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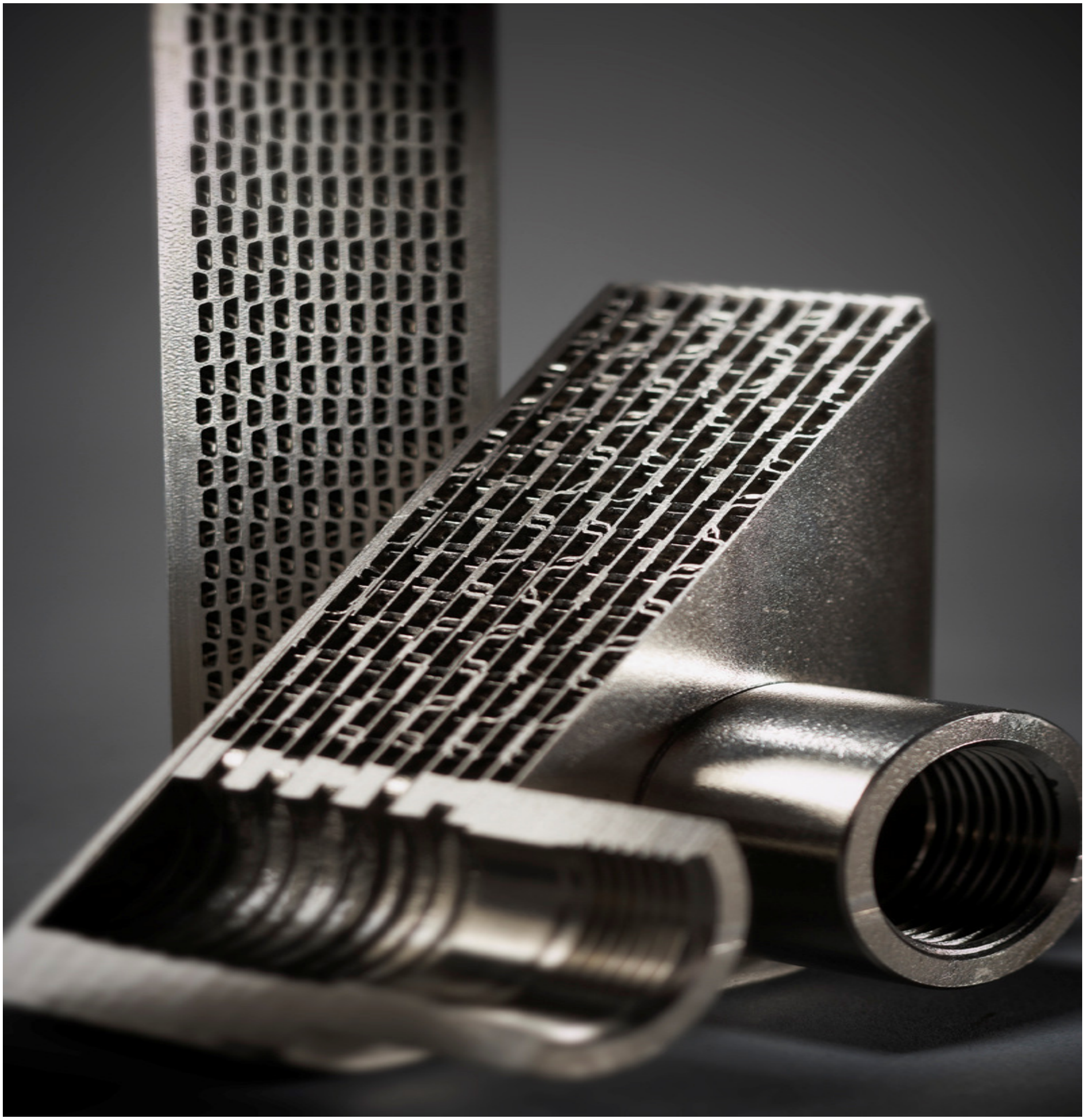
Brazing with Nickel Based Brazing Filler Metals



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Introduction

The American Welding Society defines brazing as "a group of welding processes which produces coalescence of materials by heating them to a suitable temperature and using a filler metal having a liquidus temperature above 840 ºF (450 ºC) and below the solidus temperature of the base materials. The filler metal is distributed between the closely fitted surfaces of the joint by capillary attraction."

Brazing is probably the most versatile method of joining today, for a number of reasons. Brazed joints are strong. On non-ferrous metals and steels, the tensile strength of a properly made joint will often exceed that of the metals joined. On stainless steels, it is possible to develop a joint whose tensile strength is 130,000 pounds per square inch (896.3 mega Pascal [MPa]). Brazed joints are ductile, able to withstand considerable shock and vibration and tend to resist gases and liquids. As mentioned above, brazing is ideally suited to the joining of dissimilar metals. Also, because the brazing process doesn't involve the melting of the metals that are being joined, the possibility of base metal warpage and distortion are greatly reduced. Brazing is essentially a one-process operation. There is seldom any need for mechanical operations such as grinding, filing or mechanical finishing after the joint is completed. Brazing is comparatively an economical process. The cost per-joint compared quire favorably with joints made by other metal joining methods.

Brazing can be done with the same handheld torches that are used in gas cutting or welding operations, but those torches are equipped with brazing tips for the process. Typical commercial gas mixtures can be used in brazing and Oxy-acetylene or oxygen-natural gas mixtures are most commonly used. Brazing can also be accomplished using an inert atmosphere and vacuum atmospheres.

A wide variety of braze filler metals are available today for brazing operations depending on the base metals, heating methods and final mechanical and corrosion properties required by various industries. Successful brazing often depends on following the six fundamentals of brazing as listed below:

- Good fit and proper clearances
- Cleaning the metals
- Fluxing the parts / proper atmosphere
- Proper assembly
- Proper heating method
- Final cleaning

Nickel based brazing filler metals

Of the various braze filler metals available in the market today, nickel based filler metals are primarily used with heat-and-corrosion resistant alloys, most commonly the AISI 300 and 400 series stainless steels and nickel and cobalt base alloys. Provided the right nickel brazing filler metal is selected, the braze joints may retain their properties up to 1800 °F (980 °C) and well above the brazing process temperatures. This is a possibility with the nickel based brazing filler metals because of the diffusion of melting point depressants into the base metals during the brazing process. The most common nickel based brazing filler metals available today are listed in the Table 1.

Nickel Based Brazing Filler Metals

Product Name	AWS Spec.	Solidus		Liquidus		Alloy Compositions (Main Elements)					General Applications and Description
		°F	°C	°F	°C	Cr	Si	B	P	Ni	
Hi-Temp® 720	BNi-1	1790	977	1900	1038	14.0	4.0	3.1	0.02	Remainder	SS, Ni and Co, High Strength heat resistance
Hi-Temp 819	BNi-1A	1790	977	1970	1077	14.0	4.5	3.1	0.02	Remainder	Low carbon similar to Hi-Temp 720
Hi-Temp 820	BNi-2	1780	971	1830	999	7.0	4.5	3.1	0.02	Remainder	Furnace brazing, aircraft, medical, food equipment
Hi-Temp 910	BNi-3	1800	982	1900	1038	--	4.5	3.1	0.02	Remainder	Same are Hi-Temp 720, Marginal atmosphere
Hi-Temp 930	BNi-4	1800	982	1950	1066	--	3.5	1.85	--	Remainder	SS, Ni and Co, for thin sections
Hi-Temp 850	BNi-5	1975	1079	2075	1135	19.0	10.1	0.03	0.02	Remainder	Nuclear reactor where B cannot be used
Hi-Temp 932	BNi-6	1610	877	1610	877	--	--	--	11.0	Remainder	Cr Free, good corrosion resistance, high temperature properties
Hi-Temp 933	BNi-7	1630	888	1630	888	14.0	--	--	10.1	Remainder	Honeycomb and thin walled assemblies
Hi-Temp 935	BNi-9	1930	1055	1930	1055	15.0	--	3.6	0.02	Remainder	Excellent for jet engine parts

Table 1 - Chemical composition of commonly used nickel brazing filler metals

Selecting the right brazing filler metal

Selecting the right brazing filler metal for the job is one of the most important factors in fabricating a properly brazed joint assembly. The selection criteria may be segmented as following:

- Base metal composition
- Properties of the filler metals
- Joint design
- Service requirements
- Cost and availability

Base metal composition

Base metal composition plays an important role in the selection of the right braze filler metals, essentially as both inter-alloy with each other in order to form a metallurgical bond. In some brazing applications, such as thin walled components, inter-alloying may not be desired. This may result in the erosion of the components. This includes brazing with nickel based brazing filler metals containing boron, as boron may diffuse into the base metal and alter its chemical and mechanical properties at the braze joint interface. While in some other cases, like diffusion brazing of automotive and aircraft components, inter-alloying may be an important aspect of brazing. Some base metal composition, with residual presence of Al and Ti for instance, may need additional pre – processing such as nickel plating to avoid the formation of brittle and low melting inter-metallics when brazing with nickel based brazing filler metals.

Properties of braze filler metals

Braze filler metals can be classified based on their solidus and liquidus temperatures. Some braze filler metals, because of their unique chemical composition, melt and flow at one single point rather than over a range. Such filler metals are known to have a eutectic composition. Selecting one over the other will depend on the braze joint design. If the braze joint clearance is "tight", typically "press-fit – 0.002", it is usually recommended to use a eutectic braze filler metal. Hi-Temp 932, Hi-Temp 933 and Hi-Temp 935 fall under this category. It is evident from the table that the difference between the solidus and liquidus for these braze filler metals is typically zero. Non-eutectic braze filler metals will have a wide melting range and a substantial difference between the solidus and the liquidus temperatures. Such braze filler metals can be used for wide-gap brazing or braze repair of components.

Joint Design

For the reasons mentioned above, a braze joint should have proper joint geometry and braze clearance in order to yield expected properties in the final applications. Maintaining proper braze joint design may result in a considerable cost-saving when the overall cost of brazing operation is taken in the account. Joint design component for assemblies to be diffusion brazed is very important. (Please see diffusion brazing).

Service Requirements

It is of utmost importance to know and understand the final service requirements for the brazed assembly. These may include high temperature, oxidation and corrosion resistance, joint strength at low and high temperatures and ductility of the braze joint. Properties of the base metals, braze filler metals and the joint design dictates the final braze filler metals that should be employed.

Cost and Availability

Costs with present and future availability of braze filler metals should be considered when making a decision regarding which braze filler metal to use. Though many companies will assist customer's requests with specific chemistries, these will tend to be expensive and hence the use of standard nickel based filler metals, as listed in table 1, should be exercised whenever possible.

Comparison of Nickel based brazing filler metals

Nickel based brazing filler metals can be divided into three main families based on the melt point depressants, and combinations thereof, that they contain, as follows:

- Nickel based brazing filler metals with Boron
  - These include BNi-1, BNi-1a, BNi-2, BNi-3, BNi-4, BNi-9
- Nickel based brazing filler metals with Silicon
  - These include BNi-1, BNi-1a, BNi-2, BNi-3, BNi-4, BNi-5
- Nickel based brazing filler metals with Phosphorus
  - These include BNi-6, BNi-7

Table 2 compares the various nickel based brazing filler metals, based on end use recommendations, physical properties and other comparative properties including joint strength, solution with base metals and fluidity.

Nickel Based Brazing Filler Metals (Comparison)

Type	Hi-Temp 720	Hi-Temp 819	Hi-Temp 820	Hi-Temp 910	Hi-Temp 930	Hi-Temp 850	Hi-Temp 932	Hi-Temp 933	Hi-Temp 935
AWS Specification	**BNi-1**	**BNi-1a**	**BNi-2**	**BNi-3**	**BNi-4**	**BNi-5**	**BNi-6**	**BNi-7**	**BNi-9**
Sugg. Brazing Temperature (ºF)	2050	2050	1950	1900	2050	2175	1800	1950	2150
Recommended Atmosphere*	A, B	A, B	A, B	A, B	A, B	A, B, C	A,B,C,D	A, B, C	A, B
Recommended Joint Gap (inches)	.002-.005	.002-.006	.001-.004	.002 max	.002-.004	.001-.004	.001 max	.001 max	.001-.004
Oxidation Resistance through (ºF)	2200	2200	2000	2000	1800	2200	1400	1575	2200
Joint Micro Hardness (Knoop)	175-700	175-600	160-700	175-700	150-400	200-700	175-550	175-550	150-550
Density (lb/cu.in)	0.282	0.282	0.288	0.294	0.303	0.276	0.294	0.285	0.295
***A- Pure Dry Hydrogen or Inert Gas; B- Vacuum; C- Dissociated Ammonia; D- Exothermic**									
End Use Recommendations									
High Temperature	A	A	B	B	C	A	C	C	A
High Stress	A	A	B	B	C	A	C	C	A
Honeycomb & thin materials	C	C	B	B	B	A	A	A	A
Atomic Reactor Cores*	NR	NR	NR	NR	NR	A	B	A	NR
Machinable Fillets	B	B	C	C	A	C	C	C	C
Tight or Deep Joints	C	C	B	B	C	B	A	A	B
A- Best; B- Satisfactory; C- Least Satisfactory; *NR- Not Recommended									
Comparative Properties*									
Joint Strength	1	1	1	2	2	1	4	2	1
Solution with Base Metal	1	1	1	1	2	3	4	4	1
Fluidity	3	3	3	2	3	2	1	1	2
*** 1 (Highest), 4 (Lowest)**									

Table 2: Comparison of Nickel base brazing filler metals

Recommended Furnace Atmospheres

Nickel based brazing filler metals have low vapor pressure that makes these alloys ideally suited to vacuum systems and vacuum tube applications. Atmospheres reducing to both the base metal and the brazing filler metal are recommended. Most of the nickel based brazing filler metals contain chromium that imparts them excellent corrosion and oxidation resistance properties. Nickel based brazing filler metals containing chromium should be brazed in reducing furnace atmospheres at -60 °F dew point or better or under vacuum conditions, about 10^{-4} vacuum pressure or better with a leak up rate of not more than one to two micron per hour. Nickel based brazing filler metals that contain higher percentage of Cr than others are more sensitive to the furnace atmosphere quality and hence should be brazed with a lower dew point and lower vacuum pressures. Those filler metals containing boron should not be brazed in any furnace atmosphere containing N_2. The reaction between Boron, in the braze filler metal, and Nitrogen is likely to result in the formation of BN (Boron Nitride), that may act as a braze stop-off, preventing the wetting and flow of such braze filler metals on the base metal substrate.

Diffusion Brazing

Diffusion brazing, is a modified brazing process wherein, the elements of liquid braze filler metal are diffused in to the base metal, thus augmenting its properties. It is essential in the braze diffusion process for the braze filler metal and the base metal to have mutual solubility. During diffusion brazing the brazing filler metal is distributed throughout the joints by means of capillary action. During the diffusion brazing process, the brazing filler metal isothermally solidifies at the brazing temperature. Diffusion brazing process is a function of three variables; brazing temperature, time at brazing temperature, and the braze clearance or the joint gap at the brazing temperature. These three variables are collectively known as the TeTiG, where 'Te' stands for brazing temperature, 'Ti' stands for time at the brazing temperature and 'G' stands for the braze gap/clearance between the two closely fitted faying surfaces. All the three variables are inter-related in a diffusion brazing process. In order to achieve a well diffused braze joint, the braze temperature needs to be increased, the time at the brazing temperature is increased and the braze clearance at the brazing temperature needs to be minimized. In short, the brazing temperature and the time at the brazing temperature is maximized while keeping the braze gap/clearance at the minimal.

The continuous belt furnace is not generally suitable for most diffusion brazing process cycles, however, by controlling the belt speed and increasing the furnace temperature, some brazements may be diffusion brazed. A common example is the diffusion brazing of carbon and alloy steels using a copper brazing filler metal, such as BCu-1, and a reasonably smooth surface of a press-fit joint. Some silver based brazing filler metals such as BAg-8, can be diffused brazed as well in a high dew point atmosphere in a retort furnace. Torch and induction brazing equipments are not generally used for diffusion brazing as the time at brazing temperature is relatively short and uncontrolled, as compared to vacuum or inert atmosphere and hence there is insufficient time for diffusion.

Nickel based brazing filler metals are suited for a diffusion brazing process due to a variety of reasons. Most of the nickel based brazing filler metals contain negligible amounts of low vapor pressure elements. This allows the nickel based brazing filler metals to be brazed in a vacuum or an inert gas atmosphere, such as hydrogen, argon and nitrogen (with a low dew point). The most common elements used for lowering the melting point of nickel based brazing filler metals, are boron, silicon and phosphorus. Boron has a very small atomic diameter, slightly larger than carbon, nitrogen and oxygen and hence diffuses into most metals faster than the other metal elements. Silicon, on the other hand, has an atomic size larger than nickel, chromium and iron and therefore, has poor mobility as compared to boron and phosphorus. This results in the requirements of higher brazing temperatures, longer times at the brazing temperatures and relatively smaller clearances to complete full diffusion brazing. Phosphorus, has a mobility that is somewhere between boron and silicon.

Diffusion brazing is a useful process when the design of a brazement requires the properties of the base metal. The diffusion brazing process increases the melting temperature of the brazement so that the components can withstand higher operating temperatures.

Braze Alloy Forms Available

Nickel based brazing filler metals are available in the following forms to assist in a brazing operation:

1. Powder
   a. Available in different mesh sizes from -60 mesh to -400 mesh.
   b. The standard mesh size of these powders, per AWS, includes -140F, -140 C and -325 mesh.
2. Dispensable Paste
   a. Available for torch, induction, furnace and vacuum operations.
   b. Flux may be used with torch, induction and furnace atmospheres.
   c. No Flux should be used when brazing under vacuum conditions.
3. Screen Printing Paste
   a. Available for pre-placing braze filler metals on large surface areas economically.
   b. Both water and solvent based screen printing paste are available in the market today.
4. Sprayable Form
   a. Available in both water and solvent based formats.
   b. Economical for large assemblies or for assemblies with large surface areas.

For further information, please contact Lucas Milhaupt North America Technical Service Department at 1-800-558-3856.

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