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Kaltgasspritzen: Prinzip und Einsatzpotentiale für hitzeempfindliche Werkstoffe

F. Gärtner,
A. List, K. Binder, T. Schmidt, T. Klassen

Helmut Schmidt University
University of Federal Armed Forces Hamburg
Germany

Workshop: Metallische Massivgläser, Hanau, Germany, April 28th, 2011

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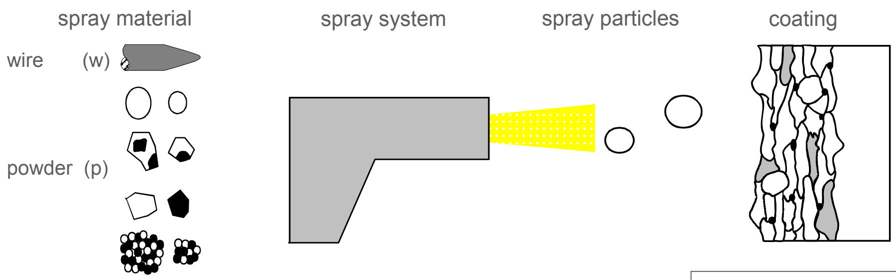
Overview of Coating Techniques

Typical Coating Thickness [µm]	Technique	Deposition from	Substrate Temperature [°C]	Typical Material
0,1 - 2,0	CVD / PVD	gas	CVD (300 - 1000) PVD (100 - 400)	TiC,....
0,5 - 150	electro / electroless plating	electrolyte	30 - 90	Ni, Cr, Cu, metallic alloys
100 - 500	thermal spraying	molten alloys	100 - 250	metallic alloys, ceramics, composites
50 – 1000 (max. 50.000)	cold spraying	solid alloy	30 - 200	ductile materials, composites
2000 – 10.000	weld cladding	molten alloys	> 1000	alloyed steels, hard alloys, (composites)
500 – 50.000	cold rolling, explosive cladding	solid alloys	30 - 150	ductile materials, (Al – alloys, steels)

hot: „warm“: cold:

The Thermal Spray Process



flame	(w, p)	
plasma	(p)	
electric arc	(w)	
vacuum plasma spraying		VPS
high velocity oxy-fuel spraying		HVOF
kinetic spraying / cold spraying		**CS**

pores
oxides
phase transformations
internal stress

Heat Sensitive Materials

- metastable phases (amorphous, quasi-crystalline)
- non equilibrium microstructures (nano-crystalline)
- highly oxidative alloys

➢ **easy to process as powder**

➢ **difficult to densify to massive parts**

➢ **possible solution:**

➢ **replacing thermal by kinetic energy input (like in explosive compaction)**

Influence on Coating Properties: Cu

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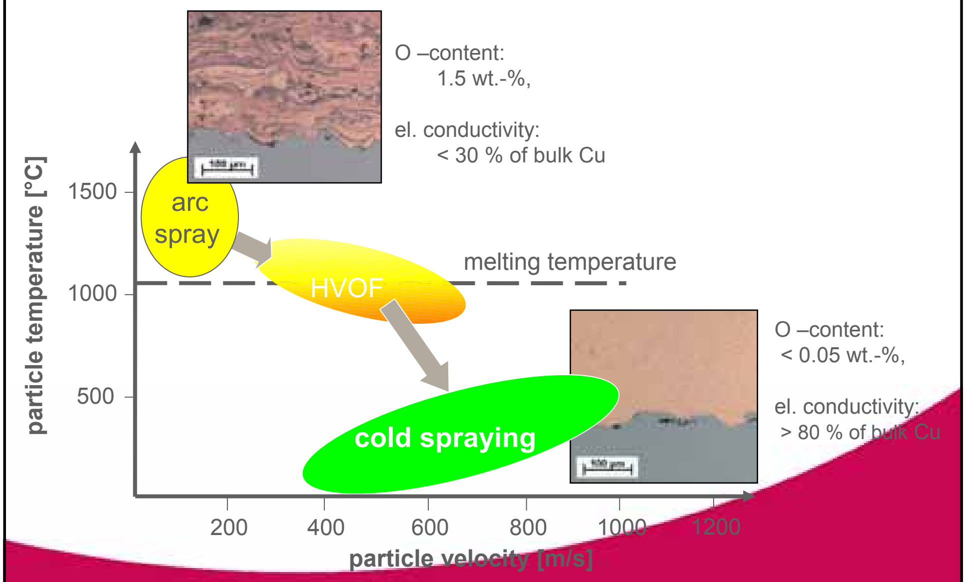

Impact Effects: Deposition and Erosion

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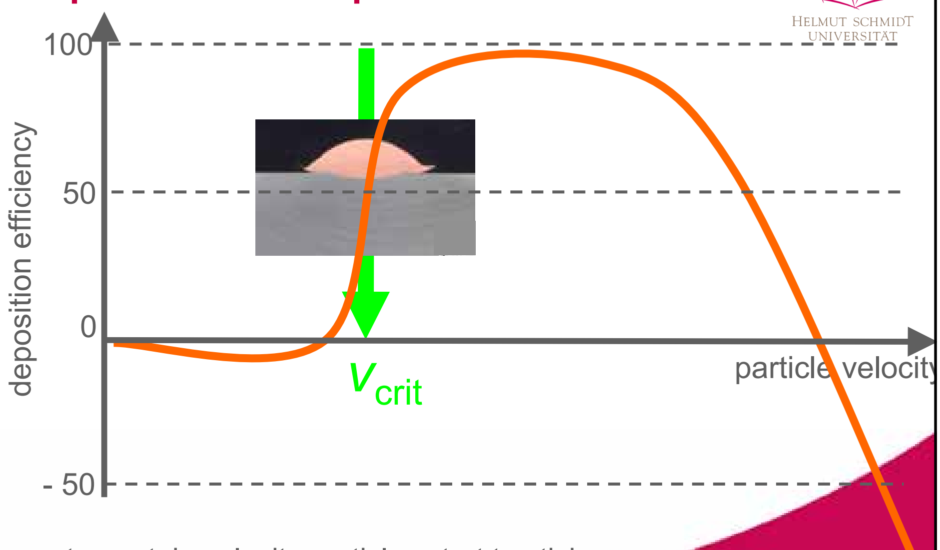

at a certain velocity particles start to stick

- ✓ at a DE of 50 % the critical velocity is defined

“Window of Deposition”

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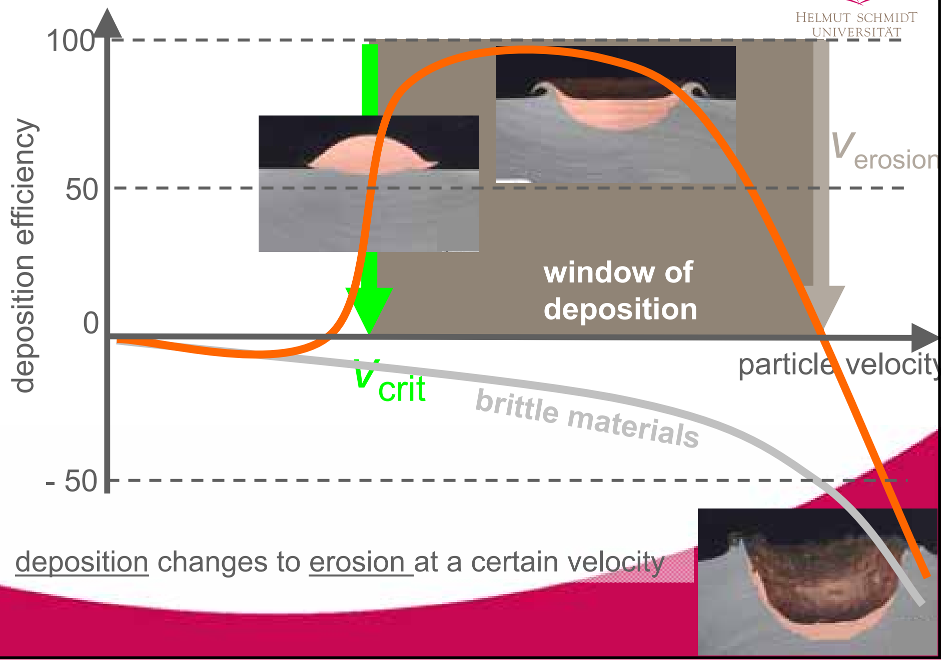

deposition changes to erosion at a certain velocity

Requirements: Powder

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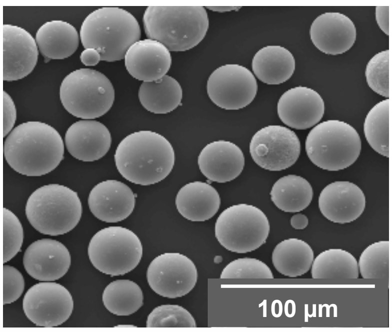
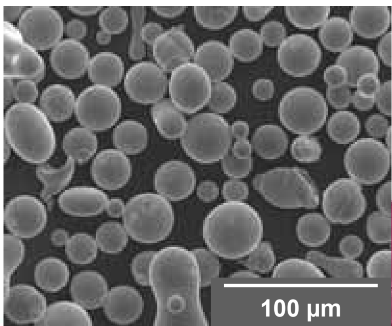
sizes: typically 15 to 50 µm, very low oxygen content

amorphous ZrCuAlNi alloy,
sizes < 45 µm



amorphous FeCrCoMoBC alloy,
sizes < 45 µm



Requirements:
Energy supply by Cold / Kinetic Spraying

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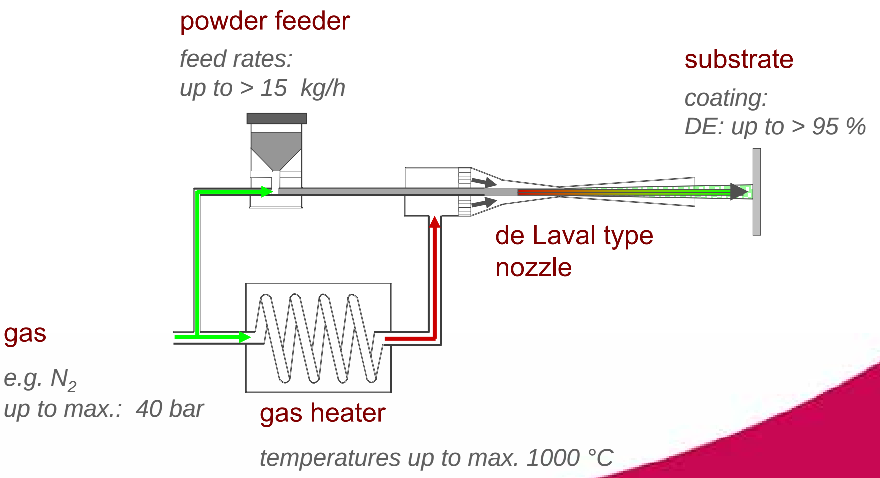

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General Features: Cu as an Example

Example: Cold Spraying of Copper

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Modeling: Particle Impact Cu/Cu

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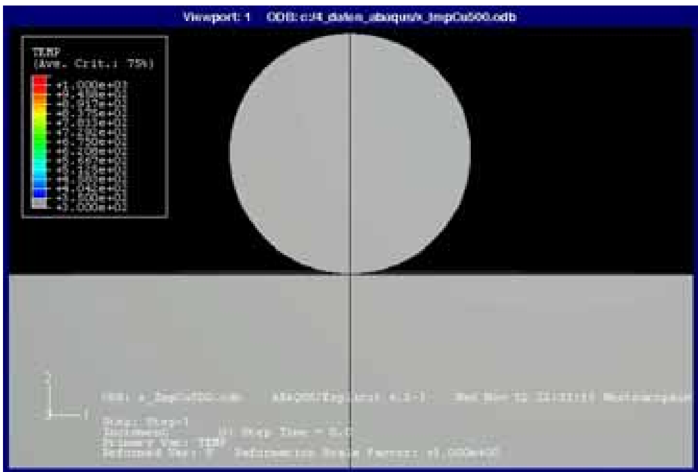
temperature field, adiabatic calculation, v = 500 m/s



Bonding Mechanisms / Critical Velocities: Bonding by shear instabilities

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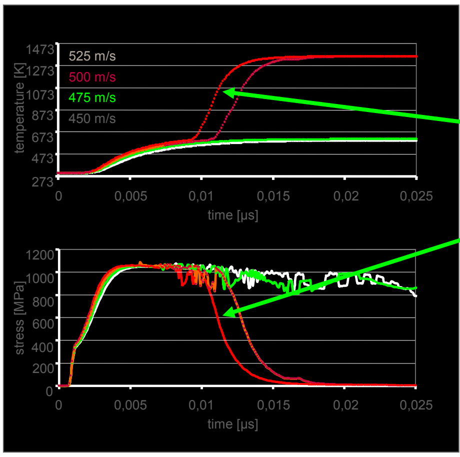

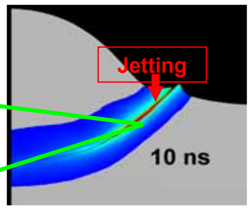

thermal softening and break-down of local stress at interfaces by viscous like flow

results from modeling impacts of Cu on Cu

time scales:

heating / quenching: ~ 10^9 /s

deformation: ~ 10^9 /s

Particle Impact - Exp. Observations

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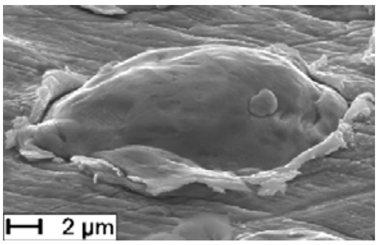
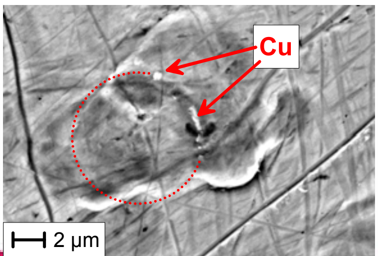


copper on copper

jet formation indicates localized plastic flow of material at the interface.



copper on steel

bonding extends from the rim of crater inwards – never reaches centre.

Area of Bonding

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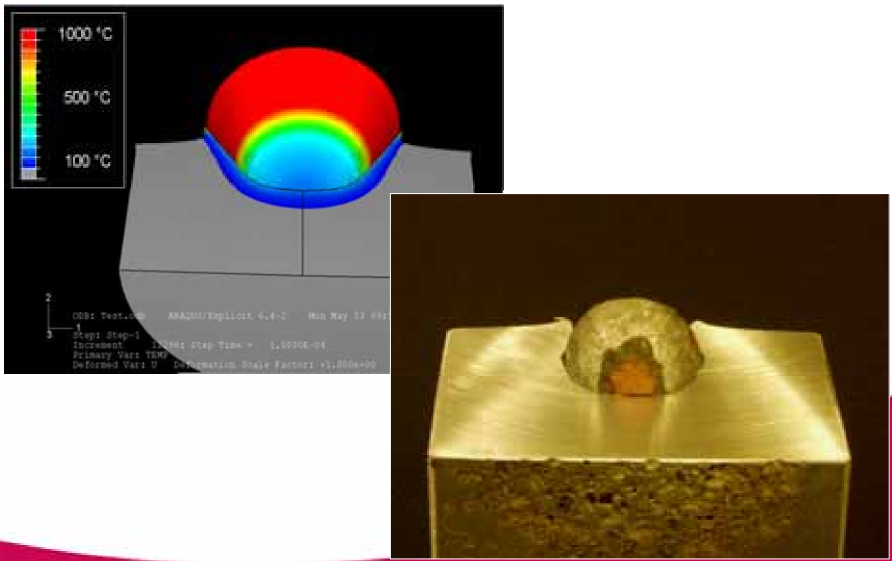

Process Improvements: Window of Sprayability

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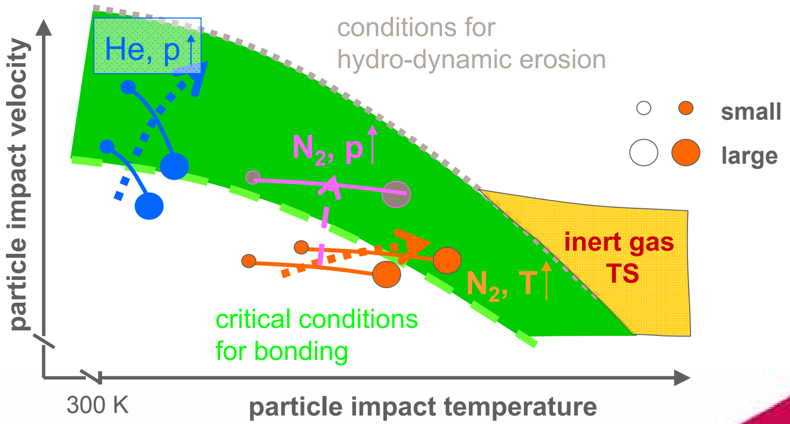

He route: very fast, **cold impact condition** (costly)

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

DE & UTS = function of impact conditions

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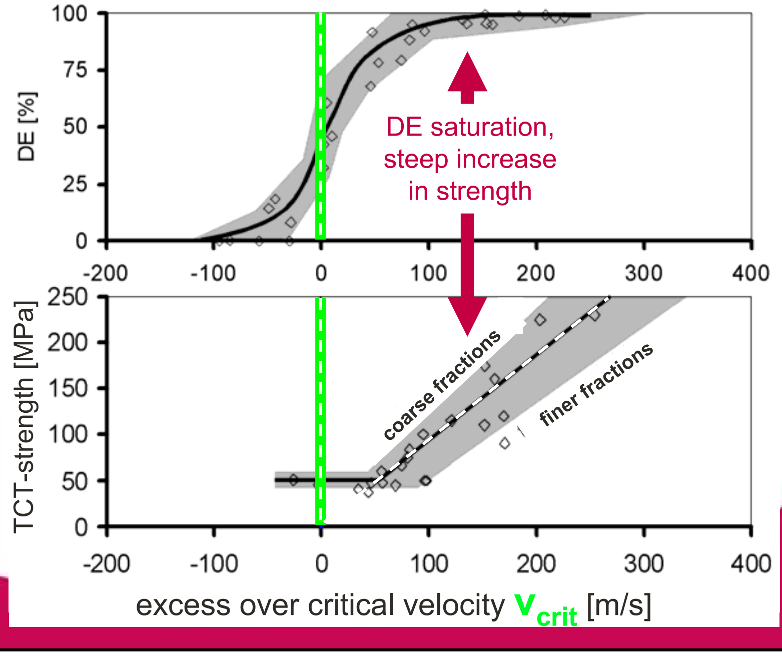

Impact conditions ⇒ microstructure & properties

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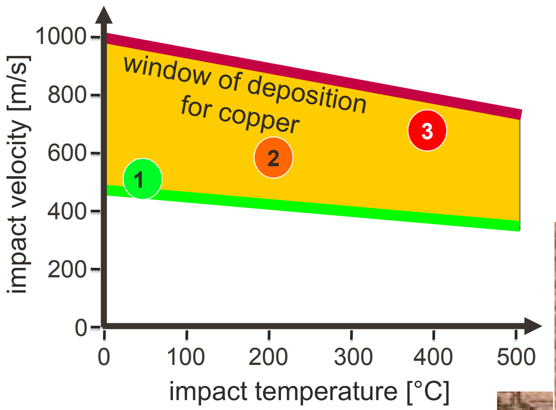
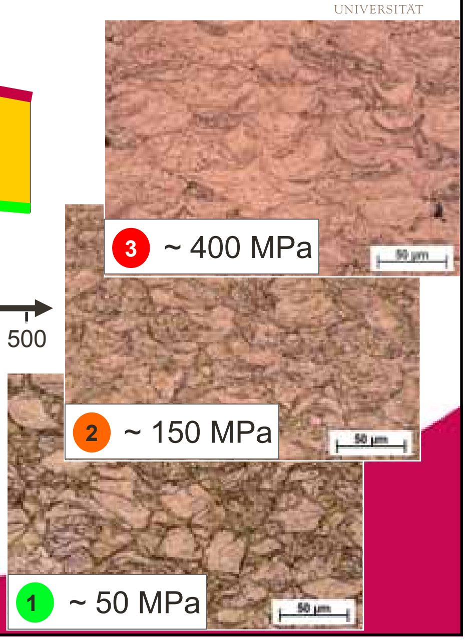


1 trumpet nozzle (Papyrin, 2001)
2 **MOC** nozzle (Stoltenhoff, 2004)
3 new spray gun **Activejet** (Schmidt, 2006)



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Zn-Coatings for Laser Gravure

Zn-, Zn-Alloy- Coating Microstructures

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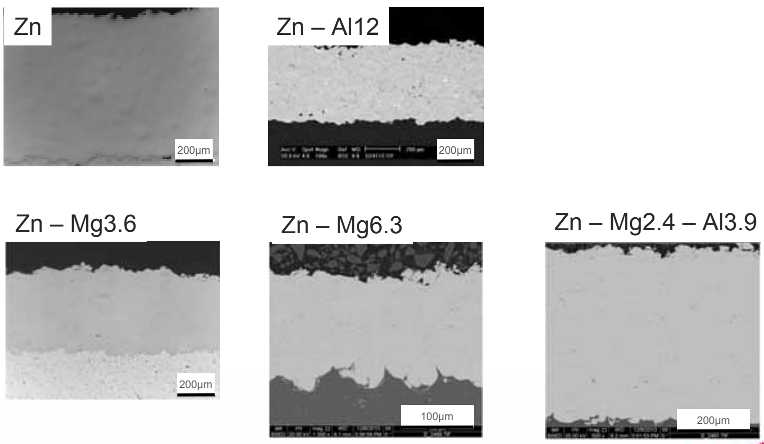

Zn-, Zn-Alloy- Coating Microstructures

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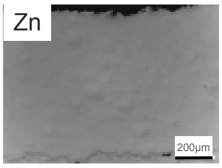
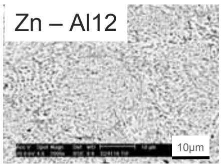
Zn

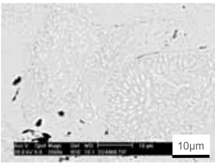


Zn – Al12

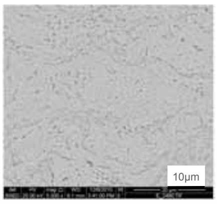


Porosity 0 – 0.3%

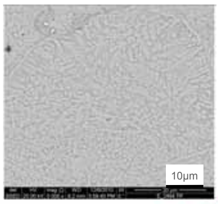
Zn – Mg3.6



Zn – Mg6.3



Zn – Mg2.4 – Al3.9



- very low porosities
- microstructures with features < 2µm

Deposition Efficiency (DE), Mech. Properties

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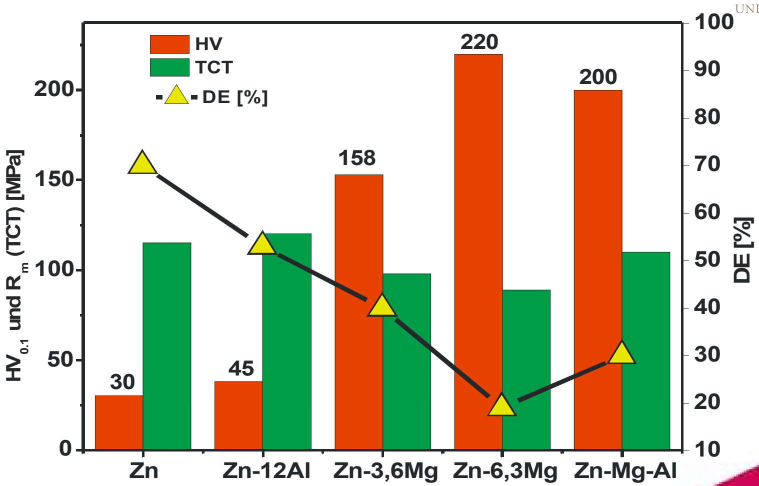
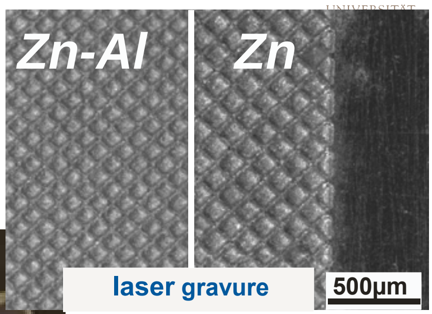


- Zn – Mg6.3 coating is 7 times harder than pure Zn coating
- DE is decreasing with increasing hardness

Prototype Rolls for Laser Engraving

Cold Spray coating
of Zn and Zn - 12Al



dimples:
- 20 ~ 32µm depth,
- 30 µm width

Cold Spray for Rapid Manufacturing

Complex **Ti**-Parts for Aviation Industry

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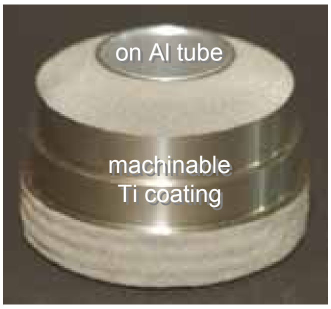
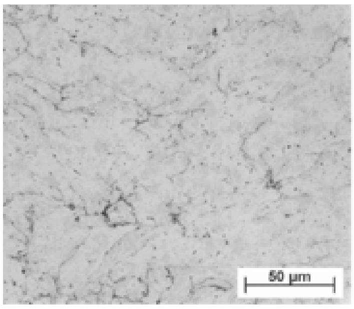
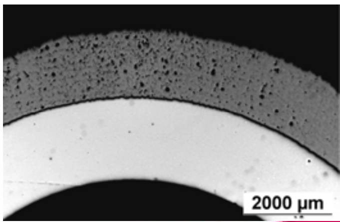
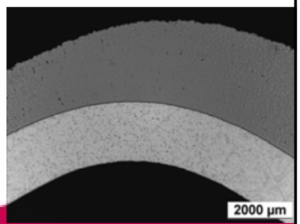




challenge:
impact angle
at contours

goals achieved:
- yield strength 465 MPa (tensile test)
- < 0.1% porosity
- > 95% DE
- < 1500 ppm Oxygen





BMBF LuFo-Project together with GE, Linde, CGT

Example: Cold Spraying of Titanium

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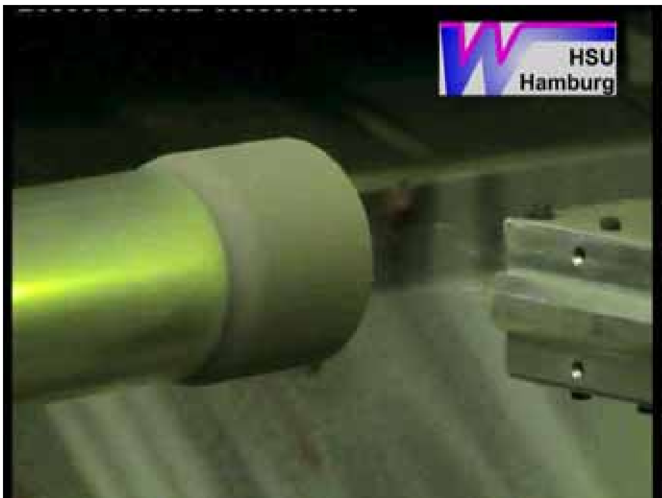

Impact Conditions for Deposition: Ti

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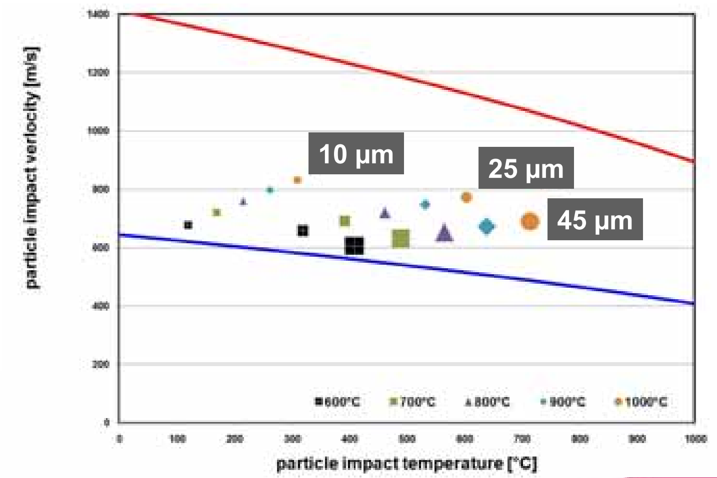

⇨ exceeding v_{crit} by > 200 m/s

Ti - Coatings: Cold Spray Conditions

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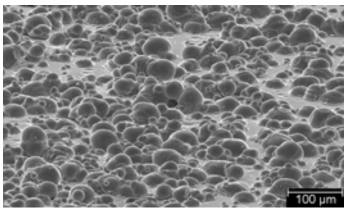
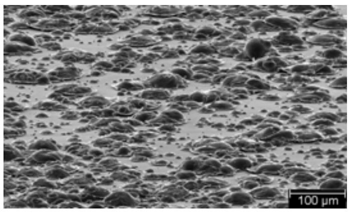
T_{gas} = 600°C, p_{gas} = 4 MPa

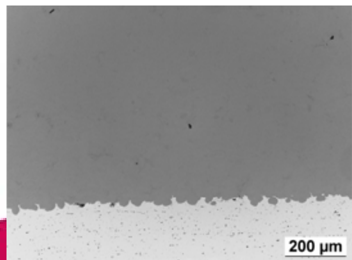
T_{gas} = 1000°C p_{gas} = 4 MPa

impact morphologies

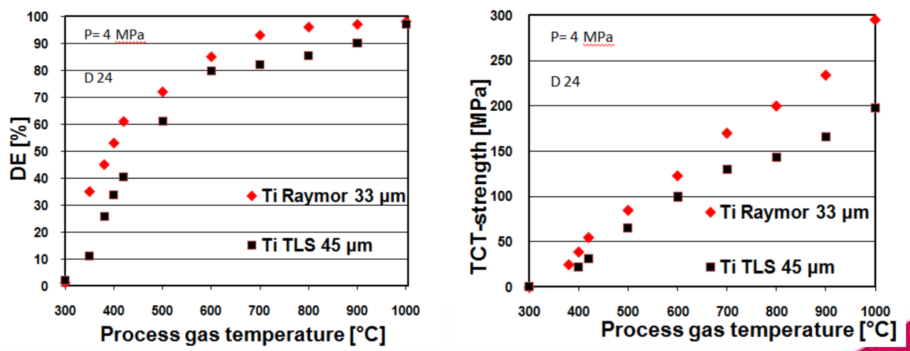




coating microstructure



Ti - Coatings: Cold Spray Conditions



Ti: Excess Velocity

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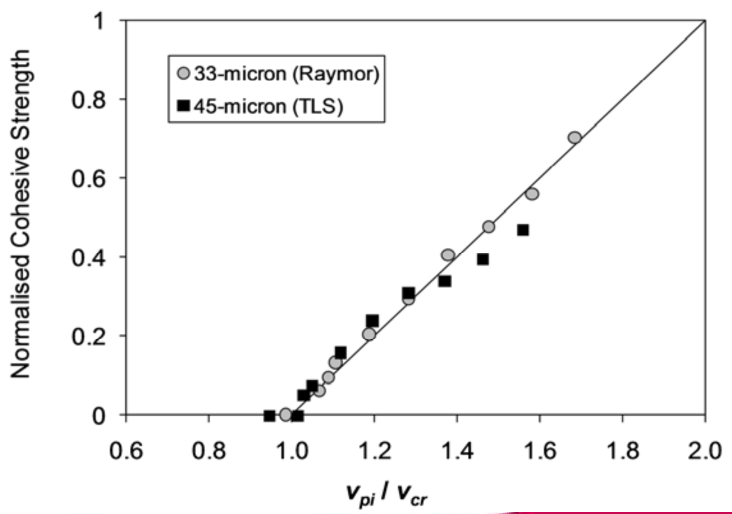

Ti: Coating Strengths

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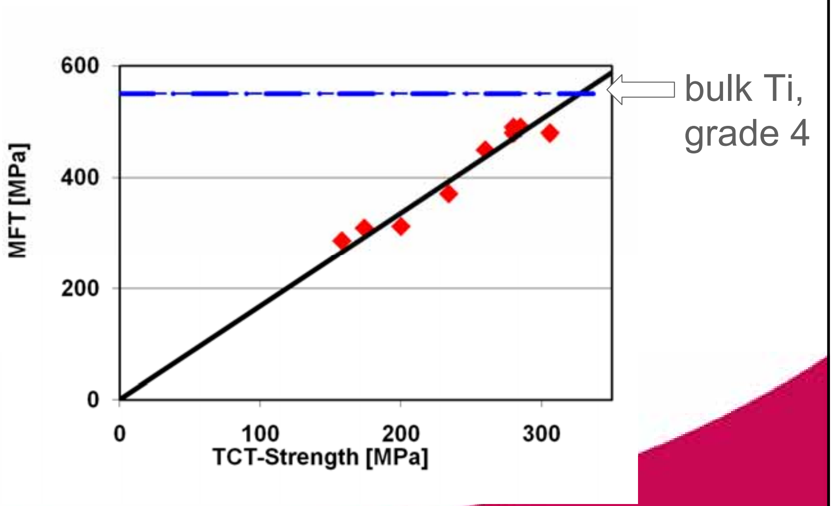

Application to Amorphous Alloys ??

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heat creation modes by kinetic energy:

$T < T_g$:
localized shear band formation by high strain rate deformation

$T > T_g$:
viscous flow

→ **localized temperature rise at regions of highest strain rates**

am. $Fe_{44}Co_6Cr_{15}Mo_{14}B_{15}C_6$: T_s = 860 °C ~ 1.3 T_g

Impact Conditions, Window of Sprayability: am. FeCoCrMoBC, Size Cut 25- 45 µm

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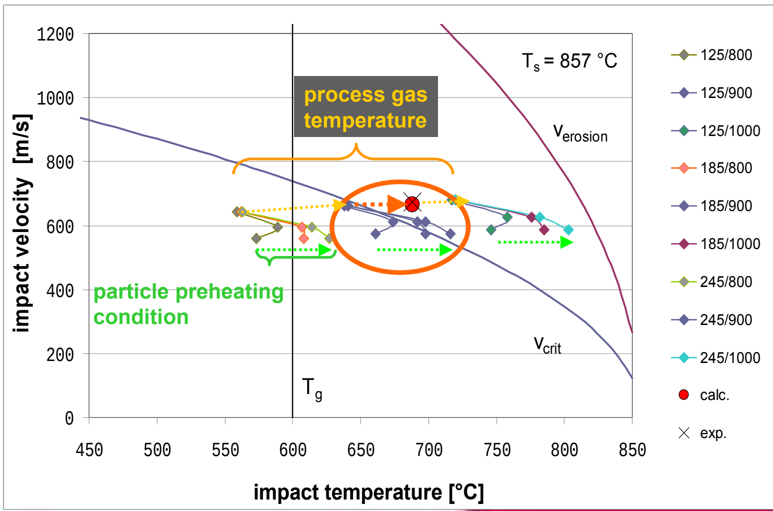

process gas : N_2

Amorphous $Fe_{44}Co_6Cr_{15}Mo_{14}B_{15}C_6$: Impact Scenarios (on steel 1.4301)

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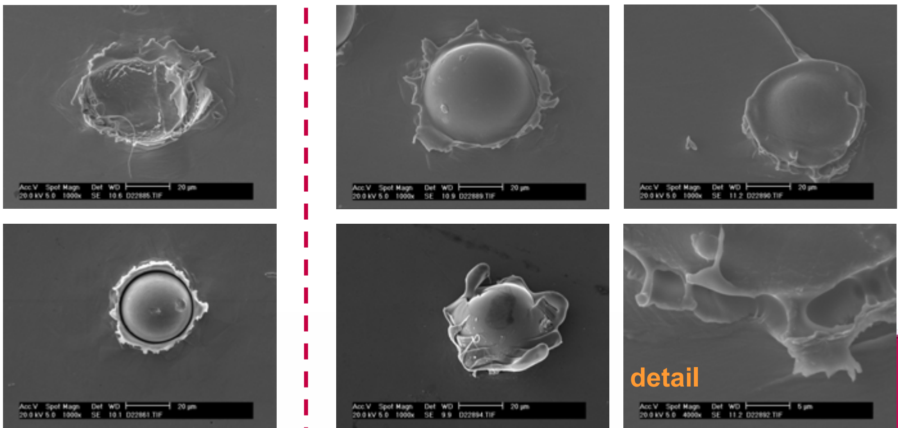
rigid | visco - plastic | viscous



erosive wear | coating formation

Influence of Gas Temp., Substrate Hardness

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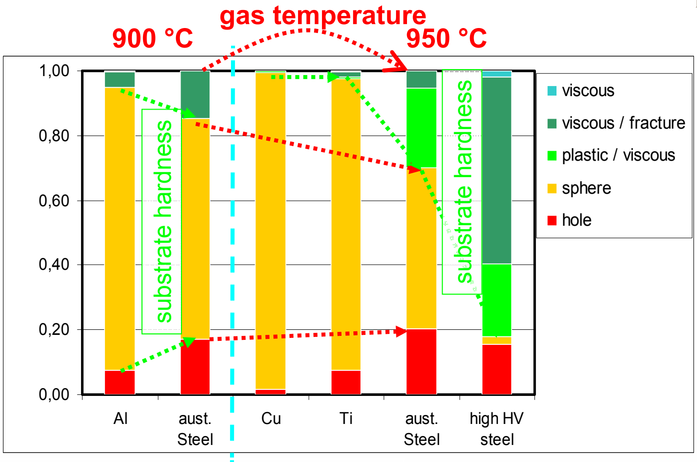

DE: 26 % 76 %

process gas : N_2

more viscous particle deformation by:

higher impact temperature

harder substrate material (higher deformation rates)

Amorphous $Fe_{44}Co_6Cr_{15}Mo_{14}B_{15}C_6$: Coating Microstructures (on steel 1.4301)

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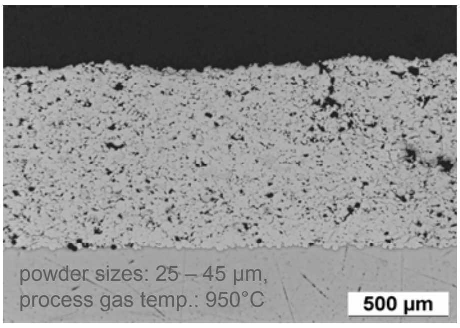

process gas : N_2

crystalline phases: < 2 % (estimated from XRD)

porosity: 2.7 vol. %

hardness: 1100 HV 0.3 (similar to the casted BMG)

tensile strength: 63 MPa

deposition efficiency: 70 %

Impact Scenario of Zr-based BMG on Steel

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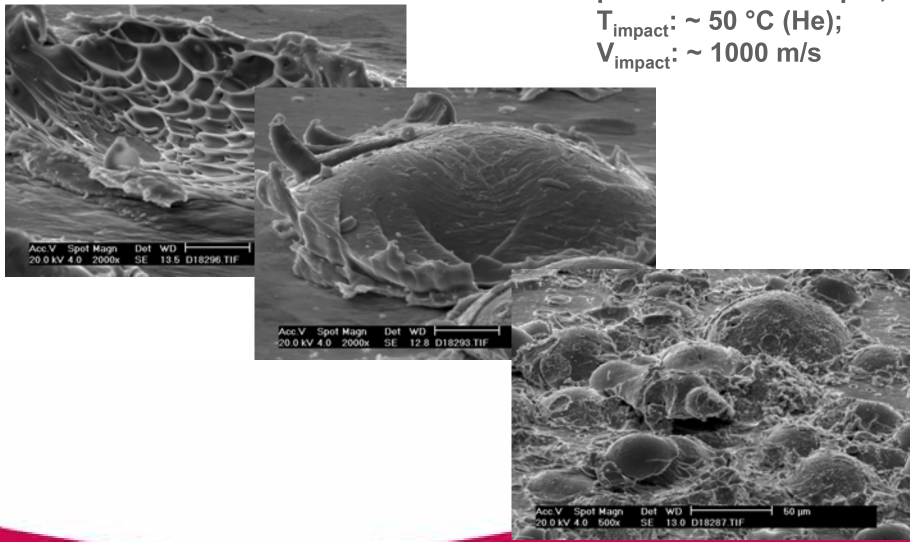
powder sizes: < 25 µm;
T_{impact}: ~ 50 °C (He);
V_{impact}: ~ 1000 m/s



$Zr_{55}Al_{10}Ni_5Cu_{30}$ (at. %) BMG on AlMg3 (He)

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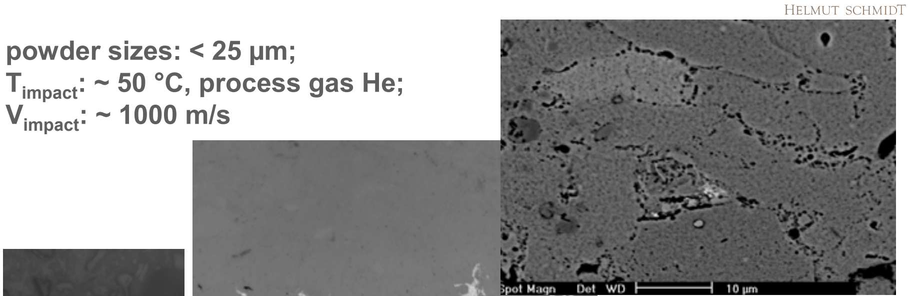
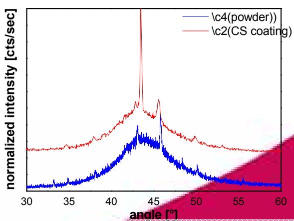
powder sizes: < 25 µm;
T_{impact}: ~ 50 °C, process gas He;
V_{impact}: ~ 1000 m/s





coating:
amorphous structure: ~ 90 %

porosity: < 0.2 %; hardness: 500 HV 0.3

Limits: Brittleness

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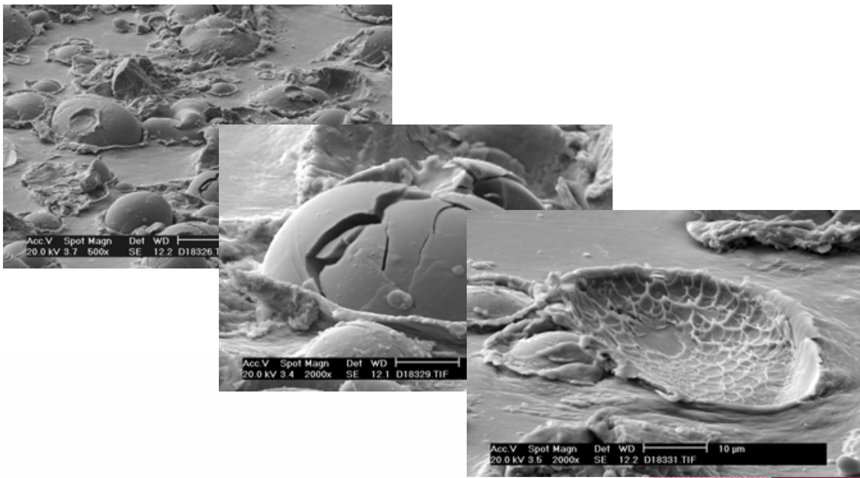
nanocrystalline Zr55 Al10 Ni5 Cu30 (at. %), on steel



→ ductility is needed to create heat and to reach conditions for shear instabilities

Nanocrystalline Alloys on AlMg3

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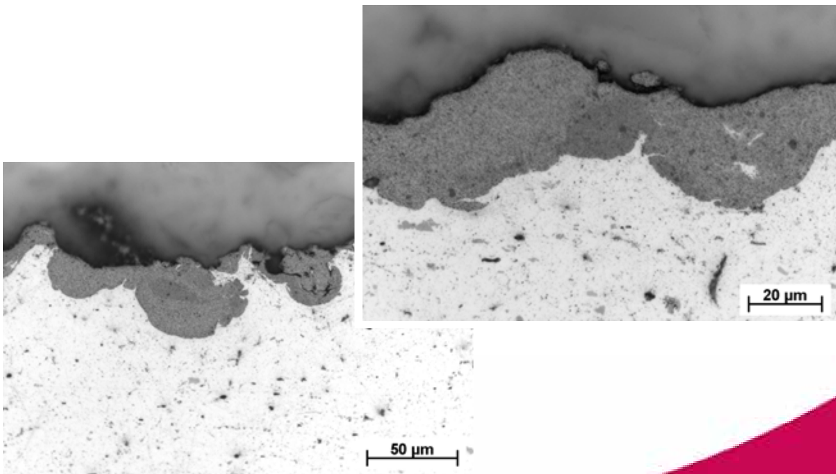
Zr55 Al10 Ni5 Cu30 (in at. %), on AlMg3



Conclusions: Kinetic Spraying

- limited thermal influence:
  kinetic spraying is suitable for processing
  - oxidation sensitive materials
  - metastable phases
- bonding by shear instabilities under
  ultra high strain rate deformation:
  - applicable to amorphous alloys
- spray conditions depend on materials properties,
  particle size and temperature