JTTEE5 17:313–315
DOI: 10.1007/s11666-008-9195-z
1059-9630/$19.00 © ASM International

Meet Our New Colleagues

This column presents selected thermal spray research from graduating Ph.D. students as a way of introducing these researchers to the larger thermal spray community and helping them to apply their skills to existing needs. Recently graduated and soon-to-graduate (within 6 months) students are encouraged to submit a short description (1-2 pages) of the research they performed during their studies to Kendall Hollis, JTST Associate Editor at: Los Alamos National Laboratory, P.O. Box 1663, MS G-770, Los Alamos, NM 87544; e-mail: kjhollis@lanl.gov. With agreement of the student's thesis advisor, selected submissions will be published in the upcoming issues of JTST.

Enhanced Coatings by Suspension Plasma Spraying

Holger Kaßner, Ph.D. student, Forschungszentrum Jülich GmbH, Institut für Energieforschung, IEF-1: Materials Synthesis and Processing, Jülich, Germany; e-mail: h.kassner@fz-juelich.de

Holger Kaßner

Thesis title: Theoretical and Experimental Investigation on Plasma Spraying with Liquids. University: Ruhr-Universität-Bochum, Germany. Anticipated graduation date: Beginning of 2009

Papers and Conference Proceedings

- Influence of Porosity on Thermal Conductivity and Sintering in Suspension Plasma Sprayed Thermal Barrier Coatings, *Proc. 32nd International Conference & Exposition on Advanced Ceramics & Composites* (Daytona, FL)
- H. Kaßner, A. Stuke, R. Vaßen, and D. Stöver, Influence of Microstructure on Thermal and Optical Properties of Suspension Plasma Sprayed (SPS) and Atmospheric Plasma Sprayed (APS) Coatings, *Proc. ITSC 2008* (Maastricht, Netherlands)
- H. Kaßner, R. Vaßen, and D. Stover, Application of Suspension Plasma Spraying (SPS) for Manufacture of Ceramic Coatings, *J. Therm. Spray Technol.*, 2008, **17**(1), p 115-123
- H. Kaßner, R. Vaßen, and D. Stöver, Study on Instant Droplet and Particle Stages During Suspension Plasma Spraying (SPS), *Surf. Coat. Technol.*, in press

Background

Suspension plasma spraying (SPS) is a rather new process in the field of atmospheric plasma spraying (APS). Usually, conventional thermal spray processes require easy-flowable powders from 10 to 100 μm. In contrast, SPS allows the processing of nanosized particles directly. Thus, new, or at least improved, coatings can be generated (Ref 1-6).

Today, yttria-stabilized zirconia (YSZ) is widely used as a ceramic top layer for thermal protection. Since high-efficiency engines need increased turbine entry temperatures, the heat flow to the metallic components is increased. Thus, not only the conductive heat transfer, but also the fraction of radiation emitted by the turbine walls increases significantly. The performance of conventional YSZ layers generated by APS or PVD is limited due to their process characteristics. In addition, YSZ is nearly transparent to radiation in the near-infrared (IR) range at wavelengths below 5 μm (Ref 7-12). Hence a significant part of the radiation directly reaches the underlying metallic substrate. Radiation transfer, as well as thermal conductivity, depends on the properties and microstructure of the coating material. Thus, an enhanced performance of YSZ-based thermal barrier coatings (TBCs) can only be achieved by an improvement of the microstructure. Here, the SPS process offers new possibilities to manufacture new microstructures. We focused on the generation of improved TBCs with enhanced thermal and optical properties including an enhanced lifetime. Therefore, the SPS process itself and the influencing parameters were investigated and a schematic of the single stages during SPS was developed.

Experimental Setup

The SPS coatings were produced with a Triplex II APS plasma gun implemented in a multicoat system from Sulzer Metco AG, Wohlen, Switzerland. The suspension injection was performed with a self-designed two-phase atomizer using a prefragmentation of the suspension. Nanosized YSZ, titania, or alumina powders served as feedstock materials. The microstructure was inspected in cross sections or free-standing coatings with a scanning electron microscope, Ultra 55 (Carl Zeiss NTS AG, Germany). Phase evolution was observed by X-ray diffraction with a D500 (Siemens AG, Germany) diffractometer. Layer pore size distributions were determined by Pascal 140 and 440 mercury porosimeters (CE-Instruments, Milan, Italy). Thermal diffusivity experiments were conducted using a laser flash device (Model: THETA, Netzsch, Germany) on free-standing disk-shaped specimens. The hemispherical reflectance and the transmittance of free-standing coatings were determined in the wavelength range 0.3-2.5 μm using a Lambda 950 IR-spectrometer integration (Perkin Elmer, USA). The in-flight particle speed and temperature monitoring was performed by the diagnostic system Accuraspray-g3, (Tecnar, Canada).

Influencing Parameters and Stages During Suspension Plasma Spraying

Based on empirical studies including in-flight diagnostics of the particles as well as splat and coating analyses, a schematic of the single stages during SPS was developed (Fig. 1). The studies on the influencing parameters were based on a simplified model including the dwell time and the energy flow. In sum, the plasma power, plasma gas flow, injection pressure, and spraying distances as well as their interactions were investigated. The injection pressure and spraying distance emerged as the main influencing parameters on coating structure and processing efficiency. An optimization of all parameters leads to an increase of the deposition rate up to 14 μm per cycle. The deposition efficiency was increased to 40%. In this juncture, the quality of the coating structure is also improved from a coating comprising primarily semimolten particles to a coating built of well-molten splats.

Enhanced TBCs by SPS

By optimizing the parameters and processing of SPS, TBCs with a significant

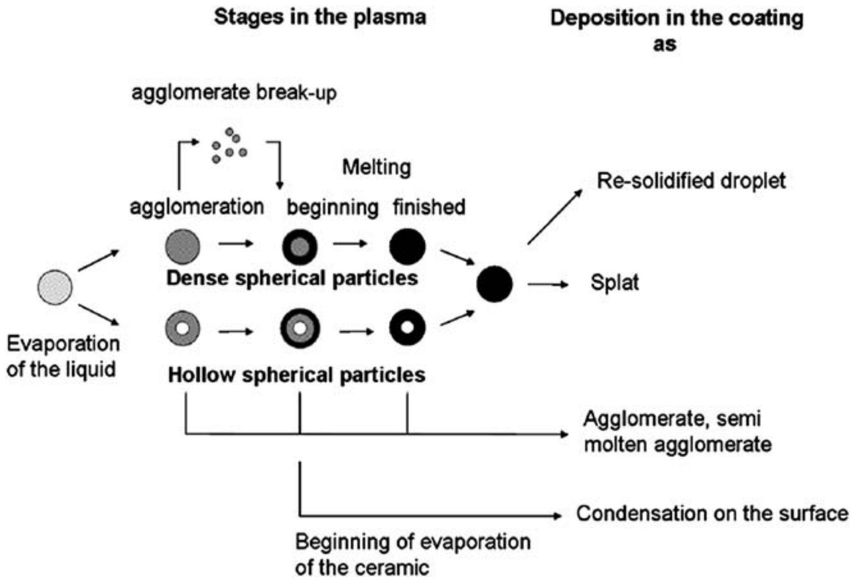

Fig. 1 Stages in SPS and its influence on the coating structure. *Source*: Ref 12

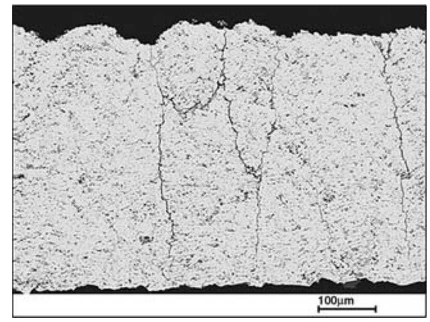

Fig. 2 SPS coating with high segmentation crack density and porosity level

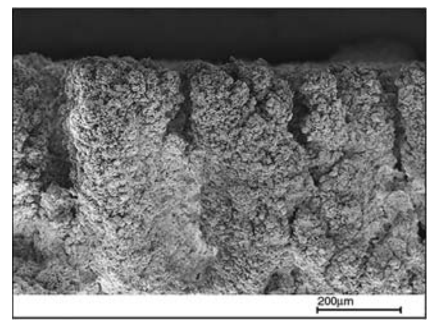

Fig. 3 Columnar structure of an alumina coating

change of microstructure were generated. One of the most conspicuous features is the wide adjustable band of microstructures characterized by the porosity levels. Depending on the process parameters, SPS coatings with a porosity level of up to 40% can be generated. Conventional APS coatings usually show porosity levels of less than 25%. Therefore, the porosity in SPS coatings, especially the amount of porosity with a pore radius lower than 2 μm, is drastically increased.

The thermal and optical properties can also be improved significantly. The generated coatings feature a superior screening of IR radiation and clearly reduced thermal conductivity. The thermal conductivity was decreased from 0.9 W/m · K at 1200 °C for an APS coating with 12% porosity to 0.4 W/m · K for SPS coatings with a porosity level of 40%. The reflectance of IR radiation was increased from 83% (APS) to 93% (SPS). The IR transmittance through the coating was reduced from 14% (APS) to approximately 3% (SPS). Also, zirconia double-layer systems made up of APS and SPS layers were investigated. The reflectance of IR radiation was increased by a 90-μm SPS top layer from 83% for the single APS layer to 90% for the double layer. A 170-μm SPS top layer reflected 93%. Also, the thermal conductivity was significantly decreased.

The lifetime of TBCs was affected positively by SPS processing. In APS coatings, a very dense microstructure is essential for the generation of segmentation cracks. In addition, the achievable crack densities in most cases are below 5 mm^{-1}. The SPS process allows much higher segmentation crack densities up to a double-digit range combined with porosity levels of up to 40%. Figure 2 depicts a SPS coating with a high microcrack density and a porosity level of 27%.

Columnar Coating Structures and Nanomultilayers

For special SPS spraying conditions, a columnar/cauliflower structure was observed for alumina and YSZ ceramics. Figure 3 shows the fracture surface of an alumina coating with columnar structure. The shape and the distance between the single freestanding columns were influenced by variation of the processing parameters. The maximum achievable porosity level was 70%. Also, the specific surface is noticeably increased.

Another interesting structure manufactured by SPS is a nanomultilayer of two different ceramics. In this case, a layer system of alumina and YSZ was investigated. The structure is a fine laminar multilayer with a lamella size from 0.1 to 2 μm.

Summary and Outlook

The SPS process offers great potential to produce new, fine-grained microstructures and to significantly improve the performance of conventional coatings. Compared to the APS process, the SPS process allows a partial improvement of the microstructure. One of the most interesting features is the widely adjustable band of microstructures characterized by porosity levels of up to 40%. The porosity, especially that with pore radii lower than 2 μm, is drastically increased. In addition, the thermal and optical properties are significantly improved. The coatings feature a superior screening of IR radiation of up to 93% and reduced thermal conductivity of up to 50% less compared to conventional TBCs. Also, the more cost-efficient double-layer systems show considerably improved thermal and optical properties. Combined with the high segmentation crack levels that affect the stress tolerance, SPS seems to be a promising technique to generate superior TBCs.

The new microstructures obtained in the SPS process might enhance the performance of conventional coatings and offer completely new application fields. The macroscopically columnar structures with their high open porosity combined with the high specific surface make these coatings interesting for catalytic or separation processes in the chemical industry or in energy systems. The nanomultilayers offer layer thicknesses reduced by several orders of magnitude compared to conventionally sprayed composites.

References

1. C. Delbos, J. Fazilleau, V. Rat, J.F. Coudert, P. Fauchais, and B. Pateyron, Phenomena Involved in Suspension Plasma Spraying, Part 1: Suspension Injection and Behavior, *Plasma Chem. Plasma Process.*, 2006, **26**(4), p 371-391
2. C. Delbos, J. Fazilleau, V. Rat, J.F. Coudert, P. Fauchais, and B. Pateyron, Phenomena Involved in Suspension Plasma Spraying, Part 2: Zirconia Particle Treatment and Coating Formation, *Plasma Chem. Plasma Process.*, 2006, **26**(4), p 393-414
3. P. Fauchais, V. Rat, C. Delbos, J.F. Coudert, T. Chartier, and L. Bianchi, Understanding of Suspension DC Plasma Spraying of Finely Structured Coatings for SOFC, *Plasma Sci.*, 2005, **33**(2), Part 3, p 920-930
4. J. Oberste Berghaus, S. Bouaricha, J.-G. Legoux, and C. Moreau, Injection Conditions and In-Flight Particle States in Suspension Plasma Spraying of Alumina and Zirconia Nano-Ceramics, *Proc. 2005 International Thermal Spray Conference, Thermal Spray: Building on 100 Years of Success*, May 2-5, 2005 (Basel, Switzerland), ASM International, 2005, p 512-518
5. R. Jaworski, L. Pawlowski, Fr. Roudet, S. Kozerski, and A. Le Maguer, Influence of Suspension Plasma Spraying Process Parameters on TiO_2 Coatings Microstructure, *J. Therm. Spray Technol.*, 2008, **17**(1), p 73-81
6. M. Gell, E.H. Jordan, M. Teicholz, B.M. Cetegen, N.P. Padture, L. Xie, D. Chen, X. Ma, and J. Roth, Thermal Barrier Coatings Made by the Solution Precursor Plasma Spray Process, *J. Therm. Spray Technol.*, 2008, **17**(1), p 124-135
7. H.B. Guo, R. Vaßen, and D. Stöver, Thermophysical Properties and Thermal Cycling Behavior of Plasma Sprayed Thick Thermal Barrier Coatings, *Surf. Coat. Technol.*, 2005, **192**, p 48-56
8. P. Scardi and M. Leoni, Microstructure and Heat Transfer Phenomena in Ceramic Thermal Barrier Coatings, *J. Am. Ceram. Soc.*, 2001, **84**(4), p 827-835
9. V. Debout, F. Enguehard, A. Meillot, P. Abélard, E. Bruneton, and P. Fauchais, Optical and Radiative Properties of YSZ Plasma-Sprayed Coatings, *Proc. International Thermal Spray Conference, ITSC Seattle*, 2006
10. J.I. Eldridge, C.M. Spuckler, K.W. Street, and J.R. Markham, Infrared Radiative Properties of Yttria-Stabilized Zirconia Thermal Barrier Coatings, *Ceram. Eng. Sci. Proc.*, 2002, **23**(4), p 417-429
11. A. Stuke, R. Carius, J.-L. Marquéz, G. Mauer, M. Schulte, D. Sebold, R. Vaßen, and D. Stöver, Optimizing of Reflectivity of Air Plasma Sprayed Ceramic Thermal Barrier Coatings, *31st International Cocoa Beach Conference and Exposition on Advanced Ceramics and Composites, Ceramic Engineering Science Proceeding*, 2007
12. H. Kaßner, R. Vaßen, and D. Stöver, Study on Instant Droplet and Particle Stages During Suspension Plasma Spraying (SPS), *Surf. Coat. Technol.*, in progress, 2008