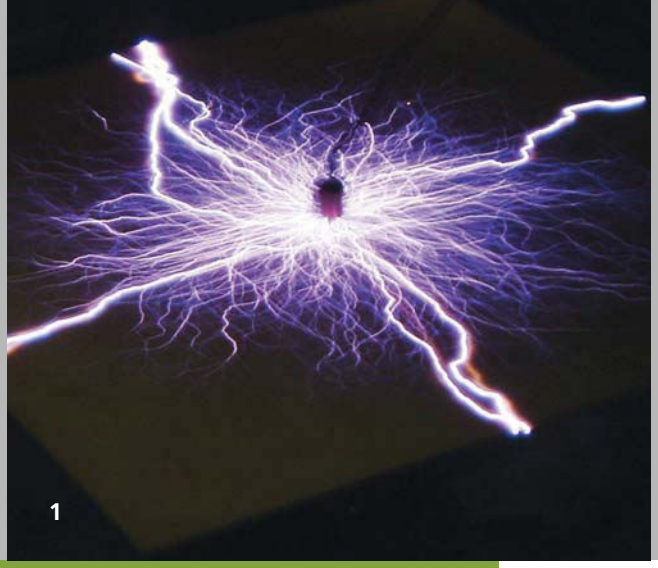

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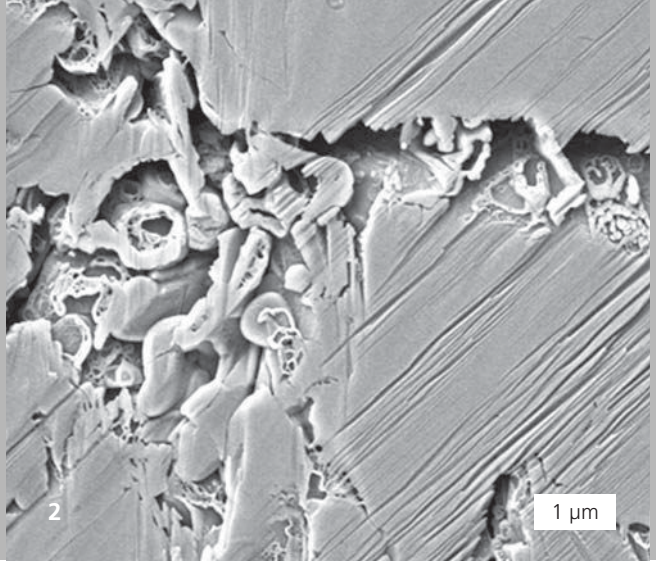

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FAILURE ANALYSIS AND CORROSION BEHAVIOR OF CERAMIC COMPONENTS

Dr. Mathias Herrmann, Dr. Sören Höhn, Dipl.-Ing. Kerstin Sempf, Dipl.-Ing. Roy Torke

The urgent need of cost-efficient production components, which exhibit longer lifetimes both under abrasive tribological and corrosive conditions, exists in broad areas of the economy. This leads to the increasing strain of existing materials and components in various applications. Besides developing high-performance materials, a substantial, stress-suitable materials selection for different applications is necessary in order to avoid early component failure. For that, detailed knowledge of the material behavior under mechanical thermal, corrosive and tribological stress is required. This knowledge can be generated, on the one hand, via well-engineered measurement and analysis methods, which can map extreme stress conditions. On the other hand, conclusions regarding the failure cause can be drawn from a profound analysis and evaluation of failure or defect incidents. Therefore, a qualification of the materials is possible. For solving research questions, a unique combination of modern analysis devices and know-how for the characterization of microstructures and properties of the entire range of ceramic materials, hard metals and cermets is available at IKTS. Due to the close linkage of the characterization with the other departments of IKTS, a substantial interpretation of the results is possible.

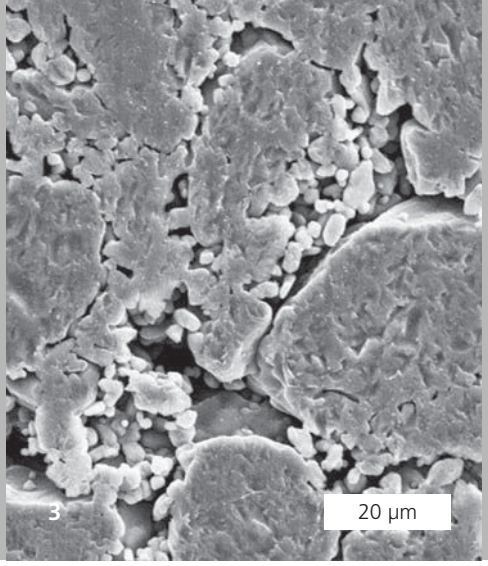
Regarding the analysis of both failure or defects incidents for customers and in-house developed components, extensive fractographic studies and changes in the microstructure and properties are performed. If necessary, accompanying simulations of stresses are possible to determine the failure causes. A fractographic analysis often clearly informs about the fracture source and fracture-causing defects. From the type and size, conclusions regarding stresses can be drawn and hence, possible failure causes. Non-destructively detetced defect in the component can be accurately prepared by mechanical or ion beam-based methods (BIB, FIB). These can be visualized with high-resolution imaging and analyzed. For this purpose, high-performance scanning electron microscopes and a transmission electron microscope are available at IKTS.

Via micro x-ray diffractometry or electron beam diffraction in the scanning electron microscope, information on the chemical analysis as well as crystalline structures of phases can be obtained.

An example for such a target preparation is shown in Figure 1 and 2. After applying thin hBN discs with a field strength of up to 80 KV/mm, puncture can be observed. In Figure 2, the puncture channel prepared via ion beam cutting is depicted. Analyses show that oxidation and melting of the hBN partially occur [1]. In contrast to other analyzed materials, hBN exhibits no microcracks around the puncture channel, which indicates an excellent thermal shock behavior.

The failure analysis can be replicated by simulating mechanical, thermal stresses via adjusted test methods up to tests in the vibration test stand (acceleration < = 200 g) or by simulating thermal shock or climate fluctuation, or respectively nummerical simulation.

Besides mechanical, thermal stresses, corrosion plays an important factor in the operating behavior of materials. At IKTS, manifold methods for corrosion testing of ceramic materials and components were established. Table 1 shows an overview of the most important methods. Furthermore, tests adjusted to specific applications (e.g. interaction with molten metal) can be generated and performed on the basis of extensive know-how. In addition to the testing of materials and components according to standardized tests, the testing of stability under various conditions is carried out in order to determine corrosion cinetics and mechanisms. The corrosion progress is characterized by various parameters, such as mass and geometry change, formation of corrosion layers, microstructure and phase change, as well as residual strength, and is then correlated with the microstructures and compositions of the materials.



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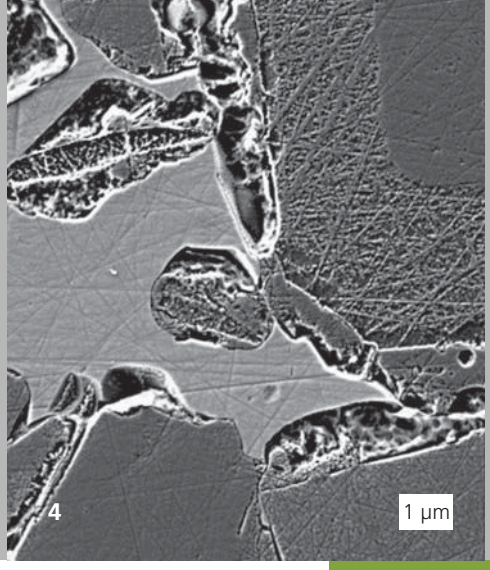

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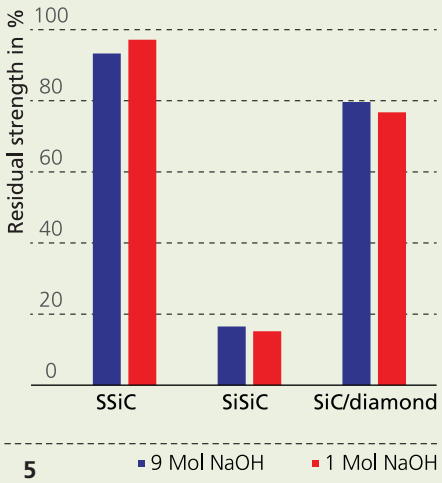

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Corrosion is a property of the system, which is why the detailed knowledge and control of the corrosion conditions is important. Figures 3 and 4 show the surfaces of SiSiC in a post-corrosion state in 1 M NaOH after 200 h at 70 °C (Figure 3) and after applying a voltage at room temperature. While SiC is stabil without the impact of the electric current and only the free silicon is dissolved by means of NaOH, SiC formed secondarily during the siliconization is attacked in the chemical corrosion. The freely available Si is not affected as much, which indicates different corrosion mechanisms [2]. Mostly, the simple measurement of the mass change or corrosion layer thickness is sufficient in order to understand the behavior of materials under application conditions. For this purpose, the measurement of the residual strength is additionally necessary. Figure 5 shows the change of the residual strength of SiSiC, SSiC and SiC diamond materials after the 200 hours of corrosion in NaOH at 90 °C. Although Si is dissolved out of both SiSiC and SiC diamond materials, the decrease of the residual strength is completely different. This phenomenon can be explained by the different formation of the SiC framework in both materials during the manufacturing [3].

Overview of the standard corrosion methods at IKTS

Method	Temperature	Media
Corrosion due to liquids under normal pressure	Up to boiling temperature	Acids, alkaline solutions, salt solutions
Electrochemical corrosion in various electrolytes	Near RT	Acids, alkaline solutions, salt solutions
Hydrothermal corrosion	< 250 °C	Pressure < 200 bar, water, salt solutions, diluted acids, water vapor
Gas corrosion	< 2000 °C	Gas with various compositions, flowing
Hot gas / burner test stand	< 1600 °C	Flow velocity v = 100 m/s, pressure 1 atm, up to 30 % water vapor
Salt spray test	35 °C	DIN EN ISO 9227 (NSS)
Humid heat	0–100 °C / 10–100 %rel.	Constant climate, also cycle tests possible
Resistance against tracking and erosion	Standard climate	Standard and aggravated requirements, DIN EN 60112; DIN IEC 60587
Electric arc reliability	Standard climate	Low voltage – high current High voltage – low current

Services offered

- Consultation regarding the application-oriented selection of materials and the component design
- Analysis of failure or defect incidents and mechanisms
- Analysis of the composition and microstructure of ceramic materials
- Different tests according to national and international standards
- Determination of the corrosion behavior and corrosion mechanisms of ceramic materials
- Determination of thermophysical, electrical, mechanical and chemically corrosive material and component parameters
- Factory calibrations according to VDI, VDE, DGQ guidelines

Sources

[1] C. Steinborn, M. Herrmann, u. a., J. Europ. Ceram. Soc., 34, 2014, 1703.
[2] M. Herrmann, K. Sempf, u.a., Ceram. Inter., 41, 2015, 4422.
[3] M. Herrmann, B. Matthey, S. Kunze u. a. cfi/Ber. DKG 2015,10; E39.

1 *Voltage puncture through a ceramic material.*
2 *FESEM image of a puncture channel in hBN ceramics.*
3 *Surface of a SiSiC material corroded in NaOH.*
4 *FESEM image of the same SiSiC material corroded under electrochemical conditions.*
5 *Residual strength after 200 h of corrosion at 90 °C in NaOH.*

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