

Frequently asked questions #7

Can aluminium be successfully vacuum-brazed?

Essentially the answer is 'yes', but there are severe limitations on the type of components that can be processed. However, to understand the problems that are inherent with this process it is first necessary to take account of the probable procedures that are involved in the removal of the surface oxides.

The mechanism of oxide-film removal in vacuum brazing

As is well known, one of the fundamental criteria that determine the successful outcome of any brazing operation is that the mating surfaces of the joint are substantially free from oxide films when the brazing alloy melts and flows. Vacuum brazing is no different in this respect to any other brazing procedure; oxide-film removal has to be achieved *before* the production of a satisfactory joint can be achieved!

The oxide removal processes in vacuum brazing only begin to operate at relatively high temperatures, indeed this consideration dictates the lower limit of the brazing temperature that can be used in any particular case since the surface films on the parent materials must be removed before wetting and flow can occur. When the heating cycle begins, and during the time where the temperature of the parts is too low to initiate 'clean-up', the films that are already present on the surfaces of the parent materials increase in thickness as they react with the residual gases in the furnace chamber. As might reasonably be expected, this is because the residual trace of the atmosphere found within the furnace almost always contains both oxygen and water vapour!

For example, during a 'normal' vacuum-brazing cycle, hitherto 'bright and shiny' stainless steel often loses its brightness and becomes grey in colour between about 600 and 850°C! In consequence when the temperature in the furnaces reaches a level where the 'cleaning action' begins it is clear that quite a lot of work has to be done to reach a level of surface cleanliness where brazing will occur. Experience proves beyond any reasonable doubt that the *cleaner* the residual atmosphere during the warming up procedure the *lower* is the temperature at which brazing will occur. For example, 304 stainless steel can, with a suitable filler material, be brazed at a temperature as low as 900°C in a 'super-clean' furnace. More often, however, the reality is that the temperature has to exceed 980°C before brazing will occur. (A similar situation exists where humpback furnaces operating under a reducing atmosphere with a dew point of around -50°C is required to braze 304 stainless steels. Here it is often the case that the lowest temperature at which brazing will occur is of the order of 1105°C!)

The question that has to be asked is how, in a vacuum-brazing situation, and also for that matter under an atmosphere of an ultra-pure inert gas, is the removal of the oxide-film achieved?

The suggestion that the films either volatilise or dissociate cannot be totally supported in the light of well-established thermodynamic information. However it is an inescapable fact that brazing can be achieved in vacuum furnaces when the degree of vacuum attained does not begin to approach that necessary to permit dissociation of the oxides on the surfaces of the parent metals and filler material.

One suggestion is that the parent materials dissolve the films. This might be true in some cases, but not in others, since there are some parent materials that can be satisfactorily vacuum-brazed but which are only capable of dissolving oxygen to a very limited extent.

Yet another explanation of oxide-film removal is that the molten filler material penetrates the oxide skin through discontinuities. The source of the discontinuities might be due to some of the film being taken into solution in the parent material. Another possibility is that the

discontinuities are formed as a result of differential expansion between the parent metal and the oxide-film. In general terms the expansion coefficient of most metals is typically 4 to 5 times greater than that of the oxides present on their surfaces. If this reasoning is correct it is clear that once the discontinuities appear the fact that there is no oxygen in their vicinity to 'heal' them would provide a reasonable explanation of the phenomenon. Having passed through the discontinuities in the oxide-film the molten filler material would wet the substrate and flow. This flow would promote the situation where the film would simply be 'floated off' on the surface of the advancing front of molten filler material!

The reality is that it is almost certainly the case that there are a number of interacting parameters at play, these, in combination, producing the desired end-result. Various parameters, such as temperature and the chemical composition of the parent metals and filler materials determine whether, once through the oxide film, the metallurgy of the situation favours liquid flow beneath the surface film. It is also clear that the degree of residual oxygen in the furnace chamber also has a major influence on the effective rate of alloy penetration through the film since the amount of oxygen is a controlling factor in the rate of 'healing' of any discontinuities that are produced in the oxide layer.

It is therefore clear that in vacuum-brazing there is a limiting pressure **above which wetting will not take place**. This varies quite considerably, depending upon the composition of the residual atmosphere and the oxide-forming constituents present in both the parent materials and the filler metal. There is, however, a substantial body of evidence that suggests that *many* of the commonly used engineering metals, other than those which contain even only modest quantities of the refractory elements, (aluminium, for example!), can be vacuum brazed once the pressure in the furnace falls below about 1×10^{-3} torr.

Vacuum Brazing Aluminium

The vacuum brazing of aluminium is not as widely practiced as the NOCOLOK® CAB furnace process and, in essence, that which is still undertaken is a remnant from the procedures that were first developed in the 1970's by the US automotive industry. As mentioned in Chapter 9 of, *Industrial Brazing Practice*¹, vacuum brazing of aluminium is normally undertaken with an alloy that conforms to either **EN1044 Type AL301 or AL302**. Both these materials contain between 1 and 2% magnesium. This element volatilises during the brazing process and the resultant magnesium 'cloud' acts as a 'getter' for the residual traces of oxygen present in the furnace at brazing temperature.

Because the temperature at which the brazing of aluminium must be carried out is never greater than about **630°C**, and since aluminium is an enthusiastic seeker of oxygen, it automatically follows that the partial pressure of any residual oxygen in the furnace when aluminium is to be vacuum-brazed must be exceedingly small. This can only be achieved by pumping the air out of the furnace, and then carrying out a series of gas-sweeps by back-filling the furnace with ultra pure dry argon in order to flush out any final traces of air from the furnace and **particularly** from the vicinity of the joints that are required to be made.

Remember, trace quantities of oxygen will react with the parent material to produce more oxide, so it is obviously desirable that after the furnace is loaded and the door closed that the gas-sweep cycle is initiated while the furnace is 'cold'. However, that is not the end of the affair. At the conclusion of the 'cold' gas-sweep programme, and heating is initiated, out-gassing will occur, and this will result at least some oxygen being released into the furnace chamber. Thus, before the filler metal melts it will be necessary to maintain the furnace at a set temperature, and then carry out a further series of gas-sweeps in order to remove the products of out-gassing. Even when following such a complicated process cycle, in order to have any realistic chance of success with the brazing operation it is necessary to pump-down to a pressure of at least 1×10^{-6} torr, and probably lower. This means a very sophisticated pumping system that will incorporate both rotary vane pumping and a diffusion pump, and clearly the vacuum chamber **must be 100% leak-free**.

¹ *Industrial Brazing Practice*, P.M.Roberts, CRC Press, 2004

Clearly, with such a low brazing temperature, **630°C**, the amount of differential expansion between the parent material and its oxide coating will be small, this inevitably meaning that the size of any stress-ruptures in the oxide film will also be quite small, and so relatively easy to heal in the presence of even only very minor traces oxygen. It is not unknown, and even for simple parts where, for example, one might be brazing a tube to a fitting, when vacuum brazing of aluminium the assembly is shrouded by the impervious shield provided by a Fiberfrax blanket. This blanket ensures that the magnesium that volatilises is kept in relatively close proximity to the work, so being readily available to react with any trace quantities of oxygen still remaining in the furnace at brazing temperature. It seems improbable, however, that such a procedure would be effective for the brazing of plate exchangers where internal joints need to be made.

That vacuum brazing using magnesium-bearing filler materials can provide acceptable results for simple tube-to-socket joints in not in question. However, from the point of view of economics and the attendant problems of ensuring that the interior of assemblies that contain, perhaps, hundreds of joints that must all be shrouded by the 'cloud' of magnesium evolved from the filler material during the brazing process in order to ensure that the filler metal will flow, and make the joint, the use of vacuum brazing for use with aluminium is very often fraught with difficulties!

Last but not least, it has to be remembered that the presence of the magnesium 'cloud' in close proximity to the joint is a *fundamental* requirement for successful brazing to occur. There is little doubt that pumping must continue during the entire process cycle in order to deal with any out-gassing that occurs at temperatures up to **630°C**. This parameter will mean that there will be a high probability that the magnesium 'cloud' will be removed from the furnace, and as the magnesium departs from the vicinity of the joints the probability of the production of satisfactorily brazed joints diminishes.

The implications of these parameters speak for themselves, and are at least part of the reason why vacuum brazing is not considered to be the 'best practise' process when aluminium radiators are to be brazed.

Possible Process Cycle

It is reasonable to describe vacuum brazing as a 'batch' process. In general terms the process will broadly follow the profile shown in **Fig 1**

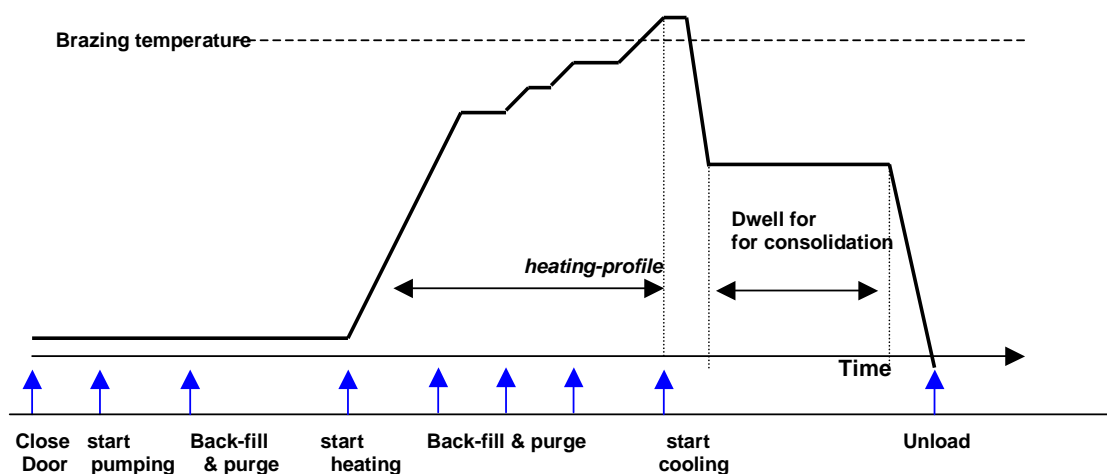


Fig 1: A possible temperature-time profile for a vacuum-brazing cycle

The overall process cycle will comprise most, if not all of the following procedures;

- The parts are loaded into the furnace chamber,
- The door of the furnace is closed,
- The pumping system is started,
- When a sufficient level of vacuum is achieved the furnace must be 'back-filled' with an inert gas in order to assist in 'flushing out' any residual air from the capillary paths of the part to be brazed,
- Pumping continues, and the 'back-filled' inert gas is removed from the chamber. (This process-cycle might be repeated a second, or even a third time dependent upon circumstances!)
- Heating is initiated, and at a temperature of around 500°C the furnace is held at this temperature and a further series of 'back-fills' and 'pump-outs' are undertaken to remove the products of out-gassing.
- The parts are subsequently raised to brazing temperature. (This may be achieved by continuous heating, but more likely by the application of a 'heat and dwell' programme to ensure that parts of differing weight attain brazing temperature simultaneously.
- Cool in order to solidify the filler material. Cooling might be initiated by simply switching off the power fed to the heating elements of the furnace, or perhaps accelerated by 'back-filling' the furnace chamber with a cool inert gas which is then re-circulated over the parts and through a heat-exchanger. The cooling procedure may continue smoothly to room temperature, or in other cases may be interrupted at a predetermined point in the cycle, and held at that temperature, in order to permit diffusion heat treatment of the joint to be achieved
- Once the parts have reached room temperature, destroy any vacuum that is remaining, open the door, and remove the brazed components.

As can be seen the process is quite complex, and because of the low temperature at which it is undertaken, coupled to the need to ensure that the joint-areas are shrouded with the 'magnesium cloud' when the filler metal melts and flows, the probability of successfully brazing complex aluminium alloy parts is remote!

Clearly, depending upon the complexity of the furnace, and its control systems, some quite complex furnace cycles can be employed. However it also has to be understood that irrespective of the complexity the procedure is still only a 'batch process' and, as such, is commercially uncompetitive compared with the use of a Continuous conveyor furnace operating in accordance with the Nocolok® Process.

N.B. One would do well to remember that for the mass-production of complex parts that are fabricated from aluminium and its alloys, (radiators, evaporators and condensers, for example), the totality of the parameters mentioned above explain why the use of vacuum brazing almost always tends to be avoided!

©Nocolok is a Registered Trade Mark of Solvay Fluor GmbH.

End of text

EABS/P.M.Roberts/May 2009

www.delphibrazing.co.uk

(2285 Words)

The author and EABS hold the Copyright to these notes jointly