Material Re-Visited: Steatite May be Old, but Still Up-to-Date!

Porcelain, the material from which plates and cups are made, was the first ceramic feedstock to be processed for electrical engineering applications. The second oldest material for such uses is soapstone. Nowadays soap-stone and its derivatives (i.e. steatites) are indispensable articles of every-day life and essential materials for industrial applications. Steatites have outstanding dielectric properties and possess great mechanical strength. Accordingly, they are used in an ever-growing number of applications and often replace oxide ceramics. Their favourable cost/benefit ratios make steatites a cost-effective alternative to oxide ceramics such as alumina and zirconia.

Introduction

A synonym of soapstone is steatite, which comes from the Greek “stéar”, meaning fat (noun). This explains the origin of the use of the terms steatite and soapstone, since the substance feels greasy or soapy to the touch.

However, the term steatite is far more often used for several kinds of technical ceramics that consist mostly of soapstone [1], but have been fired in a kiln and consequently lack the soft and soapy consistency of natural soapstone.

Technical ceramics for applications in electrical engineering are covered by the DIN EN 60672-3 standard. This standard was originally designated DIN 40685, and included steatite as early as 1940 [2]. In addition to its applications in electrical engineering, steatite is also used as a wear-resistant ceramic for production of grinding balls and linings for mills. However, in the last few years steatite has been progressively replaced in milling applications by ceramics or polymers.

History

When coal gas began being used for indoor and outdoor lighting in 1792 and after it was replaced by acetylene, demand arose for heat-resistant ceramic burners with low thermal conductivity. The raw material used for making burners was fired soapstone, i.e. steatite. Soapstone began to be mined underground in the Fichtel mountain range located in Bavaria and neighbouring parts of Bohemia. It was then used to manufacture the required burners using lathes and other similar equipment. The soapstone was then fired to make steatite, thus giving it the required mechanical strength and resistance to heat. The so-called Auer lamp fitted with a nitrate-soaked incandescent mantle, which made its appearance around 1895, also required a ceramic support ring made of steatite [3].

Their manufacture using lathes generated huge amounts of waste in the form of soapstone dust and shavings. Initially, 100 kg of soapstone was required to manufacture 1 kg of steatite burners using lathes; even as manufacturing techniques became more efficient, the waste-to-output ratio remained in the 50–95 % range. Engineers at Siemens-Schuckert developed a technique that consisted of mixing waste dust with ceramic raw materials, pressing the mixture and then firing it. By 1889 they had managed to develop a process for the mass production of ceramic components [3].

In subsequent years it became possible to manufacture smaller components from this material, since the new manufacturing method relying on pressing enabled mass production of components that complied with very precise dimensional specifications. Steatite materials received an additional boost when radio technology and broadcasting became more widespread during the 1920s.

It was discovered that steatite had a lower electrical dissipation factor than porcelain and, in many applications, also greater permittivity. When faced by the challenge of high-frequency technology, steatite materials underwent further development in order to satisfy the requirements of this new market. The addition of barium carbonate to steatite both increased its toughness and improved its high-frequency properties [4]. The resulting steatite items were sold under different trade names [3]: the Stemag company sold Frequenta and Steatit, while Hescho sold Calit and Calan. Other trade names followed.

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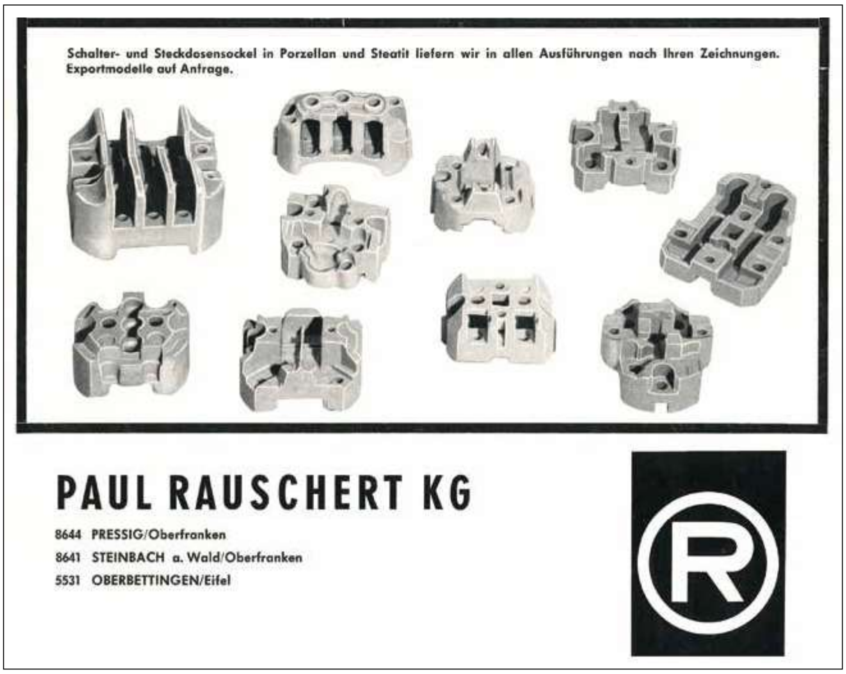

Fig. 1
Excerpt from a Rauschert brochure (undated, probably from the 1960s)

In subsequent years, steatite steadily replaced electro-porcelain in many electrical engineering applications as a material for small components, since steatite products were easier to manufacture in large quantities. This occurred for instance at the Rauschert company (Fig. 1).

Fig. 2
Steatite components manufactured by dry pressing *(Source: Rauschert)*

Raw materials

The principal raw material for making steatite is soapstone, which mineralogically speaking consists of talc (chemical formula: $Mg_3[(OH)_2/Si_4O_{10}]$ or $3MgO \cdot 4SiO_2 \cdot H_2O$). Whereas talc consists of flakes, soapstone is compact and dense, but extremely soft (Mohs scratch hardness: 1, the softest grade on the Mohs scale) [5].

The preferred raw materials for making steatite ceramics are soapstones with few impurities. If talc must be used because it is more readily available or purer, it is first calcined, otherwise talc's laminar consistency can generate prominent textures during moulding. Soapstone or talc makes up about 80–90 % of the raw material's recipe. Depending on the kind of steatite desired (see "Properties of materials" section), various other raw materials are added to the soapstone [6]:

For regular steatite C220, about 5–10 % of feldspars and plastic clays are added. To make special steatite C221, barium carbonate is added as well. Zirconium silicates can also be added to increase resistance to thermal shock (and mechanical strength) [7]. To make brown steatites, chromium and iron oxides are added for pigmentation.

Manufacture

Steatite components are usually moulded by dry pressing. Since the predominant raw material, soapstone or talc, is very soft (1 on the Mohs hardness scale), the tools used for processing steatite endure less wear than those used for other ceramics. In addition, these raw materials enable the manufacture of components with extremely complex and intricate shapes that cannot be made from other materials using dry pressing technology. The laminar consistency of the raw materials also allows a kind of "flow" when they are moulded by dry pressing. This enables economical mass production of complex components in huge numbers by means of dry pressing. Since steatites undergo only relatively little shrinkage during processing and at the same time their compression is homogeneous, their use allows the attainment of extremely narrow tolerances, while no strenuous (and therefore costly) reworking is needed once they have been fired (Fig. 2).

Steatite is hardly ever moulded by wet pressing nowadays, since dry pressing

Tab. 1
Summary of the material characteristics of magnesium silicates belonging to the C200 group; for details see DIN EN 60672 [2]

	Group C200					
	C210	**C220**	**C221**	**C230**	**C240**	**C250**
Characteristic	**Low-voltage steatite**	**Steatite, regular**	**Steatite, low dissipation**	**Steatite, porous**	**Forsterite, porous**	**Forsterite, dense**
Open porosity [vol-%]	0,5	0,0	0,0	35	30	0,0
Density [g/cm^3]	2,3	2,6	2,7	1,8	1,9	2,8
Cross bending strength [MPa]	80	120	140	30	35	140
Young's modulus [GPa]	60	80	110	–	–	–
Mean coefficient of thermal expansion [10^{-6} K^{-1}]	6 to 8	7 to 9	7 to 9	8 to 10	8 to 10	9 to 11
Thermal conductivity [$W\cdot m^{-1}\cdot K^{-1}$]	1 to 2,5	2 to 3	2 to 3	1,5 to 2	1,4 to 2	3 to 4
Dielectric strength [$kV\cdot mm^{-1}$]	–	15	20	–	–	–
Dielectric constant [–]	6	6	6	–	–	6
Dissipation factor at 1 MHz [10^{-3}]	7	3	1,5	–	–	0,5

generates components of better quality that can also have complex shapes. In addition to moulding by dry pressing, many components are manufactured by extrusion, especially long components like rods, tubes and axles.
Manufacture by injection moulding is only used in special cases, when the complex shape of the component to be manufactured does not allow moulding by dry pressing or by extrusion, sometimes combined with machining before being fired. Due to the high cost of steatite feedstock intended for injection moulding, that of processing it and of subsequently debinding the output, this manufacturing process is cost-effective only in exceptional cases. Nonetheless, the Rauschert company has for years occasionally resorted to this process to produce small and medium sized batches, since the company has its own raw material recipe and does not depend on outside suppliers of feedstock ready for processing.
Steatite components are fired at temperatures between 1280–1350 °C, except for porous steatite C230 (see beneath).

Properties of materials

The characteristics of steatite are specified in DIN EN 606072, in group C200 "Magnesium silicates". This standard lists the following steatite materials [1], the most important properties of which are summarised in Tab. 1.
An important feature of DIN EN 606072 is that it does not specify the composition of the materials, but instead their properties from the standpoint of their respective applications in electrical engineering.
No standard exists that specifies the composition of materials for electrical insulation. Typically, steatites contain 58–65 % SiO_2, 26–32 % MgO, 3–6 % Al_2O_3, 1,0–1,5 % Na_2O or K_2O (in the case of C220), or up to 5 % BaO (in the case of C221).
Each material listed in this group has its own characteristics:

- C210 Low-voltage steatite: To the author's knowledge, this type is no longer used, since it offers no advantage over other steatites. The C210 type was allowed to contain a small residual porosity of 0,5 %. In the author's opinion, it resembles the steatite ceramics that used to be made from soapstone waste.
- C220 Steatite, regular – colloquially known as regular steatite (German: Normalsteatit): This material is still used sporadically, often for applications for which many years ago special use permits were required, which were approved with C220. Switching to the far more commonly used C221 would entail cumbersome applications for a new permit; consequently this material is still in use, although rarely.
- C221 Steatite, low dissipation factor – also called special steatite (German: Sondersteatit) or high-frequency steatite (German: Hochfrequenzsteatit). This type is characterised with the addition of barium carbonate, which reduces the loss angle (*tan* δ) and thus makes the material particularly suitable for high-frequency applications. One side effect is that its mechanical strength is also greater than C220. For several decades now, C221 has been by far the most commonly used steatite, even though its favourable high-frequency properties are no longer relevant for most applications nowadays. Steatite is employed in these cases because of its good mechanical properties, because it allows the manufacture of components with complicated shapes within tight tolerances, and because it is cheaper than most oxide ceramics.
- C230 Steatite, porous: This material, deliberately made porous, holds an exceptional position in the group of steatite materials. It is made from the same raw materials as C220 and C221, but is fired at a significantly lower temperature than C220 or C221, namely at 650 °C to 1050 °C. As a result, this material has completely different applications from

Tab. 2
Typical applications for steatite materials and their major properties

Applications	Mayor property of material								
	Electrical insulation capacity	Creep resistance	Resistance to ageing	Mechanical strength	Resistance to thermal shock	Low coupling to microwaves	Resistance to wear	Resistance to corrosion	Low thermal conductivity
Fuse bodies	X	X	X	X	X				X
Lamp holders (including UV/IR-lamps)	X	X	X		X				X
Grinding balls/linings for mills						X	X		
Thermostat bases/switch pins	X	X	X		X				X
Brackets/components in microwave ovens				X	X	X			
Antenna mounts	X		X			X			
Guide rails for woodworking machines			X	X	X		X		X
Supports for resistors and potentiometers	X		X		X		X		X
Axles and shafts for pumps			X	X	X		X	X	
Housings for terminal blocks	X	X	X		X				
Terminal strips/motor terminal boards	X	X	X		X				
Thermocouple sockets	X		X		X			X	X
End bushes for tabular heaters/heating elements	X	X	X	X	X				
Stand off insulators	X	X	X	X					
Feedthroughs and bushings	X	X	X	X					
Support for heating conductors	X		X		X				X
Insulators for spark ignitors and flame sensors	X		X		X			X	

steatites C220 and C221, which become dense as a result of firing.

For the sake of completeness, it should be mentioned that the C200 group also includes the C240 Forsterite, porous and C250 Forsterite, dense. The more porous forsterite C240 had applications similar to those of steatite C230. The main difference between them is that C240 has a higher MgO content. C230 has by now almost completely displaced C240. The dense forsterite C250 distinguishes itself by having a higher coefficient of thermal expansion than C221. Accordingly, it is sometimes used in metal-ceramic compounds. This material is characterised by a higher MgO content than that of C221, however its use is restricted to a few niche applications. This article does not deal with either of the two forsterites.

Applications

One or more of the following outstanding properties of densely fired steatites define their possible areas of application (in part in accordance with [8]):

- Excellent electrical insulation properties: Steatites have enormous dielectric strength and high volume and surface resistance.
- Resistance to creep: The resistance to creep of an insulating material is influenced by its water absorption capacity and its behaviour under thermal and ionising stress (pre-discharge) [9]. Since densely fired materials (except for C210, which is no longer used, see above) absorb no moisture and are scarcely damaged by electric arcs etc., they have outstanding creep resistance [10].
- Low coupling to microwave fields: Due to the low dissipation factor (*tan δ*) and the low dielectric constant, steatite C221 in particular couples very poorly to microwaves and therefore barely heats up when used within such fields.
- Resistance to ageing: External factors like moisture, but also UV rays, for instance, do not damage steatites. They also withstand many chemicals well, but oxide ceramics resist strong corrosives better than steatites. This fact should be borne in mind.
- Rigid and resistant to thermal shock: since they are very stiff, although not as stiff as most oxide ceramics, and expand only slightly in response to heat, they withstand thermal shock well. These properties also make them very resistant to wear.

In addition, they have very low heat conductivity (2–3 W/m·K [2]). This makes steatites suitable for thermal insulation. Compared to oxide ceramics, steatites' price-performance ratio is outstanding. This advantage increases in proportion to the size of the components: raw material costs amount to only about 1/3 of those of 99,7 % alumina, while their sintering temperatures are significantly lower, which entails lower energy costs. Tab. 2 provides an overview of applications for dense steatite materials. The applications of porous steatite vary greatly. The main applications are in electrical heating technology, in particular as crushable ceramics for manufacturing cartridge heaters.

Porous steatite can be used for cartridge heaters if parts of the heating element must be thermally insulated, because magnesium oxide, which can be used for this purpose instead, conducts heat at roughly ten times the rate of porous steatite. In addition, this material is used as a diaphragm in pH-probes and for similar applications. For this purpose a small, porous rod made of steatite C230 is melted into the wall of the glass cylinder. In the process, the coefficient of thermal expansion of the ceramic is matched to that of the glass to ensure a leak-proof seam between the glass and the ceramic, and to prevent the glass from cracking as a result of thermal stress.

Summary and prospects

Although steatites are a fairly old-fashioned group of engineering ceramics, they remain indispensable for many applications. Their cost-effective price/performance ratio, their remarkable mechanical properties and their outstanding electrical properties ensure that steatites will continue to occupy a large market share in many everyday and industrial applications.

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