Whenever it Gets a Bit Warmer: Technical Ceramics in Electric Heating

Technical ceramics made of many different ceramic materials as well as in many different geometries (Fig. 1) have been indispensable for decades in electric heating technology, because only ceramics (and in some cases glass or similar materials) combine good electrical insulation with high temperature resistance and good mechanical strength. Where other materials, such as plastics, are already failing, ceramics still do their job reliably.

Fields of application of ceramics

In most cases, ceramics are used as electrical insulators in electric heating. However, it should not be overlooked that ceramic materials can also be used as heat conductors, for example ceramics based on silicon carbide (SiC), molybdenum disilicide ($MoSi_2$), PTC ceramics or zirconium oxide (ZrO_2). These materials will not be discussed at this point – only applications where the ceramic serves as an electrical insulator. In most cases, the ceramic carries the metallic heat conductor and electrically insulates it from the (metallic) housing or other heating wires, leads, etc. Depending on the application, different, long-proven designs have emerged over the years, which, apart from smaller manufacturer-specific variations, have established themselves as a kind of standard in the industry. Depending on the requirements in the specific applications, various ceramic materials are used.

In the following, some types of heating elements based on ceramic insulating materials are presented by way of example.

Band heaters and heating frames

A typical application for band heaters (sometimes also called "knuckle heaters") is in plastic technology, where extruders and cylinders of injection moulding machines are heated with such tempered heating elements. The same design can be used to produce heating mats or frames to heat, for example, larger tools or other devices.

Ceramic knuckle beads made of steatite C221 or, more rarely, cordierite C410 or aluminium oxide are used for the production. These are distributed in three sizes, but the most commonly used is the medium size with a thickness of approx 9 mm. A "mini size" with approx 6 mm and a large version with 12–15 mm can also be used, but these are much less common (Fig. 2). To produce the heating elements, the beads, which are available in various lengths from 1-hole design to 12-hole versions, are initially stacked in the required length and width. At the ends, there are special slotted versions of the knuckle beads, which allow a deflection of the heating coil without short circuit. The heating coil is then pulled through the holes of the perforated strips, which can be connected by specially slotted connecting blocks. The band heater is completed by addition of a metal jacket through which cooling air (in heating-cooling combinations) can be passed. Due to the bow-shaped design of the insulators, the band heater can be bent into a certain radius, wherein the ceramics can move in the radii at the top and bottom against each other and thus can adapt to the bending radius.

Although it has been in use for years, the suitability of steatite C221 for this application must be questioned: steatite has a thermal conductivity of 2–3 W/m·K at room temperature, but this must transport the heat from the heating coil to the outside. What speaks for the steatite is that it is a relatively inexpensive raw material and easy to process, but in the interests of better heat transfer, alumina – with a thermal conductivity of 25 W/m·K – would certainly

Fig. 1
Overview of typical technical ceramics for electric heating manufactured by Rauschert

Keywords

band heater, heating frames, heating elements, cartridge heater, crushable ceramics

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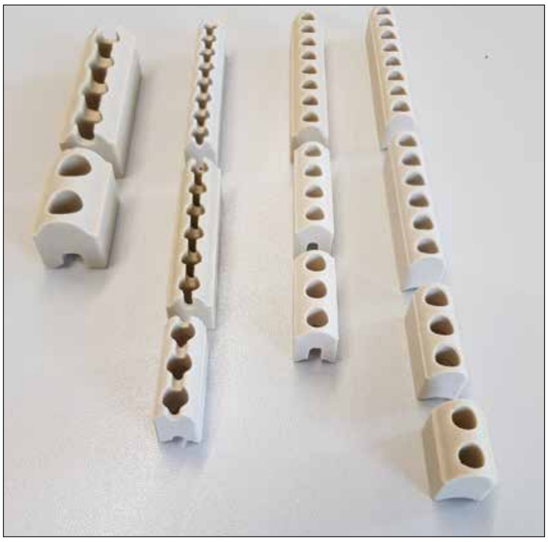

Fig. 2
Ceramic parts for band heaters, large version (l.) and medium, most common size with slots on bottom and top (middle l.), slot on bottom (middle r.) and without slots (r.)

Fig. 3
Ceramic parts for tank heater and bobbin heaters: round and flat oval shaped cordierite tubes (l.), parts for bobbin heaters including end bushes and connecting head (r.)

be the better choice. Of course, the higher price of raw materials for alumina and the more difficult shaping of this material are a disadvantage. Occasionally, alumina is already in use at present, especially in a particular design with cooling fins on the outside of the ceramics [1].

Tubular tank heaters

For the treatment of liquids, tubular heating elements, which are heated from the inside, have proven useful. The metallic jacket pipes are partially installed firmly in the container, so that the heating element can be exchanged from outside if necessary, without having to empty the container. With this type of heating element, instantaneous water heaters can also be made.

For heating elements with smaller diameters, extruded tubes made of steatite C221 or cordierite materials are used. These have 4, 6, 8 – rarely more – holes on an outer diameter and often a central hole through which tubes can be fixed by means of a tie rod or a threaded rod. The heating coil is routed through the outer holes. For heating of liquids, steatite tubes are usually used, whereas cordierite is preferred for gas heaters (Fig. 3). Since these tubes are extruded, they are available in lengths of up to approx 300 mm, lengths of 100 mm or 150 mm are widely used. In addition to round tubes, flat oval tubes are also in use. A ceramic end plate isolates the deflected heating coil from the bottom of the metallic sheath and in some cases a suitable ceramic connection head is also used.

For larger diameters of heating elements, pressed insulators based on cordierite ceramics are often used (so called bobbin heaters). These have a standard length of 50 mm – Other lengths are used in exceptional cases. The common system diameters are 32 mm, 35/36 mm, 45 mm, 47,5 mm and 57 mm. Instead of external holes, these insulators have grooves on the outside, in which the heating coils are guided (Fig. 3). By twisting the ceramics against each other, the grooves can always be crossed over the length of a ceramic against each other so that the heating coil cannot sag together when heated in vertical use. In a central bore, a tie rod holds the entire heating element together, which is completed by means of an end plate and connection head. This makes designs of several meters in total length possible. For cramped installation conditions, flexible variants are also used, in which specially designed insulators can be bent against each other with a suitably flexible tie rod.

Tubular heater

For liquid and air heating, tabular heaters are often used in industrial and domestic installations. For air heating, these have fins on the outside to create a larger area for heat transfer. These radiators can be bent in tight radii, several heating elements can also be combined in a flange.

In tubular heaters, the heating coils are embedded centrally in the heating element in compressed magnesium oxide. Usually this is filled in powder form after the heating coils have been clamped in the pipes. Only in exceptional cases are crushable magnesium oxide ceramics used here. The metallic pins at both ends of the heating coil are isolated from the sheath tube by means of steatite ceramic end bushes or more rarely alumina (at high use temperatures). These are installed before the compacting of the tubular heaters and are therefore fixed during compacting of the radiator by rotary swaging/hammering. Extralong end bushes are also used for special designs, for example in explosion hazard areas.

Cartridge heaters

For heating tools, hot runner nozzles and manifolds in plastics technology, analysers and many other applications, heating cartridges of various types are used. Cylindrical cartridge heaters are available in outside diameters of approx. 3–40 mm at maximum lengths of 1000–3000 mm. Coiled heaters have also often square or rectangular cross-sections in addition to round cross-sections and are often coiled or otherwise bent. However, the cross sections are clearly smaller than with cartridge heaters and are in the range of 1,8 mm to

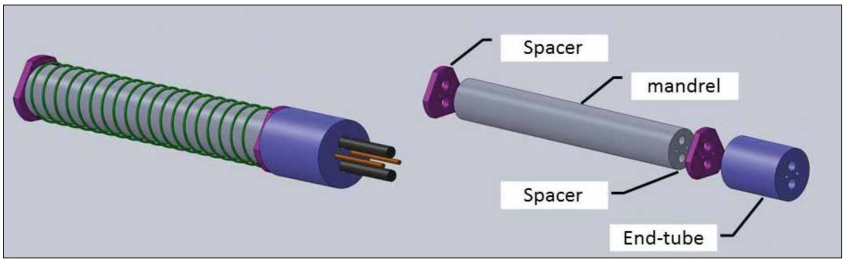

Fig. 4
Schematic design of a cartridge heater

Fig. 5
Overview of typical crushable ceramics manufactured by Rauschert

approx 8 mm max but typically in the range of 2–5 mm. For more detailed information have a look at [2].

Heating elements, (micro-)coiled heaters/tubular cartridge heaters and special thermocouples are made from crushable ceramics compacted using hammering, the procedure is also known from cold forming under the term rotary swaging. To produce high performance cartridge heaters, a thin heat conductor wire is first wound around a mandrel (Figs. 4–5). Metal rods are inserted through the larger boreholes in the centre of the mandrel via which the power is supplied. The heat conductor wire is connected to these. Targeted distribution of power can be set along the length of the heating element by varying the winding distances. The mandrel is then centred using a thin-walled tube or with the help of spacers in the sheath tube. Any remaining gaps are filled with a free-flowing MgO sand, the heating element is then sealed. The external diameter is reduced by approx 20 % by the rotary swaging. During this process, the crushable ceramic in the inside breaks into the initial grain size and this seals the heat conductor and

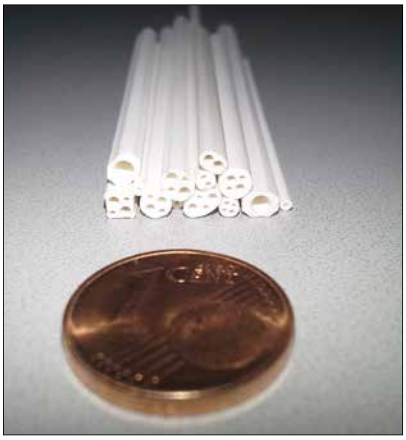

Fig. 6
Crushable tubes for micro-coiled heaters manufactured by Rauschert

any thermocouple that has been installed. Electrical insulation is thus ensured and, at the same time, good heat transfer from the heat conductor through the ceramics to the metallic sheath tube of the heating element is ensured. During the reduction of the external diameter, the parameters must be coordinated with each other such that a certain lengthening of the element occurs. This ensures that the maximum compaction of the crushable ceramic has taken place. To manufacture coiled heaters, a heating coil is first wound around a metal mandrel. This is then removed to separate the individual coils from each other. Small, thin-walled tubes with one or more boreholes are pulled over the coils (Fig. 6) and then pushed into the metallic sheath tube. This sheath tube is then compacted by swaging, the MgO is thus moved between the heating coils and into the empty interior space. After this process has been completed, the heating coil is completely embedded in MgO. These coiled heaters can be bent into astoundingly tight radii, you can even make a knot with them. As long as the degree of deformation does not go below certain bending radii that have been specified by the manufacturer, the safe operation of the tubular cartridge heaters is still guaranteed, even after they have been bent. The grain-size distribution of the MgO insulation is defined such that the maximum level of electrical insulation is ensured, but that bending of the cartridges is still permitted. The powder flows when the sheath tube is bent and ensures the dissipation of heat outwards and maintenance of the electrical insulation between the heating coils themselves and between the heating coils and the sheath tube.

Summary

Technical ceramics are widely used in electrical heating technology. Only a few designs and applications have been described here by way of example.

There are many fields of application for these ceramics, from plastics technology, analysers, medical devices, automotive industry, railway technology, household appliances, packaging machines, general gas and liquid heating, soldering iron and many more applications. In some cases, standard solutions are sufficient, but often a customised special solution has to be developed. For most requirements, whether standard or customised systems, Rauschert has a solution.

References

[1] Michels, R.: German patent, 1998, Patent No. DE19855357A1

[2] Werr, U.: Crushable ceramics – or how a knot can be tied in a ceramic pipe. CERAMIC APPLICATIONS **7** (2019) [1] 44–49