Topical Symposia

Room California - Session TS2-1

Thermal, Cold, and Kinetic Sprayed Surface Coatings

Moderators: Pylin Sarobol, Sandia National Laboratories, USA, Charles Kay, ASB Industries, Inc., USA

9:00am **TS2-1-4 Thermally Sprayed Alumina and Ceria-doped-Alumina Coatings on AZ91 Mg Alloy**, ***Sanjeet Kumar,*** ITMMEC, Indian Institute of Technology Delhi, India; *D Kumar, J Jain,* Indian Institute of Technology Delhi, India

Present study deals with the development of ceramic based coatings for Mg alloys using thermal spray technique, where Al_2O_3 is doped with CeO_2. Coatings characteristics and other responses were measured using microindenter, nanoindenter, scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), X-ray Diffraction (XRD) and tribometer. The tribological response is evaluated in terms of specific wear rates and coefficient of friction under lubricated reciprocating sliding condition for different loads and speeds. Ceria doped alumina coatings showed improved responses. The elastic modulus and nano-hardness of CeO_2 doped alumina coating was ~13% and ~53% higher than alumina coating, respectively. Under high load and velocity conditions, ceria doped coating showed ~40% reduction in specific wear rate. Also, the results suggest that ceria doping has helped in lowering the coefficient of friction during sliding. One may attribute this to the development of a new intermetallic phase.

9:20am **TS2-1-5 Langmuir–Blodgett Colloidal Assembly: Challenges and Solutions**, *H Nie,* Donghua University, China; ***Jiaxing Huang,*** Northwestern University, USA

LB assembly has been routinely used in research labs for nearly a century for preparing molecular and colloidal monolayers. Volatile, water-immiscible solvents are convenient for spreading, but they have also been a "pain" in terms of colloidal stability, processability and chemical safety, making scaled up applications difficult. The use of water-miscible spreading solvents would avoid all of these problems, but it tends to lose most materials to water subphase due to intermixing, making such LB colloidal assembly ineffective and hard to standardize or reproducible.

This dilemma can be solved by electrospray spreading, in which the small volume of the microdroplets is readily depleted during initial spreading, leaving no extra solvent for mixing. As is demonstrated with several prototypical colloidal systems, electrospray allows high-yield, high-throughput spreading of colloidal materials on water surface using environmentally benign, water-miscible solvents (even water itself), which liberates this century-old technique from many constrains related to material processing and significantly expands its scope. Electrospray apparatus can be readily automated and fully integrated with existing LB systems, which should help to standardize this technique and scale it up from LB assembly to LB manufacturing.

9:40am **TS2-1-6 Mechanical Properties of Thermal Spray Coatings on Carbon-fiber-reinforced Plastic**, ***Reinhard Kaindl,*** Joanneum Research, Austria; *M Kräuter,* Graz University of Technology, Austria; *P Angerer,* Materials Center Leoben Forschung GmbH (MCL), Austria; *W Stöger,* SECAR Technology GmbH, Austria; *M Traxler,* BVT Beschichtungs- und Verschleißtechnik GmbH, Austria; *J Lackner, W Waldhauser,* Joanneum Research, Austria

Due to exceptional properties like high strength and low weight carbon-fiber-reinforced plastic (CFRP) replace steel and aluminum in aerospace and automotive applications. However, the stability of CFRP against mechanical wear, corrosion and thermal load is limited. Thermal spray coatings are routinely used for the protection against extensive wear and/or high temperature, e.g. in power plant turbines, aircraft engines or on pulp rolls in the paper industry. The highly complex relationship between cohesion and adhesion, mechanical properties, structure and composition of course strongly influences the functionality of the compound substrate-coating material. In this contribution, scratch test derived cohesion of thermal spray oxide coatings on CFRP materials and influences of thickness, substrate and coating system will be presented.

Yttrium-stabilized zirconia (YSZ), titanium-aluminum (TiAl) and aluminum-silicon (mullite) coatings with a thickness between 0.15 and 1.4 mm were deposited by thermal spraying on a variety of CFRP materials. Scratch tests were performed using an Anton Paar micro scratch head on cross-sectioned samples embedded in resin. The tests were done with constant loads of 4, 8, 12, 16 and 20 N, scratch length 2 mm, at a speed of 2.4 mm/min with a 100 µm Rockwell C diamond indenter. Images of the cone fracture area were taken immediately after scratching and projected cone areas in µm^2 were calculated.

All cone fractures originated in the coating, confirming that the cohesion was tested. The projected cone area increases with increasing load, in most cases linear but depending upon thickness, substrate and coating system also discontinuous and exponential. This suggests the existence of different failure mechanisms. The lowest areas were observed for a coating thickness around 0.5 mm, both thinner and thicker layers resulted in increased values and decreased cohesion, respectively. The CFRP substrate seems to influence the mechanical properties of the coating. Highest cohesion was found for epoxy and phenolic resin systems. For other systems like sheet moulding compound (SMC), high temperature resins and ceramic particles in the CFRP matrix decrease of cohesion was observed. Differences were also observed for the three coating systems: the highest cohesion was found for TiAl, followed by mullite and YSZ. This is confirmed by the very low, non-economic deposition rates for YSZ during spraying.

In conclusion, scratch tests at constant load allow achieving best functionality against wear and abrasion of thermal spray coatings on CFRP materials by characterizing the cohesion and influences of thickness, substrate and coating system.

10:00am **TS2-1-7 Developments in the Understanding of the Fundamental Growth Mechanisms of Aerosol Deposition**, ***Scooter Johnson,*** Naval Research Laboratory, USA; *D Park,* Korean Institute of Material Science, Korea; *Y Park,* Pukong National University, Korea; *D Schwer, E Gorzkowski,* Naval Research Laboratory, USA **INVITED**

Aerosol deposition is an emerging technologically relevant technique to produce thick polycrystalline films at room temperature. While there have been many materials deposited by this method; including, ceramic, metallic, and even organic compounds for a wide range of applications there is still a very poor theoretical understanding of the mechanics of the film growth. The current theory of film growth is postulated to occur by a mechanism of fracture and plastic deformation of the solid particle as it impacts with the substrate and/or as-deposited particles. This talk will provide an overview of the current understanding of the theory and practice of aerosol deposition along with a comparison between recent experimental results that attempt to correlate film growth, material properties, and deposition parameters.

10:40am **TS2-1-9 Aerosol Deposition as a Method of Room Temperature Thick-Film Deposition**, ***Jesse Adamczyk,*** *P Sarobol, A Vackel, T Holmes,* Sandia National Laboratories, USA; *P Fuierer,* New Mexico Institute of Mining and Technology, USA

Creating thick (>5 µm) films of ceramics and metals typically requires high temperatures or reactive environments, limiting the integration of film/substrate materials possessing drastically different melting points. Thick films of both ceramics and metals can be deposited, using traditional thermal spray techniques. However, particle melting/solidification and splatting lead to a unique microstructure containing splat boundaries, porosity, oxide inclusions, and non-stoichiometric oxide formation. Moreover, melting/solidification can lead to loss of volatile elements, original crystal structure, and associated desired properties (e.g. BaTiO3 will lose its perovskite structure and associated dielectric properties after going through melting/solidification in a plasma spray process). The Aerosol Deposition (AD) process is being utilized to create readily integratable, high density thick-films of ceramics and metals on a variety of substrates at room temperature. In the AD process, thick-films are produced by spraying micron to submicron sized particles out of a nozzle and onto a substrate within a low vacuum chamber. AD takes advantage of the low pressure within the vacuum by allowing sprayed particles to maintain velocity and consolidate in solid-state (no melting/solidification), into a film on impact with the substrate and subsequent film. AD also takes advantage of the small particle size and the ability of ceramic and metallic particles to plastically deform and bond as coatings. Potential applications of aerosol deposition being investigated include direct applied Multi-Layered Ceramic Capacitors (MLCC), electrically conductive electrodes, thermally and chemically resistant barrier coatings, and electrically insulative films.

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Martin Corporation, for the U.S. DOE's National Nuclear Security Administration under contract DE-AC04-94AL85000.

11:00am **TS2-1-10 Residual Stress Measurement of Aerosol Deposited Films**, ***Andrew Vackel****, J Adamczyk, T Holmes, P Sarobol,* Sandia National Laboratories, USA

Aerosol Deposition (AD) is a room temperature, solid state coating process for synthesizing thick films, where sub-micron to micron sized powder is accelerated by a carrier gas through a nozzle towards a substrate within a vacuum environment, forming a coating by particle consolidation. The use of small particles and the reduced drag and bow shock from a vacuum environment allows for normally brittle materials, such as ceramics and carbides, to plastically deform and adhere to the substrate. One of the unique benefits of the AD process is the ability to deposit materials that typically have high melting temperatures or metastable phase compositions at room temperature, allowing material integration that would otherwise be prohibited by the need for high temperatures for processing. Additionally, thermal stress due to expansion mismatches between coating and substrate is eliminated. However, there is still a large degree of residual stress within AD films, due largely to the high kinetic energy impact of particles as the main consolidation mechanism for coating deposition. This talk will explore the use of in-situ substrate curvature measurement to calculate the deposition and residual stresses experienced by different materials in the AD process and how they relate to processing parameters, such as nozzle design, particle size, and process gases, in an effort to better understand and characterize AD coatings.

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11:20am **TS2-1-11 Microstructure and Properties of Room Temperature, Aerosol Deposited, Thick $BaTiO_3$ Dielectric Films**, ***Pylin Sarobol****, A Vackel, J Adamczyk, T Holmes, M Rodriguez, J Griego, H Brown-Shaklee,* Sandia National Laboratories, USA

$BaTiO_3$ based dielectrics are being explored for high temperature stable capacitor applications to enable high power electrical switching devices. The high sintering temperature of $BaTiO_3$ (T>1000°C) often prevents successful integration with low melting point substrates such as glass, metal, or plastic. In this work, we demonstrate integrated high density $BaTiO_3$ based thick films at room temperature utilizing a novel, solid-state deposition process, Aerosol Deposition (AD). In AD process, high velocity submicron particles impact, deform, and consolidate as coatings on room temperature substrates under vacuum. The aerosol deposited $BaTiO_3$ film crystal structure, grain size, residual strain, and dielectric properties were investigated. Preliminary results showed an in-plane crystallographic strain in our AD films were determined to be ~1% by XRD analysis, which corresponds to an approximate compressive stress of 1GPa. The impact of this significant crystallographic strain on dielectric properties will be discussed. The ability to deposit dielectrics at room temperature will further enable the design, fabrication, and integration of high capacitance devices.

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11:40am **TS2-1-12 Dielectrics Produced via Aerosol Deposition**, *E Patterson,* ASEE, USA*; S Johnson,* ***Edward Gorzkowski****,* Naval Research Laboratory, USA

Aerosol deposition (AD) is a thick-film deposition process that can produce layers up to several hundred micrometers thick with densities greater than 95% of the bulk. The primary advantage of AD is that the deposition takes place entirely at ambient temperature; thereby enabling film growth in material systems with disparate melting temperatures. The bonding and densification of the film and film/substrate interface are thought to be facilitated by local temperature rise, high pressure, and chemical bonding during deposition, which leads to a dense nano-grained microstructure. In this talk we present results on the deposition of dielectric and ferroelectric materials deposited by aerosol deposition including the effect of processing parameters on the resultant material properties.

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