PROVIDA MEETING

THERMAL BARRIER COATINGS BY SOLUTION PRECURSOR PLASMA SPRAYING

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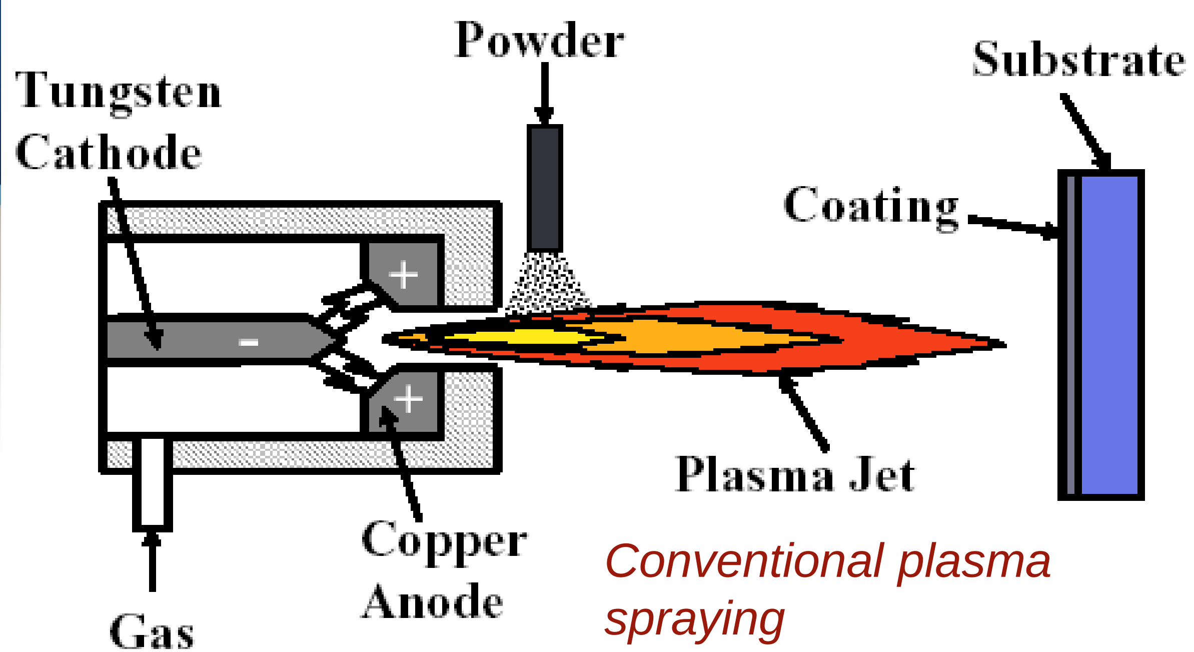
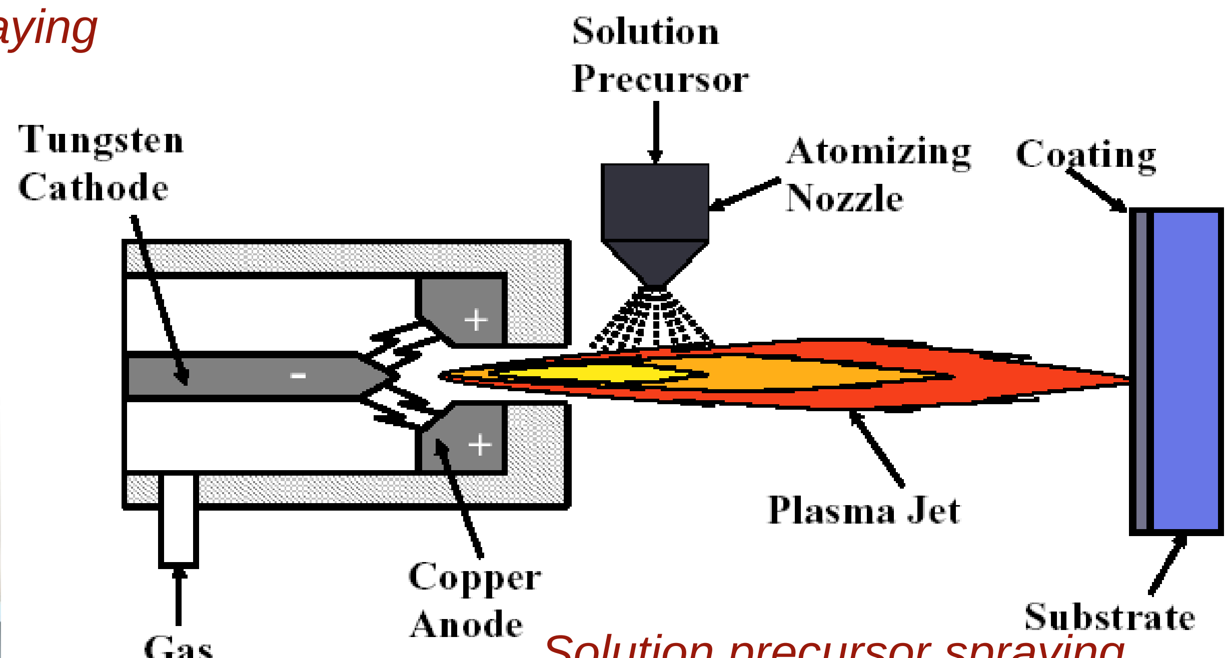
OUR FOCUS: Solution Precursor Plasma Spraying (SPPS)



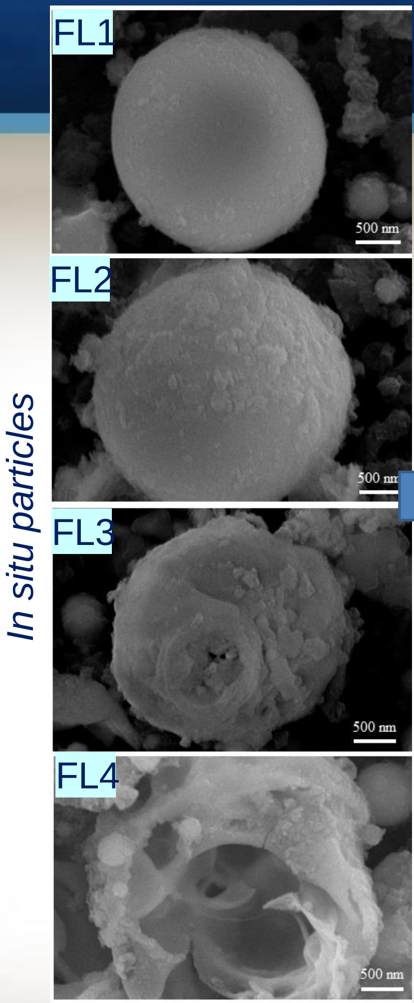
Conventional plasma spraying

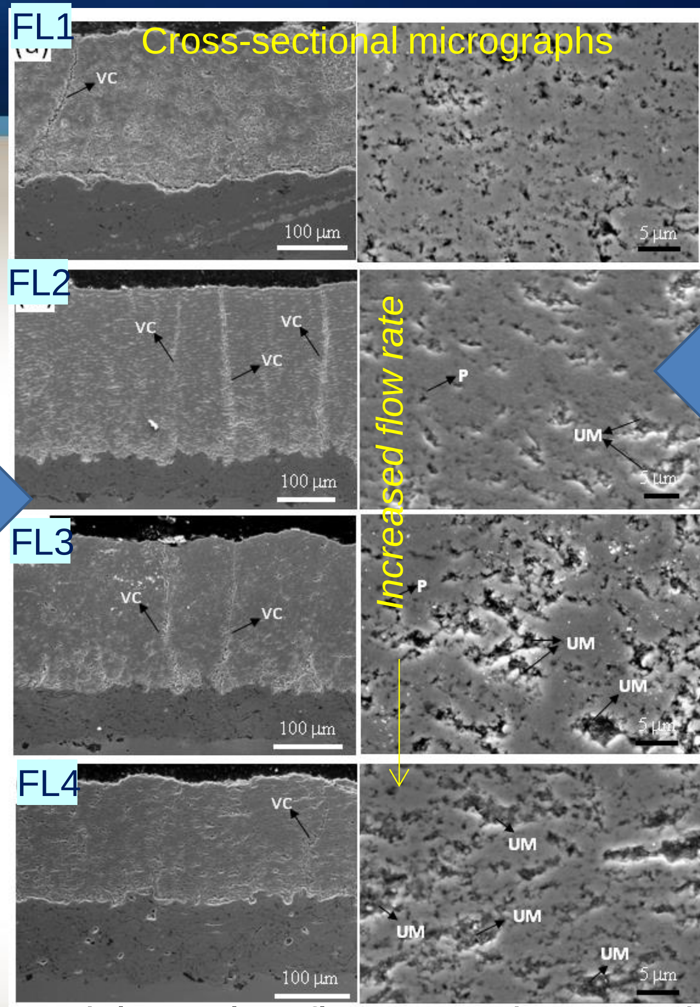
- Uses conventional atmospheric plasma spray torch
- Adoption easy for existing plasma spray users

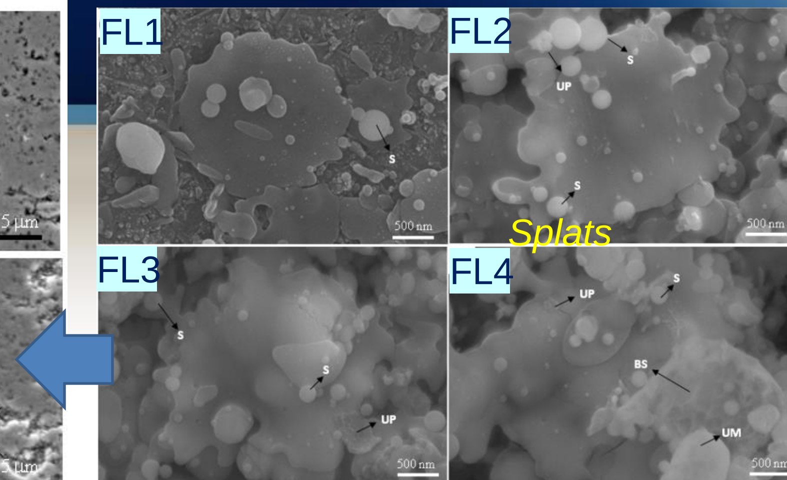


Solution precursor spraying

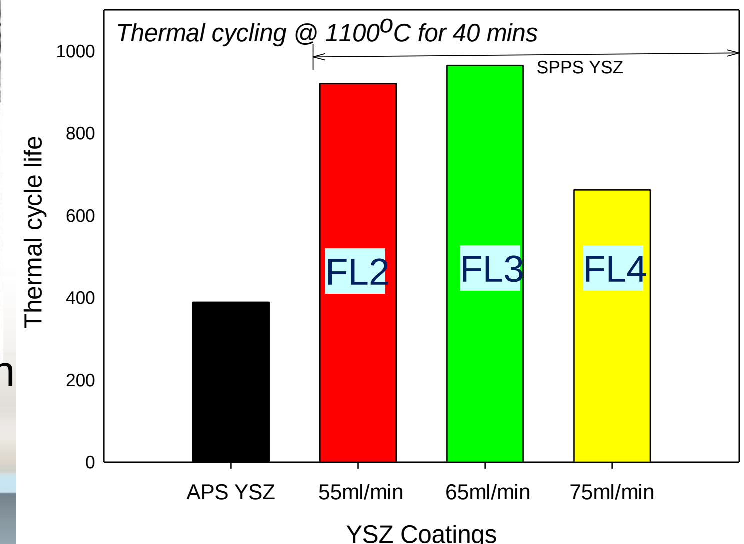
In-flight Particle Generation, Splat Formation & Coating Microstructure are Inter-related & Influence Durability







•Molten splats observed at low flow rates; Increased broken morphologies at high flow rates



•Well-defined, spherical particles at low flow rates; increase in flow rates yields hollow particles and is accompanied greater presence of unpyrolyzed precursor mass

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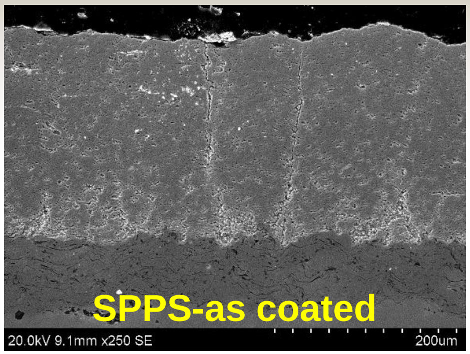
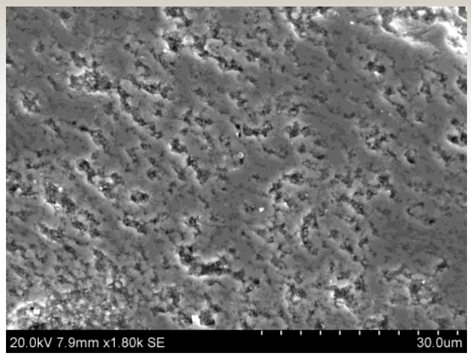
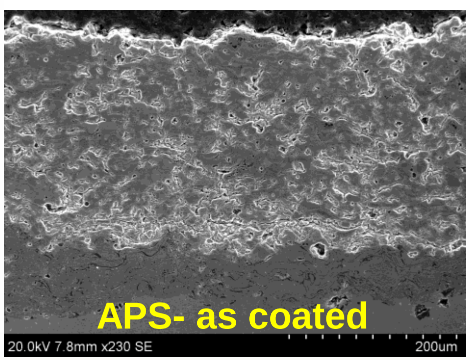
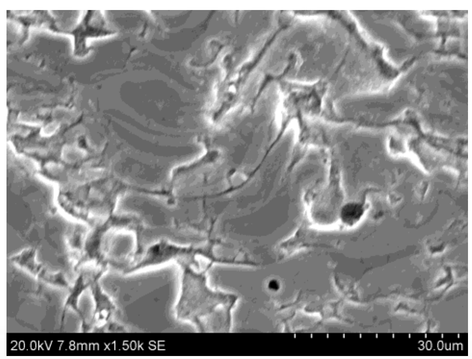
Sintering resistance : APS vs. SPPS

As coated

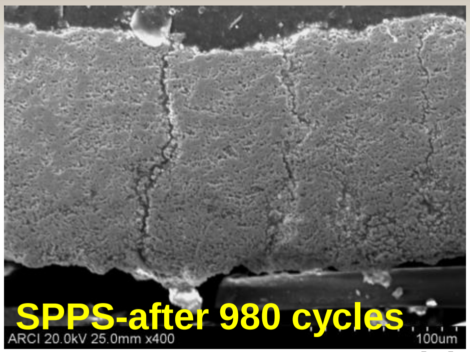


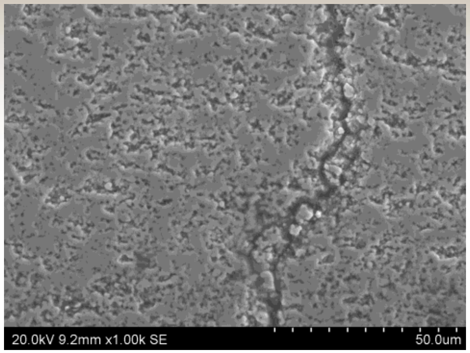




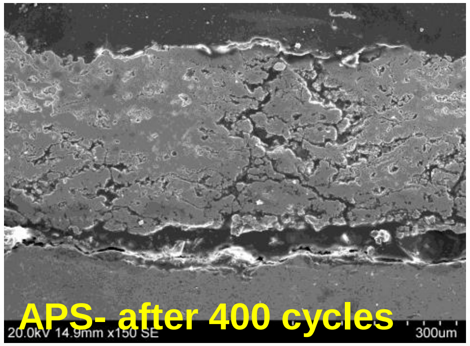


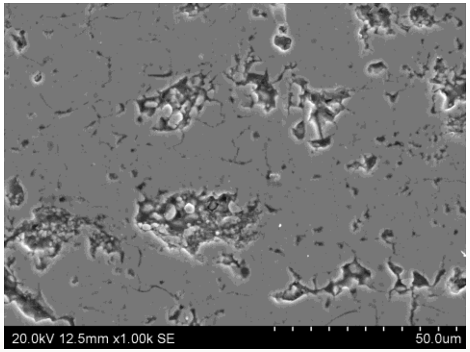
Thermal cycling @1100ºC; hold time: 40 mins





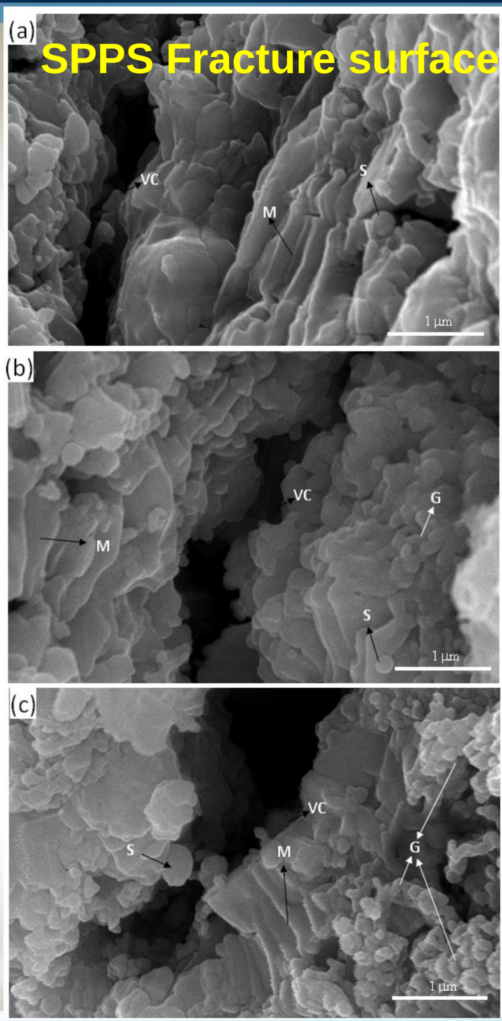
Vs

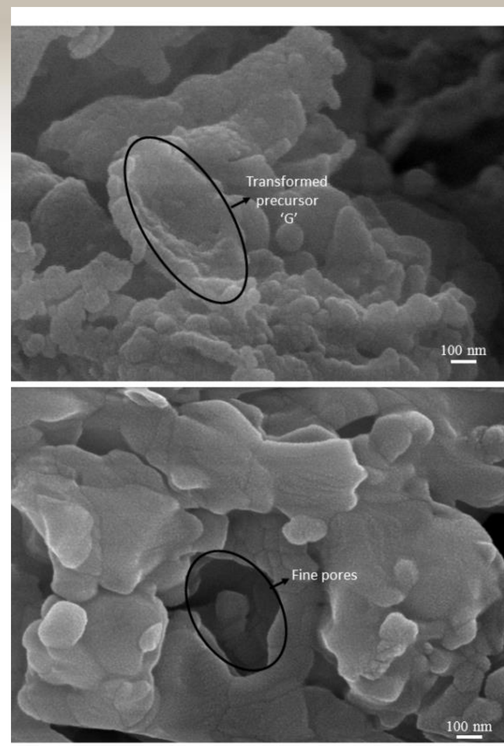


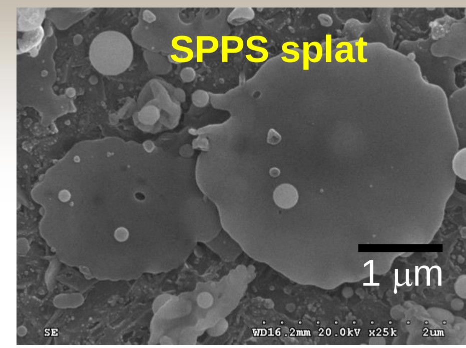


- SPPS exhibited better resistance to densification retaining the pores and voids even after long period of exposure than APS YSZ

Sintering of SPPS TBCs: Role of microstructural features







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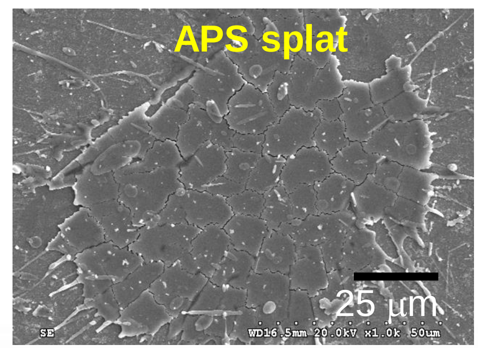
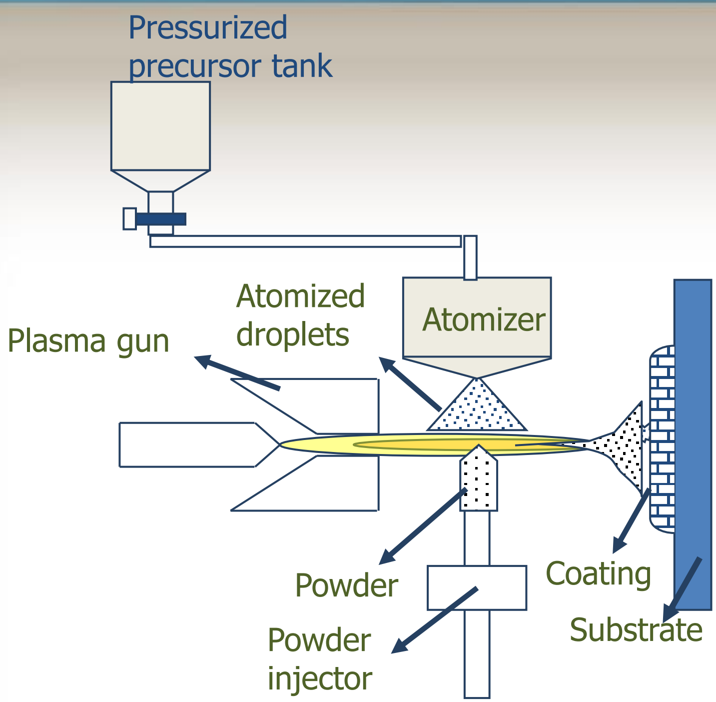
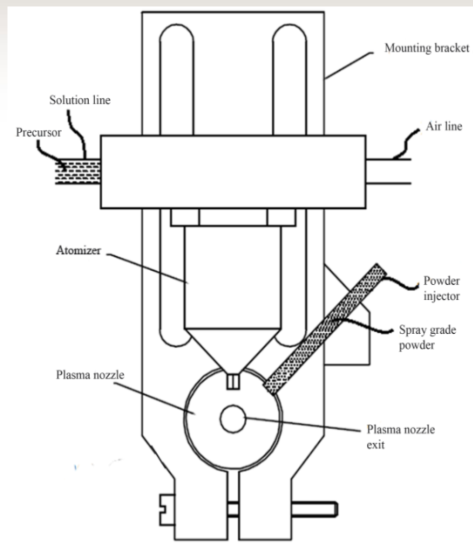


- Fine sized pores, smaller splats, strain tolerant microstructure enabled longer thermal cyclic life as well as better sintering resistance over long period of exposure

Solution precursor based TBCs

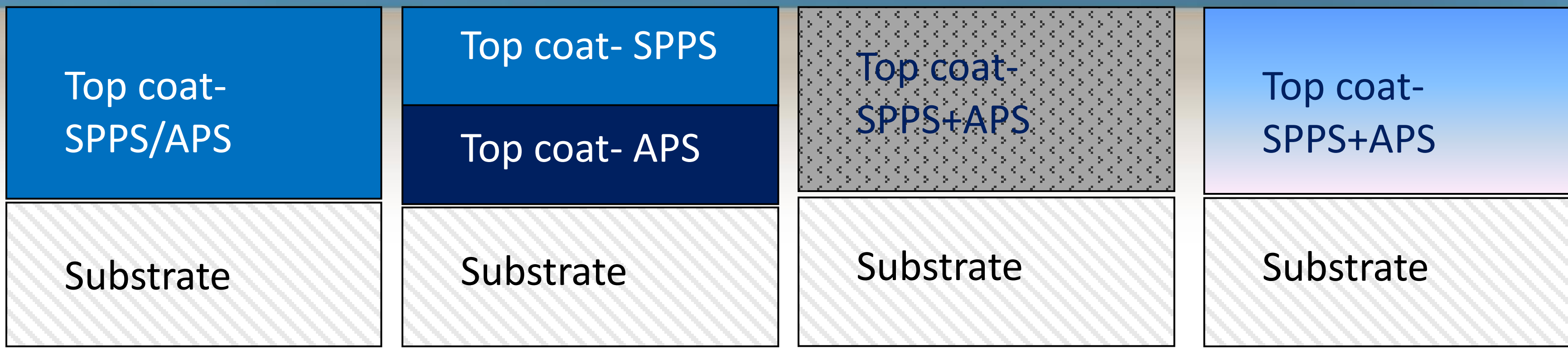




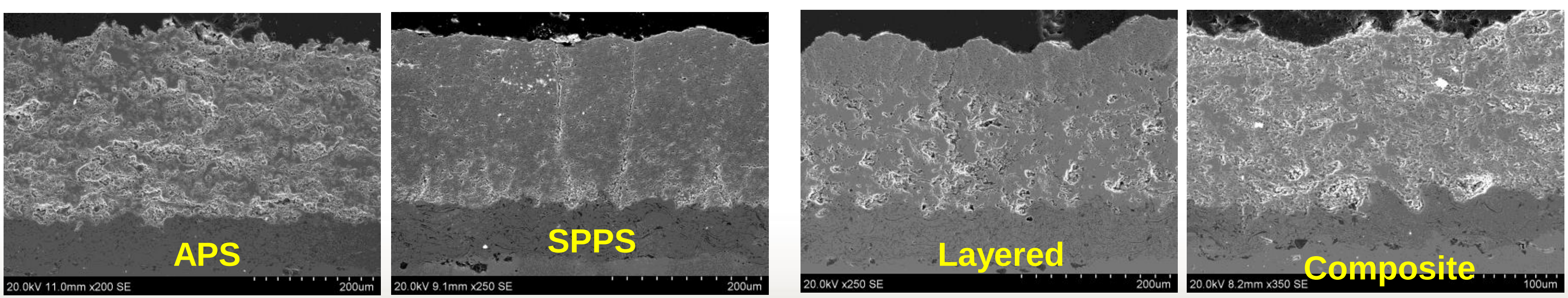
- Low deposition rates with SPPS
- Simultaneous feeding of solution & powder feedstock to tailor unique microstructures-- layered, composite and gradient structures
- Flexibility in novel material combinations

- Nano-sized features from solution precursor and micron-sized from powder feedstock yield bimodal features

Investigating Varied Architectures



Conventional architecture | ***Layered architecture*** | ***Composite architecture*** | ***Graded architecture***



Extended Durability in Layered TBCs

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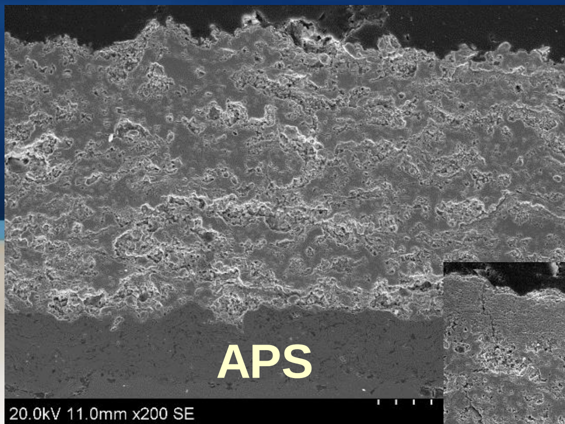
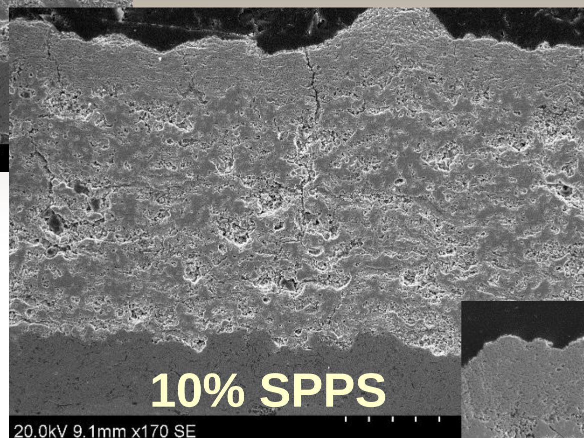
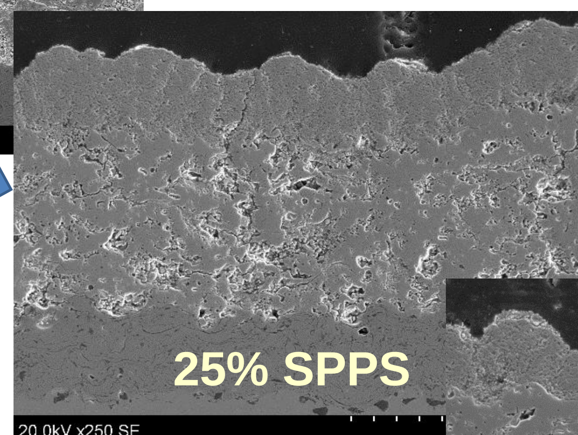
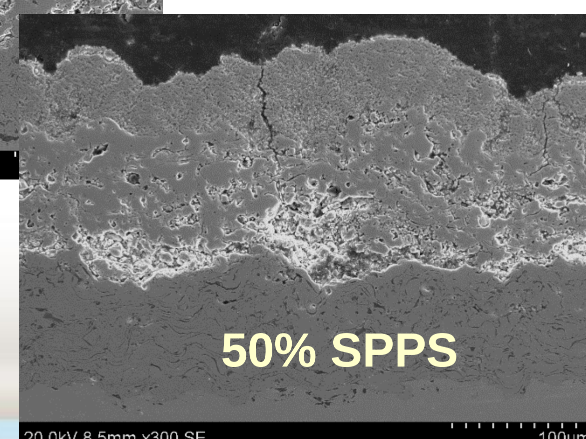
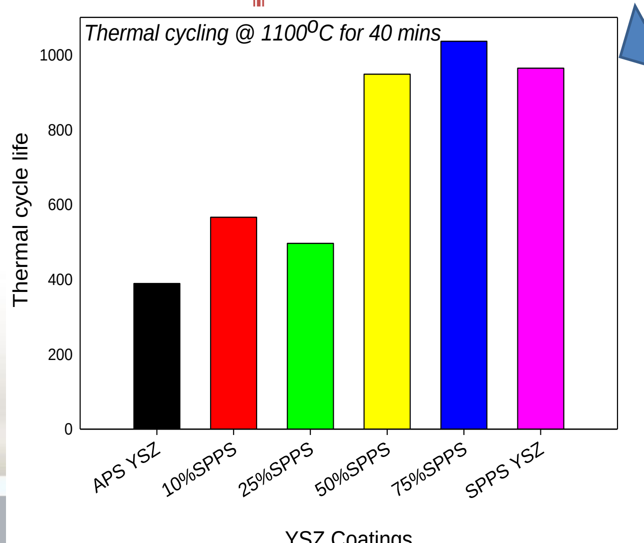




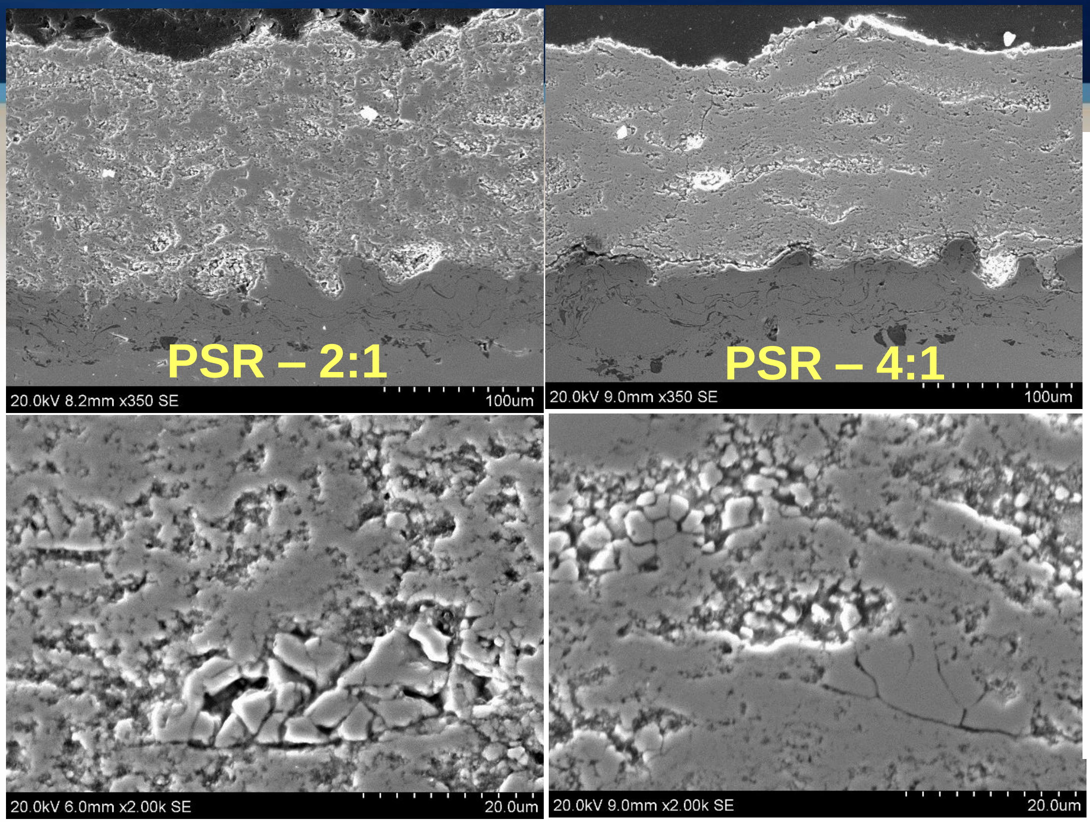
- Protective layer of SPPS YSZ over APS YSZ significantly assisted in improving the spallation life

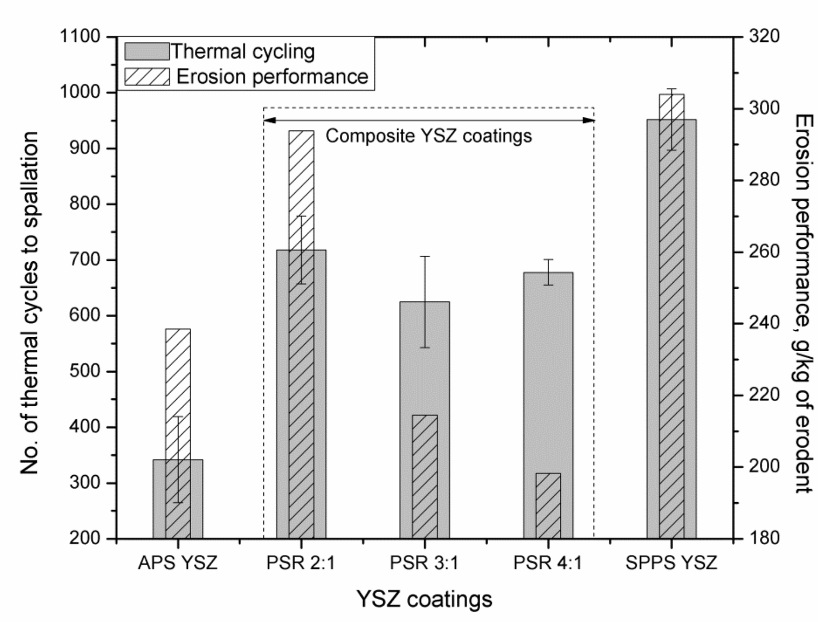






Composite YSZ-YSZ coatings





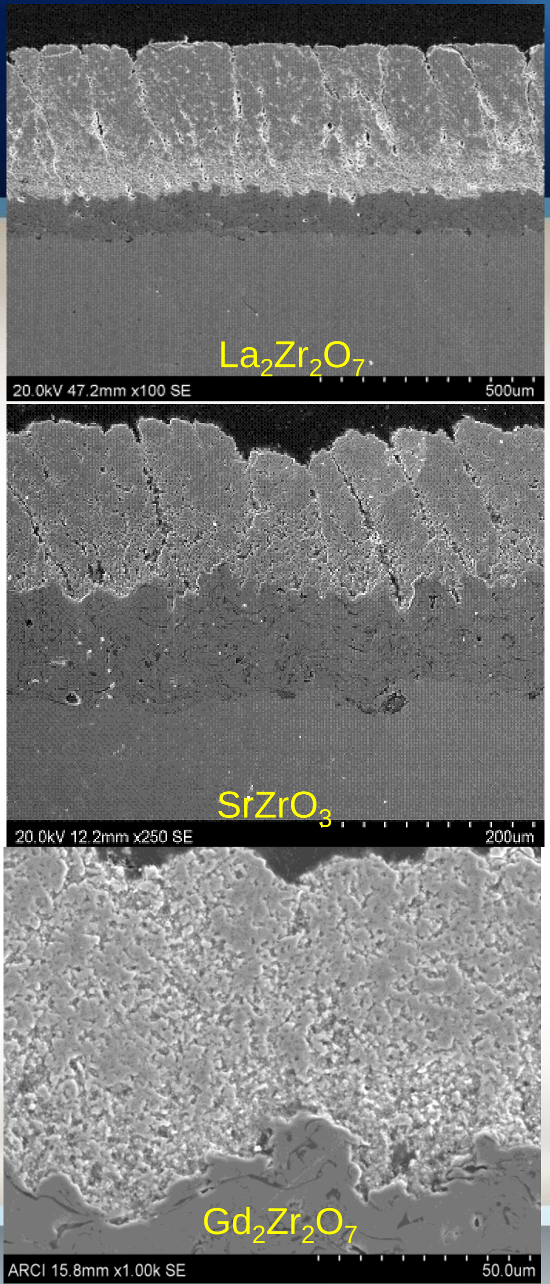
**PSR – powder to solution ratio*

- Uniform distribution of micron sized and sub-micron sized features in the coating; Higher density observed with increased powder content
- Exciting combination of thermal cycling and erosion properties for certain applications in desert environment

New TBC material possibilities using SPPS

- Apart from the standard YSZ, few candidate coatings like $Gd_2Zr_2O_7$, $Y_2Zr_2O_7$ are of interest to CMAS resistance , high temperature stability and low thermal conductivity
- SPPS can potentially deposit various combination of RE zirconates with or without additional dopants
    - *$Ln_2Zr_2O_7$ ceramics (Ln= La, Nd, Sm, Gd) with pyrochlore structure or perovskites*

- Various coating configurations in terms of composite or layered architecture



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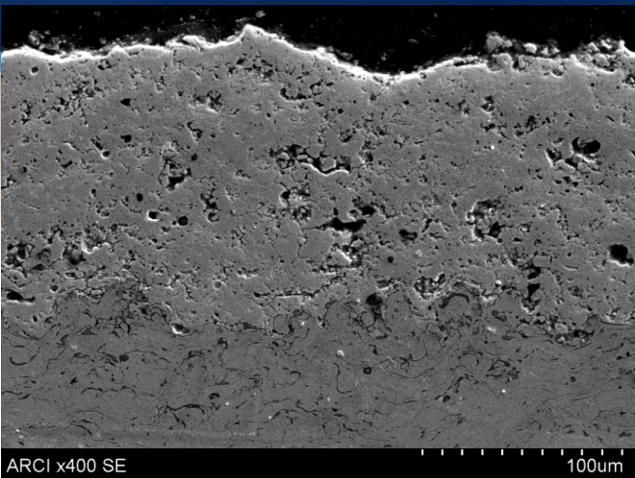
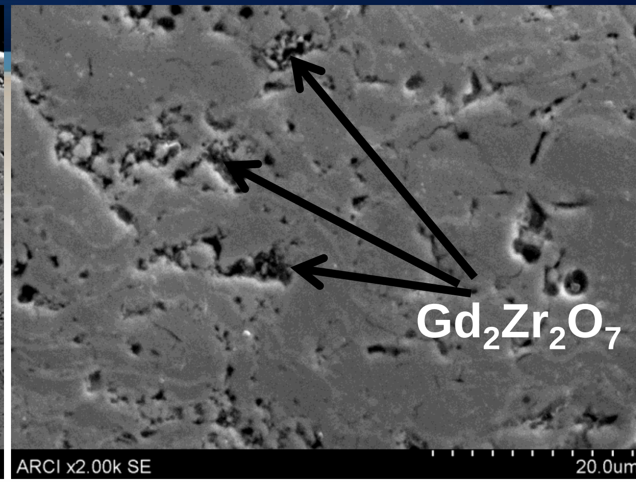
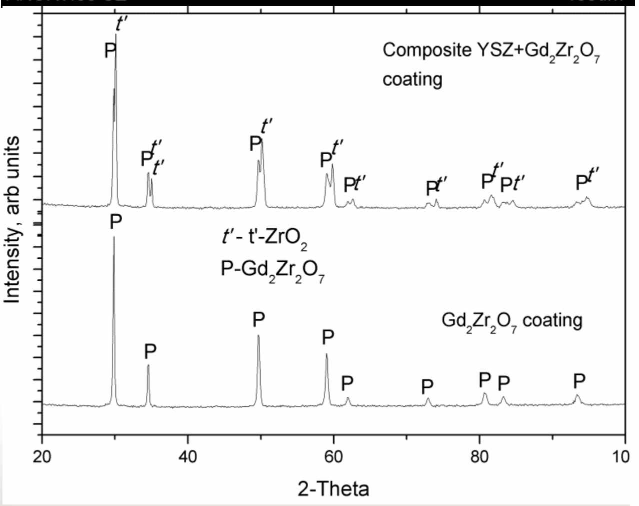
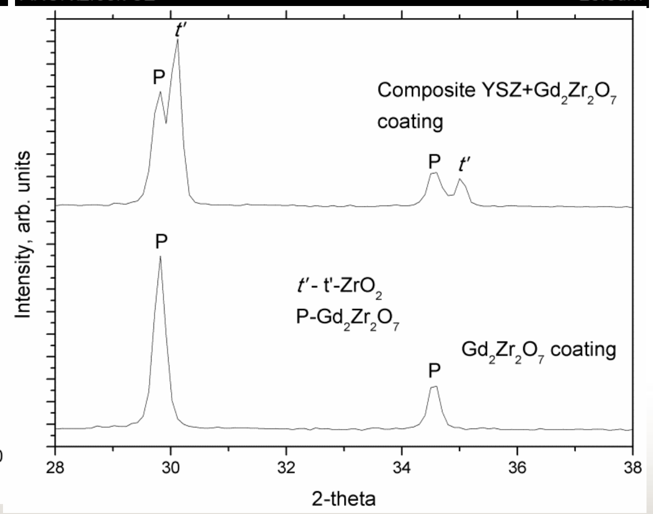
Composite YSZ + $Gd_2Zr_2O_7$









- 8YSZ powder co-deposited with $Gd_2Zr_2O_7$ forming solution
- Homogeneous distribution of $Gd_2Zr_2O_7$ at YSZ particle splat boundaries
- Combined presence of *t'*-YSZ along with pyrochlore $Gd_2Zr_2O_7$

Challenges with SPPS deposition on alumina substrates

Most of the coatings were done on super alloy substrates and while using Alumina, it posed numerous challenges!

APPROACHES ATTEMPTED

•Low-intensity grit blasting (low pressure, low grit feed)

•Emery roughening

•Laser texturing … appears most promising

PROBLEMS SPECIFIC TO SPPS

•Low spray distance

•High plasma power

•Low deposition rate, high number of passes to develop desired thickness

WHAT ELSE CAN WE TRY?

•Modified fixturing to facilitate heat extraction

•Auxiliary cooling

Quenching studies at Cambridge

- YSZ coatings were generated on few alumina specimens at ARCI
- Quenching tests at 1440ºC (hold time: 1 hour) for APS, SPPS and APS+SPPS hybrid coatings is in progress
- YSZ coatings with and without 6% Laki ash being compared under identical conditions
- So far, APS, SPPS and APS+SPPS hybrid YSZ coatings have undergone 148 cycles and are yet to fail

CONCLUSIONS – based on studies so far

- SPPS provides a convenient pathway to deposit various candidate TBC systems of interest to this project
- For a given coating chemistry, SPPS found to outperform APS in thermal cycling conditions
- Improved understanding of the SPPS process enables control over coating microstructure and can further enhance life
- Hybrid APS+SPPS can help to overcome low throughput limitation of SPPS and enable novel TBC architectures
- Certain hybrid architectures particularly good under erosion+TC environments
- Depositing SPPS coatings on alumina substrates has presented a significant hurdle

Looking ahead

- Further deposition trials on alumina substrates
- Duplex APS+SPPS coatings on alumina
- Trials with volcanic ash at ARCI
- SPPS deposition of coatings with other promising chemistries (yttrium zirconate, gadolinium zirconate, lanthanum gadolinate)

Thank You

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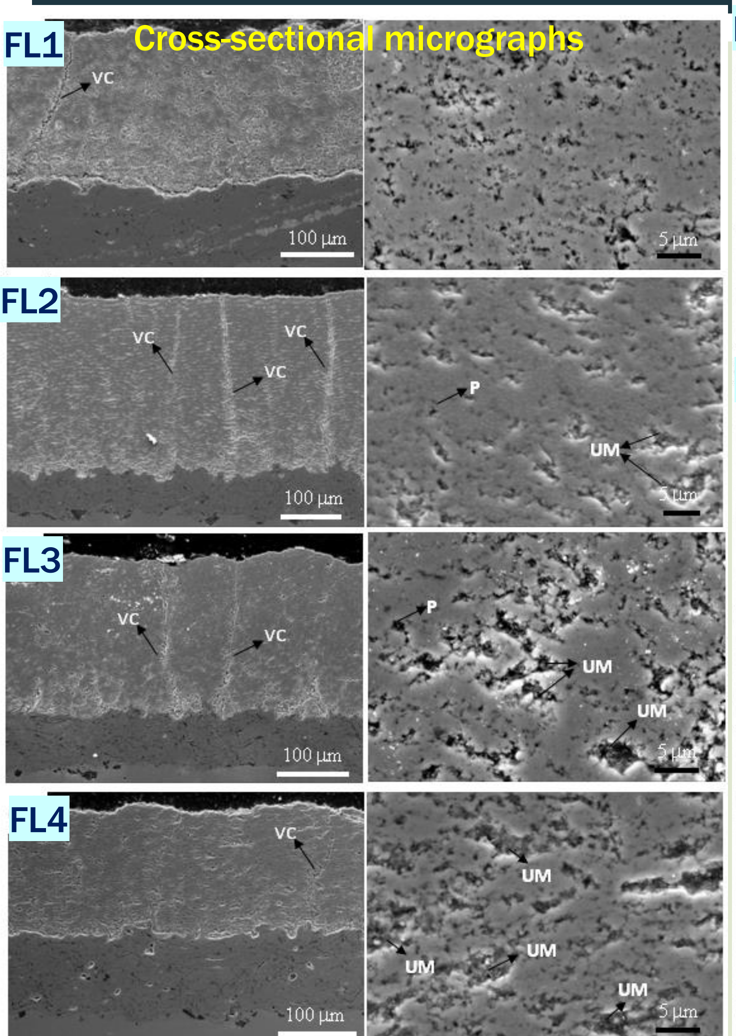
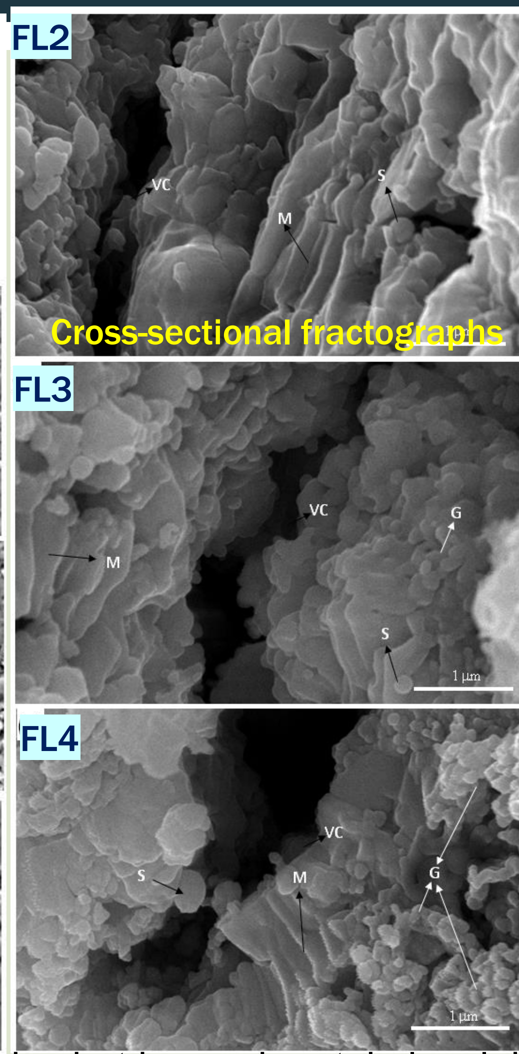
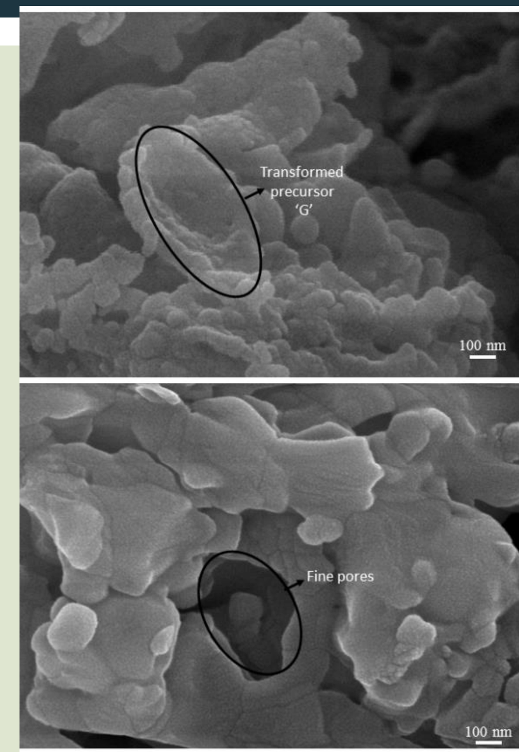
YSZ COATING CHARACTERISTICS- MICROSTRUCTURE

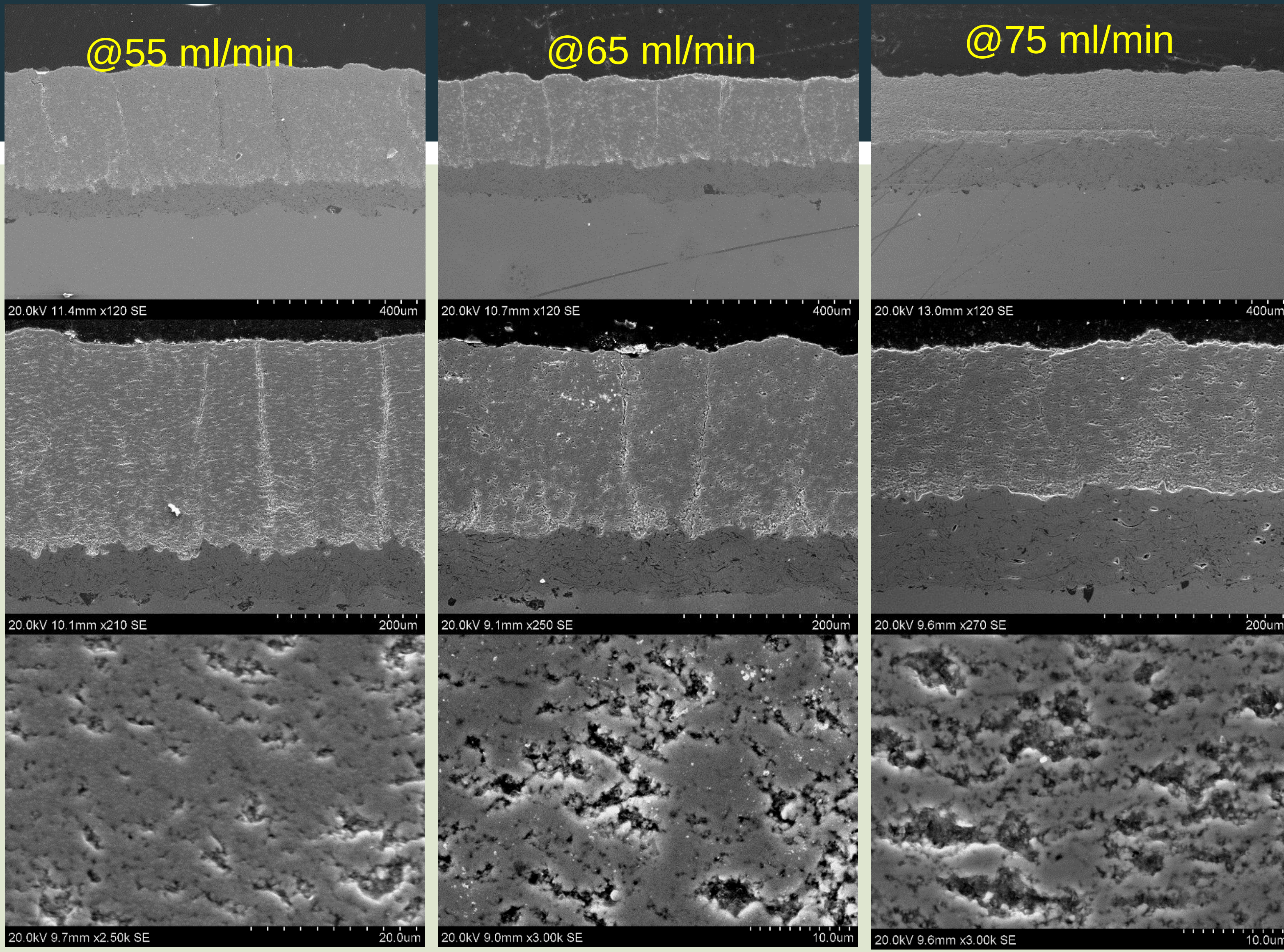






- Presence of nano-sized pores along with vertical cracks are desirable
- Increase in flow rate yield vertical cracks, but beyond certain level, it introduces excessive defects

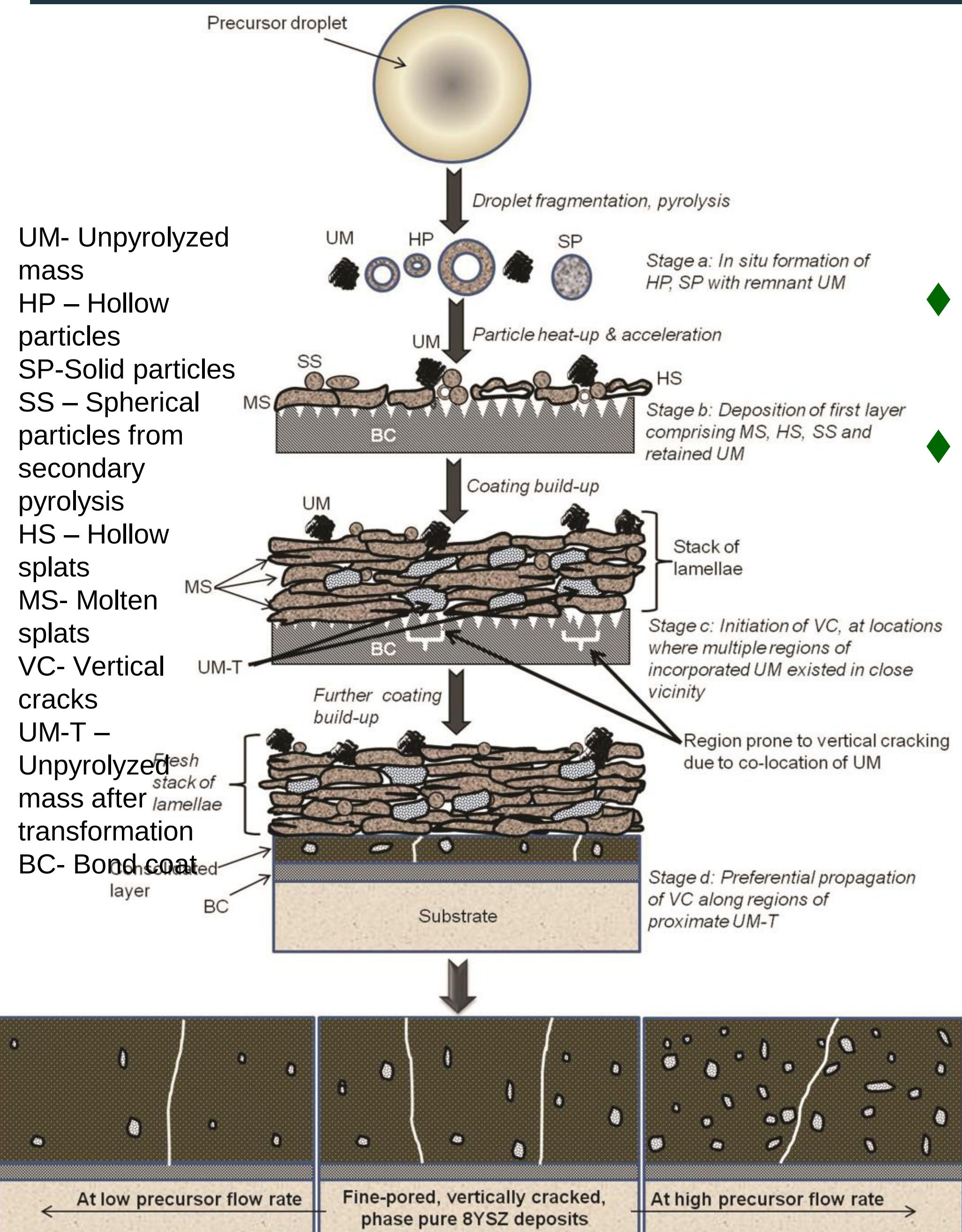
Manipulating Coating Microstructure Through Process Control



- **Significant influence of precursor flow rate on vertical cracks, porosity**
- **Excessive porosity but no vertical cracks at very high flow rates**

Understanding Origin of Vertical Cracks

UM- Unpyrolyzed mass
HP – Hollow particles
SP-Solid particles
SS – Spherical particles from secondary pyrolysis
HS – Hollow splats
MS- Molten splats
VC- Vertical cracks
UM-T – Unpyrolyzed mass after transformation
BC- Bond coat



- Incorporation of unpyrolyzed precursor along with splats
- Higher deposition temperature through
  - Substantial exothermic energy (~400 J/g) released during precursor pyrolysis
  - Substrate pre-heating (~500^{o}C)
  - Repeated plasma torch scans
  - Short spray distance

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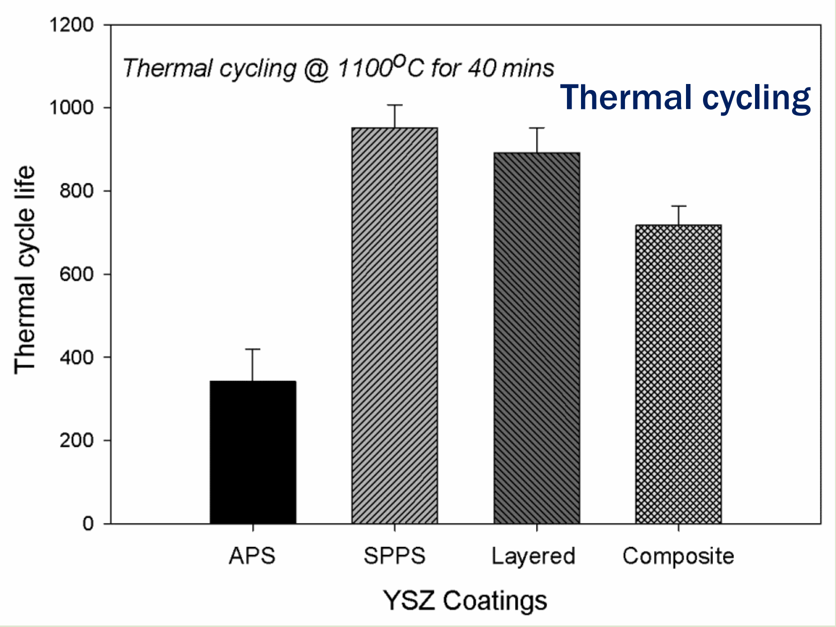
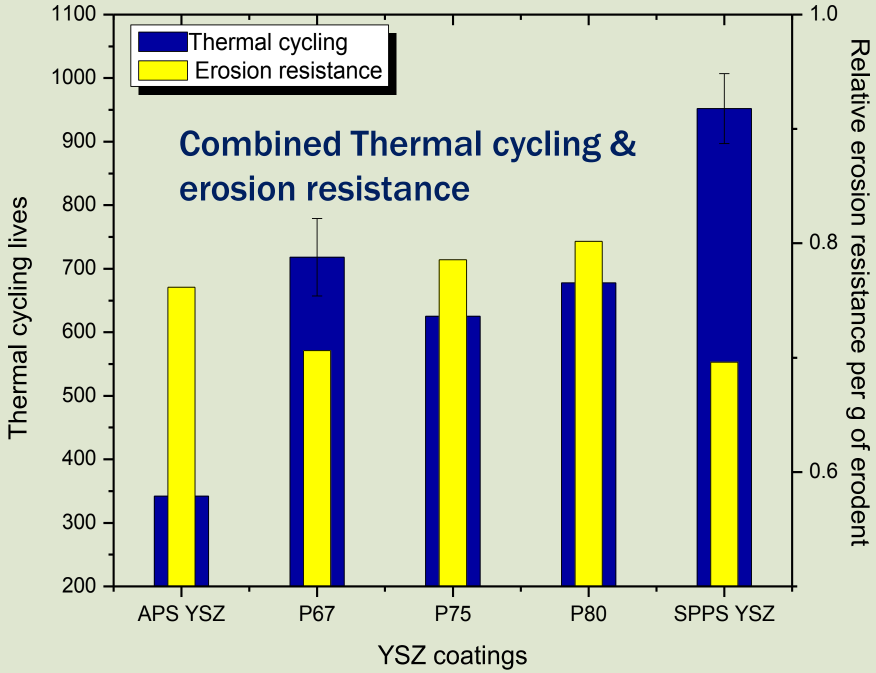
COMBINED PERFORMANCE IMPROVEMENTS OF COMPOSITE YSZ





- Layering of SPPS YSZ over APS YSZ improves the thermal cycle life almost close to that SPPS YSZ; Reasonable improvement in thermal cycling performance of composite YSZ observed – (Role of densification resistant SPPS YSZ)
- SPPS YSZ exhibited poor erosion resistance
- Improved resistance for composite YSZ through the addition of sub-micron/nano-sized features

JTST, 2014, In Press

TYPES OF COATINGS DEVELOPED AT ARCI

ZrO_2-Y_2O_3	***TBC applications***
Phase pure α-Al_2O_3	***Dielectric coating***
ZnO, $ZnFe_2O_4$, TiO_2, Fe_2O_3, $SrFeNbO_5$	***Photocatalysis***
TiO_2, SnO_2	***DSSC applications***
$LaSrMnO_3$, FSZ	***Cell components of SOFC***
$LiMnO_2$, $LiFePO_4$, $LiNiCoMnO_4$, CuO, Fe_2O_3, SnO_2	***Li-Ion battery electrodes***
La_2O_3 / CeO_2+Y_2O_3 / SrO doped ZrO_2	***REO doped TBCs***
CaO.6Al_2O_3 with & without NiCrAlY matrix	***High temp solid lubricant, layered ceramics***
Dy_2O_3	***Magnets***
Metal(s) doped ZnO	***Varistors***
Al_2O_3-TiO_2, Ag-ZnO	***Solar absorption***
ZnO-CuO-Al_2O_3	***Reformer catalyst***