Brazing Principles

History

The process of brazing has been known for at least 5000 years and must be one of the oldest of all known metal joining techniques. Brazing was practised in Sumeria as early as 3000 BC, and by 1500 BC the brazing skill of the Egyptian court jewellers had reached a level of excellence which was the equivalent of anything hand-brazed today. From Egypt, the craft spread along the trade routes eastward into India and China, north-west into the Mediterranean area and through Anatolia into northern and western Europe.

The early uses of brazing were limited to the fabrication of ornaments and jewellery, and it is not until the mid-nineteenth century that regular references to the use of the process of industrial manufacturing operations can be found. Since the turn of the century, the use of brazing has increased at a rapid rate to the present situation where some three million joints are brazed daily in the United Kingdom alone.

In recent years, the automation of the brazing process has allowed this process to be applied to many mass manufacturing operations.

Definitions

What is brazing?

Brazing is a joining process wherein metals are bonded together using a filler material with a melting (liquidus) temperature greater than 450°C (840°F), but lower than the melting temperature of the base metal.

The molten filler metal is drawn into the space between the closely adjacent surfaces of the parts to be joined by capillary attraction.

How is soldering different from brazing?

Soldering is a joining process wherein metals are bonded together using a non-ferrous filler with a melting (liquidus) temperature lower than 450°C (840°F). Whenever the filler metal liquidus is greater than 450°C (840°F), the joining process is considered to be a brazing process rather than a soldering process.

How is brazing different from welding?

Welding is a joining process wherein metallic components are joined through fusion (melting) or recrystallization of the base metal by applying heat, pressure or both. This process differs from brazing, where only the filler metal melts during processing.

'Solidus', 'Liquidus' and 'Melting Range'

The temperature at which a brazing alloy can be used to produce a joint must be higher than that at which the alloy becomes molten. Thus, the melting point of an alloy is of primary importance.

In most cases, brazing alloys do not have a single melting point, but melt over a given temperature range. The temperature at which the alloy begins to melt is called the 'solidus', and the temperature at which the alloy becomes fully molten is called the 'liquidus'. The temperature interval between the solidus and the liquidus temperatures is called 'the melting range' of the alloy.

Working temperature

As already mentioned, once a brazing material is heated to its solidus temperature, it begins to melt. As the temperature is gradually increased, more of the alloy becomes molten until, at the liquidus temperature, the alloy is 100% liquid.

Thus, throughout the melting range of the alloy, the relative proportion of the liquid phase to the solid phase increases as the temperature rises. To produce a brazed joint, the brazing alloy must be sufficiently fluid to be drawn into a capillary gap. With most alloys, this point of 'sufficient fluidity' is reached at a temperature which is above the solidus of the alloy, but below the liquidus. This temperature is known as the 'working temperature' of the brazing alloy.

Probably the best known example of working temperature is provided by the Phos series of alloys produced by Thessco Limited. Here, the solidus is about 645°C, and the true liquidus in the region of 800°C, but dependent on the composition of the alloy, the working temperature can be a low as 700°C. This means that the material is sufficiently fluid at that temperature to permit normal capillary flow to occur.

Capillary attraction

It is fundamental to the brazing process that the brazing material is drawn by capillary attraction into the joint; this progressively displaces flux, gases etc. and ensures maximum joint soundness. The physics of capillary attraction are quite complex, but it can be summarised as:

'The capillary flow of a molten brazing alloy is dependent on the ability of that alloy to 'wet' the parent metals to be joined'.

Many factors influence the wettability of a brazing alloy onto the parent metals to be joined, but probably the most important of these is surface cleanliness. Not only should surfaces be free from contaminants as assembled, but must also be maintained in this condition (at least in the immediate joint area) until flow of the brazing alloy is completed. This is achieved by the use of a suitable protective environment whether it be an inert or reducing gaseous envelope, or more commonly, an active flux layer.

Liquidation

The fact that the majority of filler materials used in brazing do not have a single melting point can be a source of trouble. This is particularly true of those brazing alloys which have a long solidus-liquidus interval (in excess of 70°C for example), and where it is desired to use these materials as pre-forms for the joining of relatively large parts. In these conditions, it is clear that the time taken to heat the brazing alloy from its solidus to its liquidus temperature will be long, and it is this factor which may give rise to concerns.

When silver brazing alloys begin to melt, the first parts to become molten are relatively richer in silver, zinc and cadmium than the starting material. This results in the remaining solid portion being relatively richer in copper. If this alloy is in contact with the mouth of a capillary joint, the liquid will be drawn into the gap and the solid portion, denuded of its low melting point constituents, will no longer have the liquidus temperature of the starting material. This phenomenon is known as liquation. In order to cause the remaining solid portion to melt, it must be heated to a much higher temperature than the original liquidus of the alloys being used. Consequently, in any brazing operation where a slow heating rate is likely to be encountered (in furnace brazing or where the parts have a high thermal mass, for example), it is necessary for alloys with short ranges to be used.

Heat sources for brazing

Torch brazing

A heating source supplied by a fuel gas flame. Gases include butane, acetylene or propane. This brazing typically uses copper phosphorous and silver brazing filler, versatile for single or large numbers of joints, but operator sensitive.

Induction brazing

Electric coils, which are designed for specific joint geometries, are used to heat the part and the brazing filler material until the liquid metal flows via capillary attraction into the joint. This process is primarily used for brazing with copper phosphorous and silver alloys. This offers rapid heating cycles, particularly on ferrous metals.

Continuous furnace

Conveyor belts transport the pre-alloyed components through pre-heating, heating and post-heating zones, where the braze alloy reaches temperature, then re-solidifies during cooling. Silver and copper phosphorous based brazing filler materials are most commonly used in these processes. This offers high throughput rates with flux-free brazing in many cases.

Retort or batch furnace

The furnace used can be refractory lined and heated by gas, oil or electricity. Atmospheres can be either generated gas (endothermic or exothermic) or an inert gas such as argon or nitrogen. Hydrogen gas is also used for brazing filler metals that oxidise in other atmospheres. Copper phosphorous and silver brazed filler metals can be brazed successfully in these types of furnaces.

Vacuum furnace

A furnace with electrically heated elements that surround the workload and heat the brazing filler metal to the liquidus state so flow and capillary attraction are achieved. To permit brazing of alloys that are sensitive to oxidation at high temperatures, a pumping system is employed that removes oxygen.

Vacuum brazing has limited applications for copper phosphorous and silver brazing alloys.

Flux

The correct choice of flux is the key to good brazing practice and many problems arise from the incorrect selection or ineffective application of flux. A good match between the flux and the brazing alloy/parent metal combination is essential if strong sound joints are to be produced.

The flux layer performs the critical function of cleaning and protecting the surface of the parent metal during brazing, and so facilitates the wetting and flow of the brazing alloy. Not only is it important that the proper flux is selected, but also that sufficient flux is applied to the joint area to provide protection throughout the brazing cycle. A further benefit is that if excess flux is applied in the immediate joint area, oxidation of adjacent surfaces may be prevented, so reducing post-brazing cleaning costs.

As a guide, the flux selected should be active at least 50°C below the solidus and 50°C above the liquidus of the brazing alloy selected.

Principal requirements

Good brazing practice requires:

- Proper joint design
- Clean materials
- Correct alloy selection
- A compatible flux or atmosphere
- Controlled heating technique