Industry

SiC30 – Silicon Carbide / Graphite Composite Material
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SiC30 – An extraordinary silicon carbide/graphite composite material

Applications
The main fields of application of the SiC30 material are sliding rings and bearings for use in media with a poor lubricating capacity. The combination of excellent properties of graphite (good emergency-running properties, thermal shock resistance, etc.) and silicon carbide (hardness, strength, abrasion resistance) combined with an exceptional structure allows solving problems that would not be possible with other materials. The best results are often achieved with the material pairing of SiC30 vs. SiC30.

Production
The material SiC30 is produced by impregnating a highly porous electrographite with molten silicon. Generated by a chemical reaction between silicon and carbon, there is a chemical reaction that changes silicon and carbon into silicon carbide. The process continues until the pores are closed by the silicon carbide that has been formed.

Composition
The main components of the material are silicon carbide with about 62 % and about 35 % graphite; the content of free silicon is about 3 % (in each case, part by weight). This represents a volume share of about 53 % silicon carbide, about 43 % graphite and about 4 % silicon. The silicon carbide is present to about 95 % in the cubic β-SiC modification.

Structure
The unique thing about the structure is an interpenetrating network of graphite and silicon carbide (relics of coherent carbon structure or the pore system of the electro-graphite). Free silicon is merely present in the form of small islands that are enclosed in the silicon carbide phase.

Figure 1: Microstructure of graphite and silicon carbide

<table>
<thead>
<tr>
<th>Physical properties</th>
<th>Bulk density [g/cm³]</th>
<th>2.65</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porosity [Vol.-%]</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Flexural strength</td>
<td>(N/mm²)</td>
<td>140</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>(N/mm²)</td>
<td>500</td>
</tr>
<tr>
<td>Young’s modulus (dyn.)</td>
<td>(kN/mm²)</td>
<td>140</td>
</tr>
<tr>
<td>Hardness</td>
<td>consists of a hard SiC- and a soft graphite phase</td>
<td></td>
</tr>
<tr>
<td>Temperature resistance</td>
<td>oxidizing atmosphere</td>
<td>°C</td>
</tr>
<tr>
<td>θ 20 - 200  °C</td>
<td>°C</td>
<td>2,300</td>
</tr>
<tr>
<td>θ 20 - 1,000  °C</td>
<td>[10¹⁰/K]</td>
<td>3.0</td>
</tr>
<tr>
<td>Coefficient of thermal expansion</td>
<td>10¹⁰/K</td>
<td>4.0</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>kW/mK</td>
<td>125</td>
</tr>
<tr>
<td>Spec. electr. resistance</td>
<td>[μΩm]</td>
<td>120</td>
</tr>
</tbody>
</table>

These data are provided as typical values based on our experience. As with any raw material or manufacturing process, variations can occur. Consequently, both values are not guaranteed and are subject to change without notice.

Table 1: Physical properties of SiC30
Running behavior under marginal lubricated conditions

Emergency running properties of hard sliding materials such as silicon carbide ceramics can be excellently characterized with a high-pressure face seal test (see figure 2).

Sliding speed: 9.35 m/s
Balance ratio: 0.79
Media: demineralized water
Media temperature: 20 - 95 °C
Media pressure: 5 - 100 bar

During testing procedure media pressure and temperature were successively increased, leading to inadequate lubrication conditions. The emergency running properties are determined by the characteristics of power consumption (friction behaviour) and the runtime without abrupt power peaks.

For materials that have poor emergency running capabilities, the friction increases sharply at an early stage and marks the end of the test. The diagram in Figure 3 illustrates this with the example of a commercially available sintered silicon carbide (SSIC). SiC30, however, does not show this effect in any way. Lubrication is also maintained under critical conditions, an effect of the high graphite content in conjunction with a unique material structure (see Figure 5).

Figure 2: High-pressure face seal test rig
Figure 3: SiC30 vs. SiC30 and SSIC vs. SSIC test runs – a comparison
Figure 4: SSIC structure
Figure 5: Structural pattern of graphite and silicon carbide
Figure 6: Sealing rings of SiC30
Blister resistance

Blistering is one of the most common causes of failure for carbon materials in mechanical seals.

However, in tribological applications, materials with dry or emergency-running properties – and therefore carbon materials – are often indispensable. There is no carbon material that is completely blister resistant.

Blistering can be generated with the help of special seal ring tests. Blister resistance indexes (IBL) have been defined to evaluate the damages caused by blister formation:

- **Blister resistance index IBL = 10**
  - Blister resistant material
- **Blister resistance index IBL = 0**
  - Not suitable, because material has been destroyed

The results in Figure 8 show that the SiC30 material as a hard sliding partner has significantly improved the blistering resistance of carbon materials and that, if used as a “soft carbon material” in a pairing, it can completely prevent blistering.

Figure 7: Typical appearance of blistering on a carbon graphite sliding surface

Figure 8: Results of a series of blistering tests

Thermal shock behaviour

The thermal shock resistance as a characteristic material property is proportional to the material’s strength and thermal conductivity but in inverse proportion to its Young’s modulus and coefficient of thermal expansion.

The testing procedure

The resistance of tribological materials to thermal shock can be determined, among other things, by means of a comparative hot / cold test and defined maximum temperature differences that the material in the following test has survived unscathed. For the test, identical specimens were heated to pre-defined temperatures and then submerged in ice water. The results were standardized; the temperature difference found for SSiC was selected as a reference value.

Classification of thermal shock resistance

<table>
<thead>
<tr>
<th>Material</th>
<th>Relative thermal shock resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSiC (sintered silicon carbide)</td>
<td>1</td>
</tr>
<tr>
<td>SiSiC (reaction-bonded silicon carbide)</td>
<td>1</td>
</tr>
<tr>
<td>SiSiC-C (reaction-bonded graphite loaded silicon carbide)</td>
<td>1.15</td>
</tr>
<tr>
<td>SiC30</td>
<td>1.3</td>
</tr>
</tbody>
</table>

The thermal shock resistance of SiC30 is superior to all current silicon carbide ceramics used in tribological applications.

Figure 9: SiC30 bearings
**Chemical resistance**

Many ceramic materials for tribological applications have limited chemical resistance to highly corrosive media since their oxide or silicon-based bonding phase would corrode.

SiC30 does not have any oxidic phases and also does not have any accessible free silicon. The excellent chemical resistance of the SiC30 material has been confirmed in sophisticated testing. To do this, sliding rings and specimens were treated with a mixture of 77% HF (40% solution) and 23% HNO3 (65% solution). This solution is a very strong solvent for silicon. No dimensional changes were detected and there was only a slight loss in weight. The flexural strength of the SiC30 material remained almost unchanged. Results of bench tests show that the sliding rings from SiC30 maintain their excellent tribological properties even after the aforementioned acid treatment. Microscopic examinations proved that only small amounts of free silicon on the surface were dissolved out. Free silicon is not a bonding face in SiC30. The relevant phases (silicon carbide and graphite) are fully resistant.

### The material is inter alia resistant to:

- Aqueous salt solutions
- Organic reagents
- Strong acids (HF, HCl, H2SO4, HNO3)
- Hot inert gases

### Only in the following media SiC30 is partially resistant:

- Air and other oxidizing gases: At temperatures >500 °C, the graphite content “burns out” slowly. But even the remaining structure of SiC still has 50% of the strength of the base material.
- Molten metals: Various metals corrode SiC and graphite with the formation of silicides (e.g. cobalt, nickel) and carbides (aluminum, iron).
- Strongly alkaline media: Depending on the temperature, pressure and concentration, silicon carbide can only be corroded by the strongest alkalis.

Designing with SiC30

Rotationally symmetric components or rectangular plates are suitable geometries. For different components the recommended dimensions are summarized in table 2. If possible, deviations from these guidelines should be avoided or at least discussed with our technical application service beforehand.

With regard to producability and cost the following recommendations should be observed:

- No sharp changes in cross section
- Avoidance of large shoulders and undercuts
- Limitation of cuts, grooves and bores to a minimum

SiC30 can easily be shrink fitted into steel housings and is, compared to other SiC materials, significantly more tolerant to edge loads.

### Recommended dimensions for components made of SiC30

<table>
<thead>
<tr>
<th>Wall thickness</th>
<th>max. height</th>
<th>max. Ø</th>
<th>max. height</th>
<th>max. Ø</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 - 20 mm</td>
<td>20 mm</td>
<td>280 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 - 15 mm</td>
<td>35 mm</td>
<td>280 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 - 10 mm</td>
<td>100 mm</td>
<td>150 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 - 7 mm</td>
<td>70 mm</td>
<td>80 mm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Recommended dimensions for components made of SiC30