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Vacuum Brazing Guide

Innovation in the Development and Manufacture of Components and Tools Using Modern Joining Technology

Overview of Possibilities and Application Areas of the Vacuum Brazing Technology

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Benefits of the Vacuum Brazing Technology

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WHAT IS VACUUM BRAZING – A BRIEF OVERVIEW

Starting from simple semi-finished products, complex components can be produced cost-effectively and/or the effort for pre- and post-processing procedures can be reduced. This increases significantly the flexibility with regard to function and costs.

The principle of vacuum brazing involves the joining of identical or different materials by using a brazing alloy as a filler material, which melts at high temperature in a vacuum atmosphere. The molten filler material wets the joining partners and subsequently bonds them to each other during cooling and solidification. The vacuum atmosphere inhibits a detrimental interaction of the brazing alloy and base materials with the environment and thus prevents damages to the components.

In contrast to other brazing processes, vacuum brazing does not necessitate any flux, which avoids defects in the bonding zone, leading to strength values in the range of the strength of the base material. This further avoids an oxidation of the components, even at high brazing temperatures. Thus, it is not necessary to remove flux residues, which are often corrosive, after the brazing process.

This universal joining technology enables developers and production managers to design and manufacture modular components. Starting from simple semi-finished products, complex components can be produced cost-effectively, reducing the effort for pre- and post-processing procedures. The flexibility in the combination of components with fundamentally different masses, wall thicknesses, and geometries as well as the use of different material properties with regard to function and costs is significantly enhanced. Additionally, media-conducting components can be equipped with a complex, internal channel structure.

The vacuum technology allows to braze a wide range of materials, from single structural steels to high-alloy cold and hot work steels, to super alloys, as well as non-ferrous metals such as copper and titanium and even ceramics, hard metals, and the cutting materials cBN and diamonds.

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ADVANTAGES AND DISADVANTAGES OF VACUUM BRAZING

Vacuum brazing is characterized by its great universality and flexibility and has the following advantages:

+ An almost unlimited range of materials can be used (base materials and brazing alloys)
+ Minor distortions due to an even furnace heating
+ Very good joining quality due to the vacuum atmosphere
+ High strength, even at high operating temperatures
+ Avoidance of fluxes
+ High reproducibility due to excellent temperature uniformity and comfortable control of modern furnace systems, including the process documentation
+ Possibility of a combined heat treatment (brazing and hardening)
+ Large-scale components can be joined
+ No oxidation and annealing colour
+ Hardening and annealing can be integrated into the process
+ Low environmental impact

The disadvantages are:

– Mostly batch processes with single batches. A continuous production is only possible with a very complex manufacturing facilities
– Eventually high effort to fix components as components cannot be manipulated in the furnace
– The whole component is heated, leading to a decrease of the hardness with already quenched and tempered materials or work-hardened materials
– High investment costs

03

VACUUM BRAZING AND WELDING IN COMPARISON

When assessing its current technical state, high-temperature vacuum brazing is in no way inferior to welding. Hence, it is time to understand and appreciate this technology.

The main difference between these technologies is that the base material is melted during the welding process, whereas during brazing only the brazing alloy melts while the base material itself remains solid. Welding may require the use of an additional material, e.g. a welding wire, which usually has a similar chemical composition as the base material. For brazing processes, a brazing filler material has to be used, which can but does not have to have a similar chemical composition as the base material. Brazing alloys can be utilized in the form of wires, foils or powders/pastes.

The melting of the base material further leads to a considerably greater distortion during welding than during brazing. Since the vacuum brazing process is carried out in a furnace with uniform heating, the distortion is especially low.

For welding processes, a post-heat treatment is often required, which is not necessary for vacuum brazing if the right brazing temperature is selected. This enables to conduct combined brazing and hardening/solution annealing processes in a time-saving and cost-effective manner.

Welding is characterized by joining properties that are often comparable to the base material. The use of a brazing alloy results in joints, which might deviate from the properties of the base material with regard to their strength properties, the hardness, and consequently their machinability. This requires a profound expertise concerning the brazing alloy properties, interactions with the base materials, and the resulting bonding properties.

When used properly, vacuum brazing is a recommendable alternative or supplement to welding, which further offers various advantages, including the homogeneity and strength of joints.

Welding and brazing techniques are important processes within the scope of manufacturing processes when producing components and component groups. Even today, although being on an equivalent technical level as the welding technology, the high-temperature brazing technology using a vacuum is still underestimated concerning its possibilities.

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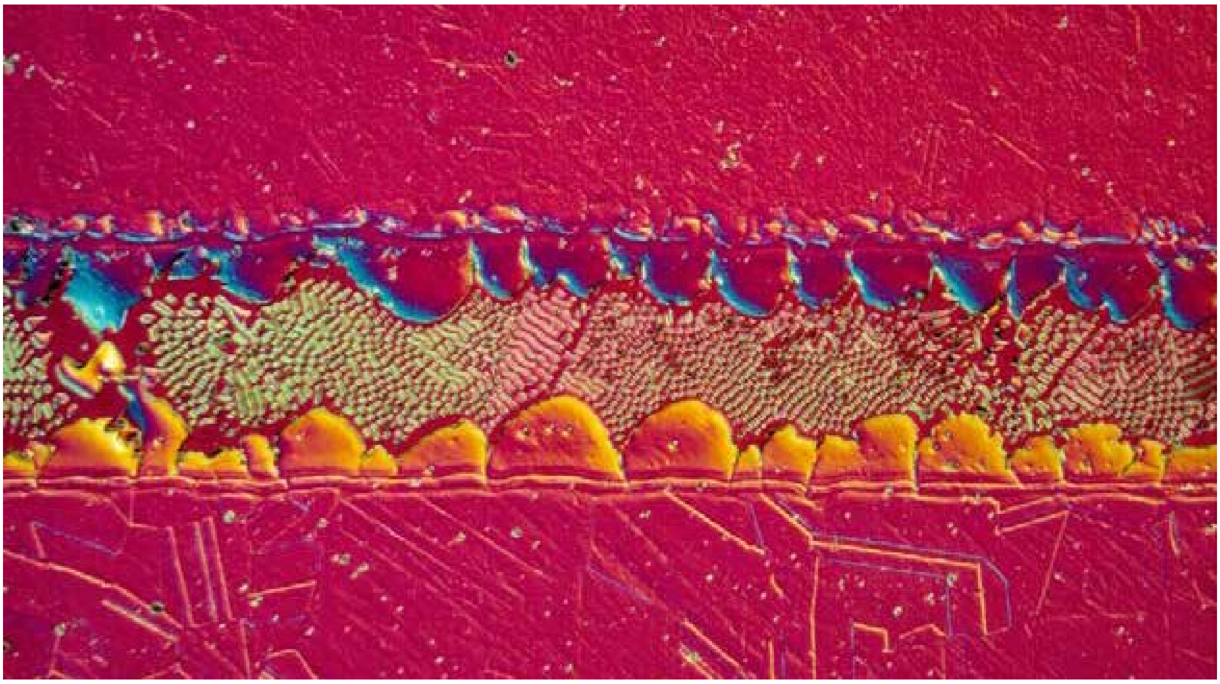
Advantages of high-temperature vacuum brazing compared to welding:

+ Combination of various materials
+ Reduction of stresses and distortions in the work pieces by means of uniform heating and cooling
+ Brazing, hardening, and tempering can be conducted in a single process
+ No use of fluxes
+ Simultaneous and reproducible joining of various components
+ Oxidation-free joints with smooth surfaces
+ Possibility to establish large-area joints
+ Utilization of capillary forces to even connect joints that are difficult to access

The **disadvantages** of high-temperature vacuum brazing compared to welding are small:

– In most cases, the brazing gap should be < 0.1 mm, which leads to higher demands concerning the component preparation
– Materials with a higher vapor pressure, such as brass, cannot be processed in a vacuum furnace



Microscopic image of a brazed joint

04

INNOVATIVE MATERIAL COMBINATIONS PRODUCED BY MEANS OF VACUUM BRAZING TECHNOLOGY

Vacuum brazing is a metallurgical bonding process that enables to assemble similar as well as dissimilar materials to be joined. Different materials, ranging from simple structural steels to high-alloy cold and hot work steels to super-alloys, as well as non-ferrous metals such as copper, titanium, and even ceramics, hard metals, as well as the cutting materials cBN and diamonds can be joined with this technology. This is possible as the decisive element, with regard to the technical properties, is the brazing alloy used and not the basic material itself. These different bonding possibilities in turn result in a wide range of applications, from the manufacturing of simple tools to applications in the field of mechanical engineering, as well as medical and aerospace technologies. The latter in particular requires highly loadable and robust components.

Further Innovation

Especially vacuum brazing gives designing engineers new freedoms concerning the design of components. This enables to develop new, highly innovative and improved functions.

The brazing of different steel qualities offers potential for cost reductions. For example, a very high-quality steel with a good polishability can be used for the cavity section of an injection moulding tool while using a standard quality for the rest of the tool. By combining materials with different physical properties allows to produce components with partially different application properties concerning their thermal and/or electrical conductivity or insulation.

If, for functional reasons, precious, expensive metals are required in a component, such metals only have to be used where actually necessary, which makes this processes extremely economical.

05

FREEDOM OF DESIGN AND IMPROVED COMPONENT QUALITY DUE TO CONFORMAL COOLING IN TOOLMAKING

In order to achieve an optimum part quality with short cycle times an efficient mould temperature control is mandatory.

Vacuum brazing enables the production of simple and flexible tools, such as injection moulds and inserts with a conformal cooling design, which not only improves the quality of the components but further reduces the time of the production cycles. Hardening according to customer specifications with this technology is effectively free of charge.

This manufacturing technology additionally opens new possibilities in terms of design and material combinations within the field of mould making. Today, this approach is used in many areas of application, ranging from simple mass-produced components to complex components exposed to high stresses as for example in turbine industry.

In order to achieve a conformal cooling design, the tool is divided into several components in accordance with the direction of the cooling channels. Subsequently, any complex design of the cooling channels can be placed into the component by means of simple mechanical processing (Figs. 1+2). This cannot be achieved by conventional drilling and plugging.

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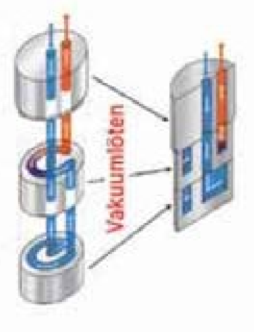


Figure 1:
Plate-shaped brazing joint

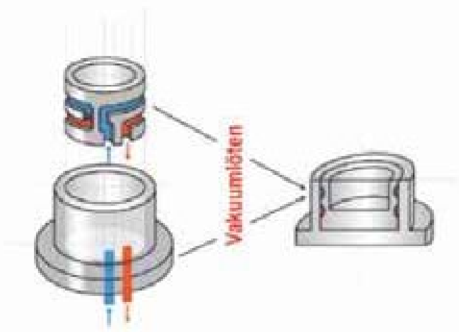


Figure 2:
Rotationally symmetrical brazing joint

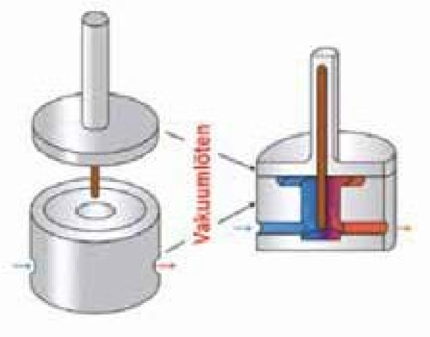


Figure 3:
Brazing of heat conducting pins

Subsequently, the individual components are firmly joined in a vacuum furnace into gas-tight and high-strength functional units.

If the desired areas of the tool cannot be reached with channels, it is possible to braze materials with a good thermal conductivity to the tool steel using a metallurgical bond (Fig. 3).

The brazing layer thickness is only approx. 50 µm. Thus, the good thermal conductivity, e.g. of copper, can almost always be completely used. In any case, the heat transfer is significantly better than with pressed-in copper pins.

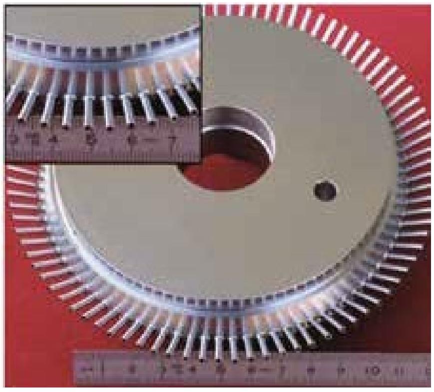
Advantages in Heat Treatments

The brazing temperature is selected so that it corresponds with the hardening temperature of the steel used. This allows the hardening of the tool to be performed within the same process. In addition to cold and hot work steels, PM steels or nitrogen alloyed steels can be brazed and hardened as well.

After hardening, the component is tempered to the hardness specified by the customer. If tools are to be coated after final machining, deep-freezing can further increase the dimensional stability of certain steels.

06

THE ADVANTAGES OF VACUUM BRAZING IN MECHANICAL ENGINEERING AND APPARATUS MANUFACTURING



The hot water components images are a typical example of a material-efficient modular design in mechanical and apparatus engineering. Individual parts are manufactured from simple, readily available semi-finished products, which are subsequently brazed.

The requirements for the component used in the food industry have to be free of gaps and corrosion resistant. Therefore, the individual parts are made of austenitic CrNi steel, brazed with a nickel-based brazing alloy with a high chromium content. An appropriate furnace size allows to treat several thousand components in a single brazing process. The vacuum atmosphere ensures absolutely smooth, gap-free components that do not require any further processing.

These advantages are also used for a component that is used to distribute a centrally fed fluid to 100 output points. The analytical conditions require the use of titanium alloy. Again, the demands for the brazed joint have to be gap-free and corrosion resistant. The brazing process was carried out with a titanium-based brazing alloy, which enables a brazing temperature of < 950 °C that is below the α-β-transus temperature. Again, the use of the vacuum brazing production technique makes a rework unnecessary.

NOTE:
Use vacuum brazing for the production of:

- **gap-less,**
- **smoother,**
- **more corrosion resistant**
- **components without further rework.**

07

CERAMIC-METAL COMPOUNDS PRODUCED BY MEANS OF VACUUM BRAZING

Vacuum brazing makes almost any material combination between high performance ceramics and metals possible.

With the aid of the universally applicable vacuum brazing technique, any high-performance ceramic can be firmly joined to almost any metallic structural material. This allows to apply special material properties exactly where they are needed.

The use of active brazing alloys in a vacuum results in the direct wetting of oxide and non-oxide ceramics as well as the super-hard materials cBN and diamonds. Besides the production of components, this process combination is also suitable for the metallization of ceramics and the application of functional structures onto ceramic substrates.

Accordingly, the following **advantages** result for this joining technique:

+ Strong metallurgical bonds and consequently highly loadable and temperature-resistant joints
+ Almost any combination of materials between ceramics and between ceramics and metals
+ Active brazing eliminates the need for a prior metallization of the ceramic, which is why basically any high-performance ceramic can be brazed
+ Flux-free soldering in air; applicable by using special alloys

The **fields of application** of this production technology are manifold:

- Food and pharmaceutical industry
- Mechanical engineering
- Sensor technology and metrology
- Cutting tool, watch and jewellery industry
- Security engineering

08

VACUUM BRAZED WEAR RESISTANT COATINGS

Edge-sharp coatings with a precise contour against abrasive and corrosive wear.

Figure 1

Figure 2

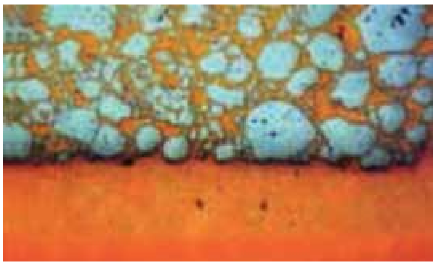


Figure 3

For wear protection, component surfaces can be locally coated with solid shaped bodies made of hard metals, ceramics, and diamond.

Figure 1 shows a saw tooth for a chain saw, consisting of a steel body and a carbide tooth. Vacuum brazing results in high-strength, reproducible joints that prevent the carbide tooth from breaking out during its use.

In the BrazeCoat®S-process, the surfaces are protected from wear by applying and melting a hard-material brazing alloy suspension. Coating thicknesses between 0.05 and 0.5 mm can be obtained.

The coatings are dense, smooth, and almost non-porous (< 1 %), with hardness values of up to 65 HRC. In most cases, a mechanical finishing is not necessary (Fig. 2).

BrazeCoat®S has proven to be an appropriate process for fans, mill housing and rotors as well as for cylinders, pistons and piston rods in hydraulics and pneumatics.

In the BrazeCoat®M process, flexible preforms made of polymer-bonded carbides and braze alloy powders (for example NiCrBSi) are precisely cut and placed layer by layer on the surface of the component. In a furnace process, the carbide layer is infiltrated by the liquid brazing alloy and bonded to the base material (Fig. 3).

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Figure 4

Figure 5

Using this production technique, it is possible to produce precisely contoured, edge-sharp layers with thicknesses between approximately 0.7 and a few mm. Typical applications of these coatings are where severe abrasive wear or a combination of abrasive and corrosive wear occurs. This technique allows to achieve significantly longer service lives for components such as pump housings, mixing blades or extruders (Fig. 4).

A vacuum sintering process is used to produce new, densely sintered wear protection plates, which are characterized by maximum wear, corrosion and impact resistance. The surface is smooth and crack-free. As prefabricated construction elements, they can be cut, welded and to some extend deformed to their final dimensions using various processes (Fig. 5). The hardness of the layers can be adjusted between 700 and 1800HV 0.5, depending on the application.

09

VACUUM BRAZED CUTTING AND GRINDING TOOLS

The active brazing process enables a high-strength metallurgical bond between the hard material and the tool carrier. This leads to better application properties in all applications where high mechanical and/or thermal loads occur.

The need for improved cutting and grinding processes, as well as the use of new materials and components with complex shapes, require the use of tools with diamonds or cBN as cutting or grinding materials. Vacuum brazing is a universal method to attach super-hard abrasive grains or shaped bodies to a tool carrier. The combination of vacuum brazing and active brazing alloys opens up new possibilities with regard to the selection of super-hard materials and the tool design. Diamonds and cBN can be joined to a wide range of tool carriers without a prior metallization. For grinding tools, the grit size, distribution, and embedment of the abrasive grains can thus be adapted to the specific application conditions.

The active brazing process enables high-strength, metallurgical bonds between the hard-material and the tool carrier. This leads to improved application properties in all applications where high mechanical and/or thermal loads occur.

Further **advantages** of this bonding technique:

+ Broader range of applicable brazing alloys
+ Variable brazing temperatures
+ Previous metallization or carbide base of the hard material not required
+ Adjusted brazing strengths
+ Increased operating temperature
+ Strong metallurgical bonds
+ Larger grain protrusion

Hard materials that can be used:

- Carbide, ceramic (silicon nitride, silicon carbide, aluminum oxide), cBN or diamond.

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