ADVANCED BRAZING AND SOLDERING TECHNOLOGIES

International Brazing & Soldering Conference Proceedings
April 2 - 5 , 2000 - Albuquerque, New Mexico

Edited by
Paul T. Vianco
Mrityunjay Singh

Cosponsered by
American Welding Society
ASM International@

Electronically Published for:
Honeywell, Metglas® Solutions 2002

http://www.metglas.com

OPTIMIZATION OF BRAZING TECHNOLOGY, STRUCTURAL INTEGRITY, AND PERFORMANCE OF MULTI-CHANNELED, THREE DIMENSIONAL METALLIC STRUCTURES

A. Rabinkin*

ABSTRACT

Today the manufacture of multi-channeled metallic structures such as plate and plate/fin heat exchangers, fuel cells for power supply of a new generation of cars, catalytic converters, turbine seals, etc. is the fastest growing application of brazing. This growth is accompanied by a precipitous increase in usage of amorphous brazing foil (ABF) as a filler metal of choice. This paper present data on effects of composition and thickness of Ni- and Co-based ABF and brazing conditions on structure/properties relationships in various metallic multi-channeled structures produced using base metals such as 3 16, 321 and 436 stainless steels, and Inconel and PM2000 alloys. It is shown that the thickness of preplaced ABF affects the joint strength of the unconstrained plate/fin honeycomb structures via complex process involving the surface tension of the liquid filler metal and the weight of structure. This process leads to redistribution of the liquid filler metal across the brazing gap cross-section at brazing temperature followed by filler metal crystallization into joints with various geometry. Detailed account is given to specifics of performance of Ni- and Co-based ABF in joining various stainless steels, superalloys and PM materials. It is found that the joint corrosion and oxidation resistances increase along the following ABF series: Ni-based alloys+Ni-based with Mo additions-+Co/Ni-based+Co/Ni-based with Pd additions.

JOINING 3D STRUCTURES USING Ni-BASED AMORPHOUS BRAZING FOIL

Plate/Fin/Plate Heat Exchangers

a) 436 stainless steel joints brazed with MBF-20 (BNi-2) brazing filler metal

Flat plates were stamped and sinusoidal shape fins were formed from UNS4360 stainless steel sheets having 100 µm and 50 µm thickness, respectively. An abrasive water jet cutting method was used to cut preforms from MBF-20 Ni-based amorphous foil that complies with AWS ANSUA5.8 Specification for BNi-2 classification.

Amorphous foils, from which these preforms were made had 25 µm, 37 µm, and 50 µm average thickness but their across-the-web profiles, measured by a profilometer with a thin tipped probe, had local troughs as deep as 15-20 µm. Three samples were assembled as stacks of 16 identical part sets. Each set consisted of the plate/preform/fin/preform/plate parts. Each sample was comprised of identical base metal plate and fin members for all samples but contained foil preforms having one of the above mentioned thicknesses. Each sample was assembled between vertical guides attached to a thick plate of a special holder permitting to all stacked parts to move freely in the vertical direction during a complete brazing cycle. A load was placed on the top of

*Honeywell, Amorphous Metals, U.S.A.

Optical observations of the failed samples under a moderate 20X magnification showed that in samples brazed using 25 μm and 37 μm average thickness foils, the failure occurred in the brazements, as depicted in Figure 3a. Also, in some samples brazed using 25 pm foil, large unbrazed spots were observed due to an insufficient amount of brazed filler metal needed to fill occasional dents or other defects in the fin form, as Figure 4 demonstrates. In the case of the 50 μm foil sample, the failure occurred in the middle of the fins, as depicted in Figure 3b. Therefore, the strength of the brazed structure in this case was determined ideally by the strength of the base metal.

b) Inconel625 Joints Brazed with MBF-51 Brazing Filler Metal
Heat exchangers for airspace applications were manufactured of 1 mm and 0.2 mm thick plates and 125 μm thick fins using 37 μm thick MBF-5 1 (Ni-15Cr-7.3Si-1.4B) foil (Figure 5). The brazing cycle applied consisted of slow heating and cooling stages and a long term, up to 90 min, brazing stage at 1155°C temperature. Such a cycle resulted in brazes which had mostly single-phase joint microstructure and no cracks (Figure 6). Only a small volume of eutectic phase mixture was present. Moreover, the observed chromium borides, segregated at the braze interfaces, had a favorable round morphology after such long exposure.

Pipe/Fin Heat Recuperators Brazed with MBF-20 (BNi-2)

For years MBF-20 (BNi-2) foil has been used in manufacturing of very large power plant heat recuperators. These recuperators are made of brazed together Inconel pipes and low carbon steel strip fins, Brazing is carried out in an open furnace with flowing nitrogen in which the pipes are moved in-line rapidly and continuously through a hot, about 1075°C zone. High joint shear strength, 127 MPa, is achieved because both these base metals in the as-delivered cold-rolled state have a clean from oxide surface. To improve economics of heat recuperators it was suggested to replace Inconel pipes with inexpensive low carbon hot-rolled ones. The first attempts to joint heavily oxidized low-carbon steel pipes using 40-50 pm thick MBF-20 foil failed. It was shown that a simple and inexpensive in-line surface cleaning operation, in which either metallic brushing or scrubbing with acetone was continuously applied to as-delivered low-carbon steel pipes, resulted in joints having the shear strength similar to that of Inconel/steel joints. No changes of the original brazing conditions were needed. The steel/steel joints have a complete nonporous interface free from any traces of oxides due to evident reducing effect of silicon and boron contained in MBF-20.

HIGH CORROSION AND OXIDATION RESISTANT SRUCTURES BRAZED USING NEW MODIFIED Ni- AND Co-BASED ALLOYS

In the last decade there has been a dramatic increase in demands for heat exchangers, catalytic converters and gas coolers that can withstand a strong corrosive and oxidizing environments. In many cases these brazed products made of thin stainless steel parts such as plates, fins, and tubes. Evidently, brazing of these parts demands low eroding filler metals. Concurrently, a new generation of jet engines working at 1200°C was developed using new materials. In both these cases new brazing filler metals capable to withstand severe service conditions are needed. To satisfy these demands we developed a modified MBF-51 (BNi-5b) alloy containing 5 wt.% molybdenum added to its (Ni,Cr)-base and a new low boron containing Co-based MBF-100 each sample in the form of a metal or graphite block. The loaded samples were placed in a vacuum furnace in the vertical position and brazed at a temperature of approximately 1090°C for 15 min. Upon brazing, each of the 16 sets became a plurality of sealed channels simulating the channels in actual heat exchangers. The samples for mechanical testing were cut and then machined by the electrical discharge method into specimens with I-beam shapes having about a 25 mm x 25 mm cross-section in the specimen "neck," as depicted in Figures la and lb. The cutout pieces were used to prepare metallographic samples. The joint dimensions and microstructure, as a function of the preform thickness, were measured using an optical microscope under a moderate 100X magnification.

Metallographic observations showed that the joint thickness in the middle portion of all brazes is the same regardless of the thickness of the virgin amorphous foil, even when comparing samples manufactured using 25 µm and 50 µm foils as Figures 2a and 2b demonstrate. This effect was observed because gaps between parts were not constrained during brazing. Indeed, the excess liquid MBF-20 alloy was partially expelled from the capillary gaps upon melting until the surface tension forces at all gap surfaces became equal to the total load applied to the specimen, the total load being the parts weight and the weight of the external block. This excessive molten MBF-20 metal, particularly in the case of 50 µm foil, flowed out of the initial gaps forming large fillets and partially climbed up on the vertical walls of the fins. The thicker filler metal resulted in larger joint fillets which had advantageous shapes without a narrow cavity-like crystallization shrinkage pattern seen in Figure 2a and, therefore, larger joint cross-sections as depicted in Figure 2b. The height of formed individual passages in all brazed specimens was measured using a standard optical comparator with the following results shown in Table 1:

Table 1 Average passage height and total height of 16 passages of plate/fin/plate samples as a function of MBF-20 foil thickness

Filler Metal Thickness, µm	Average Passage Height, µm	Total Height of 16 Passages, µm
25	3,282	52,514
37	3,287	52,590
50	3,284	52,557

Because sixteen brazing foils were preplaced in each of the samples, the initial difference between assembled packs with 25 µm and 50 µm thick foils was 400 µm. This difference decreased to near zero in the brazed structures due to above-mentioned interplay between surface tensions forces of the liquid MBF-20 and the load (see also References 11, 21). The I-beam shaped brazed samples were tensile tested at 650°C using a standard tensile testing machine. The samples evidenced the following maximum load at failure, and this load varied linearly with the foil thickness (Table 2):

Table 2 Maximum load at sample failure at 650°C as a function of filler metal thickness

Filler Metal Thickness, µm	Maximum Load at Sample Failure at 650"C, kg
25	342
37	429
50	537

series of alloys having (wt.%) 2 1 Cr, 4.5 W, 7.3Si, 1.4B and in some of them, 3-5% additions of Pd.

Corrosion testing of AISI 3 16 and 321 stainless steel coupons brazed with these new alloys was carried out in our lab in a water solution, about 10 vol.%, of a mixture of nitric, sulfuric, and hydrochloric acids. It validated improved performance of these alloys as data in Table 3 demonstrated.

Table 3 Corrosion weight losses of some brazed samples in an acid solution

Brazing Filler Metals Used In Tested Samples	Weight Change, %, Relative to the Initial Weight After 78 1 h Exposure	
	316 SS coupons	321 SS coupons
MBF-51 (BNi-5b) (Ni-15Cr-7.3Si-1.4B)	-6.14	-22.3
MBF-51+5% Mo (Ni-15Cr-7.3Si-1.4B-5Mo)	-1.74	-11.23
MBF-101 (Co-21Cr-4.5W-4.4Si-1.55B)	-0.59	-0.1
Unbrazed base metal 3 16SS and 32 1 SS coupons having the same weight as the tested samples and used for comparison	-0.3 1	-0.05

In addition, the erosion of stainless steel coupons by the alloy containing molybdenum was very limited. Still, best results were achieved with MBF-101 Co-based alloy.

New developed MBF- 100 alloys were tested as potential prototypes in manufacturing of the cell-type seals made of dispersion hardened PM2000 Fe/Cr-base alloy (Reference [3]) and joining and repair of vane and blades made of superalloys (References [4, 5]). First, we tested their wettability in honeycomb type samples comprised of highly alloyed poly- and single crystalline heat-resistant superalloys used as the face plates. Heat resistant honeycomb cores made of PM2000 alloy were brazed to these plates using new brazing foils as filler metals. PM2000 has a composition (wt. %) 20 Cr, 5.5 Al, 0.5 Ti, 0.45 Y_2O_3, and the balance being iron. The tested superalloys were (Ni,Cr, Co)-based MSRR 7248 (CMSX-4), MSRR 7150, MSRR 7046, and Inconel738. One honeycomb sample was also made with PM2000 face sheets. A bulk alumina specimen with a piece of MBF-104 foil on top of it was also placed in the furnace together with metallic parts for comparison. In spite of the fact that all metal parts in the virgin state were covered by a thicker than 500Å alumina layer, they were well joined after short brazing cycle in vacuum at 1195 °C forming good metallurgical bonds and clean joint interfaces. They also had complete and well-formed fillets with wetting angles well below 45°. On the other hand, the alumina sample was not wet at all. It is suggested that difference in a degree of wetting of metallic parts with a relatively thin alumina layer and the bulk alumina specimen is due to ability of Co-based brazing filer metals containing substantial amounts of boron and silicon to dissolve and reduce a certain amount of alumina before liquid metal saturation is stepped in.

The metallographic observations were carried out only of brazed joints in which both honeycomb face and core base metal parts were made of PM2000 strips. Each sandwich-like specimen was comprised of two 100 mm wide125 μm thick strips of alloy PM2000 and a single 25 μm thick foil of one of the samples containing palladium preplaced between these strips. Brazing was made at 1195°C for 15 min in a furnace with vacuum better than $1.33X10^{-2}$ Pa ($<1x10^{-4}$ Torr). Joint microstructure was observed using SEMEDAX and Auger analytical methods. The typical microstructure of a joint prepared using previously developed MBF-100 having 2.4 wt.% boron is shown in Figure 7a. This micrograph depicts presence of a substantial amount of chromium borides precipitated inside of PM2000 base metal strips (empty arrows). These borides segregate predominantly at planes, which are parallel to the direction of PM2000 original rolling.

Figure 7b is a micrograph of a joint made using MBF-104 foil as filler metal which contains 5 wt. % palladium. This micrograph depicts a dense layer of AlPd intermetallic phase (black arrows) formed at the joint interface and protecting base metal from boron penetration and formation of detrimental chromium borides. The base metal has a substantially uniform, single-phase microstructure with a very limited amount of precipitated chromium borides.

Brazability and oxidation resistance in open air at 1165°C/65 hours of PM2000 honeycombs brazed using Ni- and Co-based amorphous alloys was studied by D. Sporer and they are shown in Table 4 (Reference [3]).

Table 4 Brazability and oxidation resistance in open air at 1165°C/65 hours of PM2000 honeycombs brazed using Ni- and Co-based amorphous alloys

MBF Alloy And Its Composition, Wt.	Honeycomb Cell Size And Height, mm	Wicking (Ml), %	Brazing/Oxidation Quality (BQN)**, %
MBF-50 (BNi-50a) (Ni-19Cr-7.3Si-1.25B	5 x 6.4	95***	6
MBF-100 (Co-21Cr-4.5W-1.6Si-2.15B)	1.6 x 10	100	61
MBF-101 (Co-21Cr-4.5W-4.4Si-1.55B	2.5 x 6.6	100	44
MBF-102 (Co-15Ni 21Cr-4.5W-4.4Si-1.55B)	2.5 x 6.8	65	61
MBF-103 (Co-15Ni-21Cr-4.5W-3Pd-4.4Si-1.55B)	1.6 x 10	59	65
MBF-104 (Co-15Ni-21Cr-4.5W-5Pd-4.4Si-1.55B	1.6 x 10	71	62

*- Brazing was made at about 12OO°C for 2-5 mm in high vacuum, <lxlO(E-5) mbar.
**- BQN $[\%]=(10xM1xH)/(10+N_b)xH_n$, where Ml is braze flow in %, H-honeycomb height, mm; Nb-number of double cell walls showing "through" or breakaway oxidation; H-normalized honeycomb height.
***-Three 25 mkm thick foils were preplaced from each of both sides of the honeycomb.

The tensile strength at room and high temperatures and microstructure of X40 superalloy joints brazed with the same Co-based MBF-100-series alloys were studied (Reference [2]). Very high joint strength, practically the same as that of the X40 base metal, was achieved when MBF-100 and MBF-101 alloys were used. L. Heikenheimo and W. Miglietti reports more details about performance of Co-based amorphous brazing foil tested very recently (Reference [3 1).

Summarizing all these results we may state that the joints manufactured from MBF-100 series alloys have high temperature and corrosion resistance. The specific advantages of these alloys include the ability to braze at high temperatures and to provide brazements that can be employed at elevated temperature under high oxidation and corrosive environment without any significant degradation of mechanical properties. In this respect they are superior to any of Ni-based series of amorphous brazing foil including MBF-50 (BNi-5a AWS classification) with 19 % chromium.

These amorphous Co-based alloys are particularly suited for joining of parts of aircraft and power plant turbines and airspace and spacecraft structures. Additional potential application may also be heat exchangers, fuel-cell elements, chemical apparatuses, medical instruments and tools.

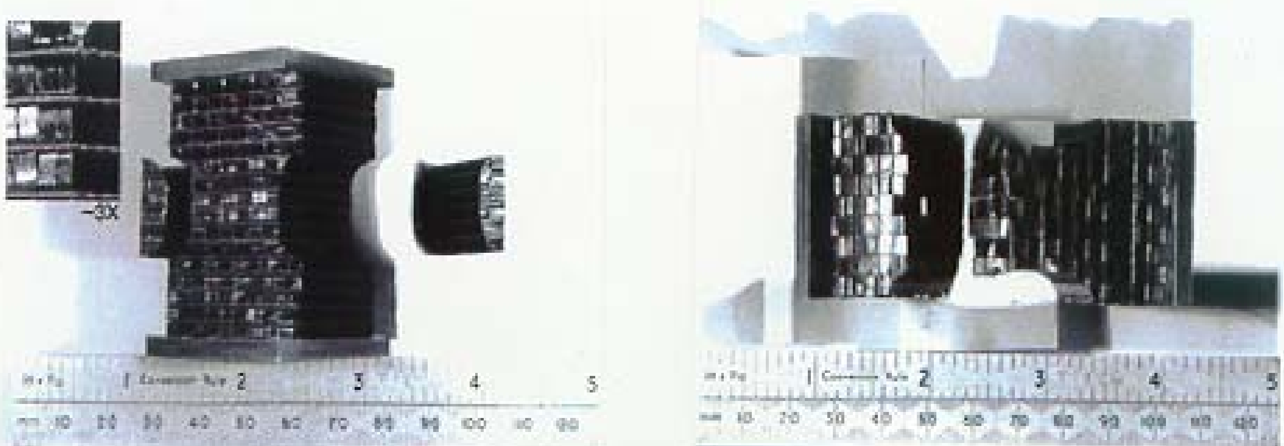
ACKNOLEDGEMENT

I am thankful to Messrs. P. Jeges and J. Cox for their help in alloy casting and sample preparation, correspondingly.

REFERENCES

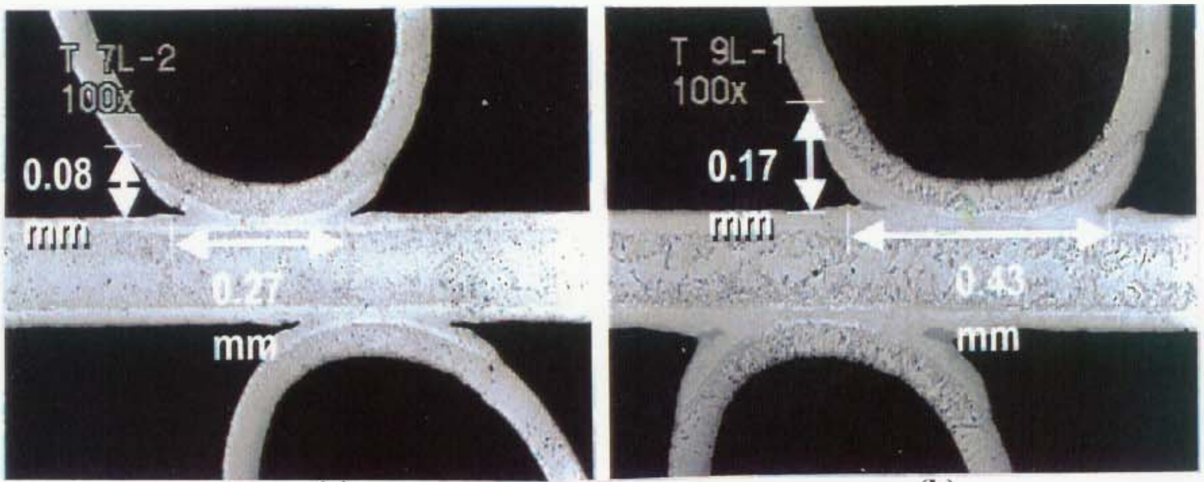
1. Rabinkin, A. and Pounds, S.; 1988. Effects of Load on Brazing with METGLAS® MBF-2005 Filler Metal, Welding Journal, 67, 33-45.
2. Yen, M.S. and Chuang, T.H.; 1997. Effects of Applied Pressure on the Brazing of Superplastic Inconel 718 Superalloy, Met. and Mat. Trans., 28A, June, p.1367-1376,
3. Sporer, D.; 1999, Plansee (private communication).
4. Migliett, W.; 1999, Braze repair of X40 Co-based turbine vanes using amorphous filler metals, IIW Document 1A-1031-99.
5. Heikinheimo, L.; Miglietti, W.; 1999. Brazing of Co-based superalloy gas turbine vanes using novel amorphous filler metals, (Proceedings of this IBSC2000 Conference)

FIGURES



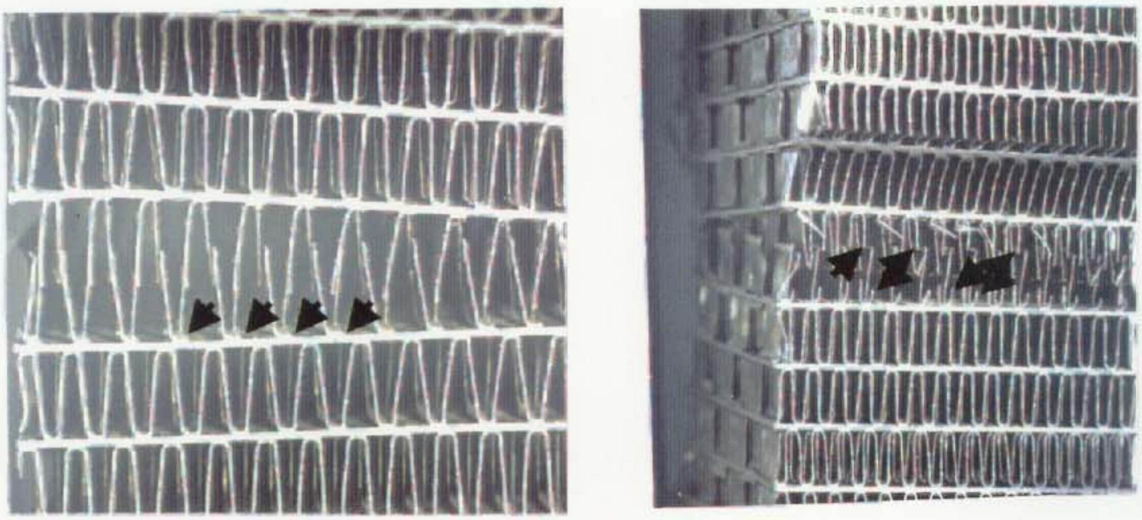
(a) (b)

Fig. 1 Samples of a brazed plate/fin structure for mechanical testing after electroerosion cutting (a) and after failure under tensile mode testing at 650°C.



(a) (b)

Fig. 2 Microstructure of two 436 stainless steel plate/fin samples brazed using 25 μm (a) and 50 μm (b) thick MBF-20 ribbon. Note that while the joint thickness inside brazes is the same, the joint cross-section is wider and the fillet height is higher when the thicker foil is used.



(a) (b)

Fig. 3 Failure location in plate/fin structures after tensile mode testing at 650°C. (a) Failure in brazements, 25 μm thick MBF-20 foil was used. (b) Failure in the base metal fins, 50 μm thick MBF-20 foil was used.

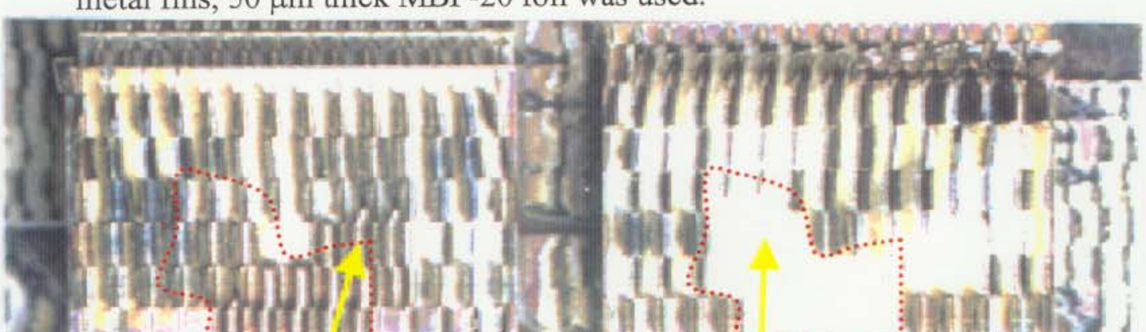


Fig. 4 Two halves of a sample made using 25 μm thick MBF-20 foil. The sample has a large unbrazed area due to an insufficient amount of the brazing filler metal.

Fig. 5 An Inconel625 heat exchanger brazed using MBF-51 foil.

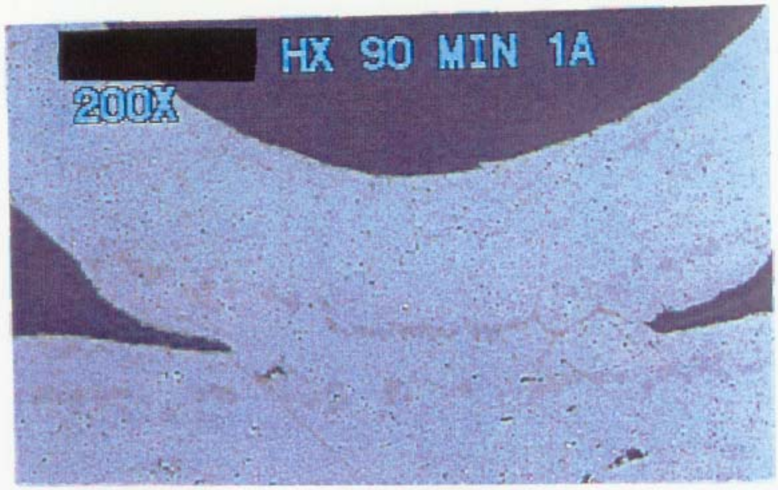
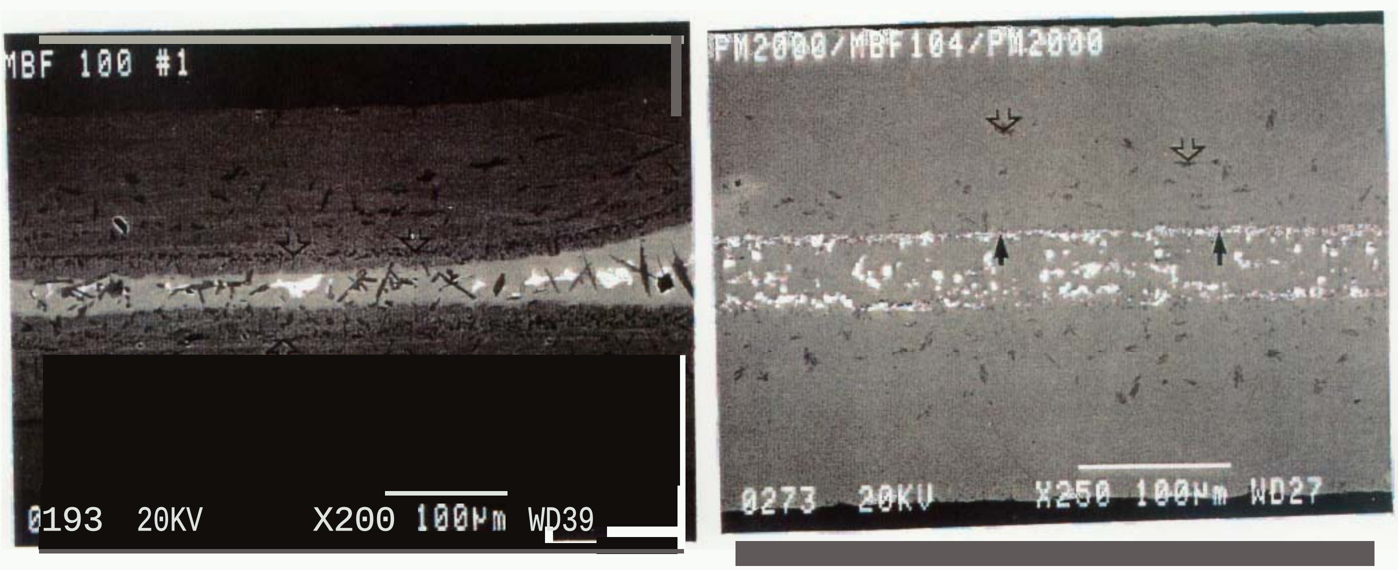


Fig. 6 Micrograph of a Inconel 625 plate/ fin braze of the heat exchanger shown in Fig. 5. The braze has mostly a single phase solid solution microstructure and a favorable morphology of the chromium borides segregated at the joint interfaces.



(a) (b)

Fig. 7 Micrographs of PM2000/PM2000 joints brazed using MBF-100 (Co,Cr)-based alloy (a) and MBF-104 alloy containing palladium (b). The dense layer of AlPd phase crystals (black arrows) was segregated at the joint interfaces preventing formation of chromium borides in the base metal.