High temperature brazing in single chamber vacuum furnaces

by **Björn Eric Zieger**

Compared to conventional soldering techniques the batch type vacuum brazing has established for various products. Also for the large-scale production of copper brazed plate heat exchangers the vacuum process is used. The compacted load assembly has highest demands on the furnace technology to achieve maximum reproducibility and efficiency.

The norm DIN 8505 describes brazing as a thermal process for the firmly bonded joining and coating of materials under the condition that a liquid phase is created through the melting of filler metal (fusion brazing) or through diffusion to the edge areas (diffusion brazing). The solidus temperature of the basic materials is not achieved. In conventional brazing the liquid filler metal is super cooled by heat removal and thermal solidification (bonding) [1].

VACUUM BRAZING

In the vacuum brazing process the working temperature is held until solidification through diffusion between the basic material and the filler metal.

High temperature vacuum brazing proved successful for joining highly stressed structures in a wide range of materials in applications like:

- Turbines for aviation or aerospace
- Turbines for stationary application
- Heat exchanger
- Plastic moulds
- Cutting tools
- Hydraulic components
- Subcontract brazing shops.

Uniform heating in the furnace minimises thermal stresses and distortion of the work pieces. A regeneration of the basic material properties is also possible through suitable heat pre-treatment and heat post-treatment (stress-free annealing or elimination annealing). Also the combined process of brazing and hardening where gas quenching starts directly after solidification of the brazing filler metal has established. Here the advantage is the discontinuation of one heating up sequence.

Another advantage of vacuum high temperature brazing is that oxidation at the joints can be reduced. This enables more narrow brazing gaps. Narrow brazing gaps are necessary to achieve higher strength in the connections, which is important when manufacturing highly stressed parts [2].

BRAZING MATERIAL

Once intensive work began in the aerospace sector. The industry increasingly demands high-strength and oxidation resistant brazing connections, particularly for connections with different materials. In the beginning, brazing with gold-based filler metals fulfilled all the construction requirements as this guarantees the necessary strength, toughness and hot gas corrosion resistance. Because of the high cost, the gold-based filler metals had been displaced increasingly by nickel-based filler metals. Nickel-based filler metals offer similar properties by much lower costs. Other filler metals, that had to fulfil the demands of the wide variety of structures, brazing connections and applications, were also developed and produced. Brazing material is offered as formed component, foil, paste or powder.

SINGLE CHAMBER VACUUM FURNACES

General construction

The casing of the single chamber vacuum furnace (**Fig. 1**) is usually cylindrical and installed either horizontally or vertically. The furnace casing contains the hot zone with insulation lining and heating elements together with the rapid cooling device including the internal heat exchanger. The high performance radial fan with electrical motor is also installed inside the recipients. The vacuum pumps, the heating transformer and the switch cabinet are installed outside the furnace vessel [3].

The furnace is electrically heated and uses the "cold wall"

Fig. 1: Single chamber vacuum furnace for brazing of plate heat exchangers

system with double-walled, water-cooled vessel. This reduces thermal load on the metallic furnace casing as the idle losses are conveyed into the cooling water in the double shell.

Vacuum equipment

A successful brazing process requires a clean and wettable surface. The vacuum brazing process produces the necessary surface quality by the mechanisms of reducing surface oxides and breaking up the oxide skins. Oxide skins are breaking because of the different expansion behaviour between the oxide skin and the basic material. The basic and filler metal materials determine the vacuum area that is requested for the process.

Most copper brazing processes take place in a fine vacuum atmosphere. First, a rotary vane pump is used to generate the low vacuum (from 1,000 – 1 mbar). On top, a roots pump is used to generate the necessary fine vacuum (10^{-2} mbar area).

For brazing processing, e. g. Ni-based filler metals, a high vacuum is also often necessary (10^{-3} – 10^{-6} mbar area). This is where e. g. three-stage mechanical pumps, oil diffusion pumps, turbomolecular pumps or cryogenic pumps are used.

Heating chamber

Vacuum furnaces are predominantly heated by operating at low voltage and high current. Striving for fastest possible process times with shortest heating up ramps, it is important to have a uniform temperature behaviour to avoid overheating and excessive holding times of the brazing parts. The practical standard which has proven itself for most processes today is single zone heater system. Multi-zone heaters are also found for special applications. These can be additional door and rear wall heaters. Auxiliary central heating zones are also possible and found in large size hot zones.

The hot zones of most heat treatment vacuum furnaces are lined with graphite insulation. The hot zone may be rectangular or round. All-metal hot zones are used for special applications and requirements for carbon hydride-free atmospheres. Several serial radiation shields made of molybdenum and / or heat-resistant materials are used for insulation with these heating elements. The furnace temperature dimensioning determines the number of radiation shields and their material. Also these hot zones may be rectangular or round.

Quenching system

In high pressure gas quenching the furnace system is flooded with protective gas (usually nitrogen or argon) at a pre-selected pressure. A cooling fan unit, comprising a three-phase motor and a fan impeller, moves a stream of cooling gas through the entire load via opened flaps or nozzles in the hot zone. During this process the heat energy of the load is taken up and transferred to a gas/water heat exchanger which is integrated in the furnace system [4].

The through stream principle with direction reversal has established for the majority of typical vacuum brazing processes. Large gas stream inlet and outlet apertures that correspond to the dimensions of the load are necessary in order to achieve uniform cooling. These gas stream inlet and outlet apertures are fitted with special gas distribution or nozzle elements.

Homogeneity of gas quenching can be increased by programmable vertical and/or horizontal gas stream reversal.

Horizontal gas stream reversal (**Fig. 2**) is typically used for plate heat exchanger loads. Herewith, a quickest possible and most uniform cooling of the load in all areas is achieved.

The reversal of the gas stream direction can be steered by time or temperature according to the demands of the brazing load. In case of temperature controlled gas stream reversal it is steered by actual temperature difference, measured on load thermocouples.

VACUUM BRAZING OF PLATE HEAT EXCHANGERS

Copper brazed heat exchangers

Copper brazed plate heat exchangers (**Fig. 3**) consist of several layers of stainless steel plates which are joined with copper filler metal to one heat exchanger component. This steady sealed component with two connections offers

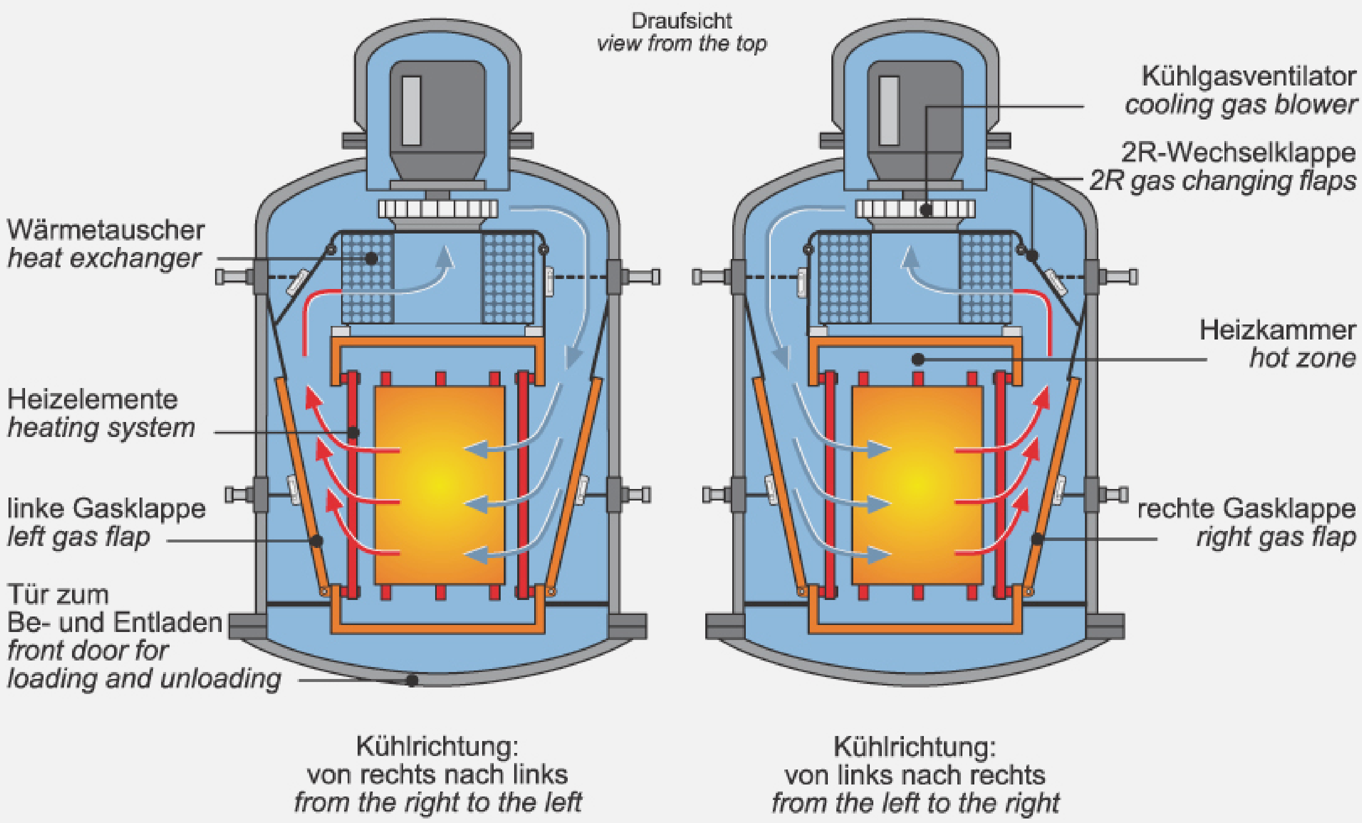

Fig. 2: Principle of horizontal gas stream reversal in single chamber vacuum furnace

highest thermal transfer from minus 180 °C to plus 200 °C at operating pressure up to approx. 35 bar. Typical application areas are e. g.:

- Heating and cooling of pure fluids
- Evaporator- and condensor-stations
- Teleheating and air sparing systems
- Solarheating and airconditioning systems
- Heat pumps and heat recovery systems.

Fig. 3: Copper brazed plate heat exchangers, here brand Fa. Sondex

Process management for vacuum brazing of plate heat exchangers

The vacuum brazing process has its fixed position in the production flow of plate heat exchangers (**Fig. 4**). In this, the basic material of austenitic Cr Ni steel is joined using copper brazing. The typical process is carried out as follows:

- Evacuation of the vacuum chamber furnace
- Heating to soaking temperature (approx. 30 K below the solidus point of the filler metal)
- Holding time for soaking
- Heating to effective brazing temperature of approx. 1,120 °C
- Holding time to achieve the effective brazing temperature in all areas of the load
- Vacuum cooling to a temperature below the solidus point
- Fast cooling to the removal temperature using overpressure gas quenching.

Evacuation of the vacuum chamber furnace

The copper-brazing process of plate heat exchangers occurs in fine vacuum atmosphere. After furnace loading (**Fig. 5**), the complete furnace recipient is evacuated by rotary vane pump and roots pump into fine vacuum atmosphere (approx. 10^{-2} mbar area).

Heating up to soaking temperature

The entire load is heated by radiation. As the setting of the entire load is very compact, the heat radiation must hit the load from all sides to achieve uniform heating. Radiation heating always takes place from the outer area of the load up to the components in the centre of the load setting and from the surface to the core of the individual heat exchanger.

Thermocouples are used to realize an absolutely reproducible and safe process. The programmer regulates the process with the help of a heating thermocouple and perhaps one or several work piece thermocouples. The fixed heating thermocouple is positioned near the heating rods. Load thermocouples can be positioned anywhere in the load setting.

Heating up to effective brazing temperature

As soon as the thermocouple in the loads core signals it has reached the soaking temperature and thus that the entire load is at a temperature tight below the solidus point of the filler metal, a uniform heating to effective brazing temperature starts automatically.

There is only a relatively small difference between soaking and effective brazing temperatures that needs to be overcome. But anyway, the outer area of the load / the heat exchanger will still reach the brazing temperature before the core area. The work piece thermocouple also signals the complete temperature balance in this case. The factual holding time on brazing temperature can be reduced to the minimum. Benefit is here the best possible microstructure of the basic material, lowest vaporisation and the most efficient process time.

Vacuum cooling

Copper filler metal is liquid in the brazing phase with a melting point of 1,083 °C. The load is cooled down to a temperature below the solidus point of the filler metal by using slow vacuum cooling. The heat energy is slowly emitted to the cold double-walled furnace recipient. Undesirable movements of the still liquid brazing filler metal and distortion of the components are avoided through this targeted, slow cooling.

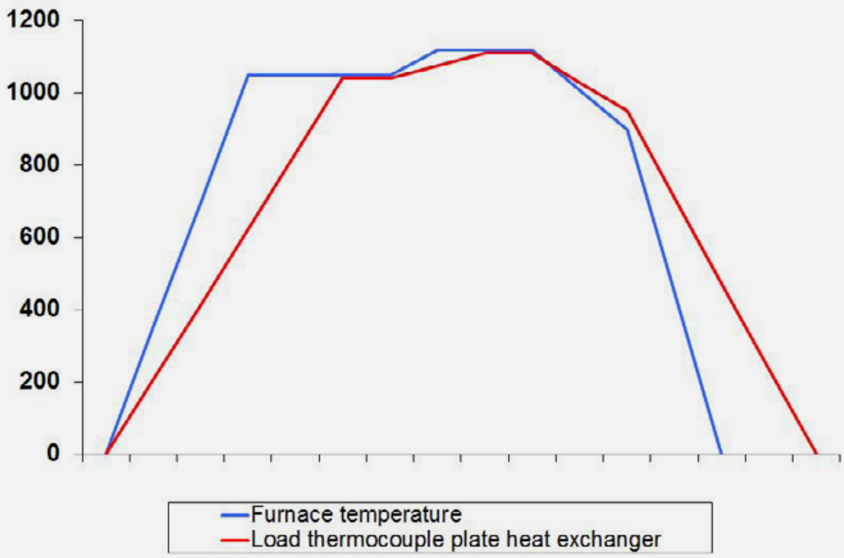

Fig. 4: Principle process brazing of plate heat exchangers

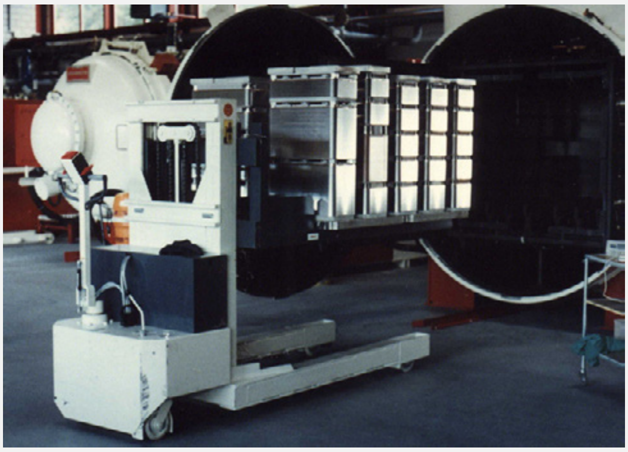

Fig. 5: Charging of single chamber vacuum furnace with plate heat exchanger load

Fig. 6: Prepared plate heat exchanger load

Fast cooling

When the thermocouples signal that the pre-selected temperature below the solidus point of the filler metal has been reached at all points on all heat exchangers, the load cooling can be speeded up by over-pressure gas quenching. Therefore, the furnace system is flooded with the process gas, in practice nitrogen, usually to a pressure of 1.5 bar (abs). The cooling fan unit produces a cooling gas stream that transfers the heat energy of the load through the opened side heating flaps backwards to the internal gas water heat exchanger unit. To avoid discoloration the complete load should be < 150 °C before removal out of the furnace. Because of safety reasons, generally a removal temperature of < 60 °C is pursued.

The direction of the gas flow can be changed using a corresponding system. The direction reversal can be controlled by time or temperature. Cooling is achieved more uniformly and distortion of the components is substantially reduced.

The well-established producer of plate heat exchangers mostly use single chamber vacuum furnaces with rectangular hot zone and horizontal cooling gas stream reversal. The piled load arrangement (**Fig. 6**) is on massive groundplates. With some ballast weight on top the necessary compression is realized. With the horizontal cooling gas stream a considerable faster heat transfer is reached compared to vertical cooling gas stream. With the gas stream reversal the load cooling is also homogenized. In comparison to vertical gas streaming, the cooling time up to removal temperature, and thus the total process time, can be shortened significantly.

CONCLUSION

High temperature brazing in single chamber vacuum furnaces has a well-established position in joining technology. For the benefits of highest productivity, reproducibility and efficiency the equipment configuration has to be adapted to the respective brazing application. For large scale brazing of plate heat exchangers the vacuum furnace with rectangular graphite isolated hot zone and horizontal gas stream reversal has sustained.

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