



Brazing Filler Metal Optimizations for Automotive and Aerospace Applications

Authors:

Michael Weinstein, Technical Services Manager, USA
BS, Metallurgical Engineering

Lydia Lee, Director of Brazing Engineering Center, USA
MBA, BSE, and MS, Engineering

Eric Krosche, Senior Applications Engineer, USA
MS, Metallurgical Engineering

Alun Battenbough, Technical Services Manager, UK
PhD, BEng (Hons) and MRes, Material Science and Engineering

Artur M. Osmanda, Manager Alloy R&D, UK
Dipl.-Ing., Mechanical and Materials Science Engineering

Abstract

Brazing filler metals designed for Automotive and Aerospace applications must have capabilities which align with all aspects of manufacturing a finished article with the designed functionality. These capabilities include manufacturability of the filler metal and base metal, application of the filler metal to the part assembly, brazeability of the filler metal, and functionality of the brazed article.

In addition to primary objectives accommodating the requirements for critical parts which ensure the safety of operation, the secondary objectives of cost effectiveness and efficiency of function are always addressed. For example, efficiency of heat exchangers can often be improved by designing with thin sections where applicable to improve heat transfer. Brazing filler metals commonly used to join heat exchanger assemblies include AWS BNi-5 (Nicrobraz[®] 30), AWS BNi-14 (Nicrobraz[®] 31), AWS BNi-2 (Nicrobraz[®] LM), and AWS BNi-1a (Nicrobraz[®] LC). Nickel base brazing filler metals continue to provide efficient joining methods given the design and service conditions for automotive and commercial vehicle exhaust gas recirculator coolers (EGR coolers) and heat exchangers for aerospace and commercial applications.

This paper explores the results of techniques performed at the powder manufacturing level which can enhance the performance of nickel base brazing filler metal(s). Certain filler metal alloy systems with high levels of chromium are

more suitable for EGR cooler environments especially where high sulfur grades of fuel yield more corrosive exhaust gas streams.

Optimization of brazing filler metal(s) to minimize diffusion induced damage to thin sections of austenitic stainless steel base metal while providing excellent corrosion resistance has been completed and the next stage of evaluation are in process. Initial evaluation work included testing of various aspects including liquidus and solidus temperature determination, general brazeability, as well as characterization of the maximum joint gap which will allow capillary flow. Microhardness has been determined below MBC (maximum brazing clearance for full diffusion) and of centerline phases beyond MBC's. Joint tensile strength has also been studied at room temperature and at elevated temperature. Mechanical properties of braze joints can give evidence of performance capabilities which can be expected in actual brazements. Evaluations of corrosion characteristics in environments simulating exhaust gas condensate have also been conducted. Additional studies to evaluate effects of diffusion interactions between filler metal and base metal have been made on a semi-quantitative basis. These studies show that optimizations can be made to filler metals which have the potential to improve the integrity of brazed articles.

Introduction

Evaluations of new techniques used in manufacturing of brazing

filler metal powder materials, quantitative and qualitative, are important so that brazing characteristics are defined at least in general terms so that the brazing engineer has a starting point regarding selection of filler metal. Whether the new technique represents efficiency improvement, a new material, or material improvement, the brazing engineer needs to be able to understand the characteristics and behavior of the material. Brazing of nickel based filler metals is a dynamic process in which the process variables dramatically affect the resulting braze joint properties.

Fundamental characterization of brazing filler metals include determination of melting properties, capillary flow capabilities, strength and fracture toughness, as well as corrosion behavior should all be made available for the brazing engineer to review. Other characteristics such as diffusion interactions between filler metal and base metal must be taken into consideration as well. It is the authors opinion that manufacturers of brazing filler metals provide basic data such as that listed above with possible other additions depending on the design intent of the filler metal. Obviously the brazing engineer may need to perform much more detailed testing to determine the optimum brazing conditions, brazing cycle, and joint configuration suitable for a particular application. The fundamental characteristics serve the brazing engineer by aiding in the filler metal selection process prior to conducting any detailed study.

Discussion

The fundamental characterization tests for brazing filler metals described herein are intended for reference purposes and are by no means all inclusive of the possible characterizations which may be meaningful depending on the design inputs for development of a filler metal material.

Determination of solidus and liquidus temperatures is needed to begin the process of evaluating any filler metal. Brazing is generally conducted above the filler metals liquidus temperature. Some applications do allow for brazing above the filler metals solidus temperature. However, brazing at these lower temperatures, while it may be practical, is often restricted due to limited capillary flow and low joint strengths. When the design calls for a fully diffused braze joint, lengthy holds in the brazing cycle may be required at temperatures near the filler metals solidus temperature. This temperature data can be extracted from a standard cooling curve or by DTA/DSC (Differential Thermal Analysis / Differential Scanning Calorimetry)¹ heating or cooling curves.

General brazeability for a particular base metal can be easily assessed using a simulated brazement such as a "T" specimen configuration². Ability to fill a horizontal joint is demonstrated via this test. Surface tension or wettability can be demonstrated by placing a known quantity of filler metal onto a base metal, running a braze cycle and determining the area covered per gram of filler metal. This can

qualitatively compare different filler metals for the same base metal. Filler metals which spread less may exhibit difficulty flowing to fill adjacent joints. Filler metals which spread too much may require the use of stop-off compounds to prevent spreading to unwanted areas.

The VVC (vertical variable clearance) test³ is often used to assess the magnitude of capillary force between filler metal and base metal. A variable clearance joint fills by capillary action against the force of gravity. The maximum clearance filled allows a comparison between filler metals to indicate the filler metals ability to fill wide or imprecise joint gaps. This can help compensate for errors in fixturing assembly or tolerances in part design. This test can also be run in the horizontal orientation, however data obtained directly opposed to gravity is more meaningful to most design engineers.

Brazing filler metals always contain one or more elements which lower their melting point. These melting point depressants are generally prone to form compounds with the main alloy element (such as nickel) or another alloy element (such as chromium). These compounds tend to have high hardness if they form in the braze joint and can act as stress risers lowering the fracture toughness of the brazed assembly.

Microhardness testing can be used to measure the relative hardness of the various phases which may be present in the braze joint. The presence or absence of detrimental phases

can be controlled through design tolerances, brazing cycle, and filler metal used. Applications where fracture toughness should be more thoroughly evaluated include brazed assemblies which undergo high degrees of vibration or cyclical loading when in service.

Characterization of joint strength can be made following the "Standard Method for Evaluating the Strength of Brazed Joints"⁴ which is published by the American Welding Society. Configurations studied per this standard can be selected based on the type of joint designed for in the brazed assembly. Methods of combining the data obtained from tensile and shear testing to quantify the design criteria for brazed assemblies to aid design engineers has been recently published⁵. This type of structural analysis becomes more important to the design engineer when the criticality of braze joint performance is escalated beyond static applications.

When designs call for small parts and/or thin cross sections, it is important to evaluate the effects of diffusion interactions, between the filler metal and base metal. Diffusion, while it creates high strength joints, can be detrimental to the properties of thin section base metals such as what are found in heat exchangers. Diffusion may create interstitial components in the base metal which are undesirable or may actually lower the melting point of the base metal enough that it begins to melt during brazing. This melting phenomenon, known as base metal erosion, can reduce the load bearing capacity of a thin section so that it becomes

unusable for its design purpose.

The work done for this paper is focused upon development of a high chromium, silicon and phosphorus bearing nickel based alloy which exhibits a minimal tendency to cause base metal erosion during the brazing of thin section parts.

To facilitate this work various components were added to standard brazing filler metals to study their effect to minimize detrimental diffusion into a base metal of thin cross section. The results reported here summarize the relative behaviors of copper, molybdenum and cobalt additions to filler metals.

Results

To provide the reader with as much information as possible the experimental results are shown in each test category. Typical commercially available filler metals are shown for comparative purposes whenever possible.

Melting Characteristics:

Filler Metal	Solidus		Liquidus	
	°F	°C	°F	°C
Nicrobraz 33	1770	966	1910	1043
Nicrobraz 152	1730	943	1875	1024
Nicrobraz 151	1820	993	1850	1010

Comparison of Wettability on 316L Stainless Steel:

Filler Metal	Sq. inch / gram			
	1950 °F	1066 °C	2100 °F	1149 °C
	Nicrobraz 33	2.48		3.0
Nicrobraz 152	2.48		4.43	
Nicrobraz 151	3.15		3.83	

Evaluation of Gap Filling by Capillary Rise Vertical Variable Clearance Test, 316L Stainless Steel:

Filler Metal	Braze Temp		Max Gap Filled	
	°F	°C	inch	mm
Nicrobraz 33	2048	1120	0.022	0.55
Nicrobraz 152	2048	1120	0.020	0.50
Nicrobraz 151	1994	1090	0.033	0.84

Microhardness of Phases:

Filler Metal	Phase Tested	Hardness Vickers 100g
Nicrobraz 33	Solid Solution	105
	Center Line	277
Nicrobraz 152	Solid Solution	140
	Center Line	195
Nicrobraz 151	Solid Solution	205
	Center Line	425

Joint Strength Evaluation:

Tensile strength of brazed joints were evaluated using butt joint specimens per AWS C3.2. These tests were done at room temperature and elevated temperature.

Room Temperature Test Results:

Filler Metal	UTS		Elongation %	Reduction of Area %
	Ksi	MPa		
AWS BNi-2	40.3	277.9	3.4	3.9
AWS BNi-5	51.0	351.6	8.1	9.5
Nicrobraz 33	33.9	233.7	2.7	1.6
Nicrobraz 151	35.9	247.5	2.7	4.7

Elevated Temperature Test Results 1670°F (910°C)

Filler Metal	UTS		Elongation %	Reduction of Area %
	Ksi	MPa		
AWS BNi-2	15.8	108.9	6.7	6.6
AWS BNi-5	16.4	113.1	10.3	7.1
Nicrobraz 33	19.2	132.4	31.0	29.0
Nicrobraz 151	15.8	108.9	35.8	25.4

Corrosion Testing by VDA230-214:

Weak acid + Salt (solution K2.1 PH 3.5)

Filler Metal	Weight Change (mg)	Observation
AWS BNi-2	+4.2	No Change
AWS BNi-5	-0.19	No Change
Nicrobraz 33	+0.68	No Change
Nicrobraz 152	+0.35	No Change
Nicrobraz 151	+0.68	No Change

Strong acid + Salt (solution K1.2 PH 1.2)

Filler Metal	Weight Change (mg)	Observation
AWS BNi-2	-10.13	Visibly Dull
AWS BNi-5	+0.75	No Change
Nicrobraz 33	-0.23	No Change
Nicrobraz 152	+0.29	No Change
Nicrobraz 151	+0.31	No Change

Erosive Propensity Towards 316L Stainless Steel:

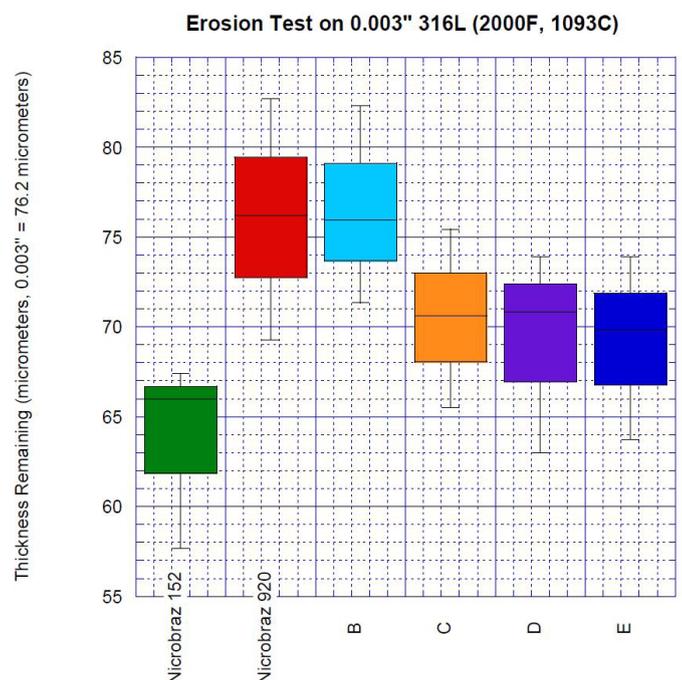
Additions of components made to filler metals were made at the manufacturing level. Copper, molybdenum, and cobalt were evaluated.

A summary of the filler metal compositions evaluated are shown in the table below.

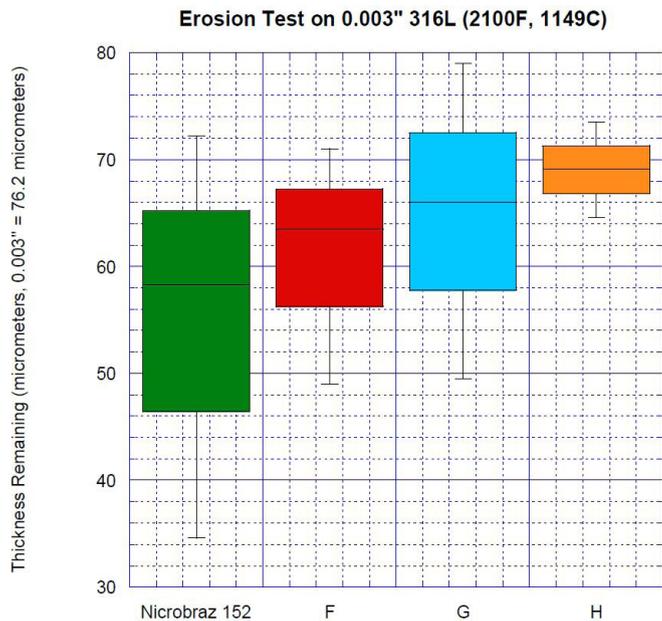
Nickel Based Filler Metal Powders	Cr	Si	P	Cu	Mo	Co
Nicrobraz 152 Composition A	30.0	6.5	4.0	0.0	0.0	0.0
Nicrobraz 920 Composition B	25.3	3.8	6.7	5.0	0.0	0.0
Composition C	24.0	3.2	6.3	10.0	0.0	0.0
Composition D	22.6	3.1	6.0	15.0	0.0	0.0
Composition E	21.3	2.9	5.6	20.0	0.0	0.0
Composition F	27.6	3.7	5.5	0.0	4.0	0.0
Composition G	27.0	3.6	5.4	0.0	6.0	0.0
Nicrobraz 151 Composition H	26.1	5.9	5.4	0.0	0.0	10.0

Braze tests were conducted using a base plate of approximately 1/16" (1.57 mm) and corrugated fin stock with thickness of 0.003" (0.0762 mm). The fin section was measured after brazing with each filler metal and the results plotted for reference.

The effect of additions of copper to Nicrobraz 920 are shown below. There is virtually no beneficial effect with respect to erosion of adding copper.

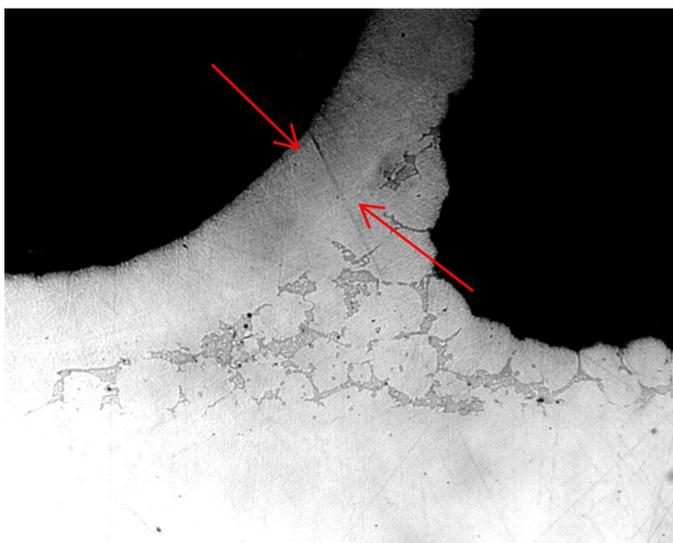


The effect of adding molybdenum or cobalt are shown below. There is a substantial improvement with respect to erosion seen by adding these elements.

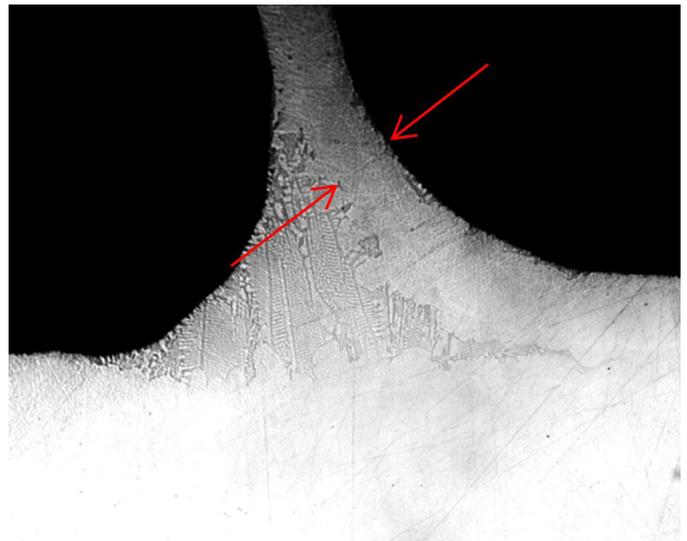


Composition H (Nicrobraz 151) exhibits the least base metal thickness degradation.

The optical photomicrographs shown below illustrate the magnitude of the benefit of a 10% cobalt addition compared to Nicrobraz 33.



Erosion of base metal thin section at Fillet brazed at 1950°F (1066°C), filler metal Nicrobraz 151, Section thickness at ~93% of original.



Erosion of base metal thin section at Fillet brazed at 1950°F (1066°C), filler metal Nicrobraz 33, Section thickness at ~73% of original.

Conclusions

No testing program dealing with multiple filler metals can encompass all of the various permutations needed to optimize parameters such as brazing cycle and joint geometry. Based on this data we can conclude that when brazing components with thin sections or thin walls there is a definite advantage to using a filler metal which minimizes erosion of the base metal.

Additions of copper were not significantly beneficial with respect to erosion at any of the levels tested (5% to 20%). Whereas additions of molybdenum at 4% and 6% were effective in reducing erosion, the wettability to the base metal was found to be better with the cobalt addition.

Addition of 10% cobalt (Nicrobraz 151) provides the desired reduction in erosion and many other desirable properties which make it a viable choice for consideration by the brazing engineer during the filler metal selection process.

In summary Nicrobraz 151:

1. Can be brazed at reasonably low brazing temperature.
2. Has excellent compatibility with 316L stainless steel as shown by its wetting properties.
3. Can fill large joint gaps in a vertical orientation.
4. Has centerline phases with moderately higher hardness than is strictly desirable. However, joint gaps below 0.002" (0.05 mm) can exhibit discontinuous centerline phases.
5. Exhibits joint strengths comparable to the yield strength of wrought 316L stainless steel even at elevated temperatures where it shows excellent ductility.
6. Has high chromium and is expected to resist many corrosive environments, especially those found in exhaust gas recirculator coolers.

The relative beneficial effect of cobalt versus molybdenum is not clear at this time. However, confirmatory testing has been completed using cobalt additions. The actual service conditions will undoubtedly determine which system is best based on the application, base metal, and cost effectiveness.

References

1. ASTM E794 "Standard Test Method for Melting and Crystallization Temperatures by Thermal Analysis" ASTM International
2. "T-Specimens", Technical Data Sheet, Wall Colmonoy Corporation
3. "Brazing Footprints", Robert Peaslee, p150, Vertical Variable Clearance Capillary Test
4. AWS C3.2, "Standard Method for Evaluating the Strength of Brazed Joints", American Welding Society
5. "Evaluation of Brazed Joints Using Failure Assessment Diagram", Yury Flom, NASA Goddard Space Flight Center, IBSC 2012: Proceedings from the 5th International Brazing and Soldering Conference

Copyright © 2013 by Wall Colmonoy Corporation. All rights reserved.

No part of this work may be published, translated or reproduced in any form or by any means, or incorporated into any information retrieval system, without the written permission of the copyright holder. Permission requests should be addressed to: Marketing Communications, marketing@wallcolmonoy.com

Disclaimer

Although the information presented in this work is believed to be reliable, this work is published with the understanding that Wall Colmonoy Corporation and the authors are supplying general information and are not attempting to render or provide engineering or professional services. Neither Wall Colmonoy Corporation nor any of its employees make any warrant, guarantee, or representation, whether expressed or implied, with respect to the accuracy, completeness or usefulness of any information, product, process or apparatus discussed in this work; and neither Wall Colmonoy Corporation nor any of its employees shall be liable for any losses or damages with respect to or resulting from the user of, or the inability to use, any information, product, process or apparatus discussed in this work.