Brazed Nickel/Columbium Dissimilar Metal Pipe Joints for 720 C Service

Best results are obtained with a BNi-4 (Ni-3.5Si-2B) filler metal using a tongue-in-groove joint configuration with a columbium alloy tongue when investigating application of brazing to dissimilar metal pipe joints for a Brayton cycle space power system

BY G. K. WATSON AND T. J. MOORE

ABSTRACT. Direct brazing was investigated as a method of fabricating Hastelloy X/columbium alloy dissimilar metal pipe joints for possible use in a Brayton cycle space power system. These joints must remain leak-tight in space for up to seven years at 720 C (1328 F). Design and fabrication of these brazements are complicated because of differences in composition and thermal expansion between the Ni- and Cb-base components.

Two filler metals, selected from eight candidate compositions, were used to fabricate five different pipe joint configurations. Joint strength and integrity were evaluated as-brazed, after thermal aging, and after rapid thermal cycling.

Results of the evaluation showed that direct brazing is a viable method for fabricating the dissimilar metal pipe joints. Best results were obtained using a tongue-in-groove joint design with a columbium alloy tongue and a BNi-4 filler metal.

Introduction

A Brayton Isotope Power System (BIPS) concept[1] was developed at the National Aeronautics and Space Administration (NASA) as part of a program on Brayton cycle technology. The BIPS concept is now being studied jointly by NASA and the Energy Research and Development Administration (ERDA) for possible use as a power generation system in space.[2]

The BIPS is shown schematically in Fig. 1. This system is designed to operate with a turbine inlet temperature of about 870 C (1598 F) for up to seven years using a helium-xenon working fluid at about 0.69 MPa (100 psi). The high temperature components, such as the heat source heat exchanger[3,4] and the turbine scroll, are to be fabricated from a columbium alloy, C-103. Because of their lower operating temperatures (720 C, 1328 F or less), the recuperator and associated piping are to be fabricated from a nickel-base superalloy, Hastelloy X.

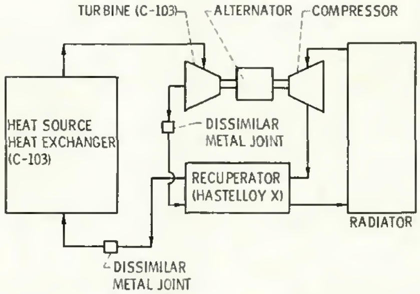


Fig. 1—Brayton Isotope Power System (BIPS) schematic

Two Hastelloy X/C-103 dissimilar metal pipe joints are required in the system as can be seen in Fig. 1. One joint is located between the turbine outlet and the recuperator, and the other joint is located between the recuperator and the inlet to the heat source heat exchanger. Both of these joints will operate at about 720 C (1328 F) and must be leak-tight for the life of the system. The design and fabrication of these joints are complicated by the large difference in the thermal expansions of the two alloys. From room temperature to 720 C (1328 F), the C-103 alloy expands 0.6% and the Hastelloy X expands 1.1%.

One purpose of this study was to evaluate the potential of direct brazing as a method of fabricating the dissimilar metal pipe joint; another was to investigate the effects of thermal aging and rapid thermal cycling on the performance of the brazed joints. In preliminary studies, eight braze filler metals were evaluated in terms of wettability, flow, and tensile-shear strength of brazed joints. The two best filler metals were selected and full size dissimilar metal pipe joints were fabricated in five different joint configurations.

In the latter tests, Cb-1Zr pipe was used in place of the C-103 for expediency. The integrity and strength of these joints were evaluated in the as-brazed, aged, and thermal cycled conditions to select a satisfactory joint design/braze alloy combination for use in the BIPS.

Materials

The preliminary brazing studies were conducted with commercial C-103 and Hastelloy X sheets. The sheet thickness of the C-103 was 0.8 mm (0.03 in.) for wettability specimens and 1.5 mm (0.06 in.) for the tensile specimens. The Hastelloy X sheet for all these studies was 1.5 mm (0.06 in.) thick.

The Hastelloy X pipe used for the full size pipe joints was machined from 63.5 mm (2½ in.) diameter bar. The C-103 alloy was not available in

---

Paper presented at the Eighth International AWS Brazing Conference held in Philadelphia, Pennsylvania, during April 26-28, 1977

G. K. WATSON and T. J. MOORE are with the National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio

Table 1—Base Metal Compositions

Base metal	Composition[a]
Hastelloy X	Ni-22Cr-18.5Fe-9.0Mo-1.5 Co-0.6W-0.5Mn-0.5 Si-0.10C
Columbium alloy C-103	Cb-10Hf-1Ti-0.5Zr-0.4 Ta-0.4W
Columbium alloy Cb-1Zr	Cb-1Zr

[a] Nominal composition in wt-%.

Table 2—Braze Filler Metal Compositions and Brazing Temperatures

Filler metals	Composition[a]	Brazing temperature, C
BNi-4	Ni-3.5Si-2.0B	1105
BNi-5	Ni-19Cr-10Si	1170
AMI-914	Ni-4.5Si-3.5B-20Co	1090
AMI-400	Co-0.4C-19Cr-8Si-0.8B-4W-17Ni	1180
BAu-4	Au-18Ni	1000
Palniro-1	Au-25Pd-25Ni	1150
Palniro-7	Au-8Pd-22Ni	1070
AMI-637	Ag-4Al-3.5Pd	970

[a] Nominal composition in wt-%.

the required form in time to fabricate the pipe joints; so another columbium alloy, Cb-1Zr, was used in place of the C-103. The Cb-1Zr alloy was in the form of 62 mm (2.44 in.) diameter pipe with a 5.0 mm (0.2 in.) wall thickness. The nominal compositions of the three base metals are listed in Table 1.

The substitution of Cb-1Zr for C-103 should have little effect on the results of the study since the thermal expansions and mechanical properties of the two alloys are very similar. Thus, the stress generated in the joints by the brazing operation and by thermal cycling should be similar. Also, the observed wetting and flow of the filler metals on the two columbium alloys appeared to be similar.

Eight brazing filler metals representative of various nickel, cobalt, gold, and silver-base alloys were investigated in this program. The nominal composition of the filler metals and the brazing temperatures used are listed in Table 2. All the filler metals were in the form of −325 mesh powder, and no binders were used.

Preliminary Brazing Studies

Screening tests were conducted on the eight braze filler metals to determine their wetting and flowing characteristics and their tensile-shear strengths. Metallographic examination and microhardness measurements were also included in the evaluation.

Wetting and Flow Tests

Dissimilar metal lap joints were made by resistance spot welding C-103 coupons to Hastelloy X coupons with nickel foil spacers to provide the brazing gap as shown in Fig. 2. The faying (mating) surfaces were sanded on 320-grit paper and degreased prior to assembly. Braze filler metal powder in sufficient quantity to fill the gap and form fillets was placed at the edge of the joint (Fig. 2); the joint was then heated to the brazing temperature (Table 2), held for 5 min, and furnace cooled. All brazing was performed in a vacuum furnace at a pressure of 1.3×10^{-3} N/m^2 (1×10^{-5} torr) or less.

The wetting and capillary flow for all the filler metals was considered good to excellent as shown in Fig. 3 (the BNi-5 joint is not shown). The gold-base filler metals were outstanding with respect to wetting and flow.

Tensile Shear Tests

The double-lap joints for the tensile shear tests consisted of a C-103 coupon sandwiched between two Hastelloy X coupons as shown in Fig. 4(a). This assembly was placed in a fixture and clamped under light pressure. The brazing cycle was similar to that used in the wetting and flow tests. Six double lap joints were prepared for each filler metal.

Three joints were to be tested in the as-brazed condition, and three joints were to be tested after aging for 1000 h at 720 C (1328 F) in a vacuum furnace at a pressure of 1.3×10^{-6} N/m^2 (1×10^{-8} torr) or less. The tensile-shear test configuration after machining is shown in Fig. 4(b). Reinforcing tabs of C-103 were resistance spot welded to the C-103 end of the specimen as shown.

Tests were run at room temperature and 720 C (1328 F) in both the as-brazed condition and after aging. The room temperature tests were conducted in air, and the 720 C (1328 F) tests were conducted in vacuum at a pressure of 1.3×10^{-4} N/m^2 (1×10^{-6} torr) or less. The crosshead speed was 1.3 mm (0.05 in.) per minute for all tests. The results of these tests for the more promising braze joints are summarized in Fig. 5 and are described further in the following paragraphs.

Both the BNi-4 and AMI-914 joints had good strengths at room temperature and at 720 C (1328 F). In general,

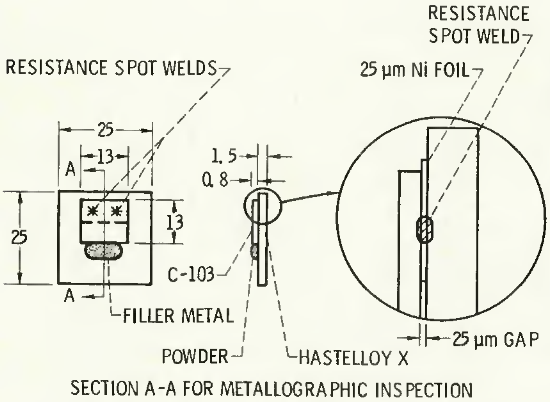


Fig. 2—Dissimilar metal lap joint specimen used in brazing studies (dimensions are in mm unless otherwise noted)

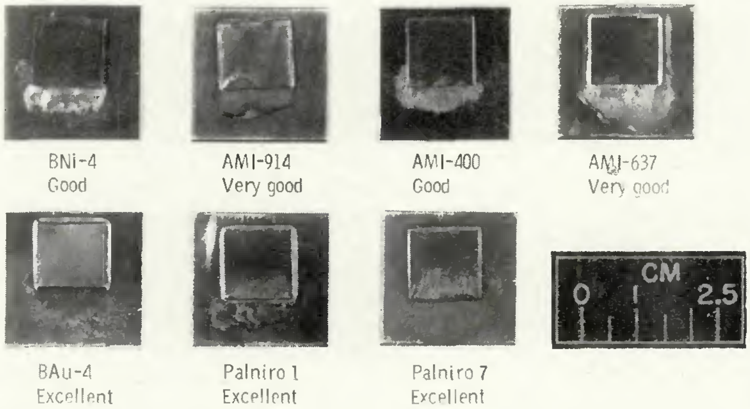
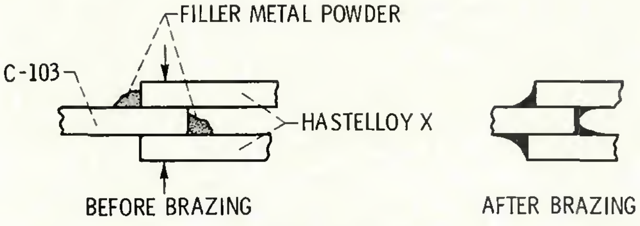
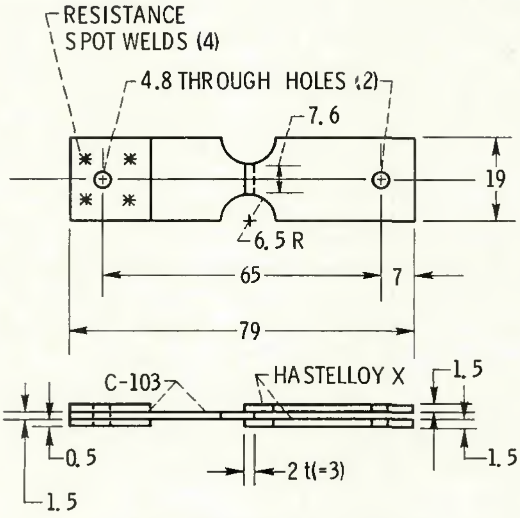


Fig. 3—Wetting and capillary flow of candidate filler metals in dissimilar metal joints



(a) FILLER METAL POWDER PLACEMENT (2 LOCATIONS) AND LOCATION OF CLAMPING PRESSURE.



(b) TENSILE-SHEAR DOUBLE LAP JOINT.

Fig. 4—Brazing technique and test specimen for tensile-shear tests; dimensions are in mm

aging had little apparent effect on the strengths of joints brazed using these two filler metals. The AMI-400 joints failed at stresses notably lower than those obtained on the BNi-4 and AMI-914 joints. Also, some brittleness was noted in the AMI-400 joints in that two of the joints broke in handling. The strengths of the BAu-4 joints in the as-brazed condition were slightly greater than those of the other joints, but aging resulted in embrittlement and lower strengths.

Even greater embrittling and weakening effects were observed for the remaining filler metals. The as-brazed Palniro 7 joints, which were similar in strength to BNi-4 and AMI-914 joints, were severely embrittled during aging and broke in handling prior to testing. Extreme brittleness was characteristic for the Palniro 1 and the BNi-5 joints, even in the as-brazed condition. Five of the six Palniro 1 joints and all six of the BNi-5 joints were broken prior to testing.

The AMI-637 joints were as strong as BNi-4 and AMI-914 joints in the as-brazed condition at room temperature. At 720 C (1328 F), the AMI-637 joints were only about one-fourth as strong as BNi-4 and AMI-914 joints in both the as-brazed and the aged conditions.

Metallographic Examination

Single and double lap joint brazements were examined metallographically in both the as-brazed condition and after aging. Microhardness determinations were made on the braze metals and base metals. Wettability and flow of all filler metals were good, and very few braze voids or other flaws were observed. Very little base metal erosion was observed with any of the filler metals.

Aging had little effect on the microstructural appearance of the braze joints. Aging did have a significant effect, however, on the maximum microhardness within the braze metals, as can be seen in Fig. 6. The hardness of most of the braze metals increased with aging.

The largest increases were observed for the gold-base alloys which probably accounts for their poor performance in the tensile-shear tests. The BNi-4 alloy had an intermediate hardness in the as-brazed condition but had the second lowest hardness of the braze metals in the aged condition. The microhardness of the Hastelloy X base metal increased only slightly due to aging, and the microhardness of the C-103 base metal was unaffected.

Filler Metal Selection for Full Size Joints

Based on the results of the preliminary studies, two filler metals—BNi-4 and AMI-914—were selected for the fabrication of full size pipe joints. These filler metals exhibited good strength in the as-brazed condition and after aging along with good flow characteristics and very little base metal reactions.

All of the other filler metals were eliminated because of lower strengths or embrittlement problems.

Evaluation of Pipe Joints

A total of eighteen, 62-mm (2.44 in.) diameter by 5-mm (0.2 in.) wall thickness Hastelloy X/Cb-1Zr dissimilar metal pipe joints were fabricated using the BNi-4 and AMI-914 brazed filler metals. (The use of the Cb-1Zr alloy in place of the C-103 alloy was discussed previously under Materials.) The integrity and strength of the joints were evaluated in the as-brazed condition, after vacuum aging for 1000 h at 720 C (1328 F), and after 100 thermal cycles to 720 C (1328 F) in vacuum.

The 1000 h aging tests were used to determine if adverse aging reactions would occur between the filler metals and the base metals at the service temperature. Although the aging tests were for a relatively short time compared to the actual service requirements, some indication of aging effects should be observed within 1000 h.

The cyclic tests were used to simulate rapid startups and shutdowns which might be encountered during ground testing of the BIPS. A maximum requirement of 100 thermal cycles has been estimated for these ground tests. In an actual space appli-

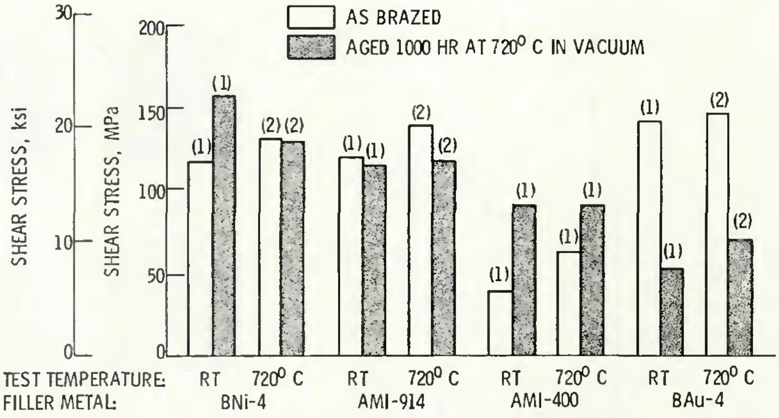


Fig. 5—Braze metal shear stress at fracture for double lap tensile-shear specimens for Hastelloy X/C-103 brazements tested at room temperature and at 720 C; the number of tests run is shown in parentheses above corresponding bar

cation, no thermal cycling would be expected because the BIPS should stay at the operating temperature for the life of the system.

Joint Fabrication and Inspection

The five joint design variations used in this study are shown in Fig. 7. The tongue-in-groove design is similar to that used by Thompson.[5]

Two joints of each design were fabricated using each of the two selected filler metals, except for the square butt joint where only one joint was fabricated from each filler metal. The design of the joints was intended to permit movement of the Hastelloy X relative to the Cb-1Zr prior to brazing in order to compensate for the difference in thermal expansion of the two base metals. The dimensions of the joints were calculated so that the joints were in an unstressed condition at the brazing temperature.

The requirement for relative movement of the two base metals resulted in a large (0.33 mm, 0.013 in.) radial gap for the tongue-in-groove joints; this caused some problems with braze voids as is to be discussed further in this paper. The chevron joints were designed so that the points would be centered in the groove at the brazing temperature. Chances of survival for the square butt joints were considered less than for the other joint designs, because the full shear stress produced by differential thermal expansion acts directly on the braze.

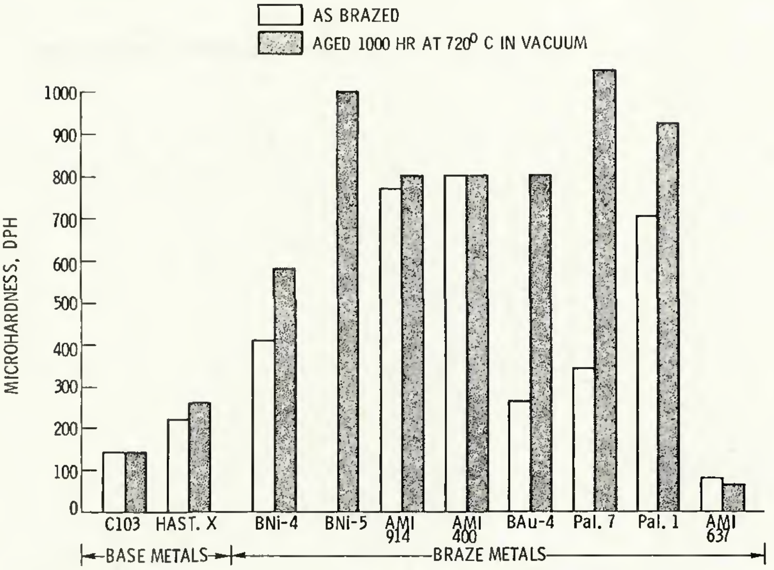
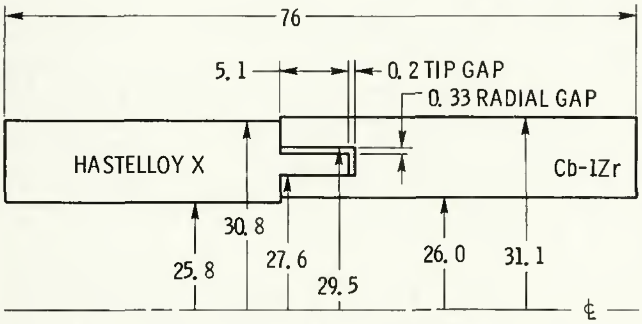


Fig. 6—Microhardness of Hastelloy X/C-103 double lap joint brazements in the as-brazed and aged conditions

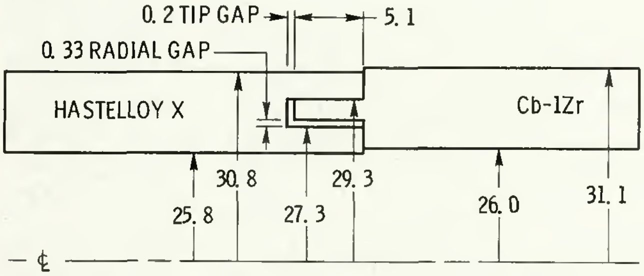
After degreasing, the joints were assembled as shown in Fig. 8. The 3.3 kg (7.3 lb) dead weight provided a force normal to the joint to ensure close contact of the braze components when the braze metal was molten. The volume of filler metal added to the joint was typically twice the volume calculated to fill the joint. All brazing was accomplished in vacuum using procedures similar to those described previously. A typical brazed joint and its component parts are shown in Fig. 9.

Visual examination of the as-brazed joints showed that adequate joint fill was achieved in almost all cases. All

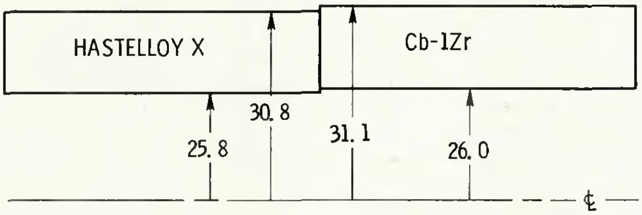


(a) HASTELLOY X TONGUE IN Cb-1Zr GROOVE

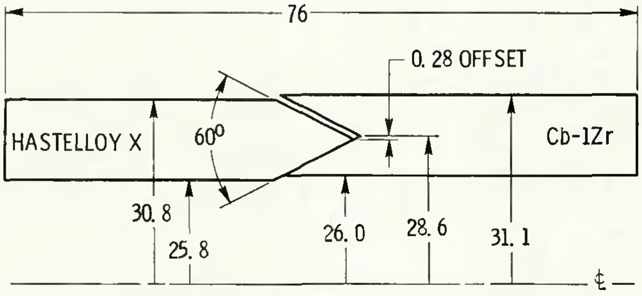
Fig. 7—Tongue-in-groove, square butt, and chevron bimetallic joint designs used in this study for nominal 62 mm diameter × 5 mm wall thickness pipe; all dimensions are in mm



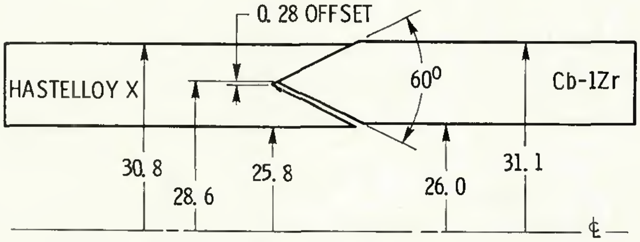
(b) Cb-1Zr TONGUE IN HASTELLOY X GROOVE.



(c) SQUARE BUTT JOINT.



(d) HASTELLOY X POINT IN Cb-1Zr CHEVRON GROOVE



(e) Cb-1Zr POINT IN HASTELLOY X CHEVRON GROOVE.

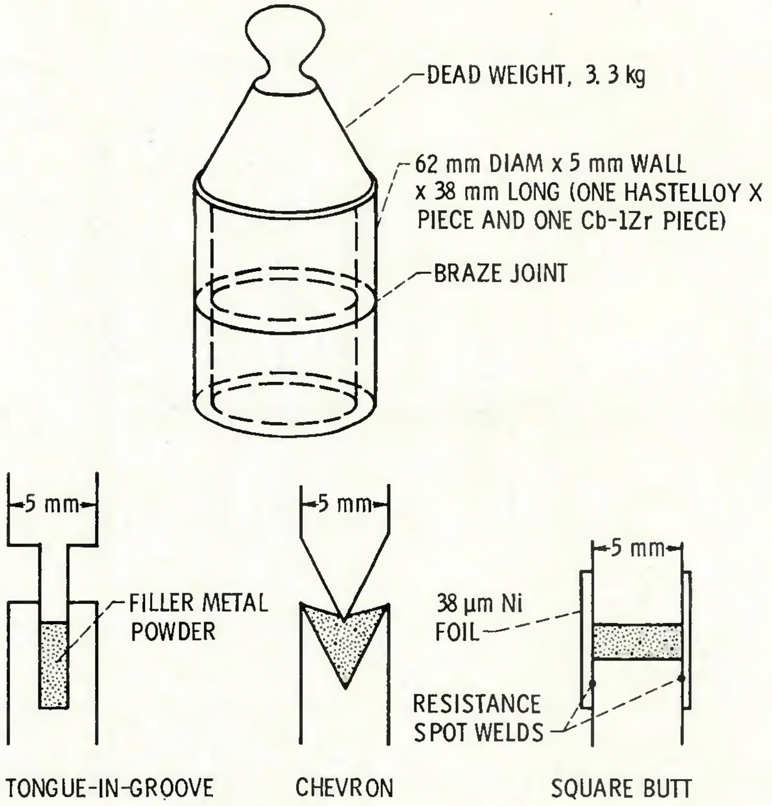


Fig. 8—The arrangement, loading and filler metal placement for brazing butt joints in 62 mm diameter pipe

the joints were examined in both the as-brazed condition and after "clean-up" machining using fluorescent penetrant inspection. The appearance of the as-brazed external surfaces was considered good (i.e., free of flaw indications) for all the tongue-in-groove joints and for the chevron joints with the Hastelloy X point. However, all the chevron joints with the Cb-1Zr point had apparent surface cracks.

As-brazed surfaces of the square butt joints were not examined because of a nickel foil wrap around the joint (Fig. 8). Examination of the joints after clean-up machining on both the inside and outside diameter surfaces showed that the number of flaw indications increased in many cases.

Based on the penetrant examination of the machined surfaces, the best joint of each braze alloy for each joint design (a total of 10 joints) was selected for the thermal cycling tests. The remaining 8 joints were sectioned longitudinally for tensile testing. One half of each pipe joint was tested in the as-brazed condition, and the other half was tested after aging for 1000 h at 720 C (1328 F) in a vacuum furnace at a pressure of 1.3×10^{-6} N/m^2 (1×10^{-8} torr) or less.

Thermal Cycling Tests

In this test the dissimilar metal pipe joints were subjected to 100 thermal cycles from ambient temperature to 720 C (1328 F) in a vacuum furnace at a pressure of 1.3×10^{-4} N/m^2 (1×10^{-6} torr) or less. The joints were thermally cycled by transferring them between the hot zone of the furnace and a water-cooled table located in the vacuum chamber.

In general, the time at temperature for each cycle was 1 hour (h). But in order to increase the total time at temperature and thereby accelerate aging effects, the hold time for the initial cycle was 100 h and the hold time for every fifth cycle was 18 h. Hold time in the cold zone was 1 h.

The integrity of the pipe joints was evaluated after cycle numbers 1, 5, 10, 25, 50, and 100 using fluorescent penetrant inspection and a helium-mass spectrometer leak detector. Penetrant inspection showed that the amount of surface flaws generally increased with thermal cycling with the chevron joints having the greatest number of indications. A more detailed examination of the flaws is presented under Metallography in this paper.

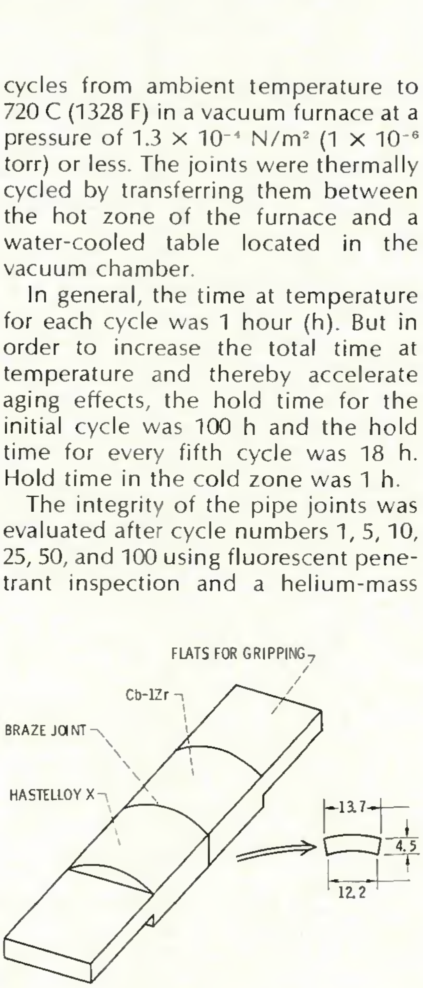


Fig. 10—Transverse tensile specimen from brazed pipe joint; dimensions are in mm

Fig. 9—Dissimilar metal pipe brazement and component parts for Hastelloy X tongue in Cb-1Zr groove

Although numerous flaw indications were observed, no leaks (less than 1×10^{-8} std cc/s helium) were detected in any of the joints using the helium-mass spectrometer leak detector. Thus, in this respect, all of the joints were considered usable for the intended application. The somewhat surprising survival of the square butt joints during thermal cycling is attributed to plastic deformation of the relatively low strength Cb-1Zr base metal.

Tensile Tests

Tensile tests were conducted on the pipe joints to evaluate the effects of aging and thermal cycling on joint strength. The joints were sectioned longitudinally, as shown in Fig. 10, and flats were machined on the ends for gripping.

All testing was done in air at room temperature at a crosshead speed of 1.3 mm (0.05 in.) per minute. Duplicate tests were run for each condition. The tensile strengths were calculated based only on the cross-sectional area of the specimen, and no attempt was made to determine shear stresses within the joint.

Test results are summarized in Fig. 11. The tensile strength variations observed are believed to be caused by small flaws in the brazes. For example, examination of the fracture surfaces showed that the low strength of the aged chevron joint with the Cb-1Zr point and brazed with the AMI-914

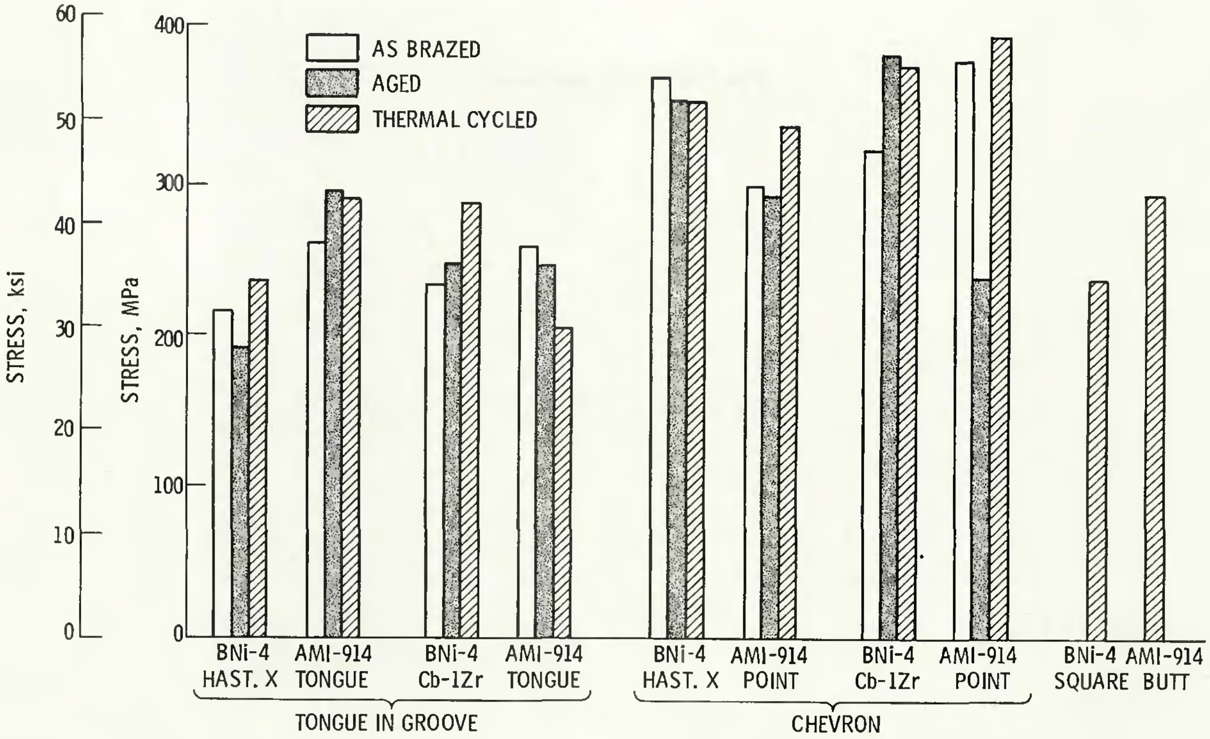
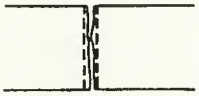


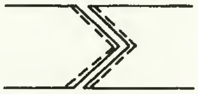
Fig. 11—Room temperature tensile test results for specimens taken normal to the brazed pipe joints; results are average of duplicate tests

alloy could be attributed to local areas devoid of filler metal.

Comparison of the tensile strengths of the various types of joints showed that the chevron joints were the strongest. The higher strength of the chevron joints can be directly related to joint geometry, braze metal area, and fracture location. As shown in Figs. 12(a) and (b), both the square butt joint and the chevron joint failed through the braze metal. The area of braze metal, however, was greater for the chevron joints with the result that they failed at a higher overall stress.



(a) FAILURE THROUGH BRAZE FOR SQUARE BUTT JOINTS.

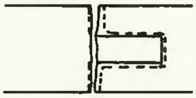


(b) FAILURE THROUGH BRAZE FOR ALL CHEVRON JOINTS.

FAILURE AT TIP OF TONGUE (11 TESTS)

FAILURE AT BASE OF TONGUE (1 TEST)

(c) FAILURE LOCATIONS FOR HASTELLOY X TONGUE IN Cb-1Zr-GROOVE JOINTS.



(d) FAILURE AT BASE OF TONGUE FOR JOINTS WITH Cb-1Zr TONGUE IN HASTELLOY X GROOVE.

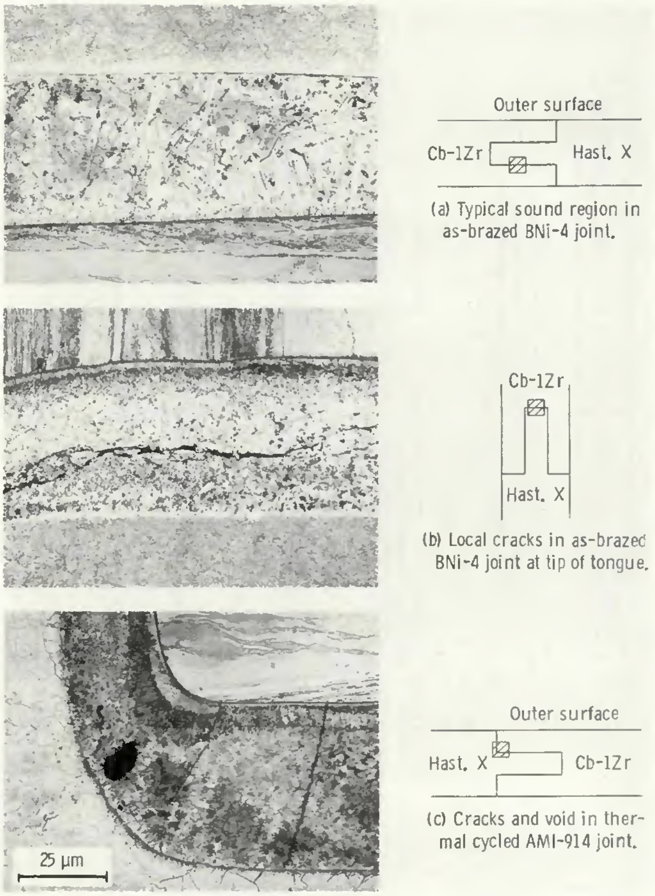
Fig. 12—Typical failure locations for brazed pipe joints tested at room temperature

The tongue-in-groove joints had the greatest braze area which caused the tensile failures to be a combination of braze metal and base metal fracture as can be seen in Figs. 12(c) and (d). In all cases except one, these joints failed through the braze metal and the Cb-1Zr alloy, which has less than half the strength of the Hastelloy X.

Based on the tensile test results, it appears that neither aging, nor thermal cycling, nor type of braze filler metal significantly affected joint strength. All of the joints appeared to be much stronger than needed for the actual BIPS application. Under static conditions, the expected stresses on the joints in the BIPS are very low (less than 6.9 MPa (1000 psi)) with the major stresses being circumferential stresses caused by the pressure of the helium-xenon gas in the system. Thus, all of these joints are felt to be acceptable on the basis of strength.

Metallography

The Hastelloy X/Cb-1Zr pipe joints were examined metallographically in the as-brazed, aged, and thermal cycled conditions. Emphasis was on areas where flaws were indicated by penetrant inspection. All flaws examined were found to be localized voids

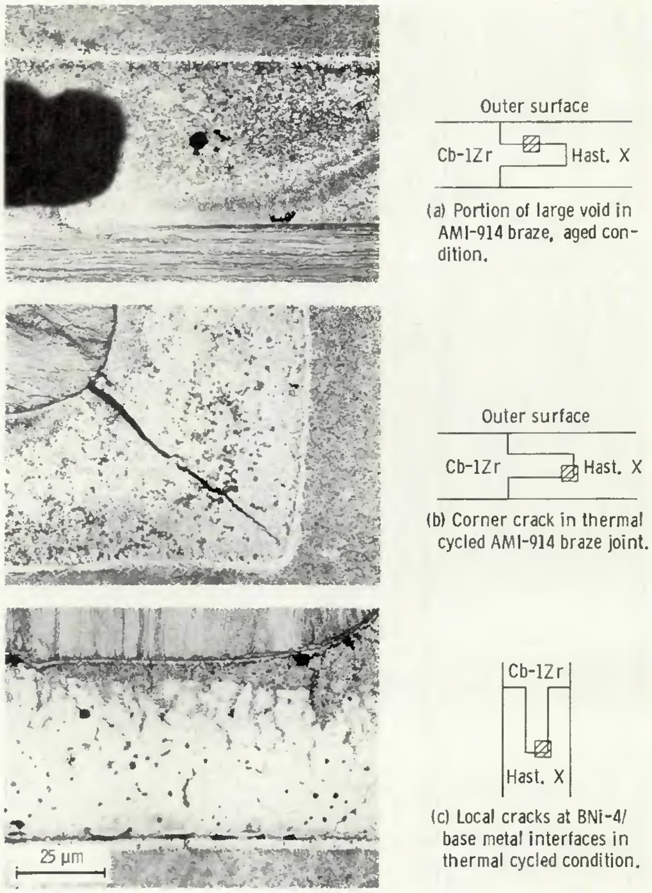


(a) Typical sound region in as-brazed BNi-4 joint.

(b) Local cracks in as-brazed BNi-4 joint at tip of tongue.

(c) Cracks and void in thermal cycled AMI-914 joint.

Fig. 13—Brazed tongue-in-groove pipe joint, with Hastelloy X tongue, showing sound region and typical flaws



(a) Portion of large void in AMI-914 braze, aged condition.

(b) Corner crack in thermal cycled AMI-914 braze joint.

(c) Local cracks at BNi-4/base metal interfaces in thermal cycled condition.

Fig. 14—Brazed tongue-in-groove pipe joints, with Cb-1Zr tongue, showing local flaws

or cracks which did not provide leak paths through the joints. The microstructure of the braze and braze/base metal interfaces for the Hastelloy X/Cb-1Zr pipe joints appeared quite similar to those of the Hastelloy X/C-103 lap joints which were examined previously.

Tongue-in-groove joints (Hastelloy X tongue). Examination of these joints showed similar behavior for both braze filler metals. Local voids and cracks were present in the as-brazed condition, but no growth of these flaws appeared to take place during aging or thermal cycling.

Examples of a sound region and typical flaws are shown in Fig. 13. As shown by Fig. 13(b), braze cracks were observed at the tip of the tongue. Some local cracks also were observed at the base of the tongue—Fig. 13(c).

Tongue-in-groove joints (Cb-1Zr tongue). These joints were generally sound with minor local cracking and void regions similar in nature and extent to those observed for the joints with the Hastelloy X tongue. The large internal void shown in Fig. 14(a) was located along the side of the tongue. The gap in this region is quite large at the brazing temperature due to the differential thermal expansions of the two base metals. Thus, filler metal distribution by capillary forces did not occur in this wide-gap region.

The crack in the braze at the corner of the tongue in Fig. 14(b) and the braze cracking near the braze metal/Hastelloy X interface shown by Fig. 14(c) apparently occurred during thermal cycling with similar results being observed with both filler metals.

Chevron joints (Hastelloy X point). All the joints brazed with the BNi-4 alloy were of good quality, except for some voids as shown by Fig. 15(a) and some small cracks in the braze. Some variation was noted in the AMI-914 joints with both the as-brazed and the aged joints having more voids than the thermal cycled joints. The appearance of the cycled AMI-914 joints was similar to all the BNi-4 joints, with voids and braze cracks at the surface of the joint—Fig. 15(b).

Chevron joints (Cb-1Zr point). These joints generally were of good quality in the as-brazed and aged condition although some voids and tip cracks were observed—Fig. 16(a). Minor cracks also were found in the braze metal near the AMI 914/Cb-1Zr interface.

Thermal cycling resulted in additional cracking of the type shown in Fig. 16(b); the cracks exhibit a tendency to follow the braze/Cb-1Zr interface and then terminate in the Cb-1Zr base metal. This type of crack produced a strong indication of a line flaw in penetrant examination.

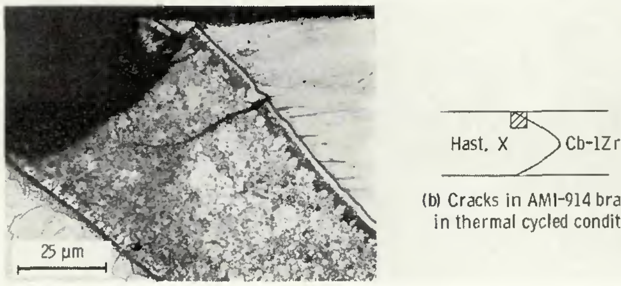
Similar results were obtained with both filler metals except that the BNi-4 joints had fewer cracks.

Square butt joints. These joints were examined only in the thermal cycled condition because only one joint was brazed with each filler metal. Examination of the AMI-914 joint showed a few small voids—Fig. 17. The BNi-4 joint was considerably wider and contained a large void which produced a strong indication of a line flaw during penetrant examination. No cracks were detected in either joint.

Discussion

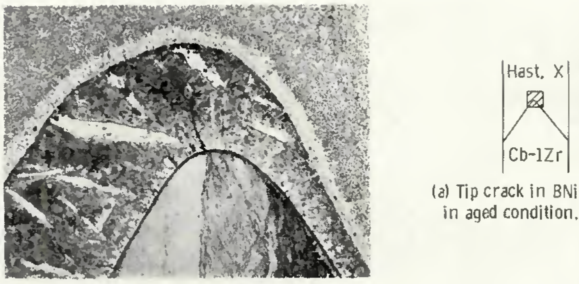
Evaluation of the brazed Hastelloy X/Cb-1Zr pipe joints showed that joints brazed with the BNi-4 or the AMI-914 filler metal should meet the expected service requirements of the BIPS. All of the joints were helium leak-tight and adequately strong. Neither aging at 720 C (1328 F) nor thermal cycling from ambient to 720 C (1328 F) affected the integrity of the joints. Both filler metals appeared to be microstructurally stable with no adverse reactions due to aging.

(a) Voids in BNi-4 joint, aged condition.

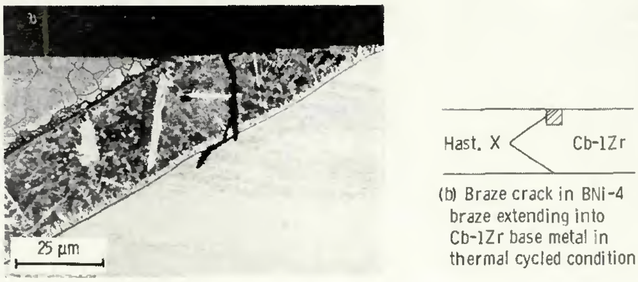


(b) Cracks in AMI-914 braze in thermal cycled condition.

Fig. 15—Brazed chevron pipe joints, with Hastelloy X point, illustrating typical flaws



(a) Tip crack in BNi-4 braze in aged condition.



(b) Braze crack in BNi-4 braze extending into Cb-1Zr base metal in thermal cycled condition.

Fig. 16—Brazed chevron pipe joint, with Cb-1Zr point, showing local flaws

Flaws such as shrinkage voids, areas devoid of filler metal, and local cracks in the brazes were present in all the joints. However, the flaws did not appear to detract from the usefulness of the joints. The internal cracking flaws are believed to have been present prior to metallographic sectioning. These cracks are not believed to be caused by the relief of residual stresses during sectioning and metallographic preparation of the pipe brazements. No work was done, however, to study this as a possibility.

Although all the joints should meet the BIPS requirements, the recommended joint is a tongue-in-groove design with a columbium alloy tongue and brazed with the BNi-4 alloy. This recommendation is based on the following factors:

1. The fractures observed in the transverse tensile tests of the tongue-in-groove joints were a combination of braze metal and base metal failure. The failures in both the chevron and square butt joints were through the braze metal only.
2. Flaws in the brazes, such as cracks or voids, have a more torturous path in the tongue-in-groove joint in order to produce a leak.
3. The columbium alloy tongue is preferred over the Hastelloy X tongue because of fewer local cracking flaws.
4. The BNi-4 filler metal is preferred over AMI-914 because of a lower microhardness and slightly less cracking tendency.

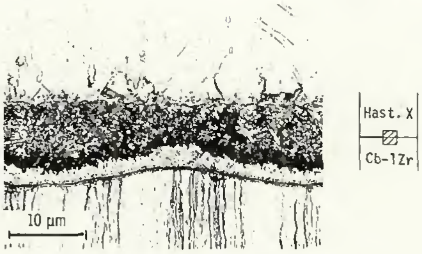


Fig. 17—Brazed square butt pipe joint showing small voids in AMI-914 braze metal

Many of the flaws observed in the joints were associated with large braze gaps. They could possibly be minimized by decreasing the brazing gap to promote better capillary distribution of the braze metal. The gap could be reduced by increasing the pressure normal to the joints during brazing and by some changes in joint design.

Changes in joint design would be particularly effective for the tongue-in-groove joint. Here the large brazing gap was necessary to allow relative movement of the two components during heating to the brazing temperature. This joint, for example, could be designed so that it would fit together only at the brazing temperature; thus, the brazing gap on both sides of the tongue could be optimized for good braze flow.

Alignment of the joint components during heating to the brazing temperature could be achieved by using a small bevel on the tip of the tongue. The braze metal corner cracking which was observed at the tip might be reduced by using a rounded tip and mating groove.

Conclusions

Based on the results of this study on the fabrication of Hastelloy X/columbium alloy dissimilar metal pipe joints for possible service in future space power systems at 720 C (1328 F), the following conclusions were reached:

1. Direct brazing is a viable method for fabricating the required joints.
2. The most promising joint design is a tongue-in-groove configuration with a columbium alloy tongue.
3. Of the eight braze filler metals investigated, the best results were obtained using a BNi-4 filler metal (Ni-3.5Si-2.0B).

References

1. Macosko, R. P., et al., "Isotope Brayton Electric Power System for the 500 to 2500 Watt Range," Seventh Intersociety Energy Conversion Engineering Conference, p. 522, American Chemical Society, Washington, D.C., 1972.
2. Kenney, W. D., et al., "Brayton Isotope Power System Ground Demonstrator," Eleventh Intersociety Energy Conversion Engineering Conference, Vol. 1, p. 201, American Institute of Chemical Engineers, New York, 1976.
3. Wein, D. and Gorland, S. H., "Design of a Nuclear Isotope Heat Source Assembly for a Spaceborne Mini-Brayton Power Module," Eighth Intersociety Energy Conversion Engineering Conference, p. 143, American Institute of Aeronautics and Astronautics, Inc., New York, 1973.
4. "Mini-Brayton Heat Source Assembly Design Study. Volume 1: Space Shuttle Mission," Report No. GESP-7103-Vol-1, 1973, General Electric Co., Philadelphia, Pa.; also NASA CR-121223-Vol-1—"Mini-Brayton Heat Source Assembly Design Study. Volume 2: Titan 3C Mission," Report No. GESP-7103-Vol-2, 1973, General Electric Co., Philadelphia, Pa.; also NASA CR-121223-Vol-2.
5. Thompson, S. R., "Brazed Transition Joints for Liquid and Alkali Metal Systems," *Report No. R-69-NSP-2*, 1969, General Electric Nuclear Systems Programs, Cincinnati, Ohio.