Systematic Tuning of Cold Spraying for Aerospace Applications

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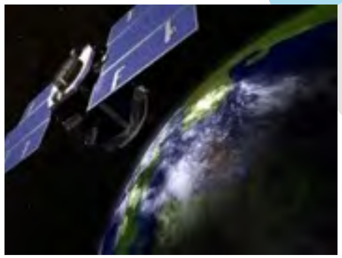
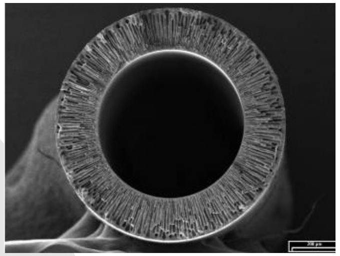
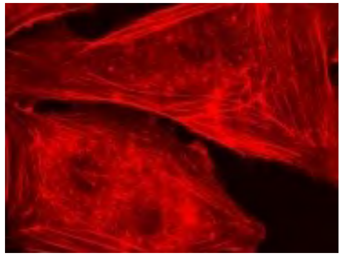
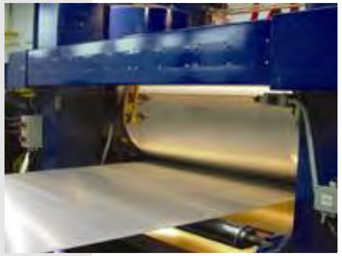
1/3 Coastal and Climate Research



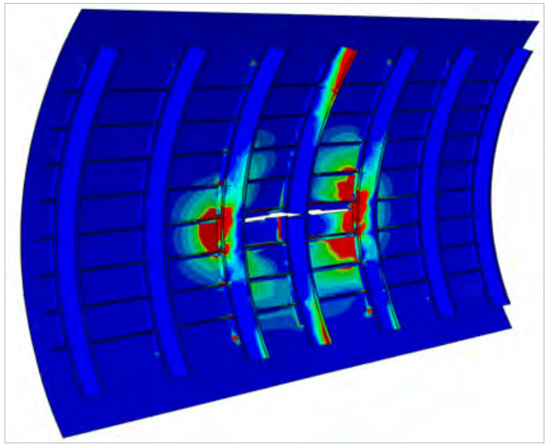
2/3 Materials Research for sustainable Energy and Mobility







Research on Novel Aircraft Structures and Manufacturing Technology



Theory

Design, Modeling & Simulation

Characterisation

Microstructure and Residual Stress

Additive Manufacturing and 3d Refurbishment

Model Experiments and Prototypes

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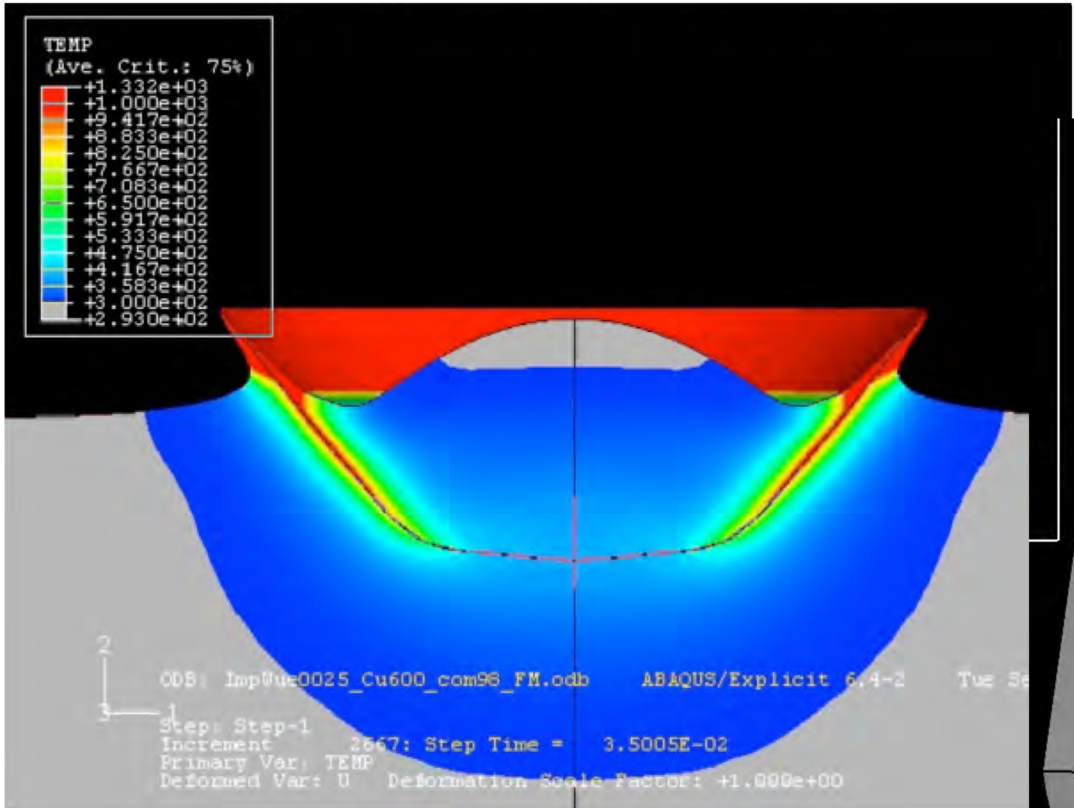
Kinetic Spraying: Basic Mechanisms

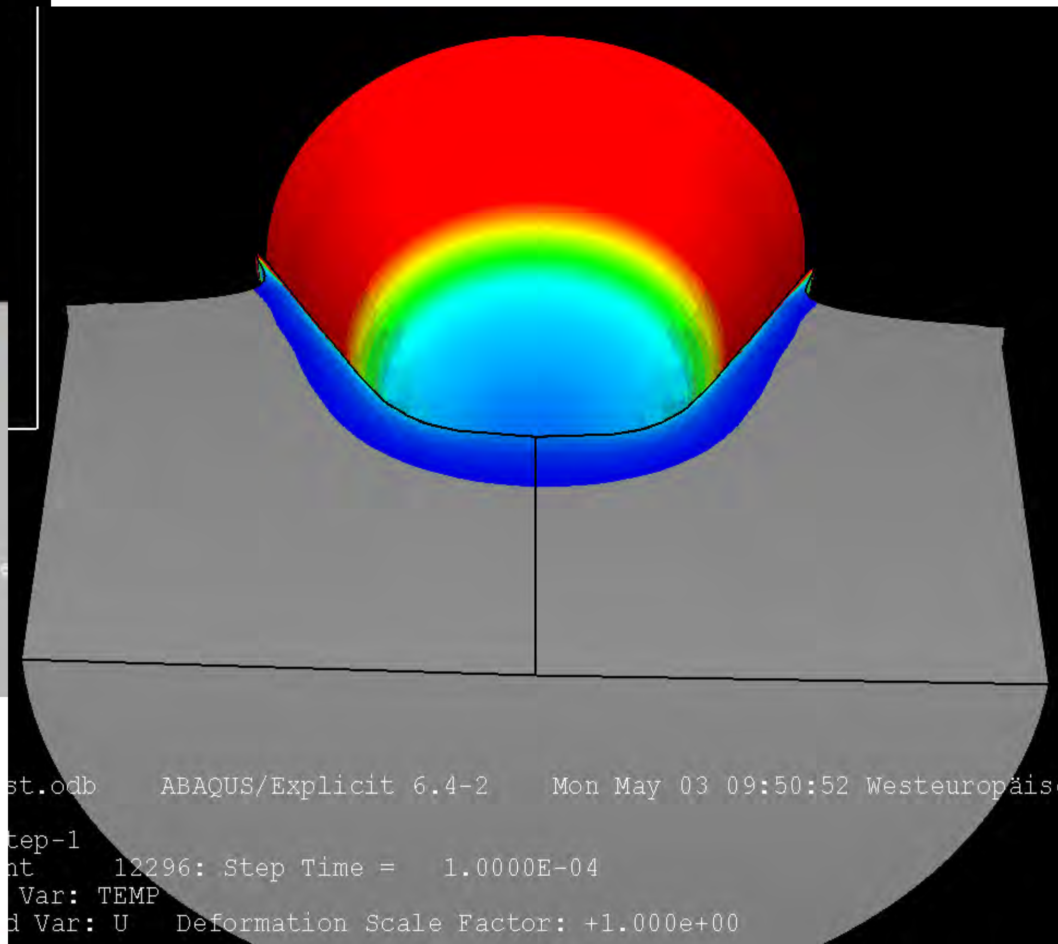
Particle Impact

temperature field showing thermal flow

25 µm, 600 m/s, 20°C, Cu

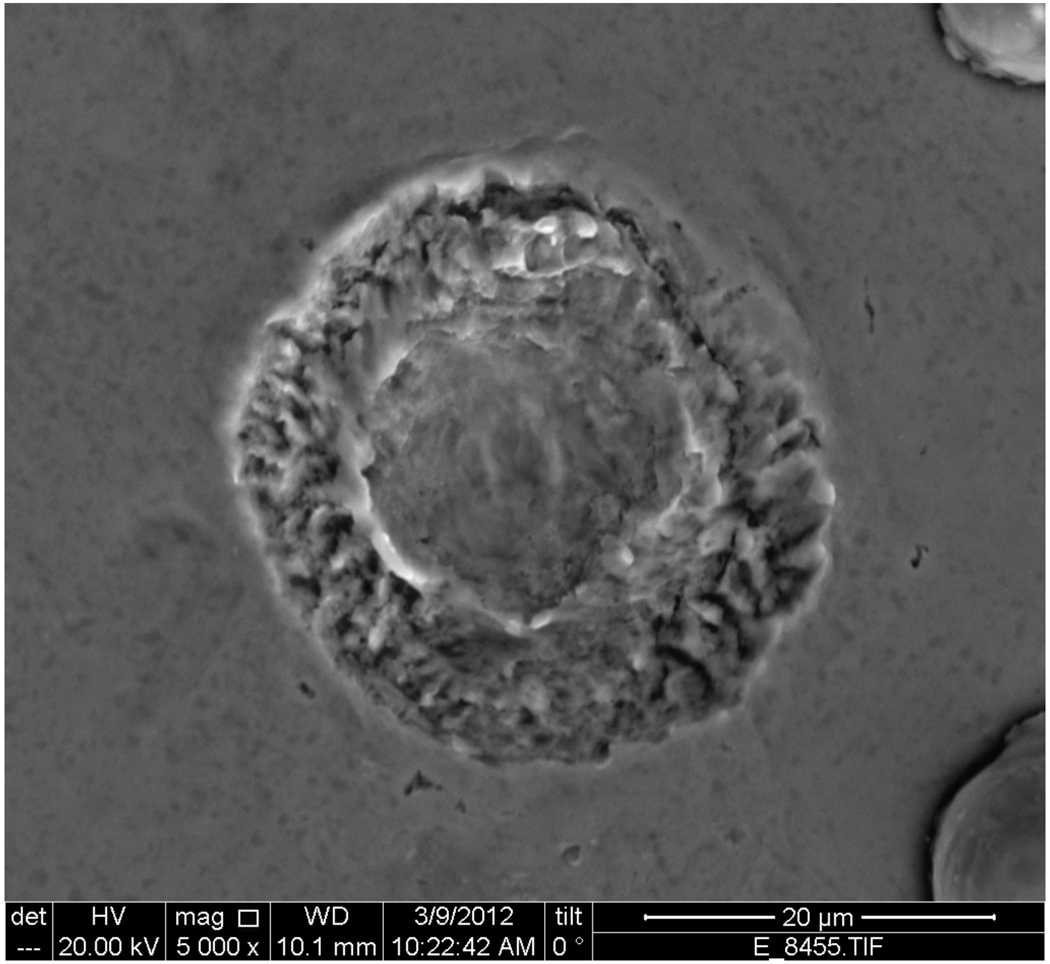


Area of Bonding



Single impact Ti-6Al-4V on Ti after cavitation

lost...



… and found

María Villa, T. Breckwoldt, A. List

Process Improvements: Window of Sprayability

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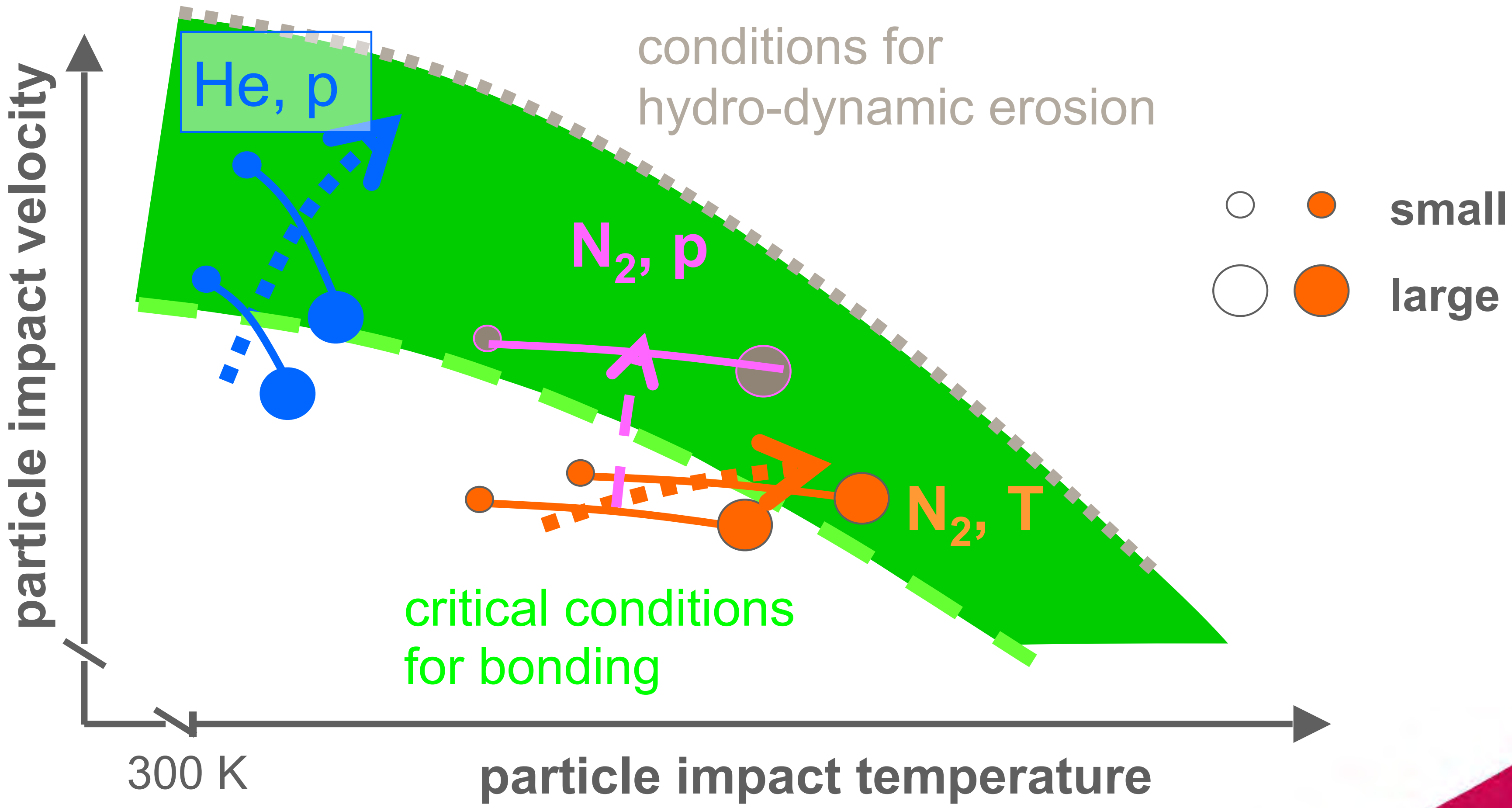


He route: very fast, **cold impact condition** (costly)

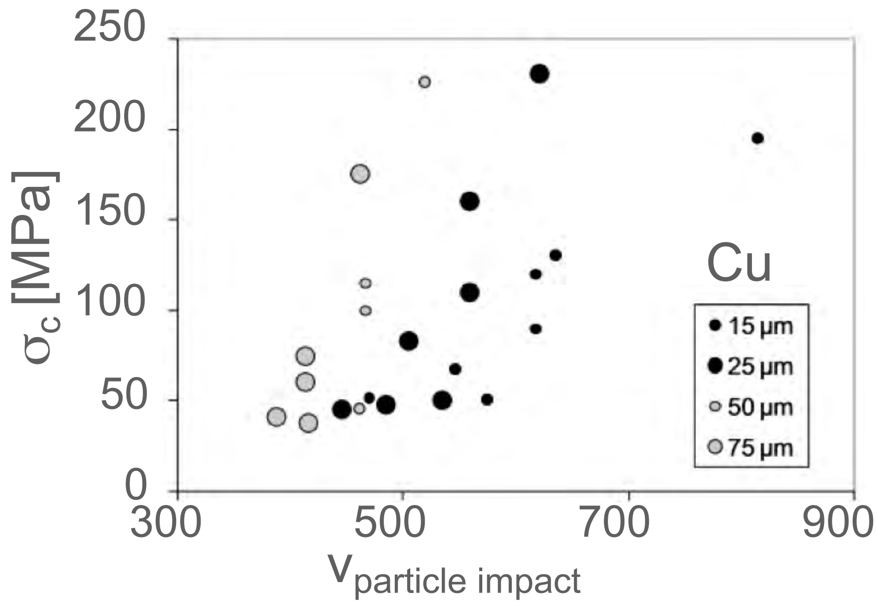
N_2 route: fast, **warm impact condition** (reactions?)

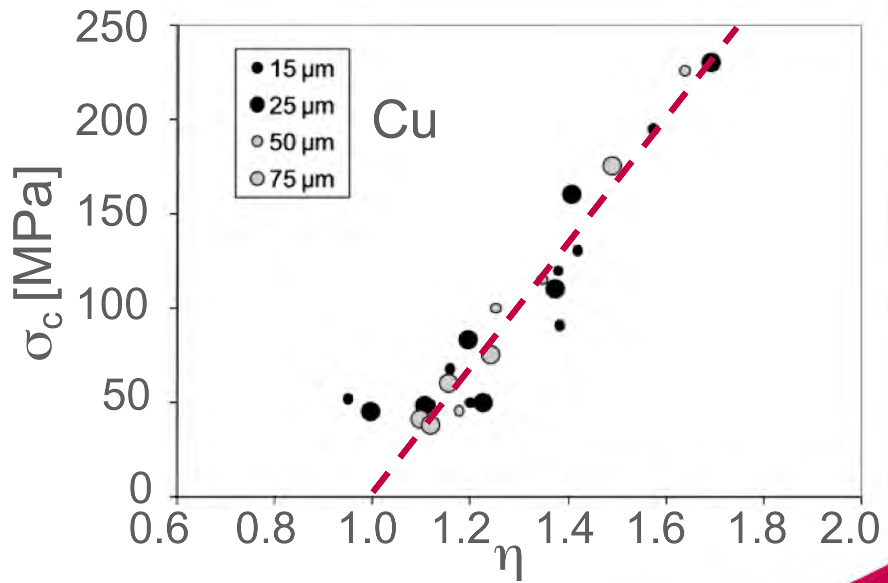
Klassen, Gärtner, Assadi, ASM Handbook on Cold Spraying

„all-inclusive“ quality parameter: η

$$\eta = v_{particle\ impact} / v_{critical}$$

(fluid mechanics) (materials properties)





H. Assadi et al.: „On Parameter Selection in Cold Spraying“, JTST 20 (2011) 1161

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coating quality is predictable!

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properties, powder size powder morphology ⇒ **spray material** ⇐ data base

⇓

equipment, nozzle type, P_{gas}, T_{gas}, … ⇒ **process conditions** v_{impact}, T_{impact} ⇐ spray jet analysis, fluid dynamic simulation

⇓

deformation upon impact, bonding ⇒ **coating microstructure coating properties** ⇐ impact simulation coating analysis

⇓

performance in applications

KINETIC SPRAY SOLUTIONS

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Powder development: single particle deformation

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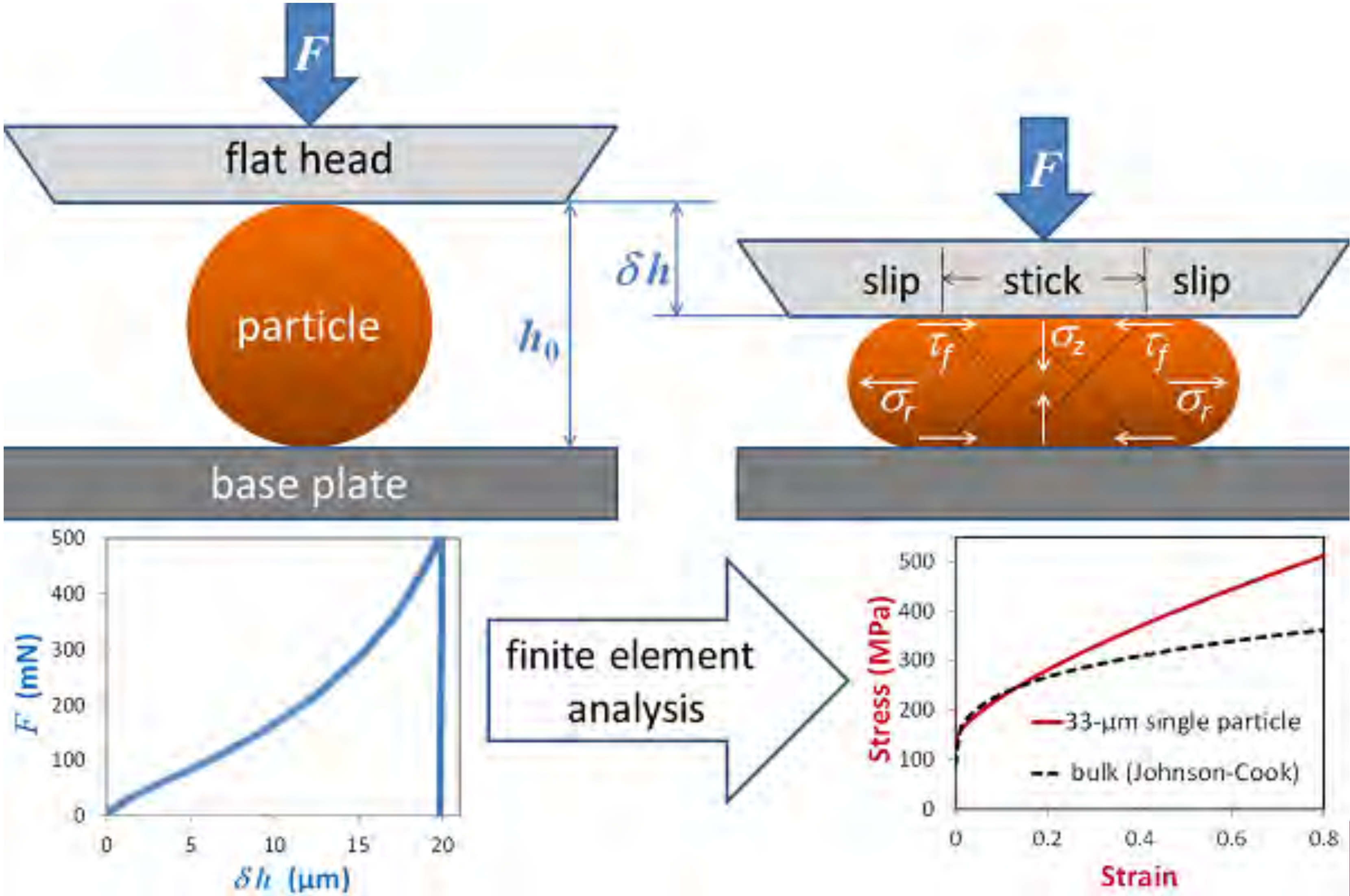

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Kinetic Spraying: Titanium

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Window of Deposition: Ti

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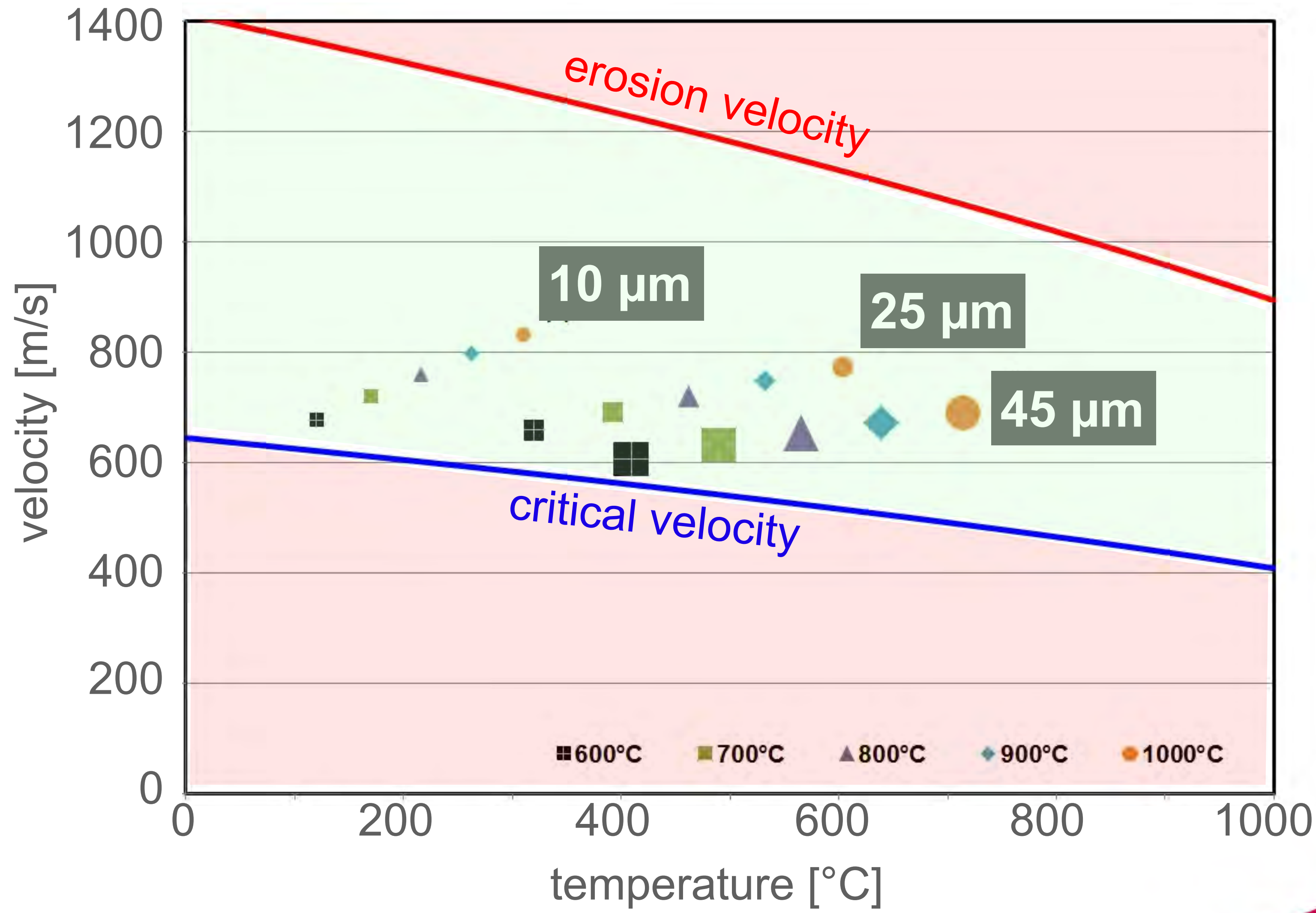

materials properties → window of deposition

process parameters → impact conditions

Ref.: K. Binder, „Kaltgasspritzen von ermüdungsfesten Titanschichten, PhD.-Thesis, Hamburg 2013

Parameter selection: optimum Ti-powder sizes

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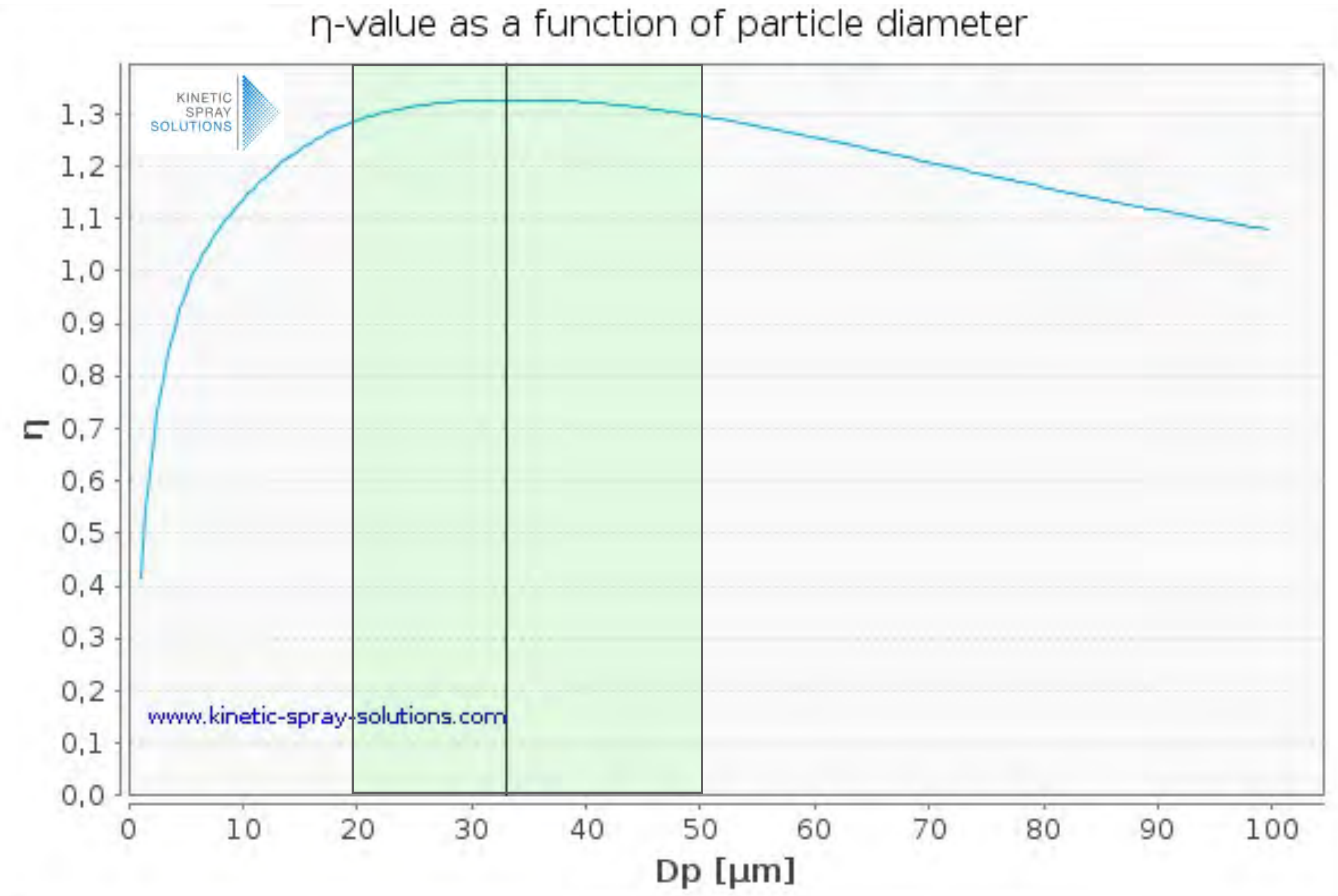


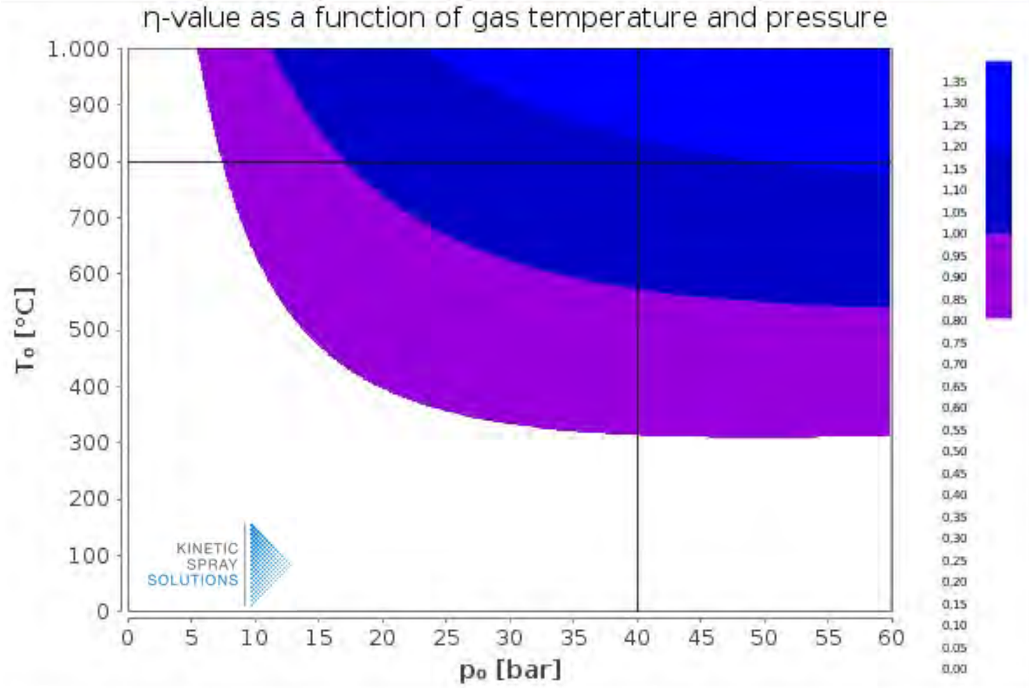
Nitrogen
nozzle 24,
p_{gas}: 40 bar,
Tgas: 1000°C

⇨ **optimum size range: 20 – 50 μm (D_{50} = 33 μm)**

Klassen, Gärtner, Assadi, ASM Handbook on Cold Spraying

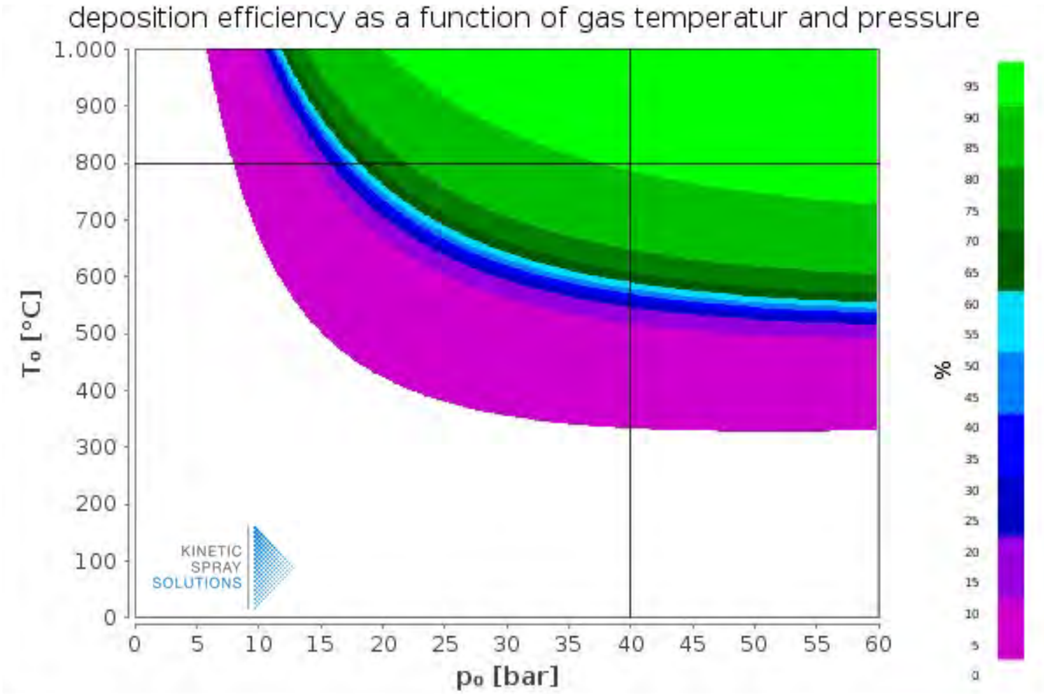
Parameter selection
η, DE (gas pressure, gas temperature)

η



nozzle 24

DE



nozzle 24

⇨ **saturation in DE: reached at η > 1.2;**
p > 40 bar, T > 800°C

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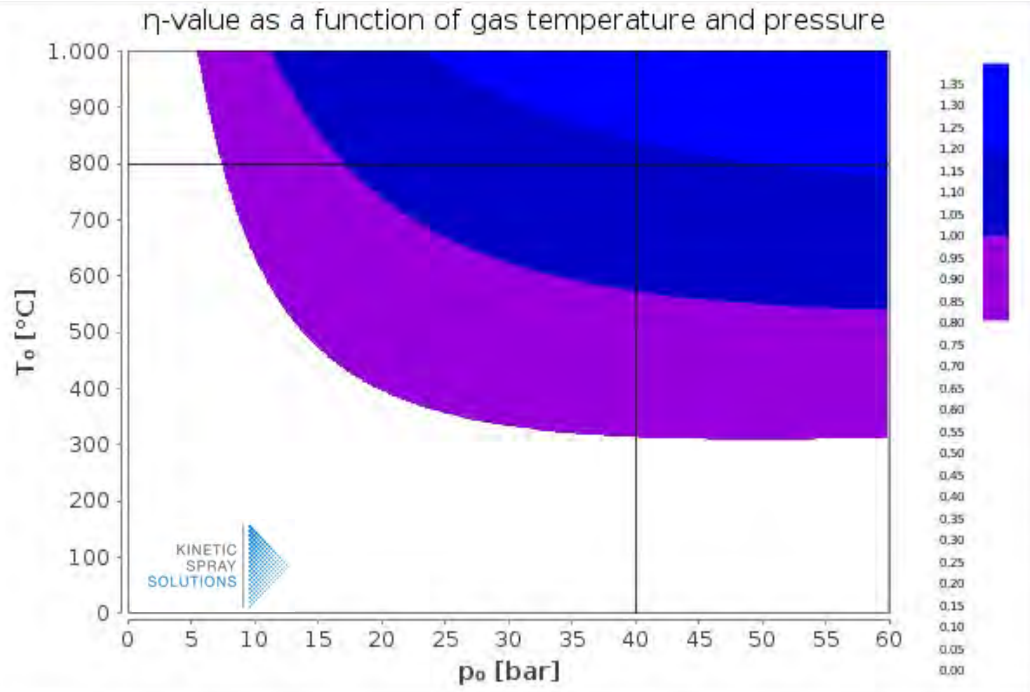
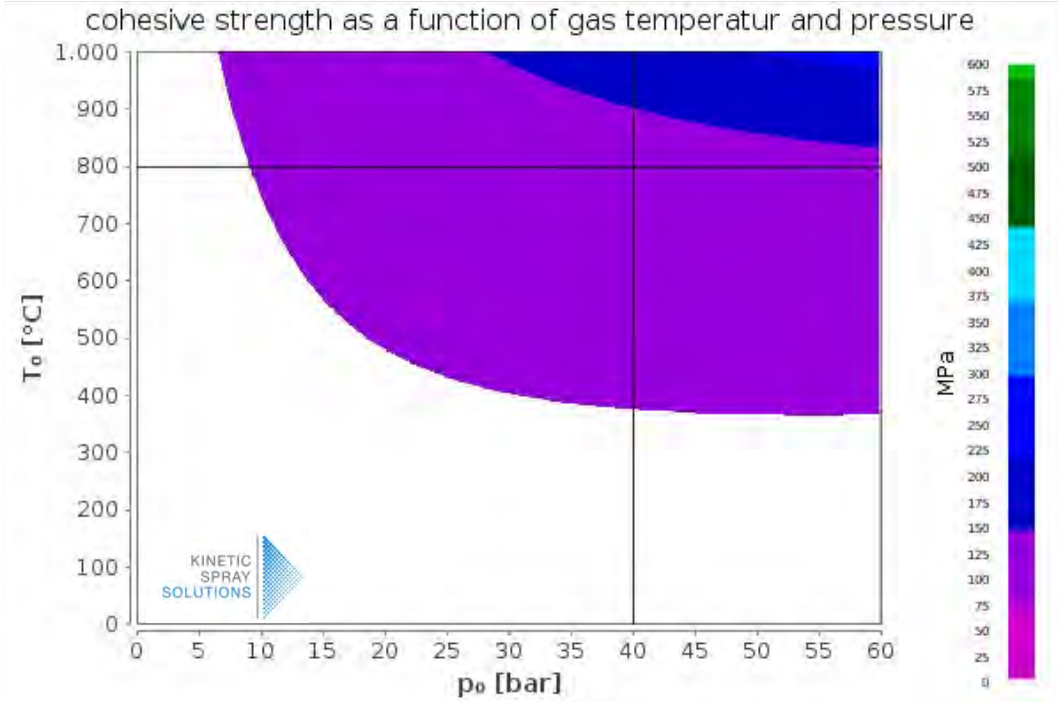
Parameter selection
η, UTS (gas pressure, gas temperature)

η



UTS



nozzle 24

⇨ **strength > 220 MPa reached at η > 1.4, here p_{gas}: 60 bar, T_{gas}: 1000°C**

Parameter selection
η, UTS (nozzle selection)

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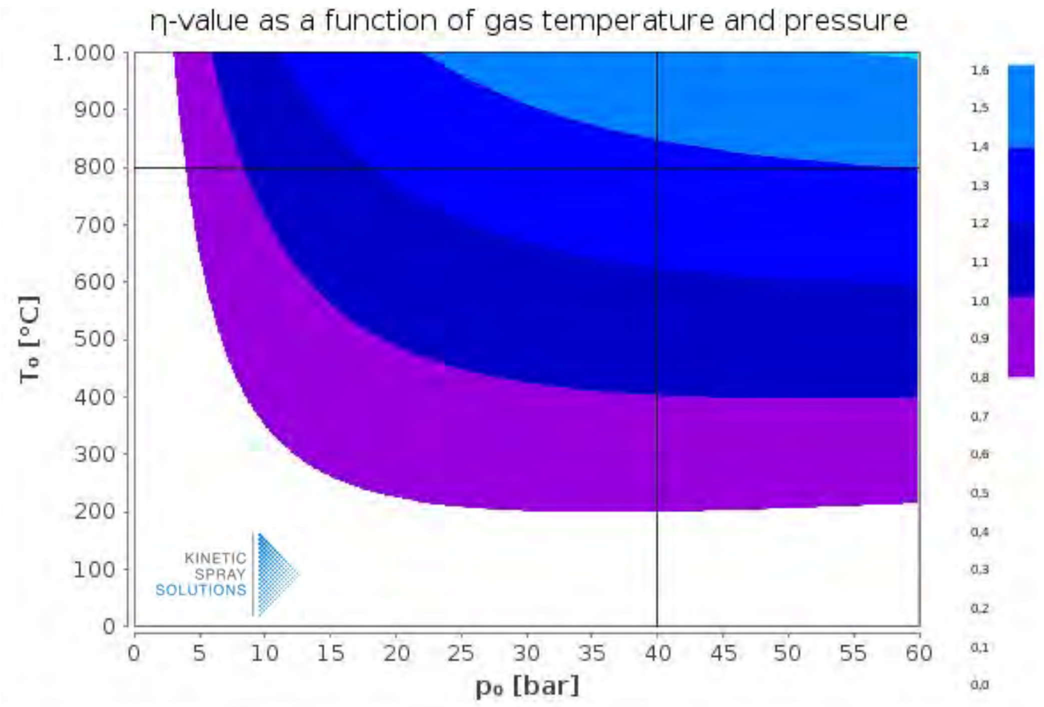
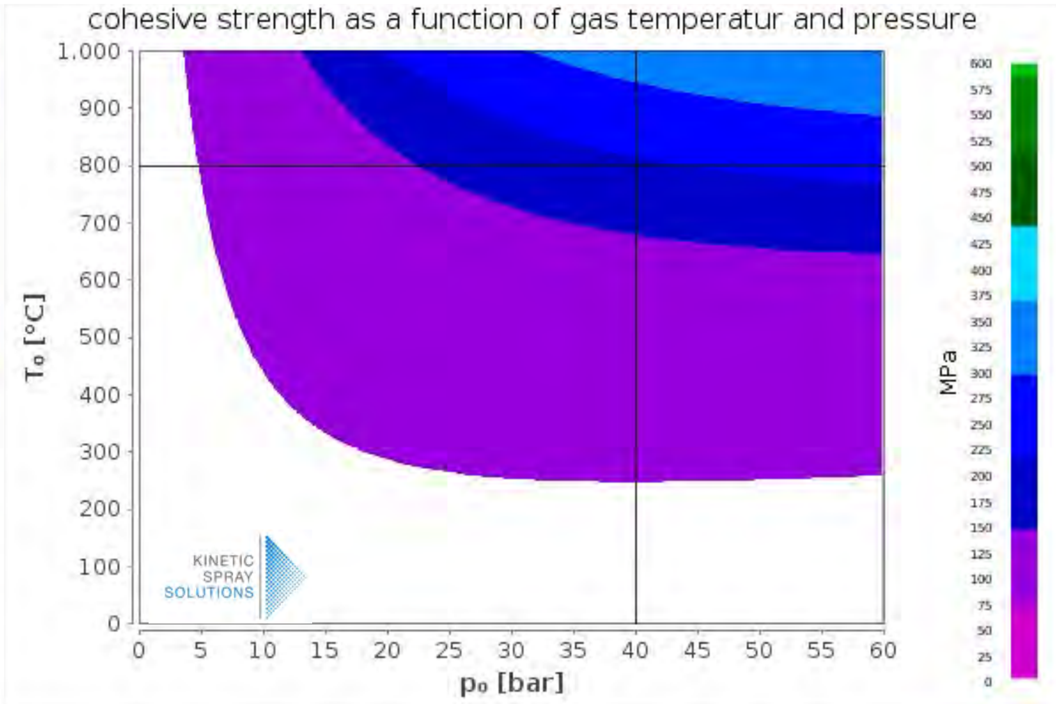
η



UTS



nozzle 50

⇨ **strength > 300 MPa at η > 1.5,**
p_{gas} > 50 bar, T_{gas} > 900°C

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properties of cold sprayed Ti

Ti - Coatings: Microstructure

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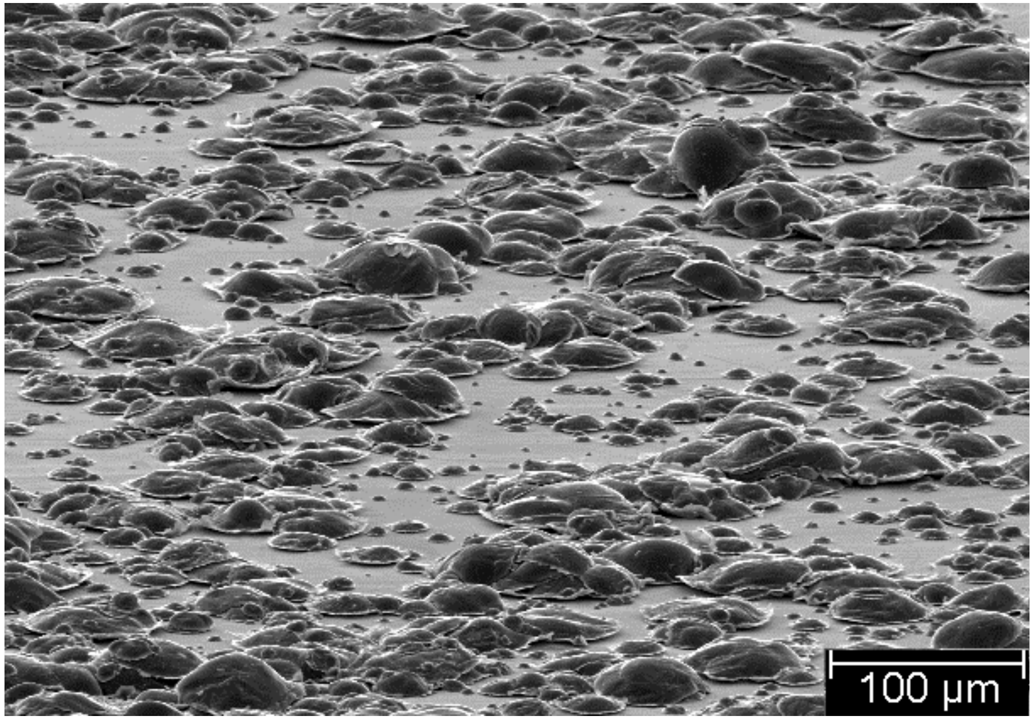
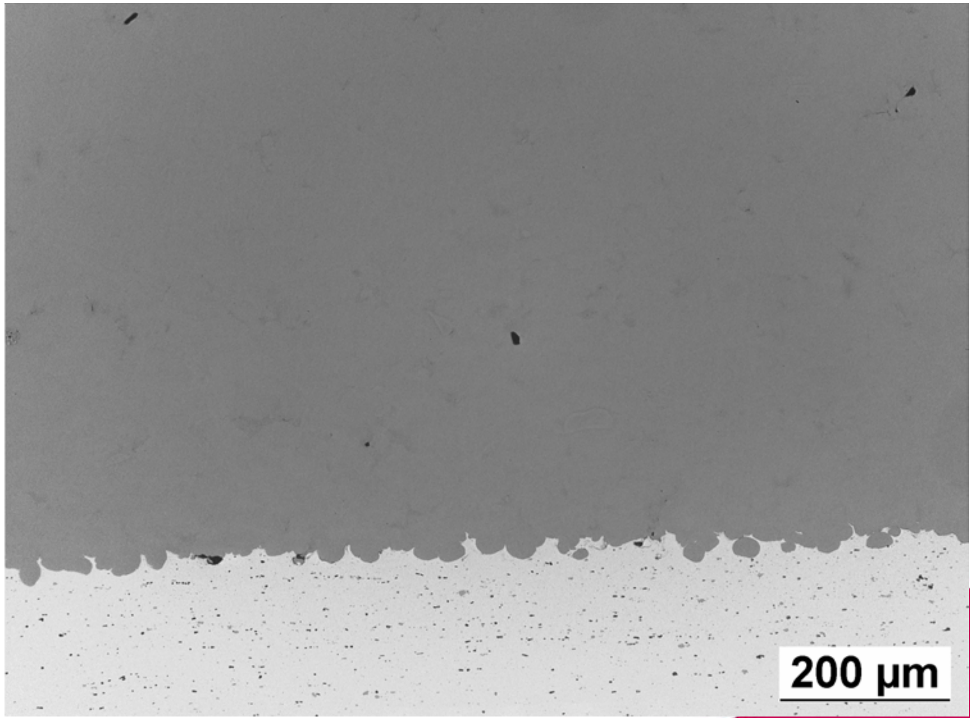
impact morphology



coating microstructure



T_{gas} = 1000°C p_{gas} = 4 MPa

Shear strength: η

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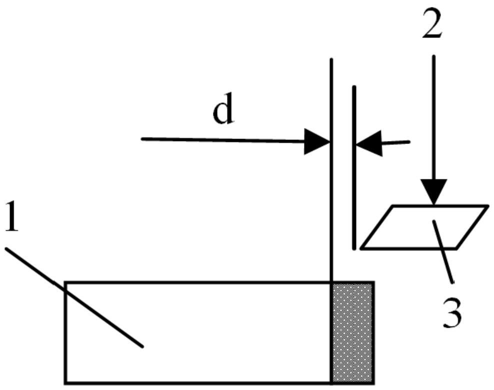

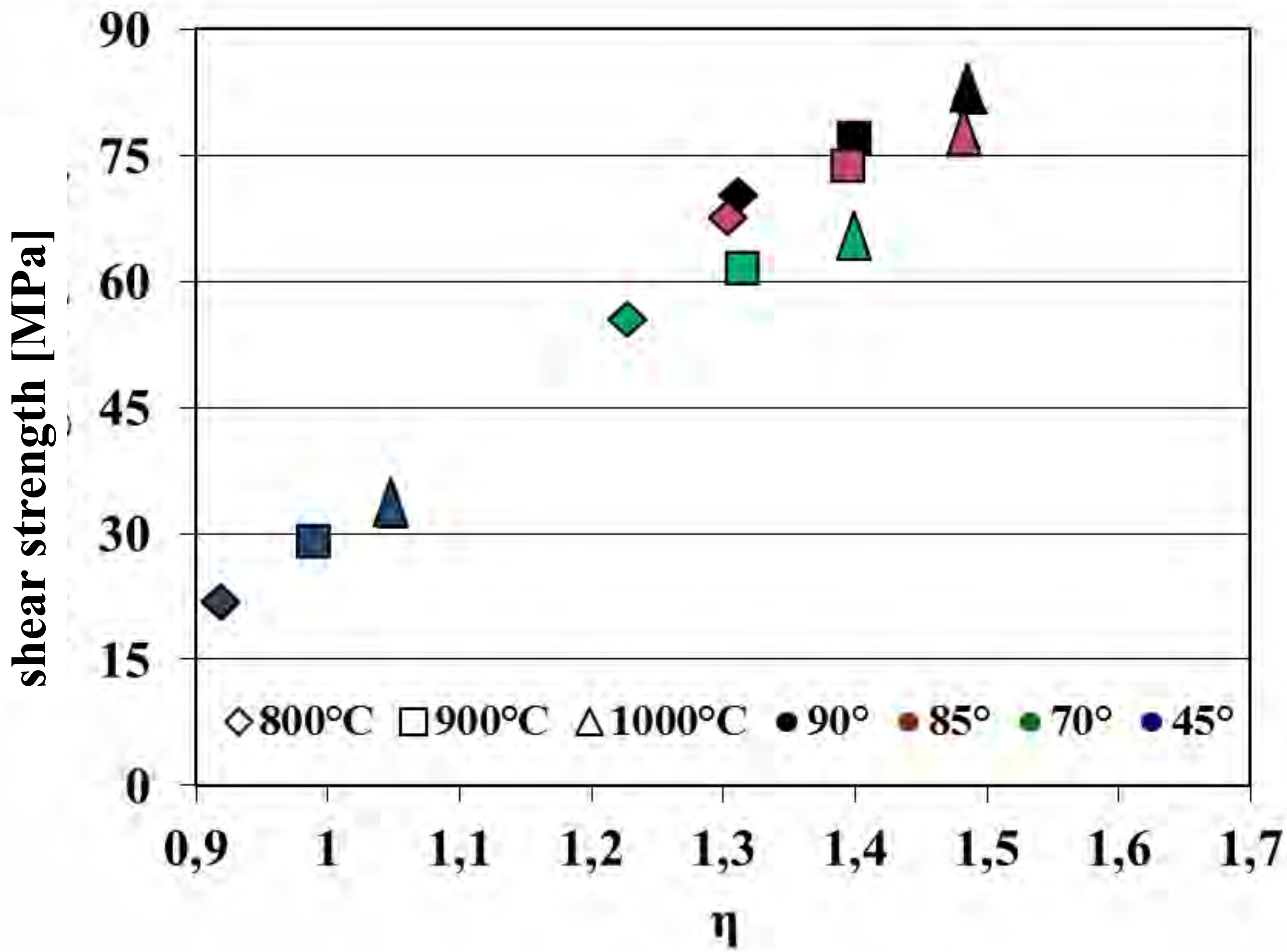

η (d_p = 25 µm, p = 40 bar)

⇨ **linear correlation with η**

Ref.: K. Binder, „Kaltgasspritzen von ermüdungsfesten Titanschichten, PhD.-Thesis, Hamburg 2013

Cohesive strength: η

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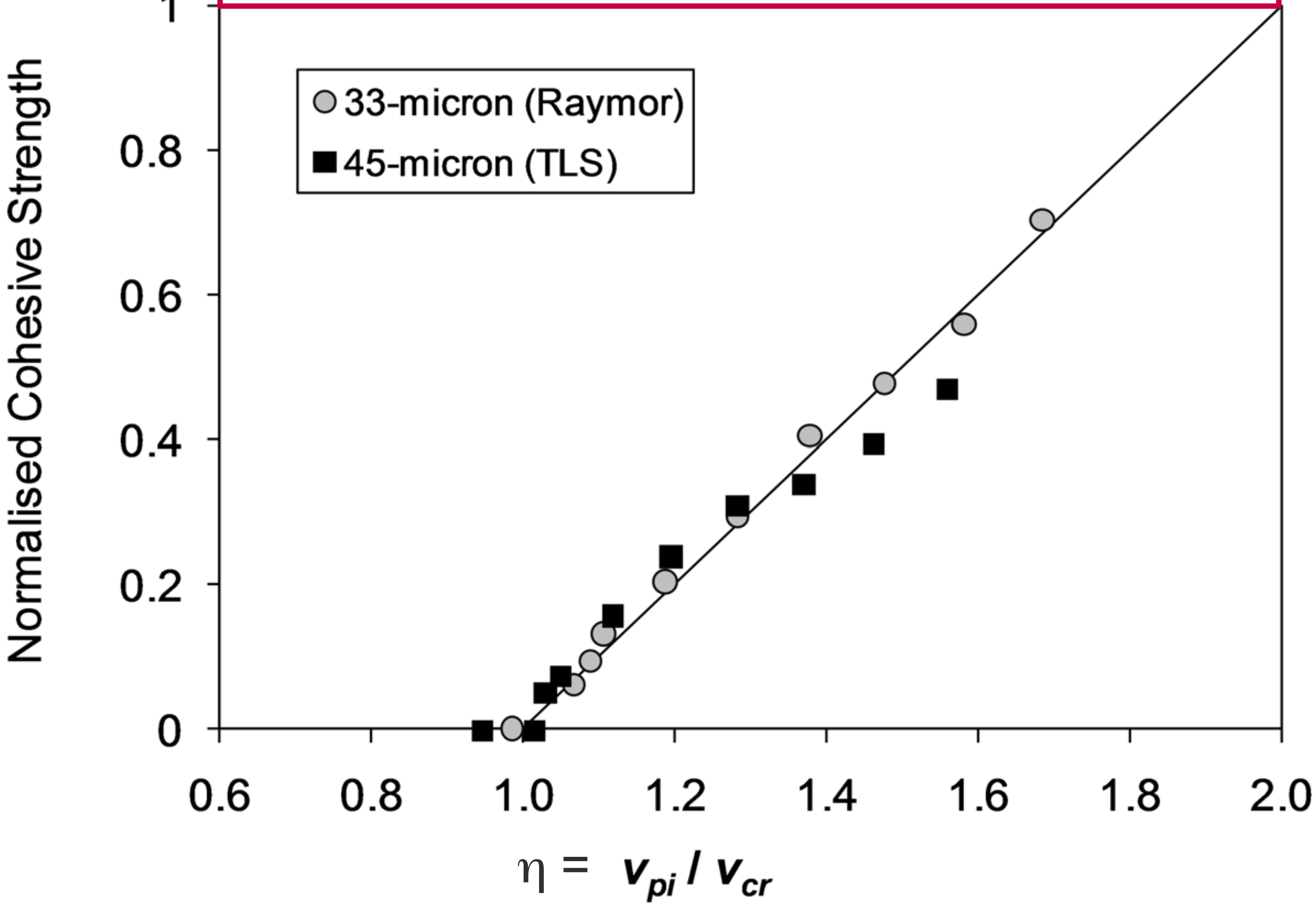
$\eta = v_{\text{particle impact}} / v_{\text{critical}}$

(fluid mechanics) (materials properties)



H. Assadi et al.: „On Parameter Selection in Cold Spraying“, JTST 20 (2011) 1161

deposit strength and ductility:
MFT-Test

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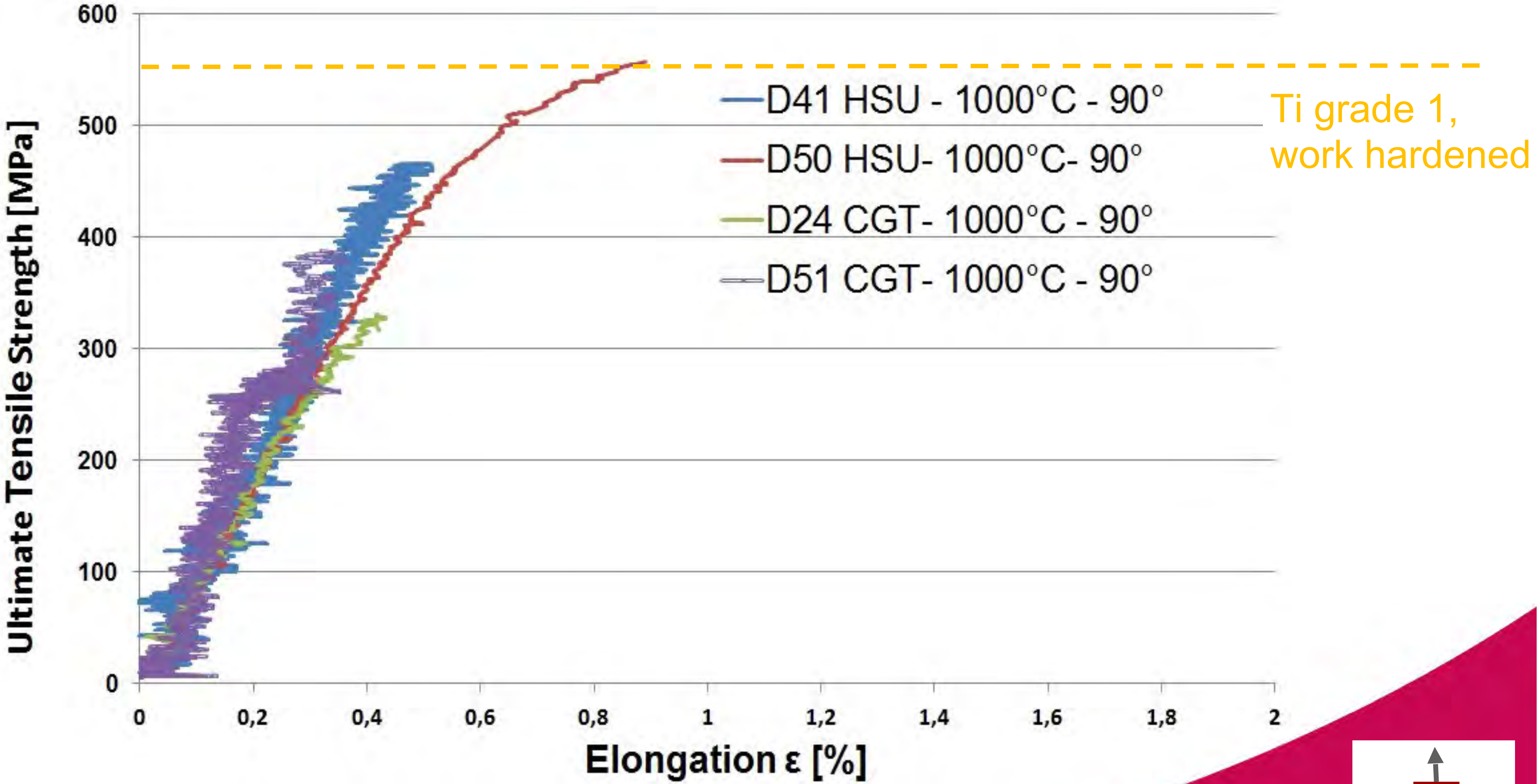

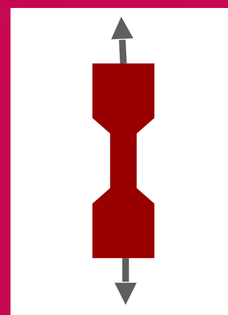

deposit strength and ductility after annealing: MFT-Test

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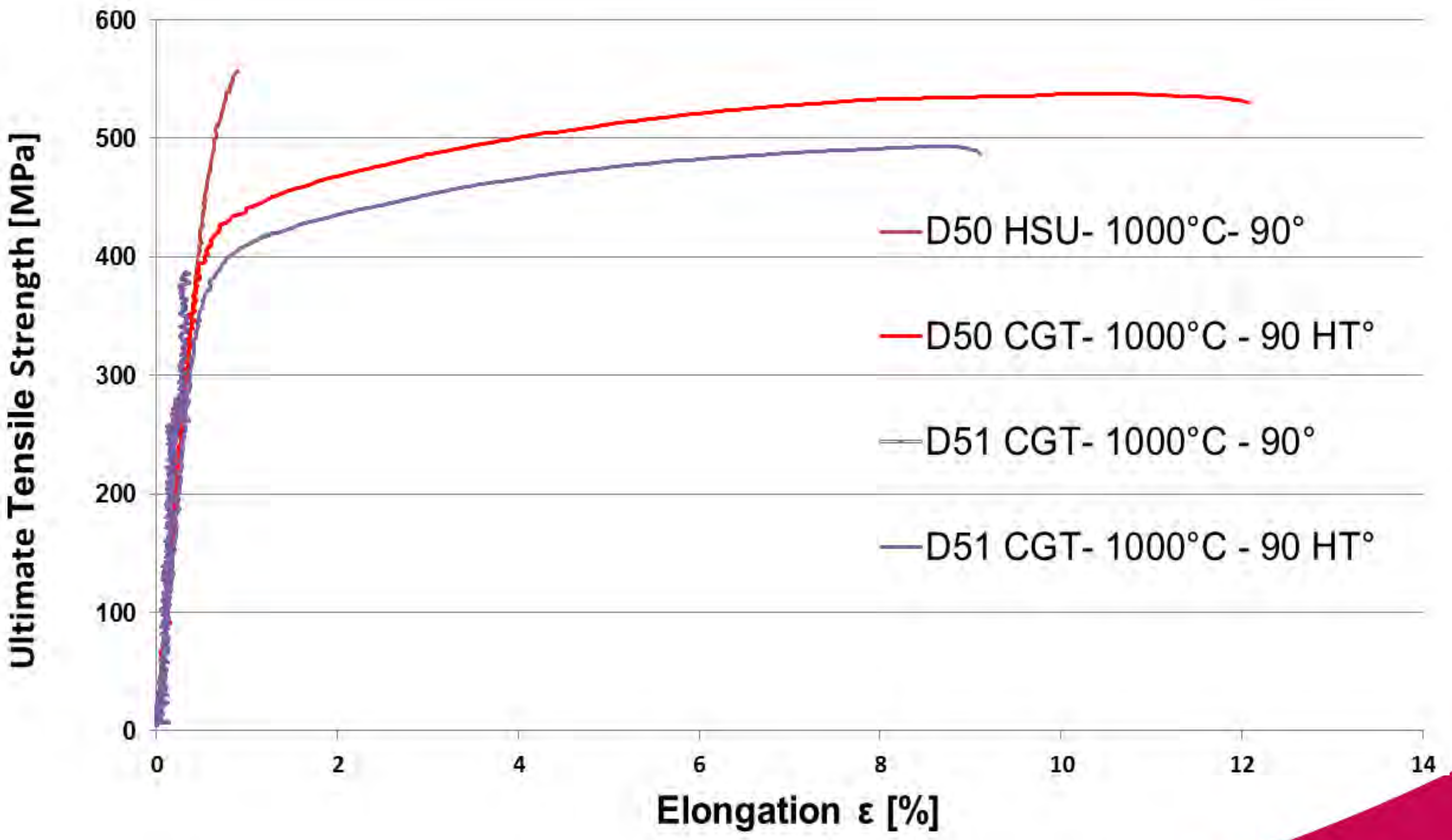

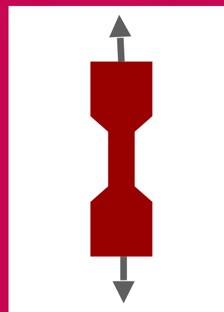

Fatigue strength similar to bulk Ti (grade 2)

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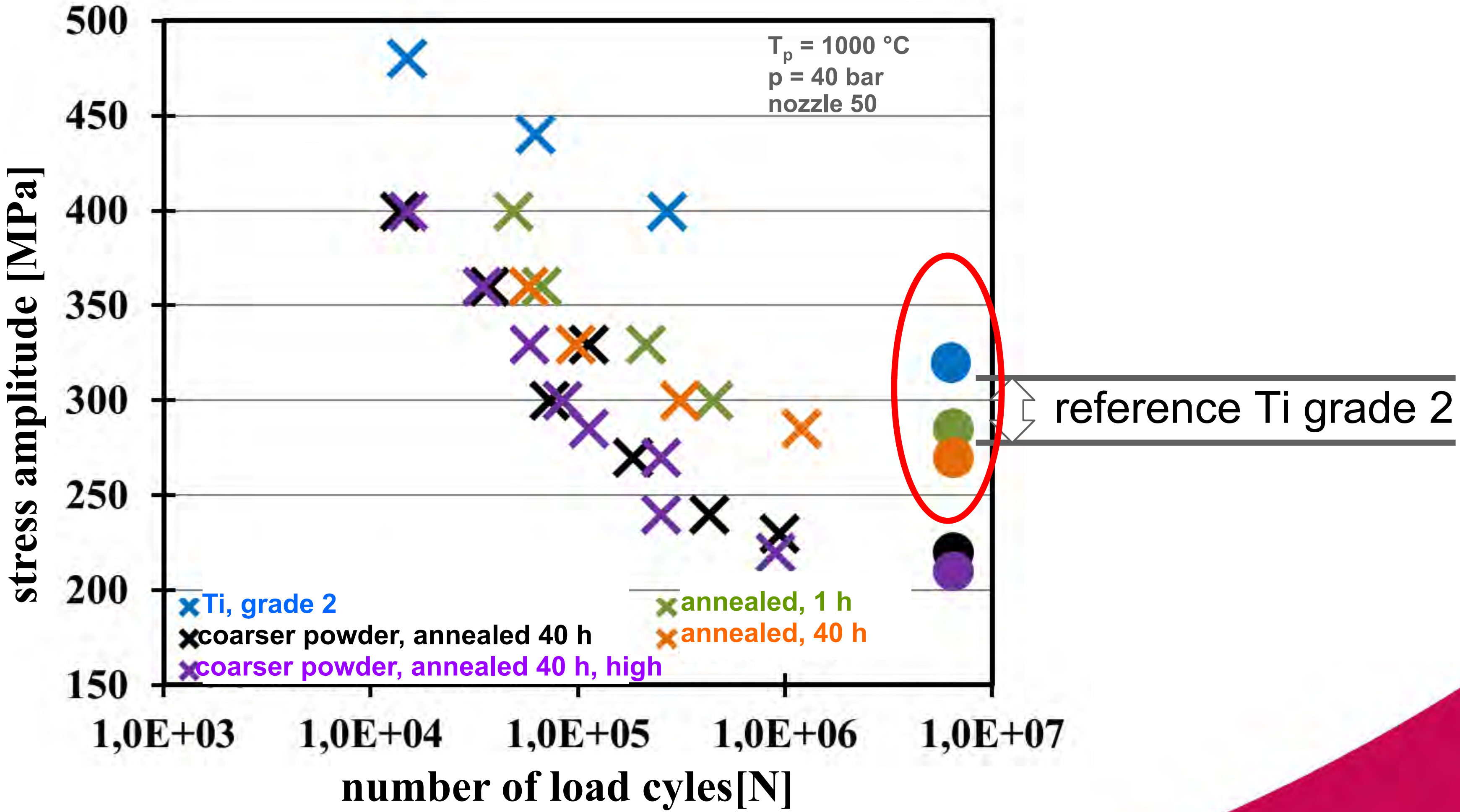

R = min. stress / max stress = 0.05
endurance limit: at > 7 x 10^6 cycles

HSU Cold sprayed Ti samples show damage tolerance during HCF-testing

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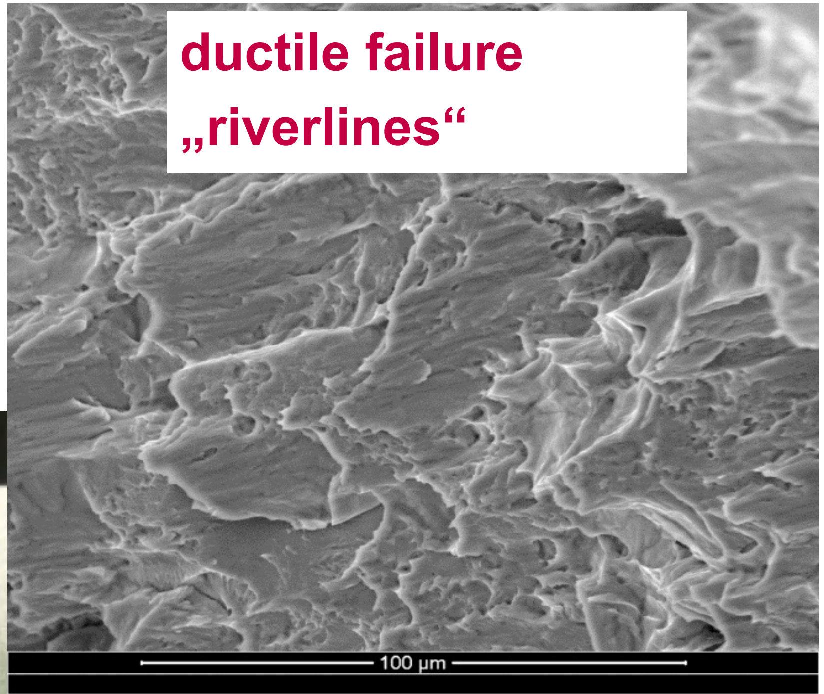
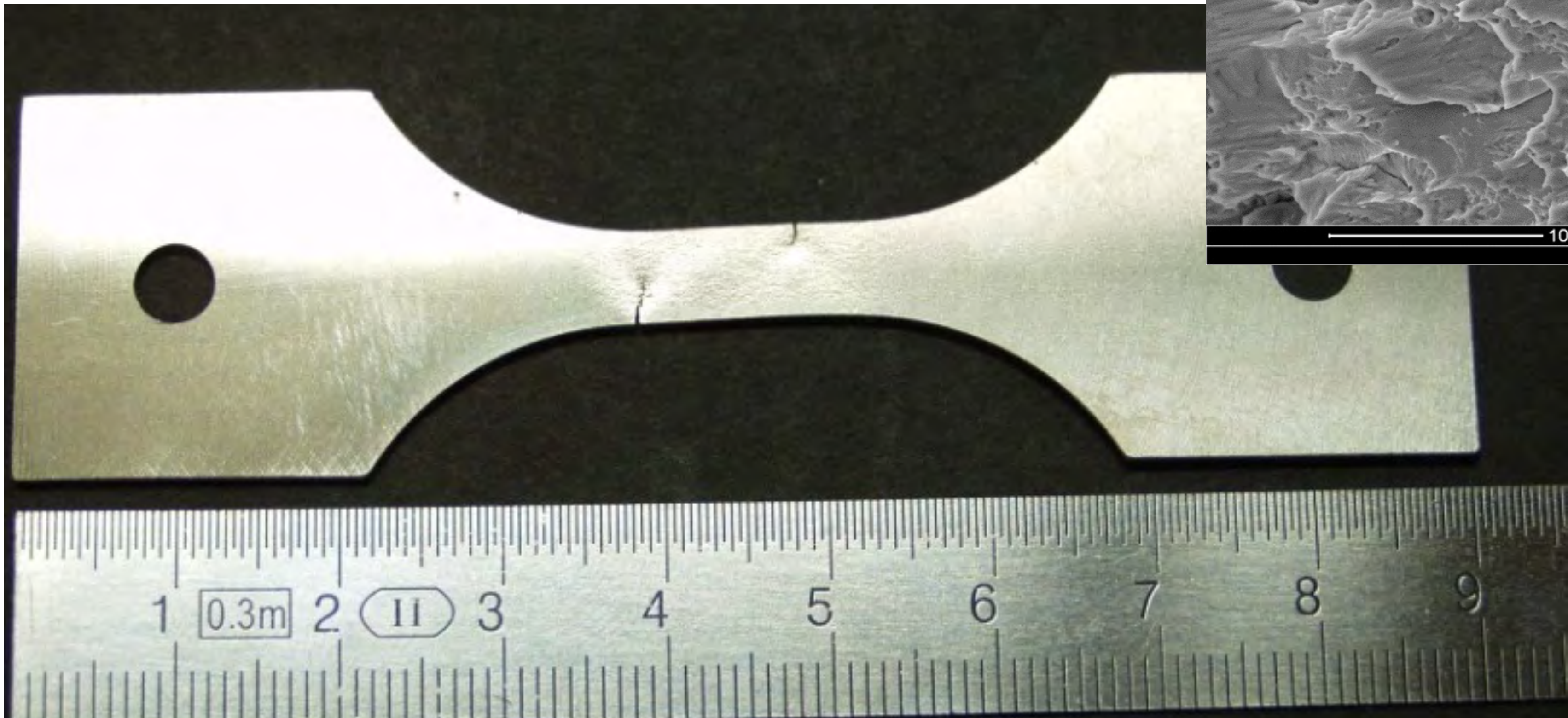


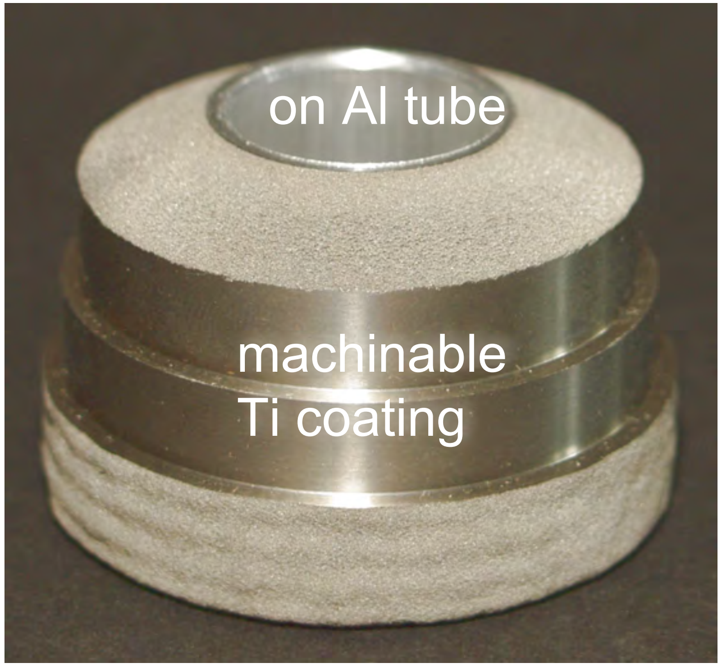
ductile failure
„riverlines“

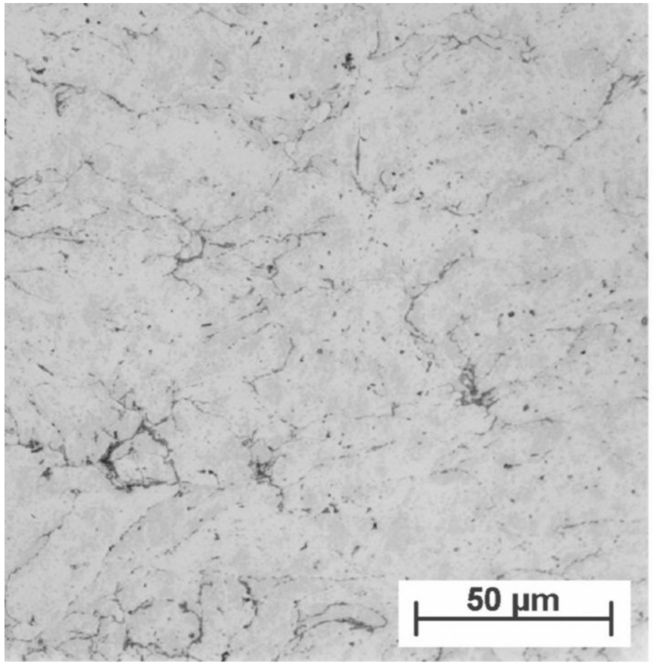
93 % of the fatigue endurance limit of bulk Ti Grade 2

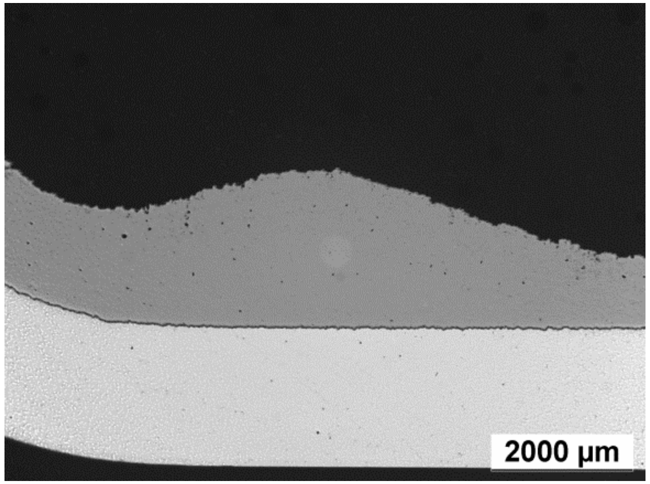


cold sprayed Ti
High Cycle Fatigue
specimen annealed for 1h

production of complex Ti-parts



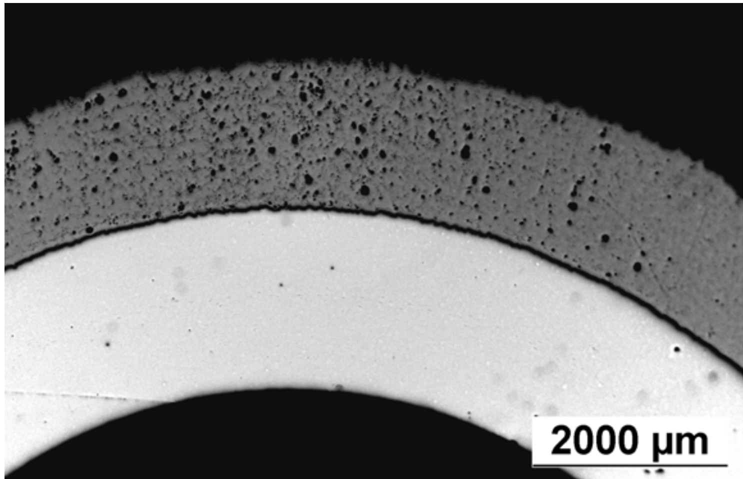


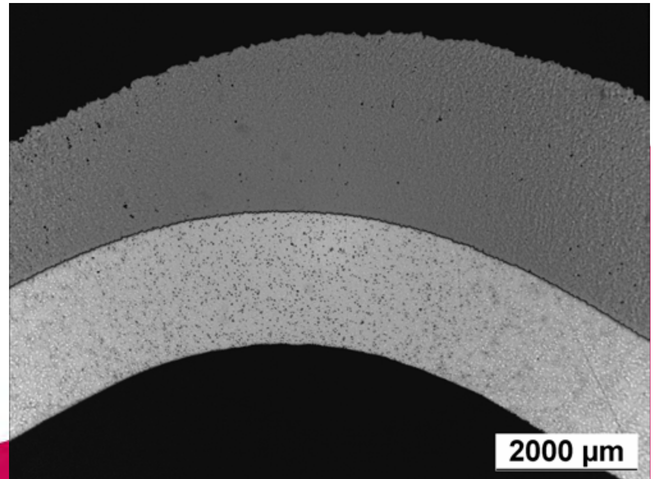


challenge:
impact angle
at contours

goals achieved:

- fatigue strength 93% bulk
- tensile strength 560 MPa
- < 0.1% porosity
- > 95% DE
- < 1500 ppm Oxygen
- > 10 kg Ti per hour





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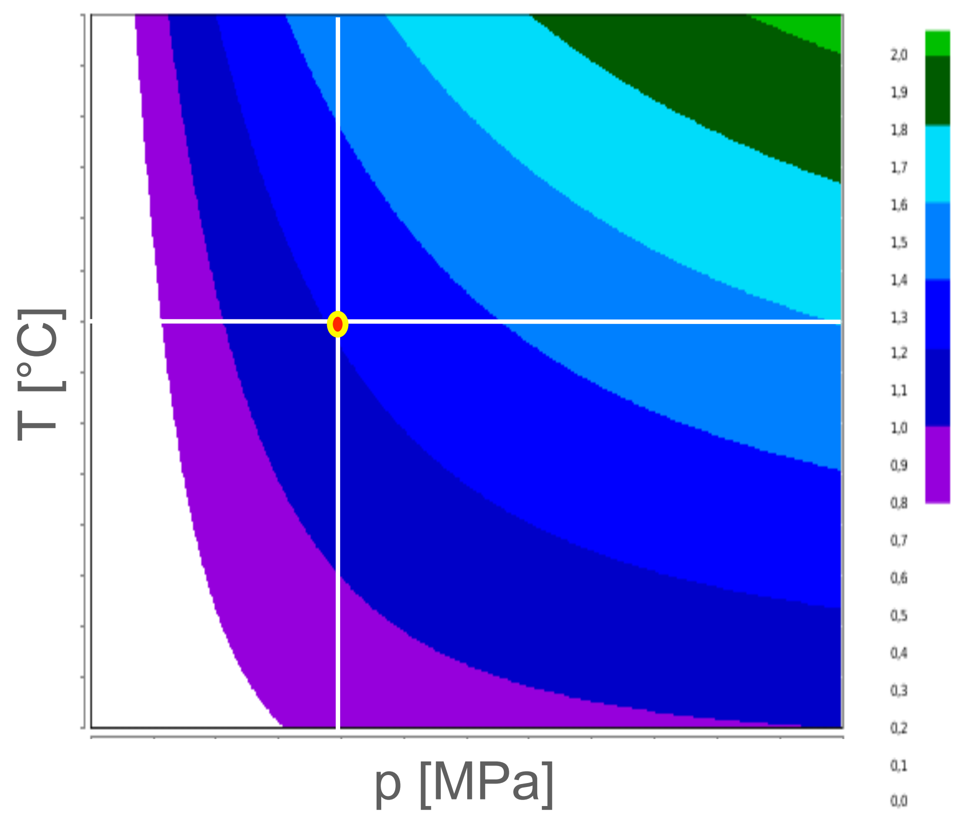
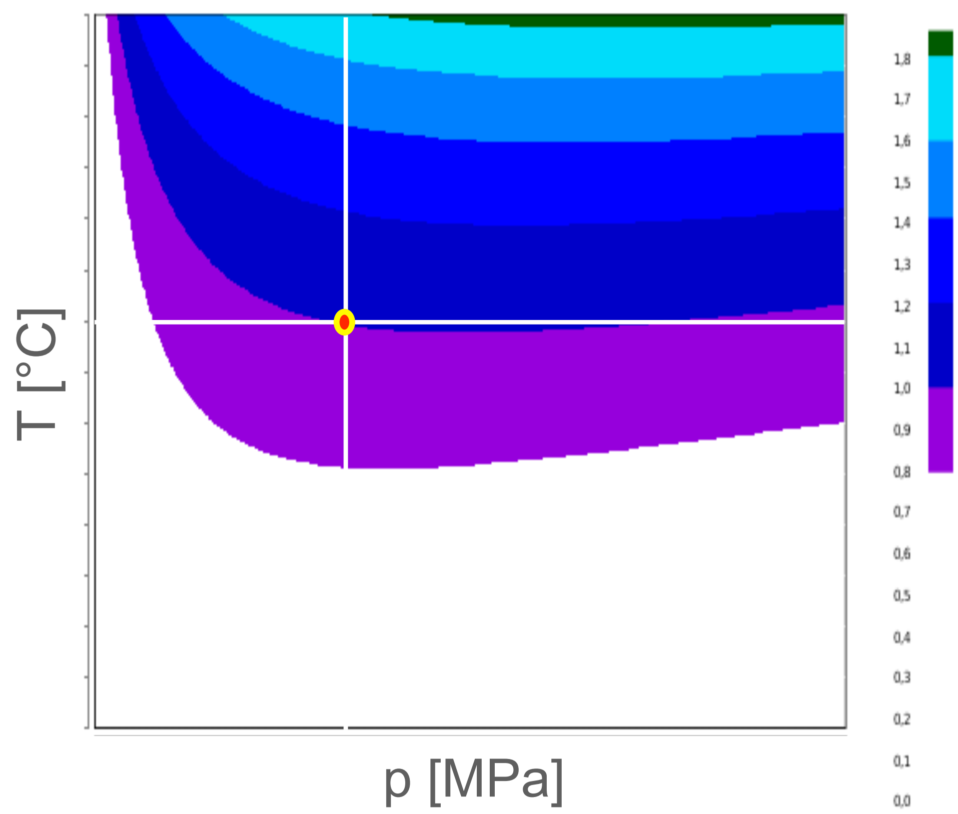
Cold Spraying of Al-alloys

Cold Spraying of Al-alloys
Parameter selection
η (gas pressure, gas temperature)

Helium



Nitrogen



Coating Microstructures

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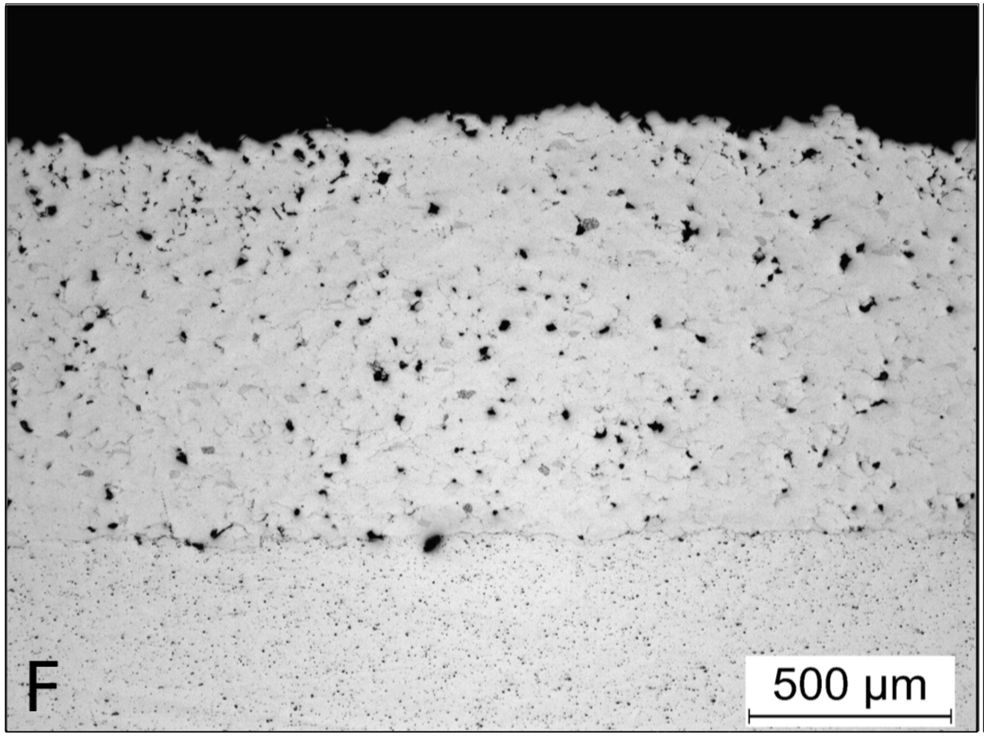
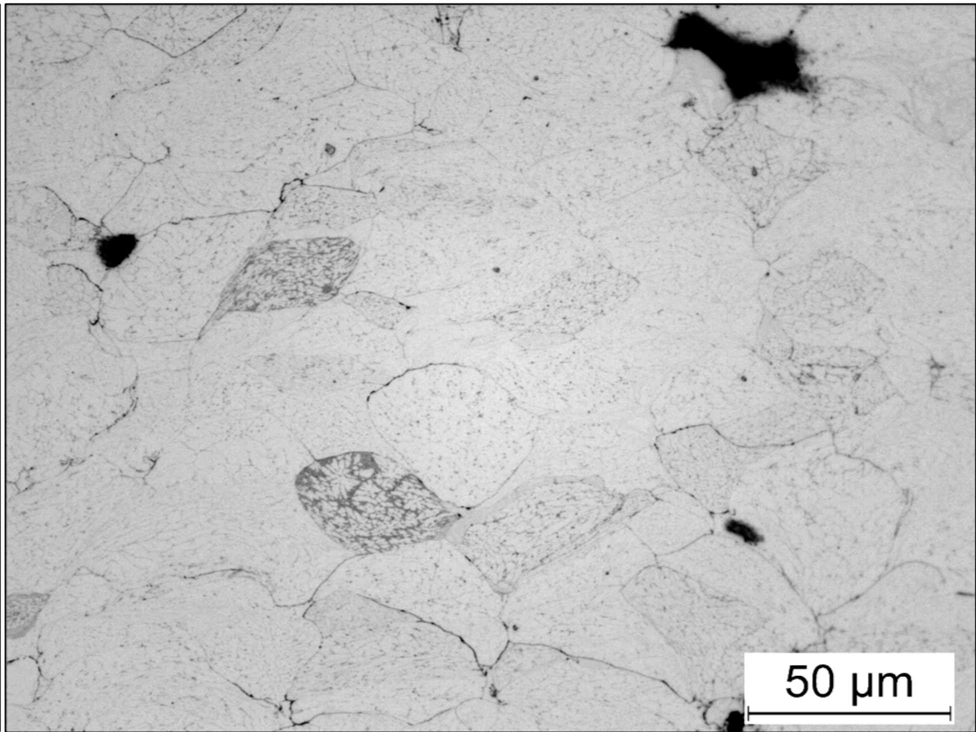
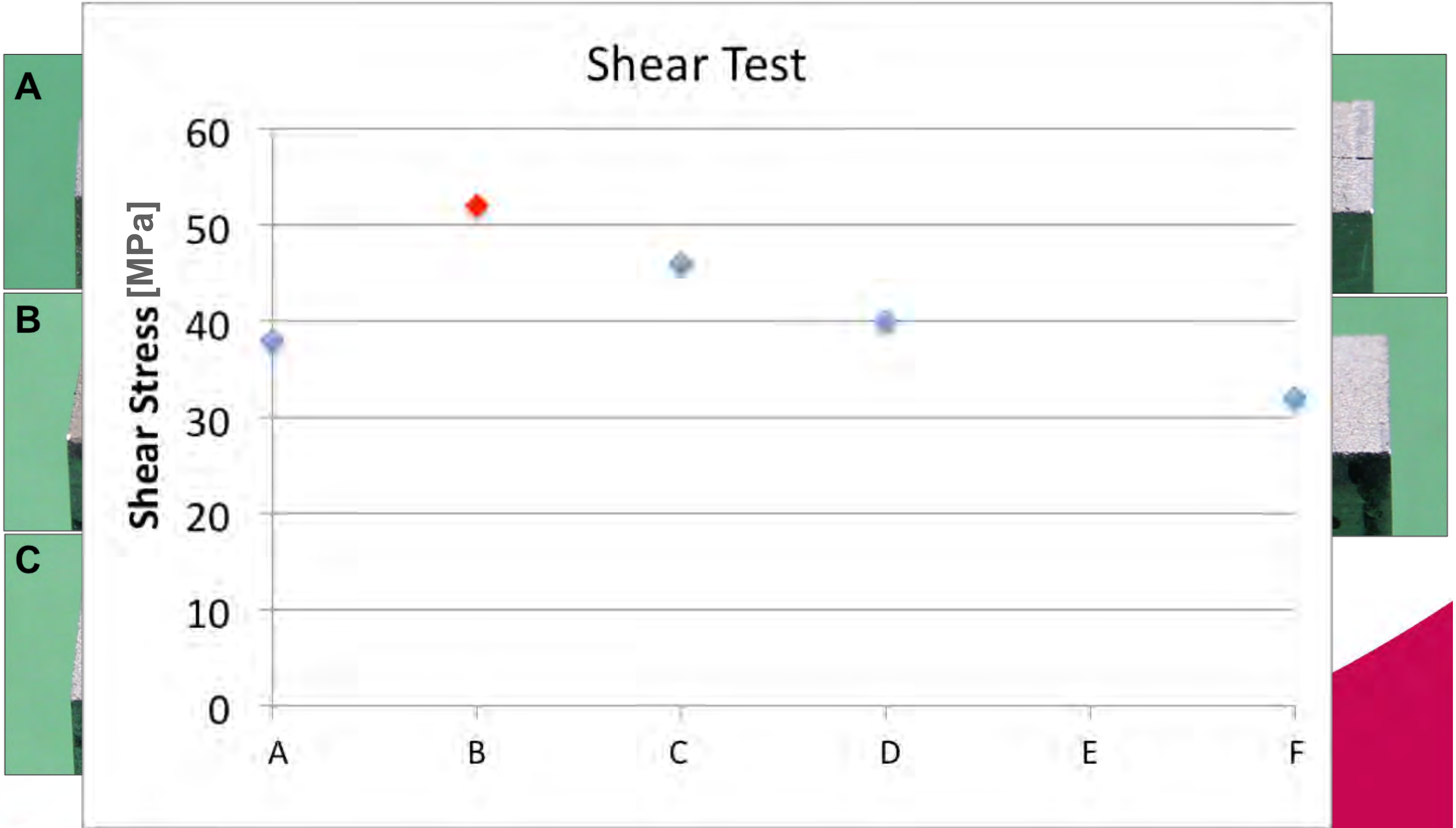
Spraying conditions	Cross-section hardness HV 0,3	Surface hardness HV 2.0	Porosity	η
A	97 ± 7	102 ± 7	0,8 ± 0,1	1.21
B	104 ± 5	105 ± 5	0,23 ± 0,05	1.35
C	106 ± 4	107 ± 4	< 0,1	1.45
D	105 ± 4	106 ± 8	< 0,1	1.14
F	89 ± 5	92 ± 6	1,73 ± 0,07	1.30





Shear Test



Coatings Strength (MFT)

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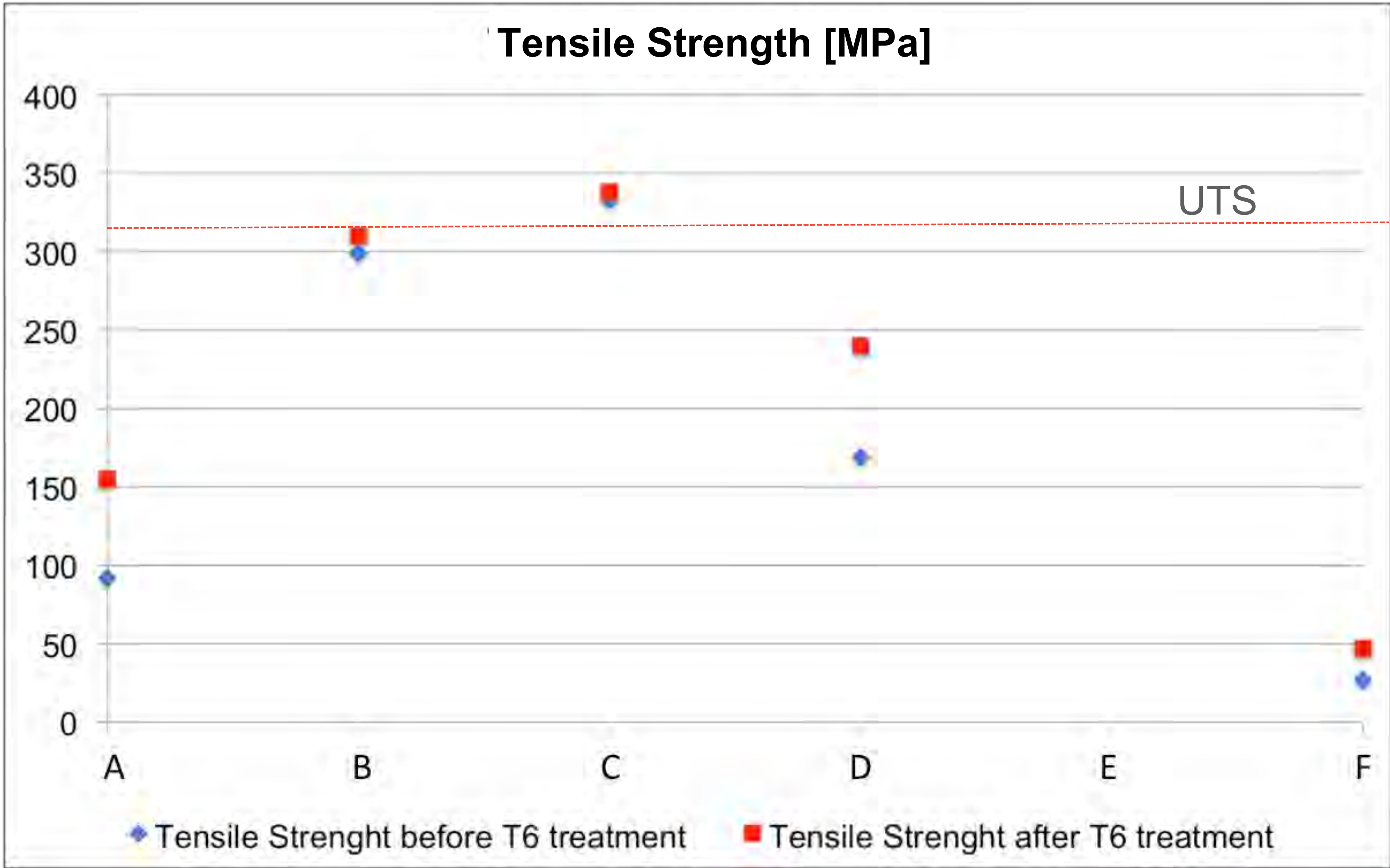

Tensile strength (MFT) vs eta

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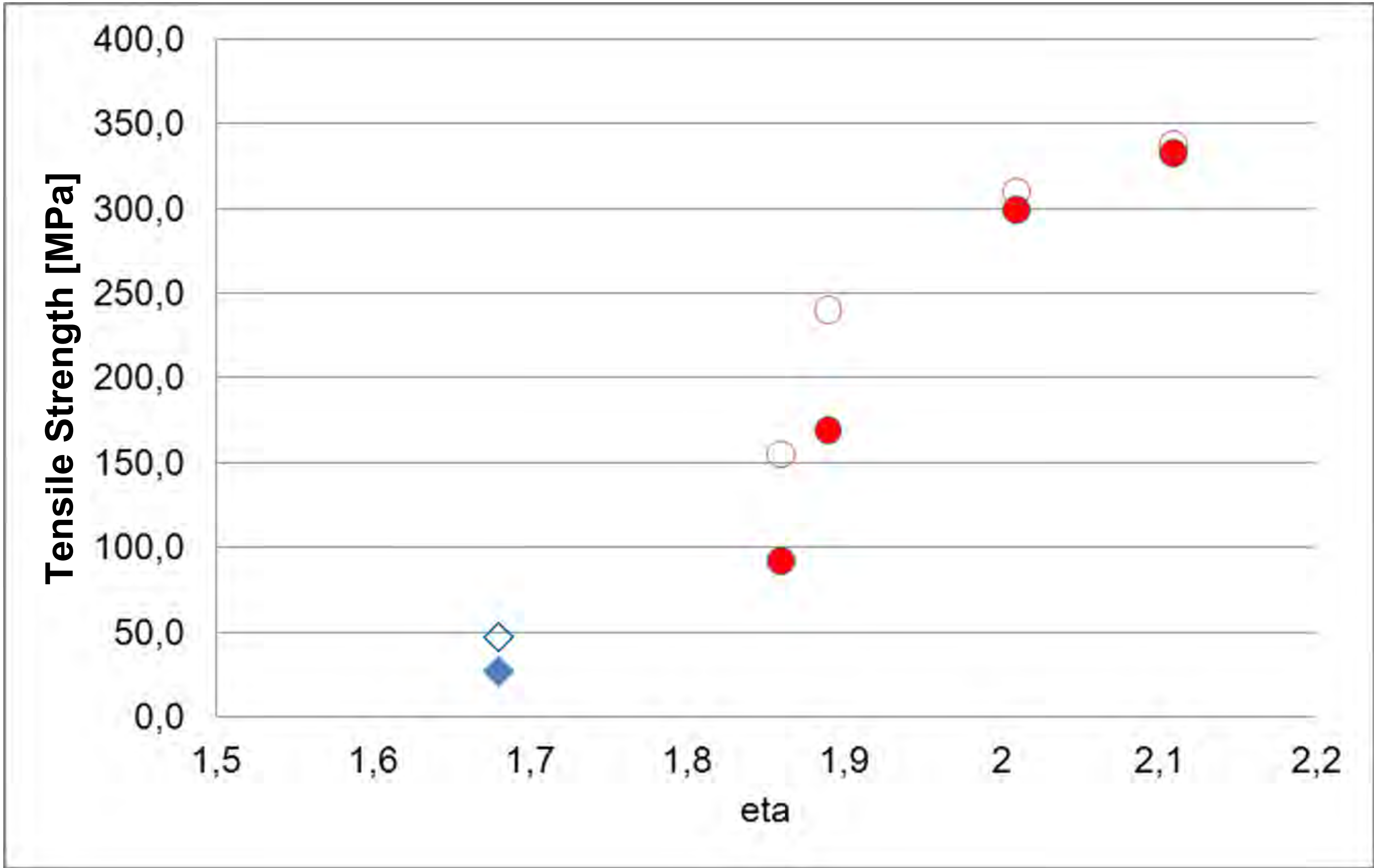
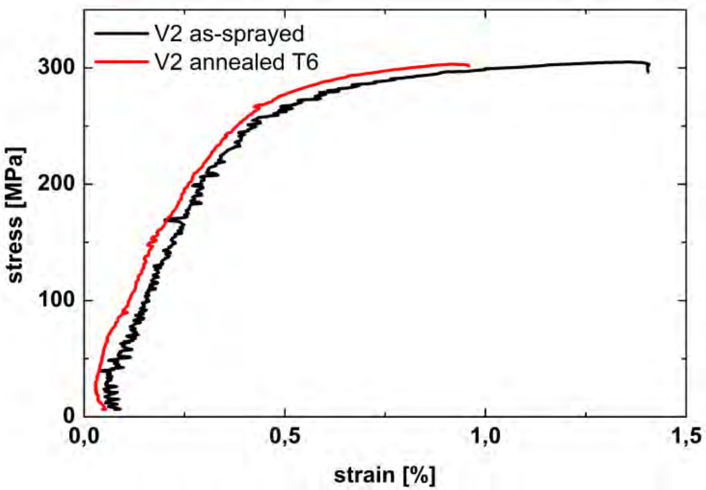
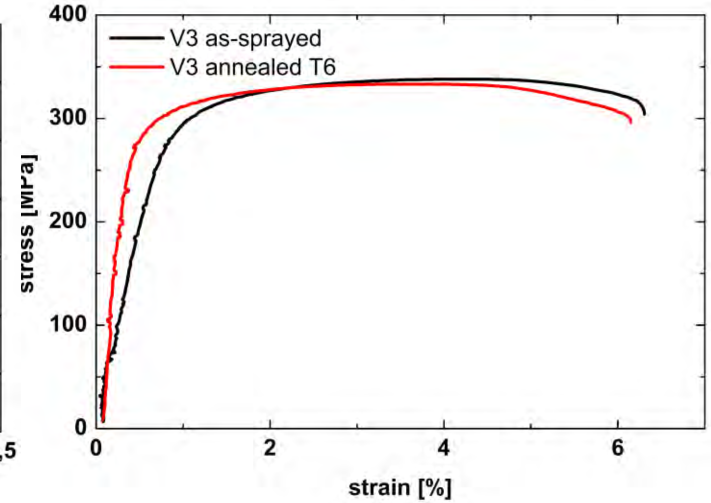
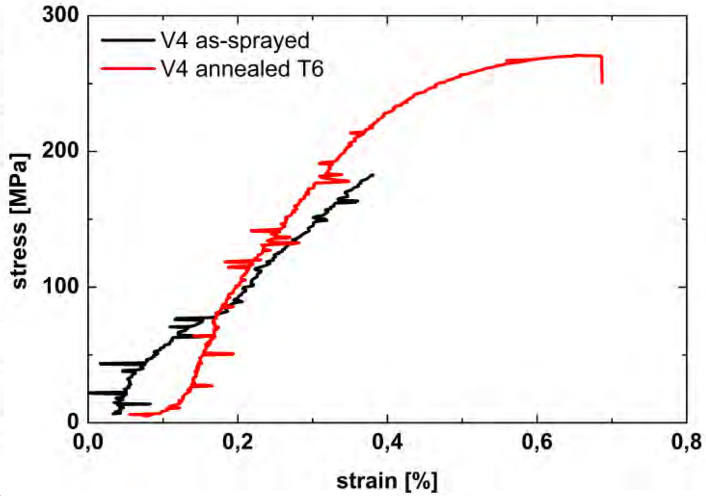


Coating Strength (MFT)

Parameters	yield strength (MPa)	UTS (MPa)	ductility (%)	total elongation (%)
B	277 ± 9	299 ± 6	0,7 ± 0,3	0,8 ± 0,3
B-T6 Treatment	289 ± 10	310 ± 4	1,0 ± 0,3	1,1 ± 0,4
C	293 ± 20	333 ± 3	2,7 ± 1,7	4,9 ± 1,7
C-T6 Treatment	291 ± 5	338 ± 7	3,1 ± 0,3	5,4 ± 1,0
D	-	169 ± 31	0,0	0,0
D-T6 Treatment	264	240 ± 36	0,1 ± 0,1	0,1 ± 0,1







Rupture Zone (MFT)

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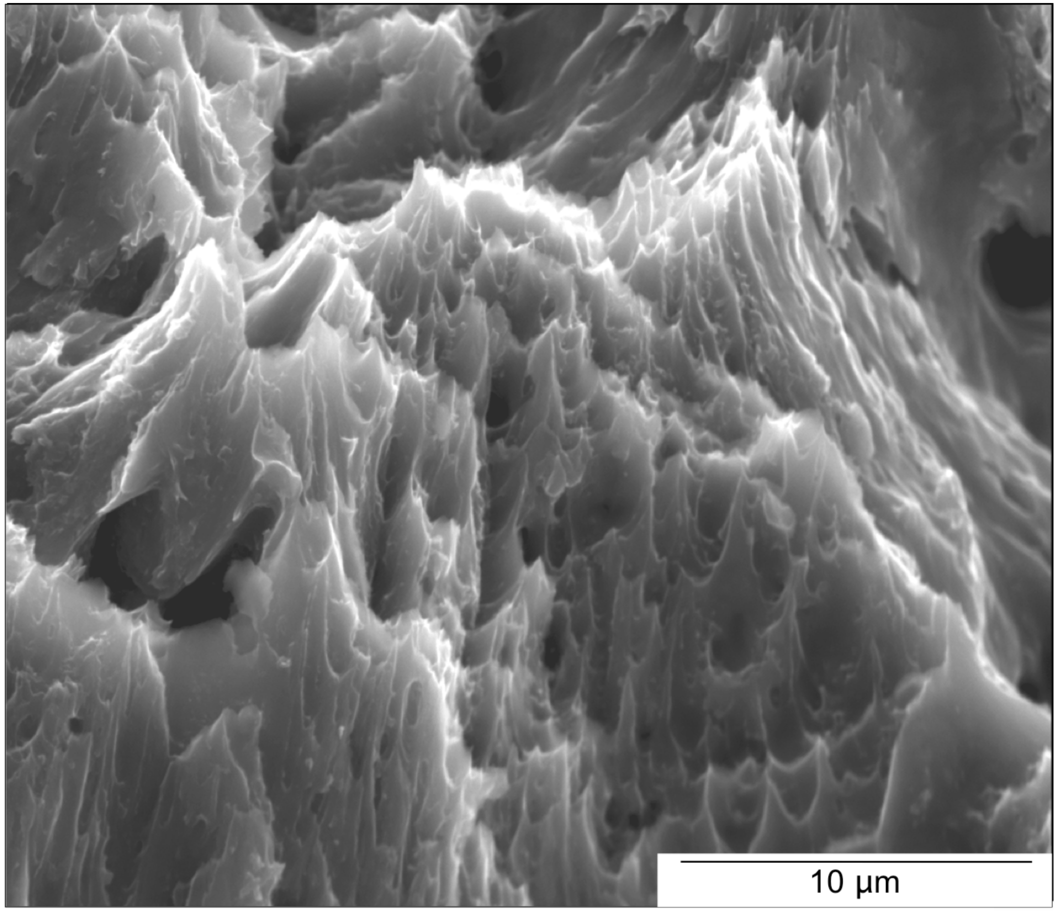

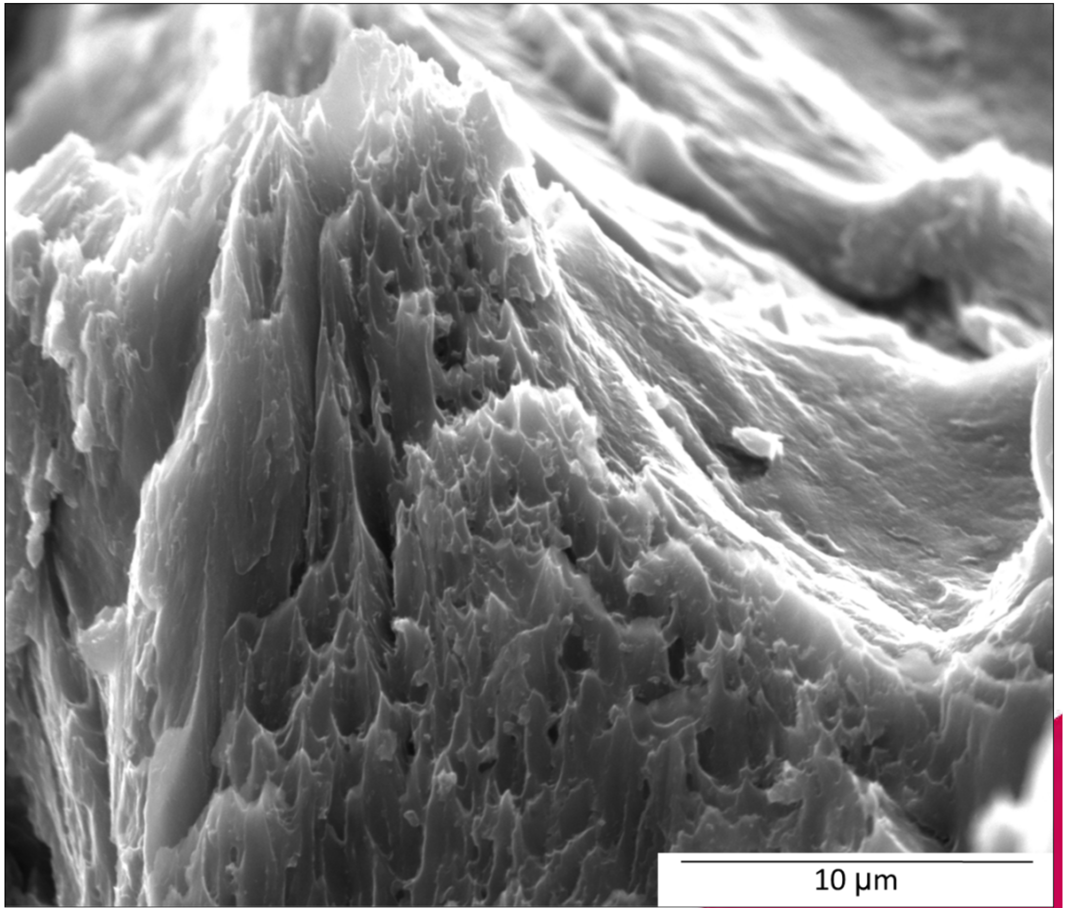

Quality Management: Electrical conductivity vs strength

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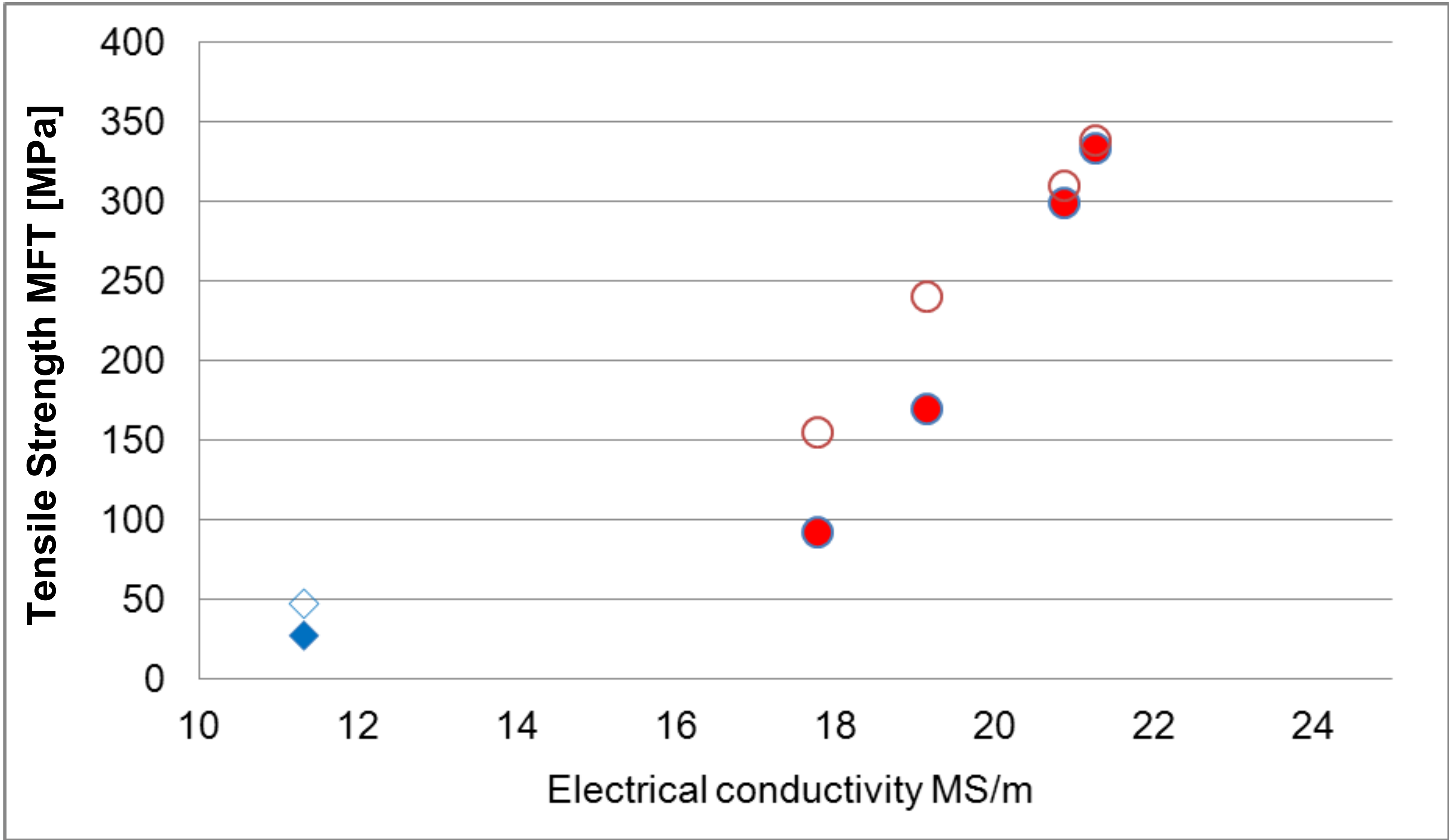

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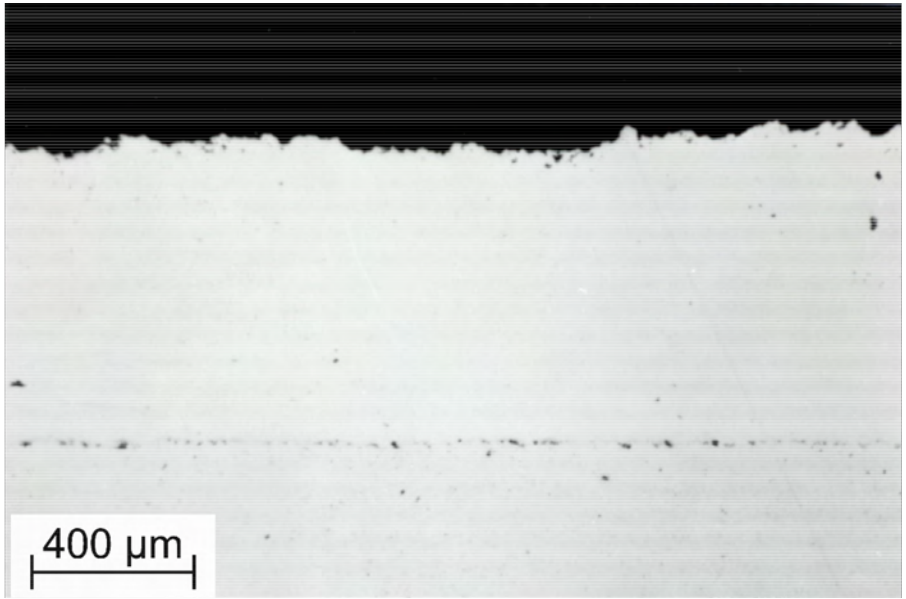
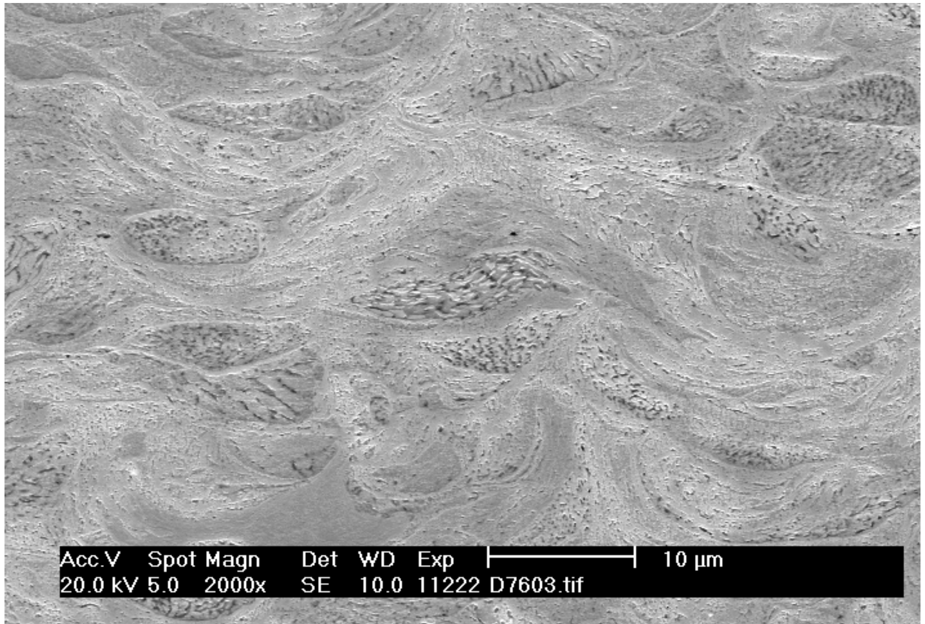
Kinetic Spraying – Ni-based superalloys

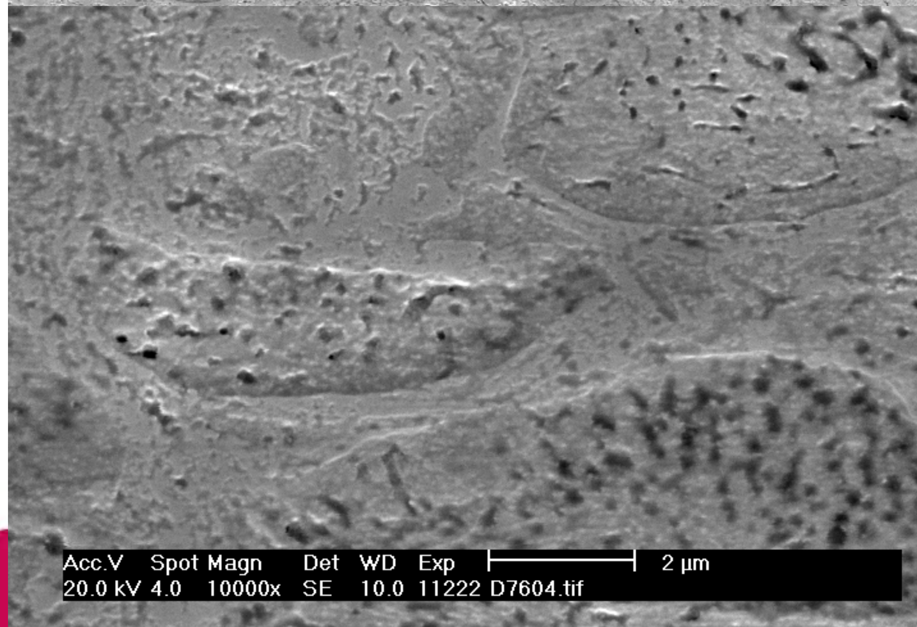
Ni-Superalloys: less brittle than expected due to deformation-induced phase transformation upon impact

- Dense coating despite low impact temperature by spraying with He

process gas: He







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Kinetic Spraying – Intermetallics

Intermetallic Fe - 40at.%Al

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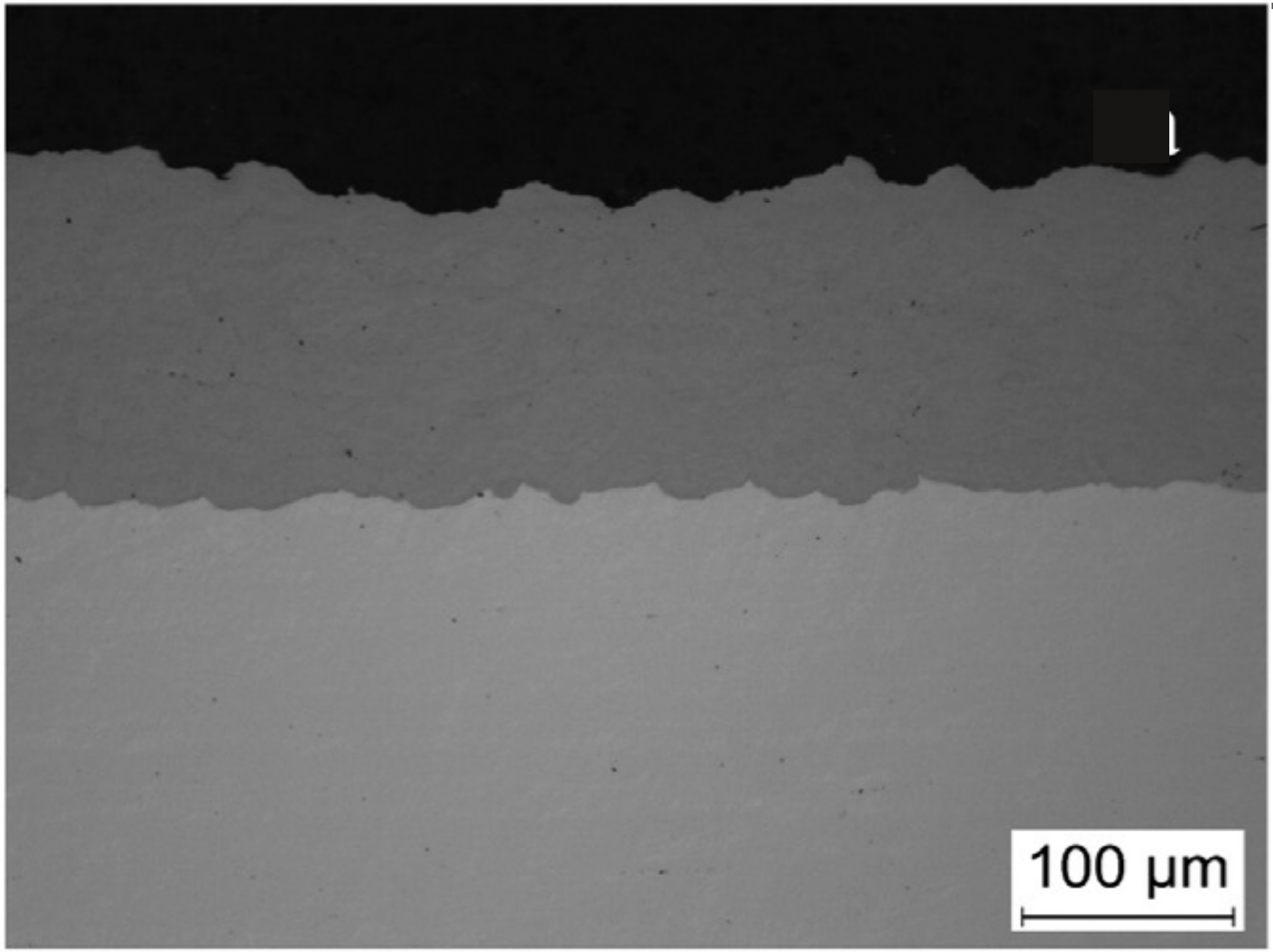
Centre de Projecció Tèrmica



Cinca, List, Gärtner, Guilemany, Klassen: Surf. Coatings Technol. 268 (2015) 99

conclusions

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Helmut Schmidt Universität

Lufthansa Technik
More mobility for the world

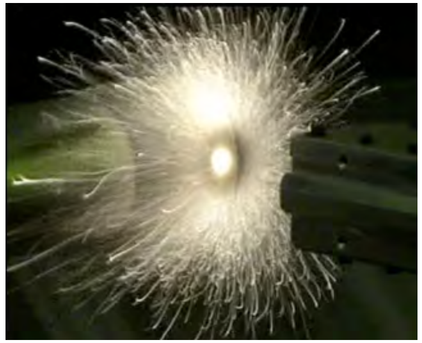
Understanding Mechanisms

Development of Spray Equipment

coating quality
„all-inclusive“ η

KINETIC SPRAY SOLUTIONS

Kinetiks 8000-X:
nozzles, p, T



Cold Spraying
for Aerospace Applications:
bulk properties
in repair or manufacturing!