Brazing aluminium

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Both aluminium and aluminium alloys can joined in a reliable and economical way using brazing techniques. The most important brazing techniques are outlined here. The most modern trend-setting technique is inert gas brazing. The quality and economy of brazing can be further improved by using brazing alloys such as modern pastes in combination with tailored application methods.

The increasing use of aluminium metal is a result of its special properties which allow a wide range of alloys having very different properties to be manufactured. Along with welding, brazing is becoming an ever more important technique for joining materials. Many products made of aluminium and aluminium alloys can only be economically manufactured using brazing techniques. The brazing techniques which are currently used will be discussed in detail below.

Material properties of aluminium

Soft ductile aluminium is covered with an oxide layer which has a hardness significantly above 4000 Mpa, thus far exceeding the hardness of heat-treated steel. This oxide layer also has a very high resistance to chemicals. This closed colourless layer is the reason for the high corrosion resistance of aluminium and its alloys in air. At the same time however this stable oxide layer puts high requirements on any joining technique, as pure aluminium melts at 660°C and most aluminium alloys melt in the range between 500 and 660°C. In contrast, aluminium oxide only becomes liquid at temperatures above 2000°C. In the potential series of metals, aluminium has a more negative potential than the heavy metals. Even zinc, which in contrast to steel can act as a sacrificial anode and which is hence used for corrosion protection, is somewhat more noble than aluminium. For that reason, combinations with heavy metals are always a problem from a corrosion point of view. Aluminium alloys which contain heavy metals general have lower corrosion resistance than pure aluminium.

Brazing alloys

Heavy metal brazing alloys cannot be used for brazing aluminium due to the melting point of aluminium and its alloys and due to the required corrosion resistance of the brazed joint. As a result, brazing alloys based on aluminium, containing no or very small quantities of heavy metals and at least 70% aluminium, are employed. There are hence alloys which themselves have to be regarded as aluminium alloys and which often have melting point intervals in the range of the aluminium brazing alloys which are used. Brazing alloys in the aluminium-silicon system with silicon contents between 7% and 13% have proven successful from strength and corrosion-chemical points of view. These alloys have melting temperatures in the range between 575°C and 615°C. A standard product here is brazing alloy AL 104 having a melting interval from 575 - 585°C. The working temperature of this brazing alloy is 585°C. Joints made with this brazing alloy show good corrosion resistance. As the base material may not be melted during brazing, only materials having melting intervals above the processing temperature of the brazing alloy (minimum temperature which is required for brazing) can be brazed with this brazing alloy. As a result, it is predominantly pure aluminium and aluminium alloys with melting intervals above 640°C which are brazed. In practice this means that chiefly pure aluminium and AlMn 1 materials are brazed.

An overview of aluminium alloys which are suitable for brazing and those which are not is given in Table 1.

Table 1: Overview of the suitability of aluminium and aluminium alloys for brazing (from the Aluminium Pocket Book)

Material type	Brazing	Soldering	Comments
Forged materials : pure and super-pure aluminium	suitable	´ suitable	
AlMn	suitable	suitable	
AlMg	conditional	gut	Mg concentrations > 0.6% make wetting more difficult
AlMgSi	suitable	suitable	Remember strength decrease! After brazing, hardening is possible
AlCuMg AlZnMg AlZnMgCu	not suitable	possible	Brazing causes irreversible damage to materials, soldering causes a considerable strength decrease
Cast alloys	see comment	conditional	Brazing difficult with AISi brazing alloys standardised in Germany, as the solidus temperature of the base material is exceeded. In the USA, brazing alloys of the type AlSi10Cu4 (4145) and AlSi10Zn10Cu4 (4245) are available, with solidus temperatures of 520°C and 515°C respectively.

Process engineering considerations for brazing aluminium

In addition to a suitable brazing alloy, for brazing one also requires a medium which removes the surface oxide from the base material and keeps this surface bare during the brazing procedure. As well as inert gases and fluxes, a vacuum is also considered a medium. In order to understand the effectiveness of each medium, the specific properties of the aluminium oxide skin must once again be considered in detail. Aluminium has a very high affinity for oxygen. That's why aluminium is always covered with an oxide skin in air. This skin is uniform and has few pores, so protecting the aluminium against further corrosion, e.g. against air and industrial atmospheres. The bare aluminium facades of many buildings are testament to this. The oxide skin must however be removed for brazing work and there are three possibilities for achieving this:

1. Dissolution of the oxide skin
2. Reduction of the oxide skin
3. Mechanical rupture and removal of the oxide skin

During the brazing process, the aluminium oxide skin must not re-form.

Vacuum brazing

The unique feature of vacuum brazing is that the aluminium oxide cannot be removed by the vacuum. The mechanism of the brazing process is as follows: The coefficient of expansion of aluminium is about three times as great as that of aluminium oxide. That's why the oxide layers crack up on heating and the liquid brazing alloy can pass through these cracks down to the bare base material. The aluminium oxide layer becomes mechanically detached. Oxidation of the aluminium in the cracks during the heating phase can only be prevented if the atmosphere is completely devoid of oxygen. As a result, there is not only a minimum requirement put on the level of the vacuum (10^{-4} mbar or better) but in addition getter-materials must be used to scavenge the last oxygen atoms from the atmosphere around the component to be brazed.

It must be clear that although feasible such a process is difficult to carry out. That's why vacuum brazing is a less commonly employed technique than brazing with fluxes.

Brazing techniques using fluxes

Fluxes

DIN EN 1045 makes a clear distinction between two flux types which are described in the standard as follows:

1. Type FL 10
These fluxes contain hygroscopic chlorides and fluorides, especially lithium compounds. The residues are corrosive and must be removed by washing or scouring.

2. Type FL20
These fluxes contain non-hygroscopic fluorides. The residues are not corrosive and may remain on the workpiece,

although the brazed joint should be protected against water and moisture.

The advantages and disadvantages of the respective fluxes are summarised in Table 2.

Figure 2 depicts the key differences between the two types of fluxes.

Table 2: Comparison of the advantages and disadvantages of the flux types

	Advantages	Disadvantages
FL 10 (chloridic and hygroscopic type)	Effective above 500°C High effectiveness. AlMg3 can also be brazed. Components are clean after washing. Scouring after washing possible to improve appearance.	Residues are very corrosive. Residues must be washed off. Wash-water must be disposed of (expensive). Scouring seldom carried out as complex and hence expensive. High emissions in exhaust air / into the environment.
FL 20 (non-chloridic, non-corrosive)	Residues not corrosive. No washing required after brazing (one less process step). No wash-water to dispose of. Higher degree of crack filling. Very low loads on the brazing furnace. With inert gas considerably lower consumption (ca. 20% of the amount of air used for FL 10).	Effective from ca. 570°C, Salt residues on the component (visual). Effectiveness somewhat less than FL 10. AlMg can only be wetted for Mg concentrations up to 0.9%. Virtually no impact on the environment.

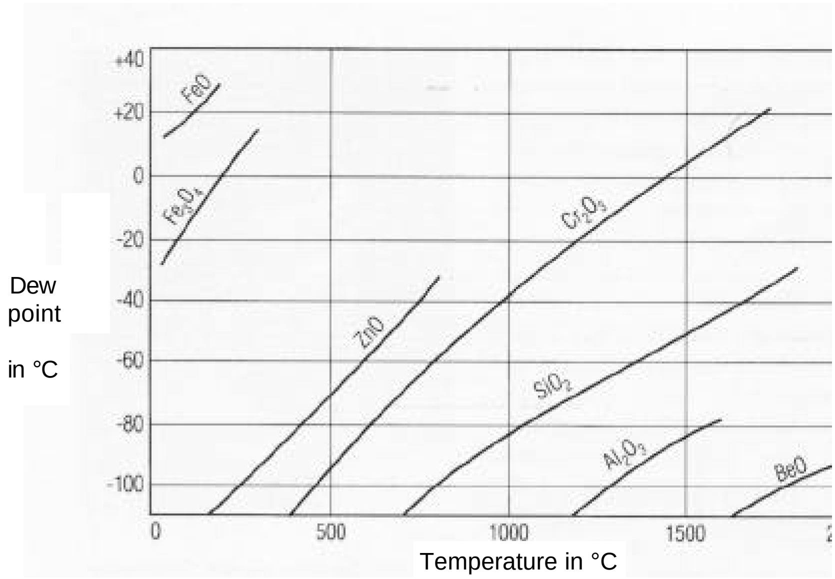

Figure 1: Metal / metal oxide equilibria in hydrogen (Graphs: BrazeTec)

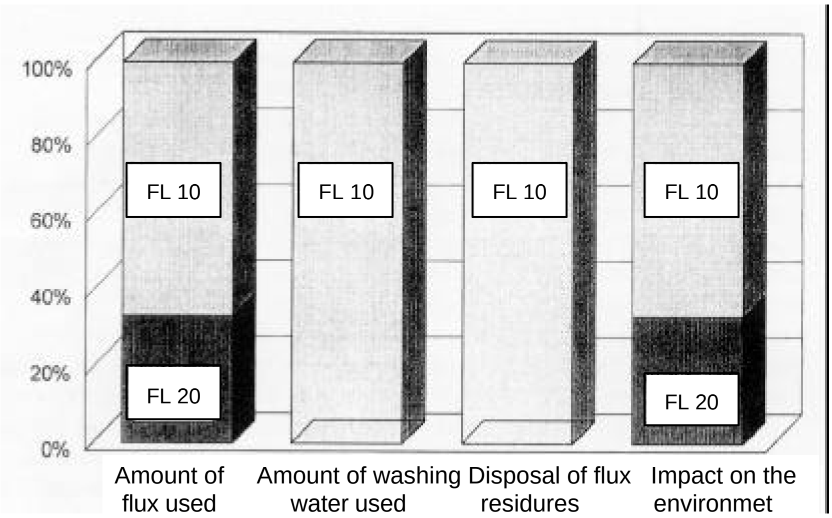

Figure 2: Differences in the application of aluminium-fluxes

Flame brazing

In flame brazing, the components are heated to brazing temperature with the burner. Natural gas, sewer gas, propane and acetylene are used as fuel gases. The fuel gases are combined with drawn-in air, compressed air and occasionally also with oxygen.

In manual burner brazing, the area of the component to be brazed is applied with flux. After melting the flux, the brazing alloy is usually applied as a rod and melted. However, moulded brazing alloy components are also used for manual brazing. For brazing bulk quantities of items, burner-heated brazing machines have been increasingly used in recent years. The brazing procedure is similar to that used for manual brazing, except that moulded brazing alloy components are however more widely used. Brazing alloy pastes are often used in brazing machines, provided that the geometry of the components permit their use. When brazing with alloy pastes, there must be a facility for storing the pastes.

In addition, special attention must be put on the heat transfer, as paste-brazing is sensitive to inadequacies in the heat transfer. Pastes are basically mixtures of brazing alloy powder, flux and an organic binder. The function of the organic binder is to make the mixture of brazing alloy powder and flux into a form which can be dosed. Special properties are however required of the paste-binder, for example it must remain at the brazing joint until the flux melts and then it must burn off / evaporate to leave no residues after reaching the brazing temperature.

Pastes can contain both corrosive and non-corrosive fluxes. For flame brazing, pastes with corrosive fluxes are still predominantly used today. This is largely because optically bare components which are attractive in appearance are desired and this is achieved due to the fact that the flux residues are water soluble. This contrasts with the non-corrosive fluxes which cover the brazed joint with an even film of salt.

Induction brazing

Induction brazing of aluminium is virtually only used for brazing compensating bases. The brazing of compensating bases involves connecting an aluminium plate to a chromium-nickel steel cooking pot. The brazing is carried out as follows:

The flux is added to water or a water-alcohol mixture in ca. 1:1 to 1:2 ratio to form a paste. This paste is applied with a brush to the compensating base. Brazing alloy grains of type AL 104 (grain size 100- 315 pm) are then strewn over the compensating base. Thereafter, both components are accurately joined in a brazing press. A medium frequency induction coil is built into one of the two press rams. The component is heated to brazing temperature by the medium frequency current.

After melting of the brazing alloy, a defined pressure is applied which presses the compensating base firmly onto the cooking pan base. The current is then switched off and the brazed joint is cooled down in the pressed state.

After solidification of the brazing alloy the finished pot is removed from the press and then cleaned to remove any flux residues. Unevenness of the brazing alloy fillets is worked over on the lathe using a stylus. Non-corrosive flux is exclusively used for this brazing work, to an increasing degree in the form of brazing alloy paste. As already mentioned, this contains the brazing alloy and the non-corrosive flux and is applied evenly by brush to the round plate. As the paste already contains brazing alloy, no brazing alloy powder has to be strewn onto the component. A processing stage is hence saved.

Salt-bath brazing

In salt-bath brazing, the assembled components are dipped into the molten flux. In general, in-laid moulded brazing alloy are used. The advantages of the method are as follows:

- The dipping into the molten flux saves a separate flux application procedure.
- Heat transfer is very uniform, meaning that thin-walled, complex-shaped components can be processed. It is possible to meet narrow manufacturing tolerances.
- As in furnace brazing, many joints in close proximity can be brazed in one work stage.
- Due to the beneficial effect of the molten flux bath with uniform heat transfer, this has proven especially successful for brazing thin-walled components such as radiators, convectors, etc.

A disadvantage is that this process has a large impact on the environment. Not only are corrosive vapours produced but relatively high amounts of flux are used. As corrosive fluxes are usually employed, large amounts of wastewater are produced and this must be disposed of at considerable cost/time. This brazing process is hence losing favour.

Open furnace brazing

In open furnace brazing, predominantly brazing alloy plated components are processed, although the use of moulded brazing alloy components is standard. The brazing joints are wetted with flux and then the component is passed through the furnace. As the brazing is carried out in air, a corrosive flux must be used for this brazing process. As a consequence, corrosive vapours which can destroy the furnace in a short time are produced. Chromium-nickel steel muffles (expensive) are used to protect the furnace. These protect the furnace lining and heating elements against the flux vapours.

If in constant operation, such muffles can however be destroyed within 6 months. In addition, extraction and neutralisation of the vapours is also necessary. After the brazing, the flux residues must be thoroughly washed off the components.

Open furnace brazing is being used less and less due to the high impact on the environment, cost of the muffles and necessary disposal of wastewater.

Furnace brazing under controlled atmospheres

Figure 1 shows that reduction of the aluminium oxide layer is not possible at brazing temperature, even in pure hydrogen. It is hence necessary to use fluxes, even in inert gas atmospheres. However, only the non-corrosive type are employed. The most commonly used inert gas is nitrogen, although nitrogen/hydrogen mixtures are also used.

Hydrogen-containing inert gas atmospheres are principally used when for example aluminium must be brazed to chromium-nickel steel (Figure 3). The technique has a number of advantages:

- Compared to open furnace brazing considerably less flux is used.
- The furnace muffle can be made from a standard steel and has a lifetime of considerably more than 1 year.
- In this method only small amounts of salt residues remain on the component.
- Neither a washing stage nor other post-treatments are required after brazing the components.

The components are first of all degreased. This can be achieved using organic solvents, alkaline cleaning agents or preferably heat treatment between 150°C and 250°C. After degreasing, the component is sprayed with a flux suspension.

The concentration is normally between 5% and 10%. Excess suspension is blown off and the component is then dried in a continuous oven at ca. 500°C.

Alternatively, other techniques are common in which flux powder is applied to the pre-heated component (a new development).

The actual brazing process is carried out after applying the flux in such a way that the component can be passed through an inert gas furnace. This is „closed“ from external air by glass fibre curtains in such a way that the components can travel in and out without undesired air entry into the furnace. The water vapour concentration of the inert gas which is used and the oxygen concentration is < 100 ppm. After leaving the treatment furnace, the components are finished and can be removed from the conveyor belt. No further treatments are required (Figure 4).

Figure 3: Paste-brazing of a continuous heater (aluminium to nickelised steel) in an inert gas

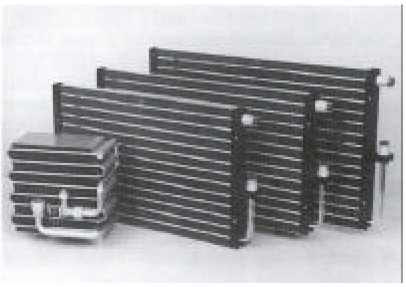

Figure 4: Aluminium radiators brazed in an inert gas and painted; in the foreground an aluminium evaporator (brazed and chromated)

Outlook

Of the brazing techniques mentioned, furnace brazing in a controlled atmosphere represents the most important technique today. This technique has cost benefits as much lower amounts of flux are used. There is also considerably less impact on the environmental compared to open furnace brazing and salt-bath brazing. This technique will hence assume ever more importance in the future.

Brazing results can be optimised in many cases by using pastes. However in many cases considerable efficiency improvement is possible.

Modern production processes have already switched over from separate manual addition of brazing alloys and fluxes to fully automatic dosing of pastes. The application of pastes is also favoured by new application methods.

BrazeTec GmbH has patented a process under the name "BrazeSkin" which allows the application of uniform thin layers of brazing alloy. This is also possible on components having complex geometries. In many cases, only a single application stage is required for several brazing positions on a component.

The thin uniform distribution of the brazing alloy also reduces the tendency of the base material to alloy during the brazing process.