th, 7th, and 8th passes as required.

*Wire brushing recommended after each pass.

FIGURE A-2
GTA (Horizontal Position)
Welded in 7 to 8 Passes
(1/16" diameter wire)
FIGURE A-3
Suggested Welding Sequence
Nominal Dimensions

Gage Length (G)  2.00 in.
Width (W)        0.75 in.
Thickness (T)    .50 in.
Grip Length (B)  3.00 in.
Grip Width (C)   1.50 in.
Total Length (L) 10.00 in.

FIGURE A-4
Recommended Tensile Specimen
FIGURE A-5
Charpy (Simple-Beam) Impact Test Specimen, Type A
Direction of plunger force applied at center of weld

Remove by machining

Overall length of specimen: 6" minimum

Machine weld (No. 5 or 7 pass) flush with plate surface

FIGURE A-6
Guided Face Bend Test Specimen
FIGURE A-7
Guided Side Bend
Test Specimen
APPENDIX B

Weld Test Specimen (A)
Welding Process Data Sheet

Date 1-4-77 Project SO-LAB-1 76-087

Material (Plate) S.S. 316L Thickness .50 Condition

Weld Surface Preparation Freon Joint Type Butt

Inspection Required N/A

Weld Power Supply AC/DC (TIG)

Weld Joint Sketch

Joint Values

Bevel Angle 37-1/2°
Root Face 3/32"
Root Opening None

Weld Current 165 Amp. Wire Size 1/16

Arc Voltage 24 Volt Wire Type 316 - Carbon Steel

Nozzle Type #7 No. of Passes 8

Tungsten Electrode: Type Thoriated (2%) Size 3/32"

Inert Gas, Type In: Argon

Nozzle Argon C.F.H. 15

Backup Argon C.F.H. 5

Backup Material N/A Groove Shape Double Vee Width .375" Depth .25"

Preheat Temp. N/A Post-Heat Temp. N/A

Interpass Temp. N/A

Welder Burns

Date 1-4-77

Inspection: Radiographic Acceptable 1-5-77

CARBON  316 S.S.

STEEL
APPENDIX B

Weld Test Specimen (B)
Welding Process Data Sheet

Date 1-6-77  Project  SO-LAB-1  76-087

Material (Plate) S.S. 316L Thickness .50  Condition

Weld Surface Preparation Freon  Joint Type Butt

Inspection Required N/A

Weld Power Supply AC/DC (TIG)

Weld Joint Sketch

Joint Values

Bevel Angle 45°
Root Face 1/16
Root Opening None

Weld Current 165 Amp.  Wire Size 1/16"

Arc Voltage 24 Volt  Wire Type 316 - Carbon Steel

Nozzle Type 7  No. of Passes 8

Tungsten Electrode: Type Thoriated (2%)  Size 3/32"

Inert Gas, Type In: Argon

Nozzle Argon C.F.H. 15
Backup Argon C.F.H. 5

Backup Material N/A  Groove Shape Double Vee Width .420" Depth .187"


Interpass Temp. N/A

Welder Burns

Date 1-6-77

Inspection: Radiographic Acceptable 1-7-77
### Weld Test Specimen (C)

#### Welding Process Data Sheet

<table>
<thead>
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<th>1-11-77</th>
<th>Project</th>
<th>70-LAB-1 76-087</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material (Plate)</td>
<td>S.S. 316L</td>
<td>Thickness</td>
<td>.50</td>
</tr>
<tr>
<td>Condition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weld Surface Preparation</td>
<td>Freon</td>
<td>Joint Type</td>
<td>Butt</td>
</tr>
<tr>
<td>Inspection Required</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weld Power Supply</td>
<td>AC/DC (TIG)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Joint Values

- **Bevel Angle**: 45°
- **Root Face**: 1/16
- **Root Opening**: None
- **Weld Current**: 165 Amp.
- **Wire Size**: 1/16"
- **Arc Voltage**: 24 Volt
- **Wire Type**: 316
- **Nozzle Type**: 7
- **No. of Passes**: 8
- **Tungsten Electrode**: Type Thoriated (2%) Size 3/32"
- **Inert Gas, Type In**: Argon
- **Nozzle Argon**: C.F.H. 15
- **Backup Argon**: C.F.H. 5
- **Backup Material**: N/A
- **Groove Shape**: Double Vee Width .420" Depth .187"
- **Preheat Temp.**: N/A
- **Post-Heat Temp.**: N/A
- **Interpass Temp.**: N/A

![Weld Joint Sketch](image)

- **Welder**: Burns
- **Date**: 1-11-77
- **Inspection**: Radiographic Acceptable 1-12-77
It was reported that a 316L manifold had been inadvertently welded with low alloy filler metal. The weld metal composition was similar to the 400 series stainless steels which are known to be brittle and impact sensitive in the as-welded condition.

A weld development program was initiated to determine the tensile and impact strength test properties of 316L stainless steel plate welded with low alloy steel filler metal.

Tests were conducted at room temperature and -1000°F on standard test specimens machined from as-welded panels of various chemical compositions. No significant differences were found as the result of variations in percentage chemical composition on the impact and tensile test results.

The weldments containing lower chromium and nickel as the result of dilution of parent metal from the use of the low alloy steel filler metal corroded more severely in a marine environment.

The use of a protective finish, i.e., a nitrile-based paint containing aluminum powder, prevented the corrosive attack.

**Key Words**

Austenitic Stainless Steel, Low Alloy Steel Filler Metal, Impact Strength Tensile Properties, Corrosion Dissimilar Metals

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