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Stony Brook University

Center for Thermal Spray Research

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LINKING RESEARCH TO PRACTICE

Going Beyond the Surface

Message from the Director

We are pleased to introduce our annual newsletter providing updates on happenings and highlights at the Center over the last year. I have poignant memories of putting the newsletter together last year in the aftermath of hurricane Sandy. Hopefully, this fall and winter will be uneventful and safe in terms of weather.

As this newsletter goes to press, we are preparing for our fall consortium meeting which will be held near-by Tinker Air Force Base in Oklahoma City. This meeting is held near Tinker to facilitate our colleagues from USAF who are involved in thermal spray repair services to be able to interact with industrial consortium members, CTSR staff and get the opportunity to witness our knowledge transfer efforts. Rotating the fall meeting around the country is becoming a recurrent feature following successful events at NRL Key West (2010), GE Learning Center (2011) and Boeing (2012).

I am pleased to report our research, knowledge transfer and human resource development endeavors have been progressing very well over the last year. Through our DoE sponsored program on TBCs and coupled with support from Consortium we have made significant progress in understanding of the TBC process-performance relations. A nugget highlighting key elements of this work was presented at the spring meeting and highlighted in this newsletter. Our work on functional oxides and using thermal sprayed ceramics as templates for bio-inspired hybrid coatings is also progressing very well. They are sponsored by NSF.

Finally, we have continued to expand the knowledge base relative to using thermal spray for *in situ* repair of steel infrastructure. The results to date point to very encouraging capabilities of HVOF sprayed metals to be able to carry mechanical load. In addition, we have been able to critically demonstrate the role of processing parameters on the state of stress in coatings and their resultant impact on fatigue life of coated systems. Some recent results are highlighted in this newsletter. The group is cognizant of industrial implications of their fundamental research and constantly strive for relevance between science and technology.

Our thermal spray facility continues to evolve with a future focus on expanded training of students in advanced thermal spray concepts. Through assistance from Sulzer Metco, two advanced spray systems have been set-up including a Unicoat HVOF control platform and a Sinplex cascaded plasma system. These spray cells have been integrated with advanced diagnostics to enable full field assessment of thermal spray process, from particle dynamics to coating properties. We are grateful to Sulzer Metco for their generous support of equipment and service to get these facilities operational.

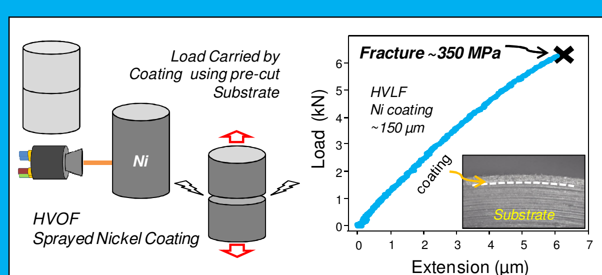
As always, I invite you to join the CTSR team to realize our common goal, to make thermal spray a household word.

- Sanjay Sampath

Load bearing capability of HVOF thermal spray coatings demonstrated

Although vast majority of thermal spray coatings have been used for surface enhancement of structural components, the roots of the technology lies in spray based reclamation of worn machine elements. Despite this legacy, there is limited scientific literature on the structural functionalities of spray assembled materials. Of concern is the large content of defects and interfaces within these coatings as well as presence of process induced residual stresses.

Over the last year, CTSR has been exploring high velocity thermal spray as a possible scheme not only to reclaim lost metal in structural elements to corrosion but as a potential method to recover and enhance load bearing capability on site on structural components. One area of interest is *in situ* repair of Steel bridge structures affected by significant corrosion induced metal loss.



Recent results show that HVOF deposited dense metals such as Ni on steel can recover the load bearing capability of the structural element by dimensional restoration. Tests on measuring tensile properties of the coating itself through a combination of tensile testing of a coated composite (substrate + coating) and a tubular tensile test configuration for the coating itself (inset figure) shows that in tested cases sprayed material has yield strengths that are far greater than those of their bulk counter part. For example, the yield strength of HVOF sprayed Ni was estimated to 350 MPa vs ~ 200 MPa for bulk Ni. This enhanced strength can be attributed to three factors, ultra-fine grain size, presence of oxides (dispersion strengthening) and compressive residual stresses. Not surprisingly, the deposited structures however lack ductility as evidenced in the load displacement plot. Detailed analysis of the operative mechanisms is currently underway, but the results point to expanded opportunities for applications as true structurally integrated coatings. This work was initiated through a seed project funded by the Transportation Research Board and presently being continued through Consortium support. In addition to static tensile testing, compressive testing, Charpy toughness and fatigue studies are planned.

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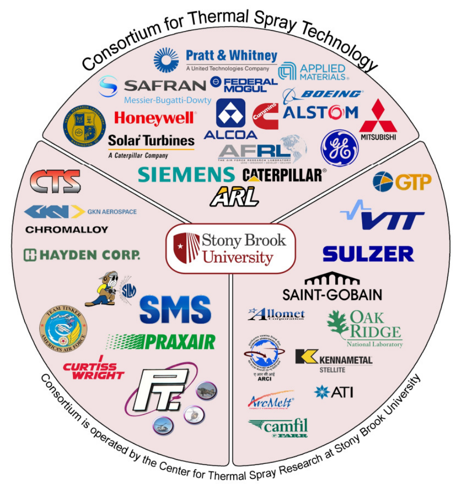
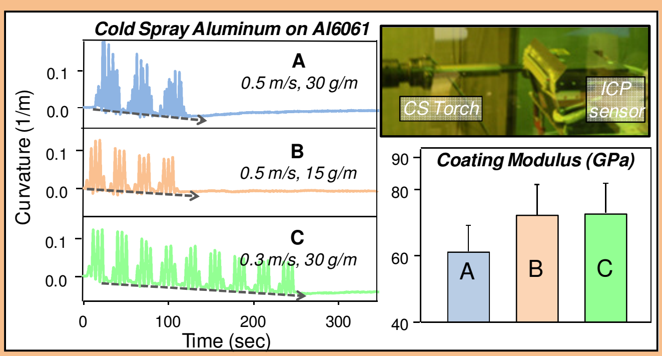
Industrial Consortium News



The Consortium for Thermal Spray Technology hosted by CTSR continues to expand and provide benefits to industry across the supply chain. Cummins engine company is a recent addition to the group, with several other companies showing interest, bringing the total membership to 36. The fall 2012 meeting hosted by Boeing at their Museum of Flight location was a significant success. The participants not only had a chance to see "cool' stuff at the museum but also had the opportunity to take a tour of the Everett assembly. We are grateful Marc Froning and Arash Ghabchi for facilitating this event. The spring 2013 meeting was one of the largest ever with more than 75 participants from 30+ organizations. The meeting was impacted due to lack DoD participation affected by the sequester. Our consortium strategy going forward will seek to rotate the fall meetings around strategic partner sites with an emphasis to involve our OEM partners. This allows larger participation of design and manufacturing engineers from these organizations which will be crucial to enhance thermal spray coating utilization in engineering systems. Each company contributes $12,500/year through membership fees which enable self-sustaining operation of CTSR following its 11-year National Science Foundation grant enabling continued research, knowledge transfer and human resource development activities. Complementary funding to the tune of $5M has been received through NSF, DoE, DoD and the University enabling CTSR to thrive and continue to be the focal point of thermal spray research in the US.

Cold spray deposition stress monitoring accomplished through field trips to ARCI- India and CNRC, Canada

Much progress has been achieved at CTSR and other international laboratories in monitoring stress evolution during deposition using beam curvature measurement such as the *in situ* coating property (ICP) sensor. In traditional thermal spray processes, stresses during deposition arise as a superposition of quenching stresses (associated with solidification and cooling of droplets) and peening stresses due to impact (primarily in high velocity processes). Following deposition, these deposition stresses are further compounded with thermal mismatch stresses resulting a net residual stresses. Quenching stresses are generally tensile, peening stresses are primarily compressive, while the sign of the thermal mismatch stress will depend on the thermal mismatch. The stress evolution dynamics involving some combination of the above three forms depends strongly on material, process and deposition conditions.



Since cold spray operates without the melting and solidification processes, one would anticipate primarily compressive stresses during deposition as a result of peening process. Two studies undertaken through collaborative field trips with ARCI and CNRC demonstrates the applicability of ICP to monitor stress evolution during cold spray. Copper coatings were deposited at ARCI while Aluminum and Titanium coatings were deposited at CNRC. Both Copper and Aluminum coatings show distinctly compressive stress evolution. The Al data (inset) shows dependence on both feed-rate and raster speed (together providing deposition rate). The data shows that at lower deposition rate the coating shows greater propensity for peening. Preliminary data on Titanium coating showed a positive curvature evolution during deposition indicative of tensile stress generation. The exact origin of this behavior is still under investigation.

The ICP method was also used to extract coating modulus through post-spray ex situ thermal cycling. The modulus data for the three coatings with different deposition rates is shown in the bar graph indicative of process sensitivities on the microstructure and properties. The results show that techniques developed for thermal sprays can readily be extended to cold spray processes. Detailed analysis of the work is underway.

We are grateful to Rogerio Lima, Phuong Vo, Eric Irrisou and Christian Moreau at NRC and to Sivakumar and Shrikant Joshi for facilitating this collaboration. Andrew Vackel, Mike Inglima and Gopal Dwivedi led the activities for the Center. Detailed reporting on the work will follow through technical publications.

Focus on CTSR Students & Post Docs

CTSR continues to make an impact on future human resource development in the field of thermal spray. Our students and staff are highly sought after by the industry with a majority of them joining Consortium member companies. Over the last 2 years, three of our students exposed to thermal spray technology during their undergraduate programs were hired by GE Energy in Greenville, SC.

This year, we have recruited several new undergraduates from the engineering science program so as to expose them to thermal spray technologies, associated materials and characterization. We intend to continue this effort to develop a thermal spray graduate pipeline for the industry.

Post-doctoral fellows have also found gainful employment: Dr. Yang Tan is now at Alcoa, Dr. Dimitris Zois is at Siemens and Dr. Yikai Chen was recently hired into the coatings group at Applied Materials.

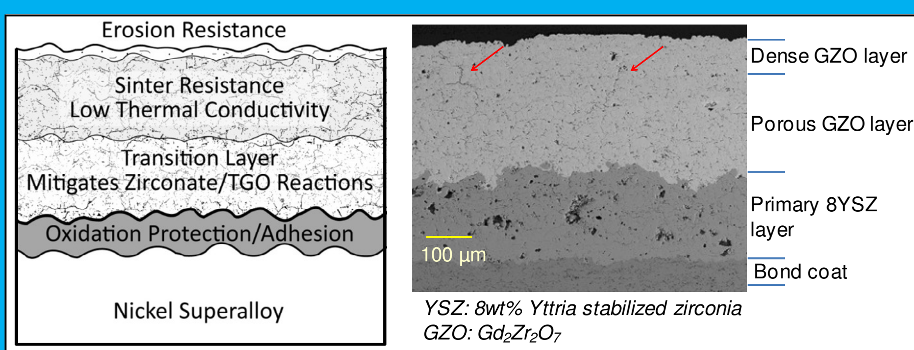
CTSR graduate student Katherine Flynn has now participated for more than a year as a student board member of the ASM Thermal Spray Society. She has actively contributed to Board projects. CTSR undergraduate Greg Smith is spending one year as an intern at GKN Aerospace (formerly Volvo Aero) in Sweden. He is the second student to participate in this international internship opportunity at GKN. Undergraduate Cathy Chan and graduate student Katherine Flynn have also had the opportunity to conduct research at partner site VTT Research Center in Finland through extended stays supported through our NSF program. Graduate student Andrew Vackel had the opportunity to conduct research at University West in Sweden.

CTSR students Vaishak Viswanathan and Andrew Vackel were recipients of the International Thermal Spray Association Scholarships in the years 2012 and 2013. Congratulations to both of them. The Center is grateful to ITSA for their continued support of student research.

Graduate Student Su Jung Han participated Sulzer Metco's Young's Professional competition at ITSC 2013. Her work on the connection between processing and electrical properties presentation was very well received. .

Multilayer, Multimaterial TBC development

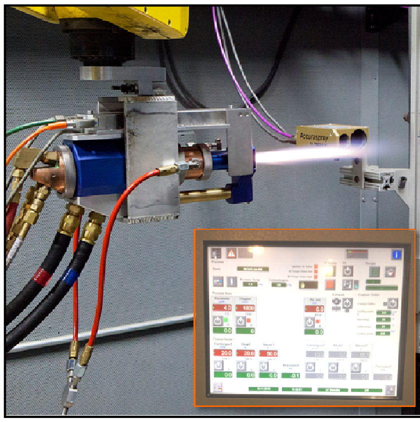
For past three years, CTSR has been involved in development of multilayer, multi-material TBCs for gas turbine engine application. Started in late 2010, the project has been supported by National Energy Technology laboratory under Department of Energy. Building upon our integrated knowledge database on YSZ developed during the past years, several trials have been made to converge on an optimal TBC via process design, which can not only offer higher durability under thermal excursions but also withstand other TBC related challenges, such as erosion, molten ash (CMAS) etc. A key element of the program is developing processing strategies for each of the required layers based on specific microstructure-property requirements followed by integrated analysis of the multilayers. Of specific importance are thermal conductivity, elastic modulus and coating fracture toughness all of which are affected by processing conditions.

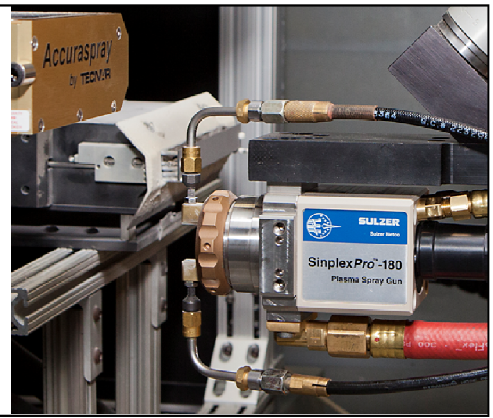


The inset figure shows an example of a notional multifunctional design strategy involving YSZ interfacial layer followed by a $Gd_2Zr_2O_7$ top coat. The latter provides higher temperature capability, lower sintering rates and resistance to CMAS. The characteristics of $Gd_2Zr_2O_7$ top coat itself is optimized through layer-by-layer parameter optimization to meet multiplicity of requirements in terms thermal and erosion properties. This was accomplished for each individual layer via advanced diagnostics and process map strategy. The figure also shows microstructure of one such fabricated multilayer sample. This particular sample matched or exceeded the durability of a standard YSZ coating. Tests are currently underway to evaluate efficacy in CMAS situations as well as erosion characteristics. The results to date point out great advantages of thermal spray methodologies to achieve such novel multilayer functionalities. We are grateful to Howard Waller of St. Gobain USA for his generous support of feedstock powders for this development.

New Process Equipment Installed: Courtesy of Sulzer Metco

Following input from various Consortium members regarding development of "hands-on" trained thermal spray graduates for our industry, CTSR has been upgrading spray process equipment and installing process diagnostics in its various spray booth. A key element of the effort is integrated training with state-of-the-art process equipment, establishing procedures for development of process maps for a range of different materials and processes and incorporation of in situ and ex situ diagnostics for characterization of processes and resultant coatings.





To facilitate this training and sure safe and operation of systems for use by undergraduate and graduate students, CTSR in partnership with Sulzer Metco has set-up two new advanced spray equipment earlier this year. A UNICOAT HVOF system compatible for operating both liquid fuel and gas fuel torches has been set-up. This fully automated facility allows quick change over between spray torches, fully automated operation enabling a large process window for metallic and cermet coatings. In addition, recently developed single cathode cascaded plasma spray system Sinplex Pro has also been set-up. This equipment became operational during summer of 2013 and several students have already been exposed to advanced training with this equipment.

We are grateful to Sulzer Metco for their generous support of this important student development initiative.

Alumni Focus: Dr. Jeff Brogan

In this newsletter, we are pleased to recognize Dr. Jeffrey Brogan, CEO of MesoScribe Technologies. Jeff grew up in the Boston, MA area and first came to Stony Brook in 1987 to pursue a Bachelor's Degree in Engineering Chemistry. Jeff's passion for materials science grew from the undergraduate summer internships spent at MIT Lincoln Laboratory working in clean rooms and developing new thin films. Jeff remained at Stony Brook University after graduating with a Bachelors degree in 1991 and began graduate study in the Dept. of Materials Science. His Master's thesis focused on developing new MRI-compatible materials and interventional biopsy devices for use during surgery.

Jeff then gravitated to the Thermal Spray Laboratory in 1993 to work with Prof. Christopher Berndt on thermal sprayed polymer hydroxyapatite composite coatings to promote bone growth on hip implants. Jeff's PhD research and contribution to the field focused on understanding the processing/structure/properties relationship for thermal sprayed polymers. Jeff gained an appreciation of protective coatings and corrosion control to protect the Nation's infrastructure through funding afforded by the Army Corp. of Engineers. Jeff's project culminated with him, fellow graduate students and professors, suspended 40 feet high, applying recycled commingled polymer coatings to the Triborough Bridge in New York City.

After completing his PhD in 1996, Jeff spent 6 months as a Post-Doc at Monash University in Melbourne Australia, collaborating with Prof. George Simon. His research led to a new understanding of polymer oxidation during deposition. Jeff returned to Stony Brook University in 1997, wrote a small business innovation in research proposal (SBIR) and thus began his entrepreneurial career. Jeff co-founded Poly Therm Corp. and transitioned his PhD research into a commercial entity. Jeff developed a number of polymer coatings for military and commercial use, including a non-skid coating used on the floorboards of special operations rotorcraft.

In 2003, Jeff joined Stony Brook University spin-off, MesoScribe Technologies. The Company was launched after licensing 4 key patents resulting from Prof. Sampath's DARPA program, Mesoscopic Integrated Conformal Electronics. MesoScribe is commercializing a new materials printing technology called Direct Write Thermal Spray. Direct Write enables additive manufacturing of sensors, antennas, and circuitry, on the party to make "Smart Structures". MesoScribe currently manufactures sensors that are integrated into commercial aircraft.