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BRAZEABILITY OF HASTELLOY X STUDY

NERVA Program, Contract SNP-1

May 1970

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AEROJET NUCLEAR SYSTEMS COMPANY

A DIVISION OF AEROJET-GENERAL

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ABSTRACT

The purpose of this program was to determine the brazeability of Hastelloy X material. The intentional additions of aluminum to Hastelloy X material as a deoxidizer during the melting process for the Phoebus II-A nozzle components resulted in a residual aluminum content of 0.3 to 0.4%. This residual amount of aluminum caused nozzle furnace brazing problems. Current AGC specifications for the Hastelloy X material control the supplier's melt practice and limit the residual aluminum content to 0.02% maximum. Production ingots as large as 10,000 lb have been produced to the new specification requirements. Brazeability tests on one-inch plate stock, rolled from these ingots, demonstrate that acceptable results can be obtained if the aluminum content does not exceed the specified amount of 0.02%. In addition to determining the brazeability of Hastelloy X material, new braze alloys and assembly procedures were evaluated.

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INTRODUCTION

The purpose of this program was to determine the brazeability of Hastelloy X containing a maximum aluminum content of 0.02%. Secondary purposes were to evaluate new braze alloys and assembly procedures.

The adverse effects of small additions of aluminum on the brazeability of high temperature base materials have been reported by others (References 1 and 2). A summary of AGC experience with Hastelloy X material containing intentional additions of aluminum was reported at the conclusion of the Phoebus II-A program (Reference 3).

The sequence of events reported are as follows:

a. Hastelloy X was selected as first choice for the Phoebus II-A nozzle because the material possessed adequate high temperature mechanical properties, good weldability and good brazeability. The pre-Phoebus II-A Hastelloy X was deoxidized with a zirconium-nickel additive.

b. The AGC specification for the Hastelloy X material allowed a combined residual aluminum and titanium content of 0.5%. Union Carbide replaced the zirconium-nickel deoxidizing additive with aluminum for the Phoebus II-A ingots. These intentional additions resulted in a residual aluminum content of 0.3 to 0.4% after ingot solidification. This quantity did not exceed the maximum AGC specification allowable of 0.5%.

c. Weldability problems were experienced early in the Phoebus II-A program. Hot cracking and poor wettability of the molten weld metal were attributed to the high residual aluminum content in the Hastelloy X base material (Reference 4).

d. Poor brazeability of the high aluminum Hastelloy X material became evident after hydroleak testing a full-length contoured Phoebus II-A sector. A dull gray translucent surface film was observed on all Hastelloy X surfaces after furnace brazing in a hydrogen atmosphere. A low pressure leak check detected a total of 67 leaks in the tube-to-shim faying surfaces; an average of two leaks per linear foot of braze joint. Electron diffraction patterns taken from the furnace brazed surfaces confirmed the presence of aluminum oxide.

e. The Phoebus II-A materials specifications (AGC-90056, -90057, -90058, and -90060) were changed to limit aluminum and titanium to 0.02% maximum each for future procurements after identification of the furnace brazing problem with the intentional additions of aluminum.

f. The supplier of the Hastelloy X material produced a 10,000 lb ingot to the new chemical requirements (Heat 2610-6-2183). Part of this ingot was reduced to 0.063 in.-thick sheet stock and shipped to AGC.

g. The existing Phoebus II-A shims and tubes were nickel plated prior to furnace brazing. The nickel plate provides a surface free from aluminum; however, the accumulated tolerances for the mating components dictated a relatively thin plating thickness of 0.0005 in. that reduced the number of leaks but did not completely eliminate leakage at the tube-to-shim faying surfaces.

h. The Phoebus II-A schedules did not permit the use of the low-aluminum Hastelloy X material.

PROGRAM

a. Specimen Component Configuration

The brazeability of Hastelloy X material produced to the AGC specifications limiting the maximum aluminum content to 0.02% was determined using the material ordered for the Phoebus II-A program (Heat No. 2610-6-2183). The 0.063-in.-thick sheet material was reduced by Ulbrich, Inc., to 0.012-in.-thick sheet that is formed into 48-in. long, straight coolant channels (Drawing No. 1135896). Shims, 0.225 in. high and 4.5 in. long, were fabricated from 0.008 in.-thick sheet stock (PN 1134993). Plate stock from Heat No. 2610-6-2183, 1-in. thick, 6-in. wide, and 18-in. long, was fusion welded to form a 48-in.-long plate, 1-in. thick and 6-in. wide (Figure 1).

The welded plate is then faced, and 9 grooves 0.039 to 0.041 in. wide for specimens 1 through 3 and 0.037 to 0.039 in. wide for specimens 4 and 5, 0.090 to 0.100 in. deep, spaced on 0.050 in. centers, were machined on the 48-in. by 6-in. face (Figure 2).

b. Assembly and Brazing

Assembly and brazing were accomplished in accordance with the applicable sections of AGC-90006, the specification used for both the technology nozzles and the Phoebus II-A nozzles. The sequence of component assembly was as shown in Figure 3 and defined in Reference 5. After assembly, the specimens were cycled in a hydrogen atmosphere to the temperatures specified for the braze alloys being used. All specimens were placed in a vertical position in the furnace retort. All specimens were inverted within the retort prior to the next scheduled furnace cycle. The heating and cooling rates were controlled to duplicate the actual rates obtained for the technology nozzles (Figure 4). The alloys, temperatures, assembly

variables, and hydrotest results are summarized in Table I. Ultrasonic inspection was accomplished for all specimens, and the results obtained will be discussed in a separate report.

c. Results

Specimen No. 1 - The braze alloy, braze alloy placement, assembly procedures, and furnace brazing cycles duplicated the technology nozzle brazing variables. The surface condition of the Hastelloy X material was bright and shiny after the furnace cycles. In comparison, the Phoebus II-A Hastelloy X components had a dull translucent surface film (Al_2O_3) after furnace brazing, which is attributed to the high (0.3 to 0.4%) residual aluminum content of the Phoebus II-A Hastelloy X material. Niore foil was applied to the shims prior to the first braze cycle. Groove widths were 0.039 to 0.041 in.

The low ΔP end caps (Drawing 1136178-1), illustrated in Figure 5, were induction brazed to the coolant channel using 0.020 in. diameter, Palniro-1 braze alloy. The induction brazing was accomplished in a quartz tube using a protective atmosphere of 80% argon - 20% hydrogen (Figures 6 and 7). Excellent fillets and braze alloy coverage were obtained.

No leaks were detected during leak check, and failure occurred (Figure 8) at 4875 psi during burst test. The initial failure was in shear at the channel-leg to groove-wall braze joint interface, then failure occurred in the tube crown.

Specimen No. 2 - This specimen evaluated the use of the Palsil-5 (95 Ag, 5 Pd), Palsil-25 (75 Ag, 25Pd), and Palsil-20 (52 Ag, 28 Cu, 29 Pd) braze alloys for the shim-to-tube external braze joints. Groove

widths were 0.037 to 0.041 in. A total of 15 leaks were recorded after the third and final braze cycle. After leak check, this specimen was committed for evaluation of oxy-hydrogen leak repair procedures and was not subjected to hydro-burst tests.

Specimen No. 3 - Specimen No. 3 evaluated Palniro-1 (50 Au, 25 Pd, 25 Ni) braze alloy for the first cycle and Palniro-7 for the second cycle. Palniro-1 is a high temperature braze alloy that is available in foil form. Duplex braze alloy fillets were omitted from the shim butt ends. No braze foil was applied to the shims prior to the first cycle. Groove widths were 0.039 to 0.041 in. The end caps were fusion welded to the formed channels. Palniro-4 (36 Ni, 34 Pd, 30 Au) braze alloy was applied to the external shim-to-tube interfaces prior to the first braze cycle. Specimen No. 3 was leak tight after completion of the second cycle, and failure occurred in the tube crown at 5000 psi during burst test (Figure 9).

Specimen No. 4 - Specimen No. 4 evaluated Palniro-7 for the first cycle. Braze foils were not used on the shims. The groove widths were reduced to 0.037 to 0.039 in. to compensate for removal of the foils. Palniro-1 filler was applied for the full length of the specimen prior to the first cycle. Duplex braze alloy fillets were omitted from the shim butt ends. Nicro powder was applied prior to the second cycle. Low pressure leak check after the second braze cycle revealed three small leaks. Nicro-80 powder was applied prior to the third cycle. Failure occurred by shear of one channel-leg-to-groove wall at 6000 psig (Figure 10).

Specimen No. 5 - This specimen was furnace brazed in a vacuum atmosphere using the same alloys and assembly procedures selected for Specimen No. 4. Foils were not applied to the shims and the groove widths

were 0.037 to 0.039 in. No leaks were detected after the second braze cycle, therefore, the third braze cycle was omitted. Failure occurred in the channel leg to groove wall braze joint at 4950 psig (Figure 11).

CONCLUSIONS

1. Acceptable furnace brazing results can be obtained using Hastelloy X base material if the aluminum content is limited to 0.02% maximum (Specimen No. 1).
2. Induction brazed end cap to coolant channel procedures have been established using Palniro-1 (50 Au - 25 Ni - 25 Pd) braze alloy (Specimens 1, 2, 4, and 5).
3. The silver-base braze alloys, Palsil-5 (95 Ag - 5 Pd), Palsil-25 (75 Ag - 25 Pd), and Palcusil-25 (Ag Pd Cu), are not as effective as the gold-base alloys for producing a leak tight shim to coolant channel braze fillet (Specimen 2).
4. Both Palniro-1 and Palniro-7 produce acceptable coolant channel leg to groove wall braze joints on the first braze cycle. The Palniro-7 braze alloy melts and flows at 1930 - 1955°F and would be preferable to Palniro-1 that melts and flows 2050 - 2060°F (Specimen Nos. 3 and 4) for the braze alloy for the first braze cycle. The lower braze temperature simplifies furnace fixturing requirements and is compatible with the recommended annealing temperature of 1800 to 2000°F.
5. In appearance, the vacuum atmosphere produces furnace brazed joints that are equivalent to furnace brazed joints that are produced in a hydrogen atmosphere (Specimen Nos. 4 and 5). The three small leaks

detected after the second cycle for Specimen No. 4 were attributed to an inadequate amount of powdered braze alloy being applied in those areas.

6. Acceptable braze joints can be obtained at the shim butt ends without application of the duplex fillets (Specimens 3, 4, and 5); however, these joints have been obtained for the specimen configuration representative of the nozzle cylindrical section. The points of tangencies for the coolant channel at the cylindrical section are at the top of the groove. Actual part configuration would dictate a point of tangency above the top of the groove resulting in a much higher shim butt end joint. The procedures developed may not be applicable to the high shim butt end joint.

7. Acceptable external braze joints can be obtained without the "V" braze alloy preforms around the shim (Specimens 3, 4, and 5).

RECOMMENDATIONS

Care must be exercised when extrapolating results obtained for the straight sections to procedures for actual nozzle components. The straight specimen configuration is representative of the nozzle's cylindrical section. The specimen configuration is not representative of the nozzle's complex geometry or the varying cross sectional areas of the exposed tube to tube braze joints in the convergent, throat or divergent areas. Based on the results obtained, it is recommended that:

1. All Hastelloy X components be ordered to the current AGC specifications that require a maximum aluminum content of 0.02%. The current AGC specifications for Hastelloy X material also control the supplier's melt practice.
2. Palniro-7 braze alloy be considered for use on future Hastelloy X nozzles. The selection of this alloy for the first braze cycle will prevent the reflow, on the second braze cycle, of the braze fillets obtained between the end caps on the first cycle.
3. If individual end caps are to be used on each end of the coolant channels, induction brazing these caps should be considered using 0.020-in. diameter Palniro-1 braze alloy.

TABLE 1

BRAZE ALLOY, CONFIGURATION AND TEMPERATURE
FOR HASTELLOY X BRAZE SPECIMENS

Specimen No.	Groove Width, in.	First Cycle Alloy and Temperature	Second Cycle Alloy and Temperature	Third Cycle Alloy and Temperature	End Cap Configuration and Cap-to-Tube Installation	Hydrotest		
						Leak	Proof	Burst
1	0.039-0.041	Nicro foil preform (U and V) and 0.020 in. wire Shims 0.008 in. Stainless Steel Braze temperature 1825-1850°F (hydrogen)	Palniro-7 powder and Nicro powder failure Braze temperature 1800-1825°F (hydrogen)	Nicro-80 powder Braze temperature 1750-1775°F (hydrogen)	Induction brazed (low ΔP) Palniro-1; 0.020 in. dia. wire	(GN ₂) 200 psig No leaks	(water) --	(water) 4875 psig --
2	0.039-0.041	Palniro-7 foil preform and 0.020 in. wire Shims (stainless steel) Palsil-25 powder filler (1/2 specimen) Braze temperature 1930-1955°F (hydrogen)	1/2 Specimen: Palsil-25 at shim ends overlaid with Palsil-5 powder 1/2 Specimen: Palsil-5 full length Braze temperature 1870-1880°F (hydrogen)	Palcusil 20 powder Braze temperature 1745-1755°F (hydrogen)	Induction brazed (flat) Palniro-1; 0.020 in. dia. wire	50 psig 15 leaks	--	--
3	0.039-0.041	Palniro-1 foil preform and 0.020 in. wire Shims (stainless steel) Palniro-4 powder filler Braze temperature 2050-2060°F (hydrogen)	Palniro-7 powder filler Braze temperature 1960-1970°F (hydrogen)	None	Welded (flat) Furnace brazed to Jacket	200 psig No leaks	1270 psig	5800 psig Tube crown failure
4	0.037-0.039	Palniro-7 foil preform and 0.020 in. wire. Palniro-1 powder filler Braze temperature 1930-1955°F (hydrogen)	Nicro powder Braze temperature 1825-1850°F (hydrogen)	Nicro-80 powder Braze temperature 1725-1750°F (hydrogen)	Induction brazed (flat) Palniro-1; 0.020 in. dia. wire Furnace brazed to jacket with Palniro-7	200 psig No leaks	--	6000 psig
5	0.037-0.039	Palniro-7 foil preform and 0.020 in. wire Palniro-1 powder filler Braze temperature 1930-1955°F (vacuum)	Nicro Powder Braze Temperature 1825-1850°F (vacuum)	None	Induction brazed (flat) Palniro-1; 0.020 in. wire Furnace brazed to jacket with Palniro-7	200 psig No leaks	--	4950 psig

FIGURE 1

FIGURE 2

STEP 1

INSTALL 0.001 INCH THICK PREFORMED
BRAZE ALLOY FOIL AND 0.020 INCH
DIAMETER BRAZE ALLOY WIRE ON EACH
SIDE OF THE GROOVE

STEP 2

RESISTANCE WELD TUBES TO PLATE

STEP 3

INSTALL SHIMS BETWEEN TUBES
(SPECIMENS INCORPORATING BRAZE
FOILS AROUND SHIMS ARE INDICATED
IN TABLE 1)

STEP 4

FUSION WELD END CAPS TO PLATE

SEQUENCE OF ASSEMBLY FOR HASTELLOY X BRAZEABILITY SPECIMEN

FIGURE 3

SIMULATED TECHNOLOGY FURNACE BRAZE CYCLE

FIGURE 4

LOW ΔP END CAP

FIGURE 5

Figure 6 - Induction Coil for Brazing End Caps to Coolant Channels

Figure 7 - Coolant Channel and End Cap Placed in Induction Coil Set Up

TWO FAILURE MODES ARE EVIDENT: (1) PARENT METAL IN TUBE CROWN,
AND (2) TUBE LEG DISENGAGEMENT

SPECIMEN SN-I FAILURE AT 4875 PSIG.

THE DISCOLORATION ON THE SURFACE OF THE SPECIMEN
CAUSED BY LOW ΔP END CAP FLOW TESTS

FIGURE 8

PARENT METAL FAILURE IN TUBE CROWN

SPECIMEN NO. 3. FAILURES AT 5800 PSIG.

FIGURE 9

SHOWING TUBE LEG DISENGAGEMENT
SPECIMEN NO. 4. FAILURE AT 6000 PSIG

3X MAGNIFICATION

FIGURE 10

FAILURE BY TUBE LEG DISENGAGEMENT

SPECIMEN NO. 5. FAILURE AT 4950 PSIG.
STRAP NORMAL TO FAILED AREA IS A HYDROTEST SIDE RAIL SUPPORT.

2X MAGNIFICATION.

FIGURE 11

REFERENCES

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