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Flame Brazing with NOCOLOK® Flux

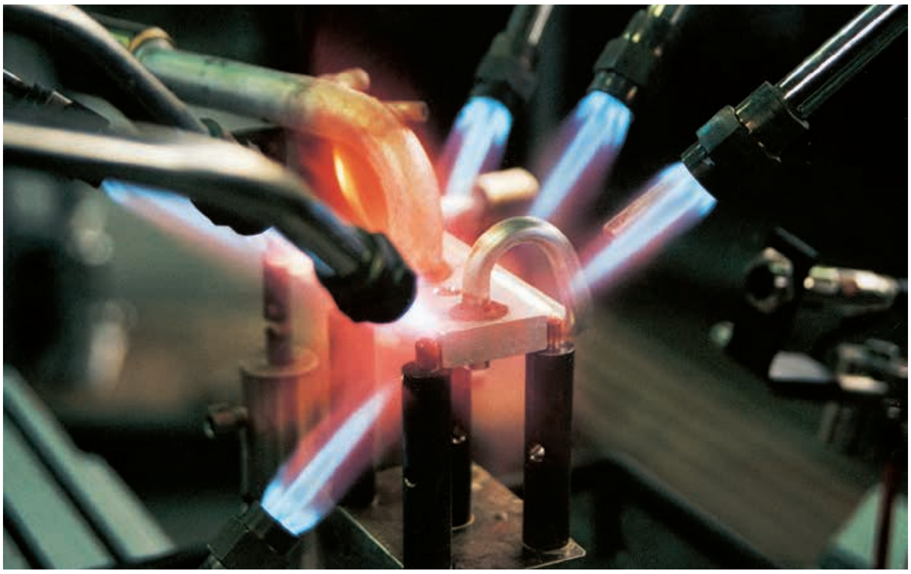
Introduction

Flame brazing of aluminum is not new. In fact the very first brazed aluminum assemblies were produced using a chloride based flux and a flame as the heat source.

What has changed over the years is the sophistication of the types of fluxes available and to a certain extent the alloy selection. However, even if one returns to the absolute basics of a flame, filler metal and flux, there remains a great deal to be learned about the fundamentals of flame brazing of aluminum. This becomes especially evident when the brazing engineer applies his techniques and equipment to NOCOLOK® flux flame brazing and years of learned practice seem to fail. This is largely due to the fact that the years of acquired knowledge of flame brazing aluminum has come from corrosive chloride-based flux brazing.

Unfortunately, the same techniques can not be directly applied to NOCOLOK® flux flame brazing. It is therefore the intention of this article to re-familiarize the brazing engineer with the fundamentals of flame brazing aluminum and use those fundamentals to realize all the advantages of NOCOLOK® flux brazing.

What is Flame Brazing?



Flame Brazing

According to the American Welding Society, brazing is the joining of metals using a molten filler metal, which on cooling forms a joint. The filler metal melting temperature is above 450 °C, but below the melting point of the metals. Flame brazing then implies the use of a flame as the heat source to accomplish what is described above.

Flame brazing lends itself well to joining components with simple configurations such as tube-to-tube, tube-to-fitting and joints having large thermal mass differences. Since much faster heating rates are possible than in furnace brazing, flame brazing is versatile and as will be explained in more detail later, can braze some Mg containing alloys.

What is NOCOLOK® Flux?

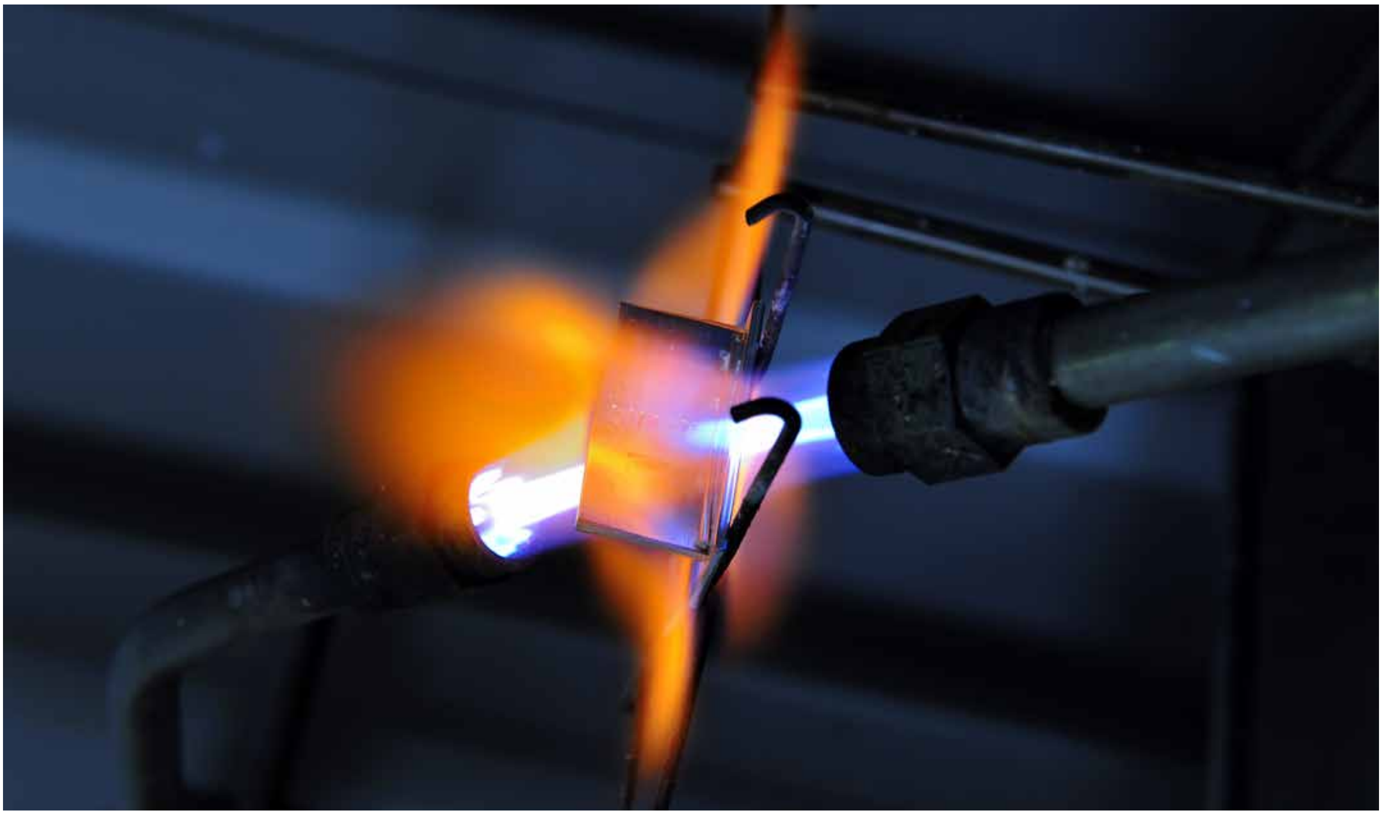
NOCOLOK® flux is a white powder consisting of a mixture of potassium fluroaluminate salts of the general formula K_{1-3} $Al\text{-}F_{4-6}$. The flux has a defined melting point range of 565 °C to 572 °C, below the melting point of the Al-Si brazing alloy. The flux is non-corrosive and non-hygroscopic and is only very slightly soluble in water (0.2 % to 0.4 %). The shelf and pot life of the flux is therefore indefinite. The flux does not react with Al at room temperature or at brazing temperature and only becomes reactive when molten.

Role of the Flux

Once molten the flux works by dissolving the oxide film on the Al surfaces to be joined and prevents further oxidation. The flux wets the Al surfaces and allows the filler metal to flow freely into the joints by capillary action. Upon cooling, the flux solidifies and remains on the surfaces as a thin, tightly adherent film, which need not be removed.

Joint Clearances

The recommended gap tolerances for flame brazing range from 0.1 mm to 0.15 mm. Larger gap clearances can be tolerated, but capillary action is reduced, gravity activity is increased and more filler metal may be required. Friction fits should also be avoided as this will restrict filler metal flow and result in discontinuities in the brazed joint area.



Flame Brazing

Recommended equipment for flame brazing

Since the principles of flame brazing can be explained using the most basic equipment, only the equipment necessary for manual flame brazing is described. From the basic principles, all other equipment is only a matter of the degree of automation the end user wishes to achieve.

Hardware

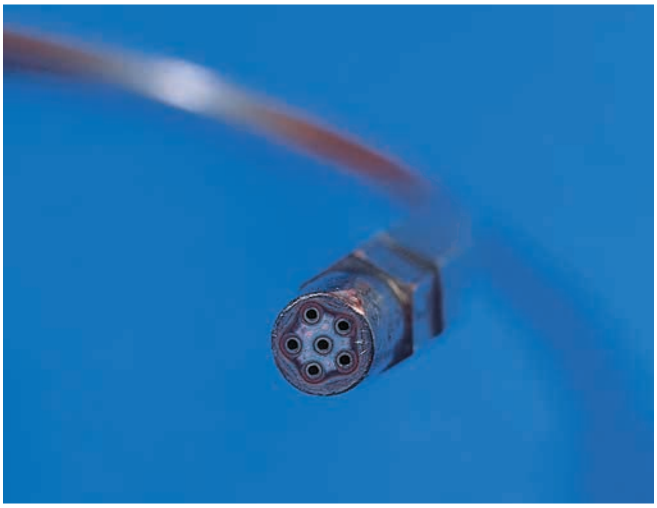
Torch

It is critical that the joint area is brought up to temperature uniformly. For this reason a dual headed torch capable of heating the joint from 2 sides is recommended.

Torch Tip

A multi-orifice tip generates a broader flame at the exit of the tip. This feature enhances component temperature uniformity during heat up. Pin-point flames should be avoided as burn-through can easily occur.

Dual headed torch



Torch Tip

Filler metal

Consumables

Gas

Most commercial gas mixtures are acceptable for flame brazing Al:

- oxygen – propane
- oxygen – methane
- oxygen – natural gas
- oxygen – acetylene (oxyacetylene)

Oxyacetylene combination produces the hottest flame and may be used, but with extreme care to avoid overheating and burn-through.

Filler Metal

The filler metal alloy most commonly used for flame brazing Al is AA4047 which contains 11 to 13 % Si. The Al-Si phase diagram shows the eutectic at 577 °C with 12.6 % Si. AA4047 filler alloy therefore has the lowest melting temperature with the highest fluidity, ideal properties for flame brazing Al.

The filler metal is available in a variety of shapes and forms including wire, rings, foil and powder. When used as a powder, it is usually mixed with flux and a carrier to form a paste (more on pastes below). The filler metal wire is also available commercially either cored or coated with flux, precluding the application of flux.

Brazing Paste

Commercially available brazing pastes consist of the flux, powdered filler metal and a binder/carrier to keep everything in uniform suspension. This paste is all inclusive, there is no need to supply flux or filler metal to the joint separately. Brazing pastes can also be applied with automatic dispensers, with syringes or by brush application.

Flux Paste

This is very similar to brazing pastes except that there is no powdered filler metal present, meaning that flux pastes requires filler metal in one form or another to be added to the joint separately. The advantage of using a flux paste is that the end user does not have to prepare his own paste.

In-House Paste Preparation

The least expensive and most common is the in-house preparation of flux pastes. The flux is mixed with either water or alcohol and/or water at 40 % to 60 % solids. Using some alcohol in the paste formulation allows for quicker drying. Using pastes prepared in-house of course requires that the filler metal be supplied to the joint separately. These pastes are not easily dispensable automatically and are most often applied with a brush.

For brazing a tube-to-tube joint, the table below summarizes the complexity level in applying the flux and filler metal in their various forms:

Flux Cored or Coated Wire	Brazing Pastes	Flux Pastes	In-House Paste Preparation
1. Preplace ring at the joint	1. Apply or dispense paste at the joint	1. Preplace ring at the joint	1. Prepare paste
2. Braze	2. Dry	2. Apply or dispense paste at the joint	2. Preplace ring at the joint
	3. Braze	3. Dry	3. Apply paste at the joint
		4. Braze	4. Dry
			5. Braze

Procedure

This section describes the necessary steps and control procedures to ensure a properly brazed joint.

1. Clean the Components
The joint area must be cleaned free of cutting and machining lubricants. Aqueous cleaning, solvent dipping or wiping are acceptable procedures.

2. Assemble the Components
The components are assembled with the filler alloy ring in place. There must be intimate contact between the two components to be joined and the alloy ring.

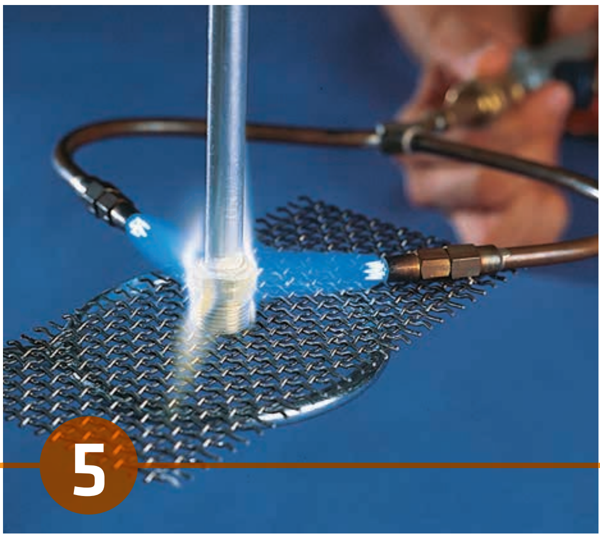
3. Apply the Flux
The flux is then applied with a small brush around the circumference of the joint at a loading of about 25 to 30 g/m^2.

4. Dry the Flux
The flux should be allowed to dry before the application of intense heat to begin brazing. This can be done by allowing the joint to air dry or alternatively by gently heating the surrounding joint area with the flame, which will heat the metal and dry the flux. Intense heat should be avoided before the flux has dried, otherwise splattering and flux fall-off will occur.

5. Heating
Once the flux has dried, more intense heat to begin the actual braze sequence can be applied. The braze flame should not be allowed to impinge on any one area very long to avoid overheating and burnthrough. The component with the higher thermal mass should be heated more. The flame should not be allowed to rest on the flux or preform ring to avoid premature melting before the joint area is uniformly heated to braze temperature. The flame should be kept moving at all times, moving back and forth between the components of different mass in such a way as to

Clean the Components

Assemble the Components



Heating

Melting point

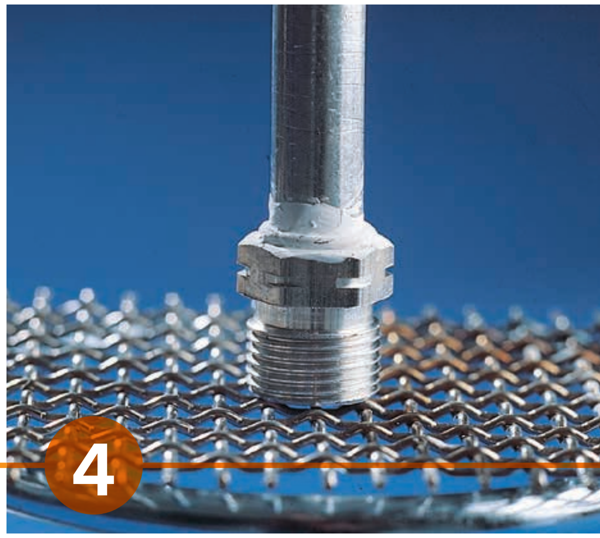
bring the entire joint to temperature uniformly.

There are three temperature indications in NOCOLOK® flux flame brazing. The first is the appearance of a yellow flame at the Al surface. This indicates that the surface is starting to overheat/burn, since the aluminum skin always runs hotter than the component center. The flame must visit the area less frequently to avoid burning. The second indicator is the first sign of flux melting, that is the fluxed area turns from white to clear. This indicates that the joint temperature is about 565 °C. At this point the flames can be played directly on the joint and filler metal ring. Very shortly after flux melting, the filler metal ring begins to loose shape (third temperature indicator) and begins to melt at 577 °C. The molten filler metal is quickly drawn into the joint by capillary action. As soon as the full preform ring is molten, the flame should be quickly removed and the brazed joint allowed to cool.

6. Post Braze Treatment

After cooling, no further treatment is required. The flux, although visible is non-hygroscopic and in standard applications non-corrosive. With the brazing conditions optimized, meaning minimal flux residue, the surfaces can be painted with relatively good paint adhesion over the flux residue. If absolutely desired, the flux residue can be removed, but only by mechanical means such as wire brushing and grit blasting. Removing the flux residue is recommended only when joint cleanliness is absolutely imperative.

Apply the Flux



Dry the Flux

Brazed joint

Alternatives

Fluxing Prior to Assembly

The procedure described above is the most common and reliable method to ensure good quality brazed joints, but is not the only one. For instance with a tube-to-tube joint, with the filler metal ring in place, the flux can be applied to the lower portion of the straight tube prior to insertion in the expanded tube. In this case, a light flux loading around the circumference of the joint after assembly is still required to cover the filler metal ring.

Feeding the Joint with Filler Metal

Another alternative to using a preform ring is to feed the filler metal into the joint with filler alloy wire or rod during heating, after the flux is molten. This method is frequently adopted by brazers who have had experience with choride flux flame brazing or who have welding backgrounds. To the novice brazer, this method is very difficult because the window between when the flux becomes molten and when the flux dries out is very small, when brazing in air. The window of opportunity is in the order of a few seconds and skilled brazers are able to work within this window. By placing the preform ring at the joint prior to heating ensures that the flux will not dry out before the filler begins to melt.

The table below lists the chemical composition and melting point range of common alloys suitable for NOCOLOK® flux flame brazing.

As shown in the Table, alloys that are considered difficult or impossible to braze by furnace methods can be flame brazed. In furnace brazing, Mg diffuses to the surface and reacts with the surface oxide to form MgO and spinels of $MgO:Al_2O_3$, which have reduced solubility in NOCOLOK® flux. Furthermore, Mg and/or MgO can react with the flux, rendering it less effective. The rule of thumb for furnace brazing is to limit the total amount to less than 0.5 wt%-Mg.

In flame brazing, higher Mg levels can be tolerated since the faster heating rates do not allow the diffusing Mg enough time to appreciably decrease the beneficial effects of the flux. Up to 1 wt%-Mg can be brazed with relative ease, while greater than 1 wt%-Mg may be possible under some circumstances (increased flux loadings, extremely fast heating rates).

Alloys suitable for flame brazing

Alloy	**Composition (% By Weight)**							**Approx. Melting Range**	
AA-	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Zn**	**Ti**	**Solidus (C°)**	**Liquidus (C°)**
3003	0.6	0.7	0.05 – 0.20	1.0 – 1.5	–	0.10	–	643	654
1145	0.55 Si+Fe		0.05	0.05	0.05	0.05	0.03	640	655
1070	0.20	0.25	0.04	0.03	0.03	0.04	0.03	640	655
3005	0.60	0.70	0.30	1.0 –1.5	0.20 – 0.6	0.25	0.10	640	655
3105	0.60	0.70	0.30	0.30 – 0.80	0.20 – 0.80	0.40	0.10	635	655
6951	0.20 – 0.50	0.80	0.15 – 0.40	0.10	0.40 – 0.8	0.20	–	616	654
3102	0.40	0.7	0.10	0.05 – 0.40	–	0.30	0.10	645	655
6063	0.20 – 0.6	0.35	0.10	0.10	0.45 – 0.9	0.10	0.i0	616	652
6061	0.40 – 0.8	0.7	0.15 – 0.40	0.15	0.8 – 1.2	0.25	0.15	616	652

Aluminum association alloy composition

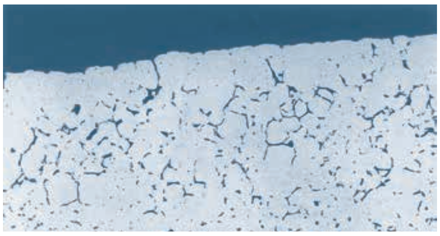
Precaution

Mg containing alloys have lower melting points than those alloys containing very low or no Mg (see Table above). The most common high strength machineable alloys for example are AA6061 and AA6063 which typically contain 1 wt-% and 0.5 wt %, respectively. Note that both of these alloys have a solidus of 616 °C. This means that these alloys, when overheated are prone to incipient grain boundary melting. The effect of overheating manifests itself as degradation of the microstructure and a roughening of the skin, commonly known as 'orange peel' effect. These effects are illustrated in the photomicrographs right.

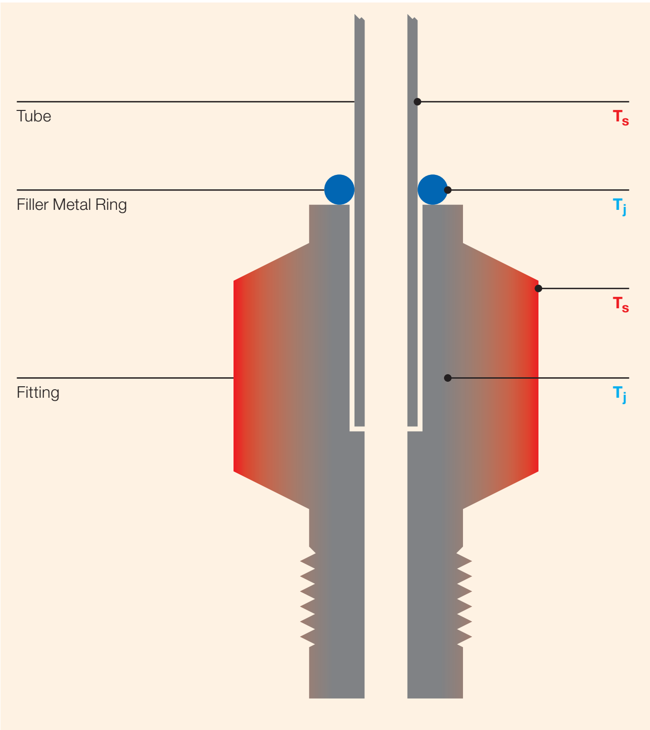
This effect is worse in the outer skin since this area sees a higher temperature (Ts surface temperature) than deeper within the component (Tj joint temperature) as illustrated below. Metallurgical degradation of this type can cause problems with the longevity and suitability of machined surfaces such as threads in fittings.

Cross-Section of As-Extruded and Overheated Machineable Alloys

Heated to 630-°C

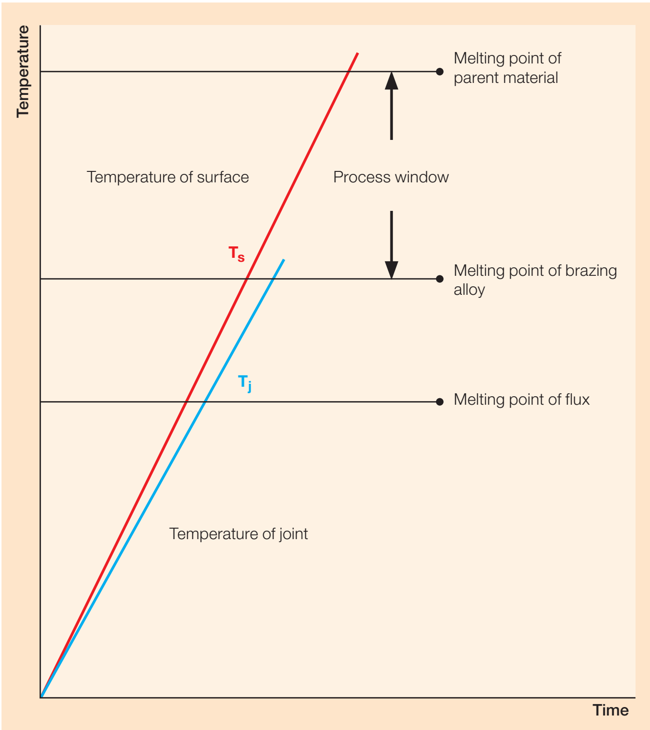


As extruded



Schematic of joint*

* Concept courtesy of Burner Flame Technology, Ltd.



Automation

The procedure described above is for manual flame brazing using a hand held torch and visual indicators (flux melting) for monitoring process parameters. Flame brazing is easily automated and the level of automation can vary between simple shuttle systems to fully automatic brazing carousels including optical pyrometry temperature measurements. Regardless of the level of automation, the principles of manual flame brazing still apply.

Shuttle Systems

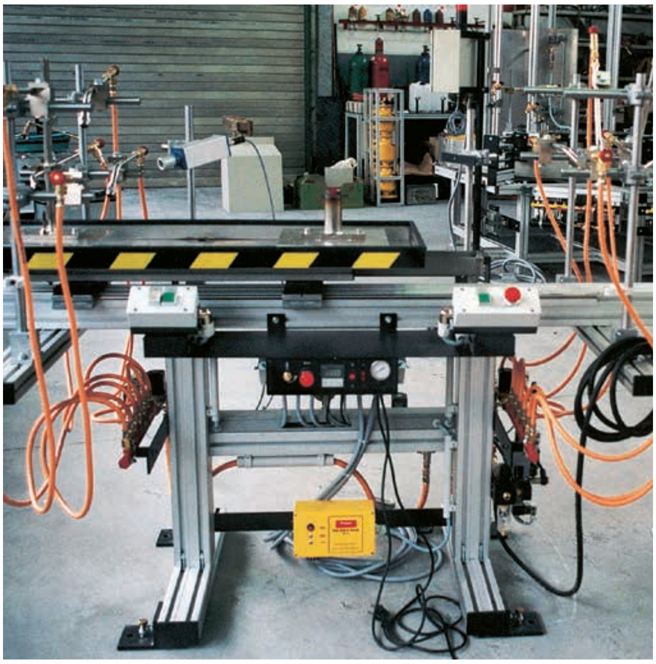
The shuttle system consists of a framework on which one or two components requiring brazing are mounted where the motor driven framework laterally shuttles the braze joints between one or two braze stations each equipped with opposing flames (the equivalent of a double headed torch). The shuttle is usually configured such that one or two new components requiring brazing can be installed on the return of the shuttle to its original position and the brazed units unloaded.

Carousels

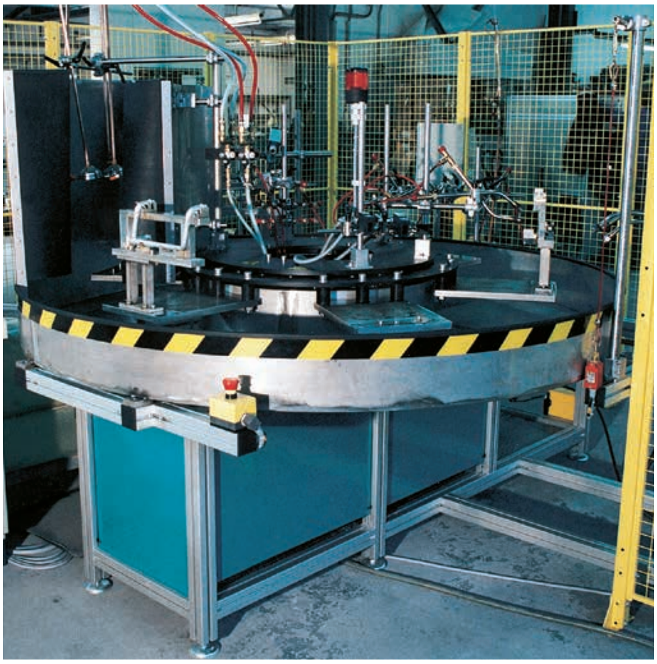
Flame brazing carousels are at the upper level of automation. The carousels move assembled components to be brazed continuously from flame station to flame station arranged in a circular pattern (hence the name carousel). Usually, each flame station consists of twostationary and opposing torches between which the joint to be brazed is indexed. As the component moves from station to station, the joint temperature gets progressively hotter. The number of stations depends on the joint configuration and weight. The joint is thus uniformly heated to brazing temperature. The last station where brazing takes place may be equipped with an optical pyrometer to monitor braze joint temperature. After brazing, the joint may be cooled by air or water spray. Other options include automatic application of filler metal and/or dispensing of flux (filler metal ring, flux/brazing paste).

Optical Pyrometry Measurements

Automatic flame brazing carousels are often equipped with infra-red pyrometers to measure the temperature of the braze joint area. The information is fed to a computer and the computer 'tells' the torches to flip away from the joint when the proper temperature is reached. The pyrometer however cannot determine an absolute accurate temperature. As aluminum heats up, the oxide layer changes and therefore the emmissivity of the surface changes and it becomes difficult to modify the pyrometer to track these changes dynamically. It is possible to get reproducible accurate relative temperatures of the heat affected zone, but not of the joint itself. In other words, optical pyrometry measurements can be used to monitor the consistency of the brazing process from part to part (for the same given part), but the information by itself for a single part would not be that useful.



Shuttle system



Carousel

* Photos from Everwand & Fell

Bimetallic Joining

Flame brazing aluminum to another metal such as bronze, copper, steel and stainless steel is possible, but requires special care and attention. Dealing with all Al-metal combinations in detail is beyond the scope of this brochure, but a few comments on Al-Cu joining is noteworthy, since this combination is common in the refrigeration industry (copper tube to aluminum roll-bond panel, for example).

There is a eutectic between Cu and Al at 548 °C. When the flux melts and the surface oxides are removed, inter-diffusion of Al and Cu is rapid and unavoidable. This means that at braze temperature, the Al and Cu materials are quickly consumed to form the eutectic metal. Management of time and temperature is critical to minimize the inter-diffusion and metal consumption. There is an advantage however. Since filler metal is created in-situ, there is no need to supply filler metal to the joint. The only requirement is that the design of the joint allows metal consumption without sacrificing joint integrity.

From left to right: Al-Cu, Al-stainless, Al-brass and Cu-Al

Conclusions

From the preceeding discussions, it is evident that NOCOLOK® flux flame brazing is not a complicated process and that if the fundamentals of manual brazing are followed, any level of automation can be achieved. The most important aspects of the discussion are as follows:

- NOCOLOK® flux melts just before the filler metal temperature.
- Once molten, the flux remains active only for a short period before drying out.
- Preplacing the filler metal in the joint is preferred, but with some skill may be fed into the joint after the flux melts.
- Temperature uniformity is critical and excessively high surfaces temperatures must be avoided.

NOCOLOK® CREATING INNOVATIVE FLUXES

FOR JOINING ALUMINIUM

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