Manufacturing of Thermal Barrier Coatings Through Plasma Spray Physical Vapor Deposition

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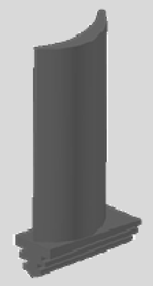
Introduction & Motivation

In order for an aircraft or a rocket to work efficiently, longer, and at higher temperatures thermal barrier coatings need to be applied. Thermal barrier coatings are used to lower the chance of oxidation and decreases the conductivity of heat applied to the surface of the material. This protects the combustion chamber for a rocket or the turbine blade for an aircraft from damage. The deposition process can have a major effect on the performance of the thermal barrier coating. Plasma Spray Physical Vapor Deposition is an emerging deposition that combines the processes of previous deposition methods to improve the quality of coatings by providing customizable microstructures and properties.

[1] Combustion Chamber



Turbine Blade

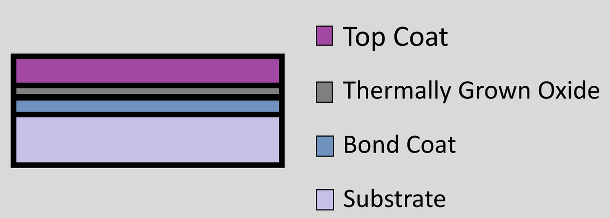
Objectives

- Understand the process of manufacturing PS-PVD coated samples and the effect of deposition time
- Study the TBC structure of samples with different thicknesses through Optical Microscopy

Background

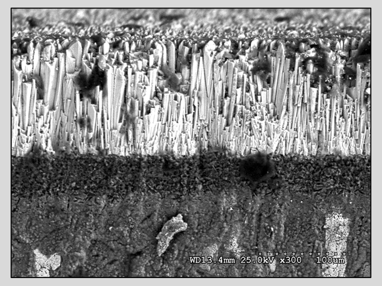
Thermal barrier coatings have played a key role in protecting engines from intense temperatures and an oxidizing environment. The coating is made up of four parts:

- A ceramic coating which provides the key protection against heat and pressure.
- A thermally grown oxide that grows as a result of oxidation
- A metallic bond coat that protects material underneath from corrosion
- The Substrate material the turbine blade or combustion chamber would be made of.

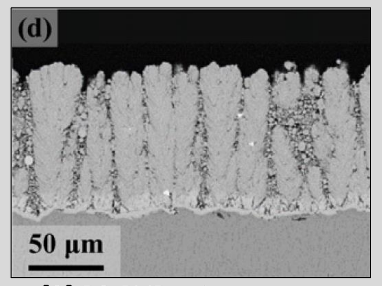


The deposition of the thermal barrier coating will affect the properties and the durability. One of the most commonly used deposition for jet engines is Electron Beam Physical Vapor Deposition (EB-PVD) known for its columnar structures. Plasma Spray Physical Vapor Deposition (PS-PVD) is a relatively newer deposition that can reproduce similar structures. In PS-PVD, the coating material is vaporized by the thermal plasma, and condenses on the substrate creating a custom microstructure based on the gas compositions, the spray power, the deposition rate, and other factors. The flexibility and low pressure is a key factor of the deposition as it leads to the custom nature of the deposition.

Here are the two different microstructures and comparisons of the depositions:



EB-PVD microstructure



[2] PS-PVD microstructure

Electron Beam Physical Vapor Deposition	PS-PVD
Columnar microstructure	Custom microstructure
High Cost	Low Cost
High Thermal Conductivity	Low Thermal Conductivity
High Strain Tolerance	High Strain Tolerance
Low Deposition Rates	High Deposition Rates
High Erosion Resistance	Custom Erosion Resistance
Coats Simple Designs	Coats Complex Designs
Less Weight	Custom Weight
Smooth Surface	Custom Surface
Non-Uniform Gradient	Uniform Gradient

Substrates:

- The substrates were machined with the following parameters:

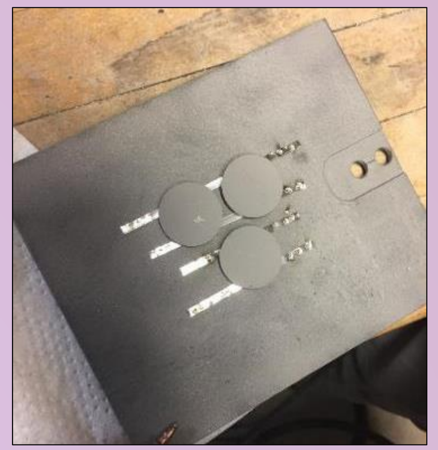
Substrate	Shape	Diameter of Substrate	Thickness of Substrate	Number of Samples
Inconel 718	Disk	25.4 mm	3.5 ± .5mm	3
Ni Superalloy	Disk	25.4 mm	3.1 ± .5mm	3

Samples before grit-blasting

Grit Blasting:

- Kind of Spray Used: Alumina – Based
- Pressure: 60 PSI
- Distance from Spray: 6 to 8 inches away
- Sprayed until a satin finish
- Roughens the surface of the material so that the coating sticks to the surface better

Grit-Blasting System

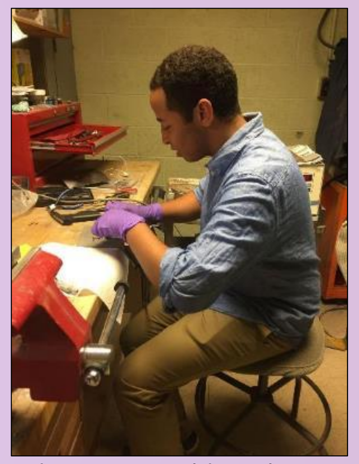


Samples after grit-blasting attached to a mounting plate

Deposition:

- The samples were spot-welded to an Inconel 716 plate with NiCr strips and then connected to an arm on the PS-PVD rig
- The pressure of the rig was decreased to about 0.78 - 0.79 torr
- They were then sprayed with a vapor of 7-8% Yttria Stabilized Zirconia particles along with Argon and Helium gas
- Two sets of samples were deposited
  - The thickness was measured afterwards through the use of a caliper
  - Thickness can change depending on deposition time, spray angle, power, etc.

Substrate	Sample Names	Deposition Time	Thickness of TBC
Inconel 718	AP0, BP0, CP0	5 minutes	90 – 120 µm
Ni Superalloy	D2P0, D18P0, D35P0	20 minutes	160 – 180 µm

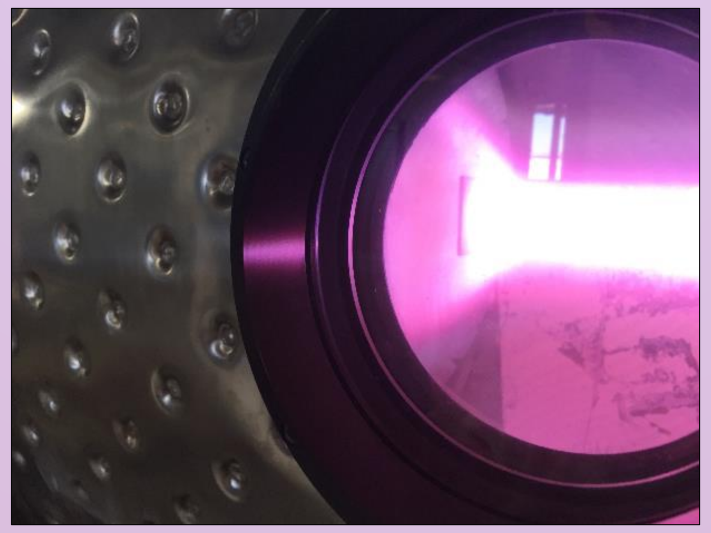


A student spot-welding the samples

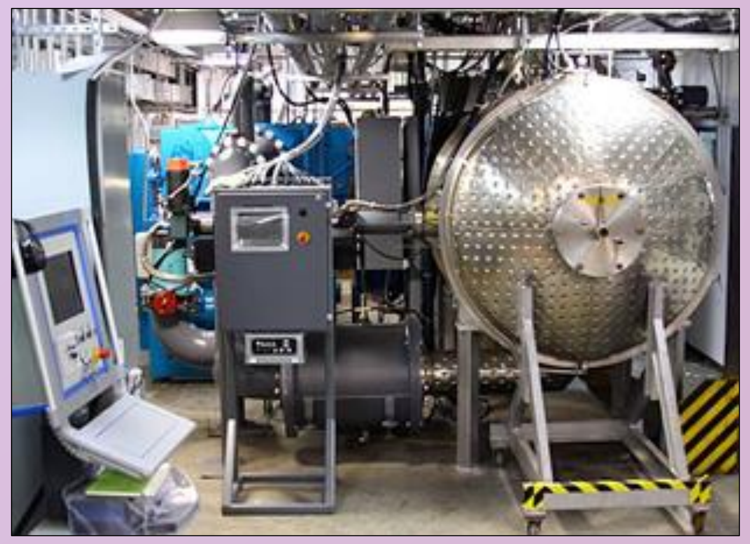
For these two sample sets the main variable examined was the difference between the two thicknesses.

Laser Parameters:

- Deposition Angle: 0˚
- Particle Size: 20 – 25 µm
- Powder Feed Speed: 150 rpm
- Current: 1800 amps
- Pressure: 0.78 - 0.79 torr
- Voltage: 45.7 V
- Power: 82 KW



The samples are being sprayed with the coating

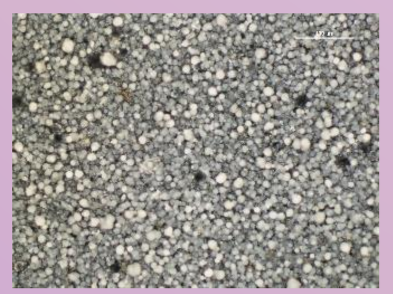


[3] Plasma Spray Physical Vapor Deposition Rig

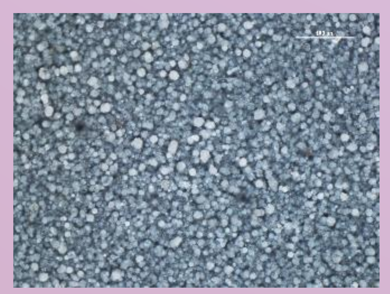
The Optical Images of the Depositions:

- Here are two sets of six samples, the first set being the samples who were deposited for 20 minutes and the next set being the samples that were deposited for 5 minutes
- The thicker coatings had a wider variation in column size than thinner coatings.
- There also appears to be more visibility of the bottom in the thicker coatings verses the thinner coatings which more has of spots of the bottom

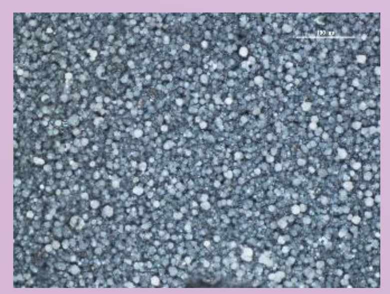
5 Minutes Deposition:



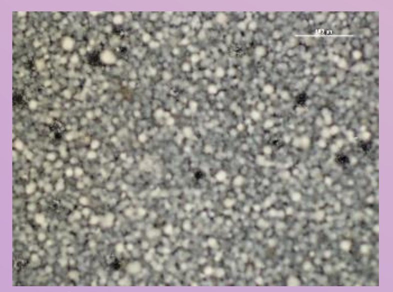
AP0 Top



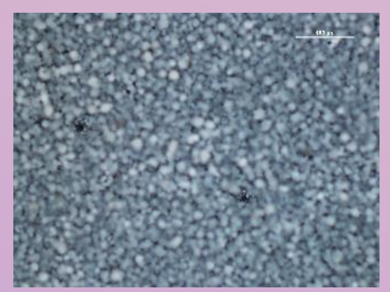
BP0 Top



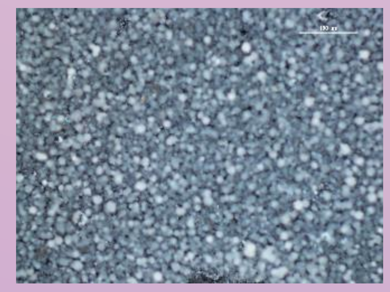
CP0 Top



AP0 Bottom



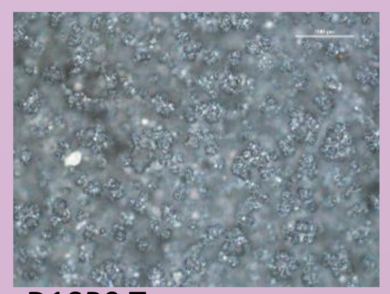
BP0 Bottom



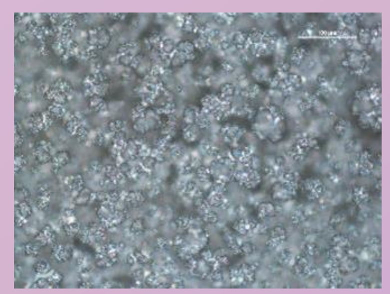
CP0 Bottom

20 Minutes Deposition:

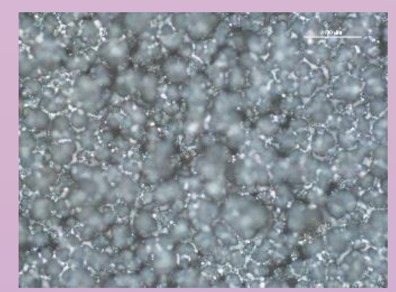
D2P0 Top



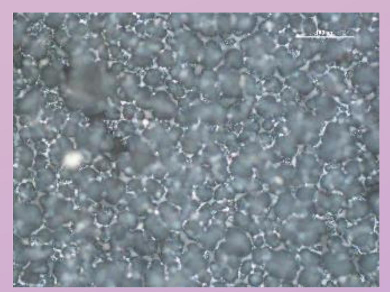
D18P0 Top



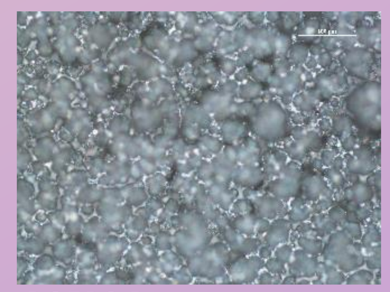
D35P0 Top



D2P0 Bottom



D18P0 Bottom



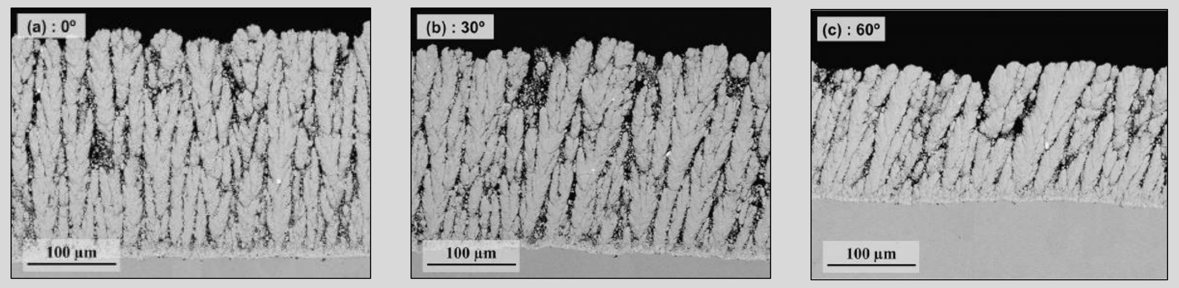
D35P0 Bottom

Results

- Acquired 6 samples coated with 7-8% yttria stabilized zirconia separated into two groups of different thicknesses prepared for future study
- Investigation of the samples through Optical Microscopy
  - Important for studying the structure of the depositions
- Developed an idea to obtain the thicknesses desired based on deposition time and laser processing parameters given
  - A 20 minute deposition leads to a thickness of about 160 – 180 µm
  - A 5 minute deposition leads to a thickness of about 90 – 120 µm

Future Work

The next step would be to gather a set of samples that had different spray angles 0, 30, and 60 degrees. Here is a schematic of the coating structures for different position angles:



[4]

The next step would be to perform Raman spectroscopy on the samples and a set of EB-PVD samples and find the peak shift which indicates residual stress using the spectrometers shown below.

The end goal is to be able to compare EB-PVD properties with PS-PVD properties to better understand the capabilities of PS-PVD coatings leading to more durable high temperature components in aerospace applications.

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Use of PS-PVD Rig and Optical Microscopy - Dr. Harder at NASA Glenn Center, Cleveland Ohio