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Rocky Flats Plant Qualification Testing
for PRESS Program

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Rocky Flats Plant Qualification Testing for PRESS Program

**D. D. Kautz
G. J. Tanaka**

Summary

We recently completed several tests for EG&G - Rocky Flats, Inc. (RFP) to qualify welding procedures for the PRESS program. The welds that we tested were the Monel 400 to vanadium friction weld used in the Sail-A and the vanadium electron beam welds from the Mast Inner Subassembly. We performed testing to determine the structural properties of the parts under conditions similar to those encountered in a weapons handling and storage environment. These tests included impact, tensile and pressure loading. Metallographic analysis was done where appropriate to document weld quality. All results were satisfactory for PRESS program purposes. We compared the data to data supplied by RFP in those cases where useful.

Introduction

Due to facility closure and personnel loss, RFP could not perform all of the testing needed for process qualification of PRESS program welded parts and subassemblies. LLNL performed the following testing to help qualify the processes used to fabricate the Sail-A and the Mast Inner Subassembly.

Several sets of welded parts were sent to LLNL by RFP for process qualification on the Sail-A. I have listed the quantities and the type of tests performed in Table 1. The first testing that we completed was Charpy impact testing at -54 °C (-65 °F), ambient temperature and 74 °C (165 °F). The next set of testing included thermal cycling, at 200 °C (392 °F), an as-welded Monel 400 to vanadium friction welded specimen. We compared the two microstructures to ensure no deleterious effects could be attributed to the thermal cycling. We also received several specimens machined to the approximate dimensions of the Sail-A part for burst testing. The final testing done for the Sail-A process qualification was tensile testing at the STS temperature extremes of -54 °C (-65 °F) and 74 °C (165 °F).

To qualify the Mast Inner Subassembly, most of the work was done at RFP. We only performed burst testing and a minimal amount of metallographic examination. This testing qualified both electron beam welds on the Mast Inner Subassembly.

Results

Charpy Impact Testing

We Charpy impact tested twenty-seven unnotched specimens. Unnotched, non-standard size specimens with dimensions of 4.1 x 4.1 x 53.3 mm (0.16 x 0.16 x 2.1 in.) were used since we were not able to machine a notch that completely intersected the irregularly shaped weld interface. The matrix of impact testing

covered three temperatures of interest, -54 °C (-65 °F), ambient and 74 °C (165 °F) for the nine welded specimens, along with nine specimens for each base material. A complete listing of impact test results is found in Table 2. All values were acceptable for these specimens and none of them broke at the weld interface. In each case, the energy absorbed by these specimens was lower than in a series run at RFP, but the RFP tests used work hardened base materials. The RFP test results are described in RFP development report PNA-92-002¹.

Microscopy and Composition

We sectioned two samples, one as-welded and the other after a 200 °C (392 °F) thermal cycle. Part of each specimen was metallographically polished and etched and then viewed using a scanning electron microscope. The remaining specimens were thinned for transmission electron microscopy. Scanning electron microscopy found both joints to be microstructurally sound, but to have irregular weld interfaces that are typical of friction welds. Figures 1 through 6 show the morphology of the weld interfaces. The bottom material that appears unetched is the vanadium in these six figures. At these magnifications, no discernible difference is noted between the as-welded and the thermally cycled samples. The thermally cycled sample does exhibit more mechanical intermixing of materials than the as-welded sample, but this is a function of the particular weld and is not related to any post-weld treatments.

Figures 1 and 2 show low magnification photomicrographs of the high quality of both specimens. Figures 3 and 4 show higher magnification photomicrographs of the as-welded interface in two different areas along each interface. Both welds show mechanical mixing of the vanadium into the Monel 400 material. On this scale, mechanical mixing looks to be the main morphological feature of both welds. The only other feature of note is the grain orientation which has been deformed so as to make it almost perpendicular to the axis of the barstock, which is typical of friction welds. Figures 5 and 6 show higher magnification photomicrographs of the thermally cycled weld interface in two different areas. The thermally cycled weld interface is very similar to the as-welded interface, except that more mechanical mixing occurred during the welding cycle.

We performed composition mapping of both weld interfaces. The transition between the Monel 400 and the vanadium occurred over an approximate 0.01 mm (0.0004 in.) band in both. This was true at the weld interface and the mechanical mixing areas. We would expect this transition region to become larger had diffusion occurred as the result of the 200 °C (392 °F) thermal cycle. Figures 7 and 8 show the as-welded and thermally cycled composition maps. Figure 9 shows a composite map of the vanadium composition change with the as-welded specimen data superimposed over the thermally cycled specimen data. We would expect that a shallower slope would result on the thermally cycled specimen if diffusion had occurred. The composition map of the as-welded transition zone plots almost identically over the composition maps of the transition zones for both the weld interface area and the mechanical mixing areas of the thermally cycled specimens.

Transmission electron microscopy was performed to determine the presence of sigma phase in the weldments. Both weldments exhibited the same microstructural pattern of vanadium-nickel-copper solid solutions separated by thin layers of sigma phase. Figures 10 and 11 show the similarity between the as-welded and the thermally cycled specimens. The photomicrograph of the as-welded specimen in Figure 10 shows thin, linear sigma phase features with highly deformed solid solution material between them. The thermally treated specimen shown in Figure 11 exhibits the same features as the as-welded specimen. Although more lines of sigma phase are found in the thermally cycled specimen, it is probably due to the magnification difference of the photomicrographs rather than any physical phenomenon. Sigma phase is known to cause room temperature embrittlement of materials when it forms. The mechanical testing of these weldments has shown that these sigma phase layers were too thin to affect the joint ductility in a deleterious manner.

Burst Testing

We received four finished specimens from RFP for burst testing. The specimens were made to a modified pressure nipple drawing to encompass the Sail-A dimensions. A schematic of the drawing is shown in Figure 12. The specimen configuration was designed to stress the weld interface as much as possible before failure. All specimens failed in the Monel 400 portion of the fitting. Some deformation was found in the weld interface area of each specimen, but no signs of imminent failure were found in any of the specimens. All tests used helium gas as the pressurization fluid and failure pressures for these specimens all had safety factors of well over 100 for the maximum system pressure expected for these parts. Table 3 shows the burst pressures for each specimen. For historical purposes, we took SEM photomicrographs of the failure areas and metallographically cross-sectioned and photographed the weld interfaces of all specimens. Figures 13 through 16 show these photomicrographs, light gray material at the bottom of the photomicrographs is the vanadium.

Tensile Testing

We received six partially finished specimens from RFP for tensile testing. After finish machining of these specimens, only four were acceptable for testing. We tested two specimens at -54 °C (-65 °F) and two at 74 °C (165 °F). All specimen and test data are given in Table 4. The results were satisfactory with failure occurring in the vanadium portion of the tensile specimen in all cases. This data compares very well with room temperature data compiled earlier at RFP. The RFP results are documented in the RFP development report AT-93-001². For historical purposes, we macrophotographed the tensile specimens after testing and these are shown in Figures 17 through 20.

Mast Inner Subassembly

We received three Mast Inner Subassemblies from RFP for burst testing. These subassemblies contained two electron beam welds on vanadium fillet weld joints.

The Jib to Mast Inner is an assembly aid weld removed during the assembly sequence, whereas the Mast Inner to Sail-A weld is integral to the final assembly. Burst test results were satisfactory with safety factors of over 50 in pressure bearing capability. The results of the testing are found in Table 5.

The Mast Inner to Sail-A weld showed no signs of deformation, which is good since this weld stays with the final assembly. The Jib to Mast Inner welds were in the failure area, but a great deal of mechanical deformation occurred in the base material before the subassemblies failed. We cut the failure area off for destructive analysis and sent the remaining portion to Pantex Plant for further development processing. Figures 21 through 23 show cross-sections of the failure areas and the Jib diaphragm in each specimen.

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References

1. Tsang, S. and V. J. Lusero, Joining Monel by Inertia Friction Welding to Other Metals, EG&G - Rocky Flats Report No. PNA-92-002 (1992).
2. Tsang, S., Qualification Test of Monel/Vanadium Friction Welds of PRESS Program, EG&G - Rocky Flats Report No. AT-93-001 (1993).

Table 1
Test and Specimen Matrix

<u>Test Type</u>	<u>Specimens</u>	<u>Materials*</u>	<u>Temperature</u>
Charpy Impact	3 each	V, Monel, V/M FW	-54 °C
Charpy Impact	3 each	V, Monel, V/M FW	Ambient
Charpy Impact	3 each	V, Monel, V/M FW	74 °C
Microscopy/Composition	1	V/M FW	Ambient
Microscopy/Composition	1	V/M FW	200° C
Burst	4	V/M FW	Ambient
Tensile	2	V/M FW	-54 °C
Tensile	2	V/M FW	74 °C
Burst	3	V (Mast Inner)	Ambient

* - Materials: V: Vanadium
Monel: Monel 400
V/M FW: Vanadium to Monel 400 Friction Weld

Table 2
Charpy Impact Test Results

Specimen	Material*	Test Temperature		Absorbed Energy	
		(°C)	(°F)	(Joules)	(ft·lbs)
V1	Vanadium	21	70	9.83	7.25
V2	Vanadium	21	70	9.83	7.25
V3	Vanadium	21	70	<u>9.83</u>	<u>7.25</u>
	Average			9.83	7.25
M1	Monel 400	21	70	12.54	9.25
M2	Monel 400	21	70	12.54	9.25
M3	Monel 400	21	70	<u>13.22</u>	<u>9.75</u>
	Average			12.77	9.40
392	V/M FW	21	70	8.13	6.00
388	V/M FW	21	70	8.47	6.25
385	V/M FW	21	70	<u>8.81</u>	<u>6.50</u>
	Average			8.47	6.25
V4	Vanadium	74	165	8.47	6.25
V5	Vanadium	74	165	7.80	5.75
V6	Vanadium	74	165	<u>9.15</u>	<u>6.75</u>
	Average			8.47	6.25
M4	Monel 400	74	165	12.54	9.25
M5	Monel 400	74	165	12.88	9.50
M6	Monel 400	74	165	<u>12.88</u>	<u>9.50</u>
	Average			12.77	9.40
393	V/M FW	74	165	8.81	6.50
389	V/M FW	74	165	7.80	5.75
386	V/M FW	74	165	<u>7.12</u>	<u>5.25</u>
	Average			7.91	5.80
V7	Vanadium	-54	-65	11.86	8.75
V8	Vanadium	-54	-65	12.54	9.25
V9	Vanadium	-54	-65	<u>12.54</u>	<u>9.25</u>
	Average			12.31	9.10
M7	Monel 400	-54	-65	14.24	10.50
M8	Monel 400	-54	-65	12.88	9.50
M9	Monel 400	-54	-65	<u>13.56</u>	<u>10.00</u>
	Average			13.56	10.00
394	V/M FW	-54	-65	12.20	9.00
391	V/M FW	-54	-65	12.20	9.00
387	V/M FW	-54	-65	<u>13.56</u>	<u>10.00</u>
	Average			12.65	9.33

* - Materials: V: Vanadium
 Monel: Monel 400
 V/M FW: Vanadium to Monel 400 Friction Weld

Table 3
Monel 400 to Vanadium Friction Weld Burst Test Results

<u>Specimen</u>	<u>Test Fluid</u>	<u>Failure Pressure</u>		<u>Failure Mode</u>
		(MPa)	(ksi)	
441	Helium	427	62	Monel 400 tube wall
442	Helium	448	65	Monel 400 tube wall
463	Helium	393	57	Monel 400 tube wall
467	Helium	393	57	Monel 400 tube wall

Table 4
Monel 400 to Vanadium Friction Weld Tensile Test Results

<u>Specimen</u>	<u>Gauge Diameter</u>		<u>Temperature</u>		<u>Load to Failure</u>		<u>Failure Stress</u>	
	(mm)	(in)	(°C)	(°F)	(N)	(lb)	(MPa)	(ksi)
1073	3.51	0.138	-54	-65	3390	762	350	50.9
1080	3.51	0.138	-54	-65	3390	762	350	50.9
1074	3.48	0.137	74	165	2409	542	253	36.8
1081	3.48	0.137	74	165	2381	534	250	36.2

Table 5
Mast Inner Subassembly Burst Test Results

<u>Specimen</u>	<u>Test Fluid</u>	<u>Failure Pressure</u>		<u>Failure Mode</u>
		(MPa)	(ksi)	
0214941/0214943	Water	122	17.7	Jib tube wall
0214942/0214944	Water	123	17.8	Jib tube wall
0214945/0214946	Water	112	16.3	Jib weld

Figure 1. Low magnification photomicrograph of the as-welded Monel 400 to vanadium friction weld. Note that the weld interface is irregular, but that it is of high quality.

Figure 2. Low magnification photomicrograph of the thermally cycled Monel 400 to vanadium friction weld. The weld is very similar to the as-welded specimen except for more mechanical mixing at the weld interface.

Figure 3. High magnification photomicrograph of the as-welded Monel 400 to vanadium friction weld. This photomicrograph from the centerline of the weld shows a defect-free weld with small amounts of mechanical mixing.

Figure 4. High magnification photomicrograph of the as-welded Monel 400 to vanadium friction weld. This photomicrograph from the edge of the weld shows a defect-free weld, but with slightly more mechanical mixing than the centerline of the weld shown in Figure 3.

Figure 5. High magnification photomicrograph of the thermally cycled Monel 400 to vanadium friction weld. This photomicrograph from the centerline of the weld shows a defect-free weld with large amounts of mechanical mixing.

Figure 6. High magnification photomicrograph of the thermally cycled Monel 400 to vanadium friction weld. This photomicrograph from the edge of the weld shows a defect-free weld, but with more turbulent mechanical mixing than the centerline of the weld shown in Figure 5.

Figure 7. Composition map for as-welded vanadium to Monel 400 friction weld. Composition varies from the Monel 400 side to the vanadium side. The interface transition region is approximately 10 μ wide.

Figure 8. Composition map for 200°C thermally cycled vanadium to Monel 400 friction weld. Several areas of mechanical mixing of vanadium into the Monel 400 are apparent. The interface transition region is approximately 10 μ wide.

Figure 9. Comparison of as-welded and thermally cycled composition maps. The as-welded transition area map is superimposed over the map of the thermally cycled interface and the two areas where mechanical mixing occurred. The slopes are almost identical, which shows that the thermal cycle caused no discernible diffusion.

Figure 10. Transmission electron photomicrograph of as-welded Monel 400 to vanadium friction weld interface. The thin linear features are sigma phase and blocky structures with high dislocation density are solid solution mixtures of nickel, copper and vanadium. The as-welded and thermally cycled microstructures are very similar.

Figure 11. Transmission electron photomicrograph of thermally cycled Monel 400 to vanadium friction weld interface. The thin linear features are sigma phase and blocky structures with high dislocation density are solid solution mixtures of nickel, copper and vanadium. The as-welded and thermally cycled microstructures are very similar.

Figure 12. Schematic of burst test fitting. Small diameter section machined similarly to the Sail-A configuration. All failures occurred in the thin wall section of the Monel 400.

(a)

(b)

Figure 13. Photomicrograph of the failed Monel 400 tubing (a) and the Monel 400 to vanadium friction weld interface (b) from burst test specimen 441.

(a)

(b)

Figure 14. Photomicrograph of the failed Monel 400 tubing (a) and the Monel 400 to vanadium friction weld interface (b) from burst test specimen 442.

(a)

(b)

Figure 15. Photomicrograph of the failed Monel 400 tubing (a) and the Monel 400 to vanadium friction weld interface (b) from burst test specimen 463.

(a)

(b)

Figure 16. Photomicrograph of the failed Monel 400 tubing (a) and the Monel 400 to vanadium friction weld interface (b) from burst test specimen 467.

Figure 17. Historical macrophotograph of failed Monel 400 to vanadium friction weld tensile specimen 1073. The failure occurred in the vanadium end of the specimen.

Figure 18. Historical macrophotograph of failed Monel 400 to vanadium friction weld tensile specimen 1080. The failure occurred in the vanadium end of the specimen.

Figure 19. Historical macrophotograph of failed Monel 400 to vanadium friction weld tensile specimen 1074. The failure occurred in the vanadium end of the specimen.

Figure 20. Historical macrophotograph of failed Monel 400 to vanadium friction weld tensile specimen 1081. The failure occurred in the vanadium end of the specimen.

(a)

(b)

Figure 21. Photomicrograph of the failed vanadium tube fitting (Jib) (a) and the deformed vanadium diaphragm in the Jib (b) from burst test specimen 0214941/0214943. Note the large amount of plastic deformation and necking that occurred before failure.

(a)

(b)

Figure 22. Photomicrograph of the failed vanadium tube fitting (Jib) (a) and the deformed vanadium diaphragm in the Jib (b) from burst test specimen 0214942/0214944. Note the large amount of plastic deformation and necking that occurred before failure.

(a)

(b)

Figure 23. Photomicrograph of the failed vanadium tube fitting (Jib) (a) and the deformed vanadium diaphragm in the Jib (b) from burst test specimen 0214945/0214946. Less deformation occurred in this specimen than in the previous ones shown in Figures 21 and 22. Failure occurred in the weld fusion zone in this specimen.

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