RESEARCH HIGHLIGHT

PURDUE MATERIALS ENGINEERING

Advanced Ceramic Materials: Processing and Applications

Prof. Rod W. Trice

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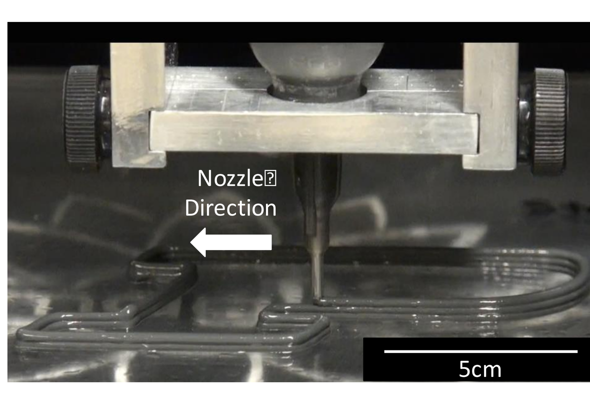
Professor Trice's research focuses on structure-property-processing relationships of advanced ceramic materials. In particular, we are investigating novel injection molding and 3D printing processing approaches for forming boron carbide and ultra-high temperature ceramics (UHTCs) into useful shapes, as well as preparing high-emissivity coatings to improve the performance of hypersonic vehicles. We are also exploring new methods of producing transparent aluminum oxide by inducing grain alignment through advanced processing techniques. Finally, we are investigating the effect of impurities common to biofuels on gas turbine performance.

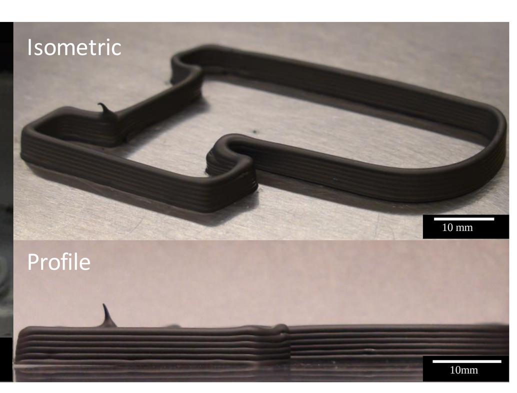
Aqueous-Based Ceramic-Polymer Processing

Background: Current bulk ceramic forming processes are limited to simple structures or require secondary machining to add intricate features. One of the main areas of focus of Professor Trice's group is investigating novel processing approaches for forming (ballistic and high temperature) ceramics into complex shapes using powder-polymer suspensions.

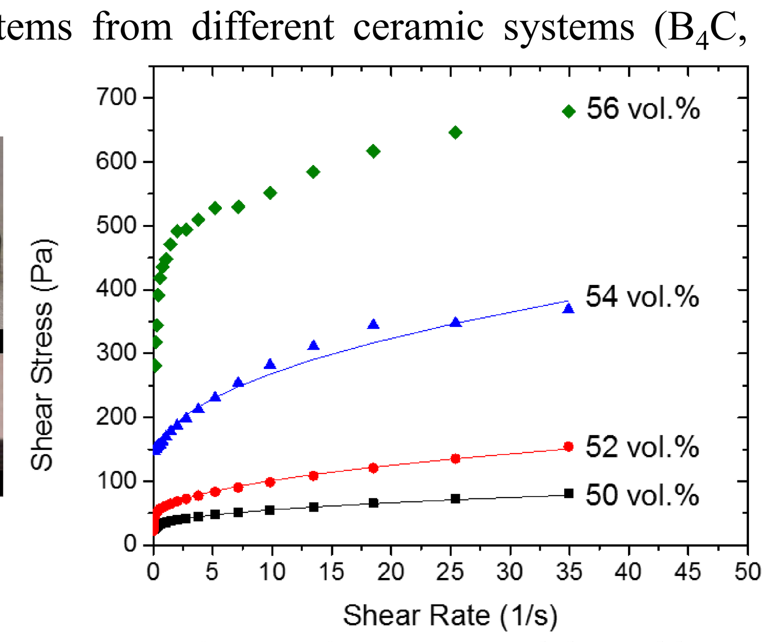
Additive Manufacturing: Additive Manufacturing (AM) can be used with aqueous ceramic-polymer suspensions with tailored rheological properties to produce complex geometries. Presently, we are developing ceramic suspensions from different ceramic systems from different ceramic systems (B_4C, Al_2O_3, Si_3N_4, SiC, ZrB_2) for use in AM.



3D printing of a boron carbide slurry

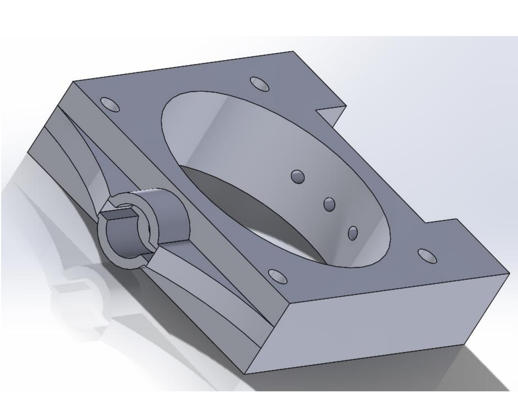


3D printed sintered boron carbide part

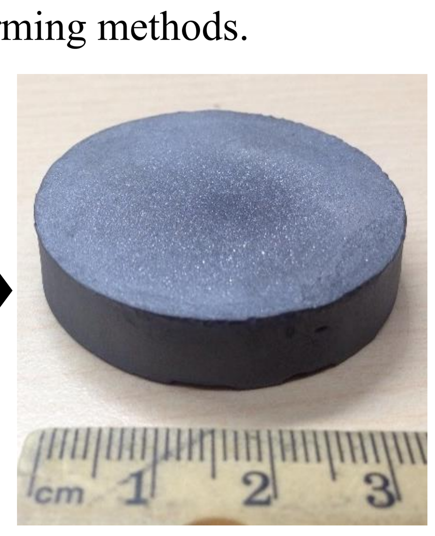


Ceramic Suspensions exhibit Yield-pseudoplastic behavior

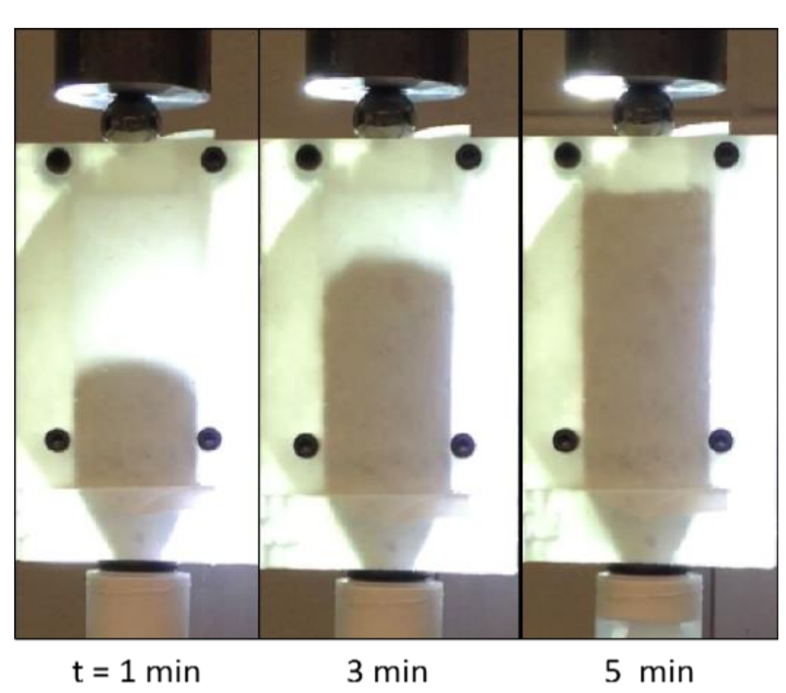
Room-Temperature Injection Molding: By tailoring the flow properties of aqueous ceramic-polymer suspensions, injection molding can be accomplished at room temperature to produce samples with complex geometries. Combined with pressureless sintering, this results in parts with high relative densities and mechanical properties comparable to samples prepared by traditional forming methods.



SOLIDWORKS model of a 3-D printed mold.



Pressurelessly sintered B_4C puck

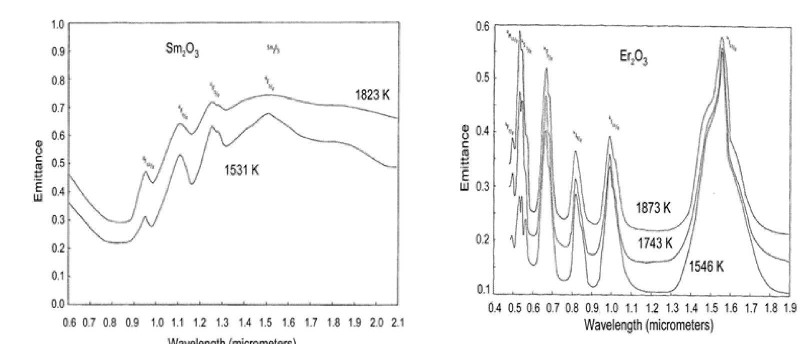


Injection molding of alumina slurry into a 3-D printed mold.

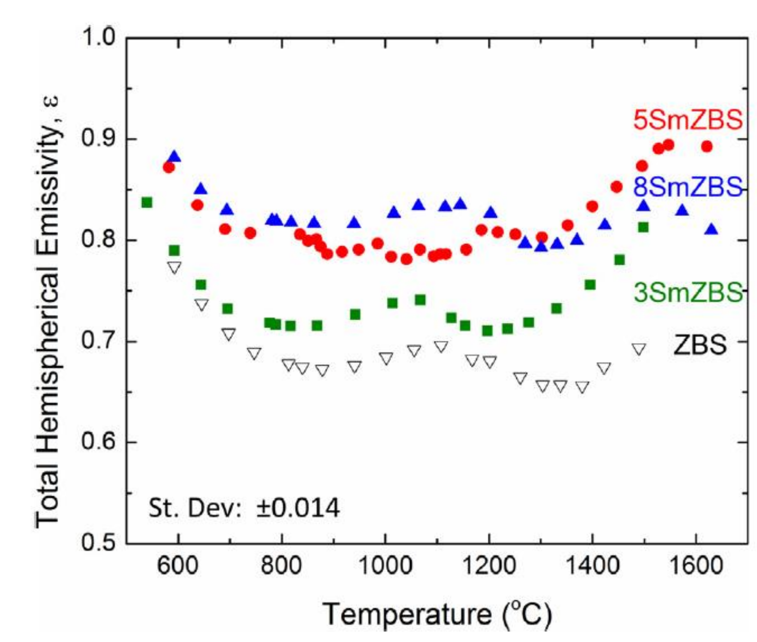
High-Emissivity Coatings for Hypersonic Flight

Background: Hypersonic vehicles require sharp featured nose tips and wing-leading edges to reduce drag on the vehicle. One approach to reducing the temperature in these components, often as high as 2000 °C, is to increase the emissivity of the surface, affording more re-radiation of the incoming heat. Phase I of this work developed a Sm^{3+}-doped SiC/ZrB_2 coating system that not only demonstrated an emissivity of 0.9 at 1600 °C, but also increased ablation resistance compared to an undoped SiC/ZrB_2 coating.

In the Phase II we will perform critical experiments to design multifunctional coatings for re-entry applications that combine high emissivity with ablation resistance. Experimental studies will focus on evaluating the effect of microstructural features (porosity size and shape, rare-earth dopant concentration and type, density and surface roughness) on emissivity and ablation performance.

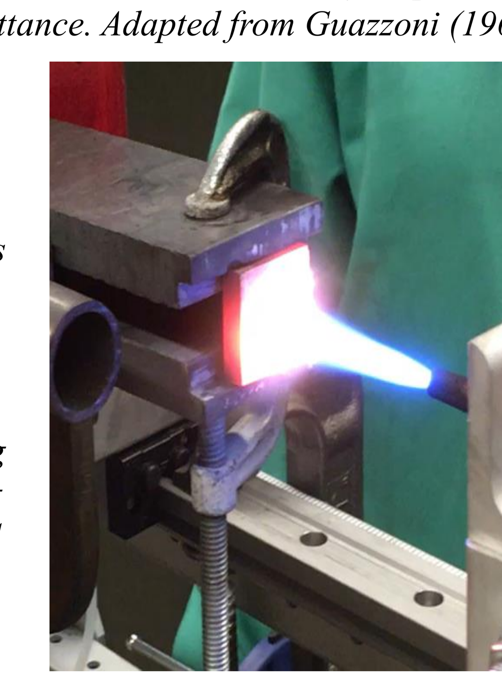


Emittance of Sm_2O_3 and Er_2O_3 as a function of wavelength showing differences in behavior. By preparing samples with both rare-earths it may be possible to tailor emittance. Adapted from Guazzoni (1968).



(Left) Results from Phase I showing high emittance at 1600°C for coatings with Sm added.

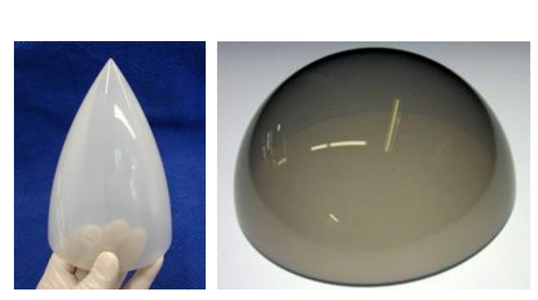
(Right) Ablation performance testing of a sample; the rig will heat to 2200°C in approximately 1 minute.



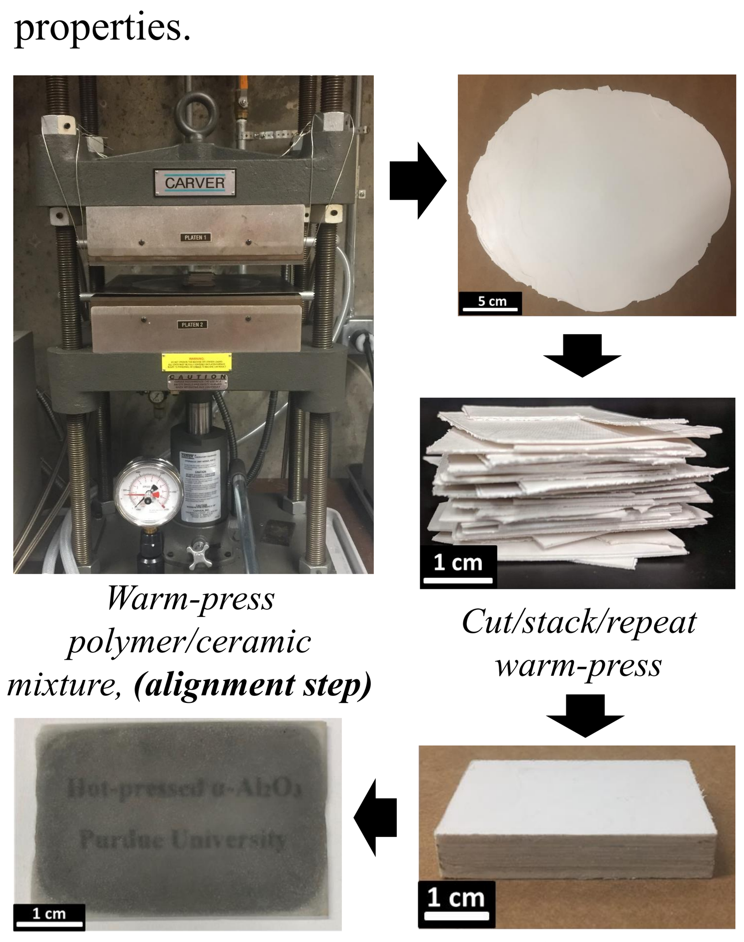
Emittance and Ablation Testing: The spectral hemispherical emittance of each coating design at room temperature and elevated temperature (up to 1200 °C) will be determined at the Air Force Research Laboratory to conclude whether or not a coating with tailorable emissivity can be developed. The coatings will also be evaluated at the Laser Hardening Materials Evaluation Laboratory (LHMEL) for ablation performance under Mach 0.9 airflow and laser heating in order to simulate the flight conditions. Comparison of the performance of co-doped erbium/samarium containing coatings with the samarium-only coatings will be made and evaluated. Furthermore, the ablation resistance of the designed coatings will be evaluated at Purdue University to temperatures > 2200 °C.

Transparent Ceramics via Particle Alignment

Background: Transparent ceramics are envisioned as an essential part of military applications, providing enhanced protection versus ballistic threats for windows, missile nose-cones, radomes, etc. Current methods for producing these ceramics involve using large magnetic fields to align ceramic particles and high sintering temperatures to obtain dense parts, which can be costly. Through repeated pressing steps of a mixture of platelet-grain alpha-alumina in a thermoplastic polymer, a high degree of crystallographic alignment can be achieved, leading to increased optical properties.



CeraNova's polycrystalline alumina – CeraLumina™

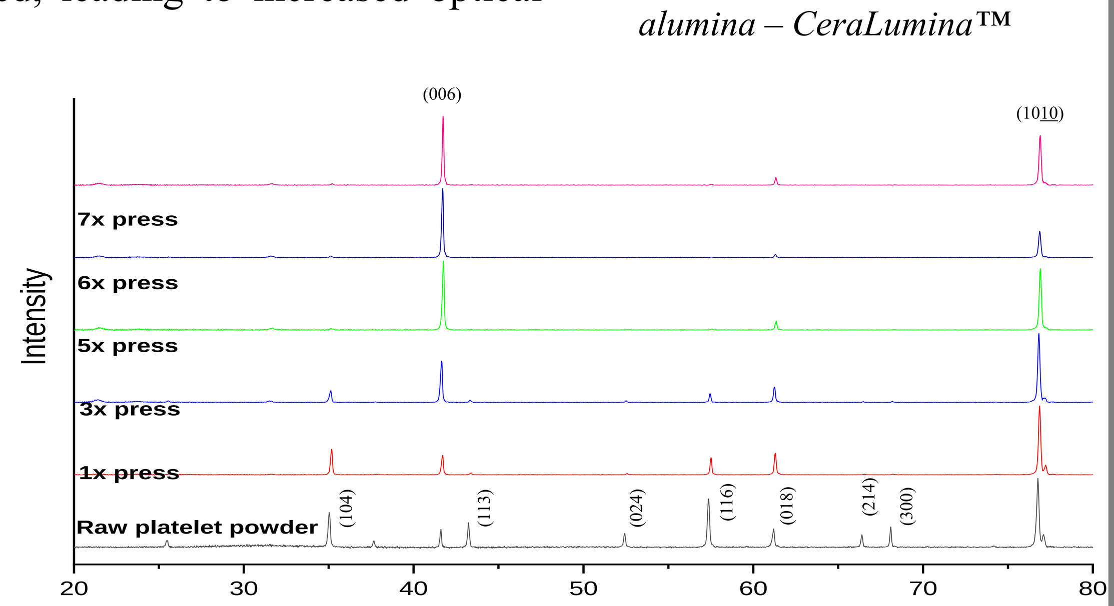


*Warm-press polymer/ceramic mixture, **(alignment step)***

Cut/stack/repeat warm-press

Burnout polymer and hot-press

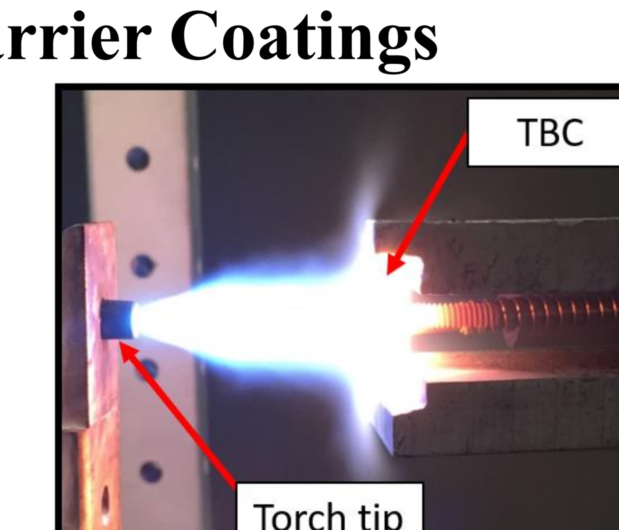
Cut/press into final shape



Particle Alignment via Shear/Elongational Flows: The velocity gradients that are evident in shear/elongational flows cause high aspect-ratio alumina platelets to rotate and eventually align. XRD analysis of polymer/ceramic sheets after warm-pressing steps shows increasing intensity of (006) basal plane with increasing pressing steps. This indicates that particle alignment is occurring.

Hot Corrosion of Thermal Barrier Coatings

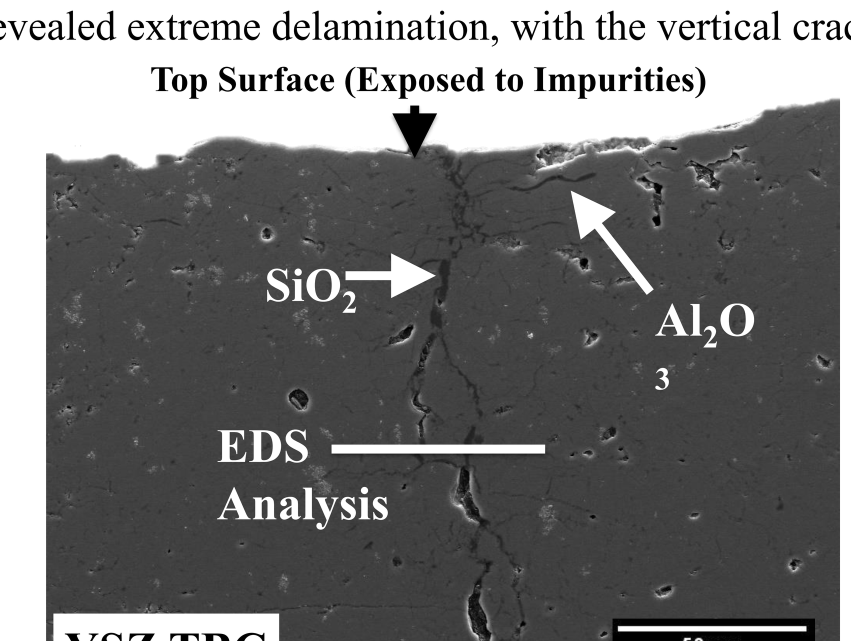
Background: Contaminates found in aviation fossil fuels such as Jet A can be incorporated into gas turbines thermal barrier coatings (TBCs), ultimately hastening their failure through different corroding mechanisms. Furthermore, while calcium-magnesium-aluminum silicates (CMAS) are typically ingested as particulate in middle-east theaters, the impurity list in biofuels includes the necessary elements to form CMAS without exposure to any environment. This is significant as CMAS is particularly destructive for operating temperatures above its melting temperature (~1250 °C), particularly affecting the lifetime of Y_2O_3-ZrO_2 (YSZ) TBCs.



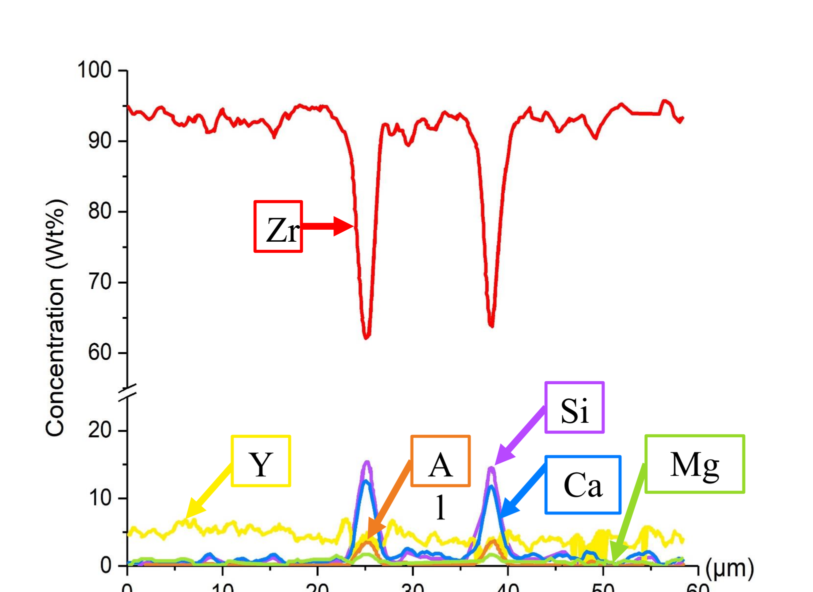
Sample ablation at 1400 °C

25 mm dia.

Biofuel Infiltration: A methodology to incorporate common impurities found in biofuels has been developed by mixing alkali and alkaline nitrates and a silicon-containing preceramic polymer in an ethanol solution to form "impurity cocktails." Thermal barrier coatings (TBC) have been sprayed with these impurity cocktails, and subsequently ablated at temperatures up to 1400 °C. Samples evaluation revealed extreme delamination, with the vertical cracks being filled by the modified silica glass.



SEM micrograph of a TBC after ablation testing



Line scan elemental analysis of a TBC after ablation testing showing the presence of modified glass

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