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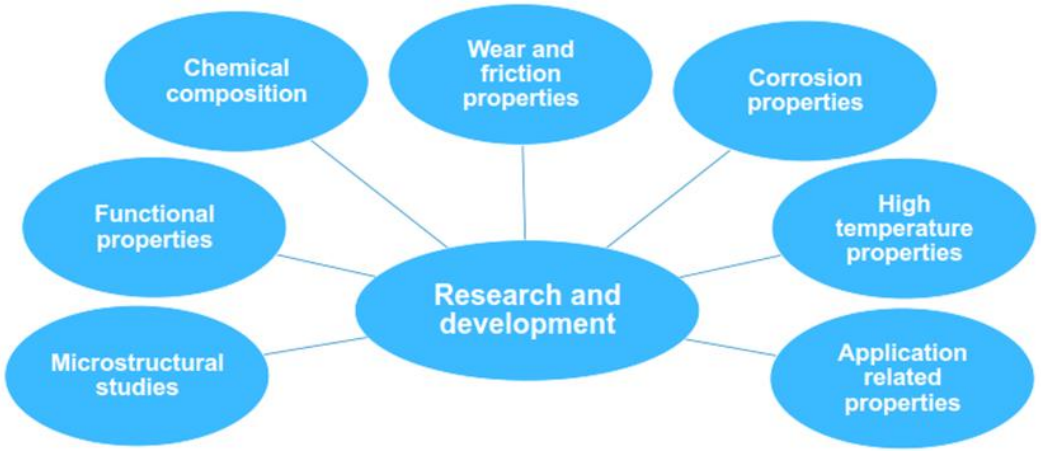
Approaches for linking the high kinetic thermal spray process, residual stresses and coating performance by utilizing in-situ monitoring

Tommi Varis
Tampere University, Thermal Spray Center Finland

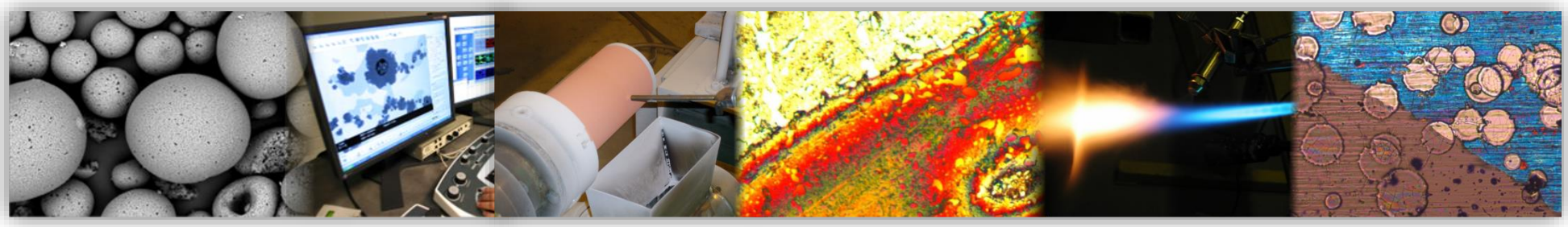
Material Science 50
Tampere 24.10.2019

Surface Engineering



- Prof. Petri Vuoristo
- Personnel appr. 10

- ***Research topics***
  - Coatings by thermal spray technologies
  - Coatings by thin film technologies (PVD)
  - Coatings by laser and weld processing
  - Surface treatments, e.g. icephobic coatings and surfaces
  - Characterization and performance evaluation and testing
  - Industrial application of coatings and surface treatments



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Surface Engineering research

Understanding and controlling of the

Processing/Structure/Properties/Performance- relationships

of advanced coatings and surface treatments

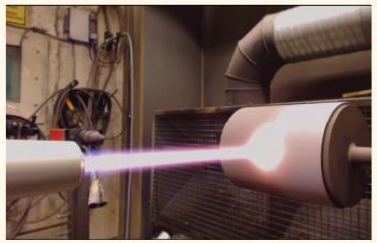
- **Processing** of advanced coatings by thermal spray, weld, laser and thin film processes
  - Novel coating processes: Plasma, HVAF, cold spray, suspension spraying, weld and laser technologies
- **Materials science** of coatings and thin films - microstructure and engineering properties
  - Materials science of engineering and functional coatings
- Application-related **properties and performance** of advanced surfaces and coatings
  - Structural properties, wear, corrosion, high temperature, friction, optical, electrical and tailored properties
- **Industrial applications** of coatings and surface treatments
  - Development of coating solutions to demanding engineering applications e.g., paper industry, energy, SOFC, wear applications

Tampere University

Laboratory of Surface Engineering

SURFACE ENGINEERING RESEARCH GROUP

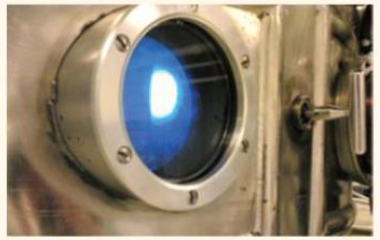
Science and engineering of advanced coatings and surface treatments



Thermal and cold spraying

Laser coating and additive manufacturing

CMT surfacing and additive manufacturing



Thin film deposition

Surface modifications

Internationally recognized research on advanced coatings and surface treatments by modern processes
Strong collaboration with industrial partners in coating processing, properties and industrial applications.
Leading-edge technology survey and expertise services for research and education for technological partners.
Educates materials and surface engineering professionals for the industry and academia.

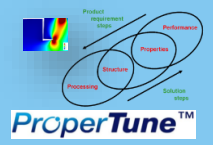
TSCF

Thermal Spray Center Finland

VTT ProperTune

Multiscale material modeling for

- Wear and friction
- Fracture, fatigue, creep
- Deformation
- Heat transfer, heat expansion



VTT ProperScan

Thermal spray coating processing

- High-kinetic (HVOF, HVAF) flame spraying
- Cold kinetic spraying
- Plasma spraying
- Flame and electric arc spraying
- Suspension and solution spraying
- Laser-assisted cold spraying

- Spray process development
- In-situ diagnostics
- Materials development

Coating structure and performance

- Optical and electron microscopy
- Chemical and phase analysis
- Corrosion properties
- Wear and friction properties
- Functional properties
- High-temperature resistance
- Electrical and thermal properties

Powder Piloting Service

Design based, demo powders for

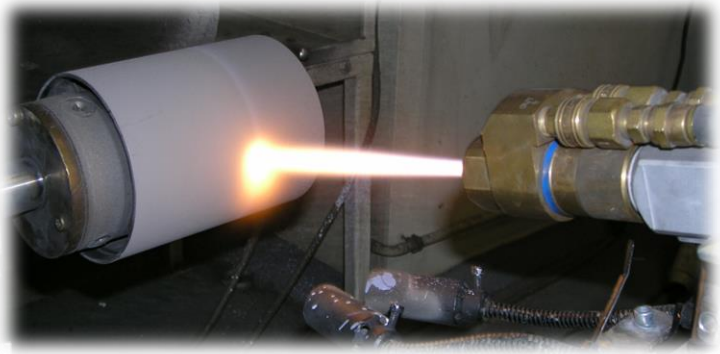
- Coatings
- 3D printing
- Additives, reinforcements

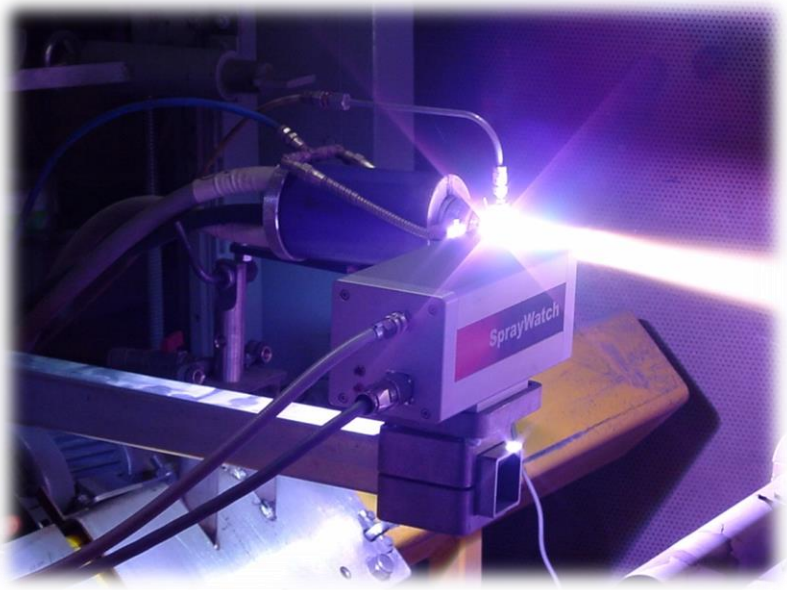
Scientific and industrial collaboration

National and international projects

Tampere Wear Center
Laser Application Laboratory
SMACC

- Atmospheric Plasma Spraying – F4 and ProPlasma
- High-Velocity Oxy-Fuel Spraying – DJH and TopGun
- High-Velocity Air-Fuel Spraying – Uniquecoat M3 and Kermetico AK-07
- Electric Arc Spraying – Metco SmartArc
- Powder Flame Spraying – Metco and Castolin
- Wire Flame Spraying – Metco
- High Pressure Cold Spraying – Plasma Giken PCS-100 and CGT Kinetiks 3000
- Low Pressure Cold Spraying - Dymet
- Liquid/suspension HVOF Spraying – S-HVOF
- Laser spraying/cladding – High-power laser cladding
- Cold Metal Transfer weld cladding





Tampereen yliopisto
Tampere University

Recent master theses (examples)/ Surface Engineering Research

N. Tyynelä: Termisesti ruiskutettujen pinnoitteiden korroosionkesto (2019)

H. Järvinen: Laser shock peening in aircraft applications and its effect on fatigue life of 7075-T7351 aluminium alloy (2019)

L. Ojaniittu: Corrosion of cruise vessel outfitting parts (2019)

P. Mattila: Development of the quality of corrosion protection (2019)

S. Ahmed: Hardfaced wear resistant coatings for mining tools (2019)

D. Meschini: Corrosion Properties of Thermally Sprayed Bond Coatings (2018)

S. Terho: Properties of Coatings for Continuous Galvanizing Line Heat Treatment Hearth Rolls (2018)

S. Peregrina: Cavitation and Slurry Erosion Wear of Thermally Sprayed Hardmetal Coatings (2017)

K. Penttilä: Quality improvement of plasma sprayed chromia coatings by in situ dry ice processing (2017)

etc. etc.

Tampereen yliopisto
Tampere University

Recent and next year doctoral theses / Surface Engineering Research

M. Kotilainen: Temperature-Induced Ageing Mechanisms and Long-Term Stability of Solar Thermal Absorber Coatings (2014)

J. Puranen: Protective Spinel Coatings for Solid Oxide Fuel Cell Interconnectors by Thermal Spray Processes (2015)

A. Milanti: Characteristics of Iron-based Thermal Sprayed Coatings Manufactured with High Velocity Oxygen Fuel and High Velocity Air Fuel Spraying for Wear and Corrosion Applications (2016)

J. Laurila: Structure and Properties of Nickel Based Braze Surface with Diamond Grits - Interaction Phenomena between Brazing Alloy and Diamond Grits (2017)

L. Janka: Thermally Sprayed Cr_3C_2-NiCr Coatings: Improving the Abrasion Resistance (2018)

J. Näkki: Properties of alloy 625 claddings made with laser and CMT methods (2018)

J. Kiilakoski: Damage tolerance of thermally sprayed oxide coatings - Measurement and development (2020)

T. Varis: Approaches for linking the high kinetic thermal spray process, residual stresses and coating performance by utilizing in-situ monitoring (2020)

D. Fantozzi: Properties of coatings for boiler applications (2020)

V. Matikainen: On the Formation, Properties and Performance of High Velocity Flame Sprayed Hardmetal Coatings (2020)

H. Niemelä-Anttonen: Multiphobic performance of Slippery Liquid Infused Porous Surfaces (2020)

Surface Coatings are 'mission critical' in a wide range of key industry sectors

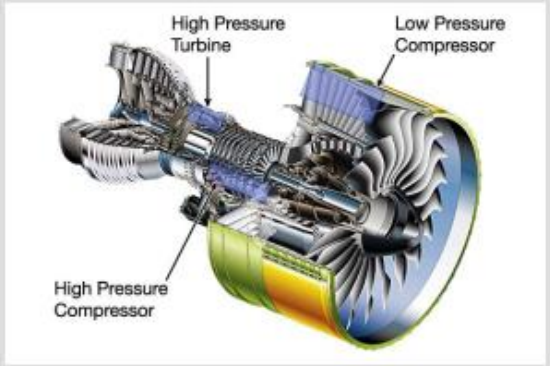
SULZER

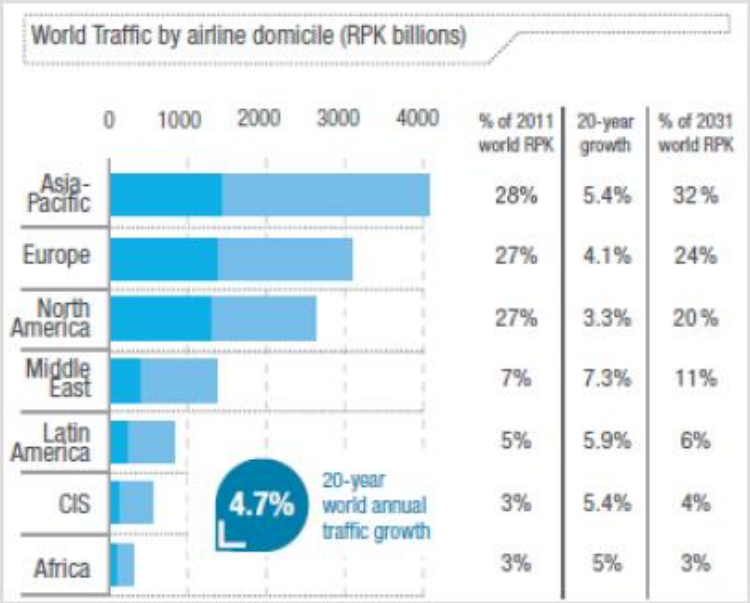
Sulzer Metco

Coatings in the aerospace industry reduce fuel consumption globally by 1 million liters per hour

SULZER

Sulzer Metco

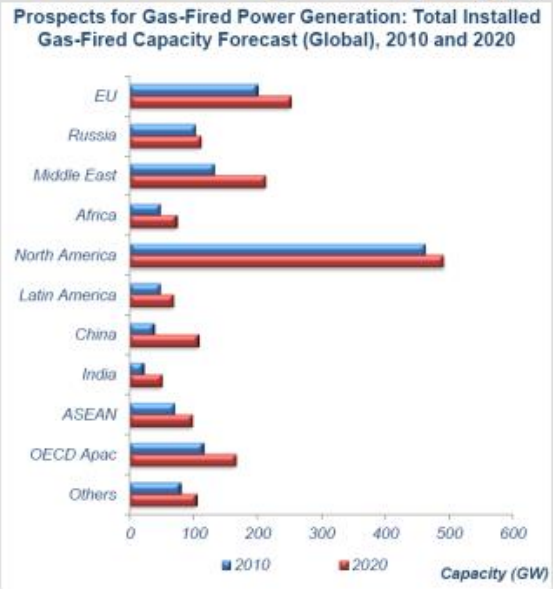




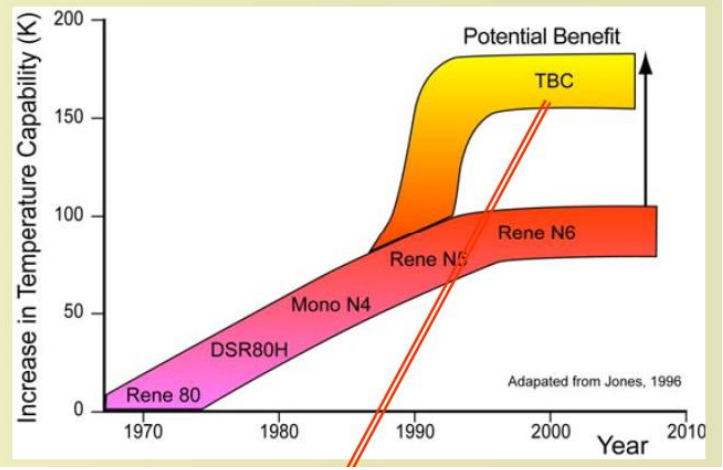
- Reasons for coatings
  - Less wear, corrosion and oxidation
  - Increased operating temperature
  - Gap clearance sealing (abradables)
  - Hardchrome replacement for landing gear
- Value of the coating
  - Higher fuel efficiency
  - Less noise
  - Less weight
  - Increased safety
  - Extended time between overhauls

Coatings in the IGT (Industrial Gas Turbine) industry increase turbine efficiency by >5%

SULZER
Sulzer Metco



- Reasons for coatings
  - Gap clearance reduction using abradable seals
  - Temperature resistance
  - Reduced wear and friction
  - Corrosion resistance against the impact of poor quality fuels
- Value of the coating
  - Increased turbine efficiency
  - Increase time between overhaul/ maintenance (TCO)



1% increase in engine efficiency results in
– > $2 M in fuel cost savings/per year
– ~ 25,000 tons CO2 reduction/year
Per combined cycle ~ 300 MW power plant

Coatings in the automotive industry reduce lubricant oil consumption by 50%

SULZER

Sulzer Metco

- Reasons for coatings
  - Improved wear protection
  - Corrosion resistance
  - Enhanced surface hardness
  - Chrome-6 replacement
  - Weight reduction
  - Target fuel consumption per km reduce by 50% by 2030 – also in China
- Value of the coating
  - Reduced oil and fuel consumption
  - Reduced component cost
  - Reduced CO_2 emissions
  - Extended durability

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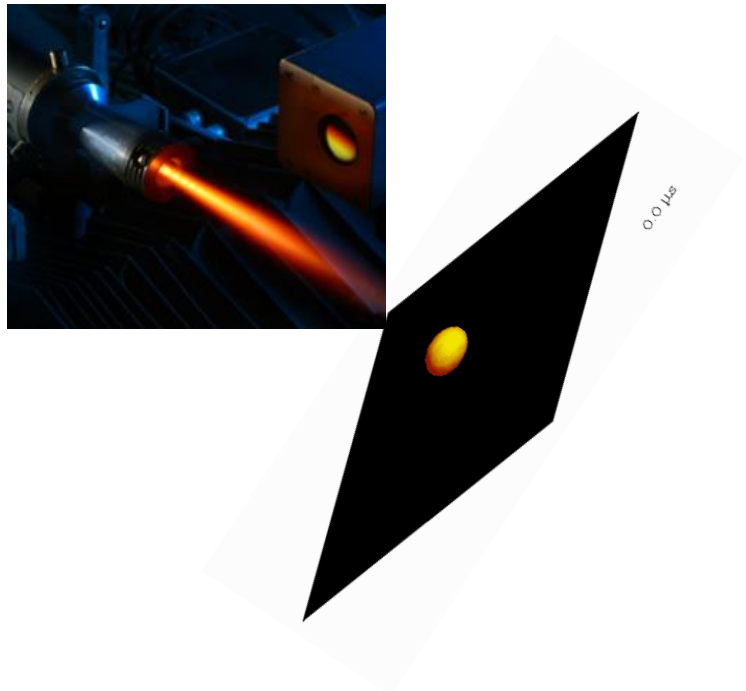
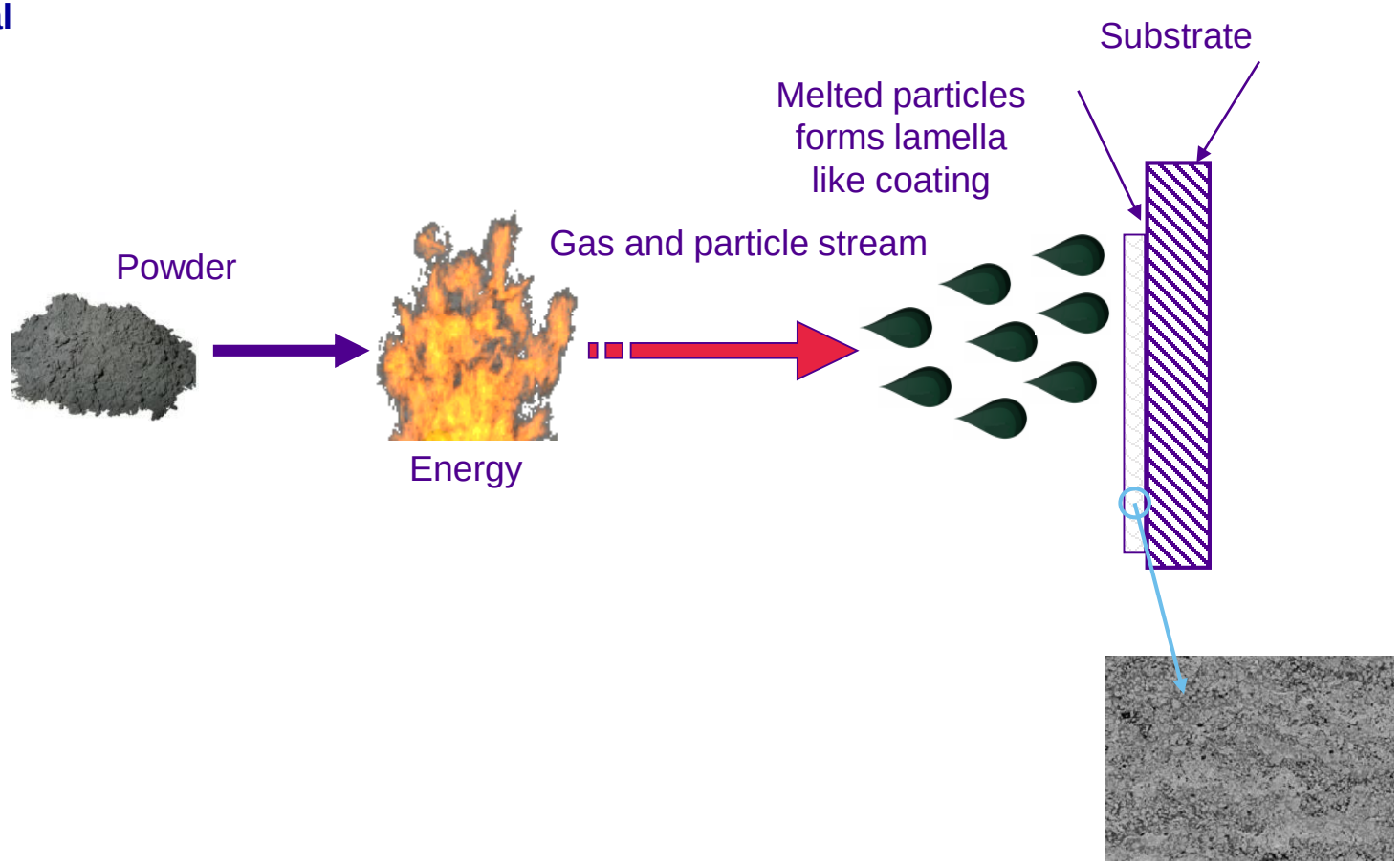
Thermal spraying

- **An effective method to produce functional coatings from special, tailored materials.**
- **Does not effect on the properties of base material**





Motivation / target / tools

- In situ monitoring of residual stresses of **High kinetic HVAF** and high pressure-HVOF
- Understanding the effect of **residual stresses** on the mechanical response and fatigue behaviour of the coating
- Understand process – performance relations by utilizing **in situ monitoring techniques**

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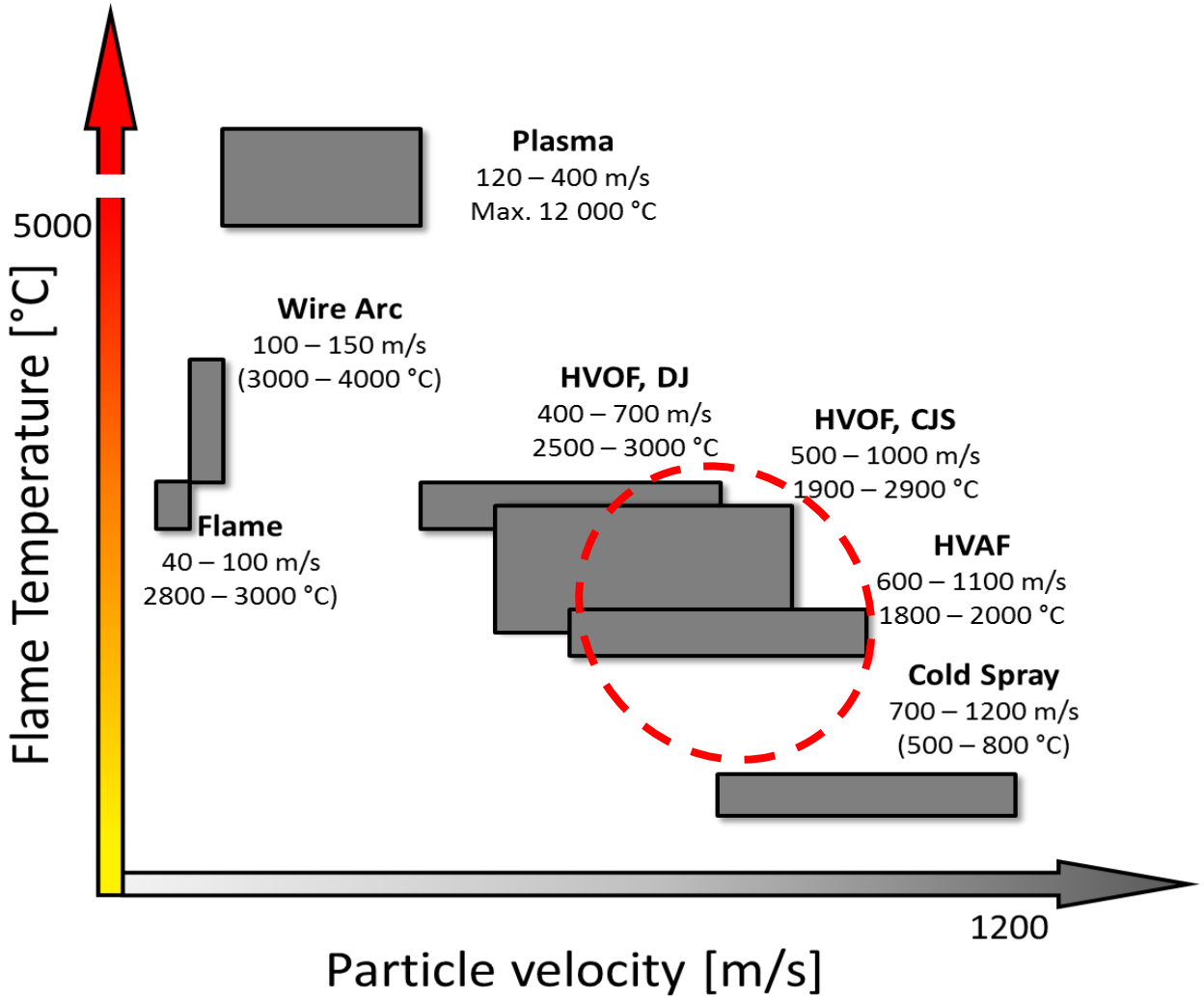

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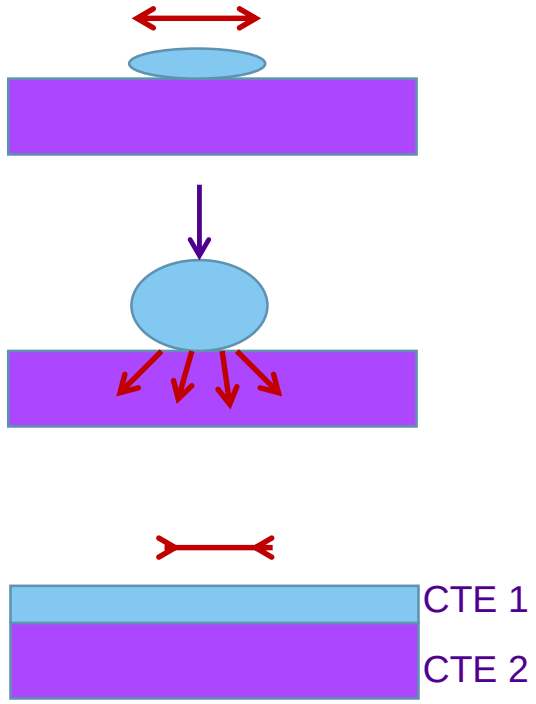

- Quenching Stress from the individual particle cooling – tensile
- Peening Stress from the particle impact – compressive
- CTE Mismatch Stress during coating and substrate cool doown – tensile/compressive

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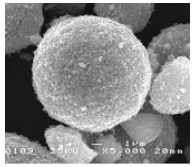
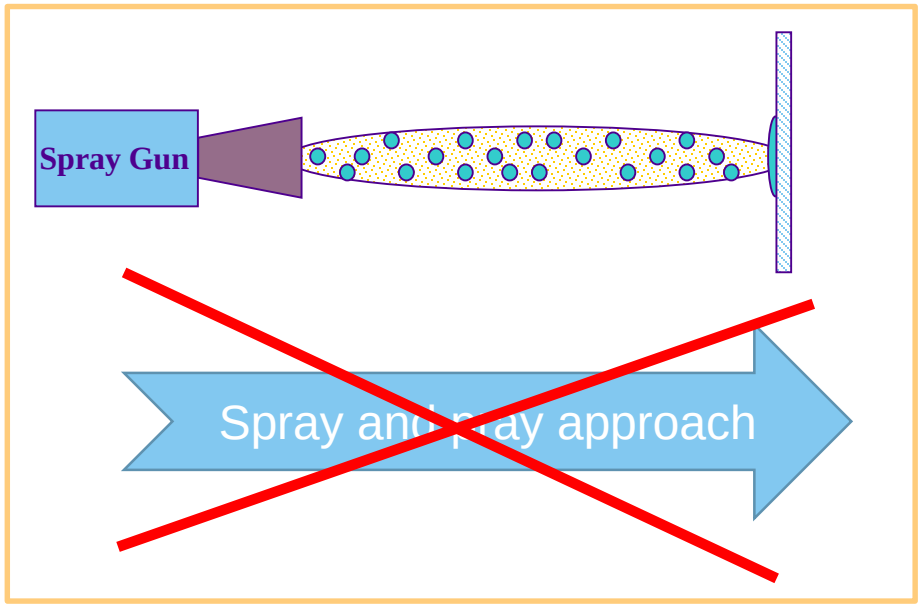
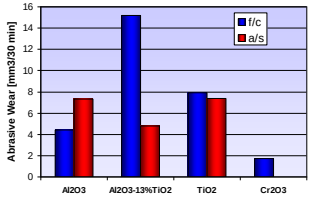
From material to performance - in situ monitoring



Material

Selected powder

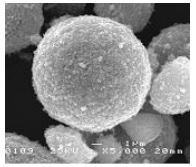


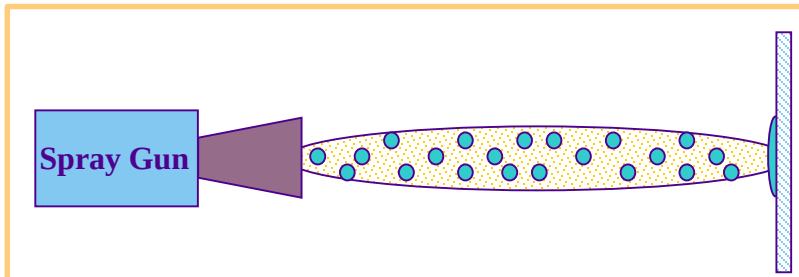


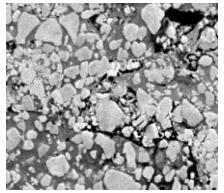
Properties and Performance

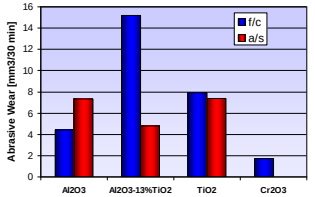
Specifications from the application

From material to performance - in situ monitoring









Material

Gas dynamics

Gas – particle interaction

Deposition / Impact cond.

Micro-structure

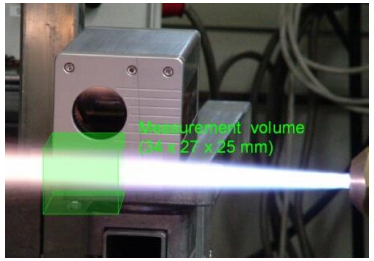
Properties and Performance

Manipulate gas flows

Particle conditions

Curvature monitoring

Spray Watch: Particle temperature, velocity



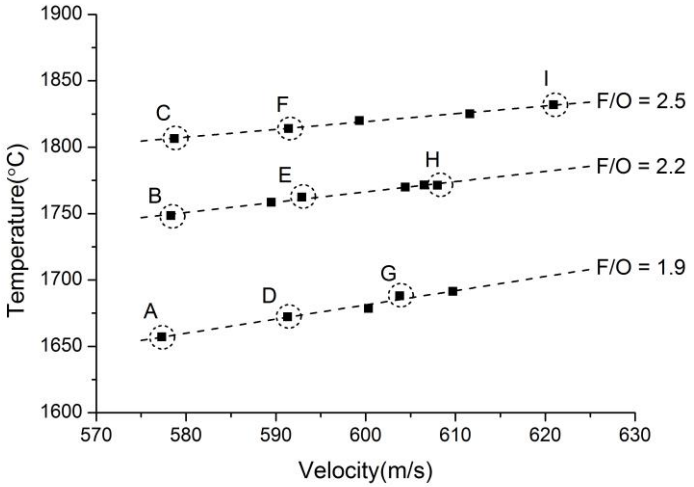
Process Mapping – linking the process to performance

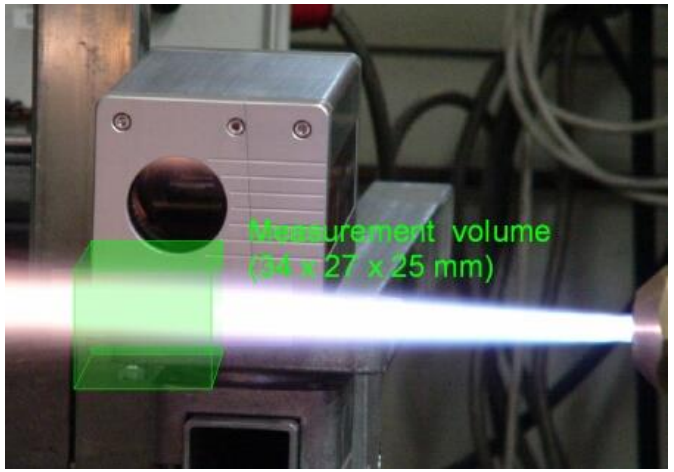
Particle conditions

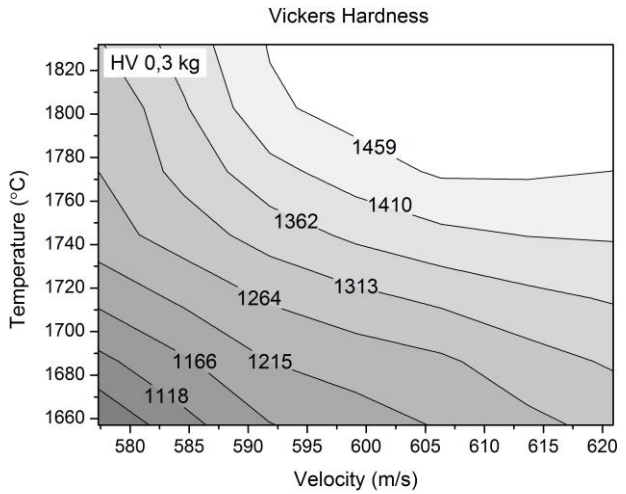
Controlled approach

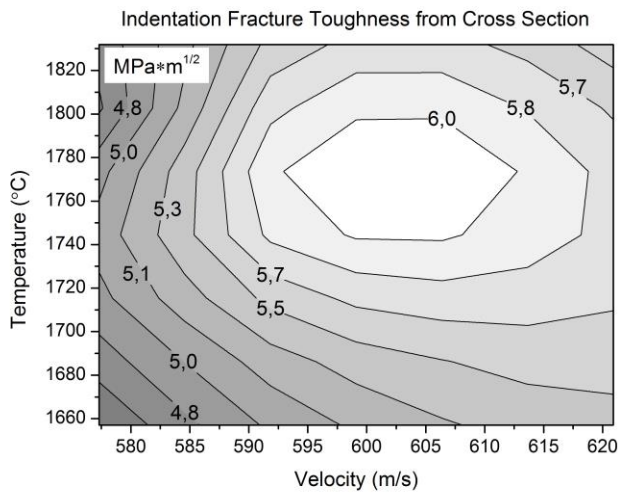
Properties and Performance

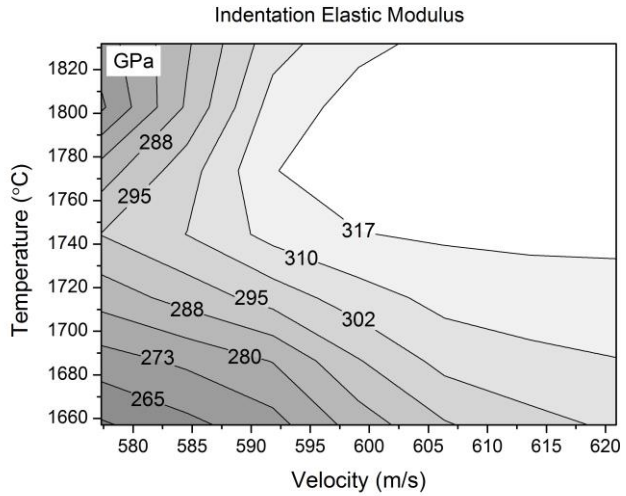
HVOF
WC-CoCr

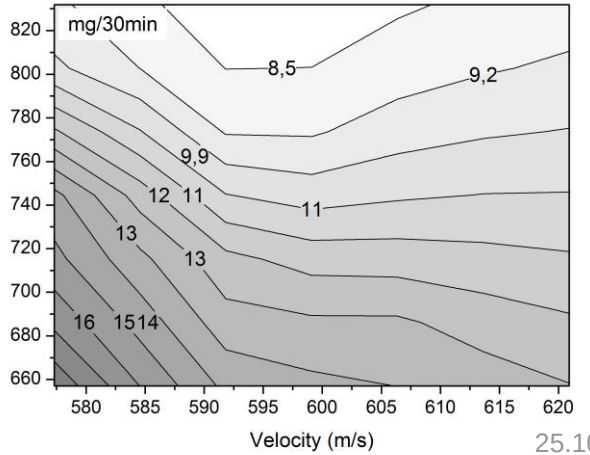




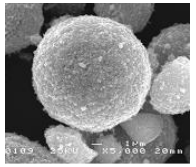


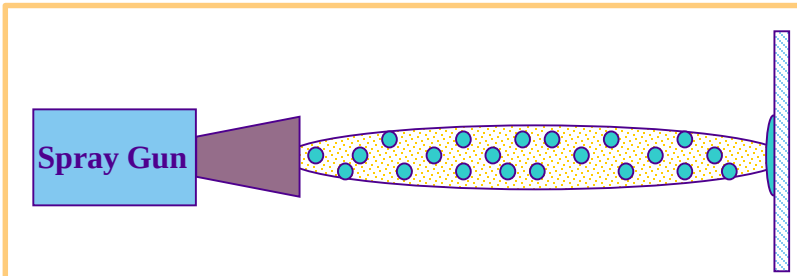


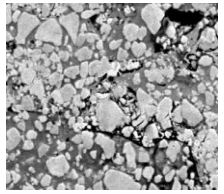


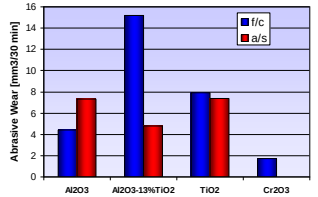


From material to performance - in situ monitoring









Material

Gas dynamics

Gas – particle interaction

Deposition / Impact cond.

Micro-structure

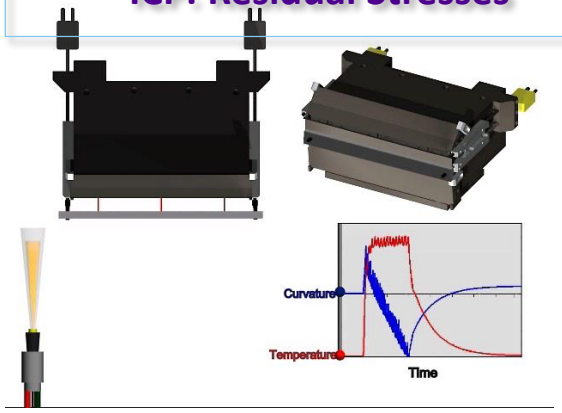
Properties and Performance

Manipulate gas flows

Particle conditions

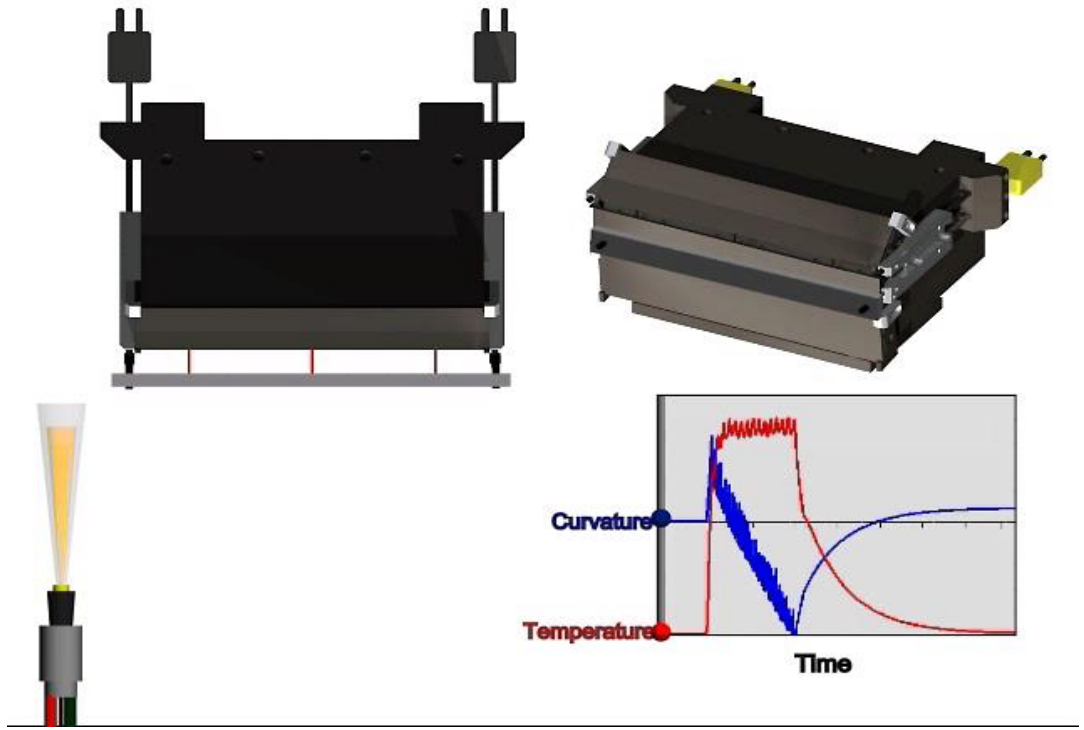
Curvature monitoring

ICP: Residual Stresses



Coating thermal history and residual stresses by ICP

- Works with three lasers for curvature measurement
- Thermocouples attached to the back side of Substrate



Provides:

- final residual stress level
- information from the different stress sources (CTE mismatch, peening/quenching)

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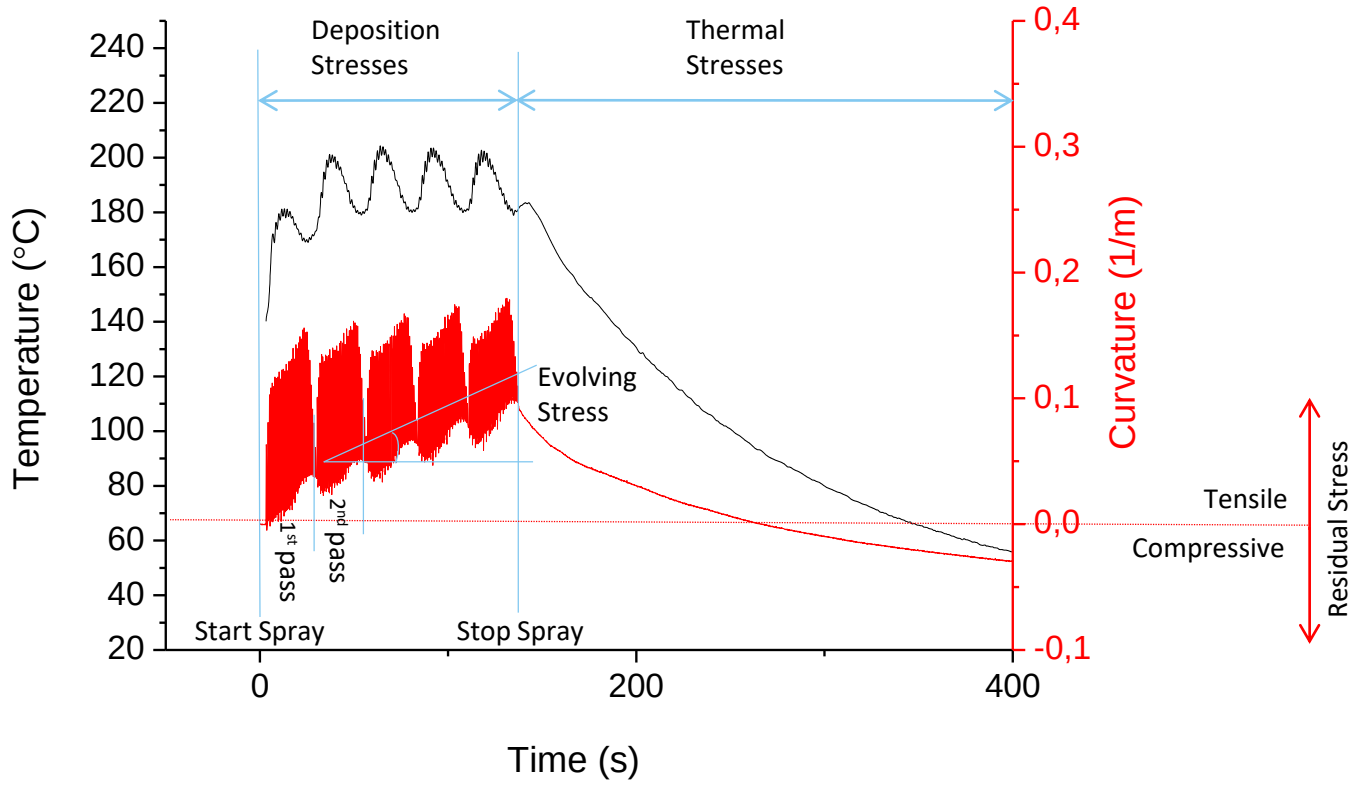
Coating thermal history and residual stresses



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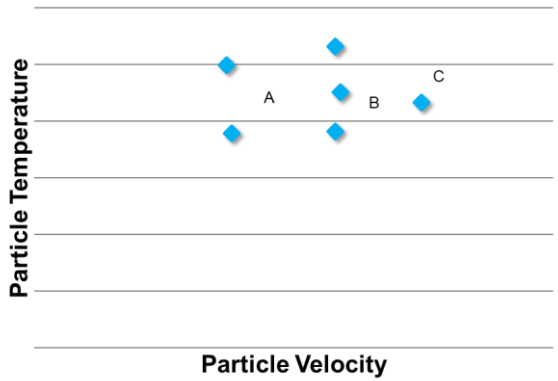
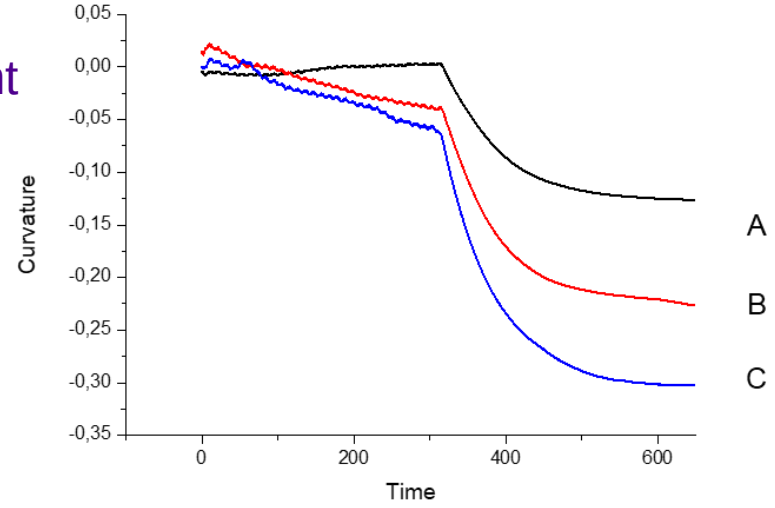
Optimisation of Residual Stresses for HVAF sprayed WC-CoCr

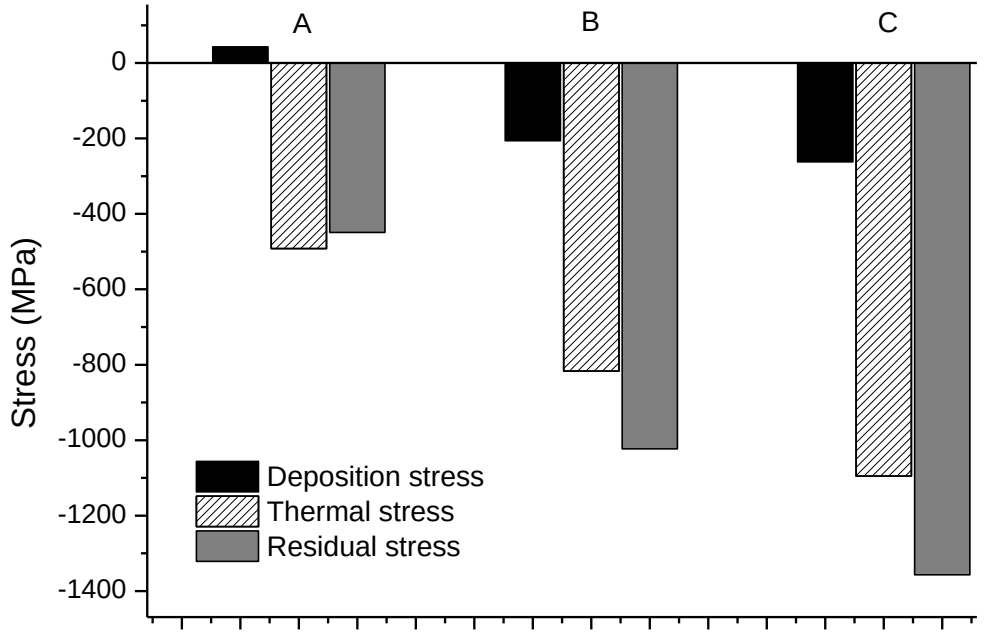
Particle diacnostics



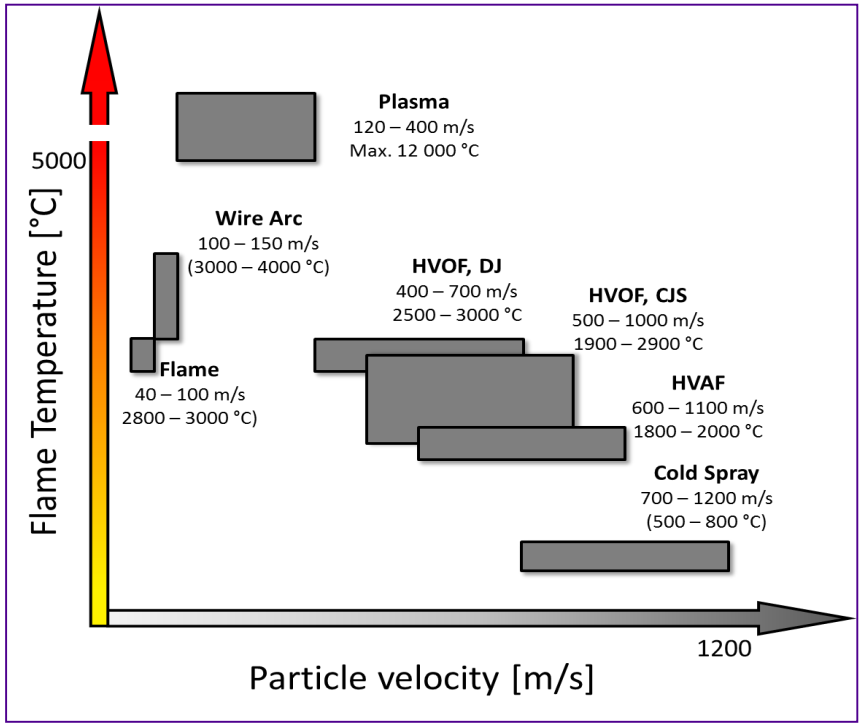
Curvature measurement



Residual Stresses



Comparison of Residual Stress for different processes

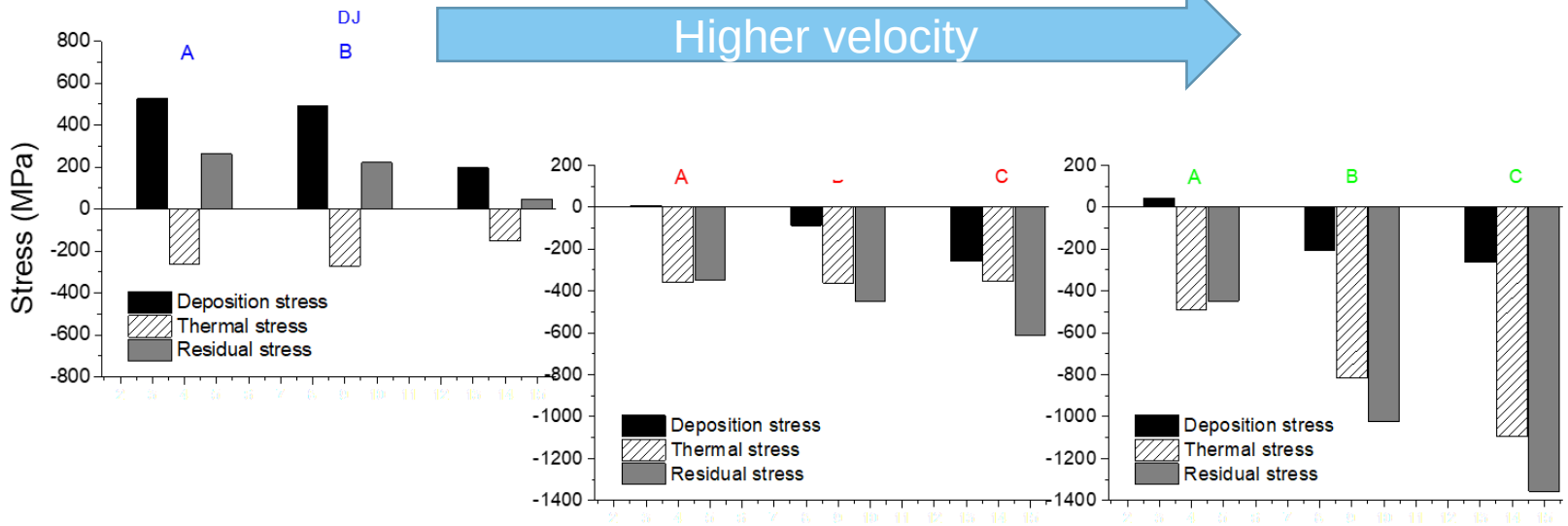


HVOF
DJ Hybrid

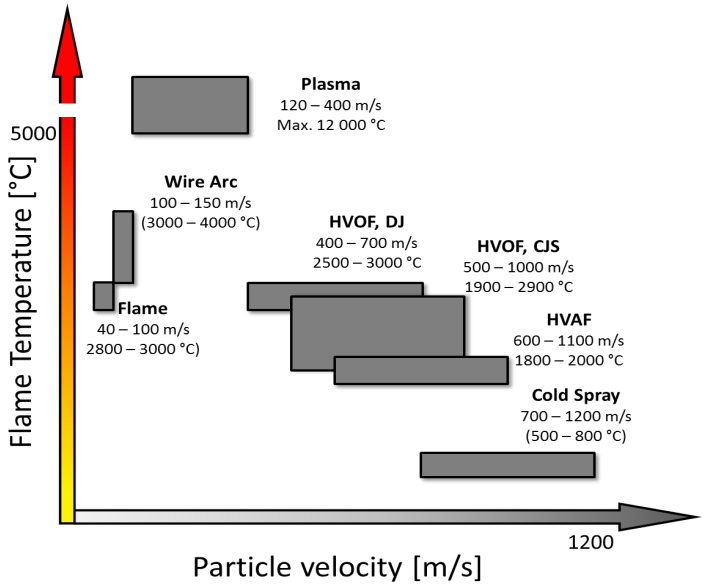
HVOF
Thermico CJS

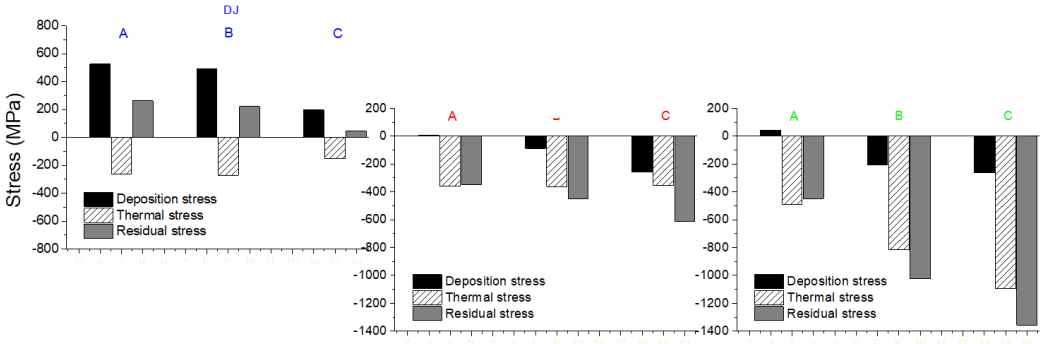
HVAF
Kermetico

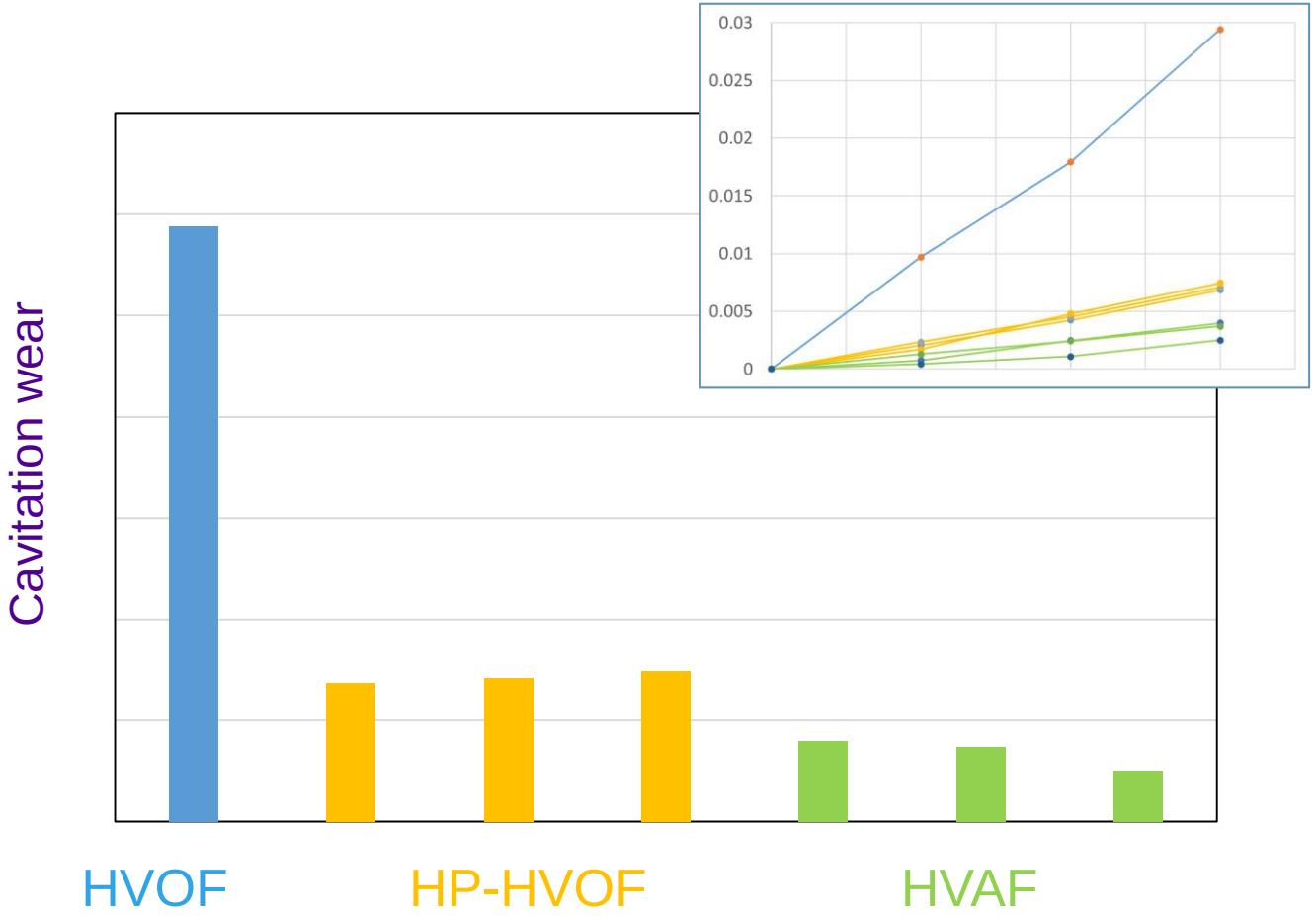
Higher velocity



Excellent cavitation resistance with HVAF and High Pressure HVOF due to compressive residual stresses

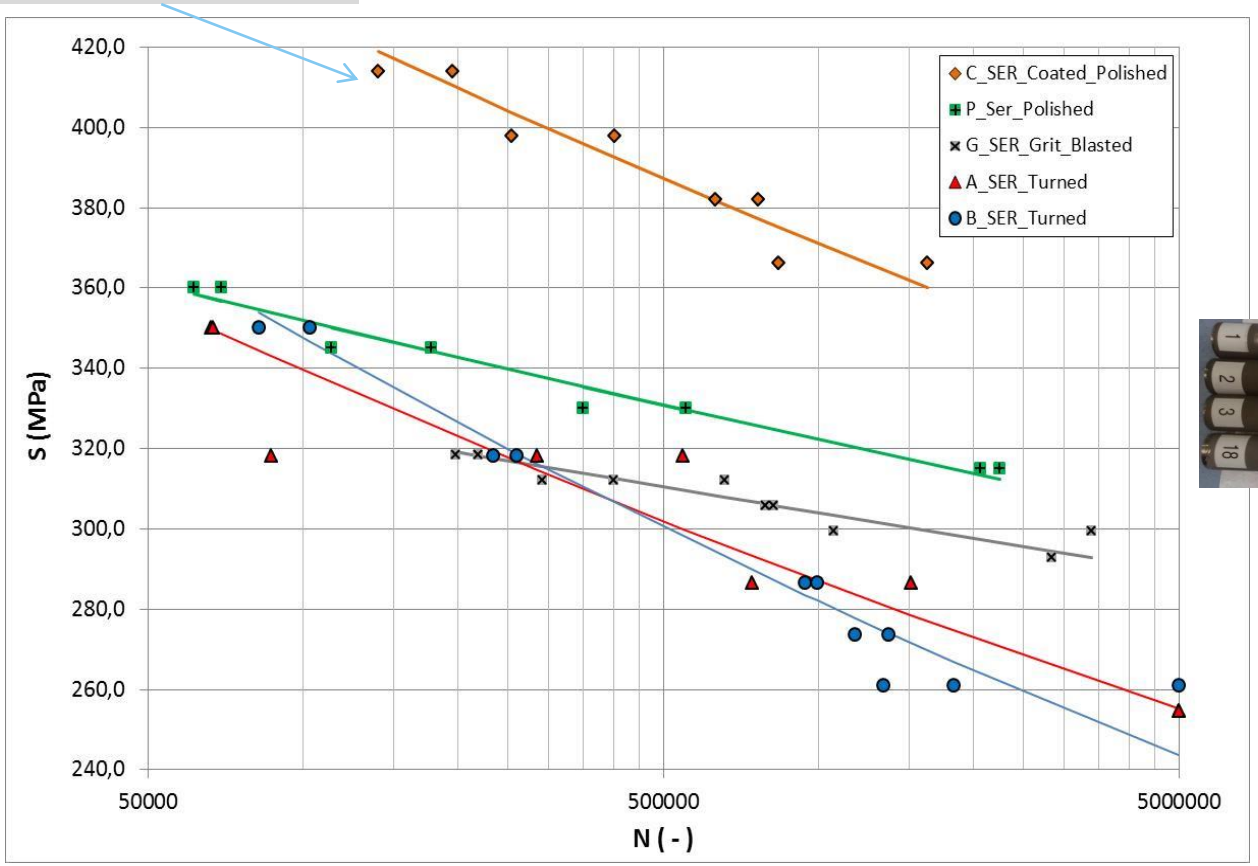






Improved fatigue performance

CJS Sprayed Cr_3C_2-NiCr
High compressive stress



And research
continues……

Thank You !