ULTRA-HIGH TEMPERATURE THERMAL BARRIER COATINGS

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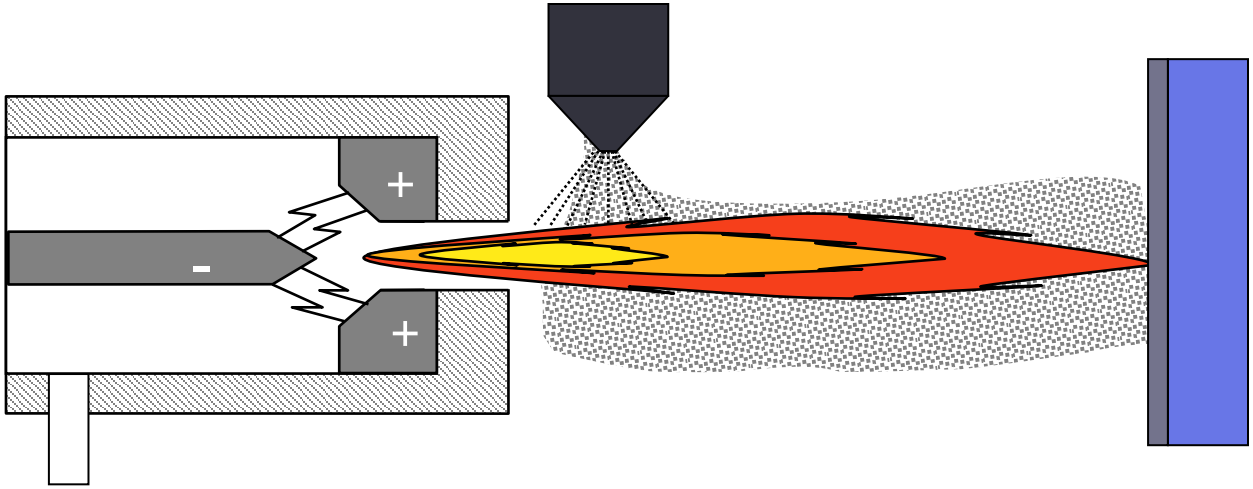

DOE STTR Phase II Grant # DE-SC0007544
DOE UTSR 2014 Presentation

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SPPS TBCs: Presentation Outline

- **Background**
  - ➢**Processing, Microstructure & Properties**
- **SPPS YAG Thermal Barrier Coatings**
  - ➢**Benefits**
  - ➢**Processing & Microstructure**
  - ➢**Engine Critical Properties**
  - ➢**Industry Collaboration**
- **Summary & Conclusions**

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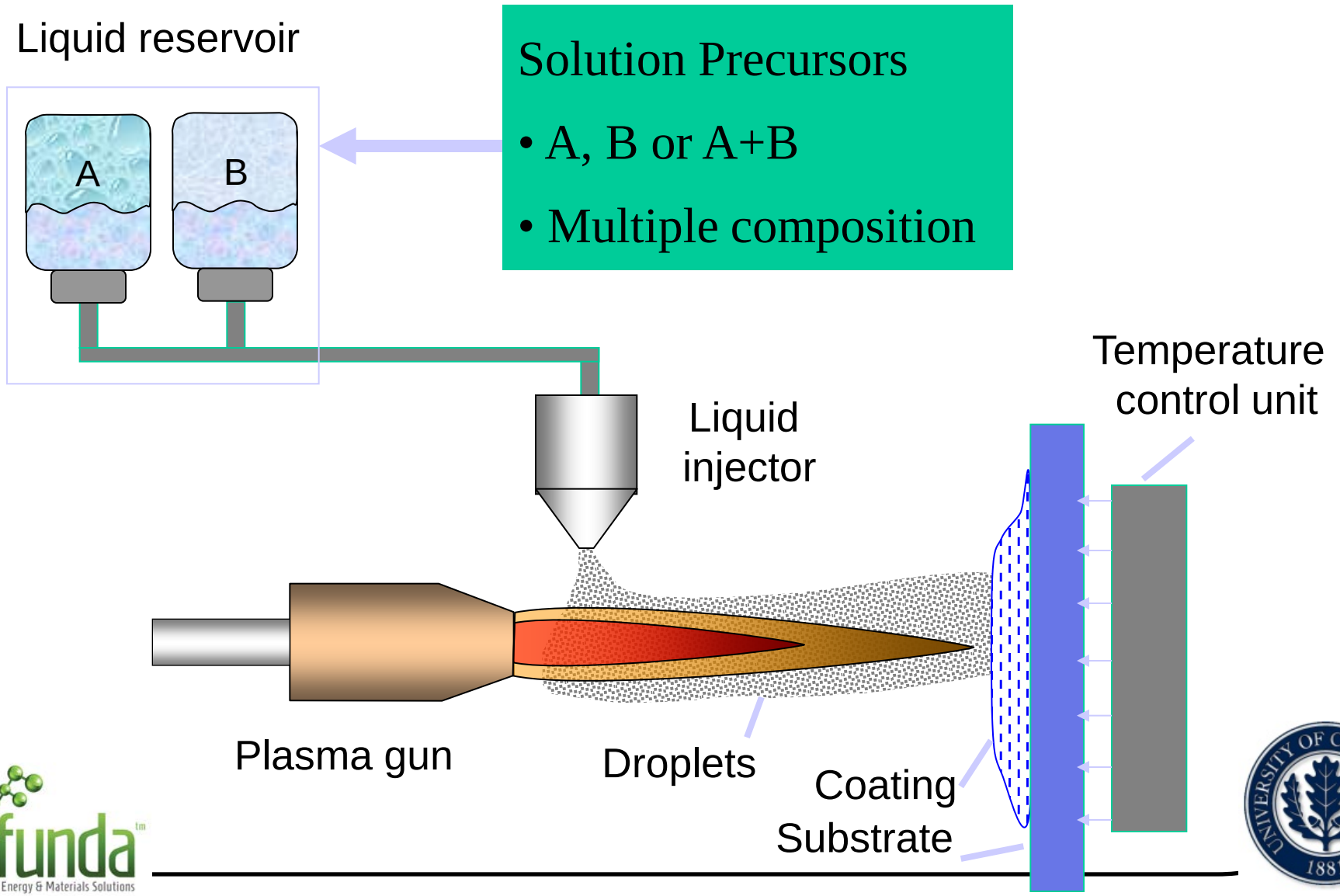
Solution Precursor Plasma Spray (SPPS) Process



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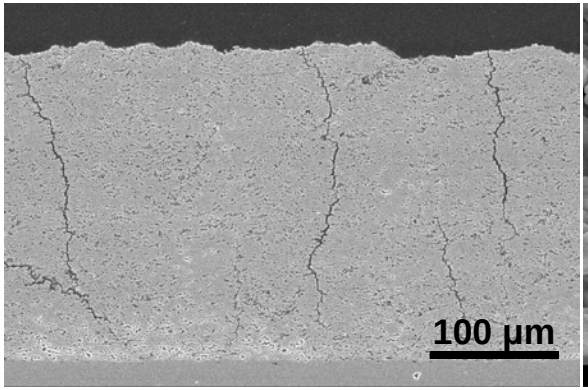
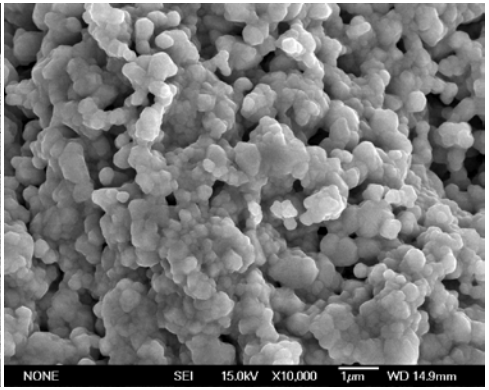
Solution Precursor Plasma Spray:

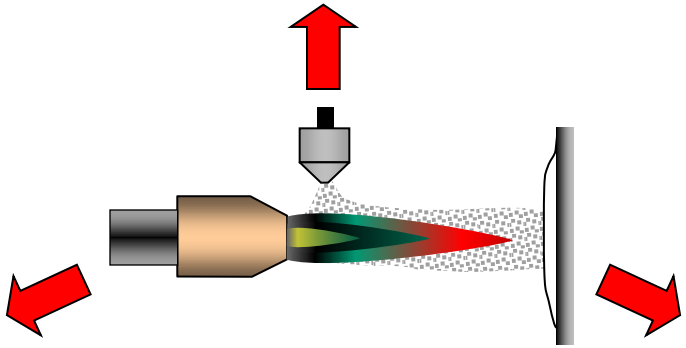
Unique Microstructural Features

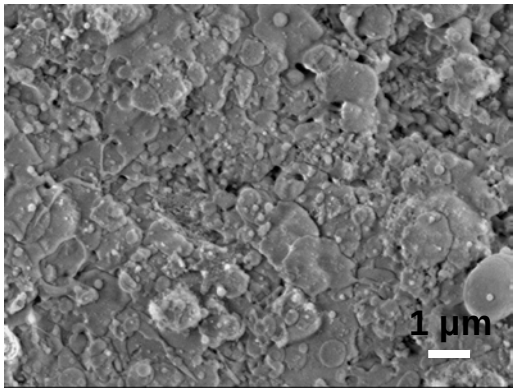
Through-thickness vertical cracks





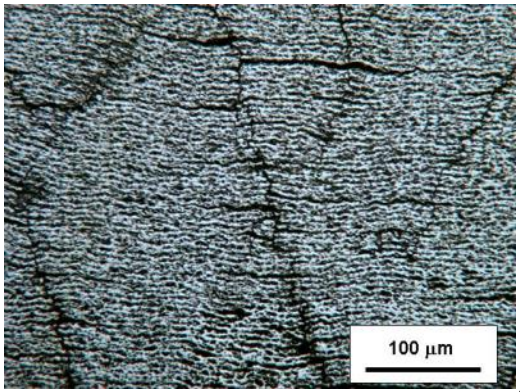
Varied nano/micro-scale porosity: 0~40%





Splat diameter < 2 µm
Splat thickness < 1 µm
Splat area is 1/2500 of that in APS TBCs

Layered porosity: inter-pass boundaries.



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SPPS YAG TBCs: Project Objectives

- **Develop a Higher Temperature (+200°C), Lower Thermal Conductivity Thermal Barrier Coating Using Yttrium Alumina Garnet (YAG) and the Solution Precursor Plasma Spray Process (SPPS)**

- **Demonstrate That YAG's Greater Thermal Expansion Mismatch Strains Can be Overcome By The Strain-Tolerant Microstructure of SPPS TBCs**

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Anticipated Benefits

- **A New TBC That Can Tolerate Surface Temperatures of 1500^{o}C Can Be Game-Changing For the Gas Turbine Industry Due to Higher Turbine Efficiencies and Lower Fuel Consumption**

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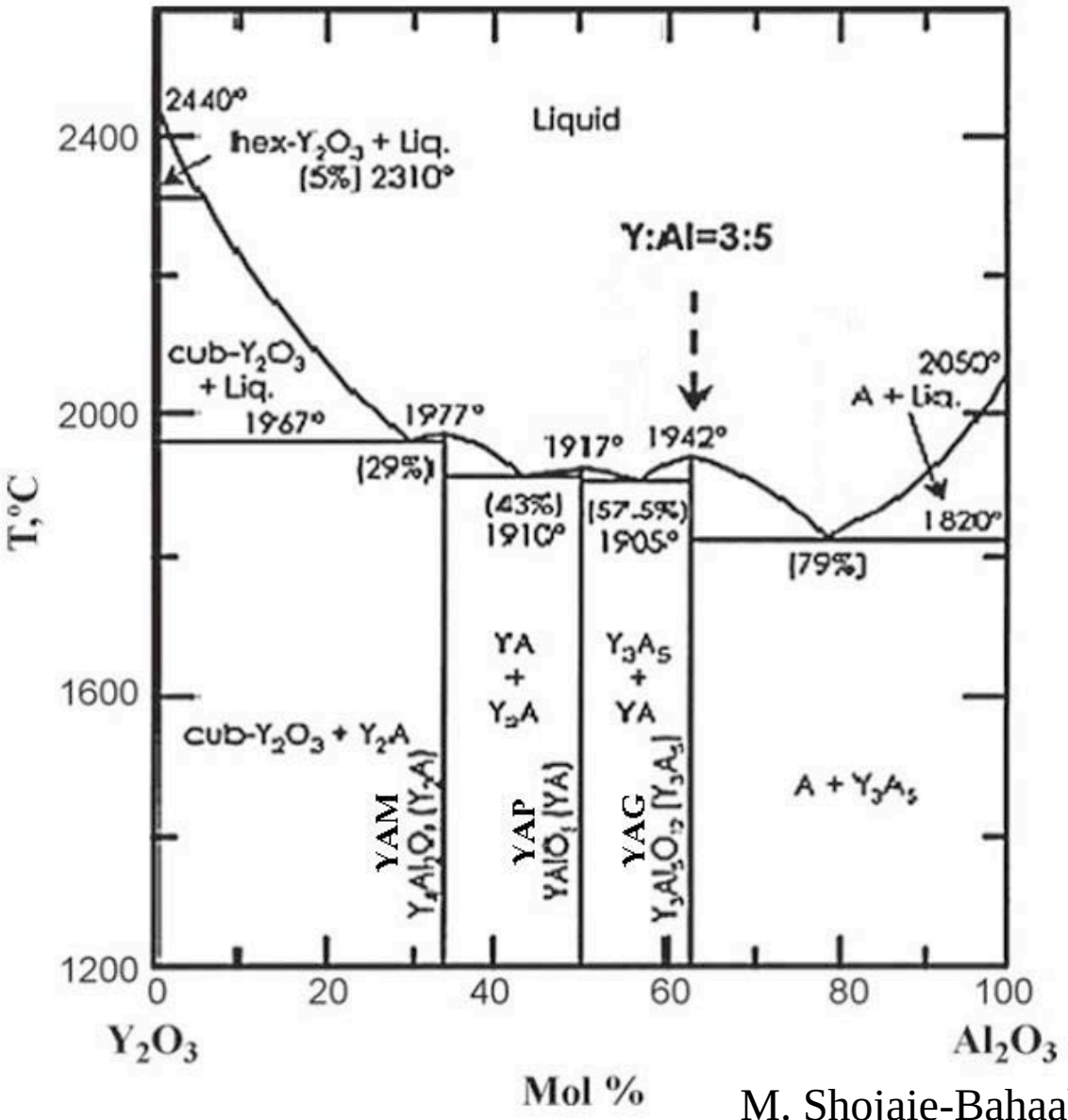
Processing & Microstructure

Yttria-Alumina Phase Diagram



M. Shojaie-Bahaabad et al, Ceramics Intl.,Vol 35, 2009

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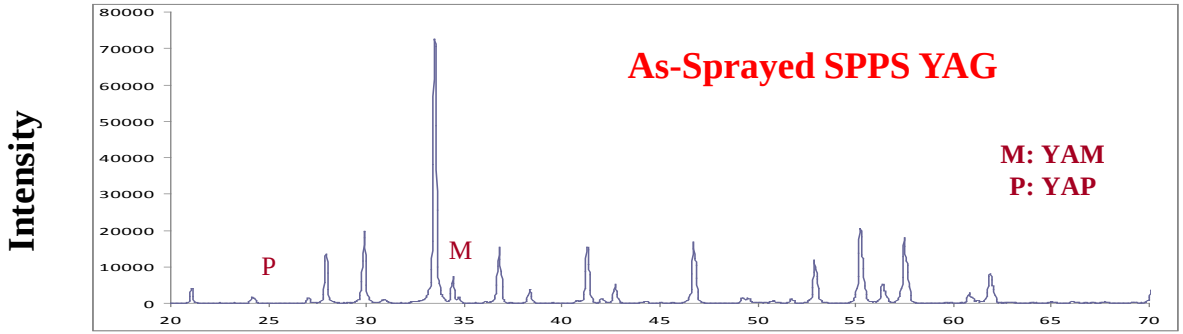
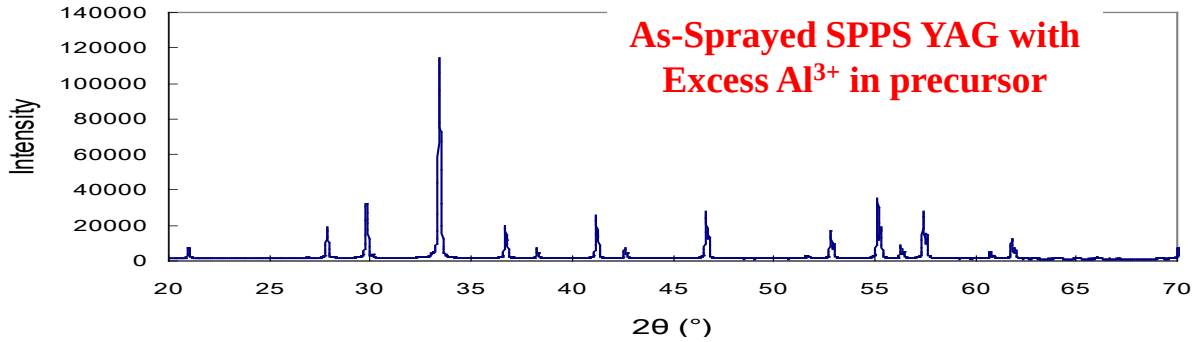
Stoichiometric YAG Deposited By SPPS Process



- **Predominantly YAG Phase with Minor Amounts of YAM and YAP**



- **Pure YAG phase**

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SPPS YAG TBC: Processing

- **Over 100 Plasma Spray Trials**
- **Sulzer-Metco 9MB Plasma Torch**
- **42-45 KW Power**
- **Aqueous Precusor: Yttrium Nitrate, Aluminum Nitrate, Urea**
- **Key Processing Variables:**
  - **Precusor Energetics, Cation Loading, Viscosity**
  - **Stand-Off Distance**
  - **Atomizing Pressure**

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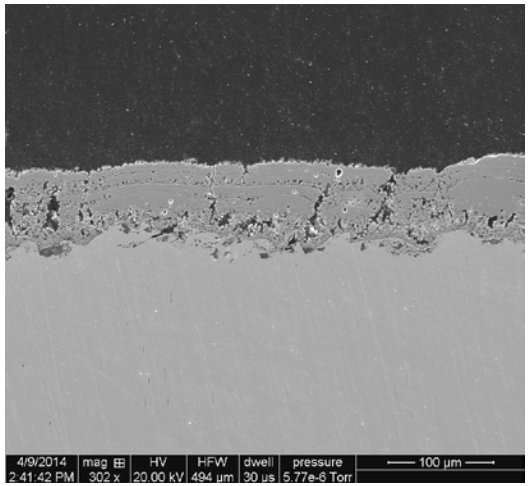
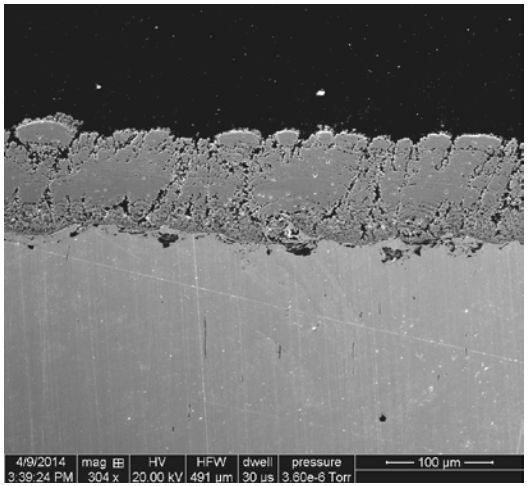
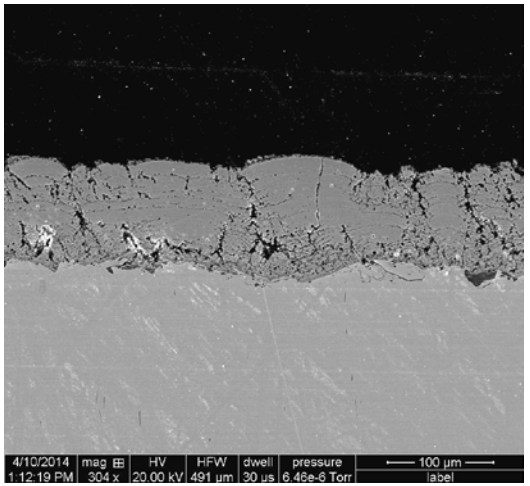
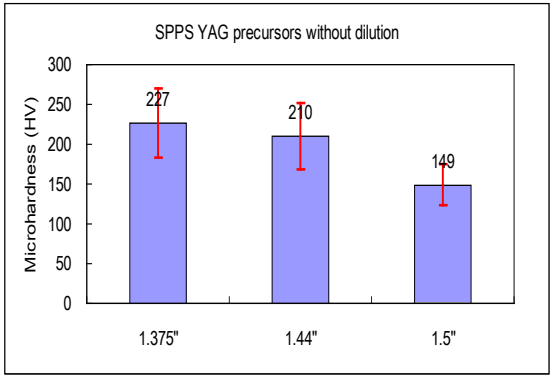
SPPS YAG TBCs: Effect of Precursor Concentration

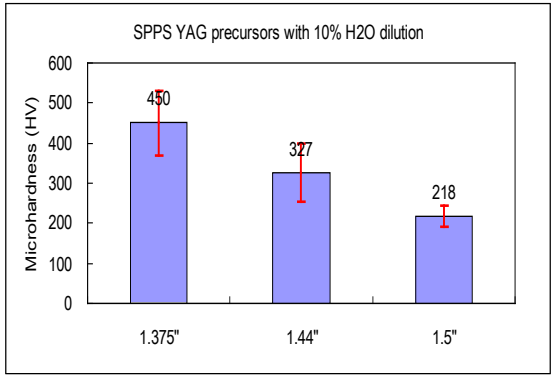




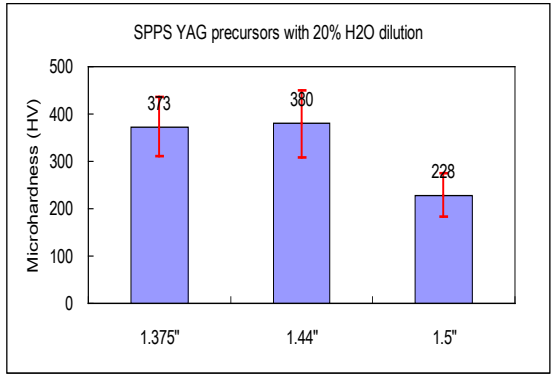




SPPS YAG 5 wt% urea, 1.375”, on SS.



SPPS YAG 5 wt% urea, 10% H2O dilution, 1.375”, on SS.



SPPS YAG 5 wt% urea, 20% H2O dilution, 1.375”, on SS.

- **Increased Precursor Dilution Produces Denser Harder TBCs**

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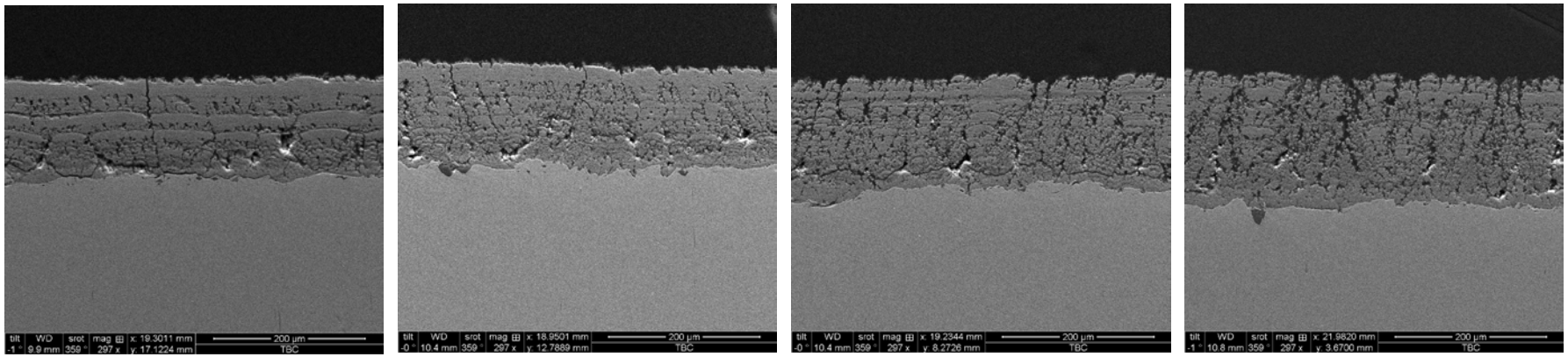
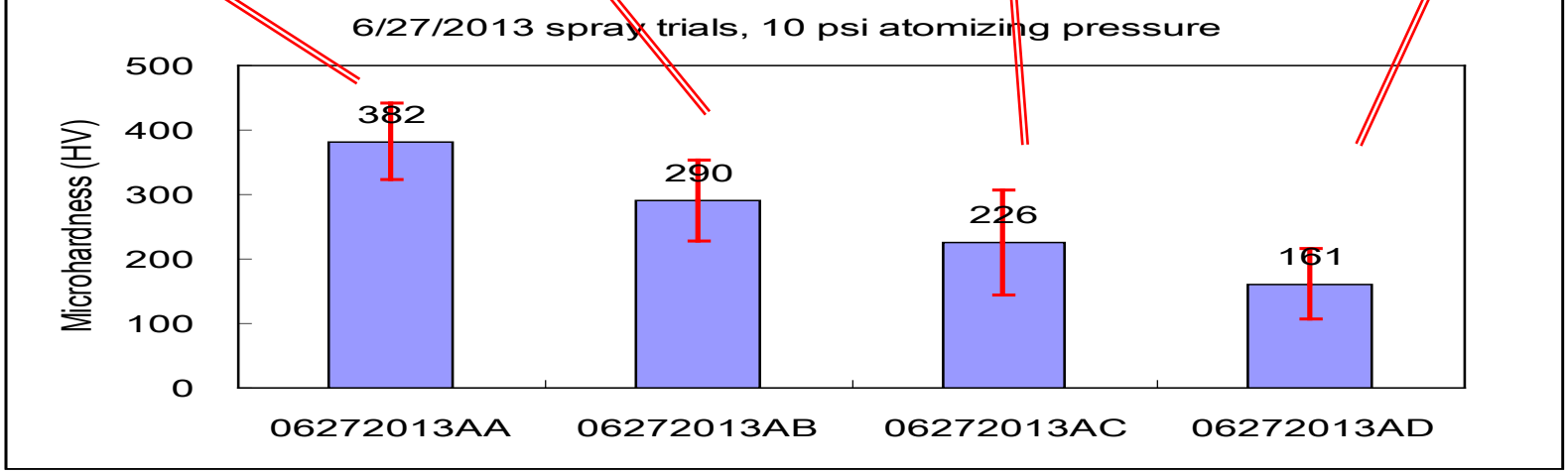
SPPS YAG TBCs: Stand-Off Distance

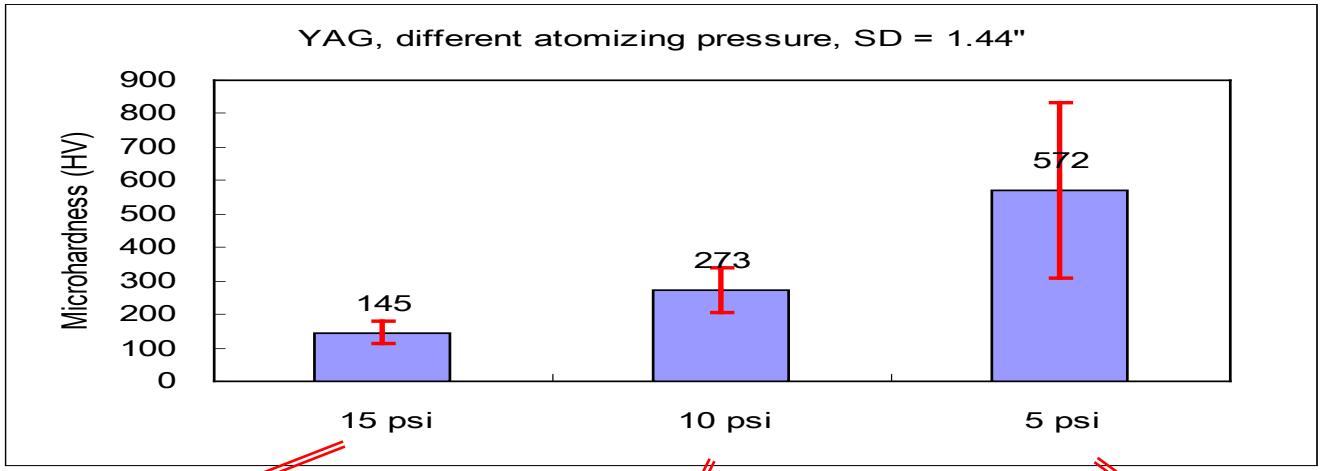


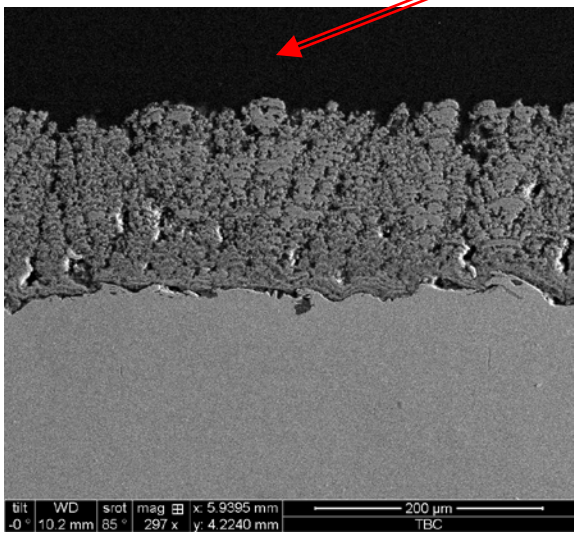


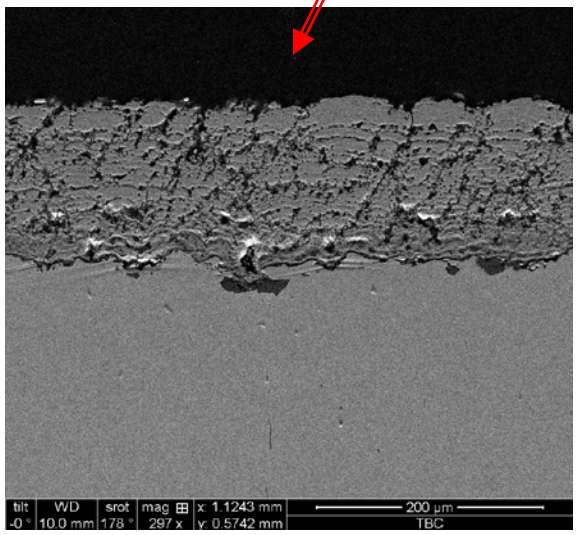
SD (cm) : **3.2** **3.5** **3.6** **4.1**

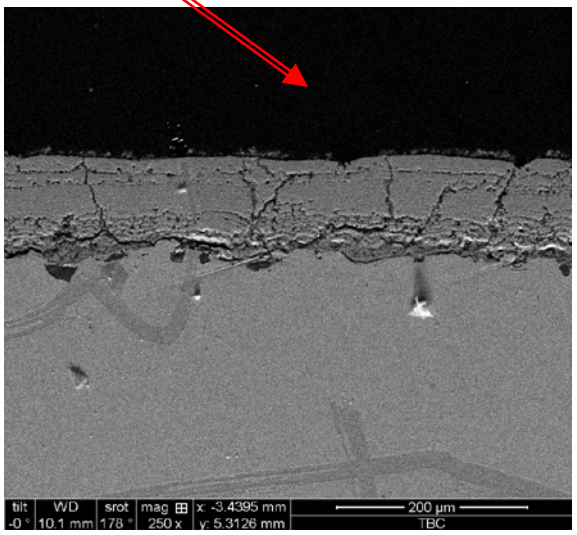
- **Decreased Stand-off Distance Increase Plasma and Substrate Temperature; Produces Denser, Harder YAG TBCs**

SPPS YAG TBCs: Atomizing Pressure









- **Reduced Atomizing Pressure Increases Plasma Temperature, Droplet Penetration and TBC Hardness**

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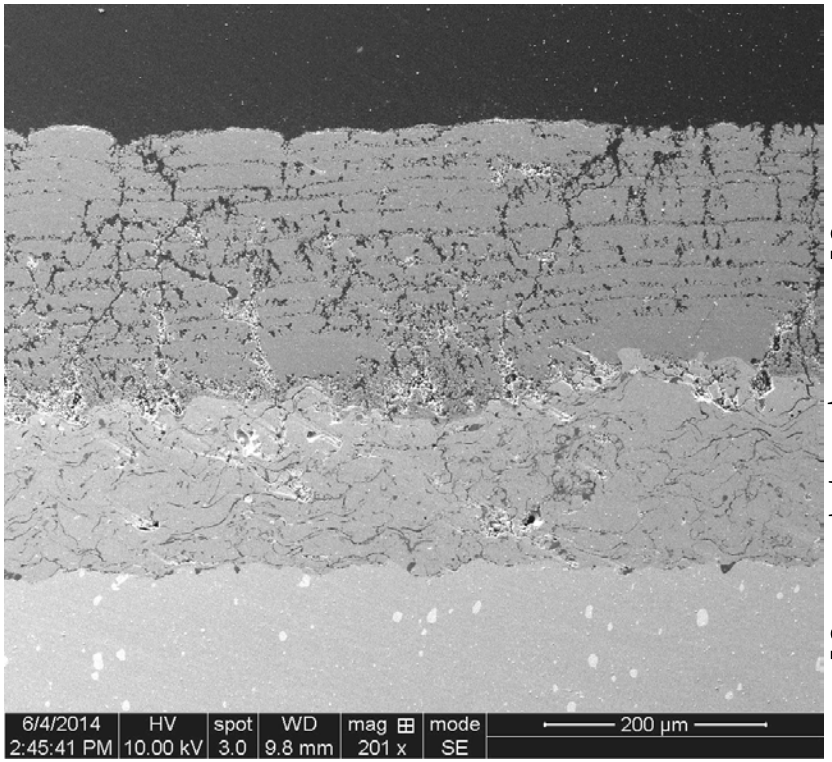
Engine-Critical Properties

SPPS YAG TBCs: Standard Microstructure
--Used for Engine-Critical Properties Tests--



SPPS YAG

APS YSZ

Bond Coat

Superalloy

- **Vickers Hardness: 200-400**
- **Porosity: 15-20%**

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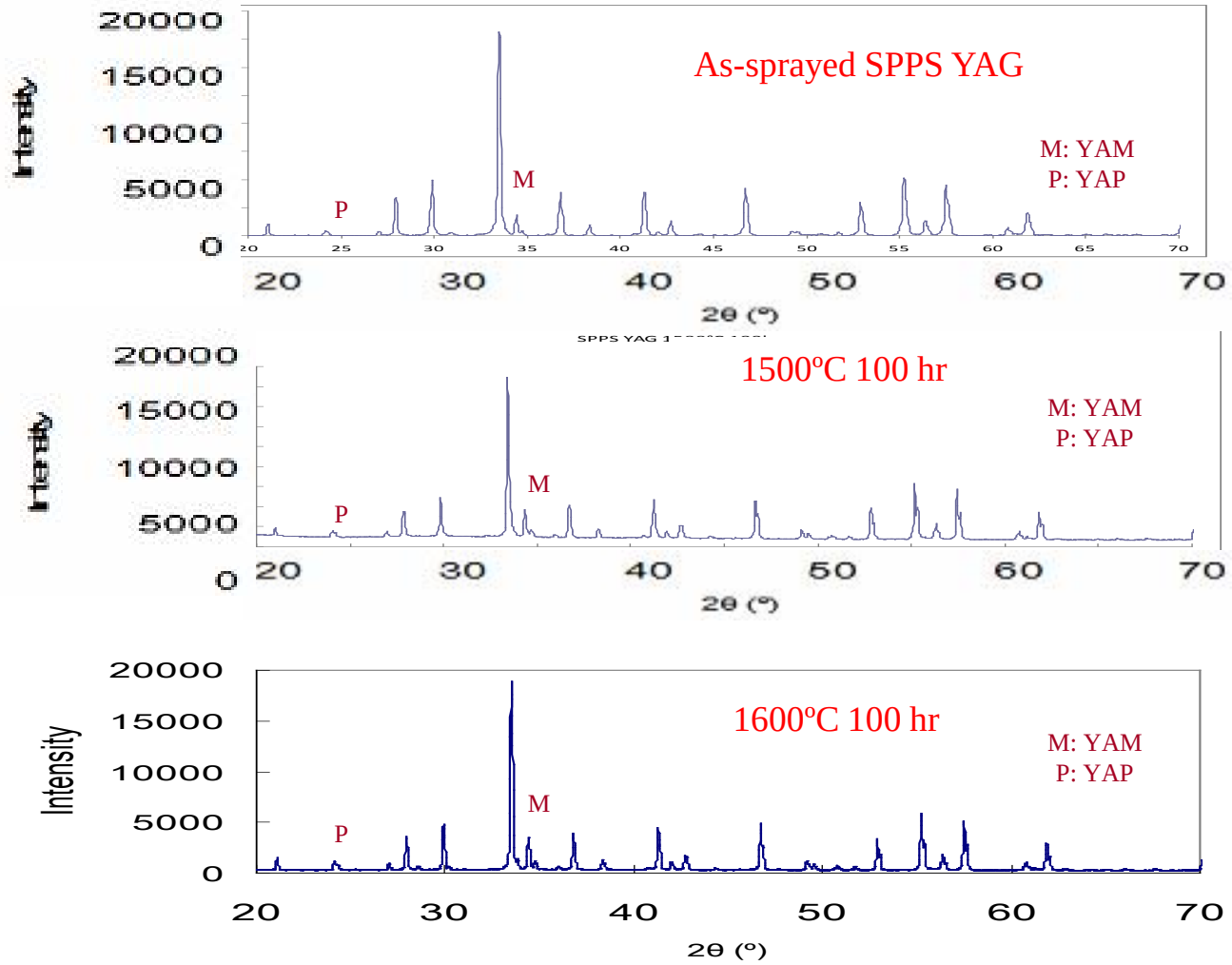
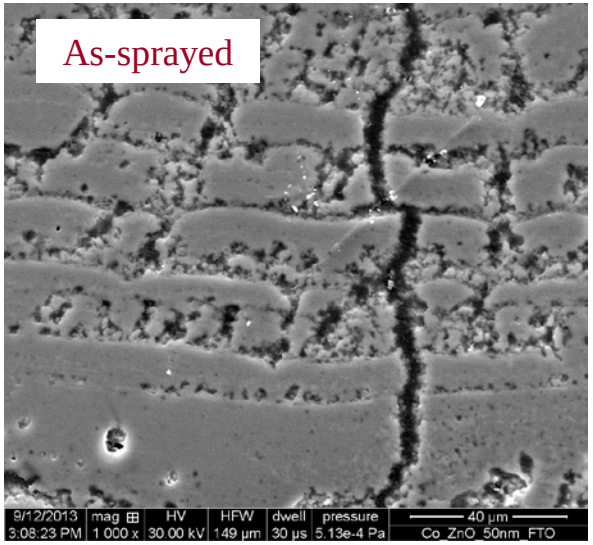
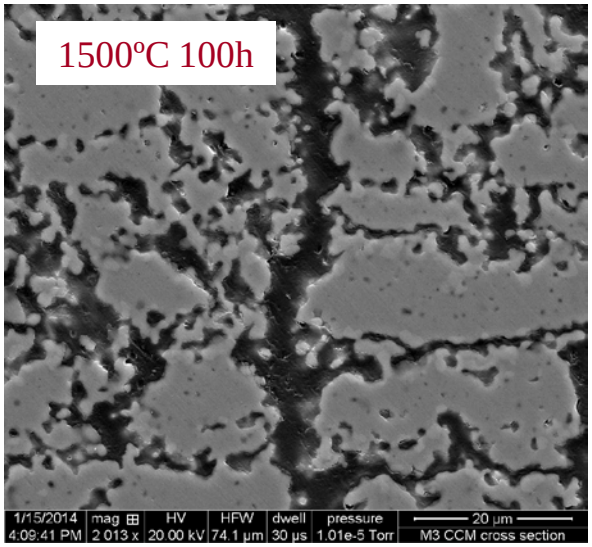
SPPS YAG TBCs: Phase Stability

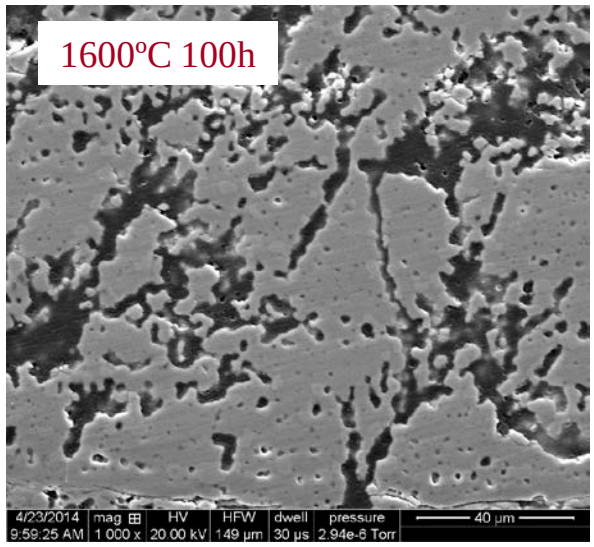


- **SPPS YAG TBCs Are Phase Stable To At Least 1600ºC**

SPPS YAG TBCs: Sintering Resistance







HV = 380±185

HV = 324±122

HV = 378±139

Sintering Effects Are Small Up to 1600ºC

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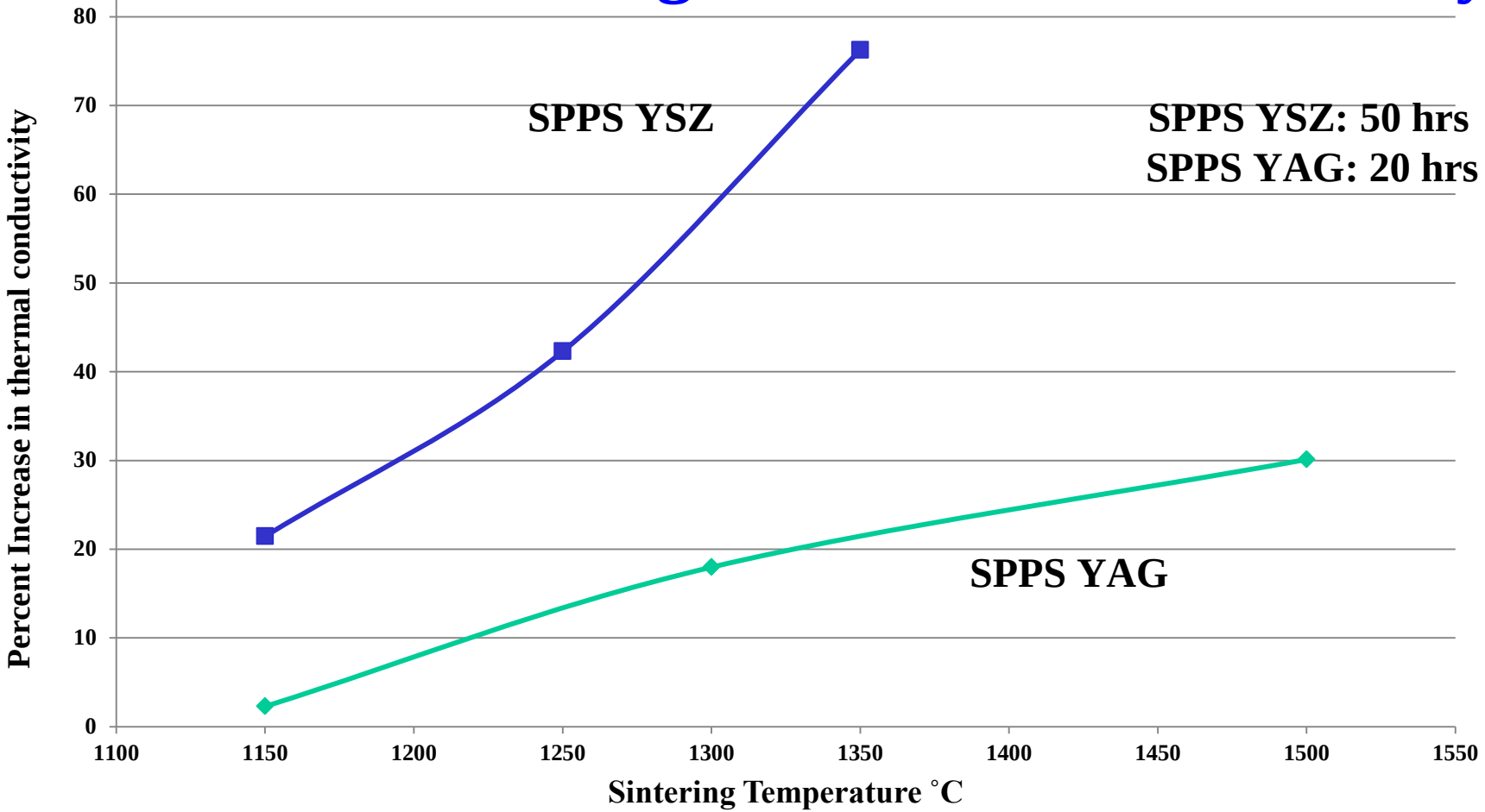
SPPS TBCs: Sintering & Thermal Conductivity



- **SPPS YAG TBCs More Sinter Resistant Than SPPS and APS YSZ**

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CMAS Reactivity Study: YSZ & YAG

Powders of YSZ, YAG, 50:50 w/o YSZ & CMAS, 50:50 w/o YAG & CMAS Prepared

- **Powder Size: YAG 2-5 microns, YSZ 50 microns**
- **CMAS Powder: Industry Standard Composition, 1170^{o}C Melting Temperature**
- **Powders Exposed For 24 hours at 1100^{o} to 1500^{o}C**
- **X-Ray Diffraction, SEM and EDAX Evaluations Being Conducted**

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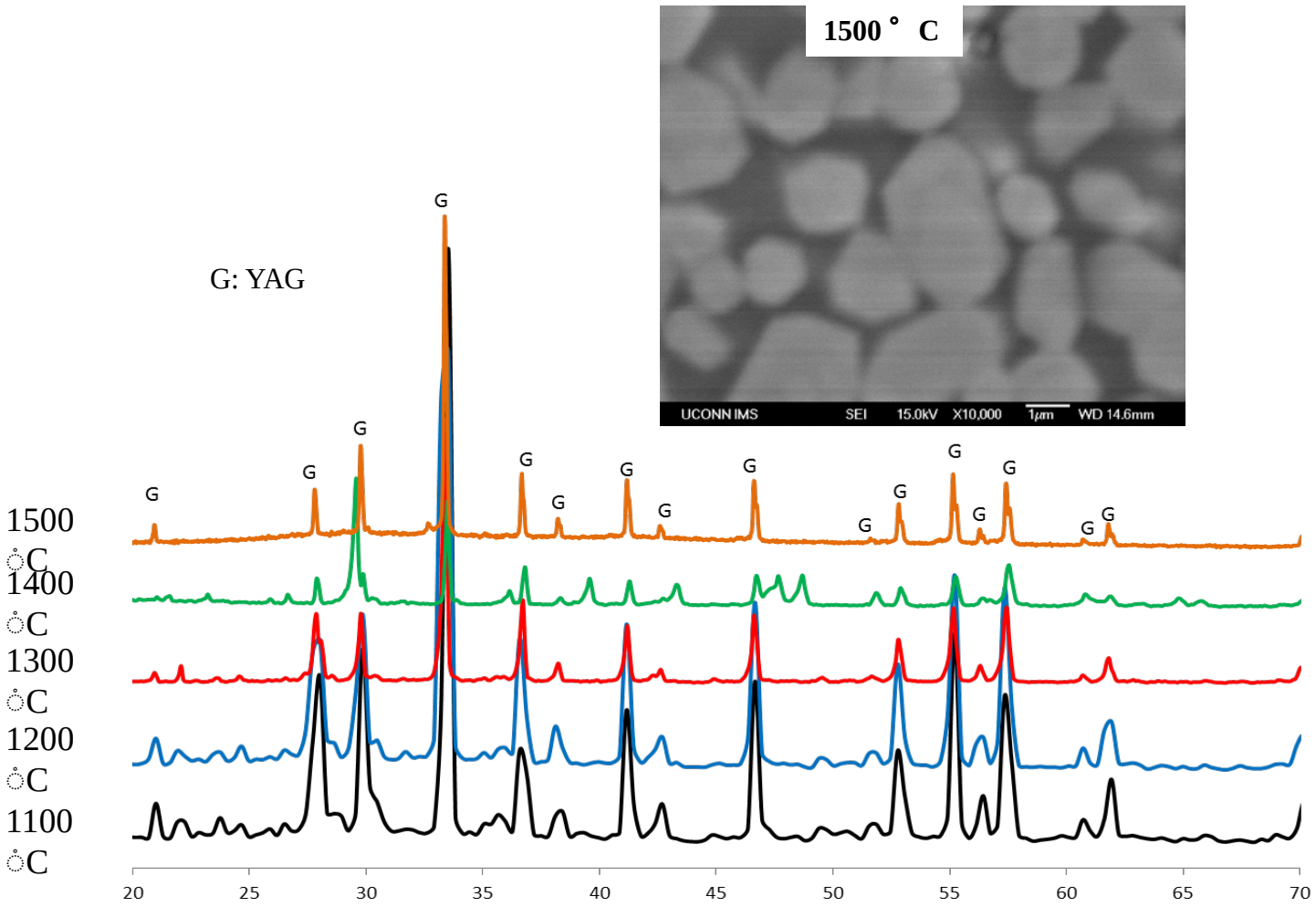
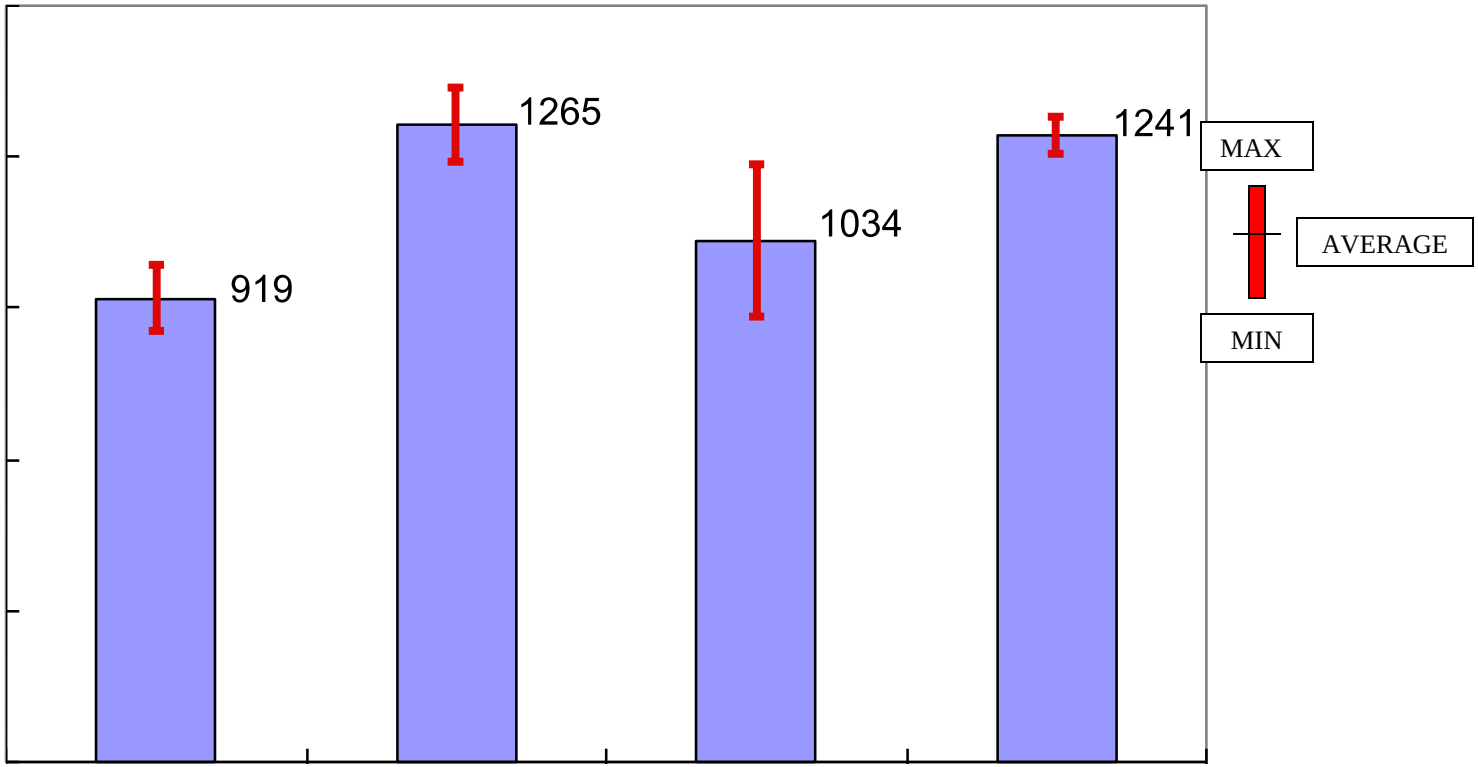
Phase Stability: 50:50 w/o YAG/CMAS Powder



- **YAG Phase Stable To 1500°C In Presence of CMAS**

SPPS YAG TBCs: Thermal Cycle Life vs Hardness



- **SPPS Strain-Tolerant Microstructure Overcomes Higher Thermal Expansion Mismatch Stresses**

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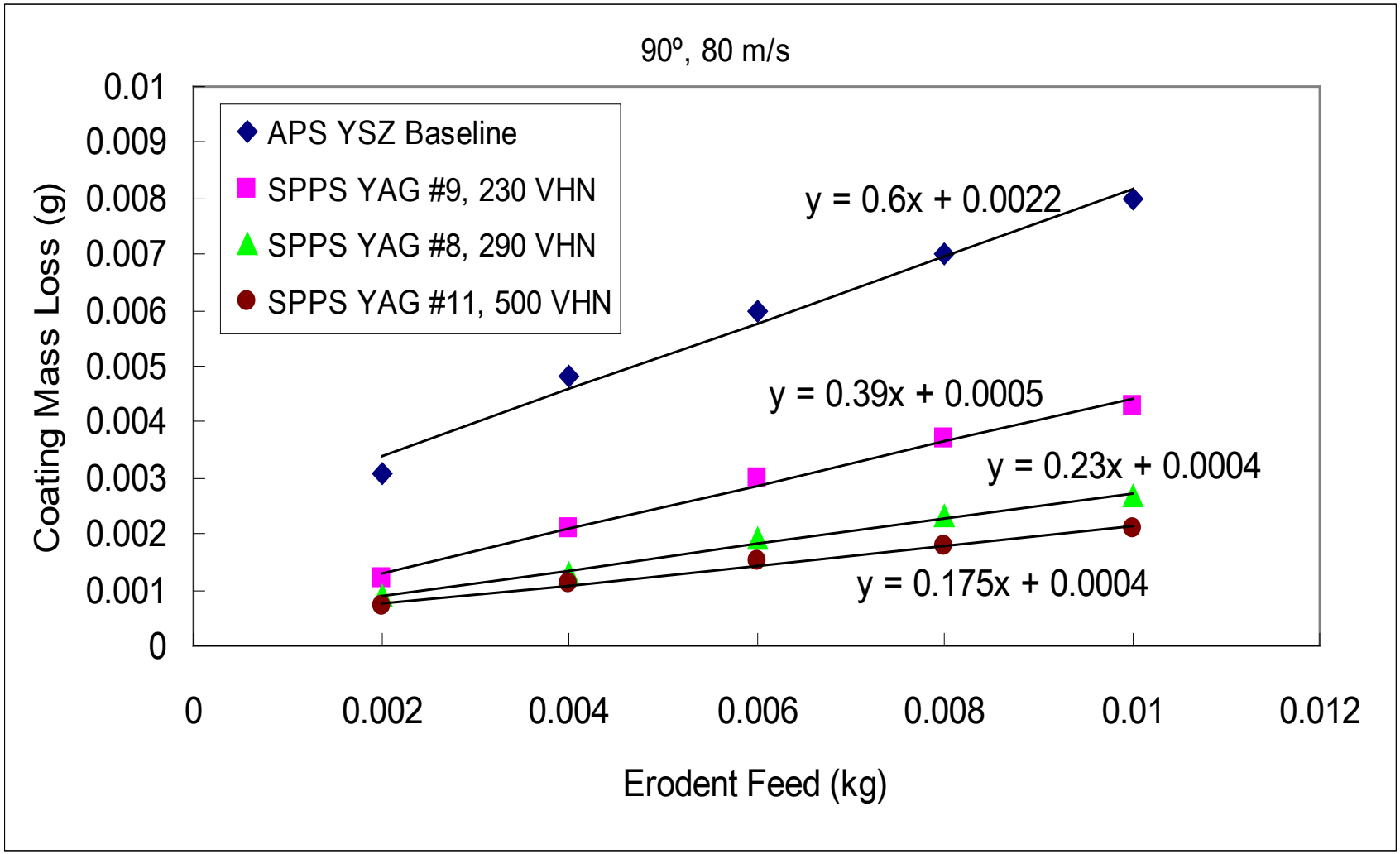
SPPS YAG TBCs: Erosion Rate vs Hardness

(Tests Performed at Penn State Univ. By Dr. D Wolfe)



SPPS YAG TBCs: Erosion Rate vs Hardness

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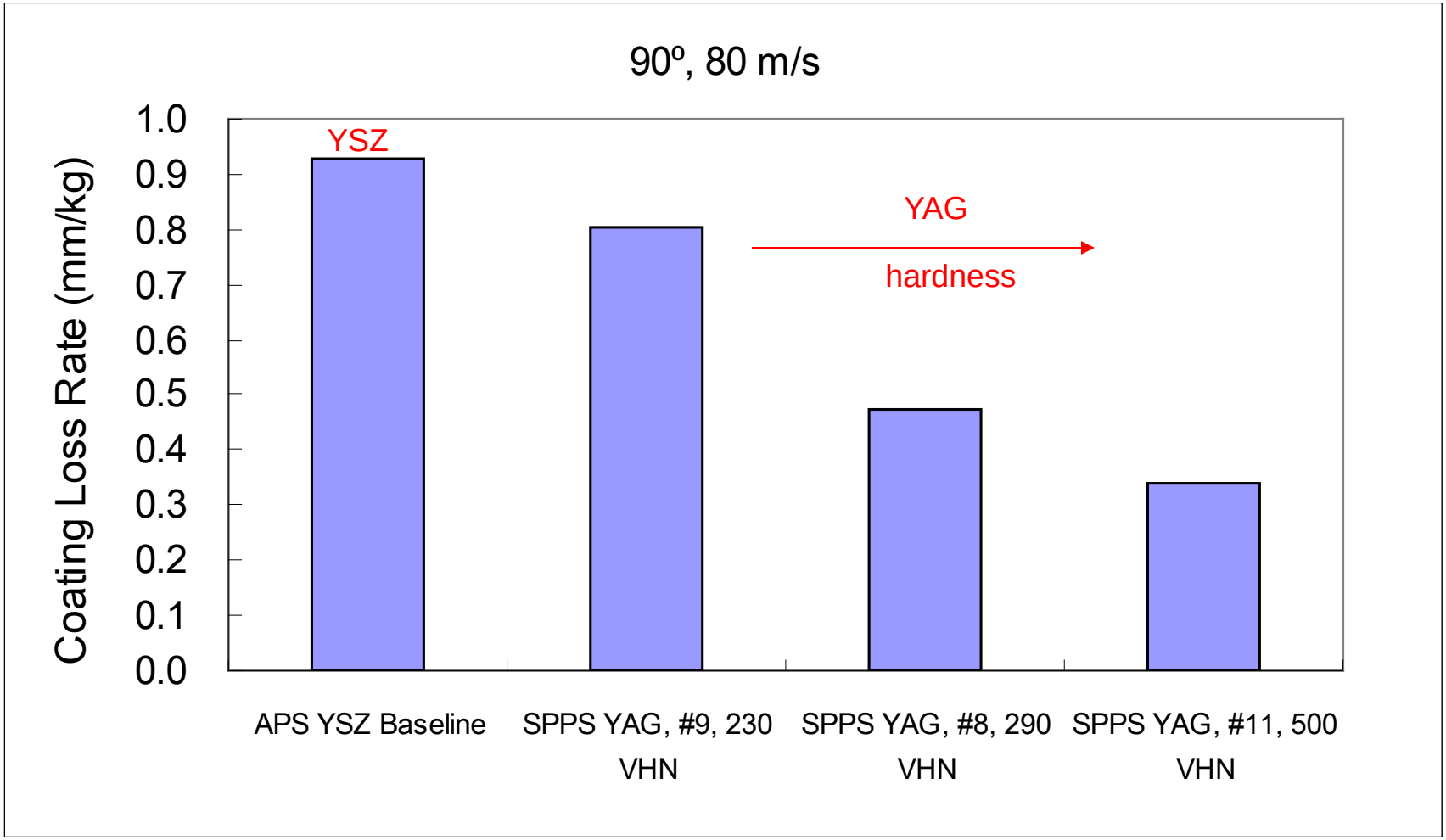

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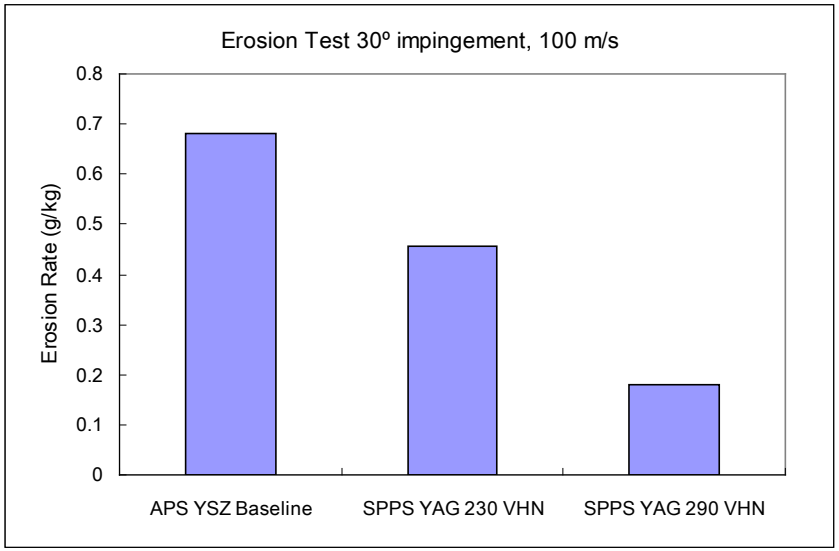
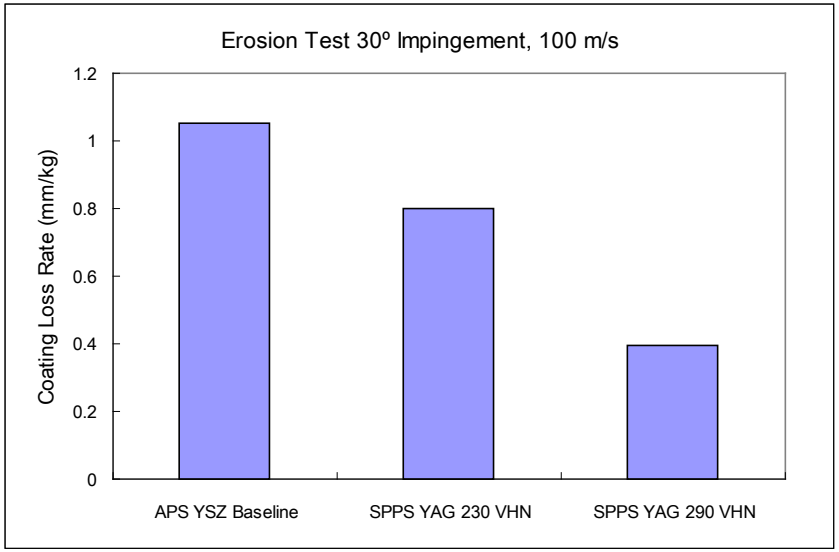
SPPS YAG TBCs: Erosion Rate vs Hardness -30º Impingement-

(Tests Performed at Penn State Univ. By Dr. D Wolfe)





- **SPPS YAG Has Superior Erosion Resistance To APS YSZ In Both 30º 90º Impingement Erosion Tests.**

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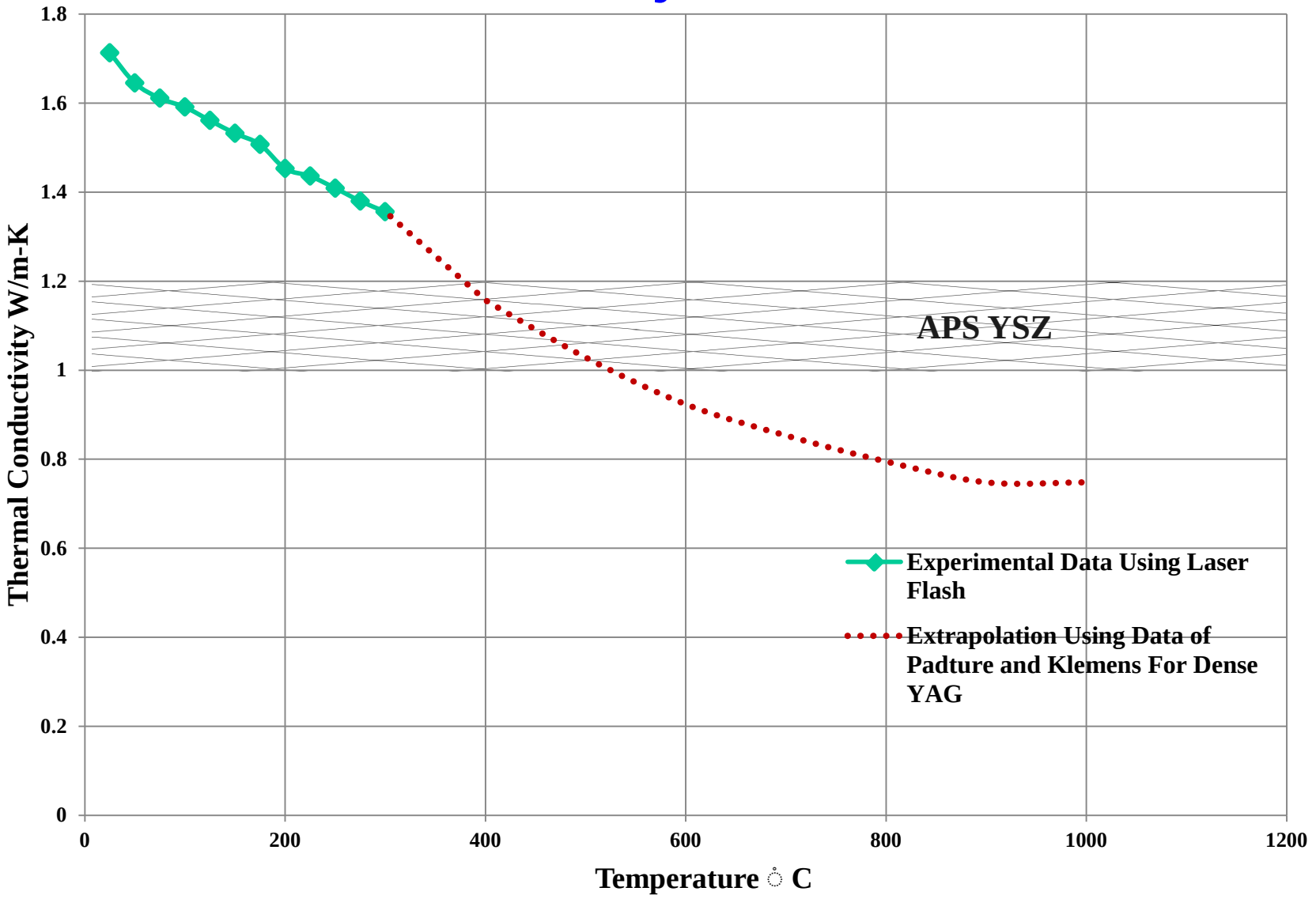
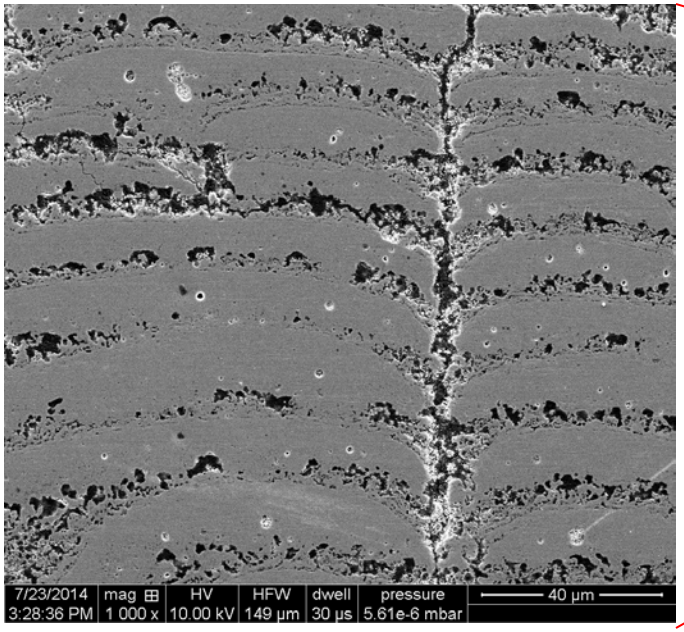
Thermal Conductivity of SPPS YAG TBCs

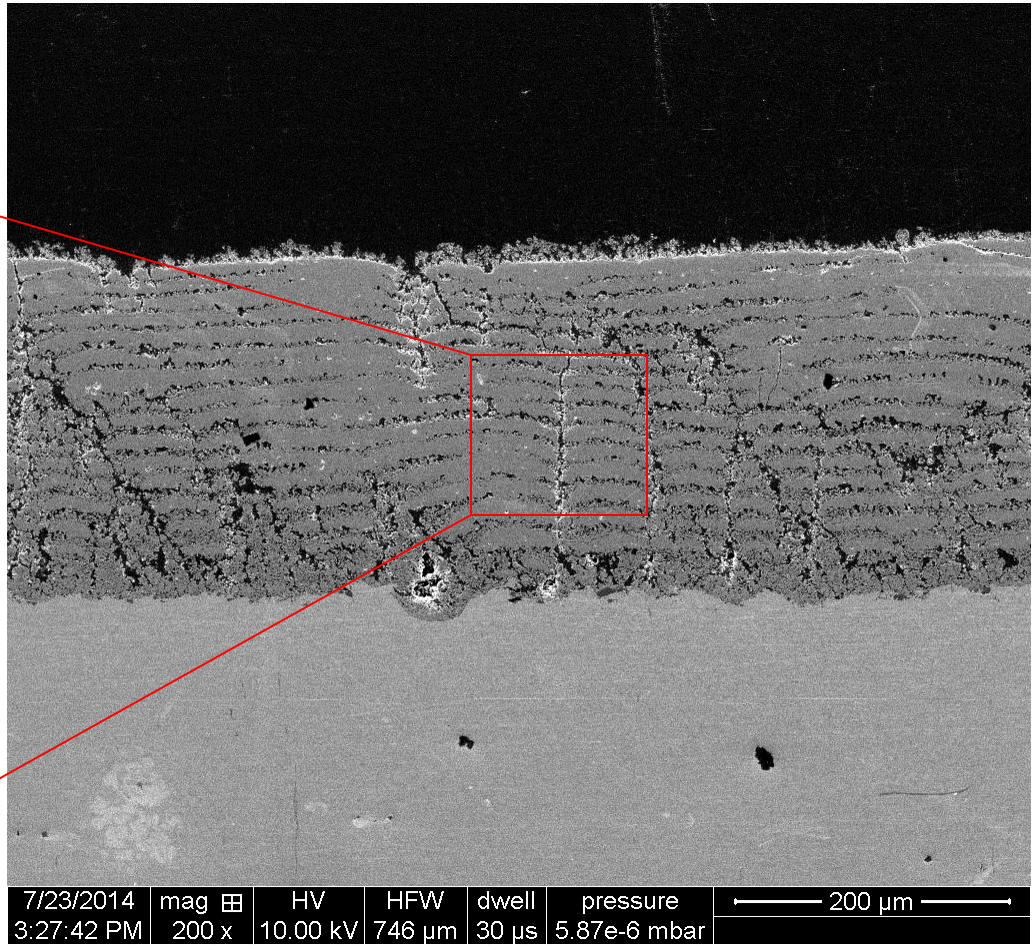


- SPPS YAG TBC Th. Conductivity Estimated To Be Lower Than APS YSZ At Elevated Temperatures

SPPS YAG TBCs with IPBs



HV= 324±60



- **Further Reductions in Thermal Conductivity Possible With IPBs & Small Compositional Modifications**

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Industry Partners

Engine Manufacturers

- Solar Turbines
- Siemens Energy
- Pratt & Whitney

TBC Coating/Equipment Manufacturers

- Praxair
- Progressive Surface

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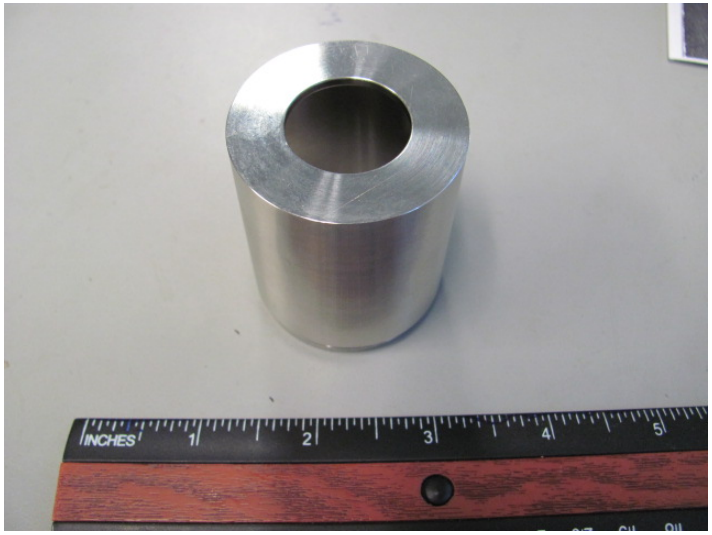
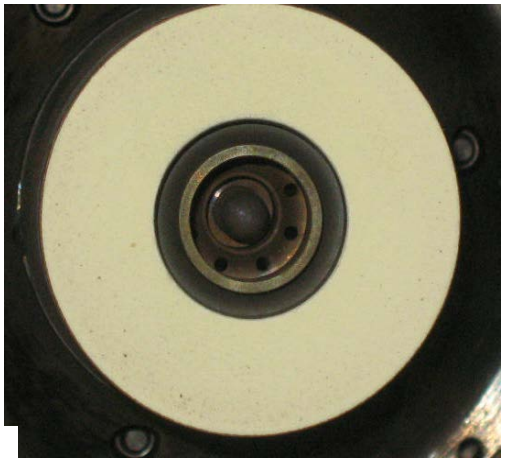
Industry Partner Coordination

- **Solar and Siemens Provided Baseline and Bond Coated Superalloy Specimens Used In Program**
- **Solar and Siemens Supplied Specimens For SPPS YAG TBC Coating For Their Internal Evaluations**
- **Technology Transfer Initiated With Praxair & Progressive Engineering Teams Visiting UConn For Full-Day Briefings**
- **Praxair & Progressive Will Demonstrate Production Process & Economics For SPPS YAG TBCs**

Solar Turbines Demonstration Component
--Fuel Nozzle Igniter--





- **Coordination Meeting Held with Praxair, Solar & UConn, 8-11-14**

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Summary & Conclusions-I

- **SPPS YAG TBCs Show Potential For >1500ºC Operation Based On Phase Stability, Sinter and CMAS Resistance**
- **This Represents A >200ºC Advantage Over APS YSZ**
- **Durability of SPPS YAG TBCs Shown To Be Equal Or Greater Than APS YSZ In Thermal Cycle and Erosion Tests**
- **Initial Measurements Indicate SPPS YAG TBC Thermal Conductivity of 0.7 Watt/mºK at 1000ºC (40% reduction compared to APS YSZ)**

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Summary & Conclusions-II

- **Engine Manufacturers Continue To Show Strong Interest In SPPS YAG TBCs; Will Conduct In-House Testing**
- **Technology Transfer Being Conducted With TBC Coating Suppliers; They Will Conduct Demonstration Trials and Provide Process Economics**
- **SPPS YAG Continues to Show Strong Promise As Higher Temperature, Sinter-Resistant, Durable TBC**

Acknowledgements

- **Patcharin Burke, DOE Program Manager, DOE STTR Phase I & II Programs on SPPS YAG TBCs**

- **Our Industrial Partners: Solar Turbines, Siemens Energy, Pratt & Whitney, Praxair and Progressive Surface**

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