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In The News

Book Review

The Science and Engineering of Thermal Spray Coatings

by Lech Pawlowski, 2nd ed., John Wiley & Sons. Ltd., Chichester, UK, 2008. ISBN 978-0-471-49049-4

Professor Lech Pawlowski of Ecole Nationale Supérieur de Chimie de Lille has now provided a welcome update of his book *The Science and Engineering of Thermal Spray Coatings.* Much information on thermal spraying has been acquired since the first edition of this book appeared in 1995. Consequently, in the second edition, the number of pages, figures, tables, and references has been extended by about 50%. The voluminous book has been conceived and written with the requirements of a practitioner of thermal spraying in mind. Hence, aspects of coating buildup from individual splats, methods of coating characterization, description of coating properties, and a survey of industrial applications of sprayed coatings are the mainstay of the text.

Chapter 1 (Materials Used for Spraying, 51 pages) describes methods of spray powder production including atomization, fusion, agglomeration by spray drying, cladding, mechanical alloying, and self-propagating high-temperature synthesis (SHS) as well as several basic methods of powder characterization. Principles of feedstock powder transport to and injection into the plasmatron and flame torch are also covered.

Chapter 2 (Pre-spray Treatment, 14 pages) deals with the surface treatment of workpieces prior to spraying such as cleaning, shaping, roughening by grit blasting, and masking. Roughening procedures are subsumed under the label of ''surface activation.''

Chapter 3 (Thermal Spraying Techniques, 46 pages) provides a very useful, brief, and concise summary of the most important thermal spray techniques applied in today's industrial environment, including the novel cold gas deposition spraying (CGDS) technique. Other new developments are highlighted including plasmatrons with axial injection, multiple cathodes, and liquid suspension feeding of fine powders. Also covered are rotating, microplasma, and radiofrequency-powered plasmatrons as well as high-energy, underwater, and pulsed plasma devices.

Chapter 4 (Post-spray Treatment, 50 pages) educates the reader on several postspray treatment procedures including application of heat by spark plasma and microwave sintering, laser irradiation, electron beam treatment, furnace heating, hot isostatic pressing, and flame remelting. The application of inorganic and organic sealants is also covered. A short paragraph relates to finishing by grinding, lapping, and polishing.

Chapter 5 (Physics and Chemistry of Thermal Spraying, 52 pages) starts with the analysis of the properties of plasma jets and flames in terms of conservation equations of mass, momentum, and energy, and moves on to describe turbulences, transport properties, modeling algorithms, and principles of determination of temperature and velocity of jets and flames. Then, the basics of momentum and heat transfer between plasma and injected powder particles, both from a theoretical and experimental point of view including a description of measuring methods are covered. A short section also deals with chemical modification of particles during flight. Compared to the content of other chapters in this book, the physical principles underlying the thermal spray processes are treated in less detail. This is regrettable as many unique aspects of thermal spraying and properties and performance of coatings can only be fully appreciated and understood in the context of a thorough analysis of the nonlinearity of the process that is a consequence of the fundamental Navier-Stokes equation of momentum transfer within a turbulent plasma jet.

Chapter 6 (Coating Build-up, 69 pages) provides an excellent introduction to the complex processes occurring during impact of molten spray droplets at the solid substrate surface. The deformation of the molten or semimolten droplets and their subsequent solidification to build up the coating microstructure are dealt with in sufficient detail starting from the classical Madejski model augmented later by modification and fine tuning attempts to account for wetting behavior, substrate roughness, particle oxidation, and other salient features. Once a molten droplet has impacted the substrate surface and spread, nucleation, solidification, and eventually crystal growth set in. The chapter continues by describing mechanisms of splat adhesion, lamellae formation, and coating development. The generation of quenching and thermal stresses is briefly explained as well as that of stresses occurring during phase transformation. The resulting microstructure is dealt with by considering the phase composition of coatings produced from refractory oxides such as alumina, titania, and zirconia, complex ceramics such as hydroxyapatite and YBCO, and tungsten carbide. Surprisingly neither development of porosity nor surface roughness as important features of the microstructure of thermally sprayed coatings has been considered in this chapter.

In **Chapter 7** (Method of Coating Characterization, 90 pages) standard characterization techniques have been described according to their working principle, degree of complexity, and power of resolution. These include analytical methods to determine the chemical composition and microstructure of coatings using electron and optical microscopy, infrared (IR) and Raman spectroscopy, x-ray diffraction (XRD), photoelectron spectroscopy (XPS), and x-ray fluorescence (XRF) spectrometry. Mechanical tests ubiquitously applied comprise determination of coating adhesion, bulk and microhardness, elastic modulus, and fracture toughness, as well as tribological features such as wear and friction. The chapter also provides basic information

on thermophysical and thermal properties such as thermal conductivity and thermoshock resistance as well as IR thermography and thermal wave interferometry. Short paragraphs on measuring electrical, magnetic, and chemical (corrosion) properties add welcome information. The chapter ends with a cursory description of nondestructive techniques (NDT) to characterize coating quality such as ultrasonic testing and acoustic emission analysis. While the aforementioned techniques are described in sufficient detail, it is rather surprising that a very critical property such as residual coating stress is dealt with in less than one page. Although there is some additional information provided in a previous chapter (6.2.3), the overriding importance of residual stresses for coating integrity and in-service performance, the problematic aspects of stress measurements, and the continuous effort spent on estimating stresses in thermally sprayed coatings worldwide are not being done proper justice.

Chapter 8 (Properties of Coatings, 158 pages) constitutes the longest and most comprehensive part of the book. The author has attempted to order the vast amount of information collected according to the order selected in Chapter 7. The chapter starts with a very brief introduction to statistical design of experiments, limited to just full-factorial designs at two levels. Given the plethora of designs available and frequently used to optimize coating properties and performance, this limitation is somewhat disappointing. In this context, the reference made to neural network analysis (NNA) is definitely a ''red herring.'' The following sections deal with *mechanical* (hardness, tensile adhesion strength, rigidity, fracture toughness, friction, wear), *thermophysical* (thermal conductivity, thermal diffusivity, specific heat, thermal expansion, emissivity, thermoshock resistance), *electrical* (electric conductivity, electric resistivity, dielectric permittivity), *magnetic*, *optical*, and *chemical* (aqueous, hot gas, and melt corrosion) properties. The chapter is rather difficult to read and comprehend despite the effort of the author to structure his diligently collected material according to physical property and materials group (carbides, oxides, metals, composites).

Chapter 9 (Applications of Coatings, 54 pages) presents a selection of industrial sectors in which thermally sprayed coatings are beneficially applied including aerospace, automotive, ceramics, chemical, electronics, energy generation, steel, machine building, medical, mining, nonferrous metal, nuclear, paper, printing and packaging, and ship building and naval industries. This chapter is particularly useful for industrial engineers who want to introduce thermal spraying into their canon of production and surface engineering technologies.

Despite the generally favorable impression this tome, made there are several shortcomings. Occasionally, symbols occurring in equations are not explained in the accompanying text, and thus the reader is forced to guess their meaning and relevance. Also, on occasion, identical figures appear in different contexts in different parts of the book. The quality of the print and, in particular, the crispness and resolution of halftone micrographs leave much to be desired and thus do not match the excellent printing quality of the first edition. Typographical errors and grammatical deficiencies were also noted.

In conclusion, the second edition of Professor Pawlowski's oeuvre is a solid piece of useful information provided to a hopefully receptive audience in the surface engineering sector dealing with thermally sprayed coatings for wear, corrosion, thermal, and environmental protection. The book can be warmly recommended to graduate students in materials science and engineering, mechanical engineering, and production engineering as well as to professionals working in a large variety of industrial engineering sectors. Technicians, technologists, and spray-shop foremen will also benefit enormously from perusing the second edition of Professor Pawlowski's book even though the high price (€ 189.00) may dissuade many potential readers from buying it.

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Recent Conferences

ITSC in the Netherlands Attracts 600 Thermal Spray Professionals

Leaders within the world's thermal spray community gathered during June 2-4, 2008, in Maastricht, The Netherlands, as the International Thermal Spray Conference and Exposition (ITSC) attracted more than 600 attendees, with more than 400 expo-only attendees from 36 countries.

The 40-plus exhibit exposition opened on Monday afternoon, and during the evening attendees were welcomed by the ITSC exhibitors at the Exhibitor Reception. TSS President Peter Hanneforth presented the Thermal Spray Hall of Fame award to Albert Kay, FASM, President of ASB Industries and TSS Past President.

Over the past years, ITSC has become a valuable worldwide exchange market for trends in thermal spraying. This year's event featured the latest developments in thermal spray applications, technology, and science. More than 40 sessions comprised 220 oral and 140 poster presentations. Topics included automotive, solid-oxide fuel cell, gas turbine, biomedical coating, printing, and paper applications.

Tuesday saw the event banquet and the presentation of the *JTST* Best Paper Award for ''In-Situ Simultaneous Measurement of Thickness, Elastic Moduli and Density of Thermal Sprayed WC-Co Coatings by Laser-Ultrasonics''

TSS President Peter Hanneforth presents the Thermal Spray Hall of Fame award to a long-time colleague of TSS and a leader in thermal spray, Albert Kay, FASM

ITSC 2008 attracted more than 600 attendees, with more than 400 expo-only attendees from 36 countries

Participants of S2TS workshop in front of Nitray Castle

Mitch Dorfman, VP TSS presents the *JTST* Best Paper Award to Basil Marple and Rogerio Lima

by C. Bescond, S. E. Kruger, D. Lévesque, R. S. Lima, and B. R. Marple. (Basil Marple and Rogerio Lima accepted the award on behalf of the authors).

The banquet was held in La Caverne de Geulham, which is a cave just outside Maastricht. How appropriate that the location should be some 30 m ''beneath the surface'' of the southern Dutch hills! Learn more about the location at http://www.xs4all.nl/~kuikj/infopag1_en.htm.

TSS Past President Rick Knight summed up ITSC this way: ''Good bread, white asparagus, beer, herrings and a great thermal spray conference—what more could anyone ask for?''

Second International Workshop on Suspension and Solution Thermal Spraying

After a first successful national meeting in 2007, the second workshop on suspension and solution thermal spraying (S2TS 2008) was held in Tours, France, June 5-7, 2008. The objectives of this meeting, organized by the CEA (The French Atomic Energy Commission) and supported by the Region Centre Council, were to promote, in a friendly social climate, scientific and technical exchanges between academic researchers and industrial application developers working in suspension or solution precursor thermal spraying or closely related fields. The International Scientific Committee was composed of L.M. Berger (I.W.S., Dresden, Germany), G. Bertrand (U.T.B.M., Belfort, France), P. Fauchais (University de Limoges, France), E. Meillot (CEA Le Ripault, France), G. Montavon (University de Limoges, France), C. Moreau (N.R.C., Boucheville, Canada), L. Pawlowski (E.N.S.C., Lille, France), R. Vassen (Univ. Juelich, Germany), and P. Vuoristo (Univ. Tampere, Finland).

The whole area of suspension, liquid, or sol thermal spraying was covered from fundamentals to applications. During the two days of presentations, more than 30 papers were presented in oral or poster sessions. Professor Eric Jordan from University of Connecticut, Storrs, CT, delivered a plenary lecture titled ''Fundamentals of the Solution Precursor Plasma Spray Process and Their Relation to Making Dense Coatings.'' After that, the 80 participants from 12 countries participated in high-level discussions about the different fields of the specialty: preparation and properties of precursors (suspension, liquid mixture, sol), injection and fragmentation, transfer and interactions (thermal, chemical,…), layer architecture and properties, and some industrial applications such as SOFC layers. Papers will be published in a special issue of *Surface and Coating Technology* in the first quarter of 2009.

After a short excursion to Nitray castle, an old Renaissance castle in the Loire Valley, for the gala dinner, the participants hoped to meet again for two upcoming thermal spray workshops in France: December 2009, in Lille, for the Fourth International Meeting on Thermal Spraying and in May or June of 2011, in Tours, close to the ITSC 2011 conference.

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