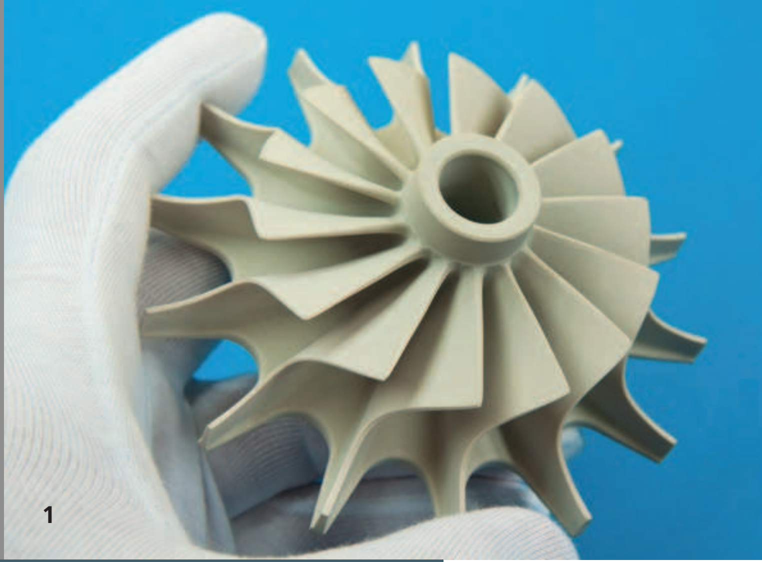

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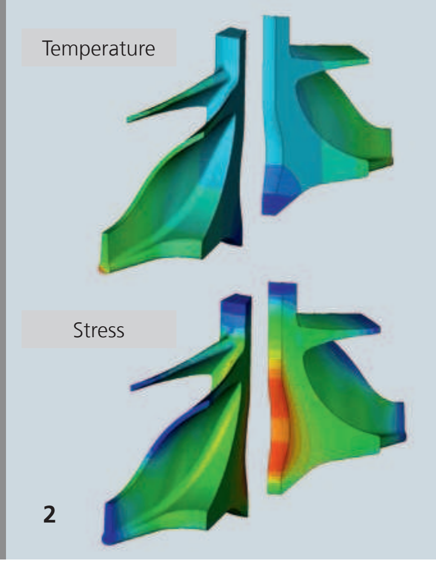

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HIGH-PERFORMANCE CERAMICS FOR GAS TURBINES – FROM MATERIALS TO COMPONENTS

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Rotor for a micro gas turbine

With the development of renewable energies, the European environmental policy aims at decreasing fossil fuel consumption and pollutant emissions, thus emphasizing the need for reliable provision of energy at peak loads. Stationary gas turbines supply power very flexibly and produce comparatively little emissions because of their high efficiency. Micro gas turbines are predestinated for local and independent energy conversion with combined heat and power generation. Recent research and development activities have been focused on decreasing emissions and fuel consumption of such turbomachines. This can be achieved by increasing the efficiency through a higher operating temperature or a lower amount of cooling. Both approaches result in significantly higher turbine component temperatures. Metal alloys are already operating at their physical limits in terms of temperature and cannot tolerate any significant increases. Hence, substitution of metal turbine parts by high-performance ceramic materials can offer tremendous benefits.

A silicon nitride (Si_3N_4) rotor for a radial-flow micro gas turbine with a capacity of 30 kW_{el} was developed within the scope of a Fraunhofer project. The ceramic rotor exhibits long-term stability up to 1200 °C at maximum operating loads and can be mass-produced.

This project was a collaboration of five Fraunhofer institutes: IKTS (material development, fabrication), IPK (tool production, final shaping), SCAI (simulation, shape optimization), IFF (testing, lean gas tests), and IWS (bonding, coating).

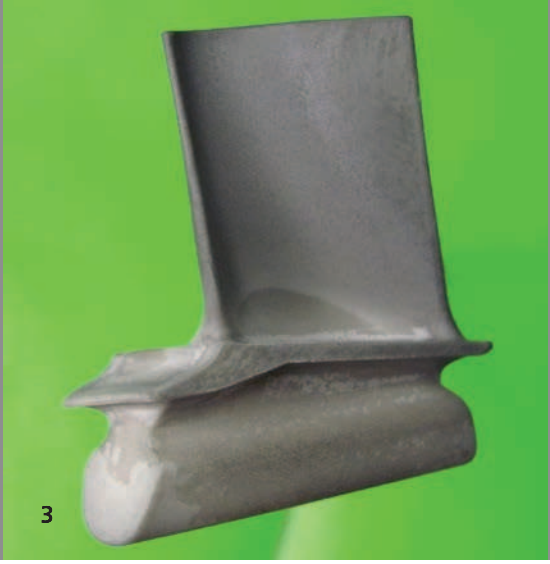
Si_3N_4 high-performance ceramics are suitable for rotating parts and high thermomechanical loads because of their excellent mechanical properties from room temperature up to 1400 °C. Dependent on chemical composition, sintering and after-treatment, specific properties can be amplified. To adapt the material properties to the operational stresses and to optimize the component design a repetitive adjustment of both is necessary.

The illustration of a realistic profile of operational demands via simulative coupling of thermal and (fluid-)mechanical loads done by Fraunhofer SCAI was the groundwork for material development. Based on this data, specific development aims could be defined. The adjustment of the material properties was done by a targeted design of the grain boundary. This led to high strength as well as high oxidation resistance and fatigue strength up to 1200 °C.

Material data for micro gas turbine rotor

Operating temperature	1200 °C
Fracture toughness	6.8 MPa $m^{1/2}$
Strength	~ 1000 MPa
Fatigue strength at 1200 °C	~ 500 MPa

The near-net-shape process of ceramic injection molding (CIM) was used for fabrication. This method is very suitable for the production of high quantities with low loss of material. In this process, a heated thermoplastic compound composed of ceramic powders and an organic binder (feedstock) is pressed into a mold cavity under high pressure to form a near-net-shaped part. The large volume of the rotor (148 cm³) imposed numerous demands on the mold cavity and the feedstock, with the



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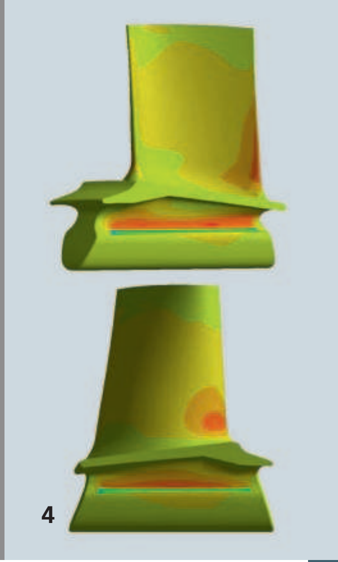

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greatest challenge proving to be the debinding process. This problem was solved by an innovative combination of chemical and thermal treatment of the part to enable sintering of defect-free rotors.

Having undergone minor structural modifications, the Capstone® C30 gas turbine located at Fraunhofer IFF Magdeburg is now ready for installation of the ceramic rotor.

Turbine blades for a helicopter turbine

Airplane and helicopter engines and stationary gas turbines basically work according to the same principle. The difference is that in the former, the energy from the turbine stage is converted into thrust, not electricity. Also, a jet engine is constructed as an axial turbine, in which the gas stream does not change direction. The rotor is usually not a single part, but rather a ring with several blades attached to it.

In another Fraunhofer project, ceramic blades for the first stage of a Klimov GTD 350 helicopter engine were developed and produced. The goal was to make the blade and its material capable for operation at 1400 °C. The first part of the material development process was similar to that of the rotor for the micro gas turbine. First, a predictive simulation of the thermal and mechanical loads was made in collaboration with Fraunhofer IPK Berlin. Small changes were made to the blade geometry based on the requirements of the ceramic material. Because of the very high operating temperature, a material exhibiting very high creep and corrosion resistance was developed.

Due to their filigree shape with free-form surfaces, the blades were difficult to fabricate with a 5-axis milling machine. Very good mechanical properties (strength and hardness) are beneficial for operation but lead to time-consuming and expensive milling and grinding processes. Tool wear and process duration can be minimized by green machining, in which compacted powder is shaped by milling. Despite the filigree geometry of the blades, green machining was found to be suitable for fabrication. After finishing the sintering process, grinding was necessary only at the fitting surfaces at the blade roots.

The fabricated blades will be tested in cooperation with EURO-K GmbH.

Material data for helicopter engine blade

Operating temperature	1400 °C
Fracture toughness	6.1 MPa $m^{1/2}$
Strength	~ 700 MPa
Fatigue strength at 1200 °C	~ 450 MPa

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1 *Radial turbine rotor made of silicon nitride.*

2 *Simulated temperature and stress distributions at maximum load.*

3 *Engine blade made of silicon nitride.*

4 *Simulated stress distribution at maximum load.*

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