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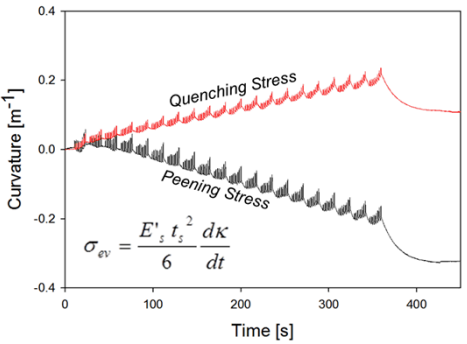

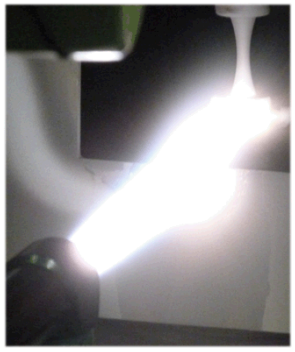

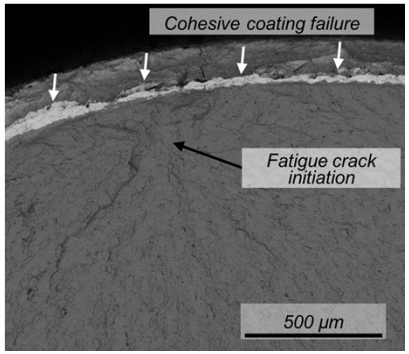

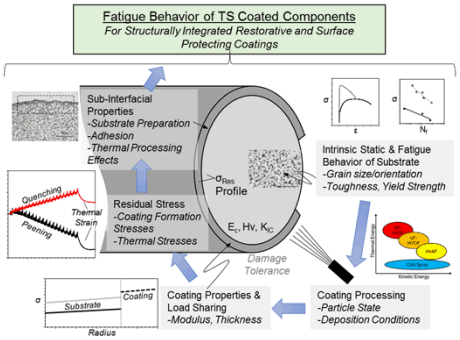

Fatigue Behavior of Thermal Spray coated systems

Andrew Vackel

U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

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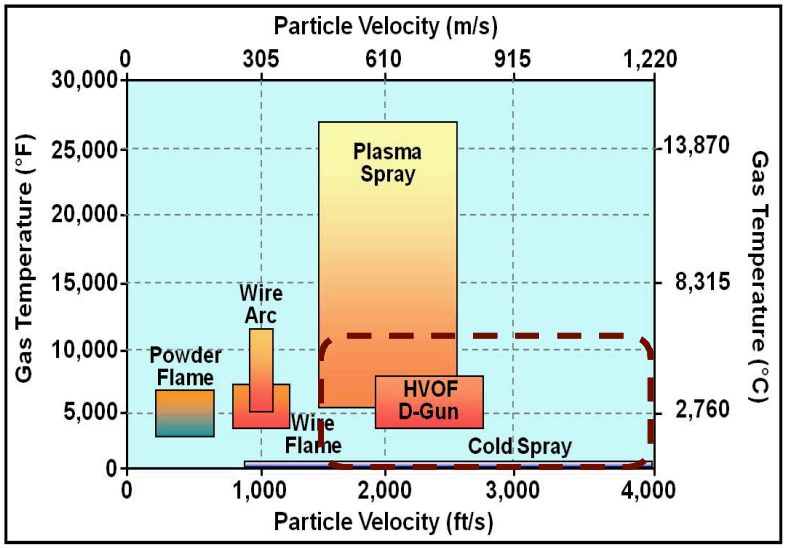
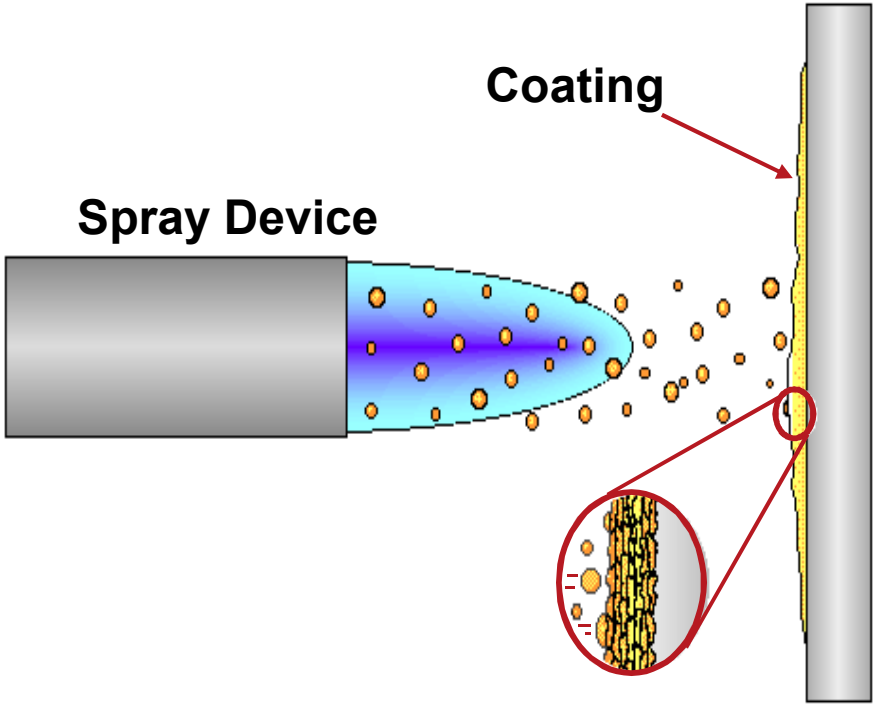
Thermal Spray Technology

- Thermal spraying = coating processes in which heated/melted materials are deposited onto a surface.
- High deposition rate over large area. *mostly constrained by line-of-sight.
- Thickness range ~ 20 um to several mms, depending on process/feedstock.
- Quality assessed by measuring porosity, oxide content (in metallic coatings), hardness, bond strength and surface roughness. Generally, the coating quality increases with increasing particle velocities.



*Adapted from plots by R.C. McCune, Ford Motor Co. & A. Papyrin, Ktech Corp.

Different Thermal Spray processes allow access to different regimes of particle temperature and velocity space.

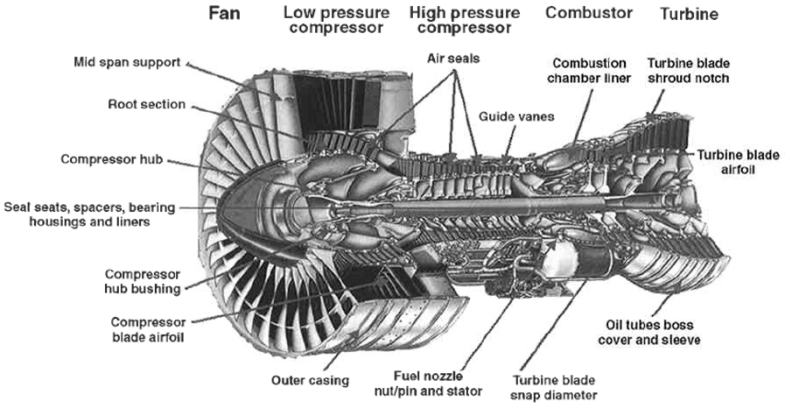


Particle Temperature & Velocity at impact determine coating microstructure and properties.

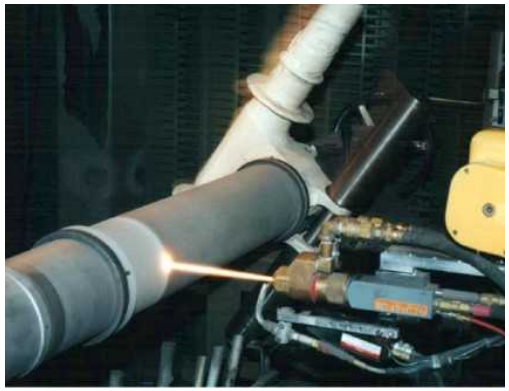
Industrial Applications – Passive Coatings

- Aerospace
  - Gas Turbines
  - Landing Gear
- Automotive
- Biomedical
- Computers
- Infrastructure
- Marine
- Paper Making
- Petrochemical
- Power Generation
- Printing
- Textiles
- Electronics

Hydroxyapatite coating on a hip implant



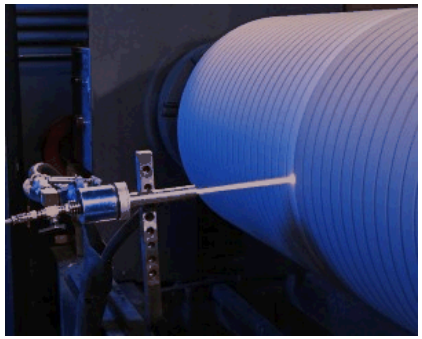
Gas Turbines are full of sprayed coatings!



Hard Chrome Replacement on a Landing Gear Strut

The Wuhan Junshan Bridge over the Yangtze River is covered with 35,000 m^2 (~8.5 acres) of thermal sprayed zinc coating!

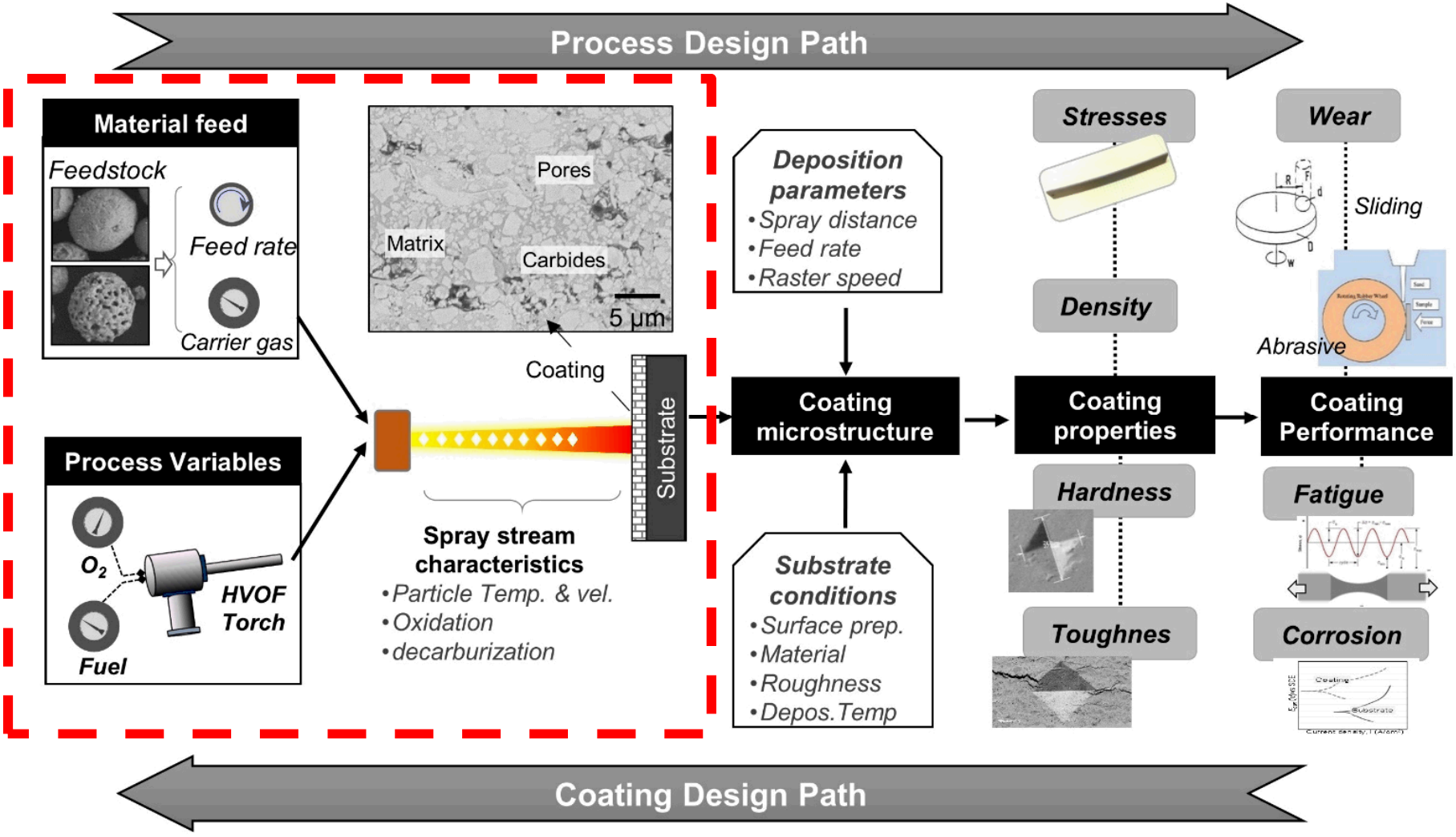
Auto applications include pistons, valves, cylinder bores, clutches, and drive train components.



Ceramic Coating a Printing Roll

Thermal Spray Coatings find niche surface modification applications in many industries.

Process Mapping



Origin and Measurement of Stresses in Thermal Spray

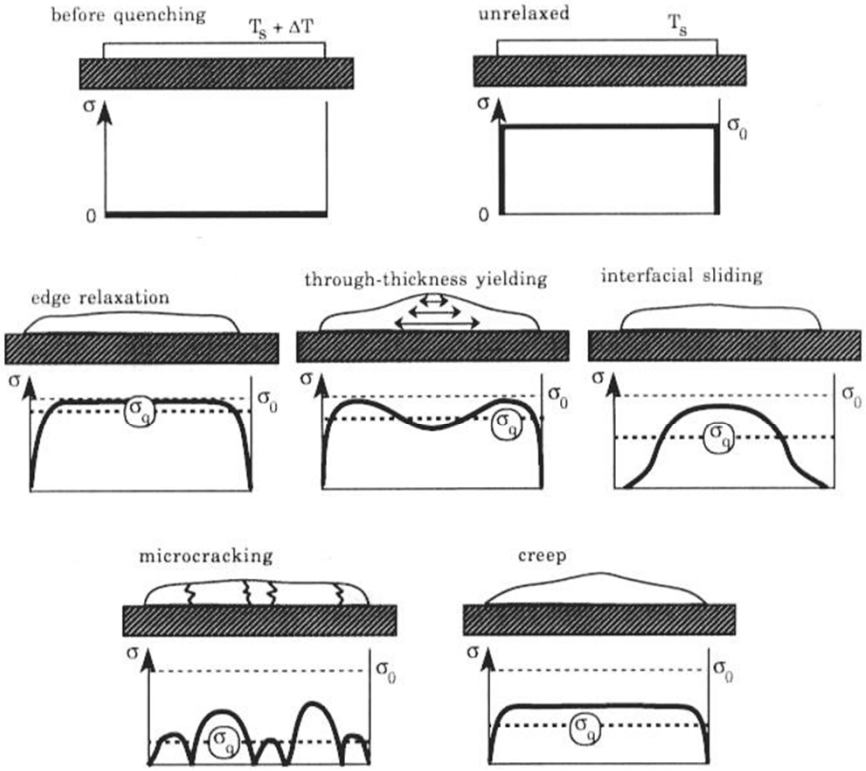
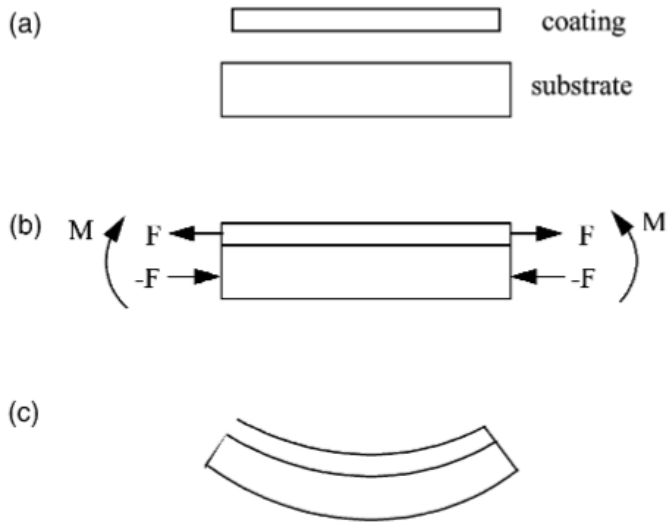


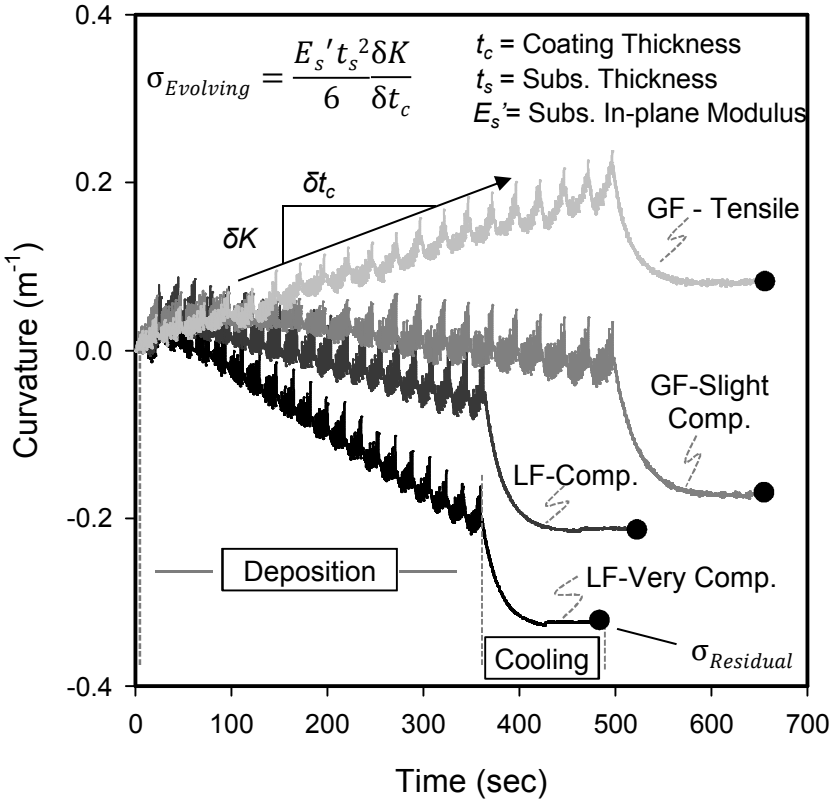
Fig. 2. Schematic illustration of the stress distributions within a single splat before and after various stress relaxation phenomena have taken place.

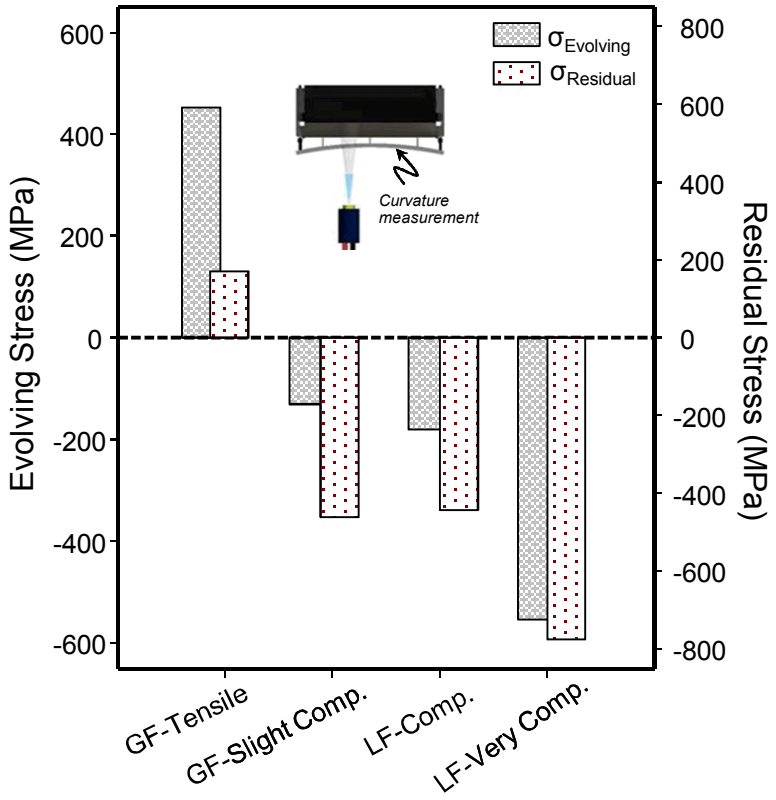
[1] *Kuroda & Clyne. The Quenching Stress in Thermally Sprayed Coatings, Thin Solid Films, 100 (1991) 49 -66*



J. Matejicek, S. Sampath / Acta Materialia 51 (2003) 863–872

Process Sensitivity on Residual Stress





High Velocity TS processes are capable of producing compressive residual stresses that reduce, neutralize, or dominate the quenching stresses associated with splat bonding

Fatigue of Coated 4340 Steel

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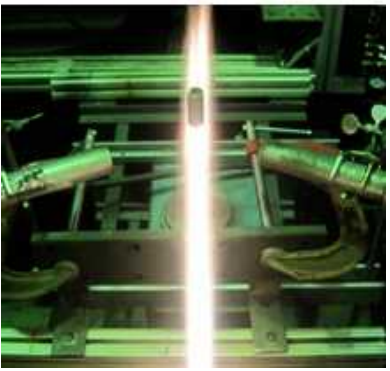
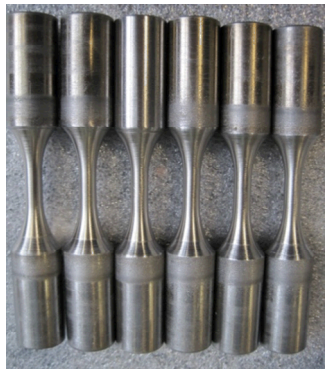
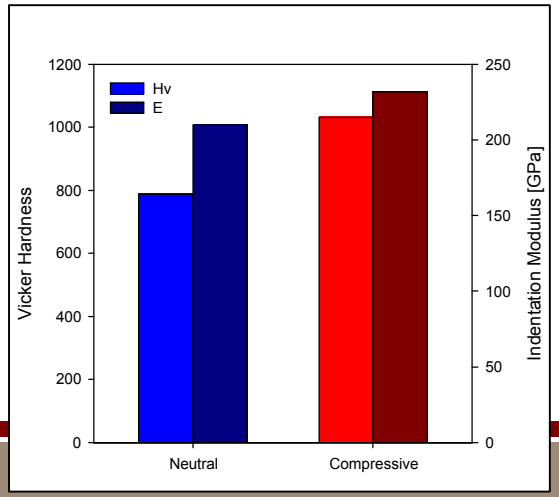
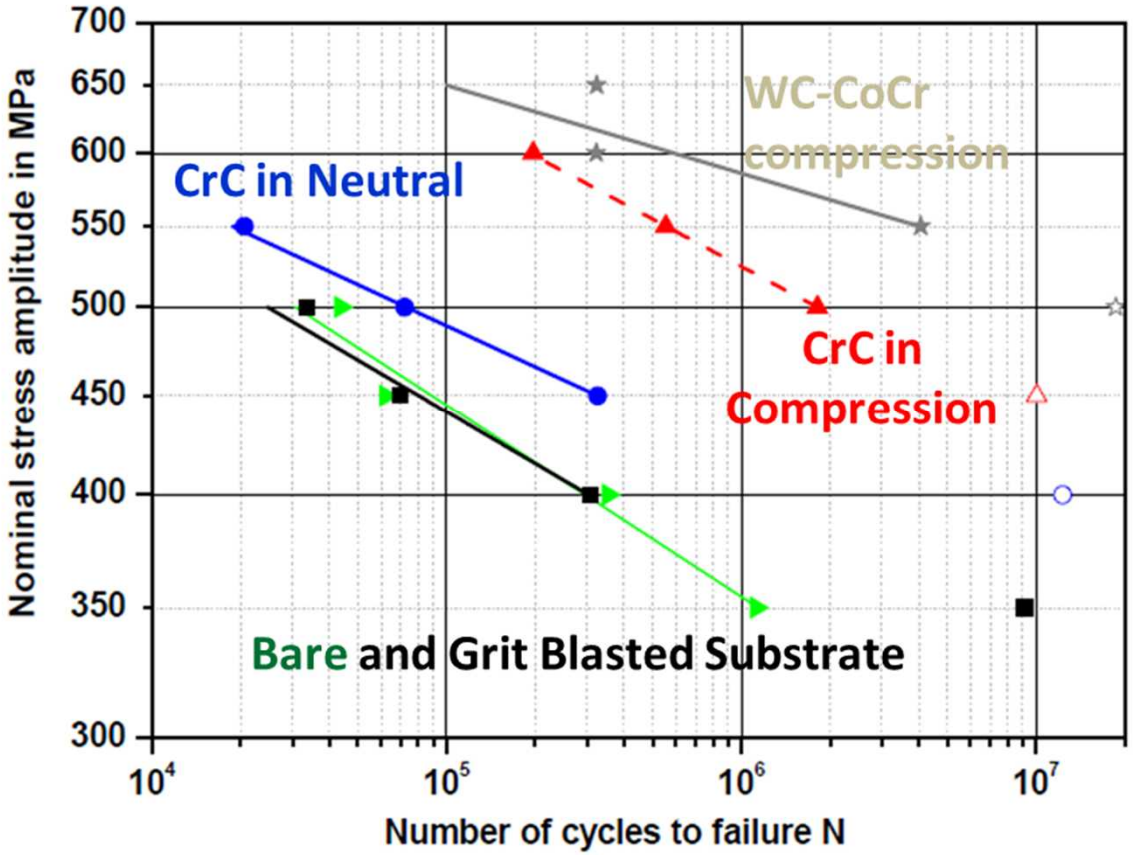




Coatings that enhance fatigue life

- *Greater degree of consolidation (modulus)*
- *Higher hardness*
- *Compressive residual stress*





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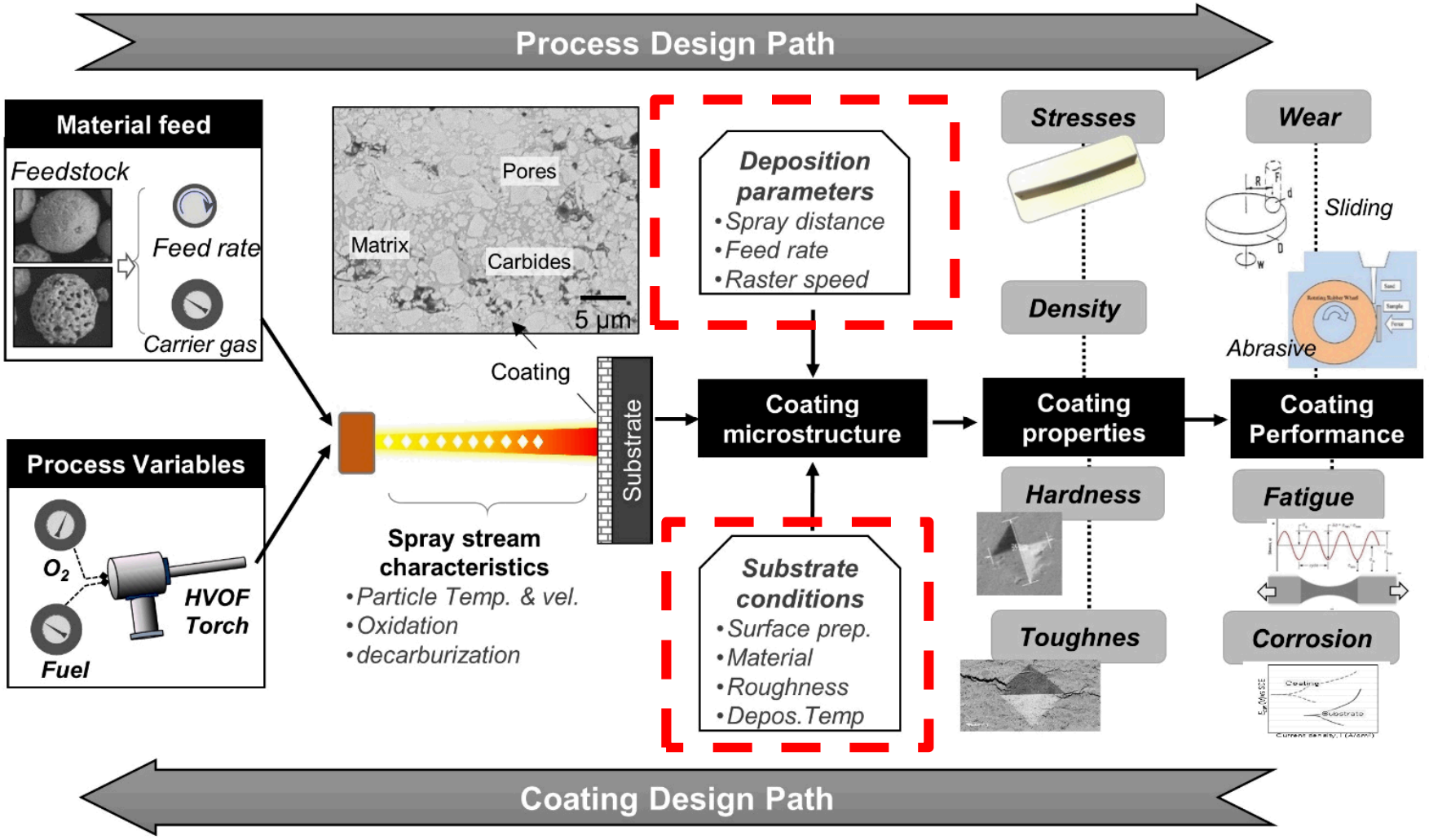
Other process manipulations?



Formation and Residual Stresses

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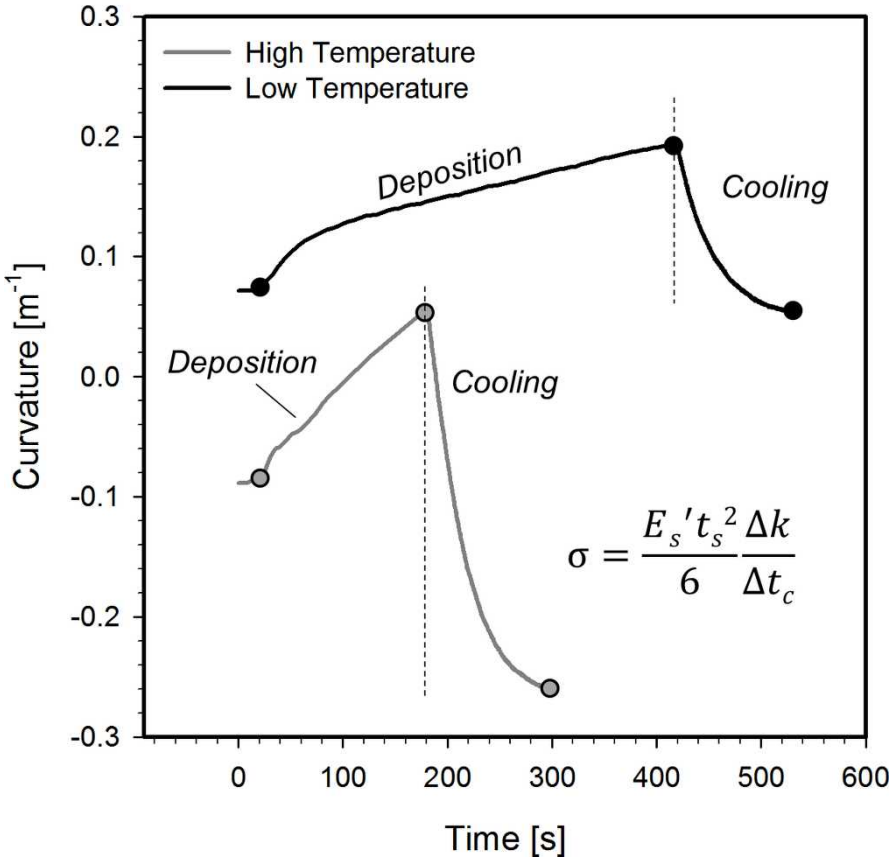
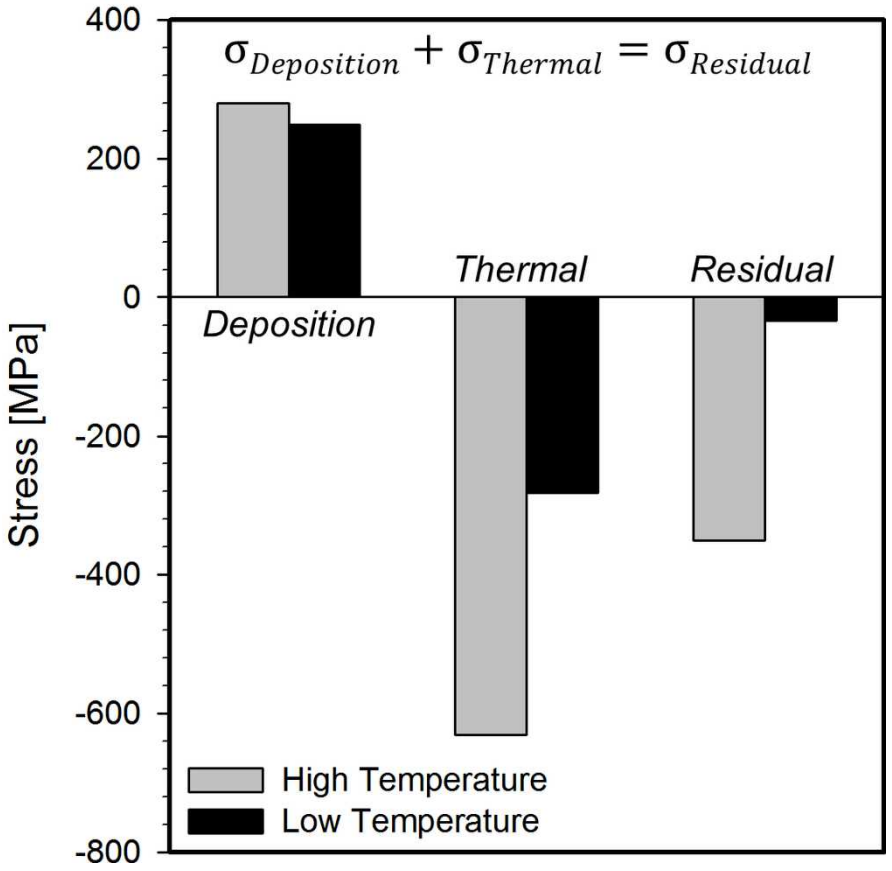
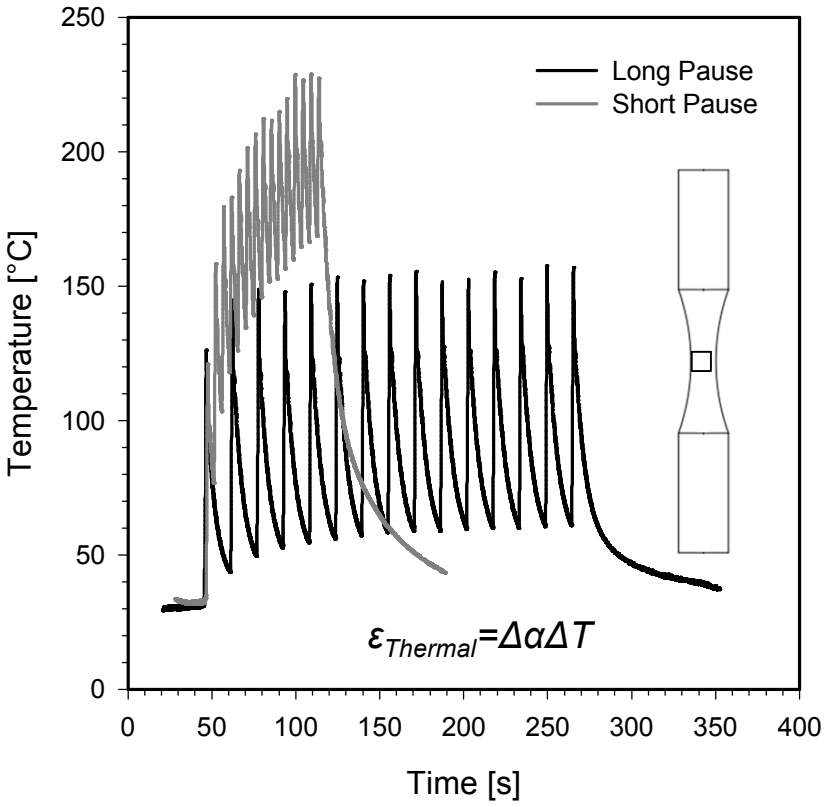
WC CoCr on Steel

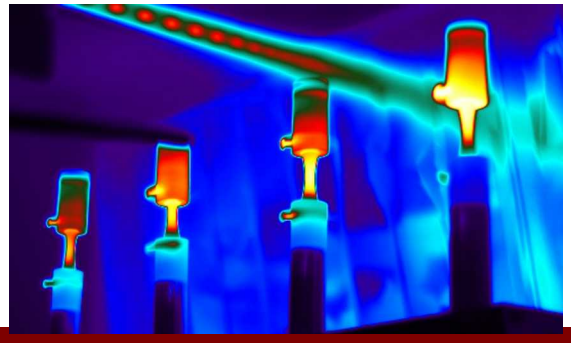


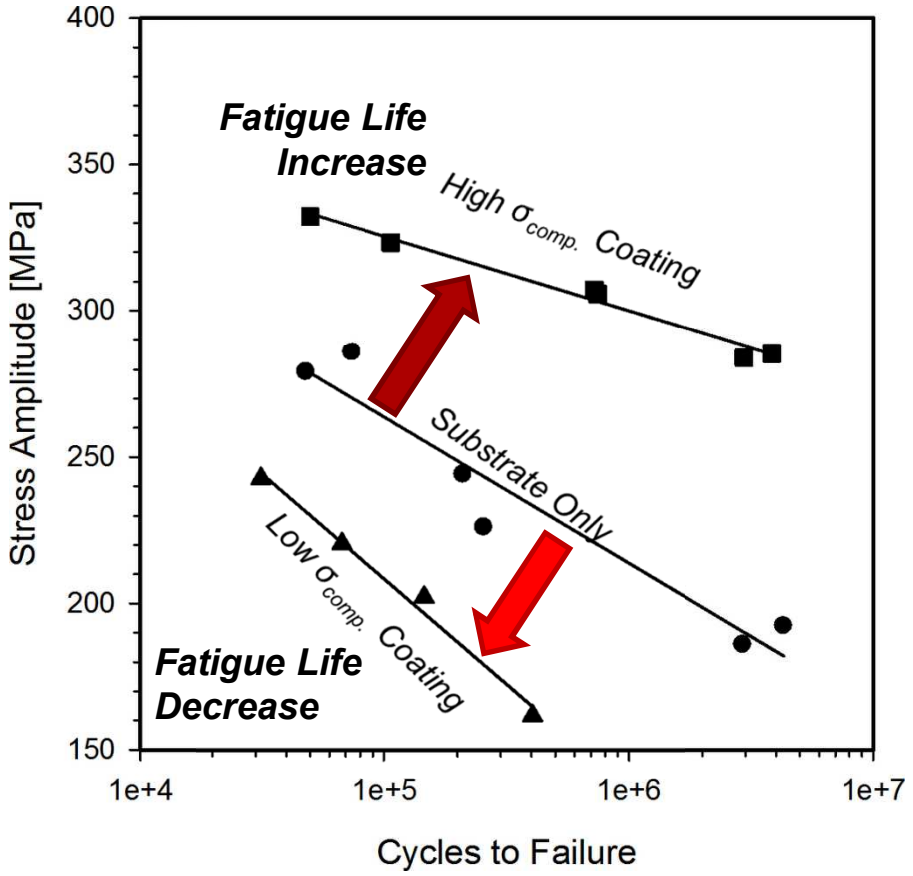


Residual Stress can be Controlled by Deposition Conditions i.e., Thermal Stress

Thermal Stress and Fatigue







Control of Deposition Conditions can affect Fatigue Life

Fracture surfaces

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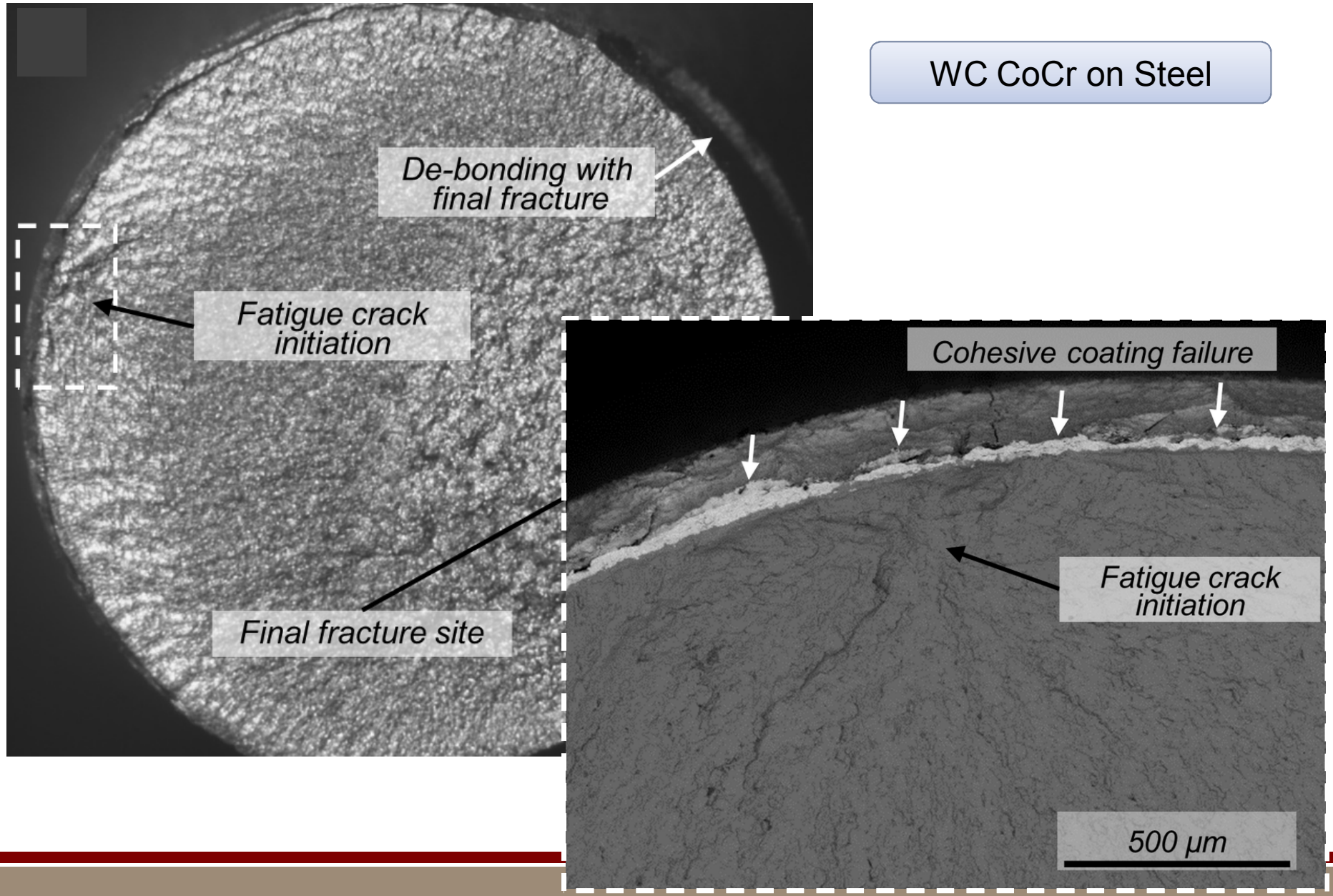
WC CoCr on Steel



Applied Stress – Coating and Substrate

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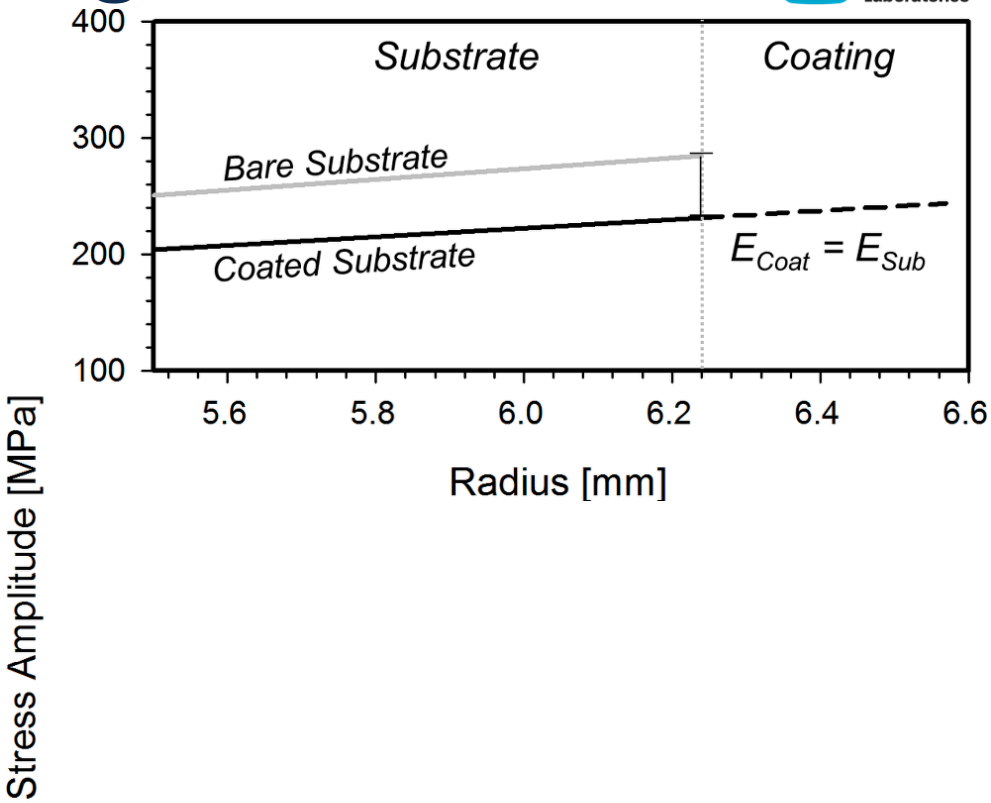
Rotating Bend Fatigue

$$K = \frac{64\ M}{E_s \pi D_s^4 + Ec\pi(Ds_{+c}^4 - D_s^4)}$$

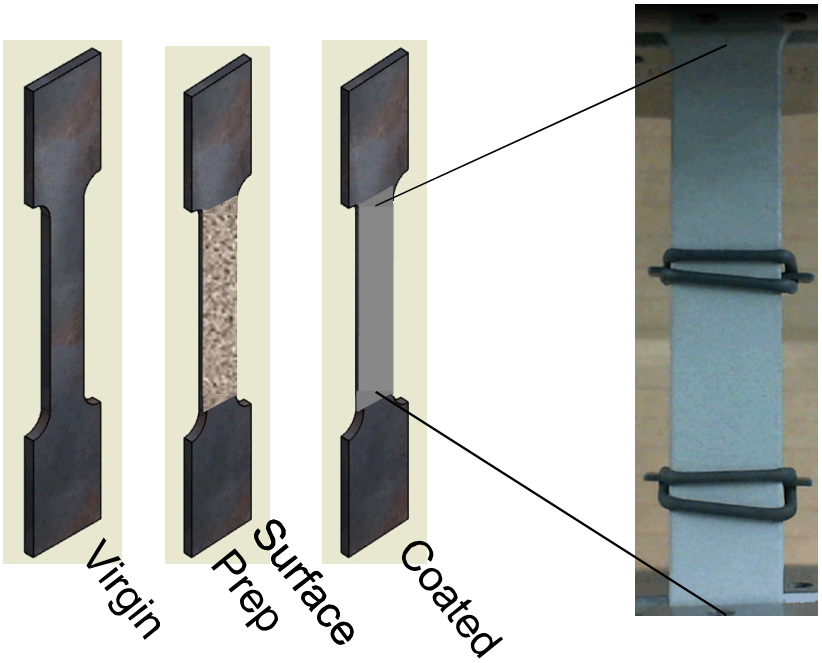
$$\sigma_s = EsKR$$

$$\sigma_c = EcKR$$

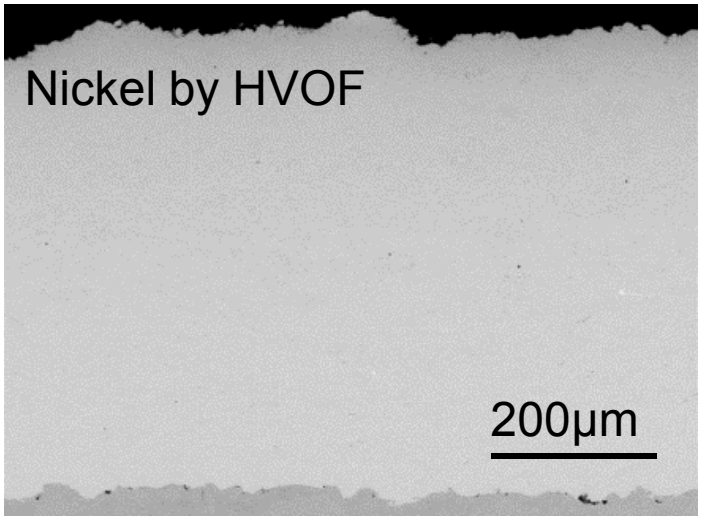


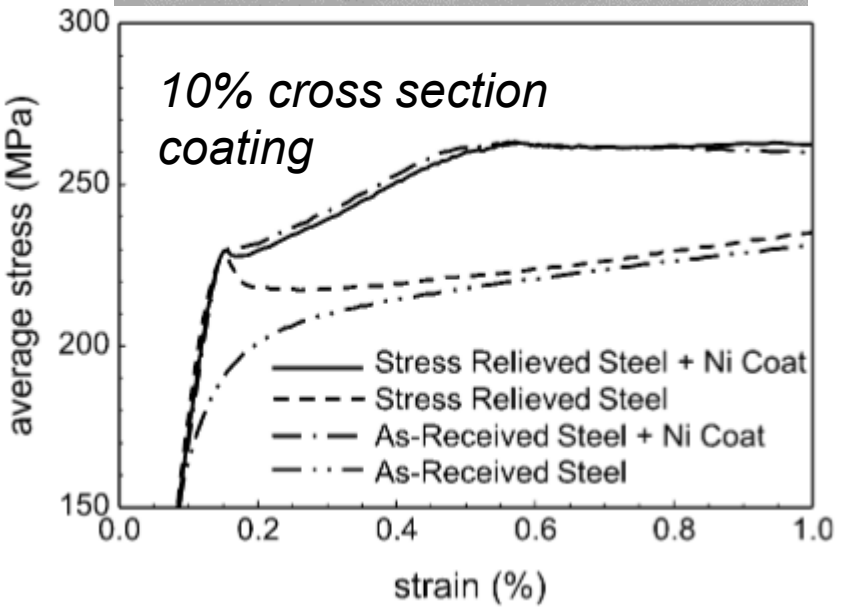
Coating-Substrate Residual Stress will be Superimposed

Load carrying capability thermal spray coatings



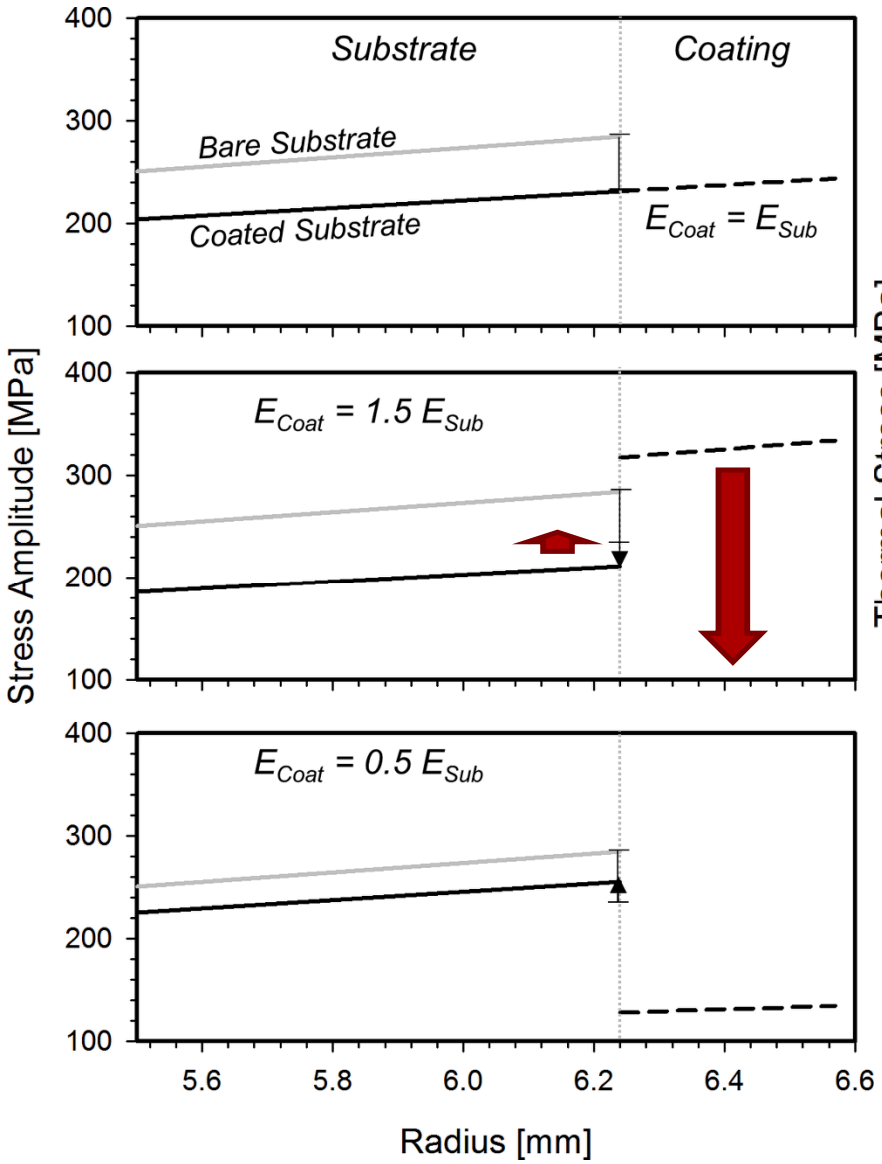
Significant load bearing capability of dense, well adhered metallic coatings

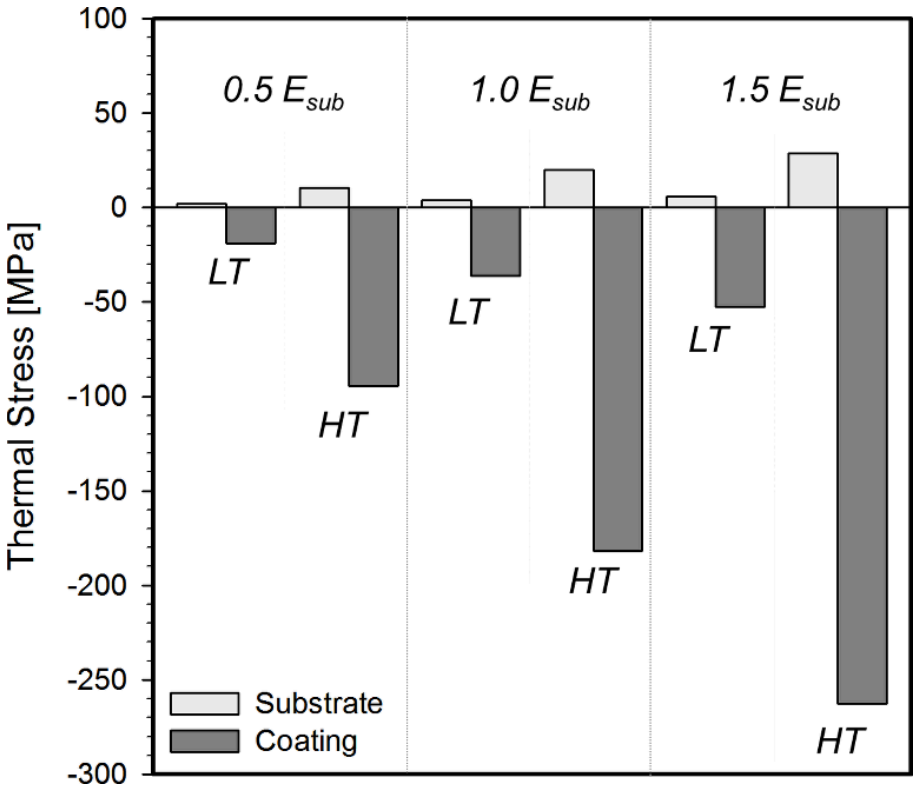




Vackel et al. *Mechanical Behavior of Spray-Coated Metallic Laminates* JTST 2106

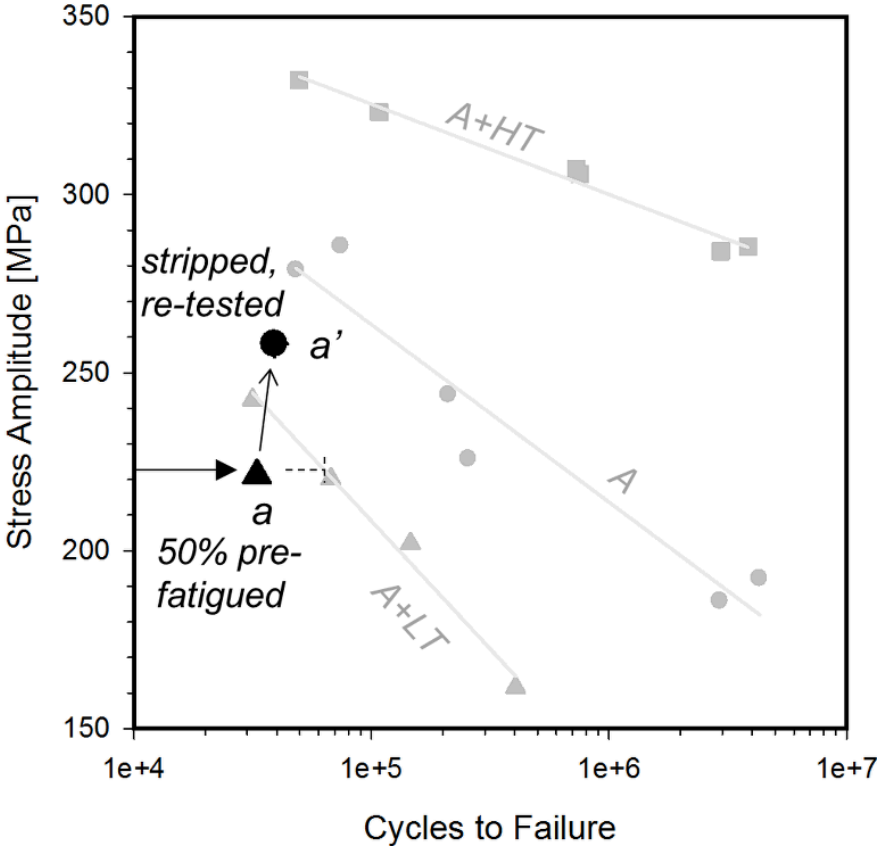
Process + Applied Stress



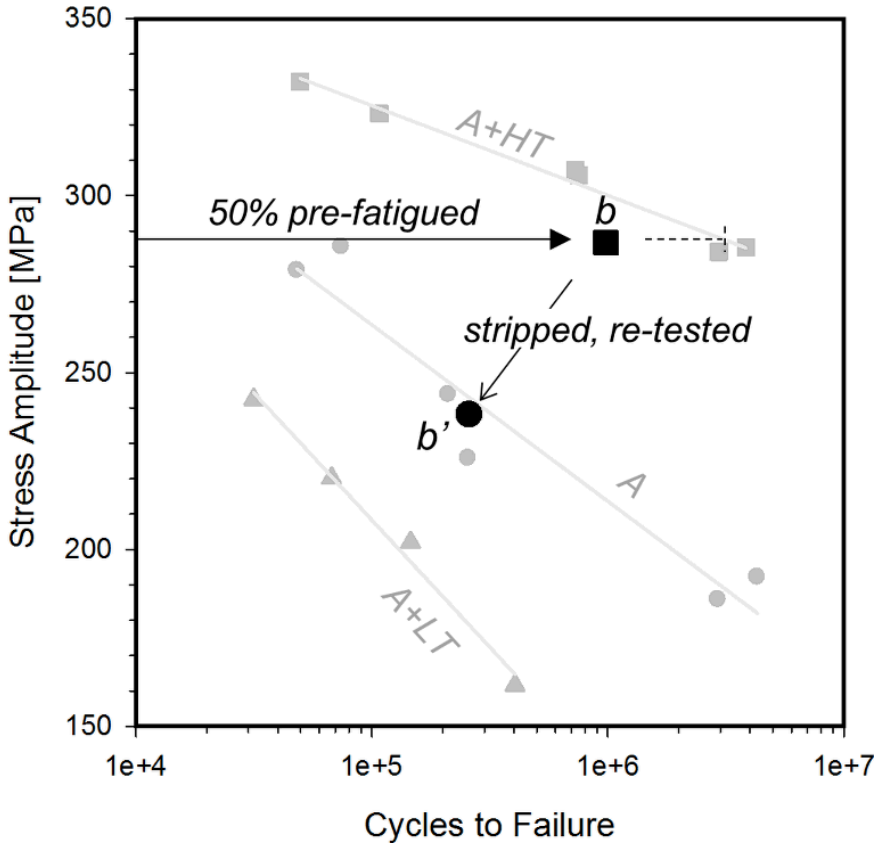


Coating has higher sensitivity to stress based on deposition temperature

Allowing or Hindering Substrate Damage Accumulation



Damage Accumulated in Substrate



Little to no Damage Accumulated in Substrate

Design Considerations for Thermal Spray and Fatigue