Thermal and Metallurgical Influences on AISI 316 and Inconel 625 by High Temperature Brazing with Nickel Base Filler Metals

Results obtained with three filler metals—BNi-2, BNi-5 and Pd 36—are evaluated

BY E. LUGSCHEIDER, K.-D. PARTZ, and R. LISON

Introduction

Tests were previously carried out systematically on the effect that brazing conditions have on the properties of AISI 316 stainless steel joints brazed at high temperatures with nickel-base filler metals. Results revealed brittle-phase-free joints for different filler metals. Brazing procedures were determined to ensure a reproducible quality of brazed seam consisting mainly of nickel-iron-chromium-silicon solid solution. The static load resistance of these joints was better than that of the AISI 316 stainless steel base metal (Ref. 1, 2, 5, 6).

Nickel-base filler metals contain silicon and boron in addition to nickel, chromium and precious metals. In the case of brittle-phase-free brazed joints, silicon in the filler metals dissolves in the solid solution of the brazed seam and in the base metal. The mechanical properties of the solid solution brazed seam differ from those of the base metal; they are determined by the diffusion conditions of the brazing process. It is to be noted that boron from the filler metal passes as borides into the base metal by grain boundary diffusion because of the extremely low solid solubility of boron in metals.

High temperature brazing is carried out for time durations and at temperatures that may cause a microstructural change in the base metal. The metallurgical influence of the solid solution composition together with boride precipitation and the influence of temperature can lead to degeneration of base metal properties, particularly dynamic load resistance.

This paper reports on the outcome of an investigation on the effects of thermal and metallurgical conditions on brazed joints and structure of the base metal in the region of the joint. The investigation was carried out using three filler metal/base metal systems—namely, BNi2/AISI 316, BNi5/AISI 316 and Pd 36/Inconel 625. Chemical compositions for the three filler metals and for the two base metals are shown in Tables 1 and 2, respectively.

Table 1—Filler Metal Chemical Compositions, Wt-%

	Pd 36	BNi-2	BNi-5
Cr	11.0	7.0	19.0
Si	2.3	4.5	10.2
B	2.4	3.1	–
Ni	47.6	Bal.	Bal.
Pd	36.8	–	–
Fe	–	3.0	–

Thermal and Metallurgical Effects on the Base Metal

High temperature brazing with BNi-2, BNi-5 and Pd 36 nickel-base filler metal requires brazing temperatures between 960 and 1200°C (1706 and 2190°F)—Table 3. The temperatures for solution heat treatment and secondary recrystallization, both of which cause a coarse-grain structure, are within this temperature range as is the temperature required to produce a homogeneous structure in the joint seam. In this temperature range, a continuous cross-dissolution of filler and base metal is observed as indicated by Fig. 1 which illustrates the braze seam of a joint in AISI 316 made with BNi-5 filler metal.

Structural grains have grown throughout the joint in Fig. 1. Nonetheless, in this case a nickel-rich zone remains in the joint. Depending on its homogeneity, the iron-nickel-chromium-silicon solid solution must be assumed to have shown an increase in hardness. The material qualities of this area differ from those for the base metal.

The results of investigations with

Table 2—Base Metal Properties

	AISI 316	Inconel 625
Composition, Wt-%		
Fe	Bal.	5.0 max.
Cr	17.0	21.5
Mo	2.5	9.0
Nb/Ta	–	3.5
Co	–	1.0
Ni	12.0	Bal.
UTS, MPa (ksi)[a]	550-750 (79.8-108.8)	800 (116)
Thermal, °C (°F)[b]	1050 (1922)	1090 (1994)

(a) UTS = ultimate tensile strength.
(b) Solution treatment/recrystallization temperatures.

Paper presented at the 13th International AWS-WRC Brazing and Soldering Conference held in Kansas City, Missouri, during April 27-29, 1982.

E. LUGSCHEIDER and K.-D. PARTZ are associated with the Technical University Aachen, and R. LISON is with the Nuclear Research Establishment, Julich, West Germany

Table 3—Temperature Characteristics for Pd 36, BNi-2 and BNi-5 Filler Metals

Filler metal	Temperature reading, °C (°F) T_s	T_L	Brazing range
Pd 36	830 (1526)	945 (1724)	960-1065 (1760-1949)
BNi-2	970 (1780)	1000 (1830)	1010-1170 (1850-2138)
BNi-5	1080 (1975)	1135 (2075)	1150-1205 (2100-2200)

T_S – solidus temperature
T_L – liquidus temperature

boron-containing filler metals BNi-2 and Pd 36 (Table 1) indicated that diffusion of boron into the base metal effected a stabilization of borides. Boride precipitates were found to extend out a short distance between braze seam and base metal, and intercrystalline further from the seam.

Fig. 1—Braze seam in BNi-5/AISI 316 joint. Brazed for 60 min at 1190°C (2174°F)

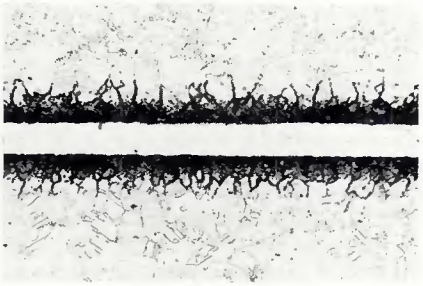

Fig. 2—Brazed joint in Inconel 625 made with Pd 36 filler metal. Brazed for 60 min at 1040°C (1904°F). X50 (reduced 33% on reproduction)

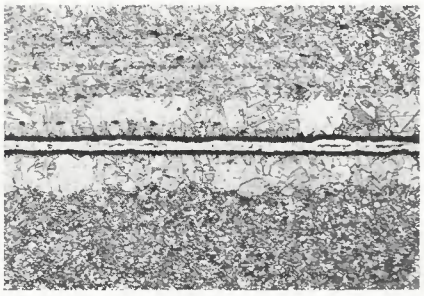

Fig. 3—Grain growth in region of brazed joint in AISI 316 stainless steel made with BNi-2 filler metal. Brazed for 10 min at 1040°C (1904°F). X50 (reduced 33% on reproduction)

Figure 2 shows a brazed joint in Inconel 625 that was made using Pd 36 filler metal. Brazing was carried out at 1040°C (1904°F) for 60 min. The braze seam and the different boron precipitates may be seen; these show different depths of formation in the base metal, depending on brazing conditions.

A third metallurgical phenomenon was seen at brazing temperatures below the approximate 1050°C (1922°F) recrystallization temperature for AISI 316. This is indicated in Fig. 3 where grain growth may be seen ranging out a short distance in the joint, giving rise to an increase from ASTM no. 8 to ASTM no. 4. It is to be noted that local, limited diffusion of carbon and columbium lowers the temperature of recrystallization, and this is supposed to have an effect on grain growth. (No further consideration is given to this in the paper.)

Thermal and metallurgical effects in the bonding area of a brazing compound can affect the characteristic quality of a high temperature brazed joint. The behavior of load resistance—particularly dynamic qualities, load resistance in the case of multi-axle strain, thermal stability, and corrosion resistance—will change. For this reason, the region of a brazed joint is sometimes called a "metallurgical notch." Care must be observed when working with thin-walled constructions because these effects can destroy the workpiece. Therefore, it is important to be thoroughly familiar with these effects precisely in order to be able to select the correct filler metal and brazing procedure.

Formation of Solid Solution Between Filler and Base Metals

Tests were conducted with all three filler metal/base metal systems with respect to joint development dependency on temperature for 10 and 30 min. The depth of solid solution was related to the workpiece surface, and here "depth" indicates how deep a structural change developed in the base metal. Braze joint clearance had no effect in a brazing gap ranging from 10 to 100 μm (0.0004 to 0.004 in.) (Ref. 1, 2).

Figures 4–7 indicate the depth of solid solution between base and filler metals. Additionally, Figs. 4 and 5 show that AISI 316 and Inconel 625, when brazed using BNi-2 filler metal, show similar tendencies with respect to solid solution depth development. The depth of solid solution in both cases is about 10 μm (0.0004 in.). With Inconel 625 from about 1070°C (1958°F) and with AISI 316 from about 1050°C (1922°F), the depth of mixture increases exponentially. At 1170°C (2138°F), the depth of solid solution with Inconel 625 is about 75 μm (0.003 in.) and in the case of AISI is about 50 μm (0.002 in.). Similar behavior is observed with the base metal when brazing Inconel 625 with filler metal Pd 36.

The recrystallization temperature is approximately 1050°C (1922°F), and the solution heat-treatment temperature for Inconel 625 is approximately 1090°C (1944°F) and even higher. Using heat treatments which take advantage of a higher diffusion in the material, filler metal elements (i.e., nickel, chromium, silicon and iron) can be soluted. This is shown by increases in the depth of the brazing seam; the effect of time is almost negligible.

Similar tests with the BNi-5/AISI 316

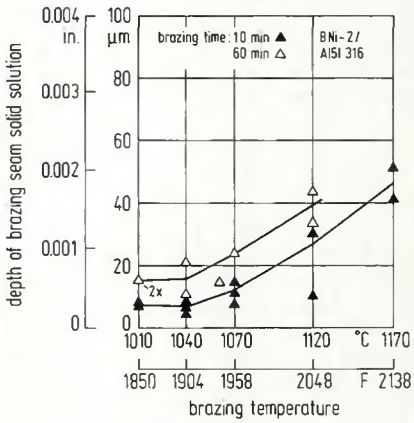

Fig. 4—Depth of braze seam solid solution vs. brazing temperature for BNi-2/AISI 316 system

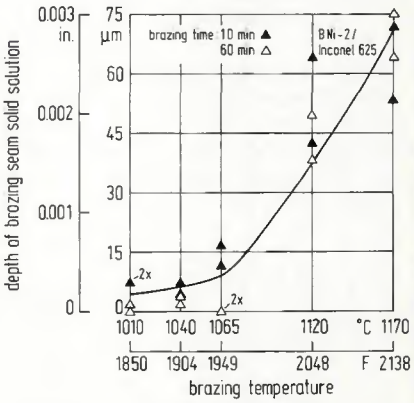

Fig. 5—Depth of braze seam solid solution vs. brazing temperature for BNi-2/Inconel 625 system

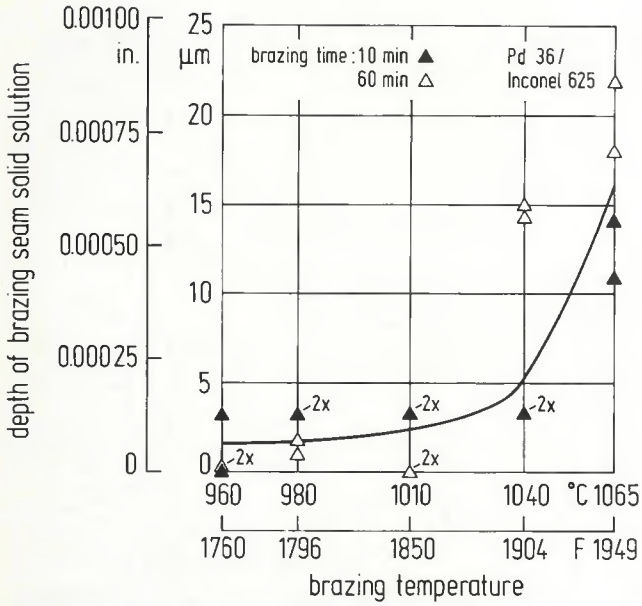

Fig. 6 — Depth of braze seam solid solution vs. brazing temperature for Pd 36/Inconel 625 system

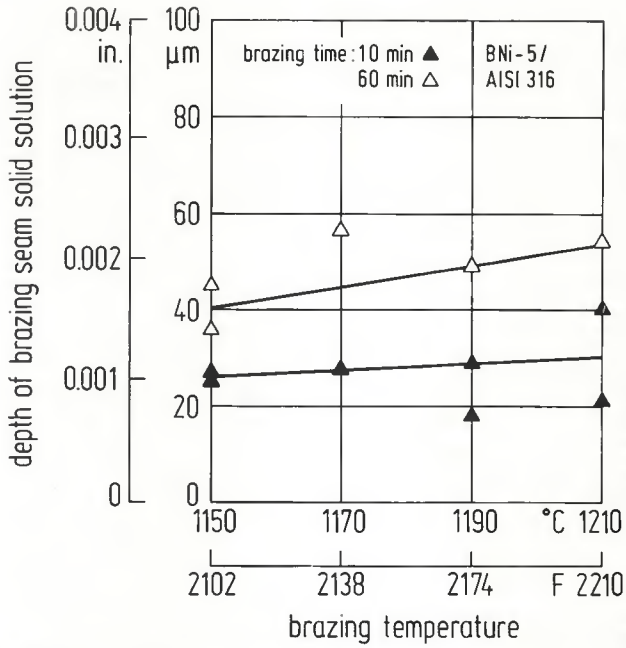

Fig. 7 — Depth of braze seam solid solution vs. brazing temperature for BNi-5/AISI 316 system

system at a temperature range far above the recrystallization temperature of 1050°C (1922°F) resulted in a maximum depth formation of about 30 µm (0.0012 in.) with 10 min brazing time and 50 µm (0.002 in.) with 60 min brazing time — Fig. 7.

Good joint structure homogenization, even with brittle silicides in braze seams obtained using phosphorless nickel-base filler metals with AISI 316 and Inconel 625, was approached at diffusion temperatures above temperatures for recrystallization or solid solution heat treatment. It is to be noted that a slightly deeper solid solution formation was obtained with Inconel 625 than with AISI 316. However, there were disadvantages associated with this brazing temperature range — for example, coarse grain structure; with filler metals containing boron, an increase in boride precipitation; and, depending on the base metal, thermal brittleness.

Precipitation in the Base Metal by Boron Diffusion

Boridic precipitation as shown in Fig. 2 was investigated for different depths of the mixtures between base and filler metals for brazing times of 10 and 60 min — Figs. 8, 9 and 10. Although filler

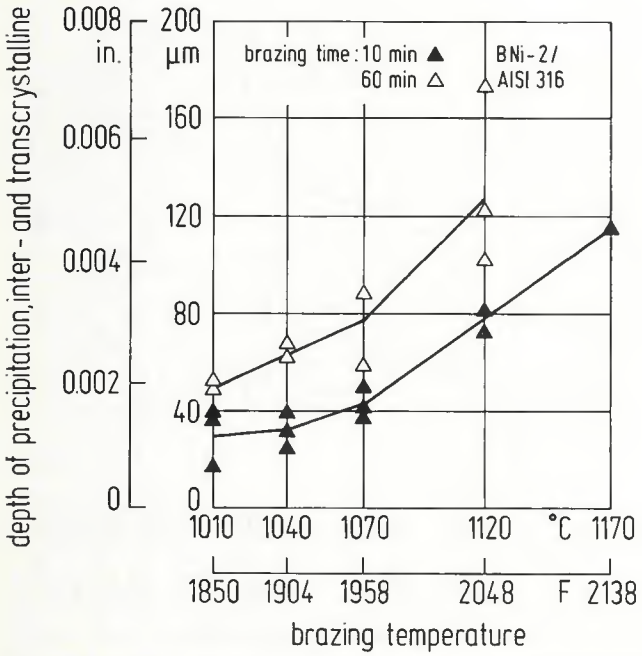

Fig. 8 — Depth of penetration vs. brazing temperature for BNi-2/AISI 316 system

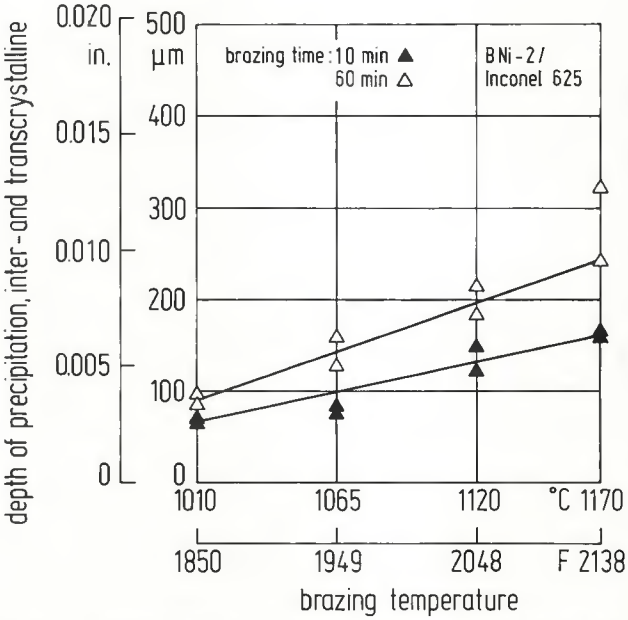

Fig. 9 — Depth of penetration vs. brazing temperature for Bni-2/Inconel 625 system

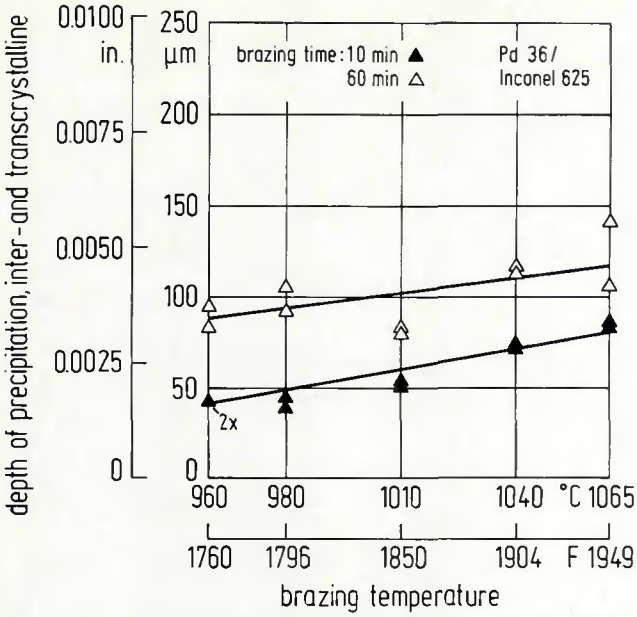

Fig. 10—Depth of penetration vs. brazing temperature for Pd 36/ Inconel 625 system

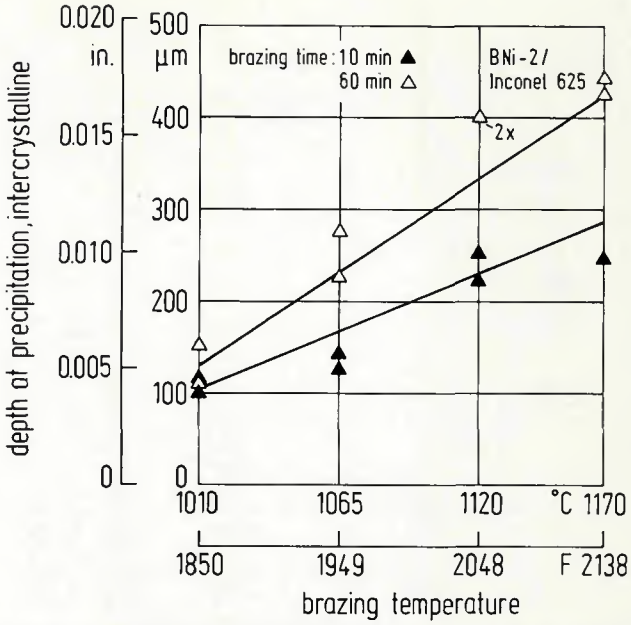

Fig. 11—Depth of intercrystalline penetration vs. brazing temperature for BNi-2/Inconel 625 system

metals containing different amounts of boron were used with two different base metals, a nearly linear increase in depths of precipitation as a function of temperature is to be seen. This, however, is to be expected because of the behavior of boron diffusion. The atomic radius of boron is very small. Therefore, it diffuses interstitially and thereby results in the diffusion rates shown. This is contrary to the diffusion mechanisms for nickel, iron, silicon and chromium.

Regardless of their differing boron contents, both BNi-2 and Pd 36 show similar depths of precipitation—Figs. 9 and 10. However, precipitation depths are less with AISI 316 than with Inconel 625—Figs. 8 and 9. At 1010°C (1850°F), the precipitation depth for AISI 316 ranges from 40 to 50 µm (0.0016 to 0.002 in.) with brazing times of 10 and 60 min; at 1120°C (2048°F), depths of precipitation are 80 to 120 µm (0.0032 to 0.0048 in.) for brazing times of 10 and 60 min. With Inconel 625, depths of precipitation are 50 and 100 µm (0.002 and 0.004 in.) at 1010°C (1850°F) and 180 (approximately) to 250 µm (0.005 to 0.0075 in.) at 1120°C (2048°F). Similar increases for intercrystalline precipitation are shown in Figs. 11 and 12 where even greater depths of precipitation are evident for boron diffusion in Inconel 625.

Brazing time exerts an important influence of intercrystalline precipitation. For example, a precipitation depth of 400 µm (0.16 in.) was obtained in 60 min at 1170°C (2132°F), while at the same temperature precipitation depth was 250 µm (0.01 in.) for a brazing time of 10 min.

Tests with AISI 316 at 1170°C (2132°F) resulted in the following depths of precipitation after 10 and 60 min of brazing time: 250 µm (0.01 in.) in 10 min and 300 µm (0.012 in.) in 60 min—Figs. 11 and 12.

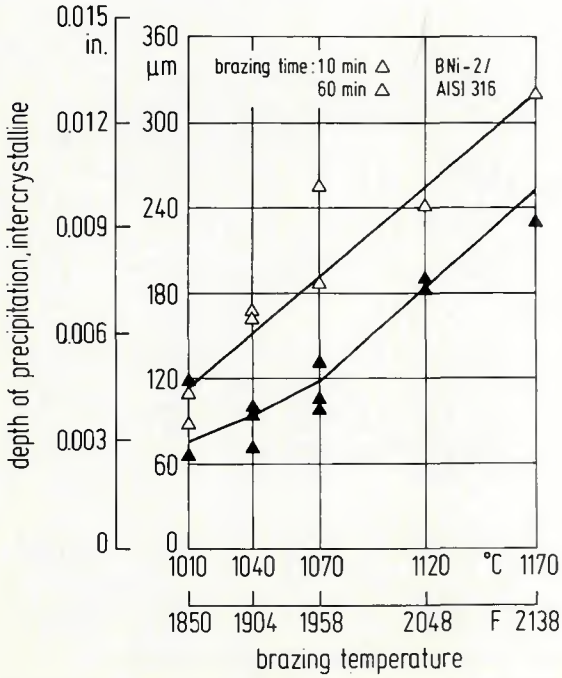

Fig. 12—Depth of intercrystalline penetration vs. brazing temperature for BNi-2/AISI 316 system

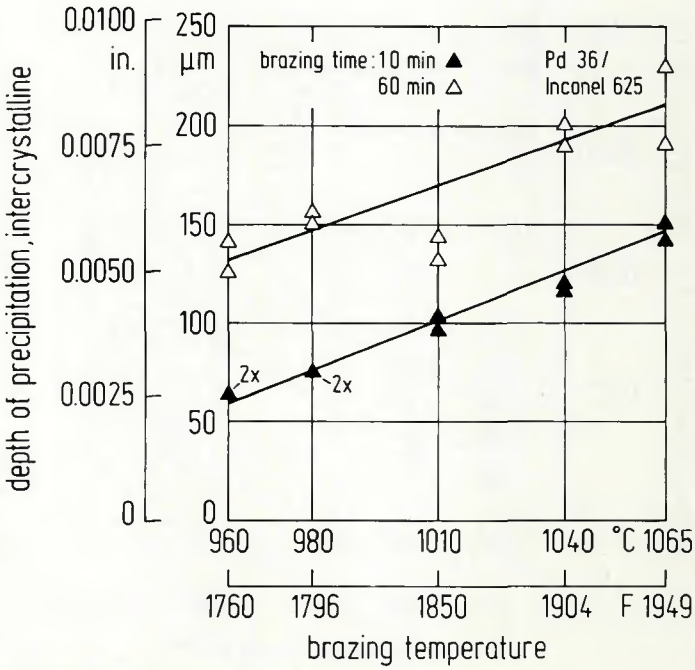

Fig. 13—Depth of intercrystalline penetration vs. brazing temperature for Pd 36/Inconel 625 system

The Pd 36/Inconel 625 (Fig. 13) and BNi-2/Inconel 625 systems displayed a similar tendency in the same brazing temperature ranges.

Precipitation may impair the load resistance behavior of a brazed joint. However, this does not occur with the BNi-2/AISI 316 system (Ref. 1, 2); here the ultimate tensile strength of the brazed joint is nearly equal to that of the base metal. The ultimate tensile strengths of BNi-2/Inconel 625 and Pd 36/Inconel 625 brazed joints ranged from 400 to 600 MPa (58 to 87 ksi) compared to the 800 MPa (116 ksi) ultimate tensile strength for the normal heat-treated base metal.

Maximum depths of precipitation must be considered when brazing thin-wall constructions in order to avoid complete erosion of the base metal. Here, just a reduction in the standard content of boron in the filler metal may result in improved precipitation behavior although the quality of filler metal might be adversely affected.

Conclusion

The metallurgical and thermal characteristics of high temperature brazing with phosphorus-free nickel base filler metals were studied with respect to their effects on the region that forms between the braze seam and base metal. The depths of braze seam solid-solution formations were determined together with boridic precipitation depths in the base metal. Tests were conducted at 10 and 60 min brazing times at different brazing temperatures.

Extensive homogenization between the braze seam solid solution and base metal can be realized at temperature ranges higher than the 1050°C (1922°F) recrystallization temperature for AISI 316 or higher than the solution heat-treatment temperature for Inconcel 625. Under the same diffusion conditions, the diffusion rate with Inconel 625 is higher than that for AISI 316. The adverse effects of thermal stress on the base metals cannot be avoided.

Boron precipitation was shown to increase linearly with brazing temperature increases. Depths of boron precipitation in Inconel 625 are greater than in AISI 316 stainless steel. The possibility of boron precipitation must be considered when utilizing nickel-base filler metals containing boron. Base metal qualities change when precipitation-affected regions are present.

Acknowledgment

This paper is based on work performed under research and development administration contract No. 4263 of the Arbeitsgemeinschaft Industrieller Forschungsvereinigungen e.V. West Germany.

References

1. Partz, K.-D., in E. Lugscheider (Hrsgb.), Techn. wiss. 1981. Berichte: Einfluss von Lötparametern auf die Zugfestigkeit stumpfgelöteter Hochtemperaturlötverbindungen-Parametercharakteristik der Lötsysteme BNi-2, BNi-5, BNi-7/ 1.4961, 1.4550. *Werkstoffwissenschaften.* RWTH Aachen.

2. Lugscheider, E., and Partz, K.-D. 1981. *Charakterisierung der lötnahtgüte und festigkeit von hochtemperaturlötverbindungen in abhängigkeit dominanter lötparameter.* DVS-Berichte Bd. 69. Düsseldorf: Deutscher Verlag für Schweisstechnik.

3. Wall Colmonoy Corporation. *Nicrobraz.* Engineering data sheet, rev. 2.1.1H.

4. D'Silva, T. L. 1979. Nickel-palladium base brazing filler metal. *Welding Journal* 58(10): 283-s to 286-s.

5. Lugscheider, E.; Kloehn, K.; and Lison, R. 1979. Strength of high temperature brazed joints—influence of brazing parameters. *Welding Journal* 58(10): 296-s to 300-s.

6. Lugscheider, E.; Partz, K.-D.; and Gundlfinger, K. 1981. Stand der festigkeitsprüfung von hart- und hochtemperaturelötverbindungen, literaturarbeit. *Werkstoffwissenschaften.* Arbeitsdokument der Comission IA im IIW. RWTH Aachen.

7. Mizuhara, H.; Coad, B.C.; and Pattanaik, S. 1981. *Evaluation of joints brazed with Ni-Pd base filler alloys.* DVS-Berichte Bd. 69. Düsseldorf: Deutscher Verlag für Schweisstechnik.

WRC Bulletin 279
July, 1982

Weldability and Fracture Toughness of Quenched and Tempered 9% Nickel Steel: Part I—Weld Simulation Testing
by A. Dhooge, W. Provost and A. Vinckier

An investigation on the weldability of a quenched and tempered 9% Ni steel using weld simulation and artificial aging to estimate the heat-affected zone ductility at cryogenic temperatures is reported in Part I. Charpy-V bars were subjected to various weld simulation cycles and subsequent heat treatments and, after notching, broken at a range of cryogenic temperatures.

Weldability and Fracture Toughness of Quenched and Tempered 9% Nickel Steel: Part II—Wide Plate Testing
by A. Dhooge, W. Provost and A. Vinckier

In addition to standard impact and tensile tests, a large number of wide plate specimens welded with various consumables and welding processes were tested to evaluate the toughness and defect acceptability of 9% Ni steel in plate thicknesses greater than 25 mm.

Publication of these reports was sponsored by the Weldability Committee of the Welding Research Council.

The price of WRC Bulletin 279 is $10.00 per copy, plus $3.00 for postage and handling. Orders should be sent with payment to the Welding Research Council, 345 East 47th St., New York, NY 10017.