Brazing with amorphous foil preforms

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Brazing is a process for joining metals in which a filler metal with a melting point lower than the metals to be joined is melted and distributed between the closely fitted surfaces of the joint. Most filler metal (FM) alloys for high-temperature brazing are eutectic compositions formed by transition elements such as nickel, iron, or chromium in combination with metalloids such as silicon, boron, and phosphorus. When they are composed of the conventional crystalline structure, all these materials are inherently brittle and cannot be produced in continuous forms such as foil and wire. Therefore, they have been available only as powders or its derivatives.

On the other hand, the very presence of metalloids at or near the eutectic concentration promotes rapid-solidification conversion of such alloys into a ductile amorphous foil. One of the first practical applications of rapid solidification (RS) technology was in the production of ductile amorphous brazing foil from alloys having compositions that previously could be utilized only in powder form, or as powder-filled pastes.

The most important advantages of RS amorphous microcrystalline filler metal alloys are their flexibility and ductility. Because a ductile amorphous alloy foil may be applied as a preplaced preform, large brazement gaps are not necessary (as they are for pastes) to achieve complete filling of the braze cross section. In this case, amorphous alloy foil has a particular edge over powder and polymer-bonded strip forms because of its superior flow characteristics.

One reason for the superiority of the foil is the fact that gas-atomized powder has a very large total surface area with resulting large amounts of surface oxides. These oxides prevent, to a certain degree, fusion of individual powder particles into a uniform liquid pool. The rapidly solidified filler metal flows more freely than any powder form. A smaller clearance also promotes improved retention of bulk metal properties because of curtailed erosion by the smaller volume of filler metal. For these reasons, a preplaced, self-fluxing, thin filler metal foil preform is superior to powder-containing paste, which requires larger clearances for filling join cross sections. The paste also results in deleterious effects on properties because of a coarser joint grain size, more fully developed intermetallic compounds, and the presence of substantial amounts of contaminants.

The manufacture of rapidly solidified products is characterized by high cooling rates (approaching 10^6 K/s). This high cooling rate enables the stabilization of certain alloys into an amorphous solid state, having a spatial distribution of atoms similar to that of liquids. Most Honeywell Metglas alloys have this amorphous structure, with a random, spatially uniform arrangement of the constituent atoms.

Because rapidly solidified amorphous materials are compositionally much more uniform even after crystallization, they melt over a narrow temperature range under transient heating. This is a consequence of the shorter distances over which atoms of different elements have to diffuse in order to form a uniform liquid phase.

The resulting "instant melting" of RS materials is only one of their important features. This is particularly important when brazing fine-gage honeycomb cores, for example, which have to be protected from erosion by molten filler metals during joining. A shorter brazing time is also beneficial in cases wherein base metal parts may lose their inherent strength due to annealing during the brazing operation. The joining of cold-deformed stainless steels and of precipitation-hardened superalloys are good examples in which a short brazing time can be critically important.

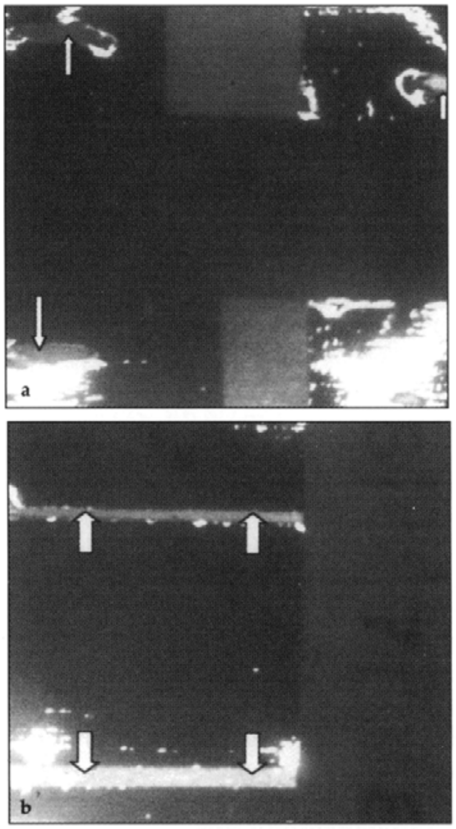

Fig. 1 — "Virgin" specimens with pieces of Metglas brazing foil having (a) holes and (b) gaps.

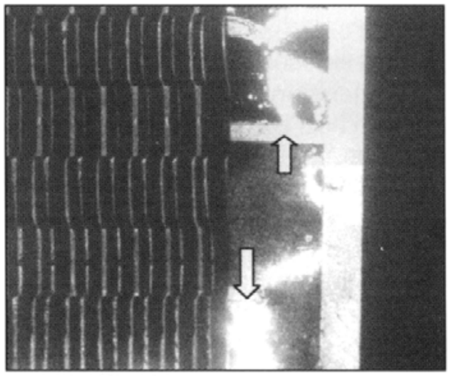

Fig. 2 — "Virgin" specimen with a piece of the offset fin tack-welded over two gaps between MBF-20 ribbons.

The absence of the residual organic solvent bases evident in powder pastes/tapes correspondingly eliminates soot formation and furnace fouling. The low level of gaseous impurities in amorphous alloy foil, due to the specific characteristics of its production technology, is an attractive feature for vacuum furnace brazing. As a consequence of these unique properties, amorphous brazing foil has become the preferred advanced filler metal for applications related to the aerospace industry, precise machinery and tools, and modern medical equipment.

When brazing parts with Honeywell's Metglas amorphous brazing foil (MBF), two potential sources of incomplete brazing should be consid-

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ered. First, gaps may exist between MBF foil preforms placed side-by-side during the product assembly. Second, MBF foil may have small holes. Both the gaps and the holes threaten to leave voids within the brazements.

To combat the formation of voids, the gaps and holes must be filled during the brazing process. This may be an important barrier when considering applications with brazed cross-sections having both width and length dimensions larger than 200 mm (8 in.). This dimension is a limit for the width of ribbon produced by today's planar casting technology. If the gaps and holes are moderate in size, up to 3 mm (0.12 in.) maximum dimension, they will be filled by the liquid filler metal during brazing. Therefore, multiple preforms may be suitable for joining parts, permitting assemblies of virtually unlimited dimensions.

As stated above, one of the most advantageous features of MBF is its superior flow when compared to powder filler metal products. This article reports on an experiment to evaluate flowability, in particular the ability to fill substantial gaps and joints in commercial products having large dimensions

Joining plate and fins

The base metal parts to be joined for this study were a 250 μm (10 mil) thick plate and 75 μm (3 mil) thick fins made of 436 AISI stainless steel. The fins had sinusoidal and offset shape and dimensions that are typical for plate/fin heat exchangers in industry. The brazing filler metal was 37-μm-thick MBF-20 foil. The following specimens were prepared with two kinds of base metal/filler metal settings:

- The first group of specimens was prepared from plates and foils. MBF-20 foil was tack-welded to AISI 436 stainless steel coupons, as illustrated in Fig. 1a. The foil contained holes having dimensions of up to 2 to 3 mm wide and up to 5 mm long. The seldom-observed holes of these dimensions are typical in MBF filler metals. Also, pieces of MBF-20 were tack-welded to the stainless steel coupons in a side-by-side configuration, with the pieces separated by 0.5 and 1.0 mm gaps (Fig. 1b). Both the holes and the gaps not covered by foil and fins are called "open" gaps.
- The second group of specimens consisted of plates, foils, and fins. MBF-20 foil was tack welded between stainless steel alloy 436 coupons and one-inch square sections of fins. Again, the pieces of MBF-20 foil had holes and were positioned with gaps very similar to that of the first setting (Fig. 2). Fins with both sinusoidal and offset shapes were studied, representing a wide variety of heat recuperator and heat exchanger applications. In these specimens, the individual fin footprint in contact with the foil and coupon may be narrow (sinusoidal fins) or wide (offset fins). In all cases, the joints have at least one small dimension within a few dozen micron range, which is a typical dimension for brazing gaps and the most favorable dimension for the capillary wetting by liquid filler metals. These gaps can be called "closed gaps."

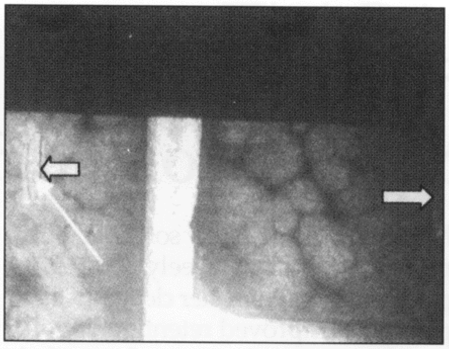

Fig. 3 — Two brazements made by applying MBF-20 ribbons with holes. Note that the non-brazed areas (arrows) are smaller than the initial hole areas.

All specimens tested were brazed in a furnace with an atmospheric pressure less than about 2.6×10^{-3} Pa (5×10^{-4} mm Hg). Specimens were brazed at 1060°C (1940°F) for 15 minutes with two intermediate temperature holds made at 300 and 900°C (570 and 1650°F) during the heating part of this brazing cycle. After brazing, specimens were subjected to optical observations at 5X to 50X magnification, and their images were photographed with a high-resolution digital camera.

Brazed joints

All the brazed samples had very clean, bright, lustrous surfaces without any traces of oxidation, as expected under good vacuum conditions. A specimen with the plate/foil setting (open gap) after brazing is shown in Fig. 3, while Figs. 4a, 4b, and 5b show specimens with the plate/foil/fin setting (closed gap) with both types of fins. Specimens made from foil containing holes can be seen in Fig. 5a, 5b, and 5c. Specimens made from assemblies containing side-by side gaps are shown in Fig. 6 and 7.

It is evident from our observations that sound, complete joints with full-sized fillets were formed in all the closed-gap specimens, including positions across holes (Figs. 5a and 5b and Fig. 7) and along holes (Figs. 5c), and across and along side-by-side foils (Fig. 4a). Moreover, the liquid MBF-20 alloy flowed laterally and filled the 4 to 5 mm gaps that existed between fins overhanging outside of the pre-placed MBF-20 ribbon, as can be seen in Fig. 4c.

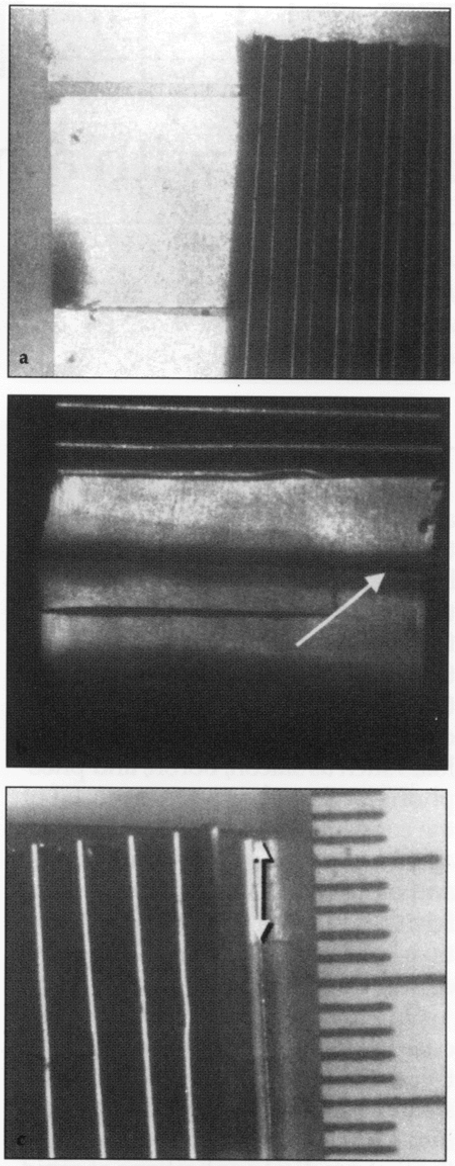

Fig.4 — Specimens with sinusoidal fins brazed to MBF-20 ribbons separated by ~1 mm wide gaps: (a) general view (b) view after cutting parts of the fins. Note complete brazing in places where initial gaps were, and also over a 4-mm long empty gap between the fin and the plate (b and c).

To evaluate the integrity of the joint, a brazed specimen with sinusoidal fins was cut in a direction perpendicular to the corrugations of the individual joints formed along a 25 mm (1 in.) long, 1 mm (40 mil) wide empty gap. It was found that each individual joint underneath the fin ridges was filled by the liquid MBF-20 that eventually

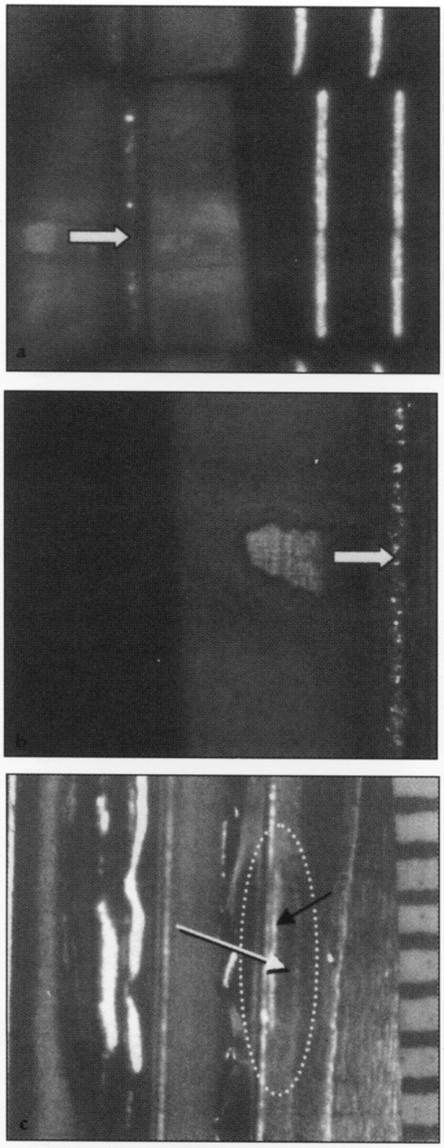

Fig. 5 — Specimens with offset fins after brazing. These reveal ;complete joints in places where (a) gaps and (b) holes existed initially. A good joint and good fillet (white solid arrow) are formed between a fin and the base metal flat plate over a long hole (5 × 2 mm) that existed in a preplaced MBF-20n ribbon.

crystallized in a complete, full fillet (Fig. 7).

In summary, optical microscopy revealed that liquid MBF-20 filled in all closed gaps in the plate/foil/fin assemblies, resulting in complete, full fillets and sound joints.

A very different picture emerged from specimens prepared with open holes and gaps. Here, the ability of molten MBF-20 to heal the defects was substantially moderated. For example, the brazing process converted a one-mm wide virgin hole into a smaller but similarly shaped unbrazed spot. The resulting spots were approximately 0.5-mm wide (Fig. 3). The same degree of uncovered space, from about 0.5 to about 1 mm, developed in open gaps with straight parallel sides.

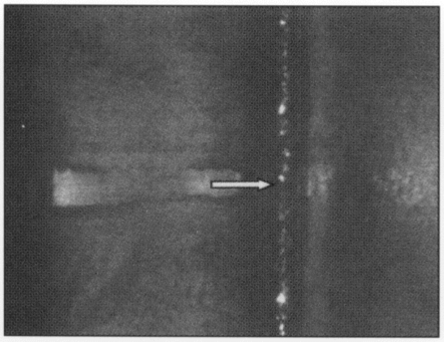

Fig. 6 — Specimen with a complete joint formed after brazing of a piece of sinusoidal fin over the gap between foils. Part of the fin was cut off to reveal the joint.

Healing the defects

Experimental observations indicate that liquid MBF-20 advances over larger distances and can heal larger defects in closed gaps than in open gaps. The fundamental reason is the relative pressure applied to the liquid metal in closed vs. open systems.

According to the Laplace formula, the additional pressure ΔP on a liquid surface in a circular capillary, applied by capillary forces, is

$$\Delta P = \gamma(1/R_1+1/R_2)$$

where γ is the liquid surface tension and R_1 and R_2 are the major radii of the liquid meniscus curvature which, in turn, is set by the capillary geometry. From the Laplace formula, it is evident that the smaller the major radii, the higher the additional pressure.

In the case of a liquid spreading over an open and flat surface, at least one of the major radii of curvature is close to infinity. In the case of closed gaps that typically exist in brazed assemblies, including those tested in this work, these radii are approximately one hundred microns or less. For example, for two flat, parallel horizontal plates separated by gap D cm with $1/R_1 = 0$, it follows that

$$\Delta P=(2_{\gamma LV}\ \cos\theta)/D$$

where θ is the contact angle determined by Young's equation for balancing surface tensions of liquid and solid metals at three contacting interfaces. When brazing various steels and alloys with nickel-base filler metals containing silicon and boron, the contact angle θ is in the 10 to 30 degree range and therefore, 2 cosθ is within the 1.96 to 1.73 range. Assume, conservatively, that the surface tension of MBF-20 is no less than half that of pure nickel: 1778/2 = 889 dyne/cm.

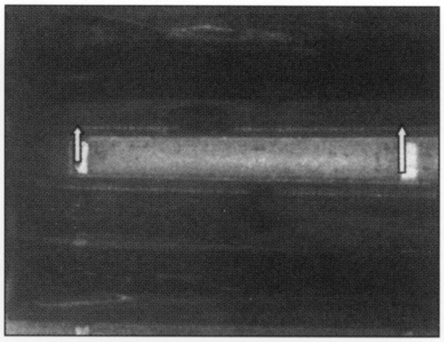

Fig. 7 — Set of complete joints formed between fins and MBF-20 plate across the gaps between the two foils. Parts of the fins were cut to reveal the joints.

Therefore, the pressure expected to be applied to the liquid filler metal in the 50 to 100 μm gaps should be at least $2 \times 8.9 \times 10^2 \times 10^{-6} \times 1.73 \times 1 \times 10^3$ kg/cm^2 = 3 atm (3×10^5 N/m^2)

On the other hand, in the case of open gaps, in spaces such as uncovered holes and straight edges of foil, the major radius of an advancing liquid is on the order of a thousand microns, i.e., many times more. Therefore, the driving force that "pushes" the edges of the molten filler metal to advance in closed gaps is a few orders of magnitude larger than that in open gaps.

This effect is routinely implemented in industrial heat exchanger production, where multi channeled plate/fin cores are brazed with filler metal foil arranged in side-by-side configurations. These heat exchangers have cross-sections as large as 23.1 x 56.4 cm (15 x 22.2 in.), yet reveal no leaks and have high burst pressure.

When vacuum brazing 436 AISI stainless steel plate/fin structural parts with MBF-20 ribbon having 37 μm (1.5 mil) thickness, sound joints with complete fillets are formed in places where gaps and holes appear in these ribbons. The dimensions of gaps and holes may be as large as at least 3 mm.

The same picture is observed with other base and filler metals. Therefore, manufacturers who braze in vacuum or inert gas environments may braze multiple set side-by-side preforms made of MBF ribbons and separated by gaps, yet still fabricate joints that have no leaks and high overall integrity and strength. ■

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