WELDING RESEARCH

SUPPLEMENT TO THE WELDING JOURNAL, OCTOBER, 1979
Sponsored by the American Welding Society and the Welding Research Council

Nickel-Palladium Base Brazing Filler Metal

36Pd-48.7Ni-11Cr-2.2Si-2.1B filler metal provides brazed joints with (1) better oxidation resistance than Mn- and P-containing alloys and (2) superior stress rupture life than joints brazed with 82Au-18Ni filler metal

BY T. L. D'SILVA

Introduction

Some gamma-prime superalloys such as Inconel 718 must be solution-treated in the temperature range 1750 to 1850 F (995 to 1010 C) to prevent a deterioration in mechanical properties, resulting from grain growth. For such alloys it is desirable to perform a brazing operation simultaneously during solution treating.

Table 1 is a list of alloys available for brazing in the temperature range 1750 to 1850 F. The expensive 82Au-18Ni filler metal is used in applications requiring excellent resistance to oxidation and corrosion. However, because of its high cost, it is a constant target for replacement with less expensive copper- or nickel-base filler metals, especially in the aircraft engine industry.[1,2] The phosphorus-containing filler metals are prone to excessive base metal erosion.[3] The manganese containing alloys have poor oxidation resistance beyond 1000 F (538 C).[2]

The objective of this study was to extend the brazing temperature range of the nickel-base filler metals below 1850 F (1010 C), without significantly reducing the heat-resistant properties. The Ni-Pd binary system exhibits complete solid solubility and a minimum melting composition of 60Pd-40Ni, which melts at 2260 F (1237 C).[4]

The metallurgical behavior of palladium (Pd) in the Pd-B, Pd-Si and Pd-Cr binary systems is similar to that of Ni in the Ni-B, Ni-Si and Ni-Cr binaries in the sense that it forms similar intermetallics.[4,5] Also, the Pd-rich eutectic in the Pd-B and Pd-Si binary alloy systems is lower melting than the corresponding eutectic in the Ni-B, Ni-Si binaries. Thus, Pd was a suitable candidate for lowering the solidus and liquidus of the Ni-based filler metals. Additions of Pd were also reported to improve the flow characteristics of silver-copper base filler metal on stainless steel.[6]

Experimental

Selection of Filler Metal Composition

The liquidus and solidus temperatures of a number of compositions in the Pd-Ni-Cr-Si-B system were determined by Differential Thermal Analysis, as a first step towards preliminary investigation.

The composition selected for extensive testing was 36Pd-48.7Ni-11Cr-2.2Si-2.1B (filler metal #36), which had solidus and liquidus temperatures

Table 1—Brazing Filler Metals in the 1750 to 1850 F (954 to 1010 C) Temperature Range

Filler metal composition	Solidus, °F (°C)	Liquidus, °F (°C)	Brazing Temperature, °F (°C)
82Au-18Ni	1740 (950)	1740 (950)	1800 (984)
20.5Au-3.4Si-5.3Cr-2.3B-2.3Fe-66.2Ni	1725 (941)	1780 (970)	1800 (984)
41Au-1.75Si-1.0B-0.5Fe-55.5Ni	1725 (941)	1830 (999)	1850 (1010)
11P-89Ni	1610 (877)	1610 (877)	1800 (984)
14Cr-10P-76Ni	1630 (890)	1630 (890)	1800 (984)
7Cr-3.1B-4.5Si-3.0Fe-82.4Ni	1780 (970)	1830 (999)	1850 (1010)
37.5Mn-9.5Ni-53Cu	1610 (877)	1690 (922)	1750 (955)
23.5Mn-9.0Ni-67.5Cu	1700 (927)	1750 (955)	1800 (982)
31.5Mn-10Co-58.5Cu	1645 (896)	1830 (1000)	1825 (997)

Paper presented at the 10th International AWS-WRC Brazing Conference held in Detroit, Michigan, during April 3-5, 1979.

T. L. D'SILVA, formerly with GTE WESGO, Belmont, Calif., is now with WACKER-SILTRONIC, Portland, Ore.

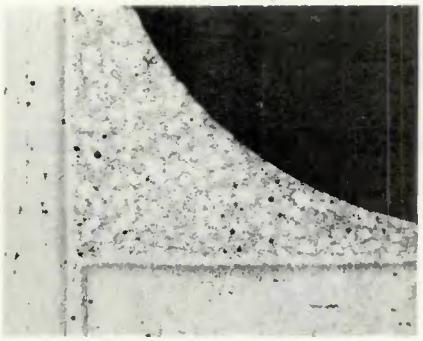

Fig. 1—Cross-section of filler metal #36/ Inconel 718 brazed joint, 1750 F (955 C), 60 min. X100 (reduced 50% on reproduction)

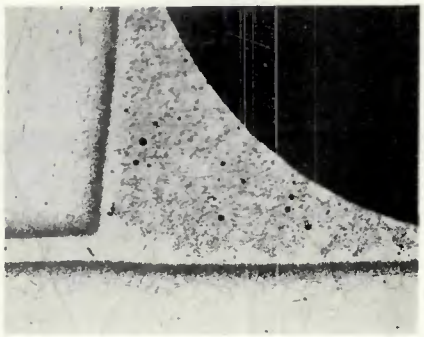

Fig. 2—Cross-section of filler metal #36/ Inconel 718 brazed joint, 1850 F (1010 C), 60 min. X100 (reduced 50% on reproduction)

Table 2—Joint Microhardness and Depth of Penetration in Filler Metal #36/ Inconel 718 Joints

	Brazing Temperature	
	1750 F (955 C)	1850 F (1010 C)
Brazing time, min	60	60
Microhardness, DPH:		
Joint	260	280
Edge	490	400
Depth of penetration, microns	22	34

of 1530 F (830 C) and 1735 F (945 C) respectively. The B and Si content of this filler metal was sufficient to depress the liquidus temperature into the desired range and yet provide a relatively low hardness of RC45 for the filler metal. The Cr content of 11 wt-% was in the range where the liquidus temperatures were minimum, with varying Cr content. Further reduction in liquidus temperature could have been attained by increasing the Pd content. However, from cost consideration, the Pd content was selected at the minimum level (36%) required to provide the desired liquidus temperature.

Two other compositions of 16Pd-68.7Ni-11Cr-2.2Si-2.1B (filler metal #16) and 28Pd-56.7Ni-11Cr-2.2Si-2.1B (filler metal #28) were selected for determining the effect on the lap shear strength, of replacing Ni with Pd. The three filler metals (#16, #28, #36) were atomized into powder and screened through a −150 mesh screen. The screened powder was converted into a paste of 84% metal content, and this paste was used to make brazed joints for all subsequent testing.

Selection of Base Metal

The base metal selected for extensive testing was Inconel 718 with a nominal composition of 18.6Cr-3.0Mo-5.0Cb-0.5Al-1.0Ti-18.5Fe. The recommended solution treating temperature range for obtaining the highest fatigue strength for this superalloy is 1700-1850 F (927 to 1010 C). Filler metal #36 was also tested for oxidation resistance and base metal erosion on AISI410 and AISI347 stainless steel T-joints, at Pyromet Industries.

Joint Microhardness and Depth of Penetration

T-joints of Inconel 718 were brazed in vacuum (10^{-4} mm Hg) at 1750 F (955 C) and 1850 F (1010 C) for 60 minutes (min). The mating edge of the vertical arm of the inverted T was ground square, and the finish on the horizontal arm was retained at the as-received mill finish. The T-joints were degreased before application of filler metal paste, along one side of the joint. The joint gap was maintained at "zero" by clamping in a molybdenum fixture.

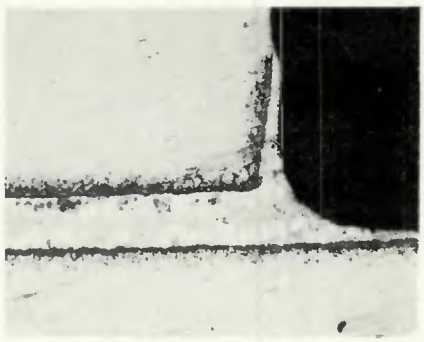

Fig. 3—Cross-section of AISI410 joint brazed with filler metal #36 at 1800 F for 30 min. X150 (reduced 50% on reproduction)

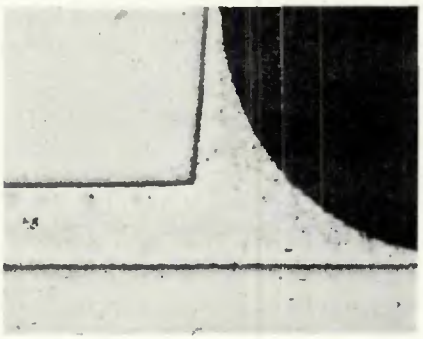

Fig. 4—Cross-section of AISI347 joint brazed with filler metal #36 at 1800 F for 30 min. X150 (reduced 50% on reproduction)

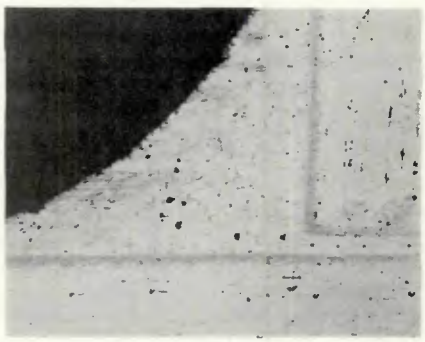

Fig. 5—Cross-section of filler metal #36/ Inconel 718 joint oxidized at 1300 F (705 C) for 200 h. X100 (reduced 50% on reproduction)

Sections of these T-joints were mounted and polished for metallographic examination. A number of microhardness (DPH) measurements were made within the joint and edge of fillet, for both the 1750 F (955 C) and 1850 F (1010 C) brazed sections.

Oxidation Test

T-joints were prepared according to the procedure described previously and brazed at 1800 F (984 C) for 60 min in vacuum (10^{-4} mm Hg). Oxidation tests were performed in air at 1300 F (705 C) and 1500 F (816 C) for 200 hours (h) at each temperature. The oxidized joints were nickel plated before mounting for metallographic examination.

Lap Shear and Stress Rupture Tests

Specimens for both lap shear (1T, 2T, 3T, 4T, 5T and 6T) and stress rupture (2T) were prepared based on the specimen design recommended in AWS C3.2-63. A "zero" joint gap in the overlap was maintained through the brazing cycle by clamping in a molybdenum fixture. The finish on the mating surfaces was intentionally retained at as-rolled mill finish, to verify the oxide cleaning capability of Pd.

Lap shear specimens were degreased and brazed for 60 min in vacuum (10^{-4} mm Hg) at temperatures of 1800 F (982 C), 1850 F (1010 C) and 1925 F (1050 C) for filler metals #36, 28 and 16 respectively. The lap shear tests were performed only at room temperature and the average unit stress at failure was determined as recommended in AWS C3.2-63.

The stress rupture tests were performed in air at 1300 F (705 C) at a shear stress level of 5000 psi (34.5 MPa) in the joints.

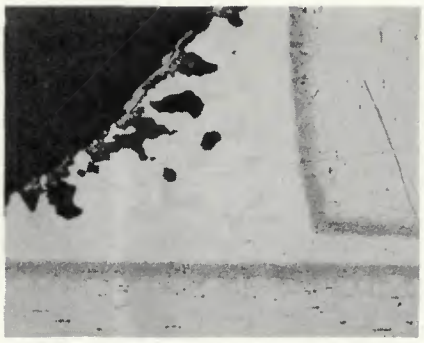

Fig. 6—Cross-section of filler metal #36/ Inconel 718 joint oxidized at 1500 F (816 C) for 200 h. X100 (reduced 50% on reproduction)

Fig. 7—Cross-section of filler metal #36/ AISI410 joint oxidized at 1400 F (760 C) for 500 h. X150 (reduced 50% on reproduction)

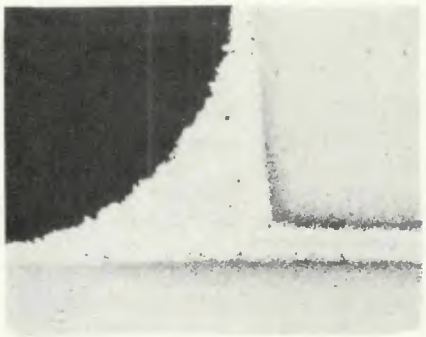

Fig. 8—Cross-section of filler metal #36/ AISI347 joint oxidized at 1400 F (760 C) for 500 h. X150 (reduced 50% on reproduction)

Wettability Test

Filler metal #36 was compared with BNi-2 for wettability on Inconel 718. A 0.2 gram sample of each filler metal in the form of powder was melted on Inconel 718 in vacuum (10^{-4} mm Hg). Each alloy was heated to 50 F (27.8 C) above its liquidus temperature and held for 5 min. A qualitative judgement on the wettability was made from observing the spreading behavior of each filler metal on Inconel 718 base metal.

Results and Discussion

Joint Microhardness and Depth of Penetration

Figures 1 and 2 are micrographs of cross-sections of T-joints brazed at 1750 F (955 C) and 1850 F (1010 C), respectively. The depth of penetration measured on the micrographs, and average microhardness values within the joint and edge of fillet are shown in Table 2.

The microhardness at the edge of fillet of the 1750 F (955 C) brazed joint was the same as the hardness of the filler metal. The hardness at the edge of the fillet on the joint brazed at 1850 F (1010 C) was lower. In both cases, the hardness within the joint was considerably lower as a result of diffusion of boron into the base metal. The depth of penetration of boron into the base metal was 22 and 34 microns at brazing temperatures of 1750 and 1850 F (955 and 1010 C), respectively. Although the brazing time was 60 min, there were no signs of base metal erosion probably because of the relatively low brazing temperatures.

Figures 3 and 4 show joint cross-sections of AISI Types 410 and 347 steel respectively, brazed with filler metal #36 at 1800 F (984 C) for 30 min. Although base metal penetration of boron is evident, there is no erosion of the base metal.

Oxidation Test

Visual examination of the fillet, oxidized at 1300 F (705 C) for 200 h, showed that the oxide layer was continuous with that on the base metal. A cross section of the 1300 F (705 C) oxidized joint (Fig. 5) shows no sign of oxide penetration into the fillet or joint area. However, the 1500 F (816 C) oxidized joint in Fig. 6, showed oxidation of the intermetallics near the surface of the fillet, but no signs of oxygen penetration into the joint area.

Figures 7 and 8 are cross-sections of AISI Types 410 and 347 steel joints, respectively, oxidized at 1400 F (760 C) for 500 h. The joints show resistance to oxygen penetration and an increased

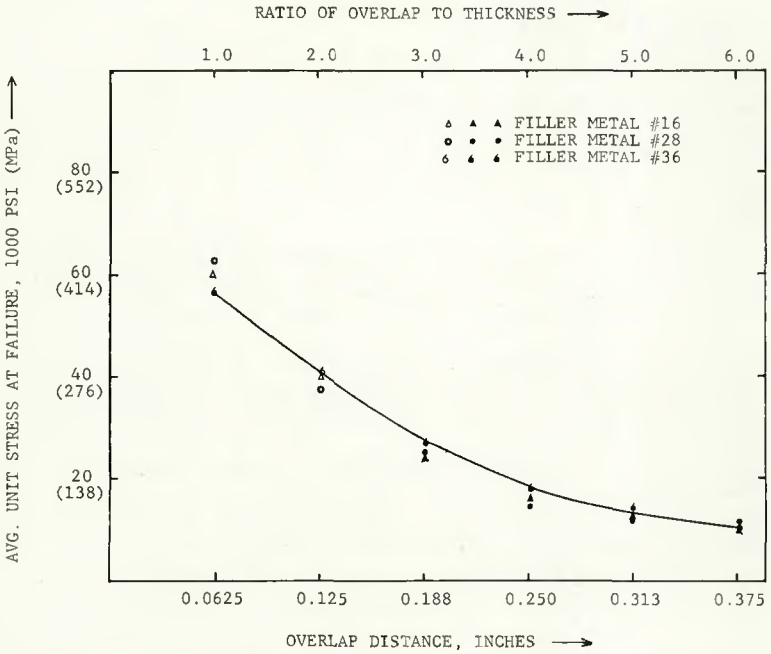

Fig. 9—Average unit shear stress at failure vs. overlap distance for Inconel 718 joints brazed with filler metals 16, 28 and 36. (Filled symbols represent failure in the base metal)

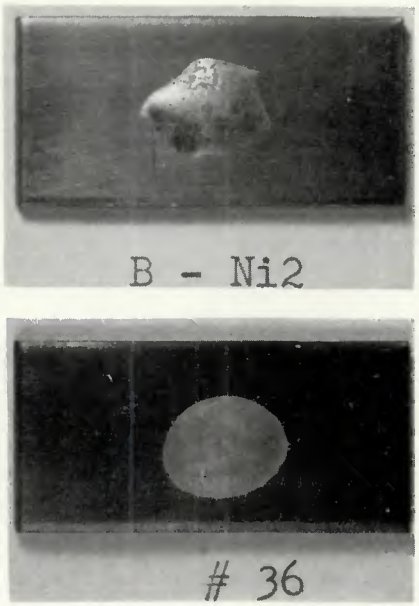

Fig. 10—A comparison of wettability of BNi-2 with #36 on Inconel 718 substrate, by heating to 50 F (27.8 C) above the liquidus temperature of each filler metal

diffusion of boron into the base metal.

Lap Shear and Stress Rupture Tests

Figure 9 shows shear strength data at room temperature performed on standard lap shear specimens of Inconel 718, brazed with filler metals #16, 28 and 36. Failure occurred in the base metal at joint overlaps of 3T and above. The lap shear tests showed that the shear strength was virtually unaffected by varying the palladium content. The magnitude of the shear stress values were also comparable to those of joints brazed with nickel-base alloys.[7]

The stress rupture life of filler metal #36/Inconel 718 joints with a 2T overlap, was over 100 h at a temperature of 1300 F (705 C) and a shear stress level of 5000 psi (34.5 MPa). In comparison, the reported rupture life on an 82Au-18Ni/Inconel 718 joint, is 32 h at 1200 F (650 C) and a shear stress level of 5000 psi (34.5 MPa).[8]

Wettability Tests

A comparison of the spreading behavior of filler metal #36 with BNi-2, on Inconel 718 base metal, is shown in Fig. 10. The filler metal #36 showed superior wetting and the melt bead was spread uniformly in all directions.

Tests conducted at Pyromet Industries in the repair brazing of knife-edge seals showed that filler metal #36 could be brazed in dry hydrogen.

Conclusions

1. Additions of palladium in substantial quantities lower the brazing temperatures of nickel-base brazing alloys thereby enabling brazing of joints at 1750 F (955 C).
2. The oxidation resistance of filler metal #36 is superior to the manganese-and phosphorus-containing alloys.
3. The lap shear strength of the brazed joint is not affected by replacing nickel with palladium.
4. The stress rupture life of joints brazed with filler metal #36 is superior to joints brazed with 82Au-18Ni.
5. Additions of palladium improve the wettability of nickel-base filler metal, and brazing can be performed even in a hydrogen atmosphere.

Acknowledgments

The author expresses his gratitude to Howard Mizuhara and Ruben Lopez of the laboratory staff for their help, and to Tom Hikido and Dave Reed (Pyromet Industries) for evaluating this alloy in the repair brazing of knife-edge seals.

References

1. Eng, R.D., Ryan E.J., and Doyle, J.R., "Nickel-Base Brazing Filler Metals for Aircraft Gas Turbine Application," *Welding Journal*, 56 (10), Oct. 1977, pp. 15 to 21.
2. Schaefer, R.P., Flynn, J.E., and Doyle, J.R., "Brazing Filler Metal Evaluation for an Aircraft Gas Turbine Engine Application," *Welding Journal*, 50 (9), Sept. 1971, Research Suppl., pp. 394-s to 400-s.
3. Amato, I., Baudroco, F., and Ravizza, M., "Spreading and Aggressive Effects by Nickel-Base Brazing Filler Metals on the Alloy 718," *Welding Journal*, 51 (7), July 1972, Research Suppl., pp. 341-s to 345-s.
4. Hansen, M., *Constitution of Binary Alloys*, McGraw-Hill Book Company, Inc., New York, 1958, p. 1030.
5. Elliot, P.R., *Constitution of Binary Alloys, First Supplement*, McGraw-Hill Book Company, Inc., New York, 1965, p. 732.
6. Rhys, D.W., and Berry, R.D., "The Development of Palladium Brazing Alloys," *Metallurgia*, 1962, p. 255.
7. Peaslee, R.L., "The Brazing Test Specimen—Which One?" *Welding Journal*, 55 (10), Oct. 1976, pp. 850 to 858.
8. Barb, R.P., and Sutar, W., U.S. Patent 3,764,307, 1973.