The Cold Spray Process
and its Optimization

Solid state impact of particles:

- ✓ particle bonding is caused by high strain rate deformation during impact
- ✓ the collision of particle – substrate interfaces generates shear straining
- ✓ particles must exceed a critical velocity to produce an out-flowing material jet and shear instabilities, necessary for bonding
- ✓ this bonding mechanism is similar to the bonding in explosive cladding
- ✓ the critical velocity depends on spray material and the powder quality, particle and substrate temperature and particle size

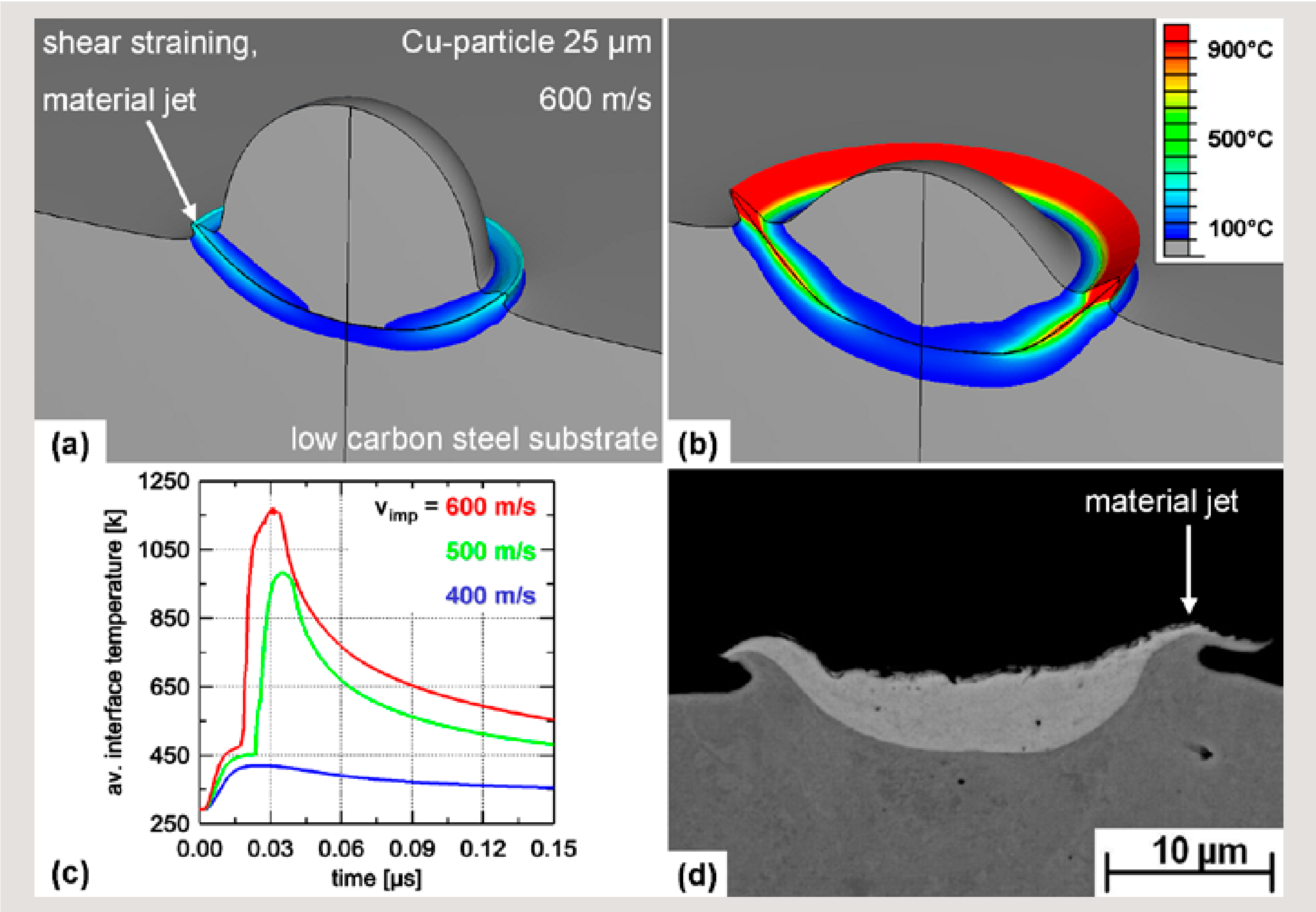


Figure 1: Jet formation at colliding interfaces: (a) temperature field 15 ns after impact, (b) 30 ns after impact, (c) temporal evolution of interface temperature calculated for different impact velocities, (d) cross-section of a single particle impact from a wipe-test [4].

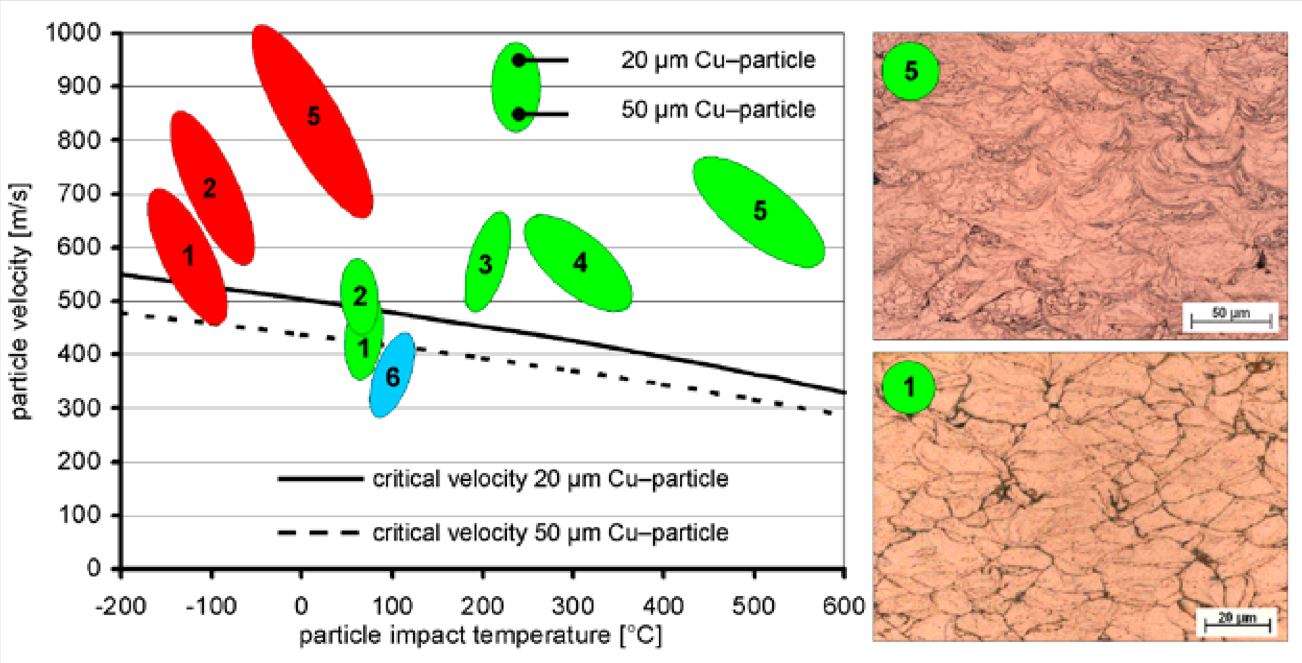


Figure 2: Critical velocity of copper as a function of particle impact temperature and particle impact conditions for different spray parameters (bubbles), see table 1. Resulting microstructures for conditions 1 and 5, etched cross-sections [5].

1	std. nozzle	**N_2 30 bar 300°C**	**Kinetiks 3000 (20 kW)**
2	MOC nozzle	**N_2 30 bar 300°C**	**Kinetiks 3000 (20 kW)**
3	MOC nozzle	**N_2 30 bar 600°C**	**Kinetiks 3000 (30 kW)**
4	MOC nozzle, el. prechamber	**N_2 30 bar 600°C**	**Kinetiks 4000 (17 kW)**
5	MOC nozzle, el. prechamber	**N_2 40 bar 900°C**	**Kinetiks 4000 (34/47 kW)**
1	std. nozzle	**He 25 bar 300°C**	**Kinetiks 3000 (20 kW)**
2	MOC nozzle	**He 25 bar 300°C**	**Kinetiks 3000 (20 kW)**
5	MOC nozzle, el. prechamber	**He 30 bar 700°C**	**Kinetiks 4000 (47 kW)**
6	low pressure systems	**air 5 bar 550°C**	**5 – 10 bar (3–8 kW)**

Table 1: Development of the process conditions in cold spraying: higher particle impact velocities and particle impact temperatures due to higher gas temperatures, higher gas pressures and due to particle preheating using a new injection method [5, 6].

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 T. Stoltenhoff, H. Kreye, and H.J. Richter: An Analysis of the Cold Spray Process and its Coatings, *J. Thermal Spray Technol.*, 11, 2002, p 542-550.

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

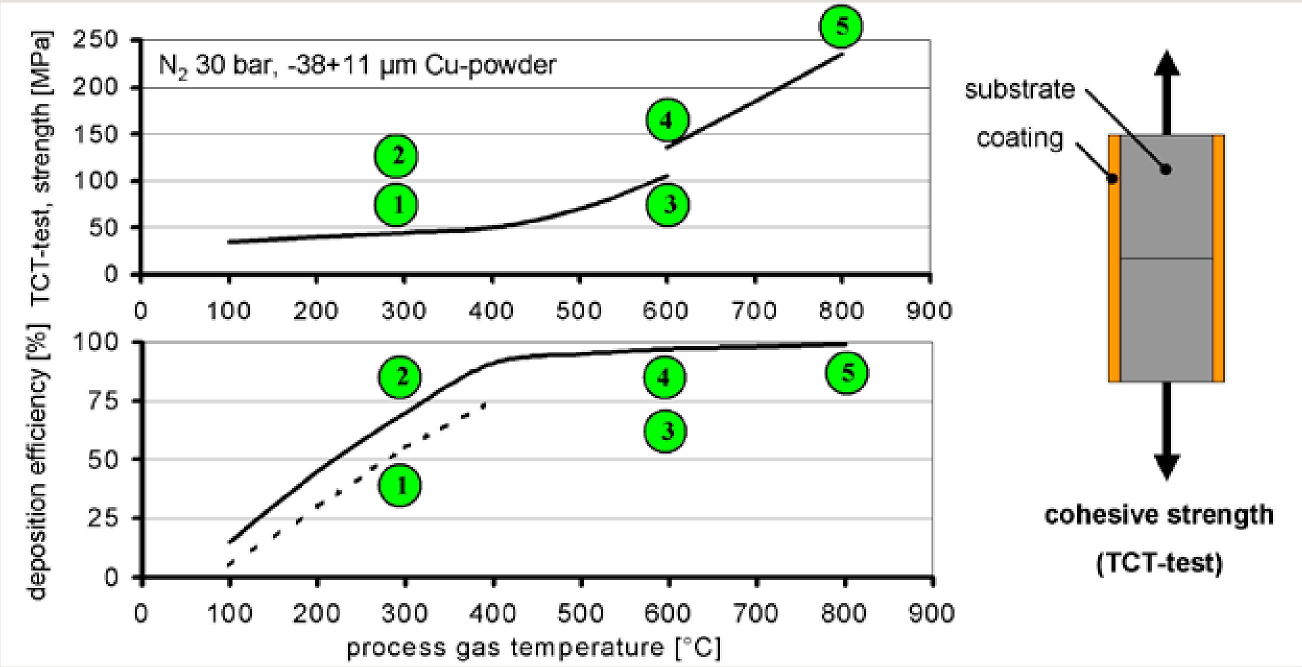


Figure 3: Cohesive strength of the coating (TCT-test) and deposition efficiency (DE) as a function of process gas temperature; for particle impact conditions see figure 2, for process conditions see table 1 [6].

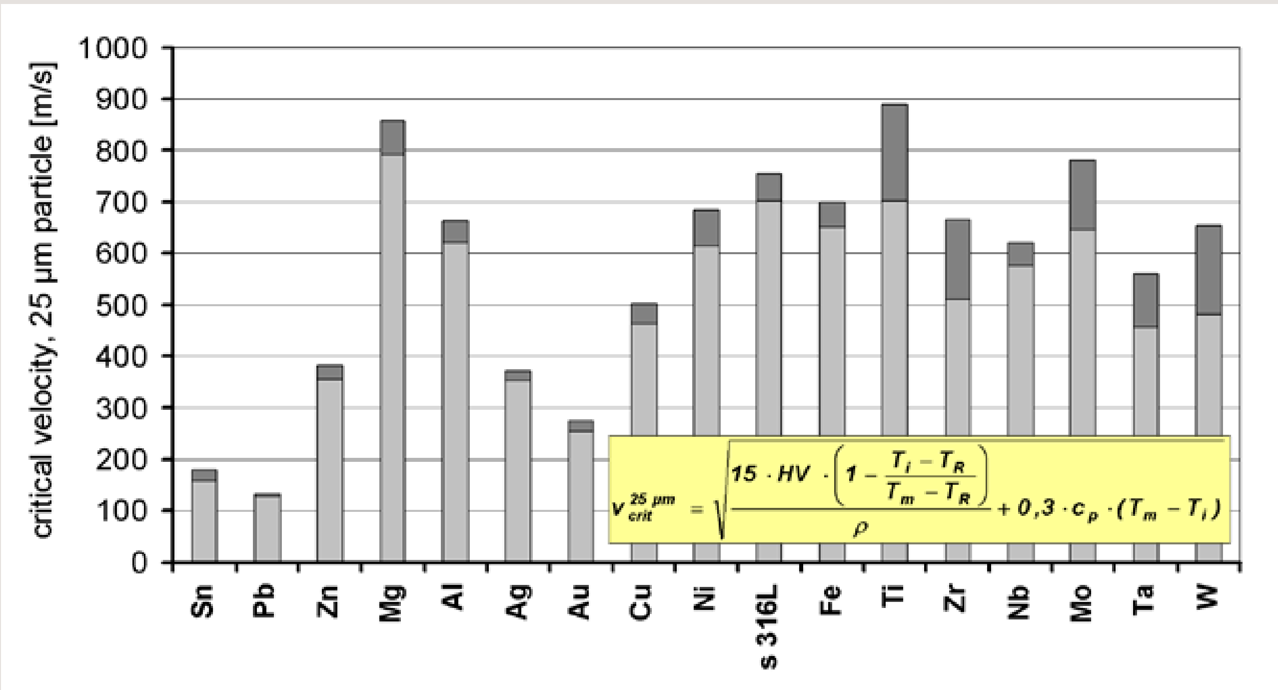


Figure 4: Critical velocities of different metals, calculated for a particle size of 25 µm and an impact temperature of 20 °C, using general material properties [4].

4 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.

5 H. Kreye, T. Schmidt, F. Gärtner, T. Stoltenhoff, The Cold Spray Process and its Optimization, "Thermal Spray 2006: Science, Innovation, and Application", Eds. B. R. Marple, C. Moreau, ASM International, Materials Park, OH, USA, 2006, ISBN 0-87170-809-4, on CD, article no.: s2_1-12011.

6 T. Schmidt, F. Gärtner, and H. Kreye, New Developments in Cold Spray Based on Higher Gas- and Particle Temperatures, "Thermal Spray 2006: Science, Innovation, and Application", Eds. B. R. Marple, C. Moreau, ASM International, Materials Park, OH, USA, 2006, ISBN 0-87170-809-4, on CD, article no.: s2_2-12003. Same article: to be published *J. Thermal Spray Technol.*, 2006

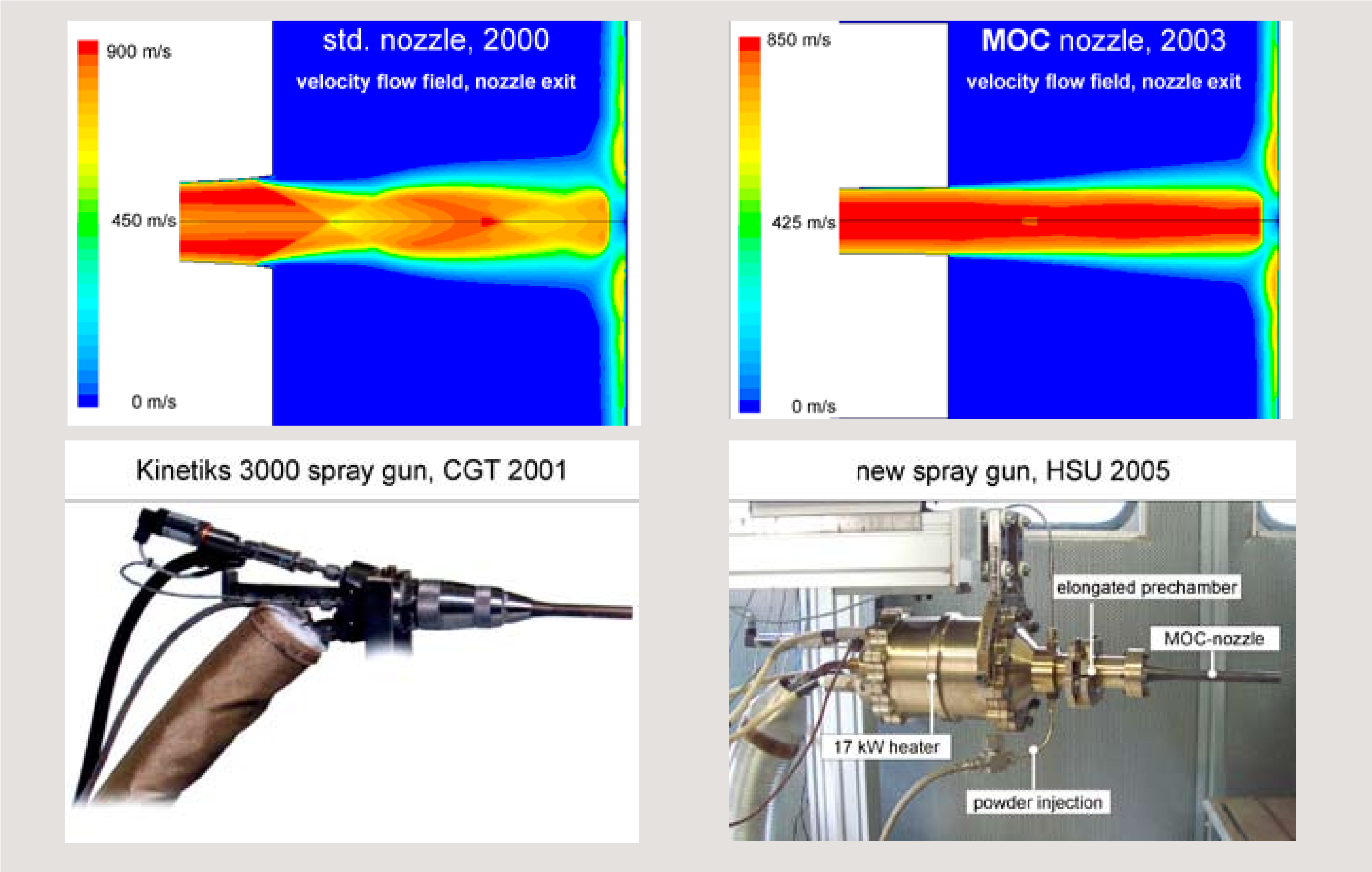
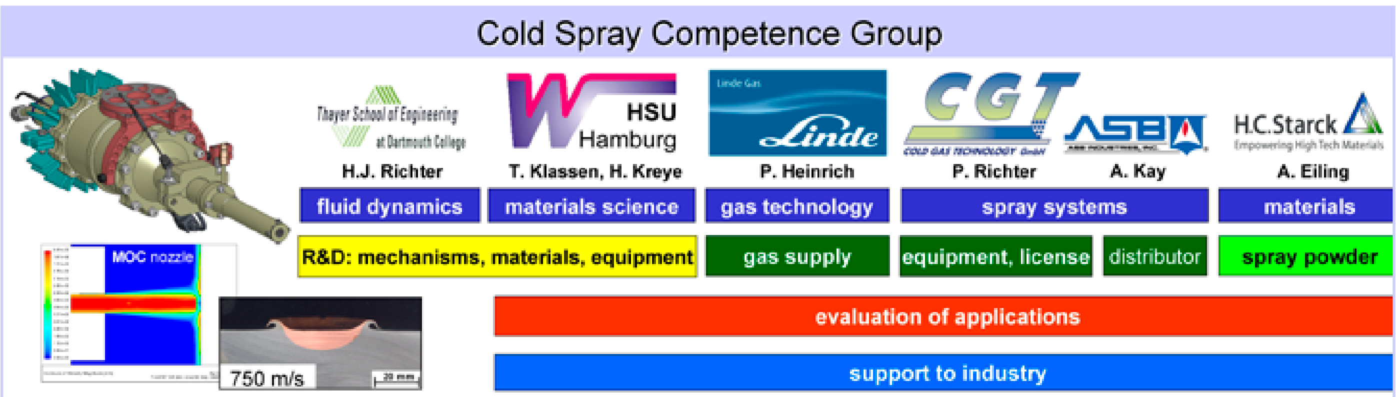


Figure 5: Optimised particle acceleration by a new nozzle design, MOC-nozzle. Enhanced process conditions due to the design of a new spray gun [2, 5, 6].

Advantages of recent process improvements:

- ✓ higher impact velocities and impact temperatures of particles
- ✓ deposition efficiencies (DE's) of more than 90 %
- ✓ cohesive strength and bond strength are significantly increased
- ✓ coarser powders can be sprayed, e.g. –38+11 µm, -75+25 µm
- ✓ a larger variety of spray materials can be processed
- ✓ in most cases He is not necessary as process gas (cost efficiency)



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