Warm Spray Technology for Ti, Ti6Al4V and WC-Co

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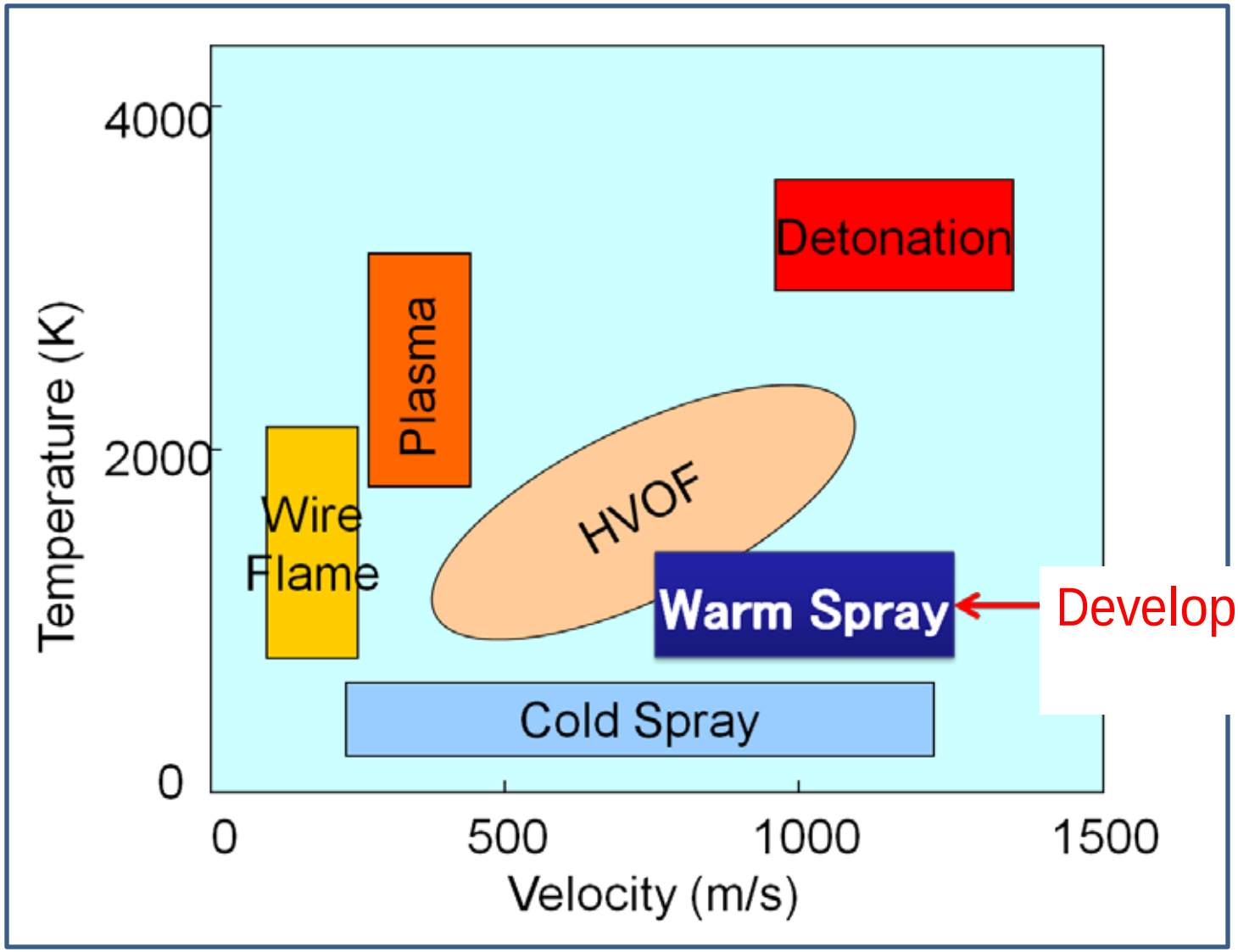
Outline

1. Warm Spray vs. Cold Spray

   Status of WS equipment development
2. Ti and Ti6-4
3. WC-Co
4. Summary

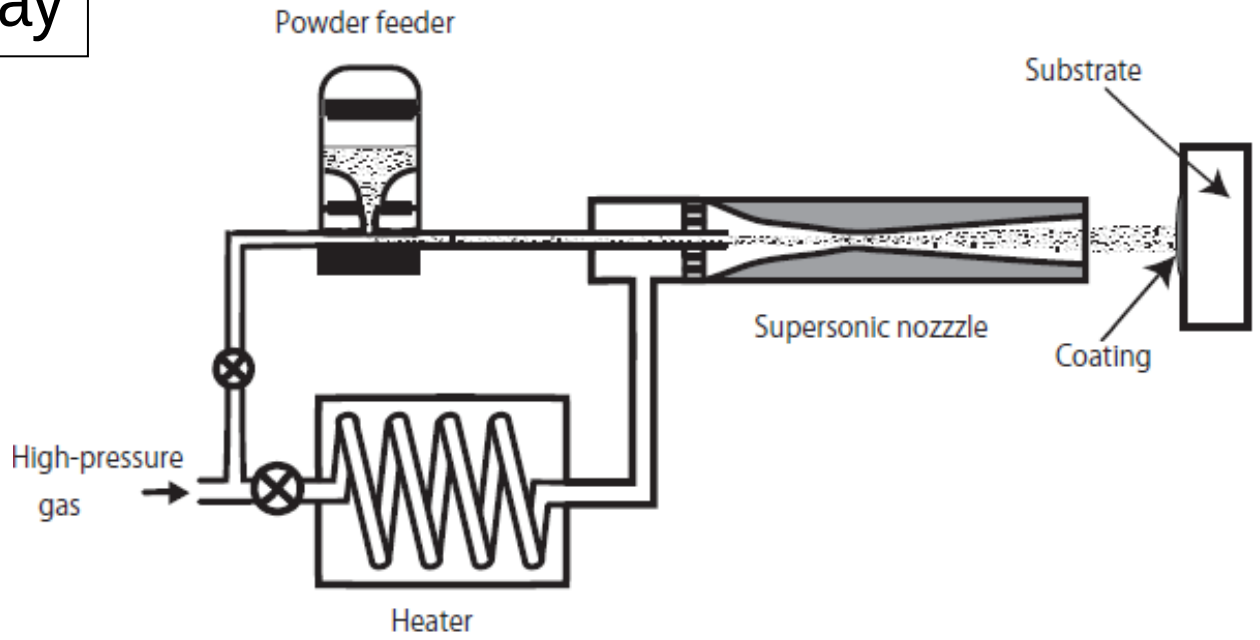
Spray processes: an overview



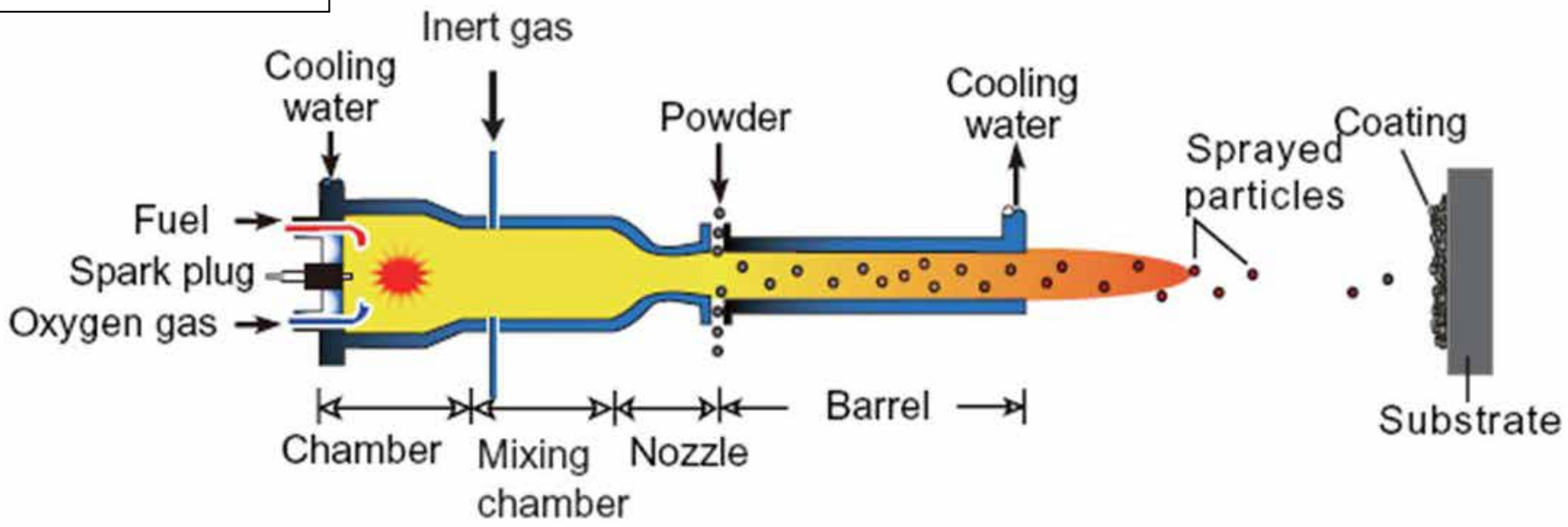
Developed by NIMS since 2006

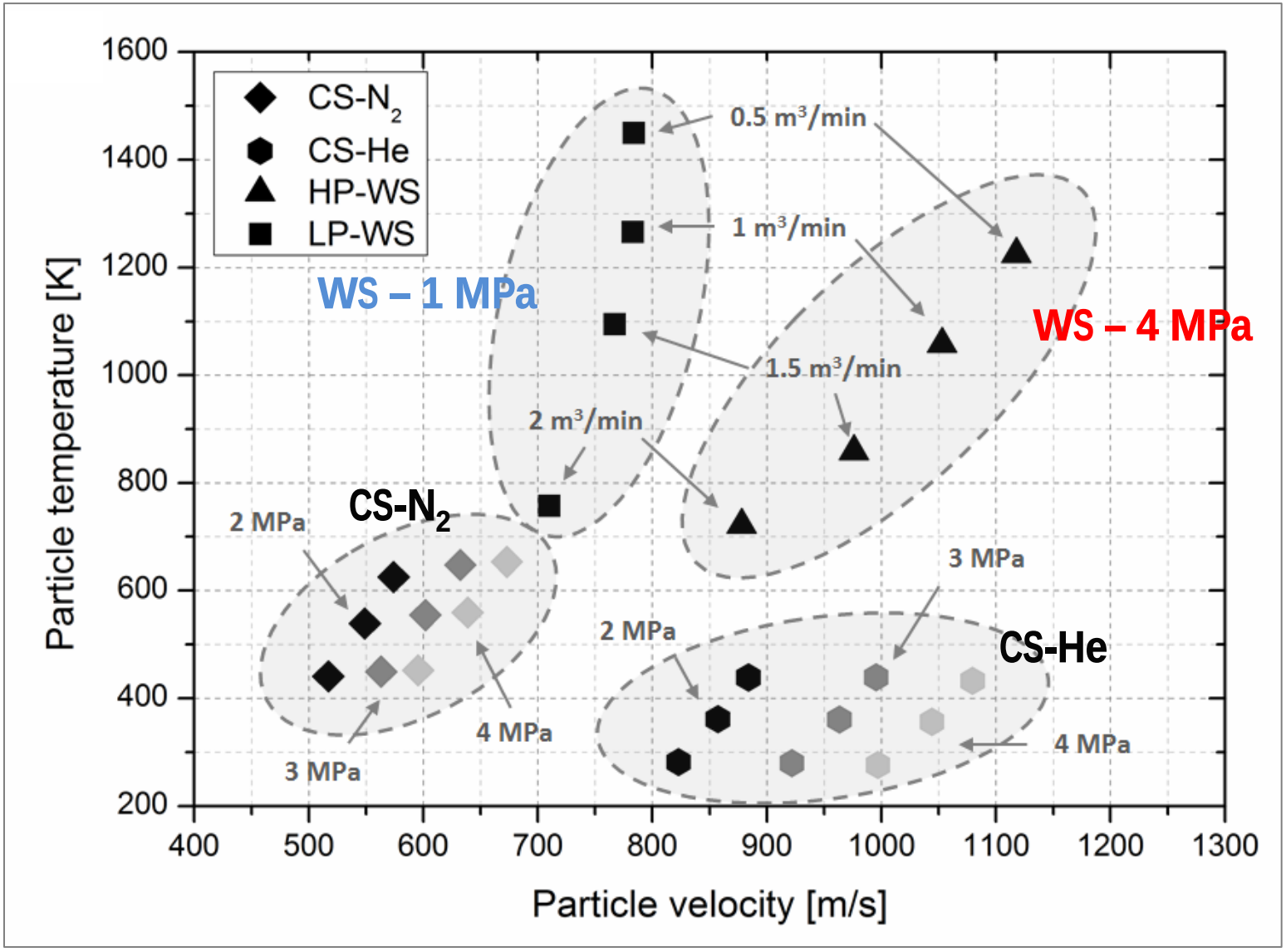
Classification by the temperature & velocity of sprayed particles

Cold spray



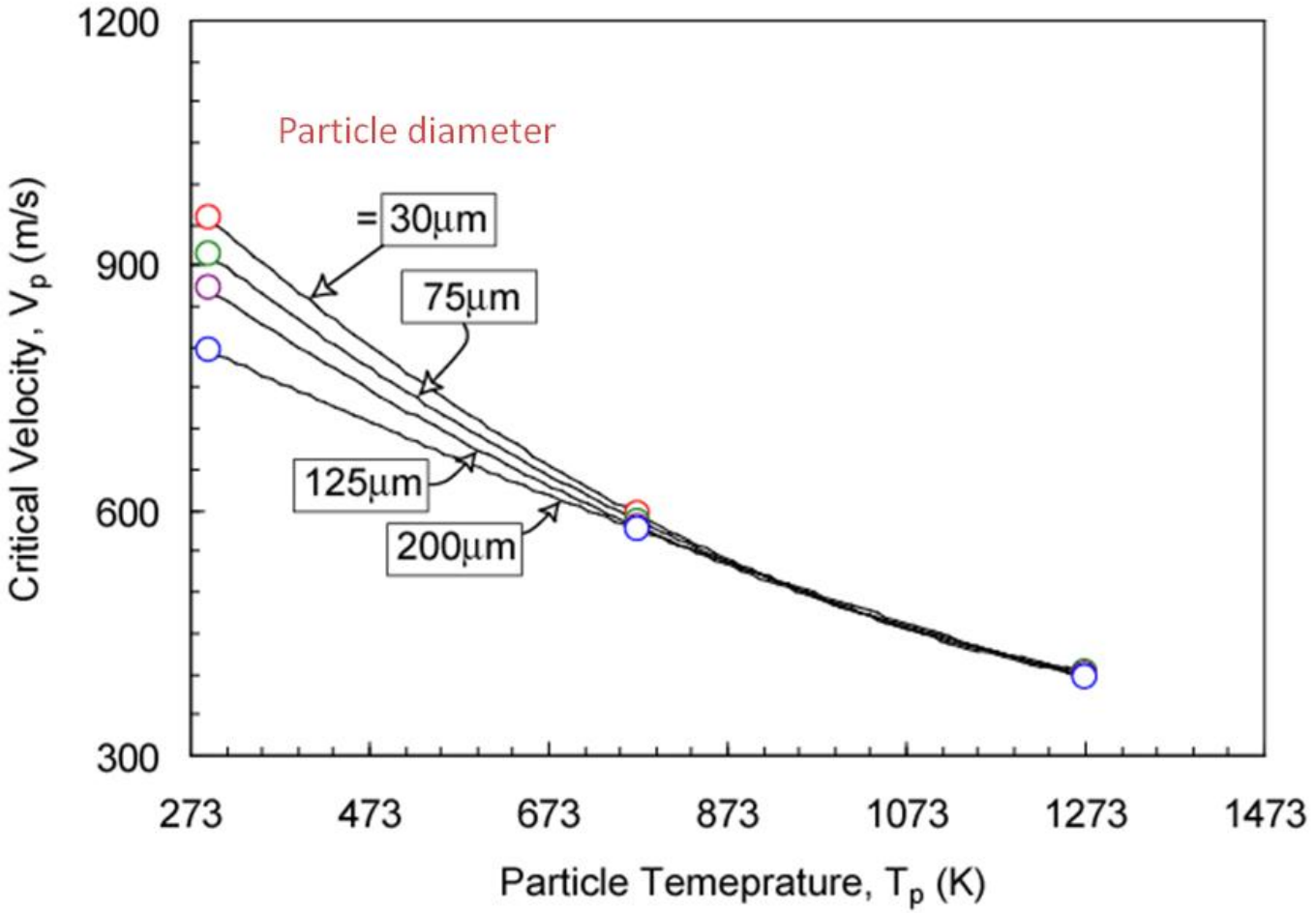
Warm spray





*at substrate position of 200 mm

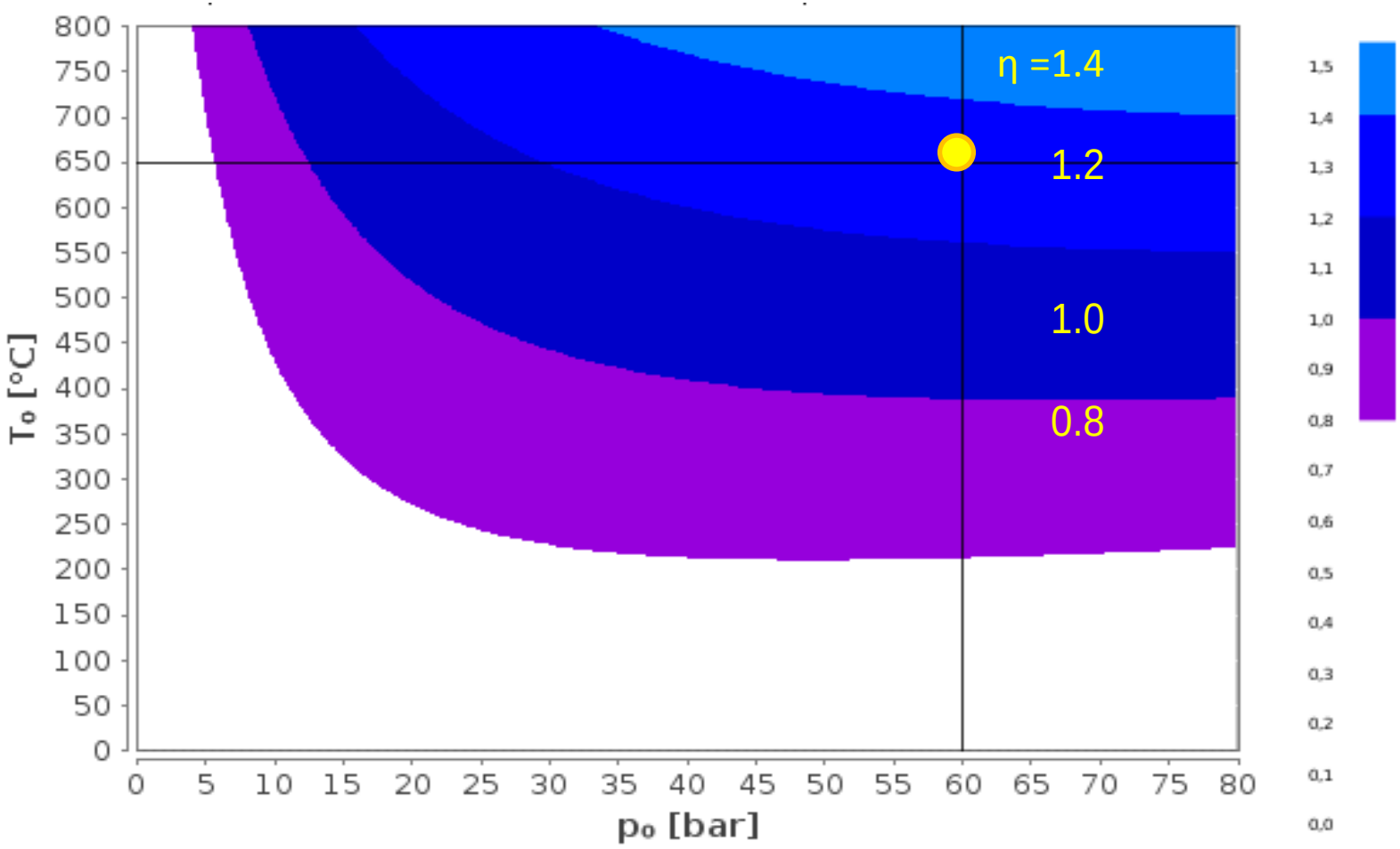
Critical velocity vs. particle temperature



M. Watanabe

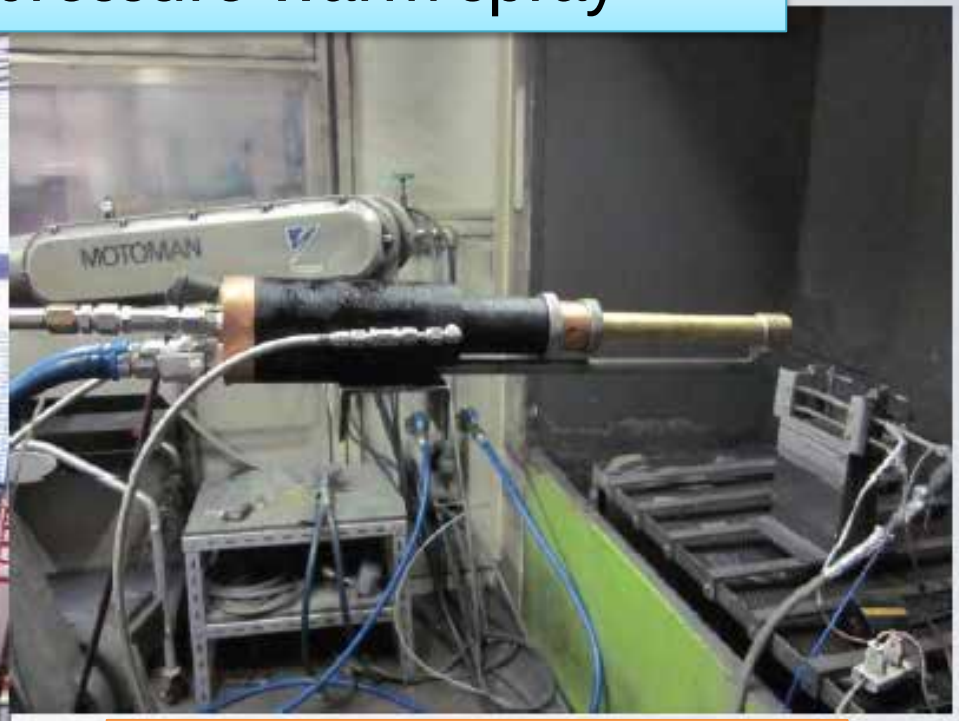
Work with HSU on high strength Cu-alloy

$\eta = v_p / v_c$



Data by S. Krebs, Helmut Schmidt University

New development: High-pressure warm spray



2011 METI
Support industry program

Plasma Giken
NIMS, Kagoshima U.

Gas: mass flow meters.

Ignition, gas flow rates control, powder feed
à Program operation

Case 1: Titanium & alloy

- Excellent corrosion resistance
- Superb specific strength
- Highly reactive with oxygen and nitrogen at high temperature
- Effects of nitrogen gas flow rates

List of spray conditions

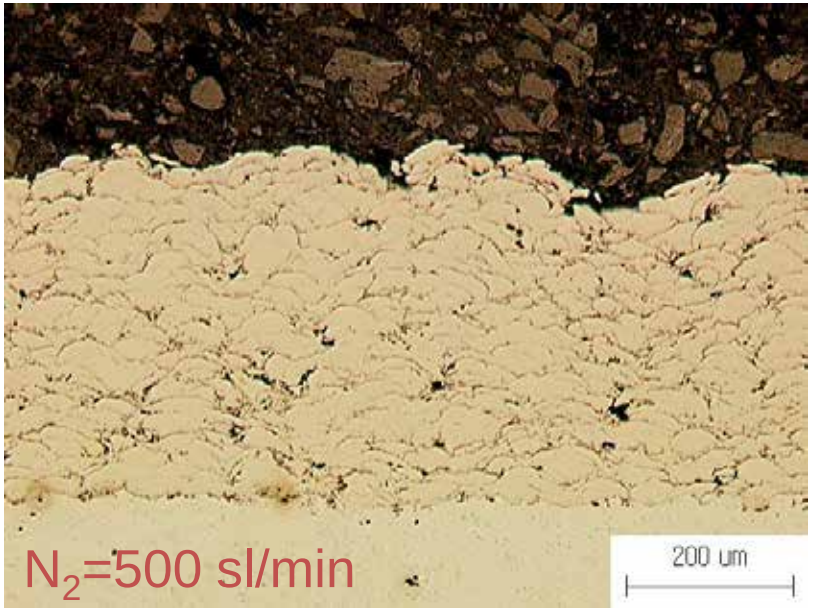
Powder: Sumitomo TILOP -45 μm

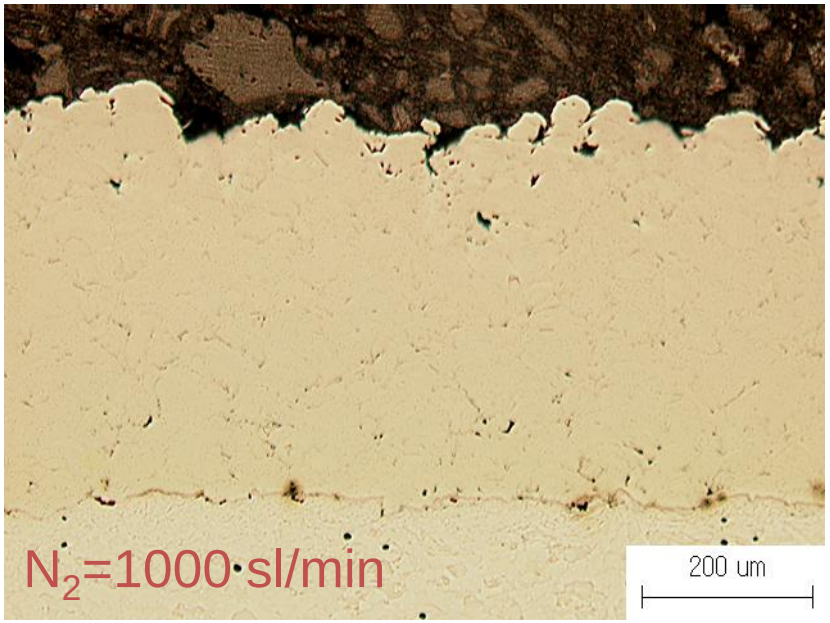
Condition ID	Kerosene (dm^3/min)	Oxygen (dm^3/min)	Nitrogen (dm^3/min)	Spray distance (mm)	Barrel length (mm)
WS1	0.39	805	500	180 - 300	200
WS2	0.35	714	1000		
WS3	0.3	623	1500		
WS4	0.27	545	2000		

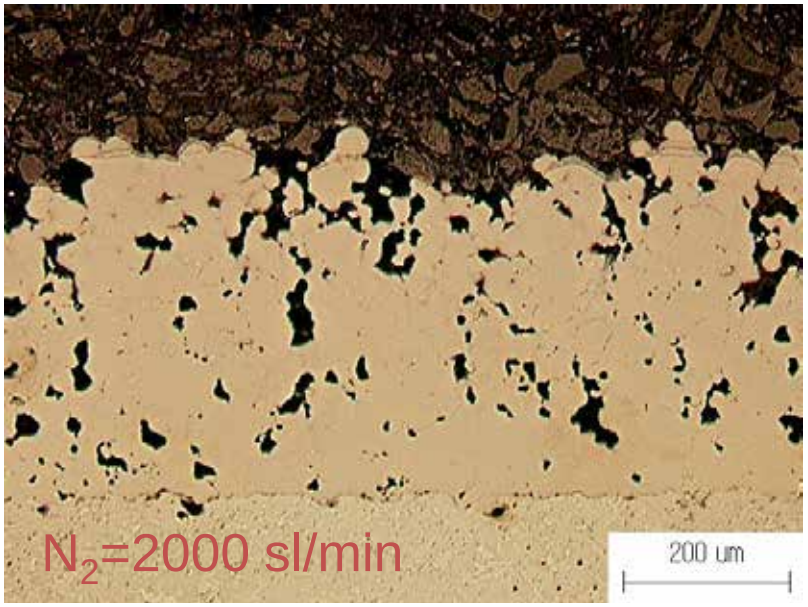
Cross sections

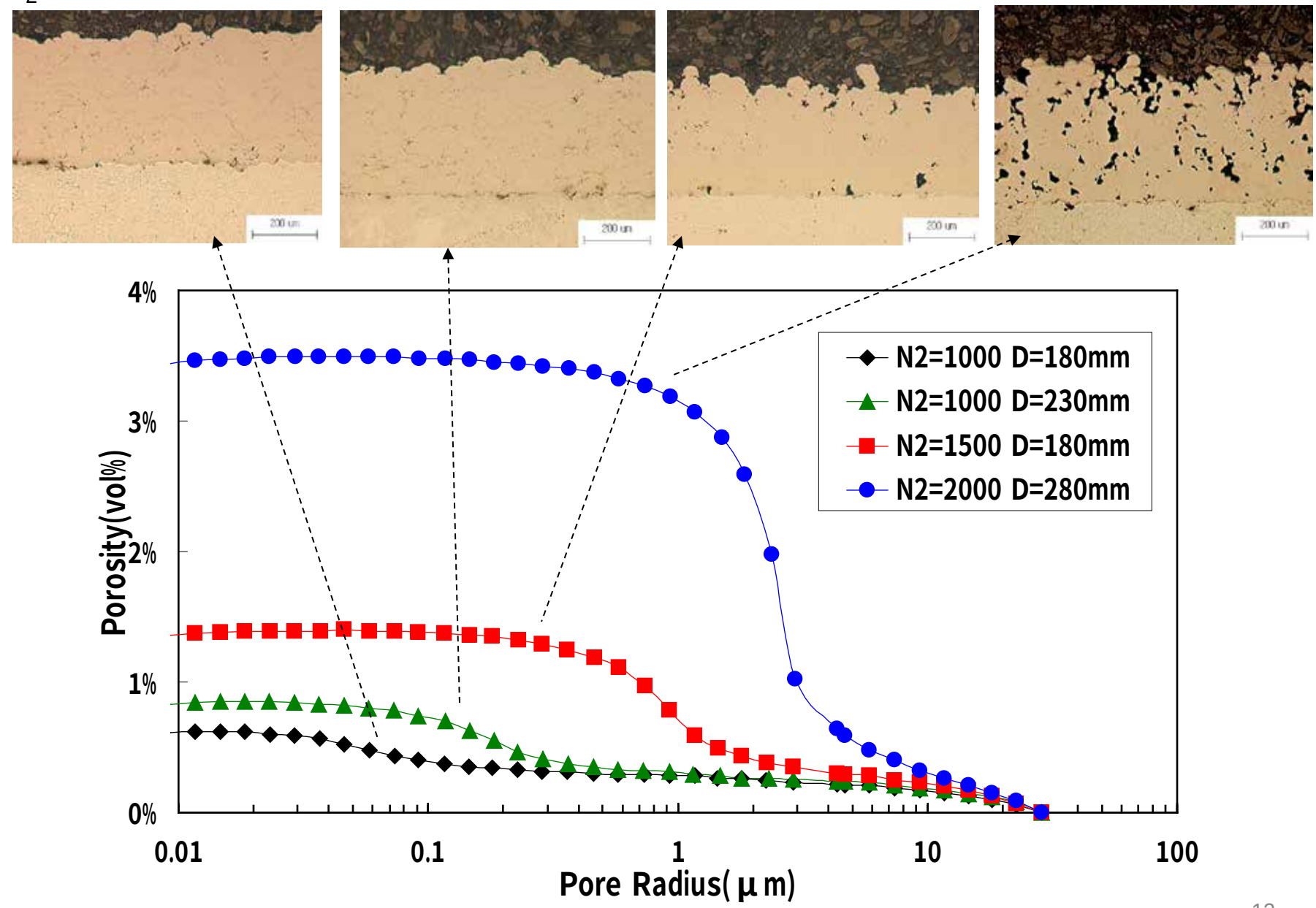
- Z=280mm

Coating structure by solid particles

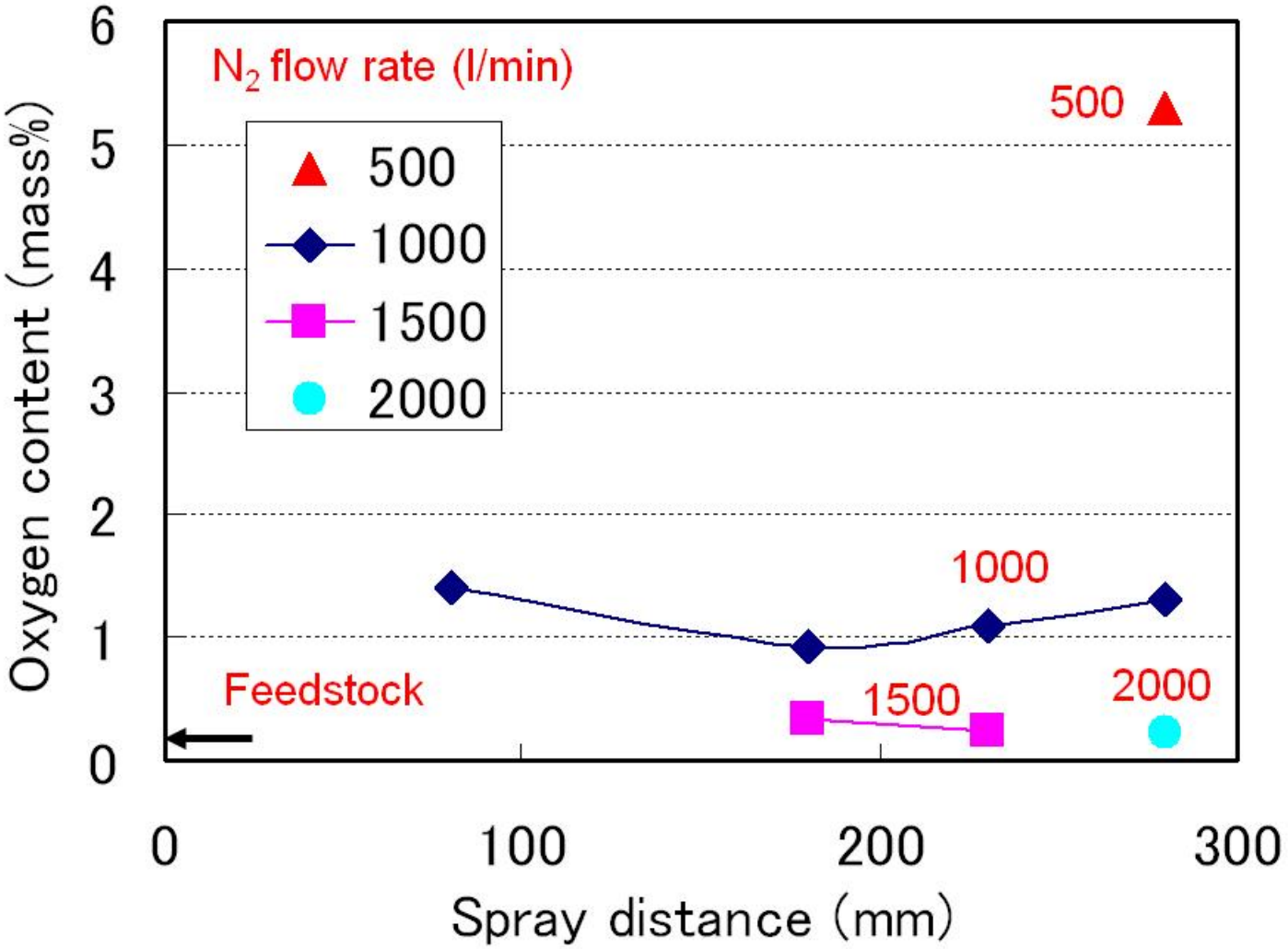




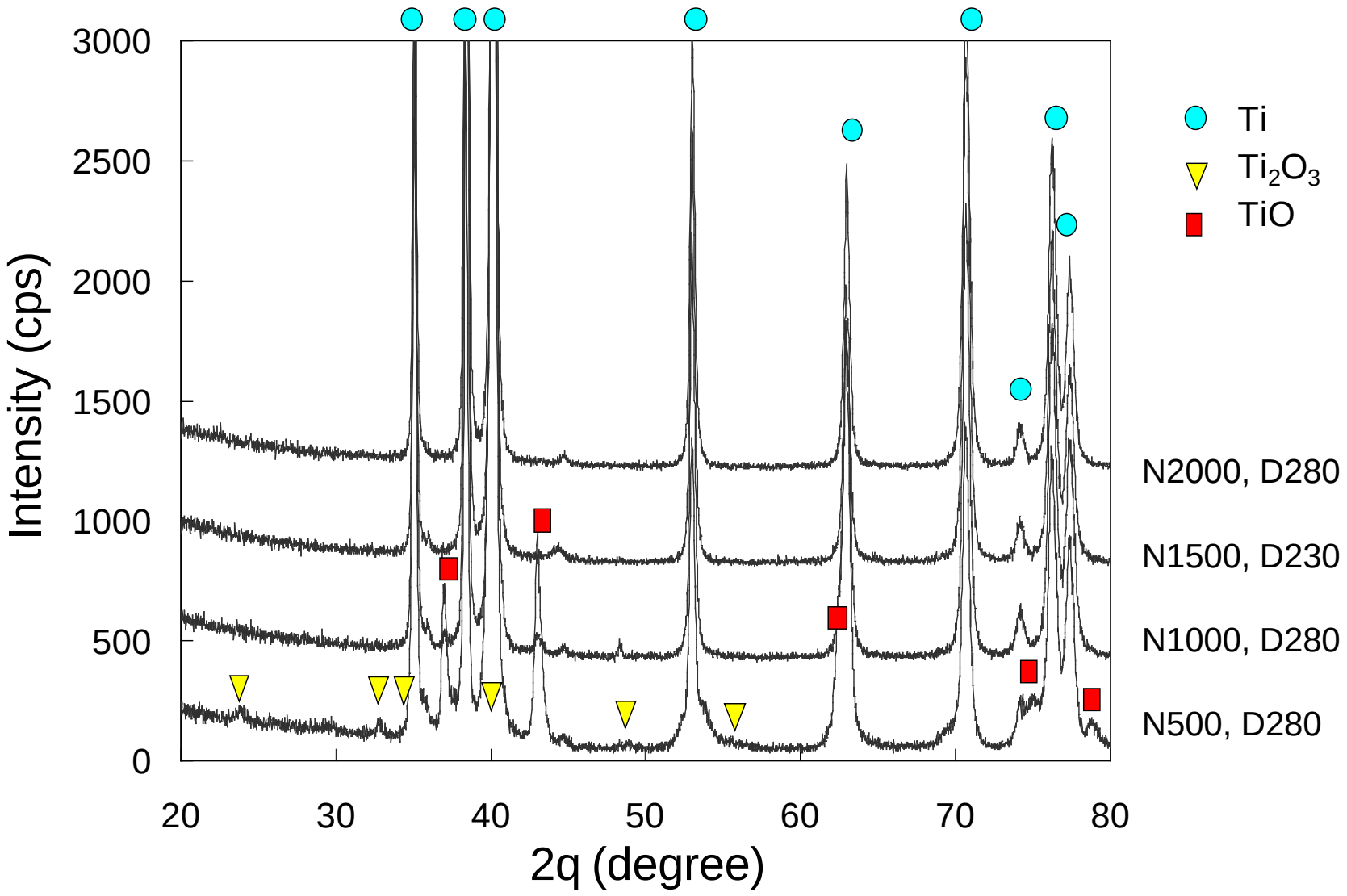



N2/S.D.: 1000/180
1000/230
1500/180
2000/230
4%
3%
2%
1%
0%
Porosity(vol%)
0.01
0.1
1
10
100
Pore Radius(μm)
N2=1000 D=180mm
N2=1000 D=230mm
N2=1500 D=180mm
N2=2000 D=280mm

Oxygen Content of Coatings

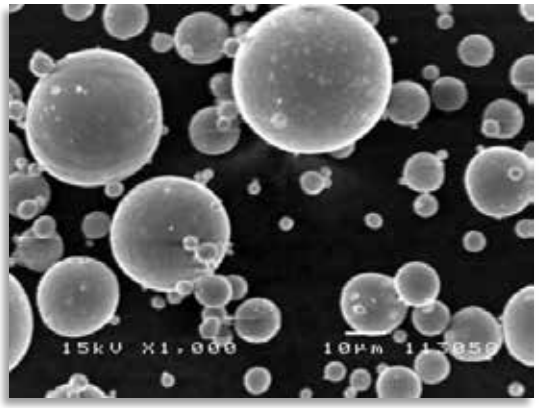


XRD spectra of sprayed coatings

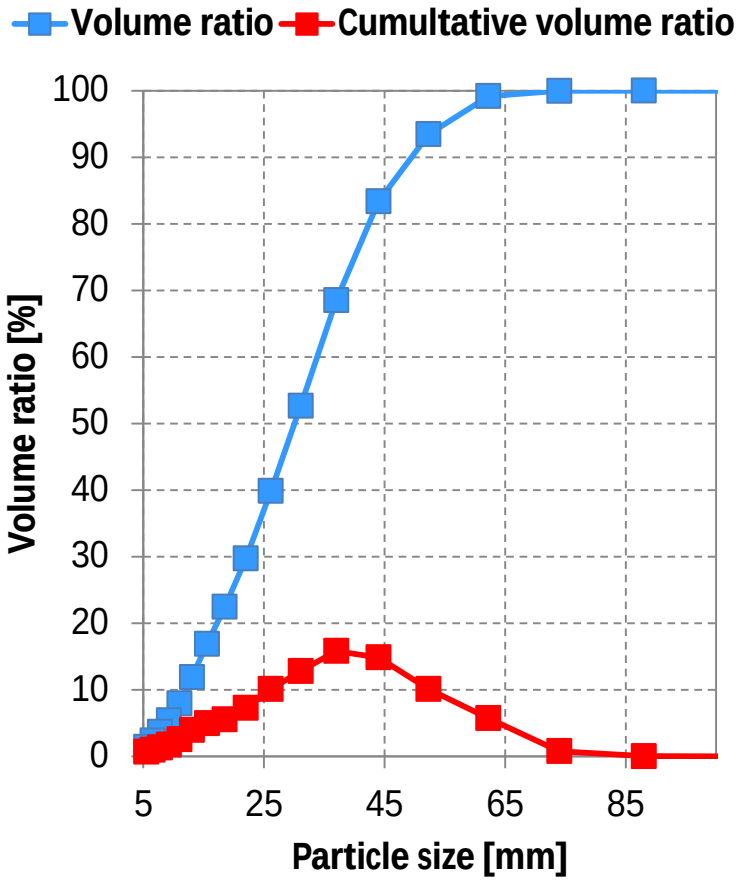


Ti6Al4V: FEDSTOCK POWDER

Base material: SUS 304
Powder: Ti-6Al-4V ELI (RAYMAR Industries Ltd.)



SEM image of feedstock powder



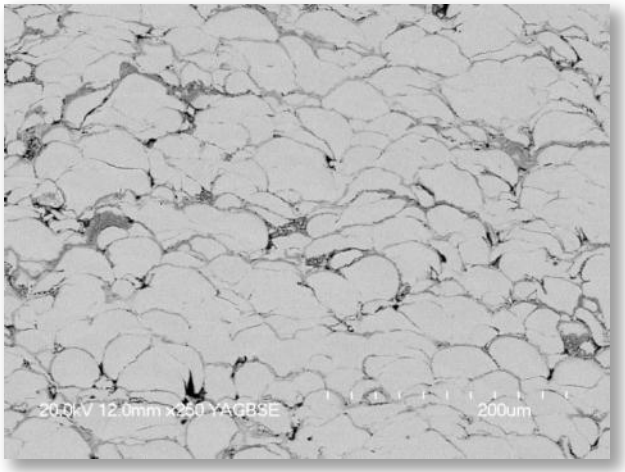
Average powder particle size: ~35 mm

Element	N max	C max	H_2 max	Fe max	O_2 max	Al	V	Residual (total)	Ti
wt [%]	0,01	0,02	0,004	0,14	0,155	6	4	0,1	balance

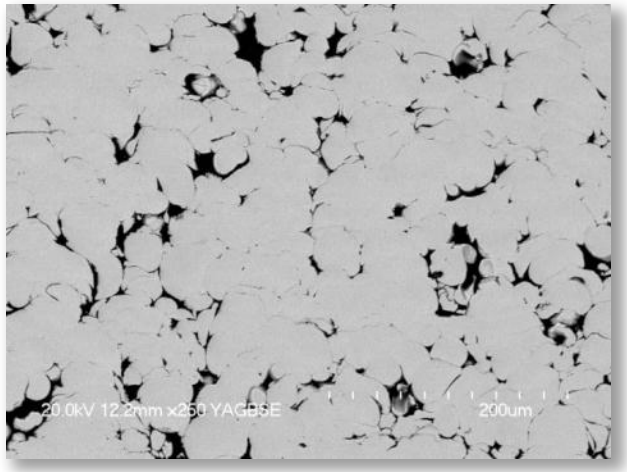
Microstructure of Ti6Al4V formed by HIGH and LOW Pressure Warm Spraying

1 MPa

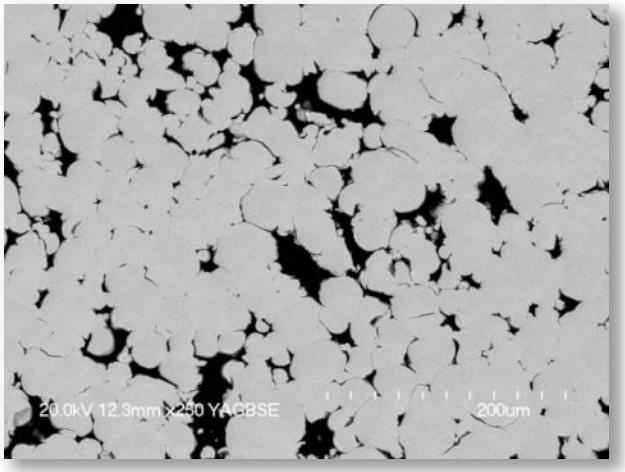
500dm3/min



1000dm3/min

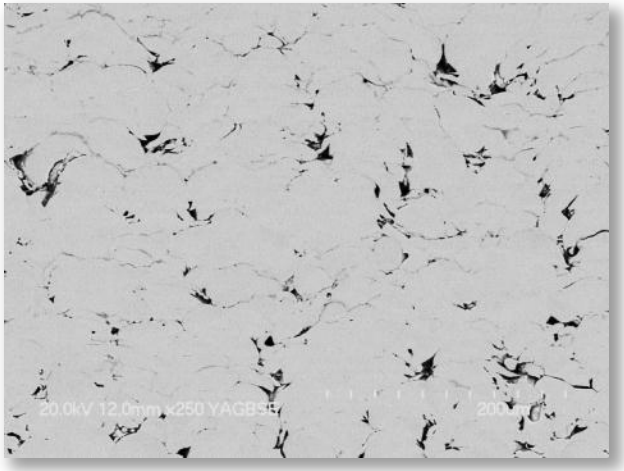


1500dm3/min

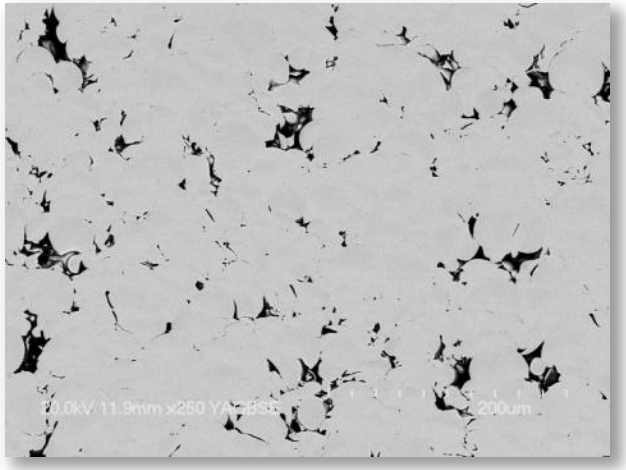


4 MPa

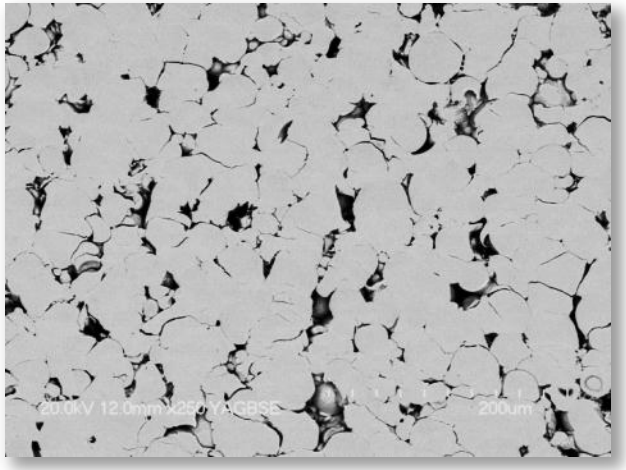
500dm3/min



1000dm3/min

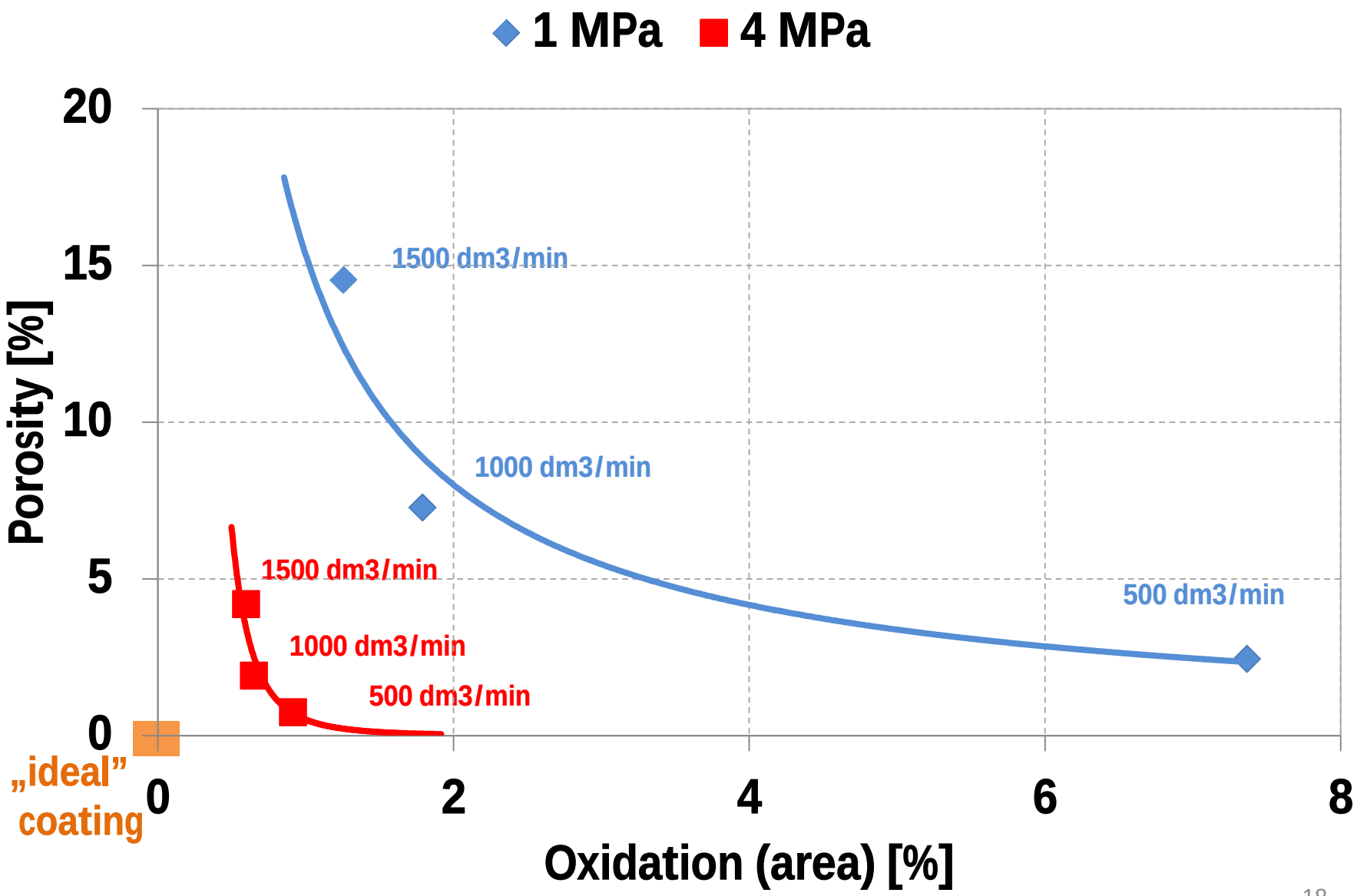


1500dm3/min



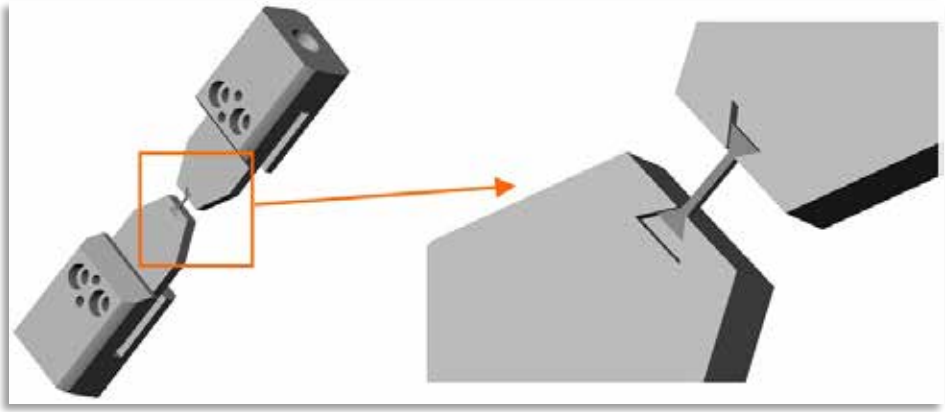
Porosity and Oxidation dependence

Ti6Al4V formed by HIGH and LOW Pressure Warm Spraying



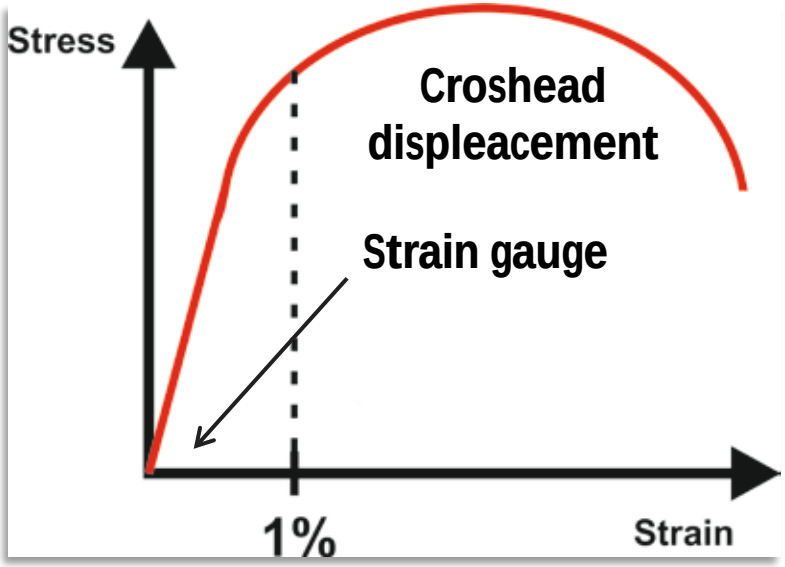
TENSILE TEST OF MINI SPECIMENS

Size and shape of mini specimen: 8mm L x 2mm W



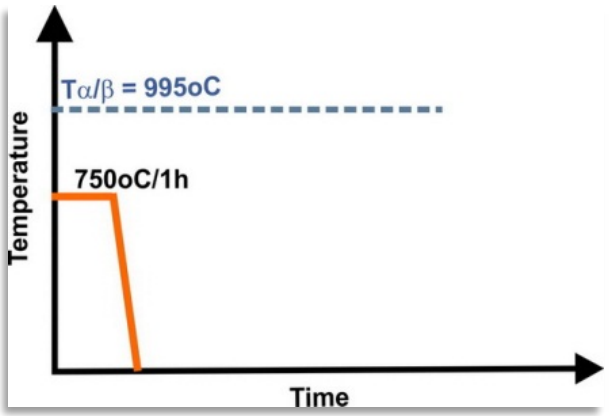
Grips for tensile test of mini specimens

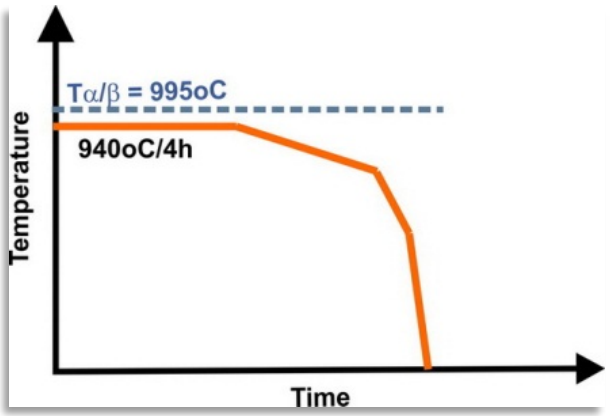
Way of specimens' elongation measurements

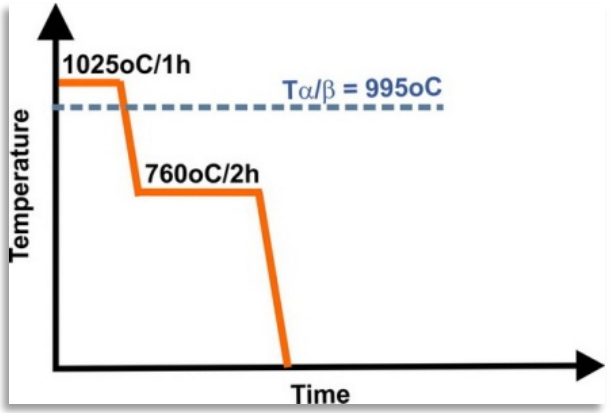


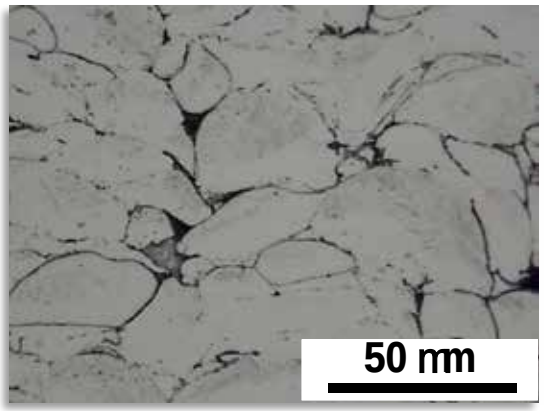
HEAT TREATMENT (sintering, composition and distribution of a and b)

Ti6Al4V– mill, recrystallization and beta anealing (vacuum);

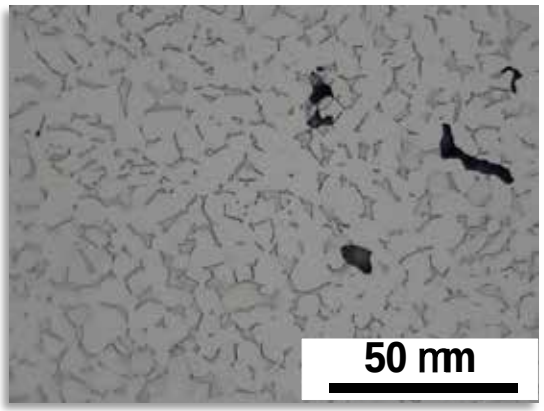






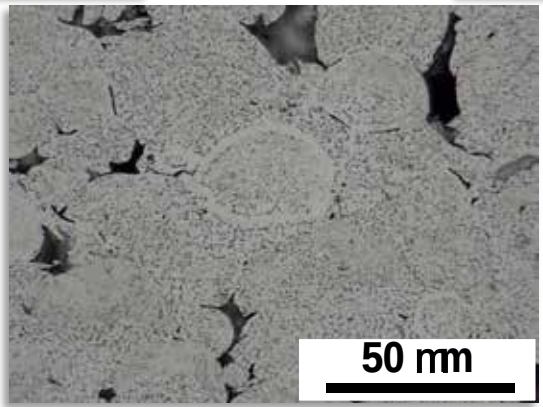


As-sprayied

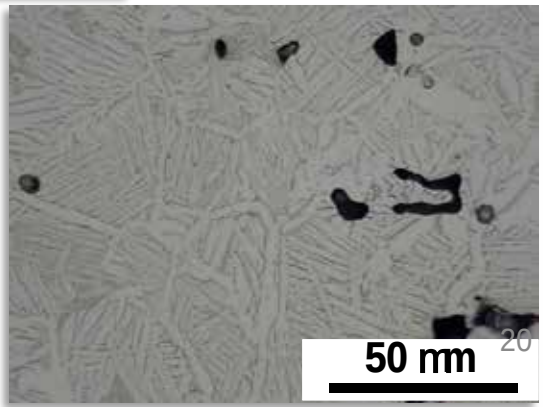


Recrystallization anealing

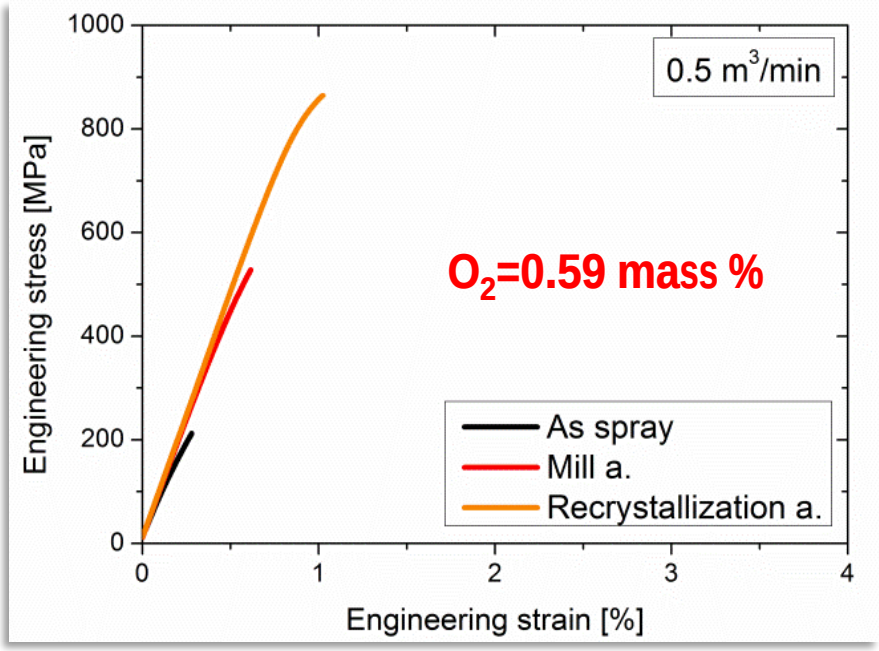
Mill anealing

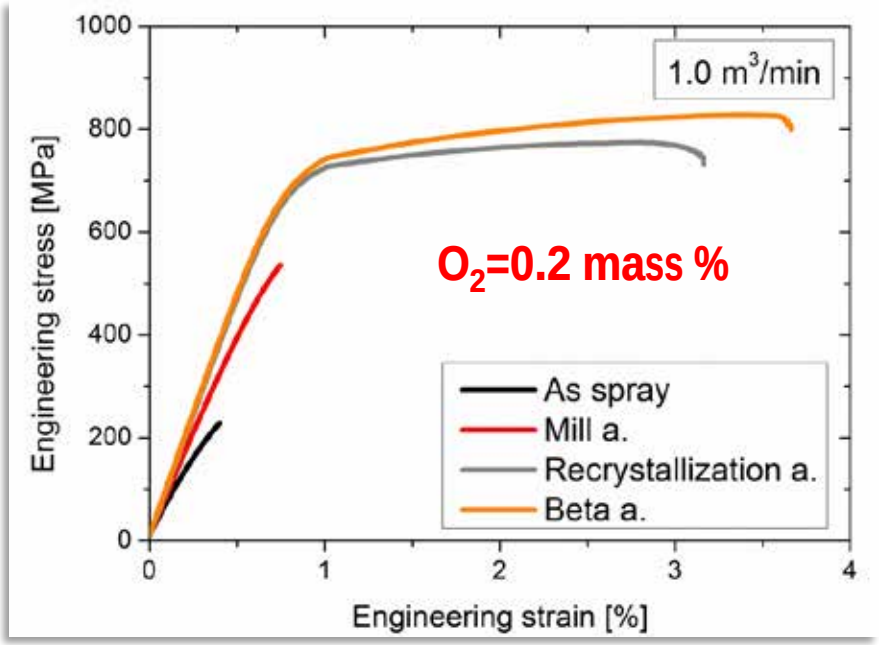


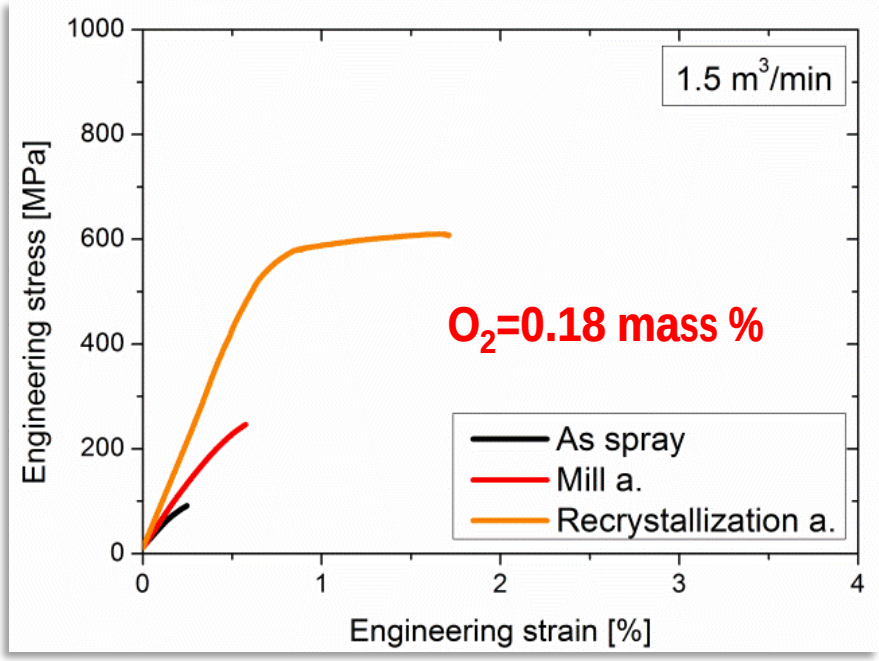
Beta anealing



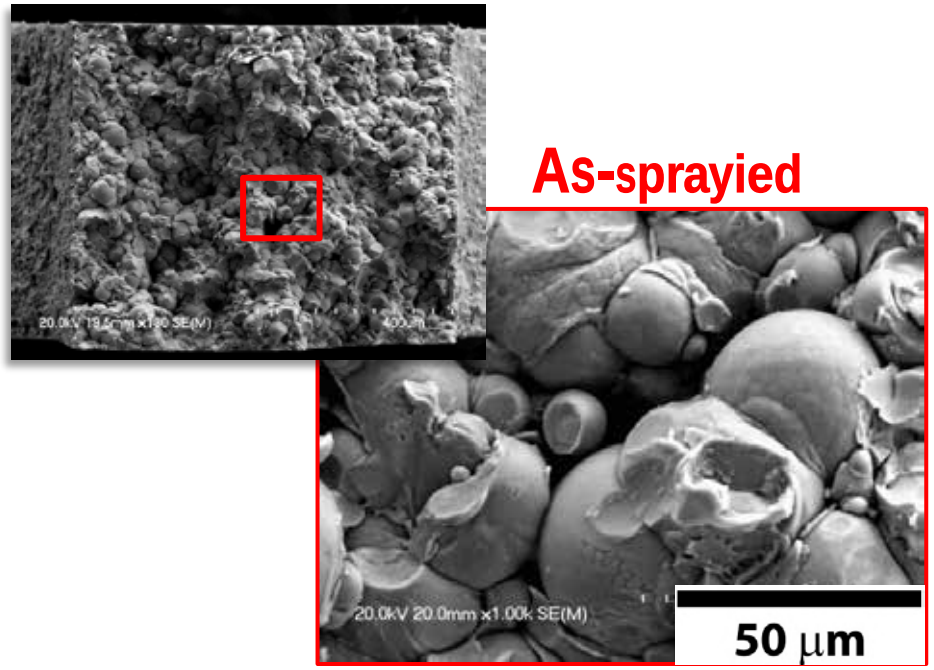
ENGINEERING STRESS-STRAIN CURVES

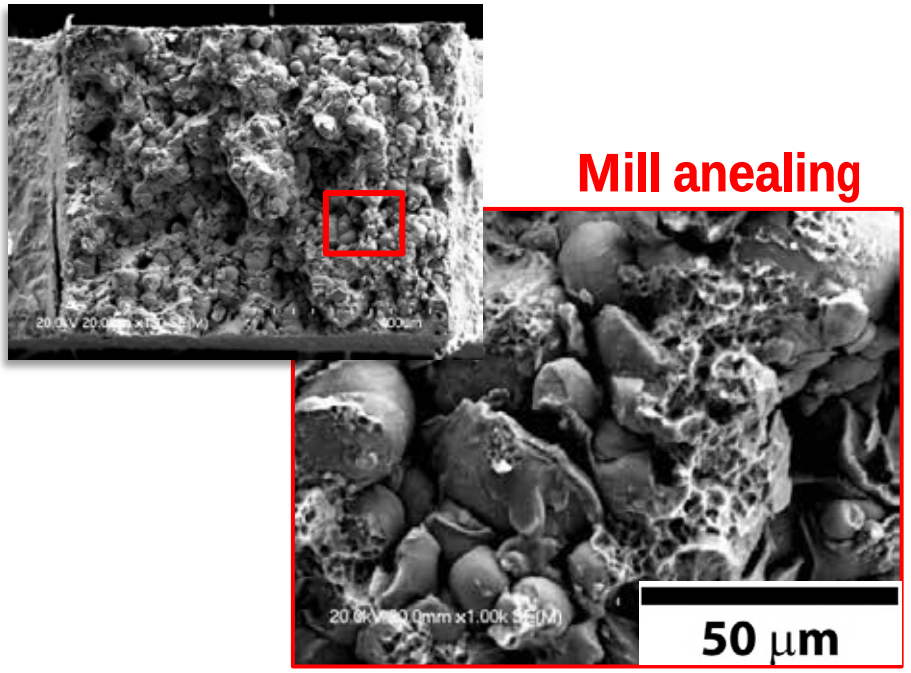


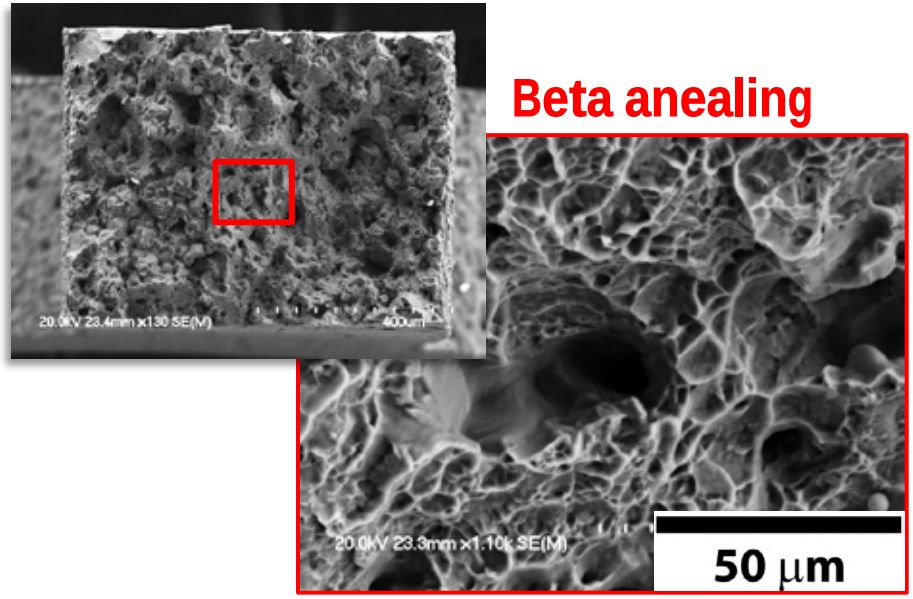


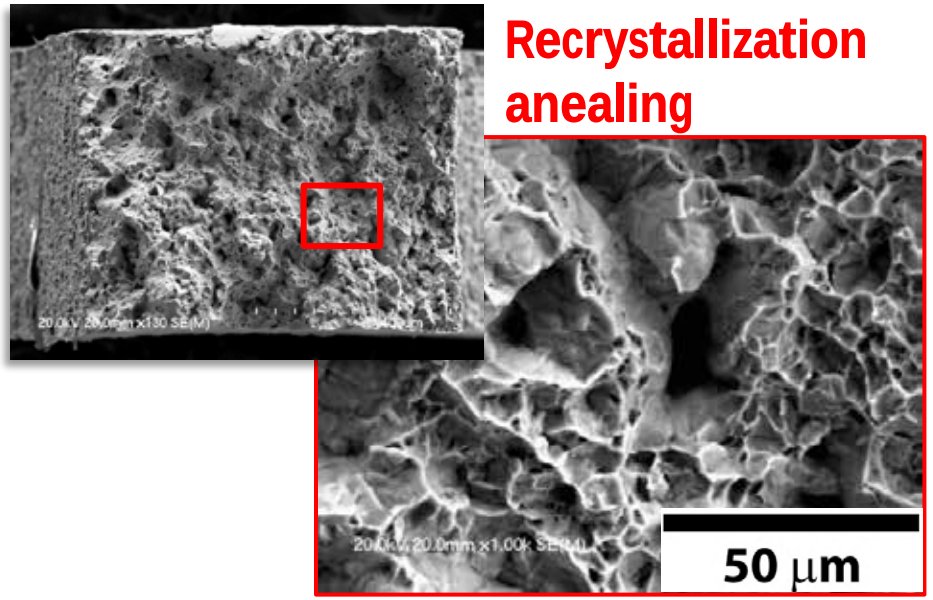


FRACTURE SURFACES of 4 MPa-WS at 1.0 m^3/min NFR

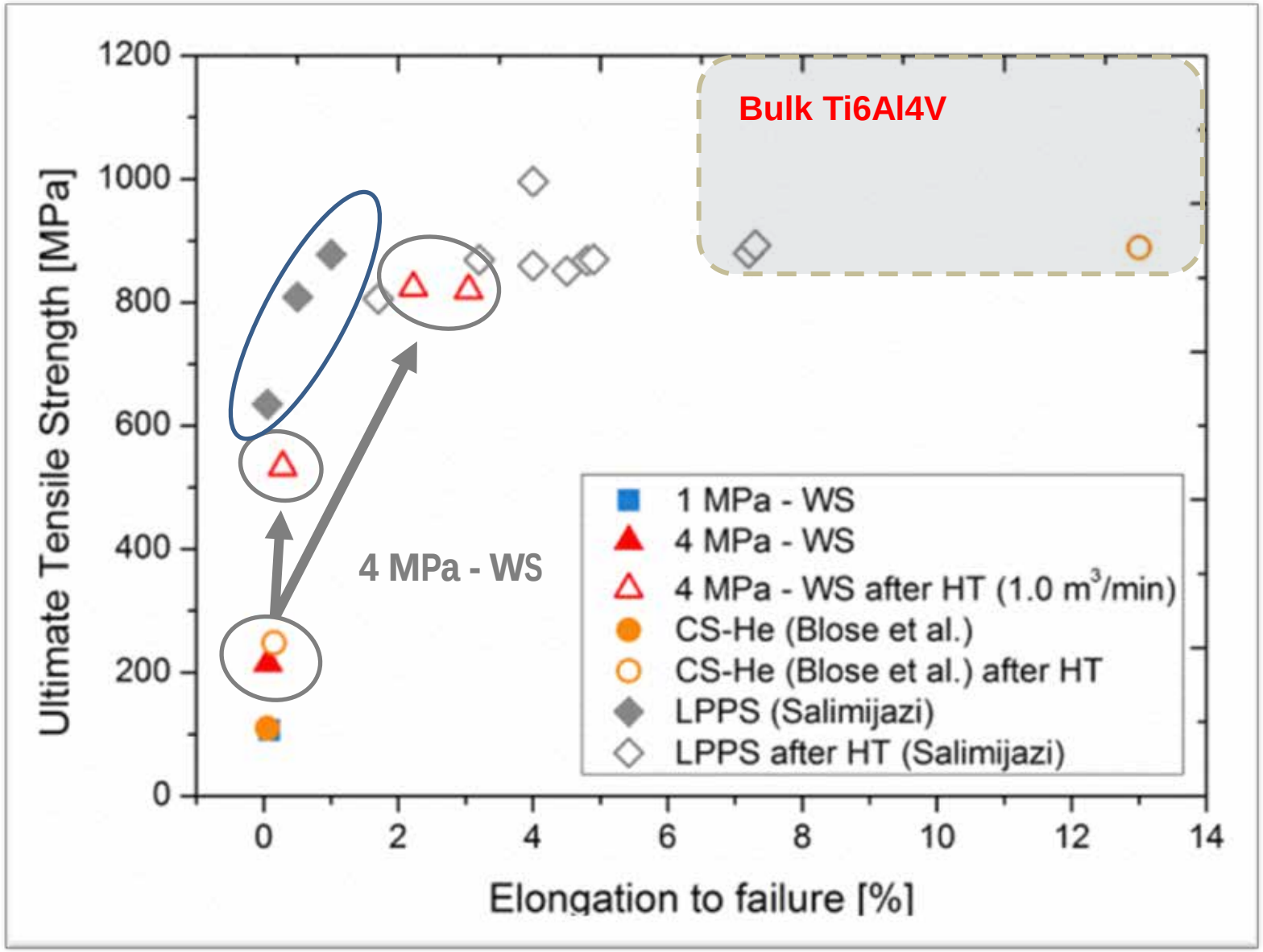




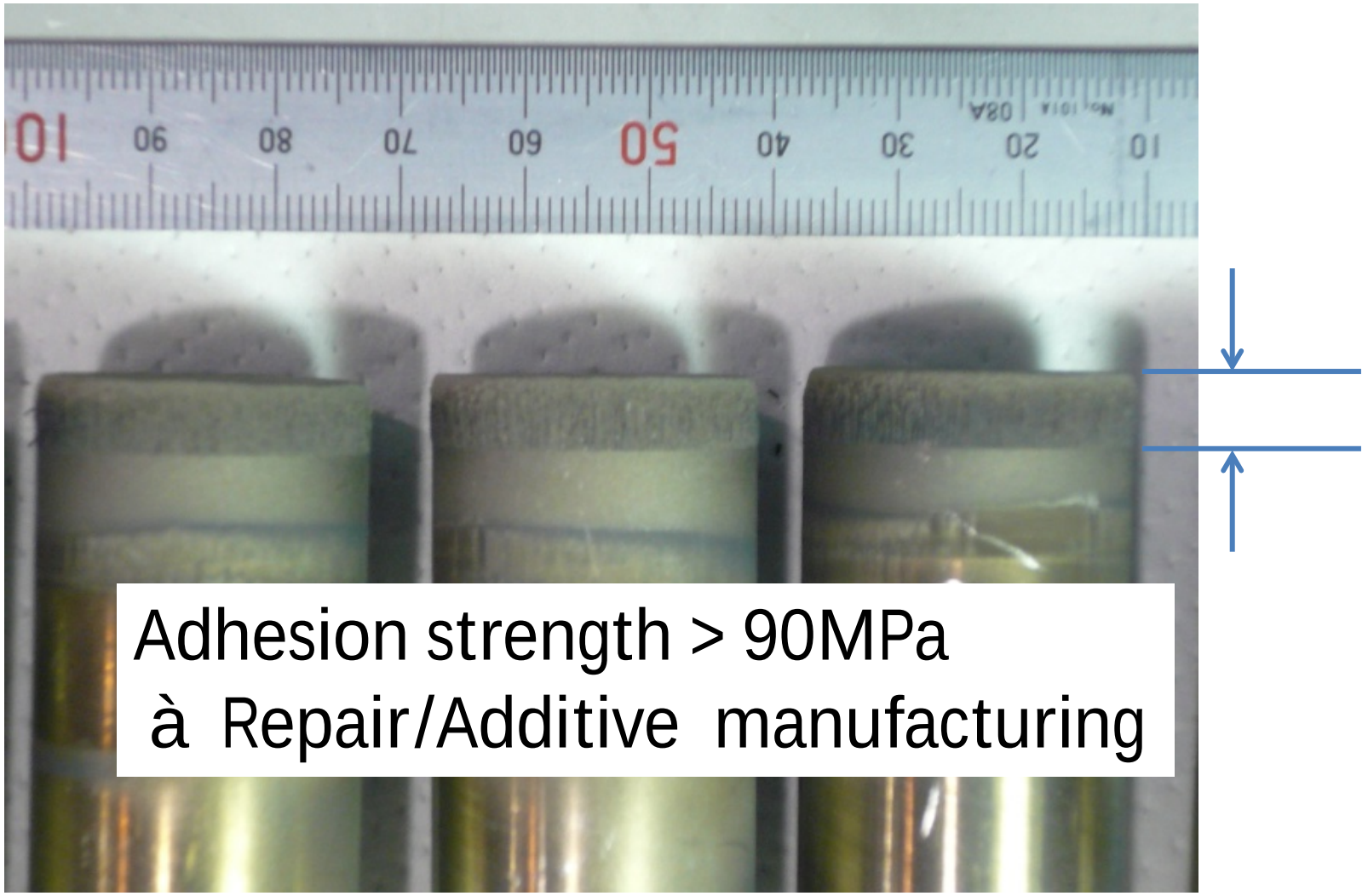




SUMMARY – CORRELATION BETWEEN UTS and e_{PL}



> 5mm deposit of Ti6-4 on Ti6-4 by HP-Warm Spray



Case 2: WC-Co Cermet coatings

Hard Chrome Replacement

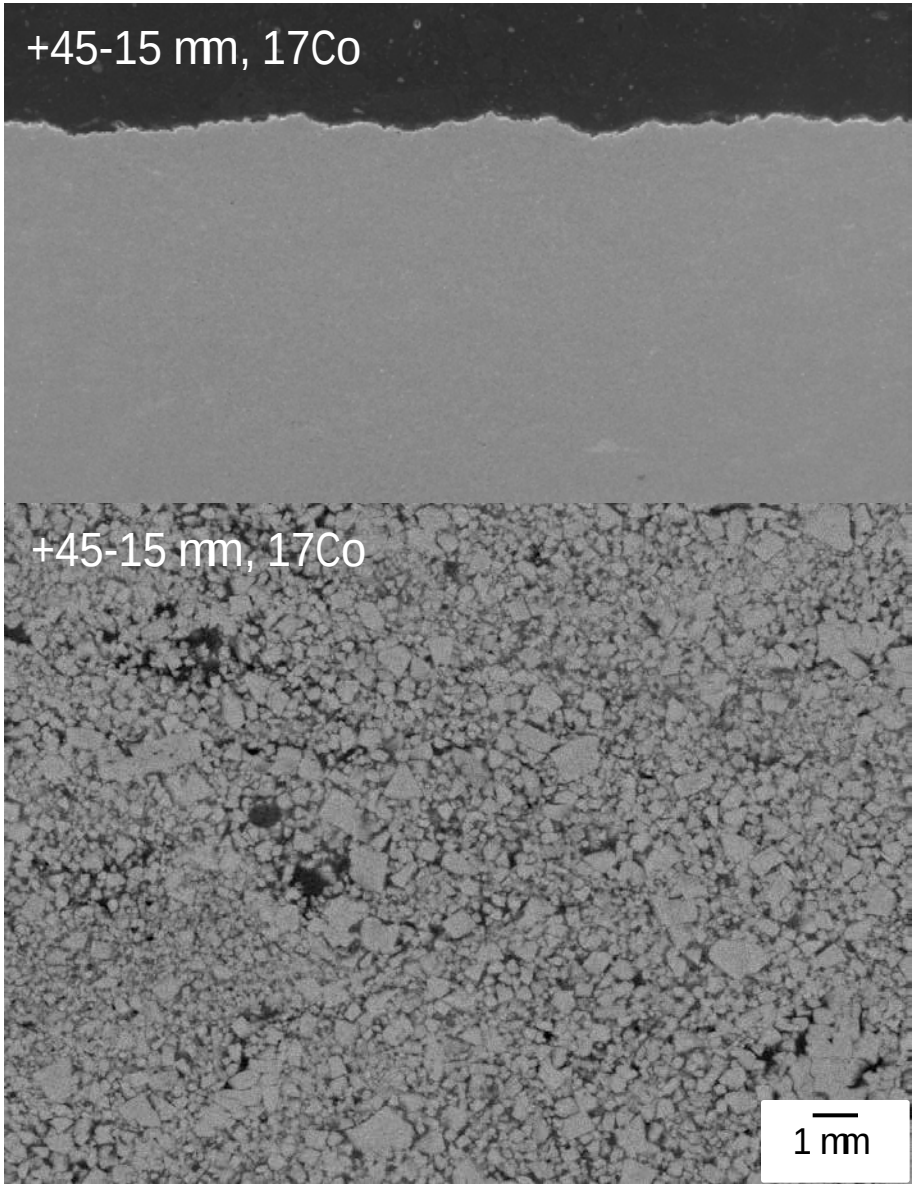
Landing gears, Construction machines

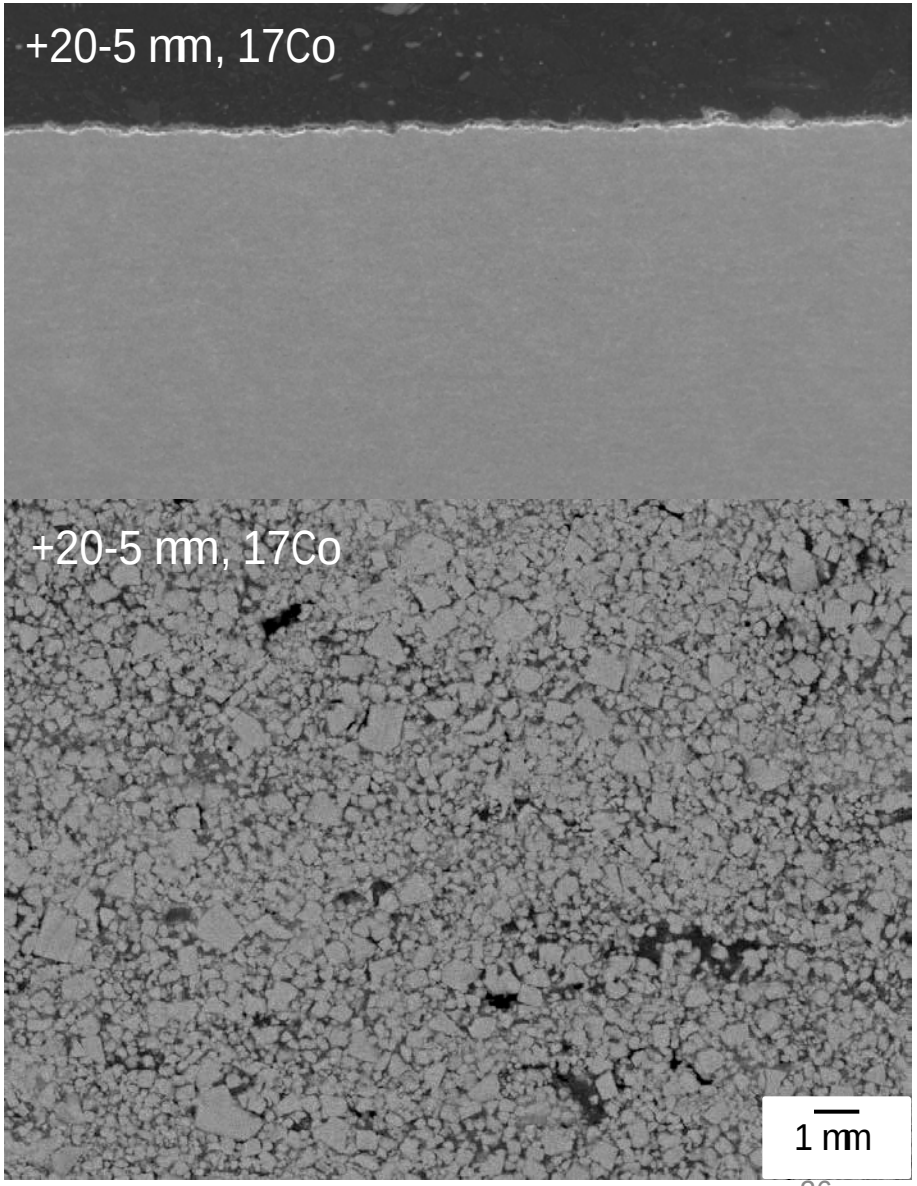
Rolls in steel and paper plants

Blades in turbine engines

Molds for casting and forming

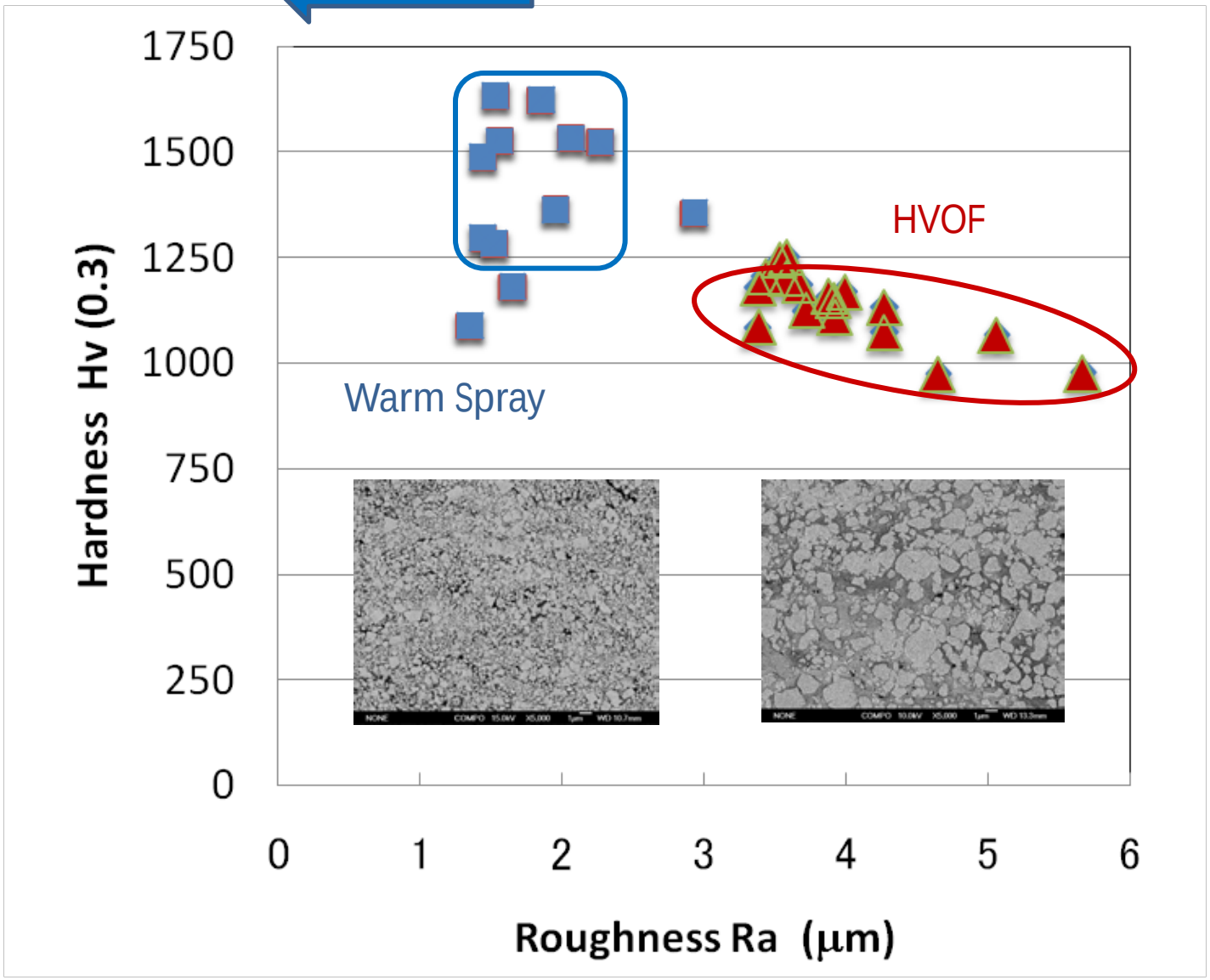
Microstructure Observation





Lapping, polishing cost

WC-Co



Summary

- Warm spray takes advantages of both kinetic and thermal energy to form dense and thick metallic and composite coatings.
- With WS one can explore a wide range of v_p, T_p.
  - HP-WS can reach the velocity range close to He-driven CS.
- Oxygen pickup is not as low as CS but acceptable for many engineering applications.
  - Examples: Ti alloy and WC-Co
- Other materials: Ni, Co, Cu, amorphous alloys, PEEK.

If you are interested,

Contact: Kuroda.Seiji@nims.go.jp

References:

- S. Kuroda et al. : “Current Status and Future Prospects of Warm Spray Technology” J. Therm. Spray Technol. **20**[4] (2011) 653-676
- R.M. Molak et al. : “Warm Spray Forming of Ti-6Al-4V” J. Therm. Spray Technol. **23**[1-2] (2014) 197-212

Acknowledgement

- J. Kawakita, M. Watanabe, H. Araki (NIMS)
- H. Katanoda (Kagoshima University)
- H. Fukanuma, N. Ohno (Plasma Giken)
- R. Molak (WUT)