How to Choose Nickel-Based Filler Metals for Vacuum Brazing

Selection of the right filler metal can lead to more economical and functional brazements

BY MICHAEL WEINSTEIN, ROBERT L. PEASLEE, AND FORBES M. MILLER

Nickel-based filler metals can braze any type of high-melting-point base metal. They find use primarily with heat- and corrosion-resistant alloys, most commonly the AISI 300 and 400 series stainless steels and nickel- and cobalt-based alloys. Provided the right filler metal is selected, the brazed joint will retain its properties up to 1800°F (980°C). The nickel-based fillers are not generally used on mild steel because other, less costly, filler metals will do. In some special cases, however, the nickel series is used on steel.

What to Consider

Selection of filler metal for a brazed joint depends on five main points: properties of the filler metal, joint design, service requirements, base metal composition, and cost and availability.

1. Properties of the filler metal.

Melting point or melting range. Eutectic compositions melt at a specific temperature; other compositions melt within a range of temperatures. This fact determines whether the material flows all at once or over a range of temperatures.

Fluidity. Poor or good fitup of the braze joint determines whether the job needs sluggish or rapid-flowing filler. Knowing the fluidity of the filler metal lets the designer prescribe proper joint clearance.

Joint remelt temperature. Filler material alloys with the base material at rates depending on the compositions of both materials and temperature. This interaction determines the composition and the melting temperature of the brazed joint, the temperature at which it will fail by fusion.

Vapor pressure. In vacuum brazing the filler metal should have a vapor pressure lower than the vacuum pressure to prevent outgassing of filler metal elements. Such outgassing results in a braze of poor quality.

2. Joint design. For the reasons listed previously, the designer needs to know joint geometry and clearance in order to choose the filler metal with the right flow properties.

3. Service requirements. These include joint strength, ductility, and heat and corrosion resistance. The chemistry, flow characteristics, and mechanical properties of the final braze metal determine which filler should be used.

4. Base metal composition. The base metal alloys with the braze filler. The properties of the alloyed braze metal

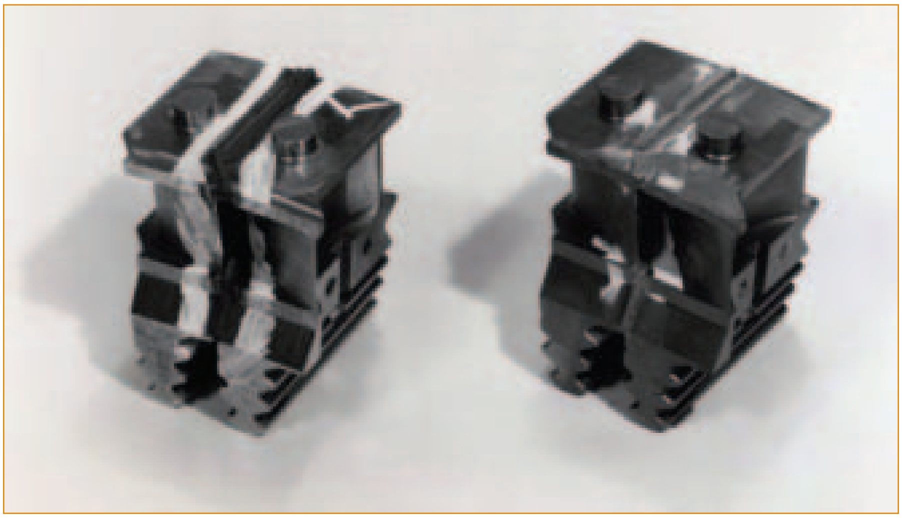

Fig. 1 — BNi-1 was the best choice for brazing these turbine vanes because when the filler diffuses into the base metal, it does not form austenite and reduce hardness.

Table 1 — Comparison of Raw Material Prices for Brazing Filler Metals

Metal	2nd Quarter 2003	6/2/2008	Price Increase
Gold (troy oz)	$300.00	$896.00	199%
Silver (troy oz)	$5.00	$16.87	237%
Nickel (troy oz)	$0.33	$0.68	106%

MICHAEL WEINSTEIN is technical services manager, Alloy Products Group, prior to his recent death, ROBERT L. PEASLEE was a brazing consultant with Wall Colmonoy Corp. and FORBES M. MILLER is former director, Brazing Engineering Center, Wall Colmonoy Corp., Madison Heights, Mich. (www.wallcolmonoy.com).

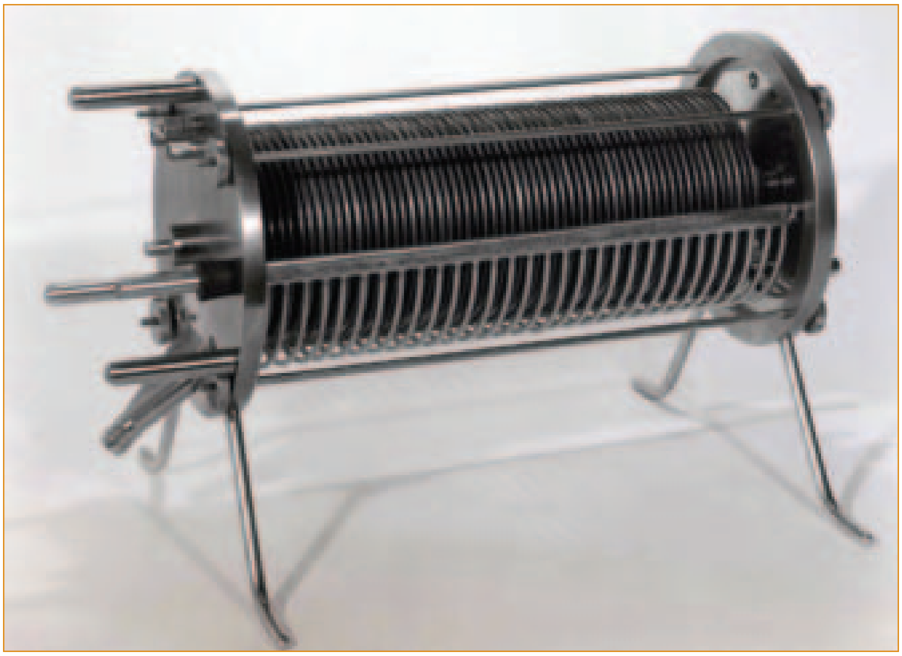

Fig. 2 — *A brazing filler metal with a high chromium content was needed for brazing this part from an artificial heart used during major surgery because it resists corrosion caused by human body fluids.*

Fig. 3 — The interior of this part, the housing for a jet engine starter, experiences high temperatures and high stresses and the joint has tight fitup, which necessitates the use of a free-flowing alloy such as BNi-2 or BNi-3.

ultimately determine the properties of the joint.

5. Cost and availability. Cost of raw materials in today's market have a significant impact on the cost of a brazed assembly. Volatile and unpredictable fluctuations in both precious metals and strategic metals markets greatly affect the cost of brazing. The effect of this unpredictability can be controlled to a degree by engineering and designing parts that utilize brazing filler metals that are less sensitive to fluctuations in the metals markets. Table 1 compares gold, silver, and nickel as primary ingredients in brazing filler metals over the past five years.

Traditionally, certain designs have specified precious metals brazing for certain applications. Today the technology exists to design assemblies that can take advantage of relatively lower cost nickel brazing filler metals such as those described by both AMS and AWS specifications.

The true material cost of a braze joint is a function not only of the metals market price but also of the metal content in the alloy and its density. That is to say, the same volume of filler metal must be used independent of the composition. Gold is more than two times more dense than nickel and will take correspondingly more weight to fill the same volume. Table 2 illustrates this relationship based only on the gold, silver, and nickel content and market value as of June 2, 2008. This cost is shown for comparison purposes — by filler metal for a braze joint thickness of 0.001 in. over areas of 1 in.^{2} and 1 ft^2. The table illustrates the magnitude of how material costs of brazing alloys will be affected by fluctuations in the metals market, and that the most significant opportunity for savings is where a gold or silver brazing filler metal can be replaced in the design by a nickel-based brazing filler metal.

Table 2 — Material Costs of Brazing Alloys Based on Their Gold, Silver, and Nickel Content

Brazing Filler	\$/in.^{2} at 0.001-in. joint clearance	\$/ft^2 at 0.001-in. joint clearance
AWS BAu-1 (38% Gold)	\$2.27	\$326.88
AWS BAu-2 (80% Gold)	\$6.45	\$928.80
AWS BAg-7 (56% Silver)	\$0.05	\$7.20
AWS BNi-5 (71% Nickel)	\$0.002	\$0.29
AWS BNi-7 (76% Nickel)	\$0.0022	\$0.32
AWS BNi-6 (90% Nickel)	\$0.0028	\$0.40

AWS A5.8:2004, *Specification for Filler Metals for Brazing and Braze Welding*, is the most recent and most complete specification system for nickel-based brazing filler metals. It should be referenced wherever possible. It includes 15 nickel-based brazing filler metals and describes the properties and primary applications, as follows:

- BNi-1 finds use for high-strength, heat-resistant joints in assemblies like turbine blades and jet engine parts.
- BNi-2, similar to BNi-1, allows good flow properties at lower brazing temperatures.
- BNi-3 flows well in less-than-perfect vacuum conditions. Ideal for tight-fitting joints and for wide-area joints.
- BNi-4 forms large, relatively ductile fillets, making it a choice for large joint clearance fitup.
- BNi-5, for high-strength and corrosion-resistant joints, finds use in nuclear and other applications where boron cannot be tolerated.
- BNi-6 is a free-flowing filler that offers only minimal alloying with nickel- or iron-based substrates.
- BNi-7 produces strong leak-proof joints with heat-resistant base metals at low brazing temperatures. Erosion is low because it has low solubility in iron- and nickel-based alloys. It is used for honeycomb structures and thin-wall tube assemblies.
- BNi-8 is also used in honeycomb brazements and on stainless steels and other corrosion-resistant base metals.
- BNi-9 is excellent for jet engine parts

and similar highly stressed components. It offers good strength at lower brazing temperatures.

- BNi-10 provides extra-high strength at high temperatures. It is good for brazing base metals containing cobalt, tungsten, and molybdenum.
- BNi-11 can be used for applications that are similar to those of BNi-10 except it offers better flow.
- BNi-12 is similar to BNi-7 except it has greater strength, and heat and corrosion resistance.
- BNi-13 offers brazing characteristics similar to those of BNi-2 but with enhanced corrosion resistance and high joint strength.

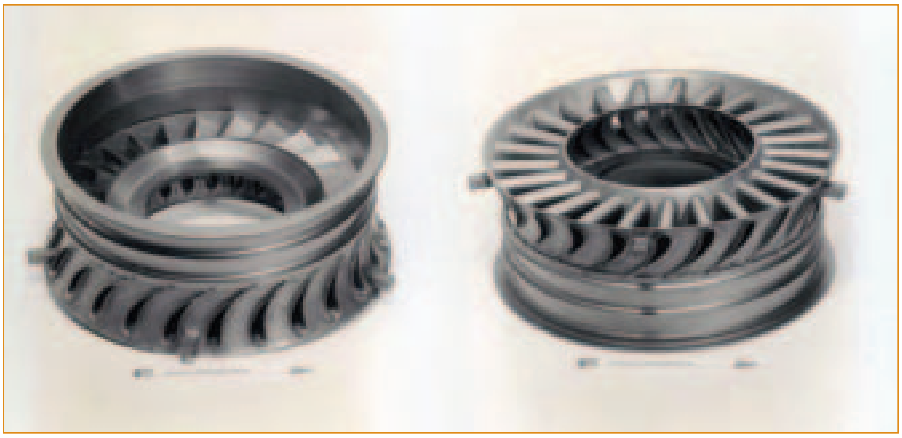

Fig. 4 — Because fitup for the joint edges on these gas engine turbines was not well controlled, a sluggish filler metal such as BNi-1 was needed.

How Designers Fit the Filler Metal to the Brazement

The following short case studies illustrate how selection of the right filler metal leads to economical and functional brazements.

Turbine vanes. After brazing, 2 × 2 × 3-in. (65 × 51 × 76-mm) turbine vanes (Fig. 1) of 422 stainless steel were heat treated to rigid hardness, tensile strength, and impact strength requirements. However, the joint needed good strength as well. Most importantly, the filler metal could not reduce the hardenability of the base metal. BNi-1, which contains 0.7% carbon, was the best choice for this job because when the filler diffuses into the base metal, it will not form austenite and reduce hardness. For this job, filler metal was preplaced, so that high fluidity was not necessary.

Heat exchanger. This 304 stainless steel component is part of an artificial heart used in a life support system for major surgery — Fig. 2. Leak tightness and resistance to corrosion from human body fluids were the main requirements. Joint fitups were tight, so the braze filler metal had to be free flowing. High chromium content handled the corrosion requirement. The designer's choice: BNi-2 or a proprietary nickel-16 chromium-3½ boron filler metal.

Housing for a jet engine starter. This assembly (Fig. 3), about 8 in. (203-mm) OD, had close-tolerance, sleeve-type joints that joined the top and bottom fixtures to the main section. The part sees high temperatures and high stresses in its interior, but the joints on its exterior are exposed to less severe temperatures and lower stresses. The determining factors, close fitup and the great length of the joints, dictated a free-flowing alloy such as BNi-2 or BNi-3.

Diffusers for a gas turbine engine. Even though these 16-in. (406-mm) OD assemblies (Fig. 4) are well supported, they require high strength to withstand considerable vibration in service. Fitup of the joint edges is not well controlled and may vary from contact to a 0.010-in. (0.254-mm) joint clearance. This situation called for a sluggish filler metal that gives good strength in the braze. BNi-1, the filler metal first used for this job, gave good results. BNi-1a, the low-carbon version of the same alloy, can also do the job. A nickel-chromium, boron-silicon filler that contains 17% tungsten gives strength to braze metal in joints with wide joint clearances. It is also sluggish at brazing temperatures, making it ideal for wide joint clearances. Some users mix filler metals to get two melting ranges for this kind of job.

Fuel meter. This 410 stainless steel brazement contained 200 joints in 347 stainless steel thin-wall tubing. In service, the meter heats up to about 200°F (90°C). Corrosive fuel mixtures flow through the meter, which must be leak-tight. Imposed pressure and stress are low, but braze joints between dissimilar metals must stand up under stresses introduced by differences in the coefficient of expansion between the base metals. With close fitup, a nickel-phosphorus-chromium alloy like BNi-7 will stand up to the stress and give a leak-tight joint. BNi-7 offers enough fluidity to fill close fitting joints of 0.001 in. (0.025 mm) or less.

Cooling cylinder with wide joint clearances. The best way to fill wide joint clearances (10 mils, 0.25 mm, or greater) with braze metal is a two-step procedure that uses a joint clearance filler. A high-melting-point metal powder was laid into the joint clearance, held in place by a binder, and heated in a furnace. This procedure sintered the metal into place without melting it. After brazing filler metal was applied to the joint, the part was heated again. The sintered material prevented the filler metal from running out of the joint. It also offered capillaries for flow. The brazed joint was ½ in. (13 mm) deep with a ¹⁄₁₆-in. (1.6-mm) joint clearance. The joint clearance filler metal was a Ni-Cr-Si mixture, melting point 2400°F (1316°C). Filler was Ni-16Cr-3.5B, a eutectic composition, melting point 1900°F (1038°C).

This stainless steel cooling cylinder, about 7 ft (2 m) long, was wound with stainless steel tubing that will carry a coolant. The gap between the cylinder and the tube windings was irregular. Designers required heavy fillets to promote cooling. First, a high-melting metal powder was laid on the joint and sintered at 2000°F (1093°C) in a protective atmosphere. The sintered metal acted as a sink for the braze metal to be added. The sintered sink required a filler that was fluid enough to fill the pores formed by sintering, but viscous enough that it would not run off the joint. Filler metal should be a nickel-chromium-boron type such as BNi-2 or Ni-Cr-3.5B.

On condensers of plain carbon steel for refrigeration equipment, a nickel-based filler metal, BNi-2 (Ni-Cr-B-Si-Fe), works well. The corrosive refrigerant — wet, hot ammonia — makes use of silver or copper filler metals inadvisable. The same applies to methylacetylene-propadiene bottles used for hand soldering torches. Here, BNi-06, a nickel-phosphorus filler metal, handled the job.◆