Process – Microstructure – Property Relationships in Powder Flame Sprayed Ceramic Coatings

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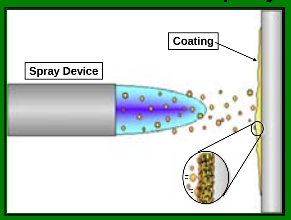
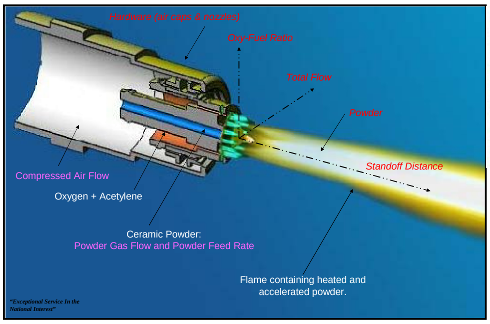
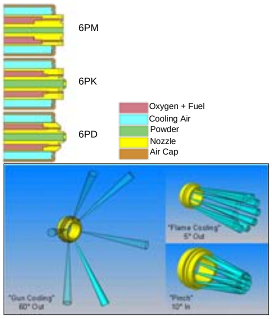
In late 2003, Center 1800's Thermal Spray Research Laboratory (TSRL) was approached by the Department of Defense to assist with stabilization of a thermal spray coating process for a critical national security application. Lack of process understanding, control strategies, and appropriate material specifications had resulted in high-risk production strategies that could limit availability of critical equipment. A science-based approach to understanding the Powder Flame Spray process has allowed for significant process improvements including: New materials specifications, improved process control strategies; lower cost materials, improved equipment, and more stable processing conditions. Current deployment of these process improvements is reducing risks associated with production of this coating and helping guarantee equipment availability.

What is Thermal Spray?

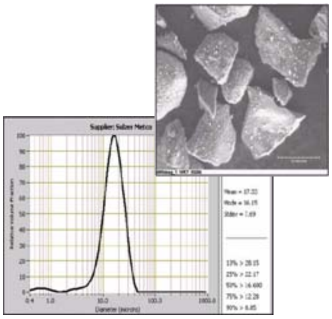


~ 10 - 100 µm Molten or Semi-Molten Droplets are Sprayed onto a Target Surface Where they "Splat" Cool at Rates up to 10^4 -10^8 K/sec Forming a Lamellar Microstructure





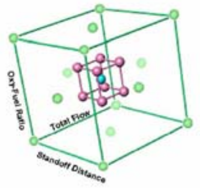
Powder Flame Spray *is a complex process involving many variables, each of which affect coating microstructure and properties. The TSRL developed a science – based understanding of powder flame spray by thoroughly characterizing process – microstructure – property relationships using a designed experiment approach.*

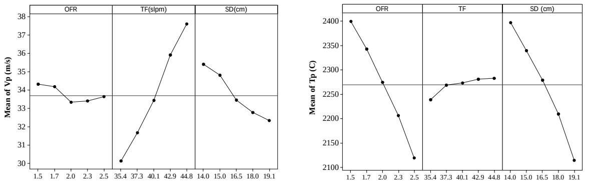


Fused and crushed ceramic powder used for process characterization.

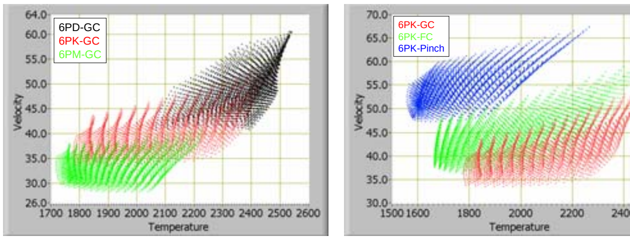
Augmented Central Composite Design

- 21 experiments + 6 Center Points
- Total Flow: 35.4 - 44.8 SLPM
- Oxy-Fuel Ratio: 1.5 - 2.5
- Standoff Distance: 14.5 - 19.1 cm
- Cooling air flow = 165.2 SLPM
- Powder feed rate = 10 g/min
- Powder gas flow rate = at 4.7 SLPM.
- Tafa 9000 Hopper



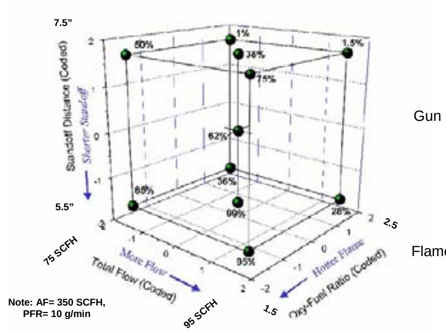


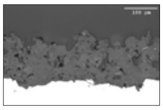
Main effects of factors on particle velocity (Vp) and temperature (Tp) for 6PM-GC



Accessible Regions of Tp, Vp Space *are shown graphically by plotting equations developed from experimental data. These data allow specific points in Tp, Vp space to be accessed by choosing the appropriate hardware, and torch operating conditions.*

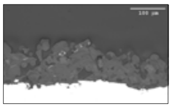
Hotter, faster particles increase deposition efficiency (DE)





Gun Cooling, Vp =41.1m/s, Tp =2127ºC

Effect of Air Cap on DE and microstructure for 6PK Torch. All coatings sprayed at 2.0 OFR, 40.1 SLPM TF,16.5 cm SD

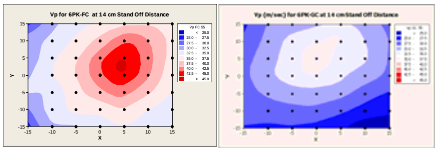


Flame Cooling, Vp =44.7 m/s, Tp =1950ºC

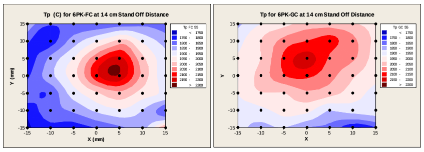
Pinch, Vp =55.0m/s, Tp=1786°C

Torch Hardware	T_p (ºC)	V_p (m/s)	TF (SLPM)	OFR	SD (cm)	DE (%)
6P-K-FC	2108	45.2	37.3	1.92	14.2	64.0
6P-D-GC	2101	44.9	44.8	2.00	18.8	36.8
6P-K-GC	2109	44.5	44.8	1.80	14.0	75.2

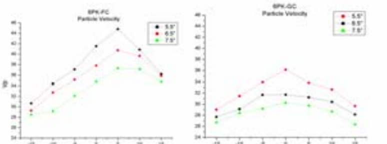
Deposition Efficiency *is simply the ratio of material sprayed to material deposited No coating process is 100% efficient. Understanding the effect of particle temperature, and particle velocity on deposition efficiency is the first step in establishing process – microstructure relationships. Surprisingly, similar Tp and Vp do not necessarily yield similar deposition efficiencies in the powder flame spray process!*



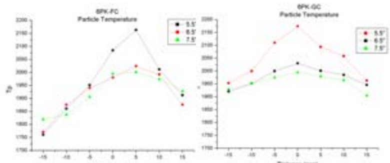
Flame cooling (FC) air cap yields a higher particle velocity in smaller area than gun cooling (GC).



GC air cap has less variation over the flame in particle temperature than FC.



FC air cap yields a higher particle velocity than GC, also velocity decreases as stand off distance is decreased.

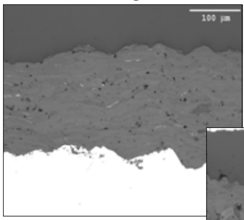


GC air cap has less variation in particle temperature over the flame area than FC and particle temperature is higher closer to the torch.

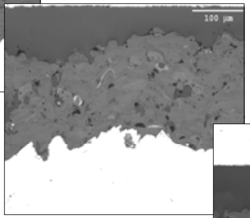
Understanding Process – Microstructure – Property Relationships:

Understanding process – microstructure – property relationships is critical to process stabilization, quality control, and process monitoring. The science based understanding of the powder flame spray process developed at Sandia has allowed process improvements to be developed including:

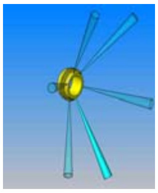
- New materials
- New specifications
- Stable operating conditions
- New quality control tools
- Improved process monitoring



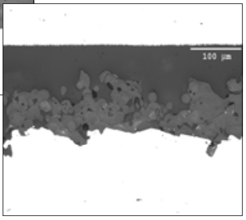
4.5" Stand off Distance



5.5" Stand off Distance



6PD-GC: TF= 85 SCFH, OFR= 2.0, AF= 350 SCFH, PG= 10 SCFH, PFR= 10 g/min



6.5" Stand off Distance

Plume cross sections were made by using the DPV-2000 to measure Tp and Vp every 5 mm within ±15 mm of the torch center at stand off distances of 13.97 cm (5.5"), 16.51 cm (6.5"), and 19.05 cm (7.5")

Torch Conditions: TF= 85 SCFH, OFR= 2.0 OFR, Air Flow (AF)= 400 SCFH, Powder Gas (PG)=10 SCFH, and Powder Feed Rate (PFR)= 10 g/min

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