BrazeTec®

SAXONIA
TECHNICAL MATERIALS

Brazing Techniques

Brazing is BrazeTec

The brazing techniques are categorised according to various aspects, following DIN 8505.

1. Categorisation according to the liquidus temperature of the soldering/brazing alloys

1.1 Soldering

Soldering uses alloys whose liquidus temperature is below 450°C.

1.2 Brazing

Brazing uses alloys whose liquidus temperature is above 450°C.

1.3 High temperature brazing

High temperature brazing is flux-free brazing in an air-free atmosphere (vacuum, inert gas) with brazing alloys having liquidus temperatures above 900°C.

2. Categorisation according to the nature of the brazed joint

2.1 Surface brazing

Surface brazing is coating via brazing.

2.2 Joint brazing

Joint brazing is joining via brazing.

2.2.1 Gap-brazing

Gap brazing is the joining of components, whereby a narrow gap between the components is filled preferentially with brazing alloy by capillary pressure.

2.2.2 Joint-brazing

Joint-brazing is the joining of components, whereby a wide gap (joint) between the components is largely filled via gravity.

3. Categorisation according to the nature of the oxide removal

3.1 Brazing using fluxes

3.2 Brazing in a reducing inert gas

3.3 Brazing in an inert gas

3.4 Brazing in a vacuum

4. Categorisation according to the way of application of the brazing alloy

4.1 Brazing with “contacted” brazing alloy
Brazing with “contacted” brazing alloy is a method whereby the workpieces are heated to brazing temperature at the brazing joint and the brazing alloy is largely brought to melting by contact with the components to be brazed.

4.2 Brazing with an “applied or inserted” brazing alloy
Brazing with applied/inserted brazing alloy is a method whereby the brazing alloy is applied to the brazing joint before heating and is simultaneously heated up to the brazing temperature with the components to be brazed.

4.3 Dip brazing
Dip brazing is a method whereby the components to be brazed are heated to brazing temperature in a bath of molten brazing alloy.

5. Categorisation according to the method of manufacture

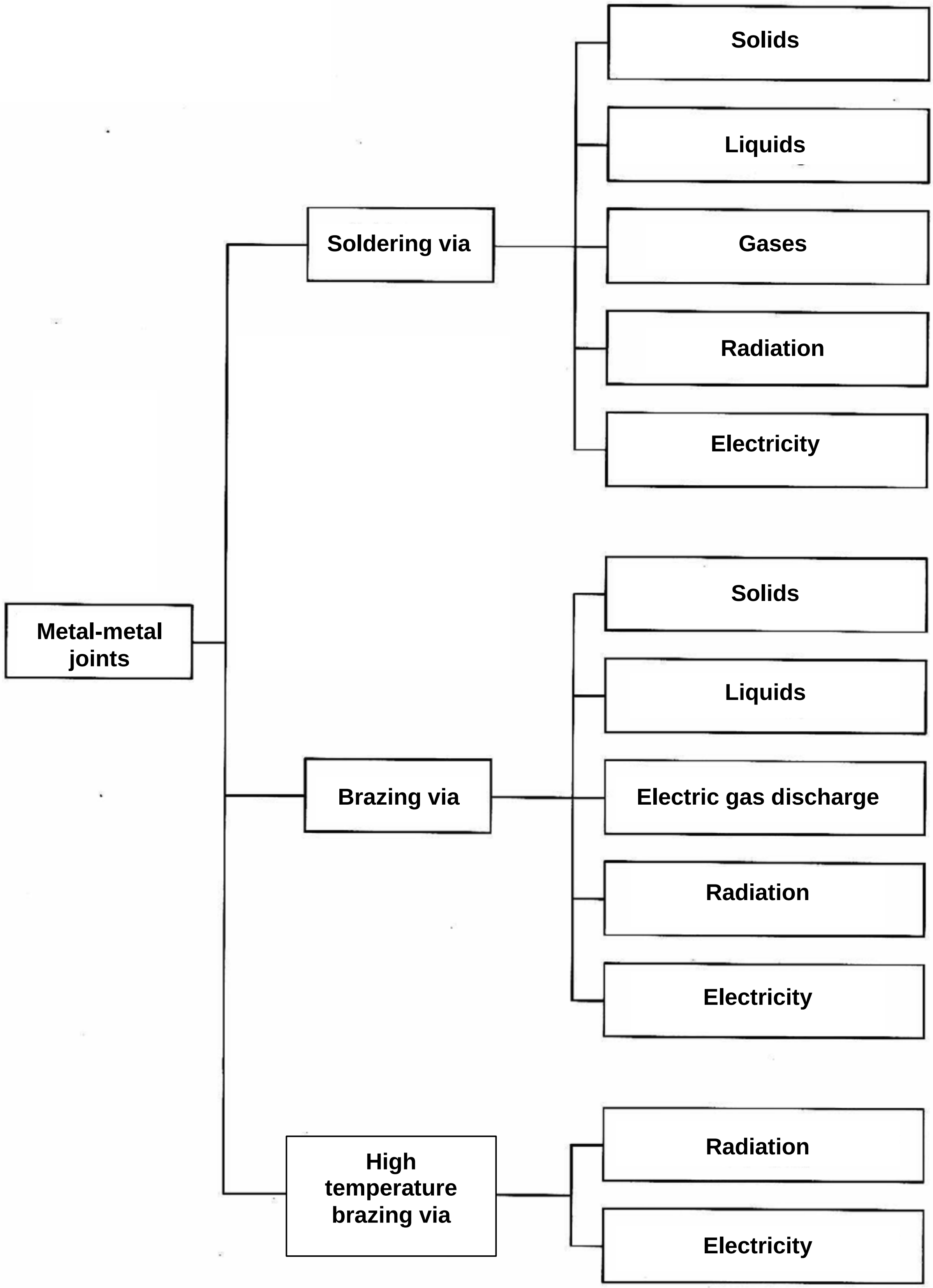
5.1 Manual brazing
All parts of the brazing process are carried out manually.

5.2 Semi-mechanical brazing
Some parts of the brazing process are carried out mechanically.

5.3 Mechanical brazing
All parts of the brazing process are carried out mechanically.

5.4 Automatic brazing
All parts of the brazing process, including all secondary activities such as changing the workpieces, are carried out automatically following a program (possibly having different run options).

Table 1


Metal-metal joints
Soldering via
Solids
Liquids
Gases
Radiation
Electricity
Brazing via
Solids
Liquids
Electric gas discharge
Radiation
Electricity
High temperature brazing via
Radiation
Electricity

6. Categorisation according to energy suppliers

Table 1 gives an overview of the categorisation according to energy suppliers, taken from DIN 8593 „Production techniques for joints – joints via brazing“.

The following heating methods have proved themselves in practice:

6.1 Soldering techniques

6.1.1 Copper-bit soldering (Figure 1)

Copper-bit soldering is the heating of the joint and melting of the solder using a manual or machine-operated soldering bit. The heat capacity and shape of the bit and point must be adapted to the joint to be soldered. With the help of flux (separate or in the form of a rod of solder with flux-sheath, both components to be joined are brought up to working temperature with the solder, prior to the start of the actual soldering process.

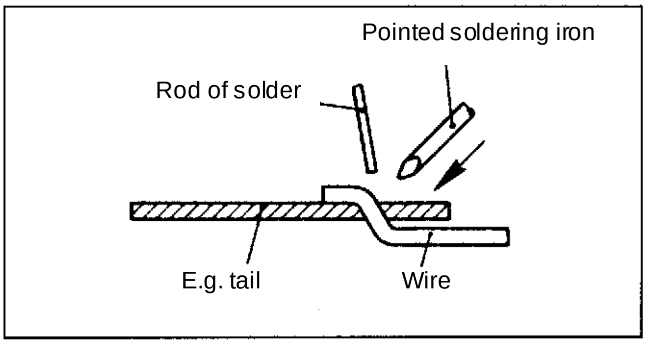


Figure 1

6.1.2 Solder bath soldering (Figure 2)

In solder bath soldering, the components to be joined are dipped in a bath of liquid solder and the soldering process is then carried out. Before dipping in the bath, the components are wetted with flux. The *immersion speed* should be chosen such that the soldering temperature is reached on the workpiece during every dipping phase. A visible sign of this is a positive meniscus at the interface of the solder surface and the component. Before being immersed, the component to be soldered can be cold or pre-heated.

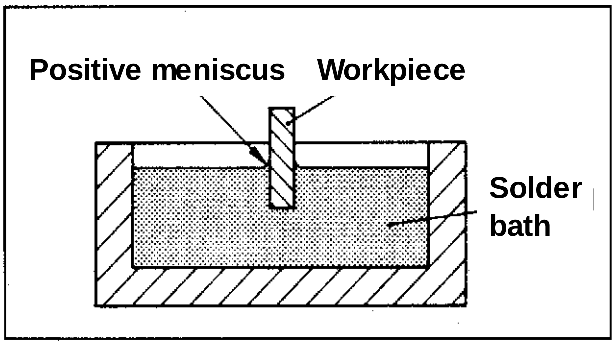


Figure 2

6.1.3 Wave-soldering (Figure 3)

Wave-soldering is the addition of liquid solder via a wave made of solder, which is produced using a pump and a nozzle. This technique is chiefly used with a flux bath and drying stage (to dry the flux) for soldering printed circuit boards. For soldering circuit boards, a pulling angle of 7° to the bath surface has proven favourable.

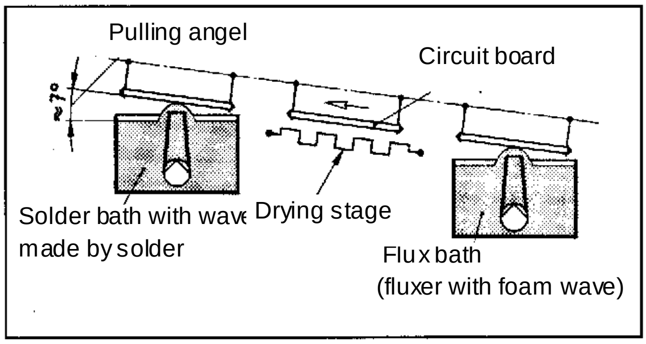


Figure 3

6.2 Brazing techniques

6.2.1 Blowlamp brazing (Figure 4)

Normal combinations of gases:

6.2.1.1 Natural gas, sewer gas, liquid gas or acetylene draw in atmospheric air (injector burner, Bunsen burner; only one gas supply hose is required).

Figure 4: Blowlamp brazing

6.2.1.2 Natural gas, sewer gas, liquid gas or acetylene are mixed with compressed air (higher flame energy than drawn-air burners; two supply hoses are required).

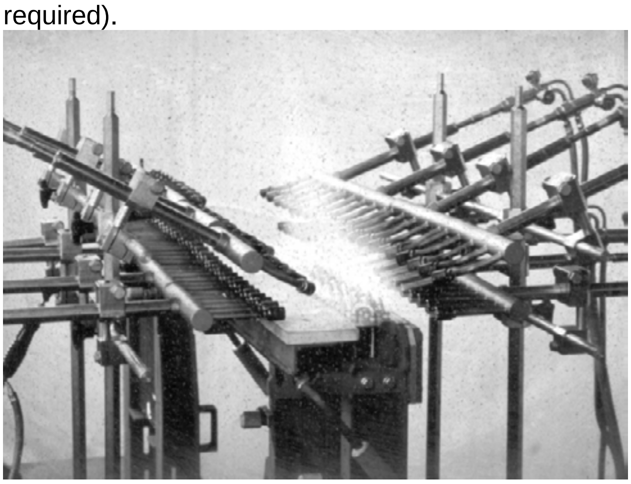


Figure 5: Brazing a heat exchanger with a propane/ compressed air burner station

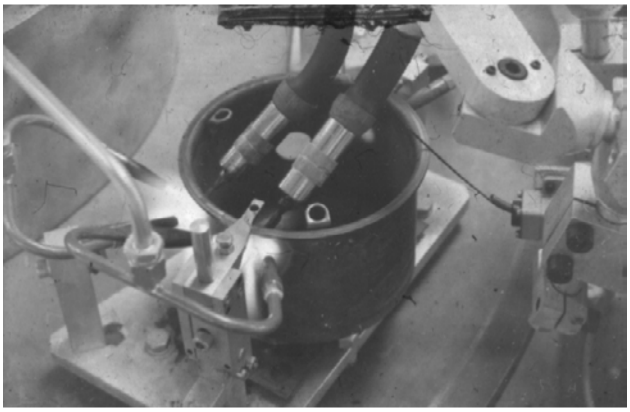


Figure 6: Brazing compressor pots using an acetylene / compressed air burner (Figure 6)

6.2.1.3 Natural gas, sewer gas, liquid gas, acetylene or hydrogen are mixed with oxygen (even higher flame energy than compressed air burners; usually too hot for thin-walled components).

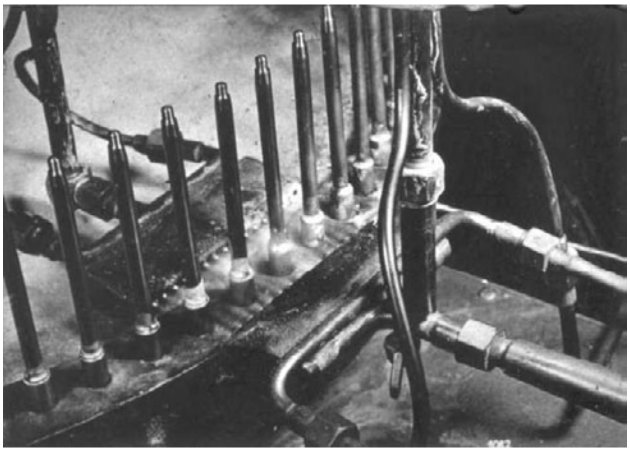


Figure 7: Brazing Cu-bolts with a water-cooled acetylene / oxygen burner

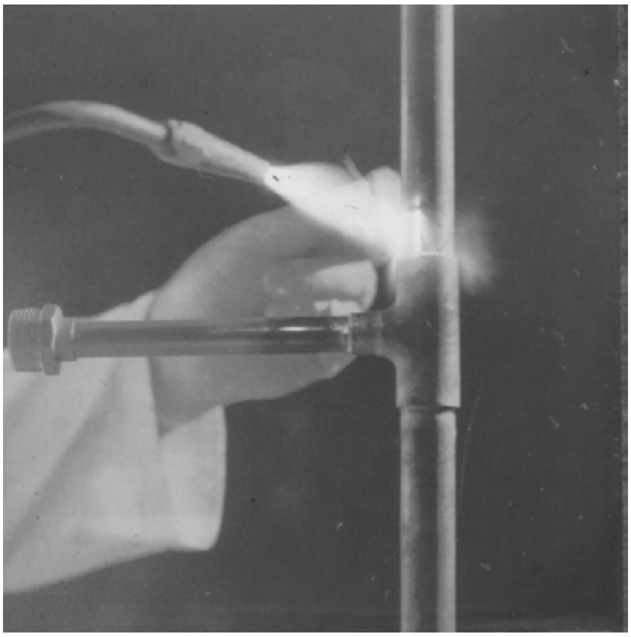


Figure 8: Manual brazing using an acetylene / oxygen burner

6.2.2 Electrical resistance brazing

The workpieces are incorporated in the electrical circuit.

6.2.2.1 Brazing with metal electrodes (Secondary voltage about 1-2 Volts)

This technique is preferably used for workpieces which have relatively high electrical resistance. The current heats the workpieces immediately. The electrodes should as far as possible be arranged so that no current has to flow across the brazed joint.

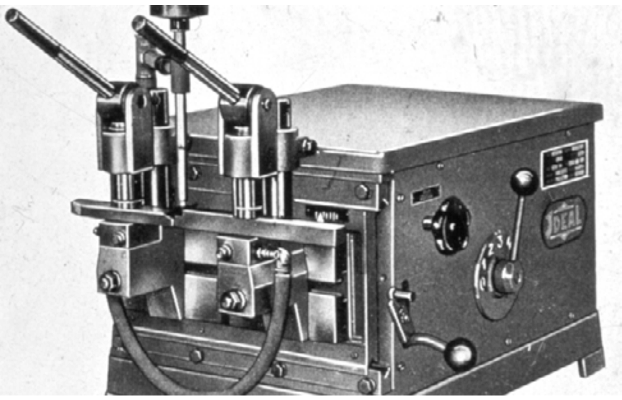


Figure 9

6.2.2.2 Brazing with carbon electrodes (secondary voltage about 8-10 Volts)

This technique is mainly used for flux-free brazing on copper base materials using phosphorus-containing brazing alloys. The current heats the carbon electrodes, which transfer the heat to the workpiece.

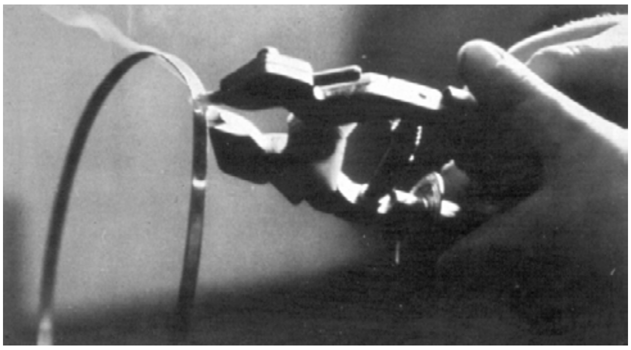


Figure 10

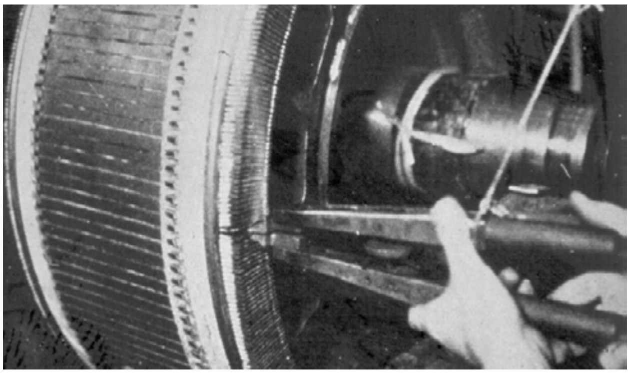


Figure 11: Brazing a rotor with resistance brazing tongs

6.2.3. Induction brazing

The workpieces are not incorporated in the electrical circuit.

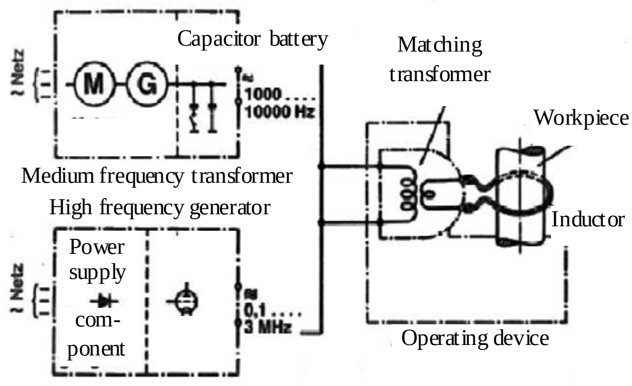
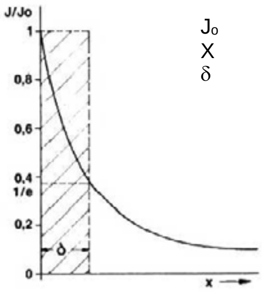


Figure 12

The current flowing into the inductor has an electromagnetic pulsating field which is very strong inside the inductor but is much weaker at the ends and on the external surfaces. An electrically conducting workpiece which is brought into the induction coil is penetrated by the electromagnetic field and eddy currents are generated in it. Due to the skin effect, these currents are increasingly forced from the inside to the outside of the workpiece, following an exponential function, and essentially only induce the desired heating. The layer thickness into which the current penetrates 1/e-times is called the *penetration depth* or *effective depth* (Figure 13). About 85% of the induced energy is converted in this into heat.



J_o = Current strength at the surface
X = Distance from the surface
δ = Effective depth

Figure 13

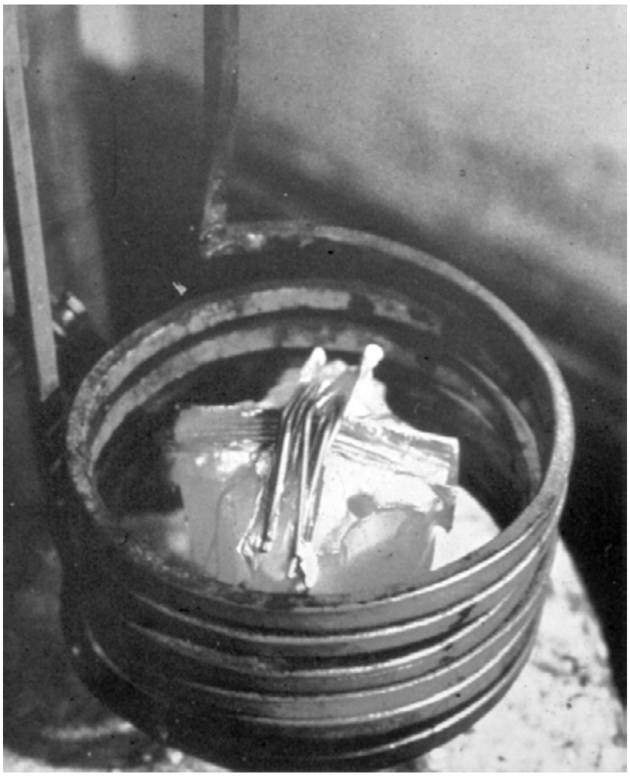


Figure 14

Material		Temp.	Effective depth in mm for t=			
		°C	50 Hz	500 Hz	10 kHz	1Mhz
Steel	μ=1	900	70	23	5	0,5
	μ=10	620	14	5	1	0,1
Brass		600	26	8,5	1,8	0,18
Copper		600	17	5,5	1,2	0,12

Brazing drill crowns via MF-heating (no contact between drill crown and coil). Due to the „loose“ interaction, the energy density at the surface is reduced so much that the heat-energy of the steel permits uniform through-heating (Figure 14).

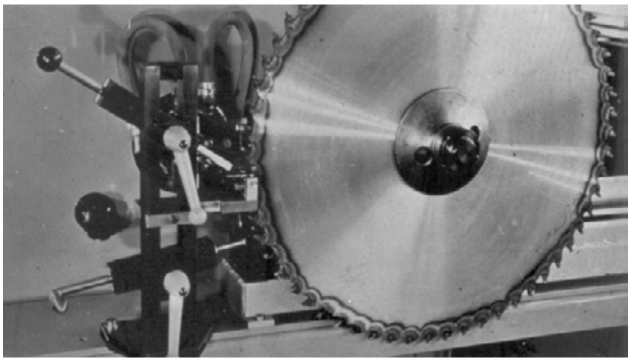


Figure 15: Brazing hard metals onto a saw blade with HF-heating (clearly visible, restricted heating; brazing alloy - BrazeTec 49/Cu; flux - BrazeTec special h.

6.2.4 Furnace brazing

In furnace brazing the workpieces to be brazed, the brazing alloy and (if required) the flux are heated in a furnace chamber to the required temperature. The correct oven temperature is in general about 50 – 100°C above the working temperature of the brazing alloy being used.

6.2.4.1 Furnace brazing using flux

In this brazing technique there are no special requirements with regard to the choice of brazing alloy and flux. It must singularly be remembered that in this brazing technique the rate of heating is often considerably lower than in other brazing techniques. For that reason, brazing alloys with narrow melting intervals are preferred so that no segregation of brazing alloy occurs. The effective period of the flux must also be heeded. Workpieces which require heating times of more than 5 to 10 minutes run the risk of flux-overrun. In order to prevent this, inert gas must if necessary be fed into the furnace chamber.

6.2.4.2 Furnace brazing with flux and inert gas

Where longer heating times are required, the use of an inert gas as well as flux is necessary. As the oxide skins are removed by the flux, the inert gas does not have to have a reducing effect at the brazing temperature; it suffices if it hinders new formation of metal oxides.

Not all furnaces are suitable for brazing. For brazing with fluxes, only furnaces with a closed muffle should be used. When furnace brazing with zinc-containing workpieces or zinc-containing brazing alloys, vapours are produced which contaminate the furnace. It can be even more serious when fluxes are used. Flux vapours can damage the furnace, especially if the heating coil is not protected.

6.3 High temperature brazing

6.3.1 Furnace brazing using reducing inert gases

If reducing inert gases are used, any metal oxides which are present are removed via a chemical reaction with the reducing components of the inert gas (essentially H_2, for endo- and exo-gases also CO).

The reactions involve equilibria:

$$MeO + H_2 \xleftrightarrow[Energie]{} Me * H_2O$$

The extent of the reaction depends on the bond enthalpy of the metal oxide (Figure 19) and on the dryness of the inert gas (Figure 20).

Temperature	1000° C	800° C	600° C
Ag, 2 AgO	(+107,7)	+ 80,9	+ 54,5
Pd, 2 PdO	+ 38,5	+ 4,9	− 30,6
Cu, 2 Cu_2O	−172,6	−197,8	−223,3
Sb, ²/₃ Sb_2O_3	−230,9	−268,2	−305,5
Ni, 2 NiO	−238,4	−277,8	−317,8
Cd, 2 CdO	−258,5	−298,3	−335,2
Co, 2 CoO	−282,4	−311,7	−341,1
Sn, SnO_2	−315,5	−357,4	−399,3
W, ²/₃ WO_3	−342,3	−377,1	−411
P, ²/₅ P_2O_5	−356,1	−398	−440
Fe, 2 FeO	−360,3	−385,4	−410,6
Zn, 2 ZnO	−441,6	−481,8	−522,5
Cr, ²/₃ CrO_3	−526,7	−561	−596,2
Mn, 2 MnO	−585,8	−614,7	−644,4
Si, SiO_2	−641,5	−677,9	−714
Ti, TiO_2	−674,6	−712,3	−745,8
Al, ²/₃ Al_2O_3	−846,4	−888,3	−938,6
H_2, $2H_2O$ (moist)	−356,1	−377,1	−398
Co, 2 Co_2	−344,8	−379,6	−414,4

Figure 19

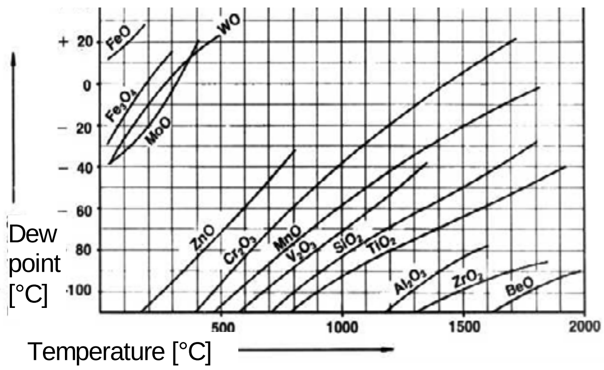


Figure 20

Figure 20 shows the reduction-oxidation equilibria for various metals as a function of the dew point of the inert gas (hydrogen, dissociated ammonia). The designated temperatures must be viewed as minimum temperatures at which the reduction of the surface oxide to metal starts.

An example of special technical importance is the flux-free brazing of chromium-containing materials, for example brazing a non-stabilised 18/8-chromium-nickel steel (material no. 14301) in a dissociated ammonia or hydrogen atmosphere with a dew point of about –40°C. According to the chromium / chromium oxide equilibrium curve, a minimum temperature of about 1000°C is required for this. Below this temperature the chromium oxide always present on the surface of the 18/8-steel is not reduced, but actually exacerbated, and so hinders the flow of the brazing alloy and the wetting process. For a titanium stabilised 18/8 steel, for example material no. 14541 with about 0.5% Ti, the titanium oxide (which is considerably more difficult to reduce than chromium oxide) can cause additional wetting problems despite the small quantity which is present. For brazing in an inert gas, the minimum brazing temperature is determined by the oxide which is most difficult to reduce and which is present in non-negligible amounts and which can form either on the base material or on the brazing alloy.

Whilst up till now the working temperature for brazing with flux was determined by the type of brazing alloy, when brazing in an inert gas atmosphere there are other important factors to be taken into account such as the composition of the base material and quality of the inert gas.

Components brazed in an inert atmosphere are bare and require no further processing (Figure 21).

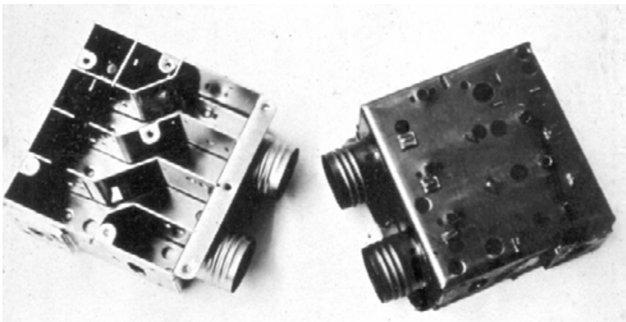


Figure 21

The vapour pressure of the base materials and brazing alloys must be taken into account when brazing in an inert gas atmosphere (e.g. vaporisation of zinc when brazing brass). This is even more important when brazing in a vacuum (Figure 22).

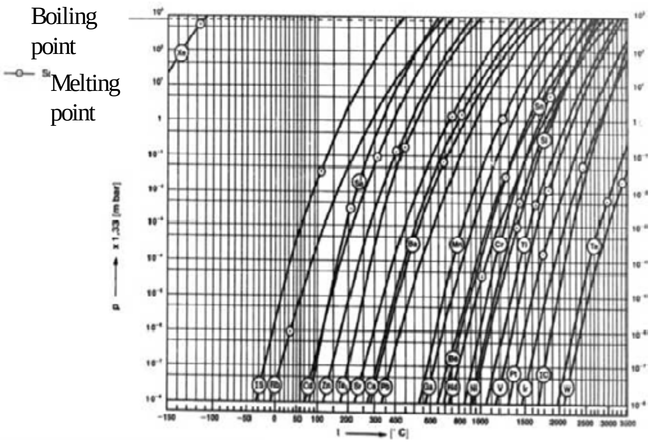


Figure 22

6.3.2 Furnace brazing in a vacuum

Vacuum brazing alloys, like the base materials, may contain no low boiling components.

For bright annealing between 700 and 1000°C, e.g. high-chromium steels, inert gases having a dew point between –40°C and 60 °C have proven to be suitable. The dryness of the residual gas in the vacuum is evident from Figure 23.

Pressure [Pa]	Dew point [°C]	For water vapour concentrations of:	
	20 Vol. %	70 Vol. %	100 Vol. %
1	-32	-17	-13
10^{-1}	-52	-40	-37
10^{-2}	-68	-58	-56
10^{-3}	-84	-75	-72
10^{-4}	-91	-89	-88

Figure 23

Figure 23 shows calculated dew points at different pressures, whereby a water vapour partial pressure in the residual gas of 20, 70 and 100 vol.-% is assumed. It can be seen that even at 10^{-1} mbar, namely a pressure which can be achieved using a simple rotary pump, the dew point is between –40 and –55°C depending on the water vapour partial pressure.

Brazing is carried out in a vacuum at temperatures above 600°C. As vacuum brazing is carried out at between 10^{-1} and 10^{-6} mbar depending on the brazing alloy and base material, oxidation is so limited that brazing can be carried out without flux.

Although flux and gases can become trapped in the brazed joint when brazing in a gas atmosphere, this is virtually never so when brazing in a vacuum, so resulting in brazed joints with a good degree of filling and higher strength. This is especially important for components which are subject to higher loads such as turbine impellers, heat exchangers and open structures. Vacuum brazing has become the favoured technique in power transmission engineering.

Before brazing, the surfaces of the workpieces to be brazed must be blanked either mechanically or chemically. The residence time at the brazing temperature should be as short as possible, especially for the high temperature alloys. This is to avoid too strong alloying of the base material (erosion) and possibly formation of brittle phases in the transition zones.

The formation of brittle phases is however non-critical if – as is often the case for nickel-based brazing alloys – a diffusion treatment is carried out after the brazing (Figure 24).

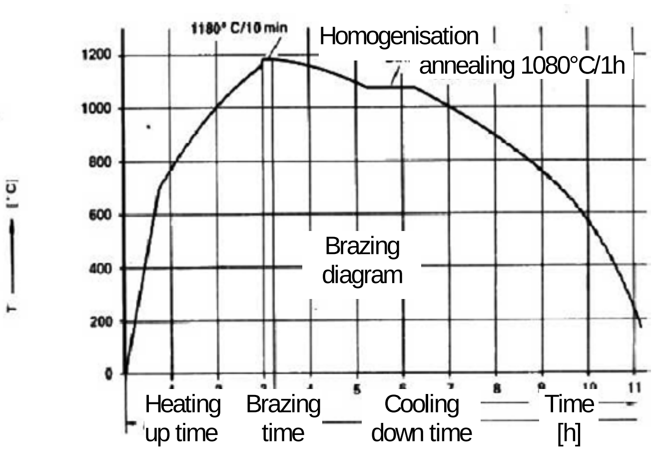


Figure 24

Brazing processes and heat treatment processes can often be combined in a single process (Figure 25).

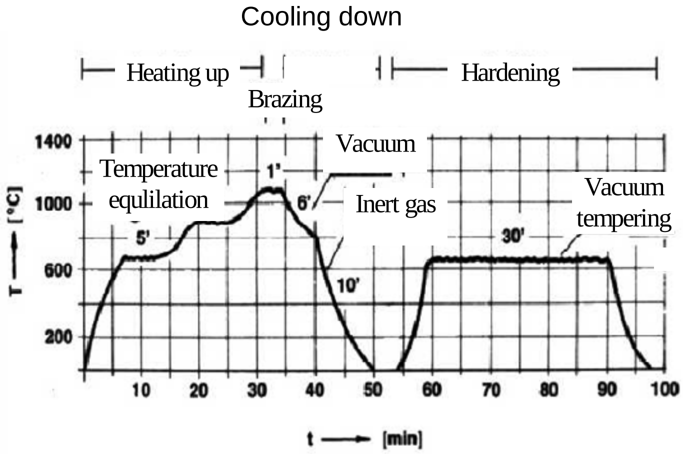


Figure 25

6.4 Types of furnaces

6.4.1 Inert gas furnaces

Brazing in an inert gas is usually carried out in continuous inert gas furnaces (Figure 26).

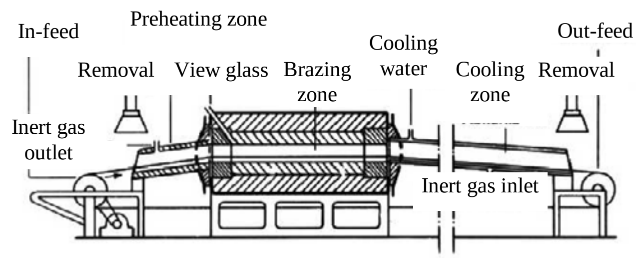


Figure 26

Exo-gas furnaces are usually used for steel components (Figure 27).

Figure 27

Dissociated ammonia furnaces are used for brass and chromium-nickel steels. These can also be operated with pure hydrogen. In order to keep the gas consumption low, these are often built as “buckle furnaces“ (Figure 28).

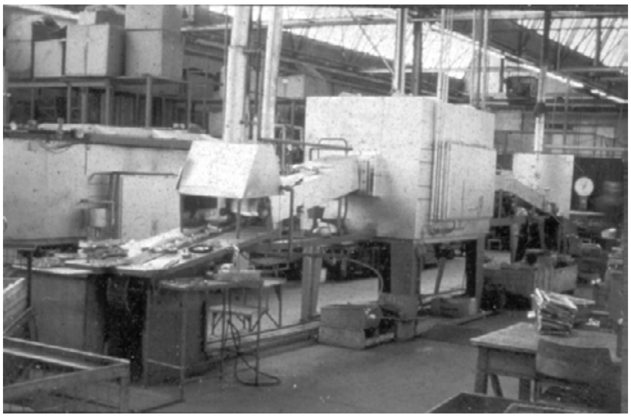


Figure 28

6.4.2 Vacuum furnaces

- Degussa chamber furnaces VKQgr 25/10/25 (Figure 29)

Effective size:	250 mm length 250 mm width 100 mm height
Heating:	Graphite cloth, programmable
Nominal temperature:	1350°C
Design:	Cold wall furnace with inert gas recirculation

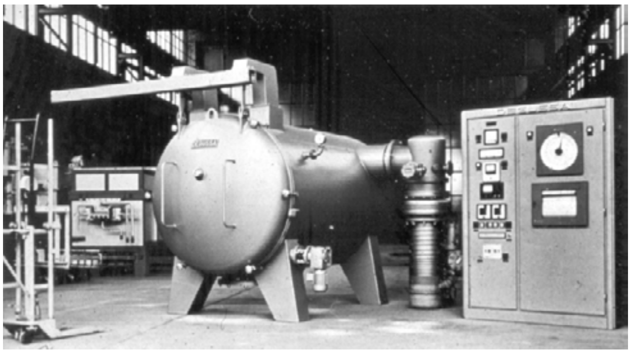


Figure 29

Figure 30

6.5 Examples of applications

- Part of a combustion chamber of a nozzle mechanism made of a Co-alloy brazed with a nickel-based brazing alloy at $5x10^{-4}$ mbar (Figure 31).

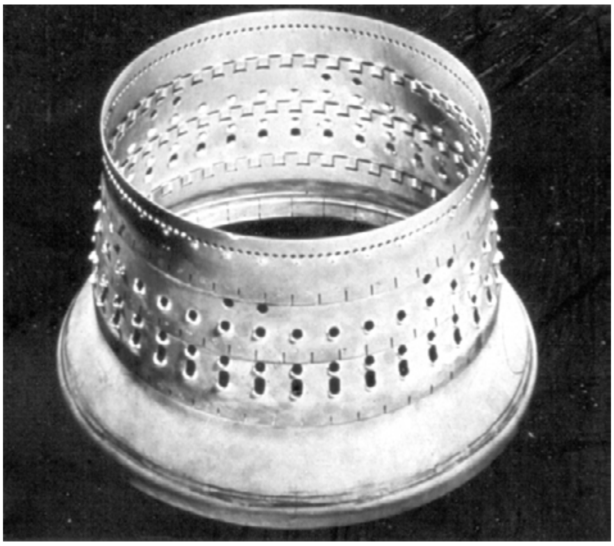


Figure 31

- Guide mechanism of a space probe; stainless steel cooling pipe wound around the combustion chamber and brazed with BrazeTec VH 950 (gold-based brazing alloy) at $9x10^{-3}$ mbar (Figure 32).

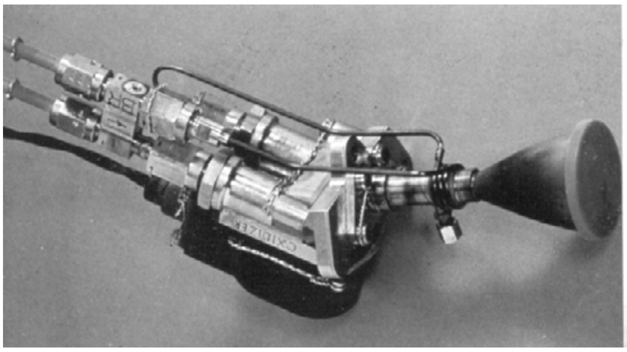


Figure 32

- Oil cooling unit made of chromium-nickel steel, brazed with copper brazing alloy in a continuous inert gas furnace in a dissociated ammonia atmosphere (Figure 33).

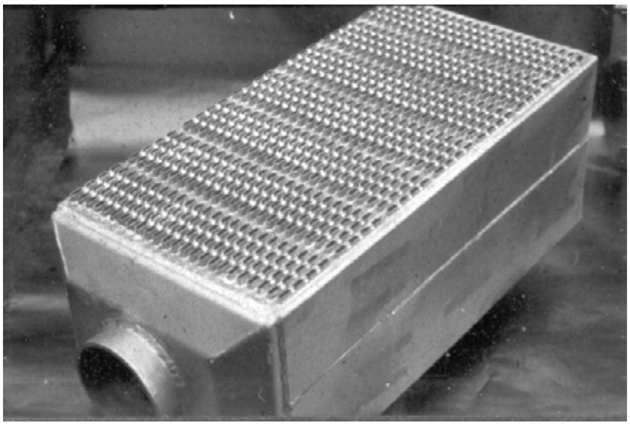


Figure 33

- Torque converter of an automatic drive unit brazed with copper brazing alloy in a continuous inert gas furnace in an exo-gas atmosphere (Figure 34).

Figure 34

- Cable trough made of copper brazed with BrazeTec Silfos 15 brazing alloy in an exo-gas atmosphere in a continuous inert gas furnace (Figure 35).

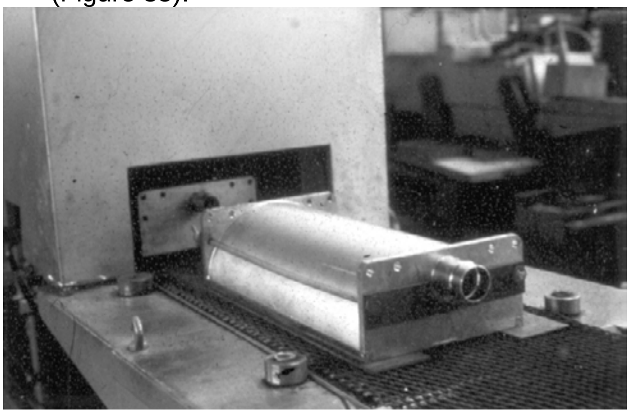


Figure 35

- X-ray tubes; tungsten electrode brazed onto a copper support in a vacuum furnace with BrazeTec SCP brazing alloy (Figure 36).

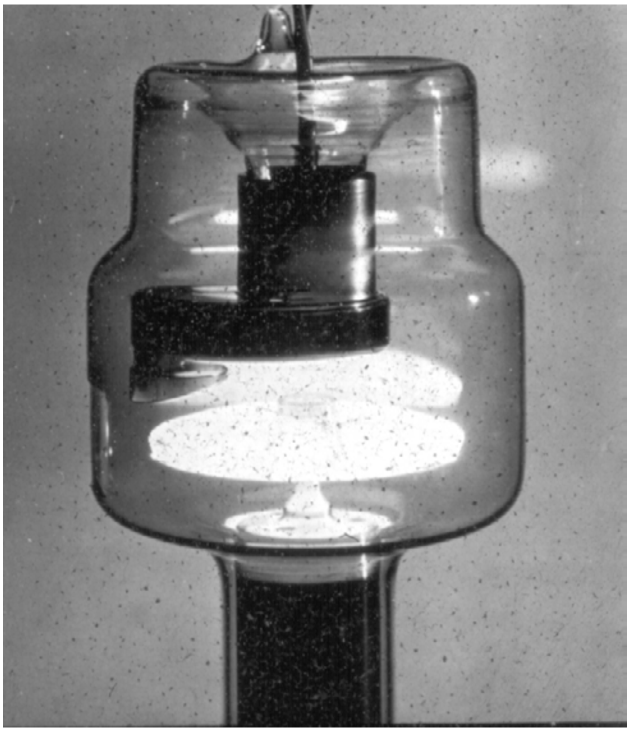


Figure 36