# “Window of Deposition”
## in Cold Spraying

**In cold spraying the particles impact in solid state [1]:**

- ✓ bonding is caused by high strain rate deformation of particle and substrate during impact
- ✓ the angular collision of interfaces generates shear straining and related heating [2]
- ✓ bonding is associated to extensive plastic straining caused by shear instabilities [2, 3]
- ✓ this bonding mechanism is similar to the bonding in explosive cladding
- ✓ efficient bonding only occurs at a certain velocity range which is called **window of deposition** [3]
- ✓ this window of deposition is restricted by the **critical velocity** (minimum velocity) and the **erosion velocity** (maximum velocity)
- ✓ below the **critical velocity** the plastic deformation is to low to cause bonding, above the **erosion velocity** hydrodynamic penetration leads to strong erosion, between these two characteristic velocities optimum conditions for deposition are reached [3]
- ✓ both, **critical** and **erosion velocity** depend on spray material, powder properties, particle and substrate temperature and particle size

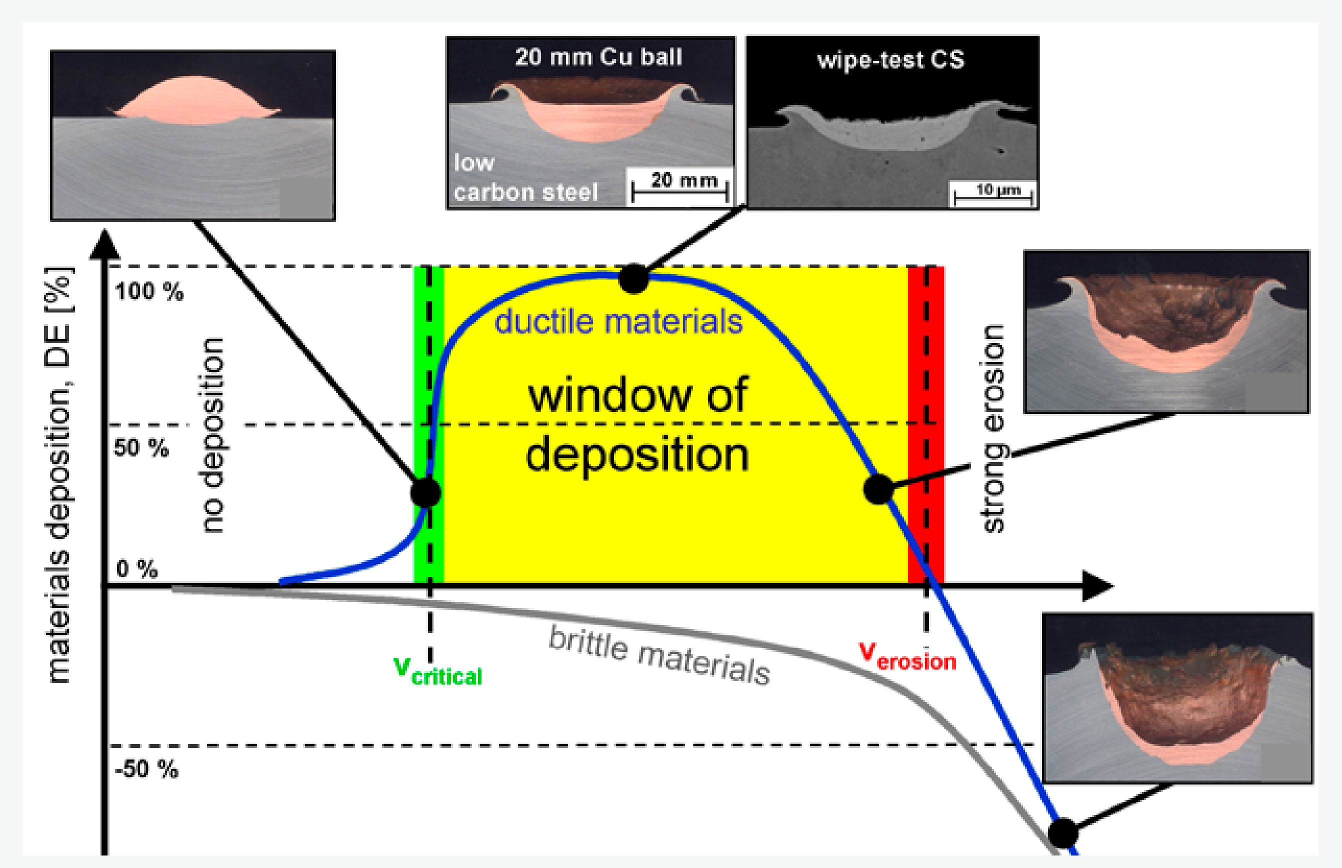



**Figure 1:** Materials deposition as a function of impact velocity. Cross-sections of 20 mm metal ball impacts accelerated by a gun and cold spray wipe -test [3].

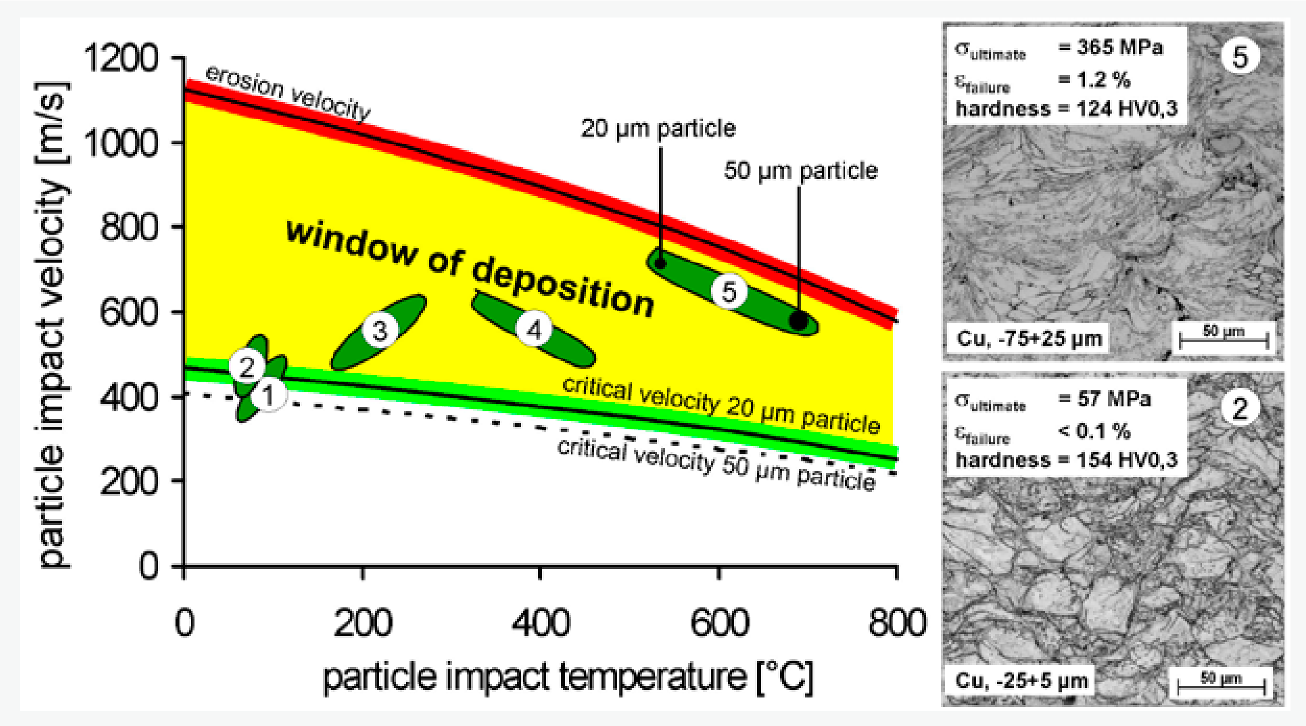



**Figure 2:** Critical (green) and erosion velocity (red) of copper as a function of particle impact temperature, superimposed with calculated particle impact conditions for different spray parameters (bubbles), see **Tab. 1** [3, 5]. Resulting microstructures for conditions 2 and 5, etched cross-sections [4, 5].

| development step | system description | typical parameter, powder | typical values (e.g. Cu) |
|---|---|---|---|
| 1 (2001) | **Kinetiks 3000**, std. nozzle (Papyrin) | **$N_2$ 30 bar 300°C Cu –25+5 µm** | DE = 60 % TCT-strength ~ 45 MPa |
| 2 (2004) | **Kinetiks 3000**, **MOC nozzle Type 24** | **$N_2$ 30 bar 300°C Cu –25+5 µm** | DE = 85 % TCT-strength ~ 50 MPa |
| 3 (2004) | **Kinetiks 3000**, **MOC nozzle Type 24, less nozzle clogging (WC-Co)**, higher gas temperatures | **$N_2$ 30 bar 600°C Cu –38+11 µm** | DE > 90 % TCT-strength ~ 125 +/- 25 MPa |
| 4 (2006) | **Kinetiks 4000**, MOC nozzle Type 24, **optimized particle injection**, **higher process gas pressure** | **$N_2$ 40 bar 600°C Cu –38+16 µm** | DE > 90 % TCT-strength ~ 200 +/- 50 MPa |
| 5 (2006) | **Kinetiks 4000**, MOC nozzle Type 24, optimized particle injection, **new Gun**, **higher process gas temperatures** | **$N_2$ 40 bar 800°C / 43 bar 900°C Cu –38+16 µm –75+25 µm** | DE > 90 % TCT-strength ~ 250 +/- 50 MPa |

**Table 1:** Development of process conditions in cold spraying: higher particle impact velocities and temperatures due to enhanced process conditions by new equipment [5].

**Publications:**

1 A.P. Alkhimov, A.N. Papyrin, V.F. Kosarev, N.I. Nesterovich, *et al.*, Gas-Dynamic Spray Method for Applying a Coating, *U.S. Patent 5,302,414*; April 12, 1994.

2 H. Assadi, F. Gärtner, T. Stoltenhoff, and H. Kreye: Bonding Mechanism in Cold Gas Spraying, *Acta Mater. 51*, 2003, p 4379-4394.

3 T. Schmidt, F. Gärtner, H. Assadi, and H. Kreye: Development of a Generalized Parameter Window for Cold Spray Deposition, *Acta Mater. 54*, 2006, p 729-742.

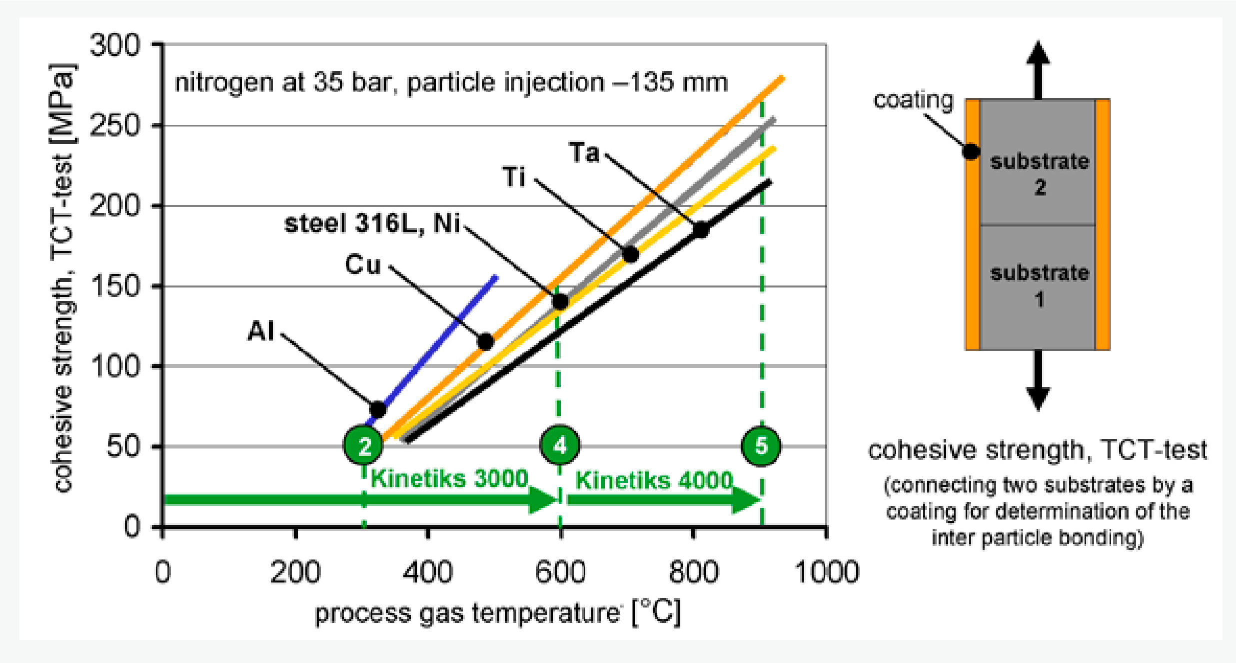



**Figure 3:** Trend lines of cohesive strength of coatings (TCT-test) as a function of process gas temperature [5] (impact conditions: **Fig. 2**, process conditions: **Tab. 1**). The strength strongly depends on the powder quality.

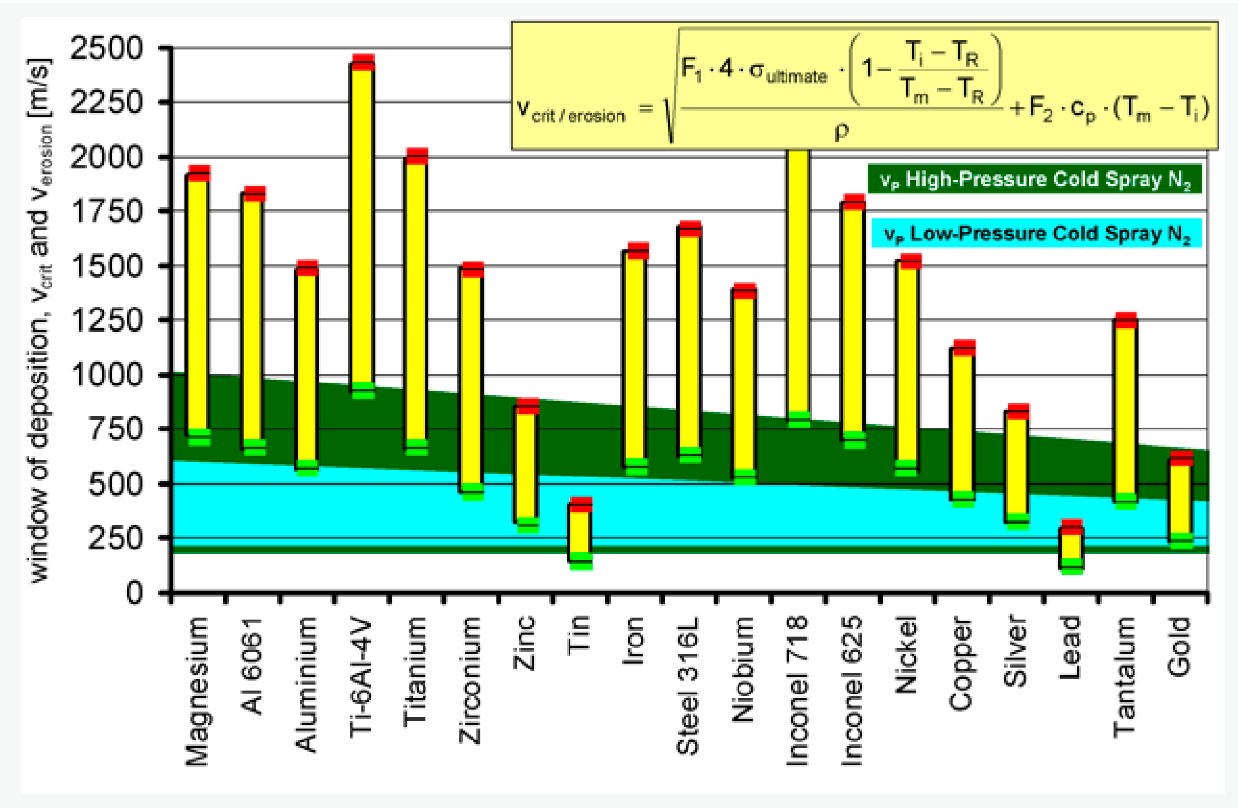



**Figure 4:** Critical and erosion velocity of different metals, calculated for a particle size of 25 µm and an impact temperature of 20 °C, using general material properties [3, 4]. Typical particle impact velocities indicated by green/blue area in the background.

4 F. Gärtner, T. Stoltenhoff, T. Schmidt, H. Kreye: The Cold Spray Process and its Potential for Industrial Application, Journal of Thermal Spray Technology, 15(2), 2006, S. 223-232.

5 T. Schmidt, F. Gärtner, H. Kreye: New Developments in Cold Spray Based on Higher Gas and Particle Temperatures, Journal of Thermal Spray Technology, 15(4), 2006, S. 488-494.

6 C. Borchers, T. Schmidt, F. Gärtner, H. Kreye: High Strain Rate Deformation Microstructures of Stainless Steel 316L by Cold Spraying and Explosive Powder Compaction, Appl. Phys. A, 2007, DOI: 10.1007/s00339-007-4314-0.

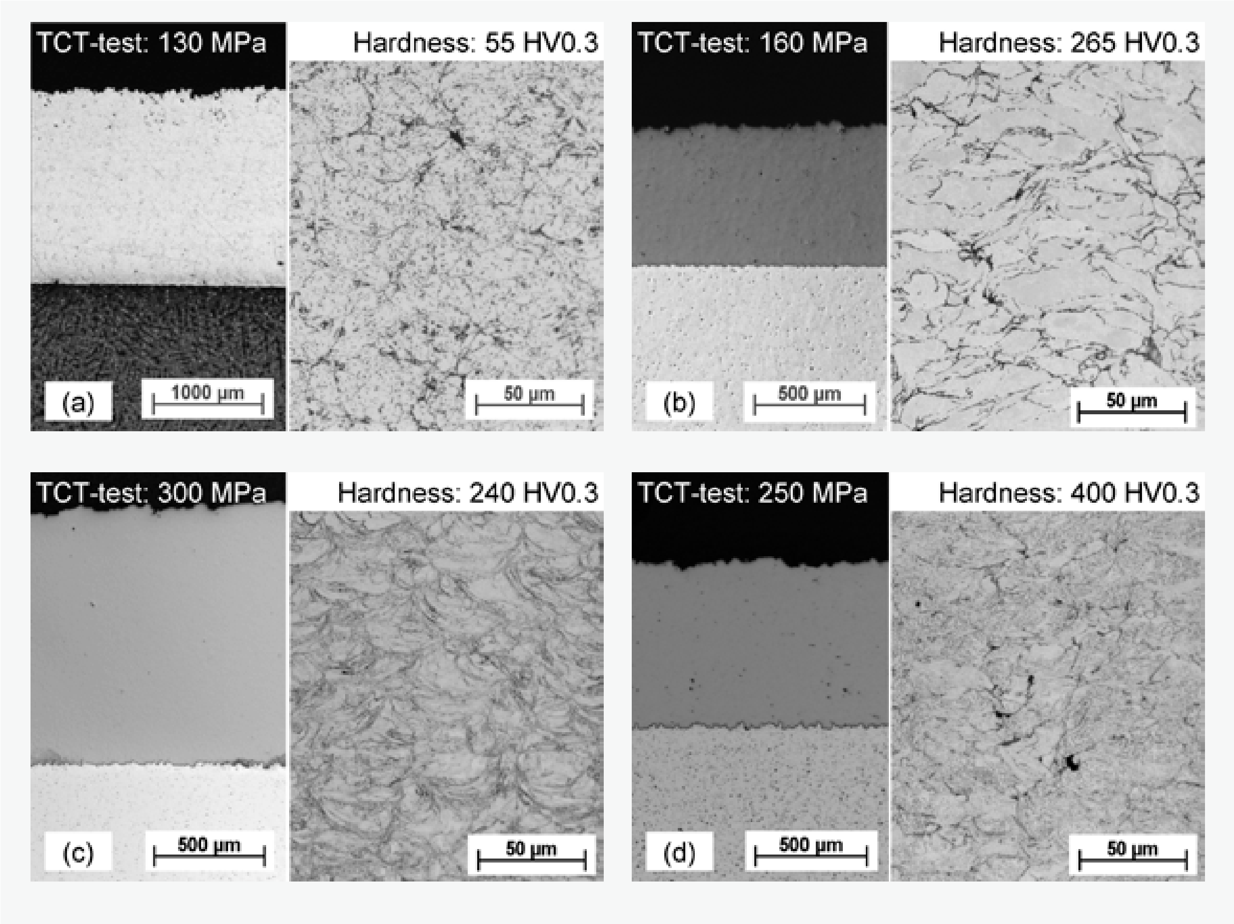
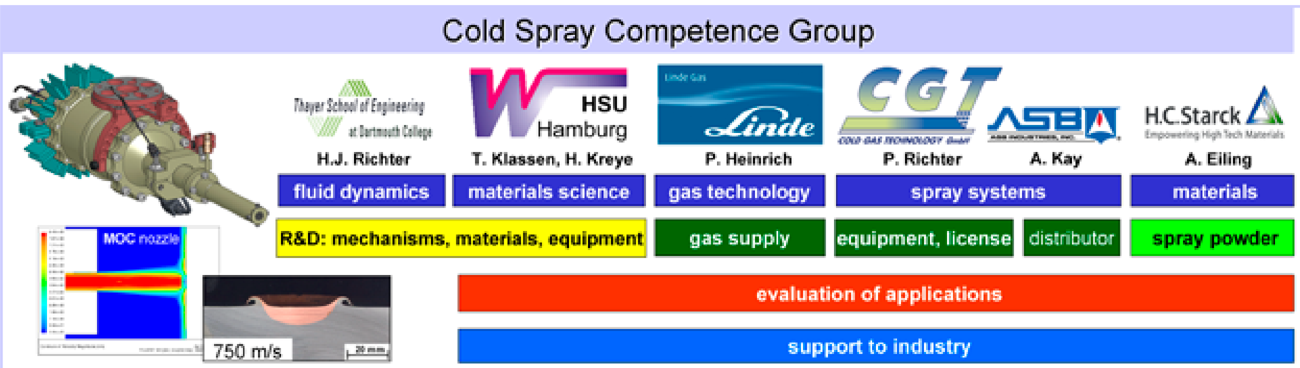



**Figure 5:** Etched microstructures of cold-sprayed coatings (process gas nitrogen): **(a)** Aluminium, **(b)** Titanium, **(c)** Nickel and **(d)** steel 316L [3, 4, 5, 6].

**Advantages of solid particle impact deposition by cold spraying:**

- ✓ low thermal load on materials (typically: substrate 50-250°C, spray material 50-900°C)
- ✓ deposition efficiencies (DE's) of more than 90 % (for suitable feedstock)
- ✓ depositon rate 1-8 kg/h, up to 15 kg/h
- ✓ focussed spray jet (d=4-8 mm), coating thickness 100 µm to cm, building up sharp edges
- ✓ mechanical properties similar to highly deformed bulk material
- ✓ deformation induced compressive residual stress in the coating
- ✓ electrical and thermal conductivity of coatings can reach more than 90 % of bulk material
- ✓ coating costs: facility 50-150 €/h + operator + spray material




**Prof. T. Klassen, Prof. H. Kreye**
Institute of Materials Technology
www.hsu-hh.de/cold-spraying

HSU Hamburg · Helmut Schmidt Universität