TRANSFORMING THERMAL SPRAY TECHNOLOGY THROUGH
INTERDISCIPLINARY RESEARCH:
FROM PROTECTIVE COATINGS TO FUNCTIONAL MULTILAYERS

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Abstract

Thermal spray is a complex technology involving many sub-processes from thermo-fluids to mechanics to chemistry to materials science. Scientific and technological progress, including development of robust new applications, require multidisciplinary thinking and research consideration. This presentation will present examples of new results and outcomes enabled by such a research strategy.

Thermal spraying is a directed melt spray deposition process, in which inorganic particles in the diameter range of 1-100 microns are heated, melted (in some cases partially), propelled and impacted onto a prepared substrate. Thermal spray has emerged as an innovative and multifaceted materials processing approach that extends well beyond the traditional application of protective coatings into the synthesis of functional surfaces and multilayer devices with complex chemistries, multiscale assemblage and defect dominated architectures. The principal materials processing advantages include: (1) Remarkable materials versatility (metals, ceramics and polymers on a wide range of substrates), (2) Cost-effective near-net-shape manufacturing of a range of materials at near ambient conditions, (3) Ability to synthesize specialized materials with novel structures and compositions, and (4) Flexible approaches to forming multilayered coatings and thick films. This versatility and flexibility with respect to materials and processes has enabled thermal spray to find widespread industrial applications. They are crucial to the economic and efficient operation of a range of engineering systems including gas turbines engines (for propulsion and energy), biomedical implants, industrial machinery, automotive components, heavy machinery reclamation/remanufacturing and semiconductor manufacturing.

During thermal spray processing, a rapid sequence of events occurs including: melting, impact (in some cases shock), spreading and rapid solidification, all of which take place in microsecond timescales, resulting in materials excursions from extreme conditions. The initial microstructure evolves within microseconds, whether process is based on powder melting, impact and solidification, or in more recent modifications involving thermal spraying of suspensions and liquid precursors. Thus, far-from equilibrium structures and compositions are common in thermal spray deposits, offering rich opportunities for fundamental materials research as well as extensive industrial applicability.

Furthermore, thermal spray materials exhibit a hierarchy of microstructural features across a range of length scales: nano-elements, micron-sized grains contained within mesoscale splat structures and a variety of nano/micro/meso-scale defects such as voids, microcracks and oriented boundaries. Nanostructured materials rapid solidification processing, layered/graded architectures etc. - subjects of major excitement in contemporary materials research over the last two decades, entered the lexicon of thermal spray long before they were
fashionable. In fact an exceptional confluence of science and engineering disciplines are engaged in thermal spray research across the globe yielding rich dividends in terms of both enhanced fundamental understanding and expanded applications.

In this context, over the last 15 years through support from the US- National Science Foundation, Center for Thermal Spray Research (CTSR) at Stony Brook University in New York USA has enabled a multidisciplinary group of investigators to critically examine the scientific underpinning behind thermal sprayed materials and unravel its complexity for enhanced utilization. Major advances have been made on a number of fronts including processing science, multi-scale characterization of complex defected structures, novel means of property extraction of layered materials and applications.

Key accomplishments include: (Detailed list of publications available at www.ctsr-sunysb.org)

- Advanced process diagnostics and physics based models providing insights into the process.
- Process maps: an intelligent approach to process optimization, coating design and reliability
- In situ methods to determine coating residual stresses including relations to deposit formation dynamics.
- Defect-property correlations and its relevance in design, performance and processing, including observation and quantification of non-linear phenomena resulting from layered coating assemblage.
- Multiscale methods for determining design relevant coating properties and relating to performance outcomes.
- Figure 1 captures important developments in fundamental science enabled by interdisciplinary research.

These interdisciplinary studies have led to several important findings of direct relevance to coating design and industrial practice of thermal spray processing. This includes:
- Methodologies for integration of coating design, materials and process selection for given application
- Appropriate utilization of process sensors in industrial environment for enhanced reliability.
- New insights coating evolution dynamics through advanced coating monitoring sensors.
- Relevance of inelastic mechanisms in metals/cermets and non-linear properties of ceramics in design and fabrication of damage tolerant coatings
- Benchmarking process-property relationships with linkages to applications and manufacturing integration.
- Science based understanding and controlling process efficiency, coating reproducibility and reliability.

Major breakthroughs have been made on a number of fronts which has enabled new considerations of the process and materials technology towards synthesis of reliable, damage tolerant coatings for variety of applications. They have also yielded rich dividends to science, technology and human resources.

These accomplishments are now being transitioned to industrial practice through a pre-competitive knowledge transfer mechanism through the Consortium for Thermal Spray Technology comprising of some 35 leading companies (see Figure). The consortium allows application of the new methods to enhance efficiency, improve reliability and translate scientific knowledge developed at Center for industrial practice. The consortium brings together academia and industry in a pre-competitive setting to:

- Rapidly examine value proposition of new technology insertion across the supply chain to demonstrate business benefits (e.g. efficiency, reliability improvements)
- Enable identification of implementation issues / adaptation requirements for innovative new ideas and products
- Establish knowledge-technology connections through innovative field trip programs and workforce training on advanced concepts
- This presentation will highlight past contributions and seek new opportunities in emergent coatings, synthesis and multiscale assembly of novel materials, and patterned functional devices.
Figure 1: Illustration of research activities at the CTSR spanning from spray plume simulation and diagnostics to in situ curvature based coating property monitoring and resultant effects investigated through novel mechanical, thermal and electrical property assessment schemes. Integrated outcomes are represented through process maps which links process to properties for various materials and applications. (www.ctsr-sunysb.org)