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Center for Thermal Spray Research

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Linking Research to practice

Going Beyond the Surface

Message from the Director

I am pleased to introduce our annual newsletter "Going Beyond the Surface," highlighting our scientific and technical achievements, industrial collaboration, and member/alumni updates. This newsletter is being developed in concert with our preparation for the Fall Consortium Meeting which will be hosted by *GE Energy in Schenectady, NY*. We are grateful to *Josh Margolies* for his assistance in organizing this event. As is typical for the fall meetings, the day-long session features presentation by the Center Staff and Students on their activities and accomplishments, with a focus on topics of importance to our hosts. This year, the emphasis will be on Thermal and Environmental Barrier Coatings (TBCs and EBCs) for turbine engines. We look forward to welcoming the membership to Schenectady in mid-November.

The Spring Consortium Meeting concluded this past summer was by far our biggest ever. We had almost *110 participants from 30 companies* and the *US Government laboratories*. The meeting spanned three days with an elaborate review session to introduce advanced Thermal Spray concepts to a large group of young engineers. Following the Consortium Meeting, CTSR also hosted *an Alumni Reunion Workshop* celebrating the 85th birthday of our founder and colleague *Prof. Herbert Herman* with over 50 CTSR alumni, many of whom still involved in Thermal Spray.

Our team continues to bring new insights into the understanding of Thermal Spray processes and associated development of microstructure and properties. *In-situ* curvature monitoring during deposition has definitively revealed the *Onset of Segmentation Cracking in Air Plasma Sprayed Ceramic Coatings*. The observations are reconciled through a mechanistic description of the events along with associated criteria to describe the microstructure evolution. Our TBC work also focuses on fundamental elements of *TBC deposition on complex geometries.*

Following our breakthrough findings on the impact of material chemistry change on the thermal expansion response of *Ytterbium Silicate EBC system*, systematic studies on the role of process parameters on silica evaporation has been quantified through both *in-situ* Optical Emission Spectroscopy and detailed characterization of coating chemical heterogeneities arising from the process-induced losses. In collaboration with Oak Ridge National Laboratory, work is being done to implement these coatings in high-temperature testing environments.

Our *Diesel Thermal Management Program* conducted jointly with Army Tank Automotive Command and managed by Office of Naval Research continues to be highly productive. In addition to a number of engine tests conducted by Army on single-cylinder diesel engines with coated steel pistons, expanded interaction with Prof. Lawler's group at Clemson University has allowed evaluation of TBC-coated pistons in advanced combustion ethanol fuel engines. Several papers are under preparation.

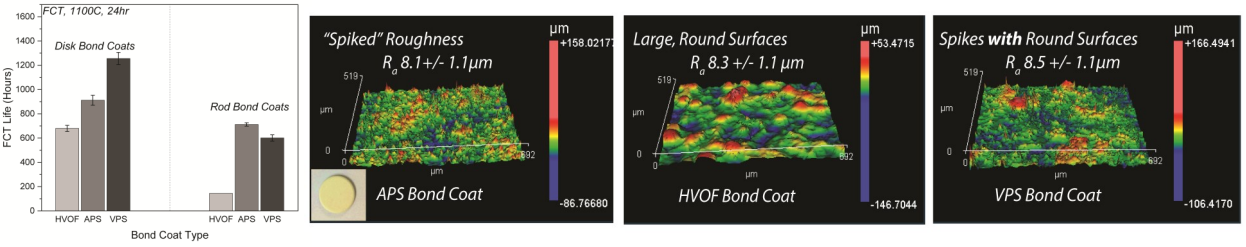
Lastly, CTSR is also focusing on human resource development for the industry. A number of Undergraduate Interns and Masters' students now work routinely along with the Ph.D. students and Post-Docs enabling exposure and experiential learning of Thermal Spray Technology. The group has also benefited from field trips to various member sites during the Fall Consortium Events.

As always, I invite you to join the CTSR team to realize our common goal, to make thermal spray a household word.

- Sanjay Sampath, Director, CTSR

Bond Coat Processing on Different Substrate Geometries

The Center in collaboration with Oak Ridge National Laboratory has recently been working toward understanding the *relationships* between *bond coat processing methods* and *furnace cycle durability* of TBCs on *disks and rods*. In the case of disks, it can be seen that with different bond coat processes, significant differences in durability can be observed. These are correlated with the *combined effects* of changing the roughness character (spiked v. rounded i.e. fractal roughness) and changing the bond coat chemistry, thus leading to VPS bond coats having significantly higher life. This trend, however, is not followed in the case of TBCs on rods for equivalent set of Bond Coats and Top Coats. In the case of rods, it is consistently seen that the FCT durability of the TBCs are maximized when an APS bond coat is utilized. This suggests that roughness is only one of the contributing factors in coating performance, with other components including the coating compliance to accommodate for example radial strains in cylinders. A paper on bond coat processing effects on disks was recently published in Surface Coatings and Technology, and another paper on the rod response is currently being prepared.



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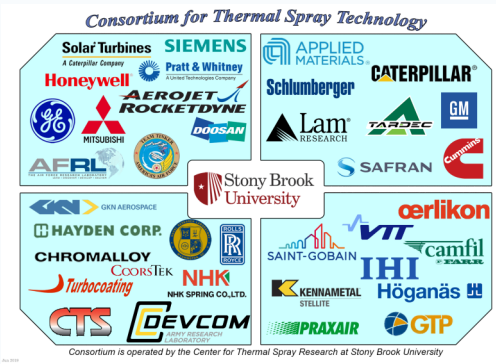
Industrial Consortium News

The Consortium for Thermal Spray Technology, hosted by CTSR, continues to expand and provide benefits to our industry across the supply chain. This past year has seen the *addition of NHK Spring of Japan*. They are a multifaceted engineering company and participating in the Consortium to bring advanced concepts into their Thermal Spray practice. The Consortium is now completing its 16th year, starting from some 10 companies in 2002-03 to *the present membership of 30 leading international companies*.



The Consortium is a pre-competitive research and knowledge transfer partnership between CTSR Researchers and Industrial Partners. The goal is to provide *Methods, Measurements, and Models* that will allow the industry to more effectively design and manufacture with Thermal Spray. Each company contributes $12,500 annually as membership fees to the Consortium/CTSR, enabling self-sustaining operations following the 11-year National Science Foundation Materials Research Science and Engineering Center grant from 1996 to 2007.

The Spring 2019 Consortium Meeting held at Stony Brook University campus was the largest ever attended by *more than 110 participants* from the member companies. Over the span of three days, CTSR staff, students, and collaborators presented updates on both science and technology as well as their value to industrial coating design & manufacturing. Fall meetings are usually hosted by a member organization.

CTSR Fall Consortium 2019: Caterpillar Inc.

Last year, the CTSR team of Ph.D. Students, Postdoctoral Associates, and Undergraduate students ventured on the road to Peoria, Illinois for the *Fall 2018 Consortium at Caterpillar, Inc*. Along the way, the team was able to visit various Consortium member companies, providing an opportunity for the team to see firsthand industrial operations. Sites visited include: *GE Aviation, Cincinnati Thermal Spray, Argonne National Laboratory, Rolls Royce, and Praxair Surface Technologies*. The group described it as an "incredible experience" to witness firsthand parts being coated and sections of assembled engines, powder manufacturing, etc. The CTSR team is thankful to *Doug Konitzer, Kirk Fick, Jan Ilavsky, Li Li, and Vaishak Viswanathan* for offering their time and showcasing their facilities to the CTSR Staff.

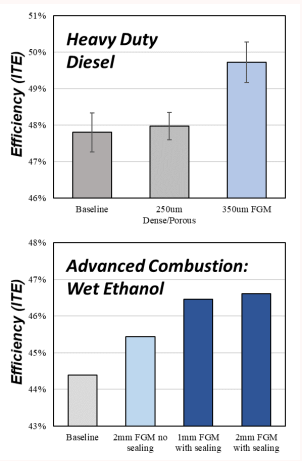
The entire group of consortium participants had the opportunity to visit a *Caterpillar Tractor Assembly Plant* during their participation at the Consortium Meeting hosted by Caterpillar. Pictured is the large group of 60+ participants. The Consortium Meeting itself was held at the Caterpillar Visitor Center with presentations from some Caterpillar personnel along with the traditional Consortium presentations. We are grateful to *Dan Sordelet of Caterpillar and his colleagues* for supporting this event. Everyone enjoyed the tour of the factory and being able to witness the assembly of these behemoths.

CTSR Spring 2019 Alumni Meeting

Following the Spring 2019 Consortium Meeting this past June, CTSR hosted an alumni reunion to celebrate the *85th Birthday or our founder and colleague Prof. Herbert Herman*. Over 50 alumni from around the country visited and participated in the event. The Thermal Spray program at Stony Brook started 40 years ago by Prof. Herman and his then graduate student the late Volker Wilms. They were trying to rapidly quench oxides to study metastability and realized Plasma Spray naturally produced these metastable phases. Since the start of the Thermal Spray Program and the subsequent establishment of the NSF Center, *over 100 graduates have emerged from the program*, many of whom continue to support the Thermal Spray Industry. A one-day workshop was organized with presentations from Center alumni highlighting their activities in Thermal Spray Science, Technology and Application Development. The workshop provided the opportunity for several generations of students to interact with each other and gain from the sharing of experiences.

Thermal Management Coatings for Diesel Engines

Recent collaborations between CTSR and US Army Tank Automotive Research have shown that the use of TBCs can *cause a relative increase in thermal efficiency* by as much as *3.5% for high load traditional diesel engines*. However, the complex interplay between the ideal insulating material and the intricacies of the combustion process have often led to surprising results.



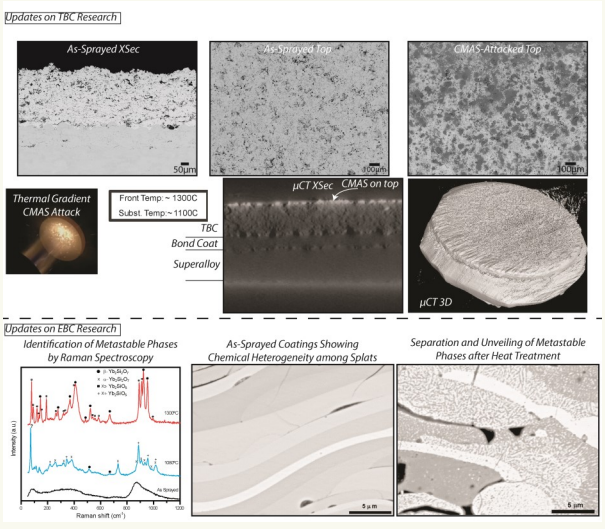
Most contemporary investigations into Thermal Barriers for Reciprocating Engines have sought to optimize the "Thermal Swing" insulation, where convective heat transfer is reduced by decreasing the temperature gradient between the insulating wall material and the combustion gases. Attempts to effectively implement this type of insulation have seen limited improvements with the underlying mechanisms often convoluted by the complexity of instrumented engine performance testing, subtle variability in part manufacturing, and the influence of unknown factors such as radiative transfer and/or transient dynamics within the system.

Interestingly, the use of "thick" Thermal Barriers has once again become a promising pathway in related applications. Stemming from the original ***CTSR**-Army collaboration*, work has started with researchers at Stony Brook and *Clemson University International Center for Automotive Research (CU-ICAR)* to develop thick Thermal Barriers for advanced combustion modes using alternative fuels. In this application it has been hypothesized that the charge heating penalties that once proved detrimental to the use of thick thermal barriers in traditional diesel combustion may be a benefit to advanced combustion modes. Preliminary work with 1-2mm thick functionally graded ceramics have shown relative *increases as large as 5%*.

Research on both fronts is ongoing with coating material and microstructure development pursued by the team at CTSR and continued *engine testing at both the Army and CU-ICAR*. Initial engine test results point to a complex interplay of combustion gases and the coating surface interactions and suggests benefits only for select microstructures and testing conditions. The team is encouraged with the initial results and have several on-going activities to harness the potential of this technology.

CTSR International Partnerships Highlight: CONACYT Mexico

Over the last few years, CTSR has been working with *Mexican National Laboratories CIATEQ and CIDESI* under a collaborative research program with *the US Air Force Office of Scientific Research and CONACYT Mexico on Thermal and Environmental Barrier Coating* fundamental research. Recently, CTSR has worked in collaboration with CIDESI on generating Micro-Computed Tomography (µCT) Images of multilayer TBCs after CMAS attack. In the figure below, the as-deposited TBC from polished cross-section and top-surface can be seen along with the top surface of the coating after CMAS attack. With this minimal CMAS exposure, it is possible to keep the TBC intact while examining the interaction between the CMAS and the TBC by post-processing methods (i.e. metallography, SEM analysis). The µCT cross-sectional image reveals the CMAS indeed does remain on the top of the sample with minimal infiltration. Similarly, a 3D rendering of the sample shows the presence of foreign species arrested at the top surface. Through continued collaboration, the goal is to establish a methodology for understanding CMAS infiltration of TBCs by combined SEM and µCT analysis.



In the EBC arena, work has been conducted at CIATEQ to study the *effects of heat treatment* on *Ytterbium Disilicate Plasma Sprayed coatings*. As seen in the figure, the amorphous coatings possess chemical heterogeneities at the splat level. As they are subjected to crystallization heat treatments, Raman Spectroscopy data reveals the *presence of metastable phases of both Disilicate and Monosilicate*. This information can be used in the future in combination with previous results to understand the mechanisms associated with the dynamic changes in CTE of the EBCs during the first heat treatment.

We are grateful to entire *Mexican research team lead by Gerardo Trapaga and supported by Juan Miguel, Salomon Zapata, Carlos Poblano, and others* for their cooperation. We also acknowledge support from *AFOSR Dr. Geoff Andersen* for supporting this initiative.

Prof Sampath Honored with the 2019 John Jeppson Award

Prof. Sanjay Sampath has been awarded the prestigious *2019 John Jeppson Award by the American Ceramic Society*. The award was presented to Prof. Sampath in recognition of his extraordinary contributions to the rigorous understanding of Thermal Spray Processes, as these contributions have enabled the evolution of Thermal Spray from an empirical art into an advanced technology with an increasing breadth of applications. The John Jeppson Award is one of the most prestigious awards given by the *American Ceramic Society* since 1958 in honor of John Jeppson (1844–1920) the 20th-century revolutionary industrialist, who founded the *Norton Company* in Worcester, MA. Photographed is Prof. Sampath receiving his award from ACERS president *Dr. Sylvia Johnson* during the society's awards dinner held in Portland, Oregon at the Materials Science and Technology 2019 meeting.

(Photo Courtesy ACERS)

Oerlikon Metco Young Professional Award: Ms. Shalaka Shinde

CTSR Ph.D. Candidate *Shalaka Shinde* recently won the *Oerlikon Metco Young Professional Competition* at the International Thermal Spray Conference 2019 in Yokohama, Japan. Photographed is Richard Schmid presenting the award to Shalaka. This follows *last year's success* by Ph.D. candidate *Edward Gildersleeve* who won the competition during the Orlando conference. The competition involves a 5-minute presentation by the participant to the entire ITSC audience followed by evaluation by a distinguished panel of judges. Shalaka highlighted the importance of her work in understanding segmentation cracking in coatings and was recognized for both scientific depth and industrial relevance. This back-to-back success is a testament to the CTSR team's ability to not only conduct robust fundamental research but also translate knowledge to industrial practice.

Alumni Focus: Dr. Anand Kulkarni

In this newsletter, we are pleased to recognize *Dr. Anand Kulkarni* of *Siemens Corporation Corporate Technology, Princeton, NJ*. Anand completed his Bachelor's degree in Metallurgy at College of Engineering, Pune and Master's degree in Metallurgical Engineering and Materials Science from the Indian Institute of Technology, Bombay, India. Anand came to Stony Brook in 1997 and did his Ph.D. under Dr. Herman's guidance in characterization of the porosity-property relationships in ceramic coatings. This work also resulted in the contribution of an array of pedigreed specimens from industrial partners like GE and Siemens, with the goal of investigating key knowledge needed to design next-generation Thermal Barrier Coatings for Gas Turbine Engines. During his Ph.D., Anand has worked closely with scientists at the National Institute of Science and Technology and at Argonne National Laboratory to understand the fundamental behavior of both thermally sprayed and EB-PVD TBCs using advanced X-ray Small-Angle Scattering and Small-Angle Neutron Scattering. His participation and contribution in the formative days of the CTSR Consortium was invaluable since it provided a crucial link between fundamental research and industrial practice.

After graduating in 2002, Anand continued an additional year and half as a post-doctoral fellow, continuing the NSF-MRSEC Program and CTSR's Consortium efforts. Anand later joined the materials and technology group in Siemens Energy in Orlando in 2004. While in Siemens, Anand has led and supported multiple research programs in the area of materials, coatings, and sensors. Notably, Anand was the Coatings lead on the DOE Hydrogen turbine and ARRA program, exploring coating behavior in the presence of hydrogen and coal syngas fuels. He was also the technical lead for sensor development on the DOE NETL program, working closely with colleagues from Mesoscribe on Conformal Direct-Write Technology-Enabled Wireless, Smart Turbine Components. In November 2012 he moved to the Siemens Corporate technology group as a Senior Key Expert in Materials, Design, and Manufacturing. He transferred to Siemens's Charlotte facility, continuing to work on coatings and sensor projects, with close involvement with CTSR's consortium and its activities. Anand was recently promoted to the position of Principal Key Expert in 2019 with a key focus on operational flexibility with continued research in extreme environment materials and data-driven intelligent manufacturing for additive manufacturing. Anand lives in Charlotte, NC with his wife Jyoti and his two daughters Aanya (9 years) and Diya (5 years).