Electric Feedthroughs and Insulating Parts
1. Introduction

Electrical feedthroughs and insulating parts are an important condition for the operating function of a variety of technical tools and plants. Many varieties of insulating materials are available for the breadth of applications of such construction parts. Figure 1 illustrates the fact that oxide ceramic materials represent only a relatively small segment of this spectrum. They will usually be applied only when there is a demand for properties which are not provided by other, cheaper materials. One example is the need for a high level of electric resistance and mechanical strength for temperatures above 500°C with a simultaneous resistance to quick changes in temperature. In such cases, alumina is usually the only suitable insulating material.

Apart from very few exceptions, it is vital for the use of products that the ceramic is joined flush and vacuum tight with metal parts. There are various joining techniques today to achieve this and these are introduced below.
2. Joining Techniques

Figure 2 [1] shows an overview of standard joining techniques used today for ceramic - metal and ceramic - ceramic joints. The MoMn procedure which is mostly used for flush and vacuum tight joints of these materials is based on research which goes back to the first half of the last century [2, 3, 4]. Active brazing has recently become more possible due to the availability of suitable brazes but is used in a comparatively limited way. Both joining techniques are summarized in Figure 3 [1].
2.1 Brazing MoMn-metallized Ceramic

The MoMn-procedure is based on a suspension of the pulverized inorganic components in an organic ink system. This suspension is applied to the surface of the ceramic and a metallizing layer is created by a firing process which clings tightly to the surface [5, 6]. As the majority of the standard vacuum brazes does not wet the metallization it is plated by 2 – 5 μm thick Nickel using galvanic or chemical procedures. The ceramic, once it has been prepared in this way, is then brazed to the appropriate metal parts in a reducing atmosphere or in a sufficiently high vacuum. Silver copper eutectic alloy is used as standard material. Figure 4a shows a cross-section of the joined area of the compound 99.7%Al₂O₃- Ceramic/AgCu28/Mo.

This combination of materials achieves strength values of more than 200 MPa during tensile tests according to [8] at room temperature.

With increased demands on application temperature, corrosion features and where metals are used which are not wetted by this braze, brazes with increased melting properties are used. Table 1 gives an overview [7].

<table>
<thead>
<tr>
<th>Braze Material</th>
<th>Interval (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag Cu 28</td>
<td>780</td>
</tr>
<tr>
<td>Ag Cu 26.6 Pd 5</td>
<td>807 - 810</td>
</tr>
<tr>
<td>Ag Cu 21 Pd 25</td>
<td>910 - 950</td>
</tr>
<tr>
<td>Au Ni 18</td>
<td>950</td>
</tr>
<tr>
<td>Cu Ge 10</td>
<td>900 - 1000</td>
</tr>
<tr>
<td>Au Cu 65</td>
<td>1000 - 1020</td>
</tr>
</tbody>
</table>

2.2 Direct Brazing

This procedure is based on the use of brazes with a low metal content, e.g. Ti, Zr, Hf. They wet Al₂O₃ which means that there is no need for prior metallization. The strength values of active brazed Al₂O₃-ceramic/Ni42-compounds achieve values of brazed and metallized compounds [9, 10]. Figure 4b gives a further example of the joining area of a ZrO₂ ceramic and steel joint brazed by AgCu26, 5Ti3. However, while active brazing is an attractive option for technical and economic reasons, it has to be said that when it is used especially on feedthroughs, the braze does not flow into the braze gap but remains in the braze depot. If this peculiarity is considered in certain constructions there are ways around this restriction.

Figure 4b: Cross-section of active brazed ZrO₂ ceramic
3. Choice of Materials and Construction

According to [11] approx 70% of variable manufacturing costs arise during construction. This value originates from the automobile industry and may be transferred to electric feedthroughs and insulating parts only with certain provisos; however it proves that responsibility to provide the customer with a product which is meeting his or her expectations lies in the construction process, while at the same time making sure the product is manufactured at a competitive price.

This means:

a) Realization of the required features using simple solutions and standardized starting products
b) construction adapted to ceramics
c) streamlined construction.

The choice of suitable ceramic and metal materials initially requires thorough knowledge of application conditions. Table 2 gives an overview over central requirements in the three joining areas ceramic, joining area and metal.

Designing the joining construction takes place in line with the geometric indications by the user and the thermal suitability of the chosen materials (Figure 5).

### Table 2: Central requirements

<table>
<thead>
<tr>
<th>Properties</th>
<th>Focus on:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ceramic</td>
</tr>
<tr>
<td>Electric:</td>
<td></td>
</tr>
<tr>
<td>Breakdown voltage</td>
<td>+</td>
</tr>
<tr>
<td>Sparkover voltage</td>
<td>+</td>
</tr>
<tr>
<td>Creepage path</td>
<td>+</td>
</tr>
<tr>
<td>Dielectric constants</td>
<td>+</td>
</tr>
<tr>
<td>Resistance</td>
<td>+</td>
</tr>
<tr>
<td>Magnetic</td>
<td></td>
</tr>
<tr>
<td>Thermal:</td>
<td></td>
</tr>
<tr>
<td>Temperature during application</td>
<td>+</td>
</tr>
<tr>
<td>Definition of temperature shock</td>
<td>+</td>
</tr>
<tr>
<td>Mechanic:</td>
<td></td>
</tr>
<tr>
<td>Strength</td>
<td>+</td>
</tr>
<tr>
<td>Geometric:</td>
<td></td>
</tr>
<tr>
<td>Size tolerance</td>
<td></td>
</tr>
<tr>
<td>Surface roughness</td>
<td>+</td>
</tr>
<tr>
<td>Leak rate: Helium</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Central requirements

Figure 5: Thermal expansion of metals compared with $\text{Al}_2\text{O}_3$ ceramic
Figure 6 shows some basic types of joint constructions which are frequently used for feedthroughs and insulating parts.

Where possible the ceramic metal joint is created in such a way that the metal part, once brazed, exerts compression strain onto the ceramic as ceramic achieves the highest strength values under this type of load.

The construction type 1 comes close to the specified target. In the case of outside circumferential brazing specially adapted metal composite materials (Ni42, NiCo 2918) or metals whose WAK is higher than that of ceramic are the preferred working materials. The adapted composite materials are also suited for inside circumferential brazing, however the thermal expansion coefficient (WAK) of other metals should generally be below that of ceramic. An exception are metals such as copper which can also be used for inside and outside circumferential brazing in spite of their high WAK, as these materials are able to reduce crack inducing tensions in the joining zone due to their ductility.

Not only does radial compression strain occur with outside circumferential brazing but, due to the varying axial shrinking process of ceramic and metal during the cooling process, shearing stress and tensile stress at the outer junction between ceramic and metal. These stresses are generally negligible when adapted composites or ductile metals are used for wall thicknesses of less than 1mm.

In order to be able to work even with few ductile metals such as austenitic steel, the wall thickness of metal parts in the brazed area is often reduced to few tenth millimetres. This allows the mechanic elasticity of the metal part to be increased. This measure allows brazing of metal parts with a brazing diameter of around 10mm without damaging the ceramic.

Greater diameters require the introduction of moveable moulded parts. Where these may be magnetic, brazing e.g. a Ni42 flange of type 1c and consecutive welding on of the steel part is sensible.

If outside or inside circumferential brazing is intended at both ends of a pipe, it is usual practice to cut a groove into the ceramic (type 1b). Such a groove causes additional notch effect, but this may be controlled by the appliance of sufficiently great radii in the area of the grooves especially when using adapted alloys or ductile metals.

The benefit of this construction may be found in the fact that brazing fixtures will be kept to a minimum and it allows for simple installation of individual parts to be brazed. However, additional effort is required for processing ceramic and this may compensate this cost benefit with the increasing size of ceramic construction parts and/or low number of items.
Applicability of construction type 1 is often limited to brazed diameters smaller than 50 mm when using non adapted metals, as the differences in WAK of ceramic and metal at brazing temperature may result in brazing gaps which may be filled with sufficient braze only at increased cost. For example the brazing gap of two Al₂O₃ Ceramic and copper pipes in axial symmetric alignment already amounts to 0.4 mm with 100 mm brazing diameter and 800°C after the WAK.

In such cases construction type 2 is often used. The same applies for brazing larger metal parts made from austenitic steel via a ductile intermediate copper layer, as this type of construction allows for great mobility of the metal parts on the front area of the ceramic. Figure 7 shows such a construction as an example. This type of construction makes increased demands of the strength properties of the ceramic, as generally only tensile stress occurs in the joining zone. With a view to manufacturing costs, brazing fixtures need to be more elaborate than for type 1 to meet narrow size tolerances. It seems obvious to design the metal parts in such a way that they are centred on the ceramic without further devices but the expense would be prohibitive except for large quantities.

The construction types 1 and 2 are not always appropriate as some applications have space restrictions which require a compact construction part. With such requirements flat soldering according to Type 3 is used. With this construction type the ceramic is stressed mainly with regards to shearing and tension. Especially with this type the joining zone must stand up to maximum loads as the joining area typically lies above that of Type 2: such constructions are manufactured using only adapted metal alloys or ductile metals.

Increasing mechanical safety of such a joint is achieved through a construction according to Type 3b using a ceramic ring which is welded on. This ring forces the metal part to shrink during the cooling process radially and symmetrically and results in reducing the stress in the joining zone.

Figure 7: Al₂O₃ ceramic brazed with austenitic steel with copper layer according to Type 2
4. Application Examples

Electric feed-throughs and insulating parts are used e.g. in the following areas:

**Electrical Engineering**
- Single terminal and multiterminal feedthroughs
- High pressure feedthroughs for onshore/offshore technology
- Isolating tubes for fluids, gases and ultra-high vacuum
- Standoffs
- Components for accelerator technology
- Components for sensor technology

**Measurement and control technology**
- Cable end plugs for thermocouples and heating elements
- Pressure-sealed feedthroughs for flow and filling level measurement
- Housing for magnetic positioner sensor

**Medical technology**
- Rotating X-ray tube for computed tomography
- Image intensifier for radiology

**Accelerator technology**
- Dipole, kicker and quadrupole chambers for beam deflection and focusing
- Coupling windows for high frequency
- Isolators for high voltage, segmented isolators for DC-Guns
- Metalized ceramics for stochastic beam cooling

**Vacuum technology**
- Feedthroughs for different voltages and currents
- Insulators and tube-to-tube insulators for mechanical engineering and construction

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**Literature**


