Integrated Simulation and Modeling for Thermal Spray

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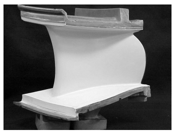
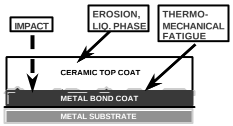
MRSEC

INTRODUCTION

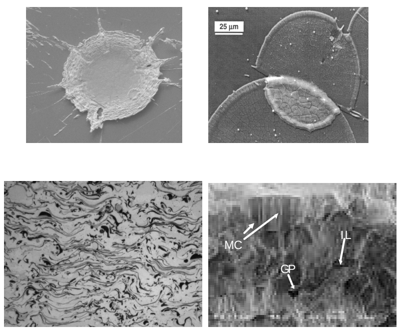
- Thermal barrier coatings consist of a thermally insulating ceramic layer covering a metallic bond-coat layer. The bond coat provides oxidation protection of the substrate and reduces the difference in thermal expansion. The insulating ability is improved by its containing delaminations and pores. On the other hand, cracks could cause spalling and failure of the coating.
- Optimal microstructure of the top coating is not a homogenous one without defects, but is rather a structure containing pores and cracks of various types at particular locations in the coating.





MICROSTRUCTURE OF PSZ COATINGS

- Deposit is built up by millions of "brick" -- splats.
- Splat is formed by the interaction of droplet with substrate /or previously formed deposit.
- Droplet spreading and solidification behavior affects the splat dimensions, grain size and phase selection.
- Splat size, morphology and pile-up determines, to a large extent, the deposit microstructure, porosity and property.



IP – Interlamellar Pores GP – Globular Pores MC - Microcracks

Particle/Flame

Particle Velocity & Temp.
- powder morphology
- partially or fully melting
- vaporization/resolidification

Particle Size Distribution
- trajectory
- microscale heat transfer

Turbulent Jet
- instability / random process
- low stability / reproducibility

Plasma flame
- electrode wear
- fluctuation

Splat Formation

Flattening / Adhesion
- substrate temperature
- roughness
- wetting / solidification

Droplet Splashing
- velocity and size
- solidification rate

Splat Morphology
- flattening ratio
- substrate melting

Stress State
- residual stresses

Microstructures

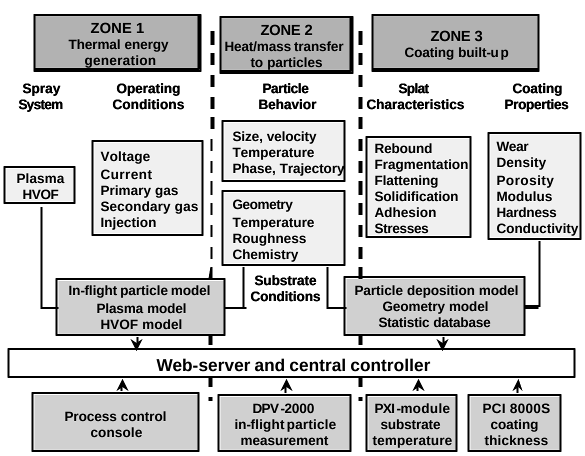
Interlamellar Pores
- enhances thermal barrier effect
- Source of delamination

Globular Pores
- introduces porosity/compliance
- origin of failure

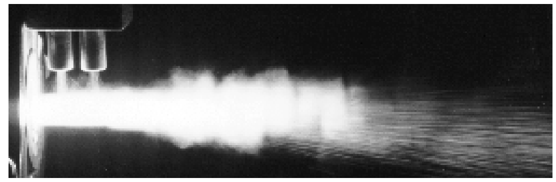
Vertical Splat Microcracks
- relieve residual stresses
- sinters during thermal cycling

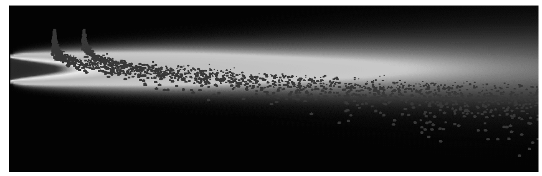
Vertical Macrocracks
- introduces in-plane compliance
- entry of corrosion products

INTERNET-BASED SIMULATION AND CONTROL THERMAL SPRAY SYSTEM



2D PLASMA JET FLOW AND FLAME/PARTICLE INTERACTION

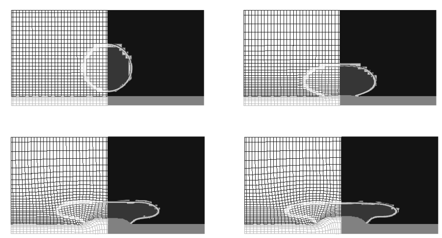




Two injectors are used for two different powders. Injection velocity for PSZ is 14.5 m/s, much higher than that for NiCrAlY (9.8m/s).

PHYSICAL MODEL

- Inertia force (impingement, shock wave)
- Surface tension (liquid/gas, triple point)
- Solidification (dynamics, kinetics, contact resistance)
- Moving free surface (shear stress)
- Instability and splash (Rayleigh, weber, capillary)
- Bond energy, adhesion, and trapping gas
- Microstructure

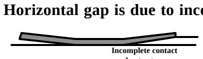


PSZ COATING POROSITY

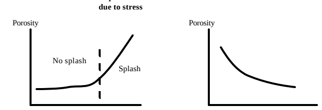
Pores are due to unmelted particles and splashing

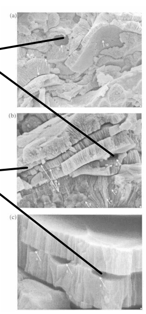
Melting Index $M.I.^{?1} ? \frac{V_p d_p}{T_p L}$ Splash Index $S.I. ? \frac{T_m ? T_{sub}}{T_p ? T_m} \frac{V_p d_p}{1 ? \cos ?}$

Horizontal gap is due to incomplete contact



$? \quad ? ? \left(T_p ? T_{sub}\right) d_p^{2.4} V_p^{0.4}$





Difficulty: Particle size, velocity, and temperature are strongly inter-related.

CONCLUSIONS

- Thermal Spray is a versatile deposit forming technology with increasing importance
- Fundamental understanding of splat formation is essential for optimization.
- The relation between the microstructure of the coating and the properties of the particles needs to be established, and the relation between the particle properties and the spray gun parameters needs to also be understood.
- Integrated model and quantitative characterization can help us to establish relationships between TBC microstructure and properties, and develop processing procedures to obtain desired microstructure.