impact

We. Spray. Future.

Global technology leader for industrial Cold Spray

Particle emission reduction for brake discs via high-performance Cold Spray Coating

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chassis.tech plus

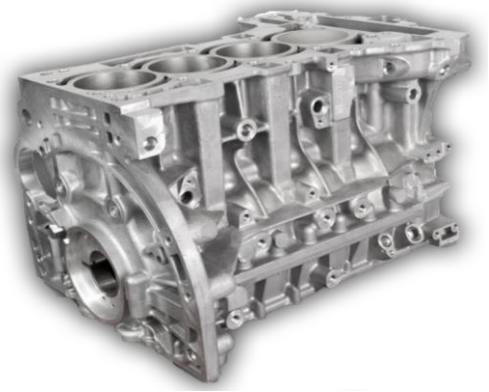
Agenda

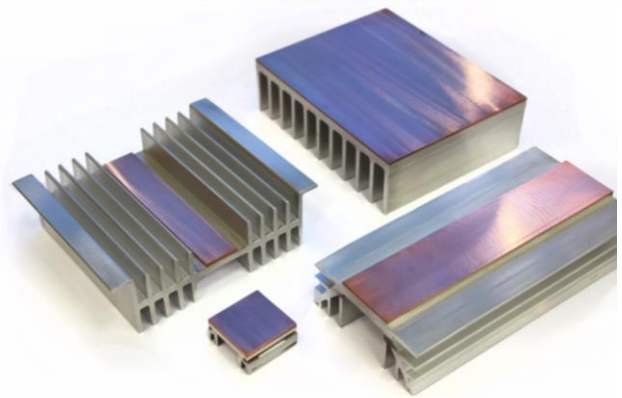
- **Company introduction**
- **Cold Spray Technology**
- **High-performance Cold Spray Coating for Brake Disc Application**

Global technology leader for industrial Cold Spray

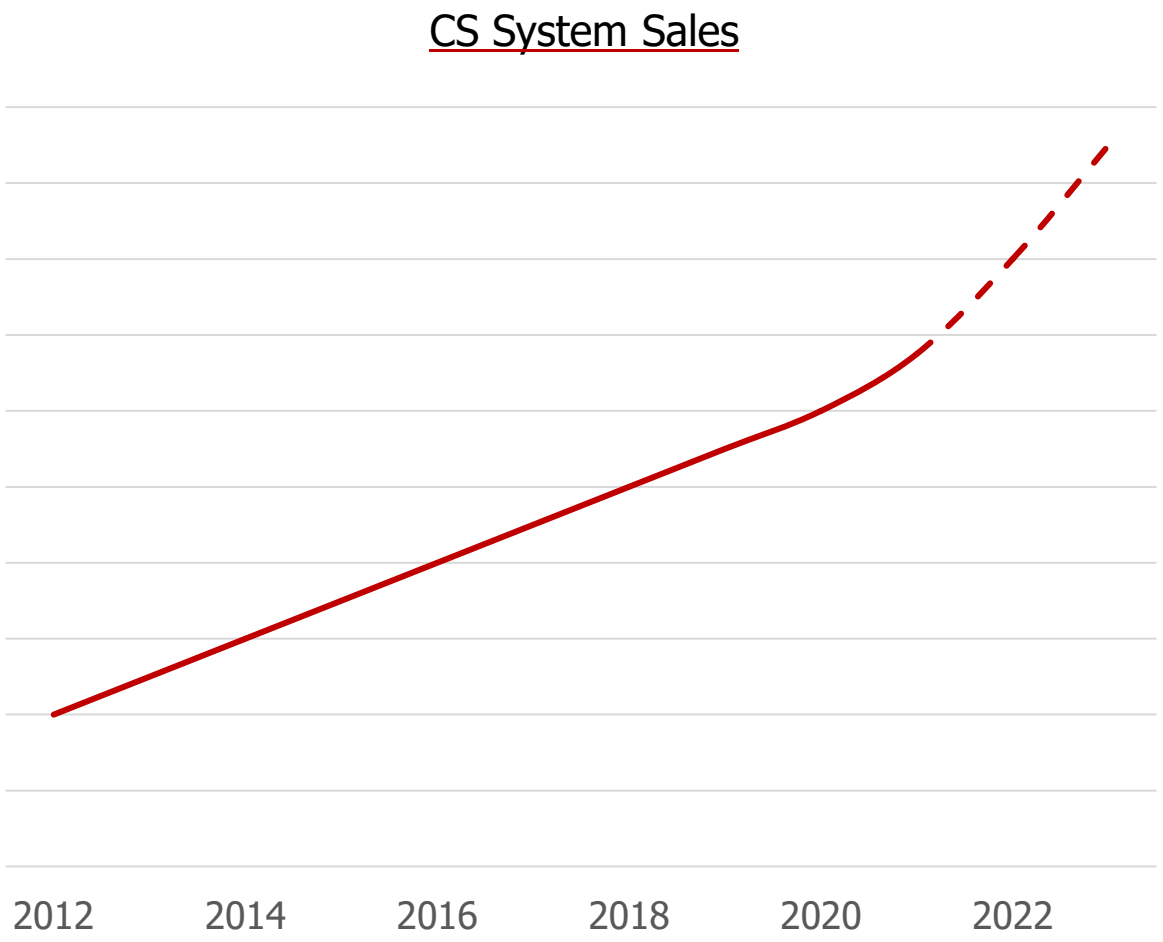
Our Impact on Cold Spray

- Year of foundation: 2010
- >20 Years of experience in Cold Spray Technology
- Focus on High Pressure Cold Spray Equipment for industrial applications
- >100 Impact Systems installed worldwide
- >40 Employees at headquarter in Germany
- 1500 m² Production area
- 750 m² Office space



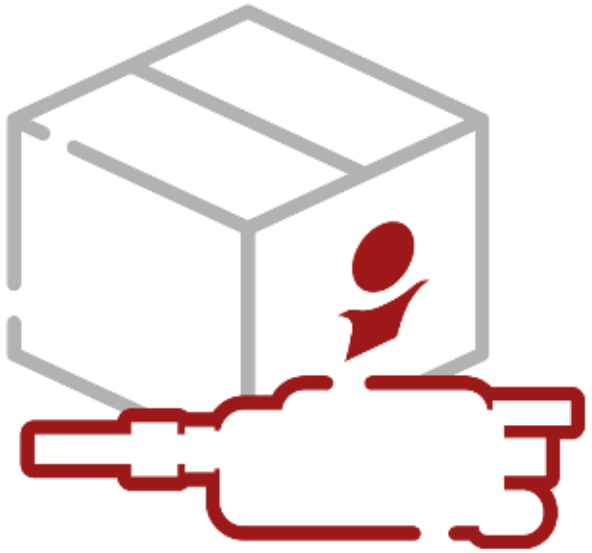


We are continuously growing since our sales start in 2012



- Development of CS Equipment in 2010 & 2011
- Presentation of new Impact Spray System at ITSC 2012
- August 2012: 1st installation of an Impact Spray System in France
- Use in industrial series production and additive manufacturing since 2015
- DEDIQ joins company as a strategic partner in 2019
- Approved growth and expansion plan for 2020-2025
  - Product road map and sales strategy
  - Expansion of company building
  - Expansion of R&D and manufacturing capacities

Corporate division



MACHINERY & PLANTS

RESEARCH & DEVELOPMENT

SERVICE

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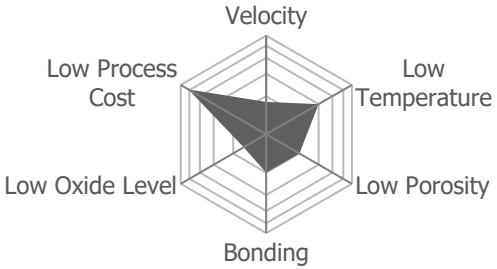
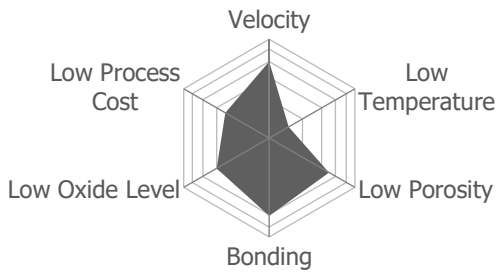
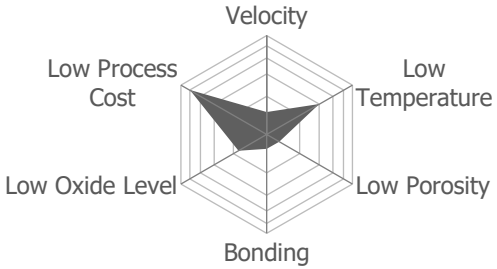
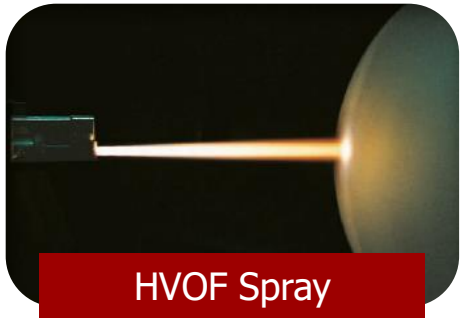
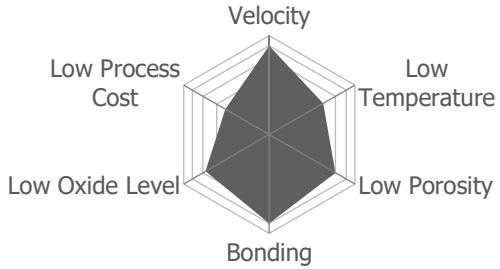
Part of the field of thermal spraying

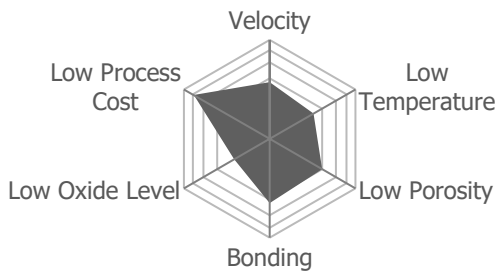


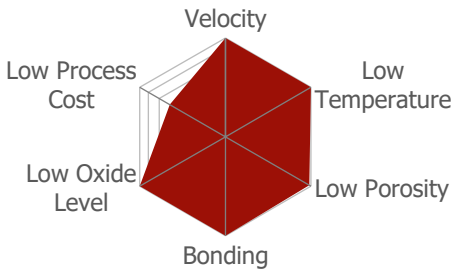




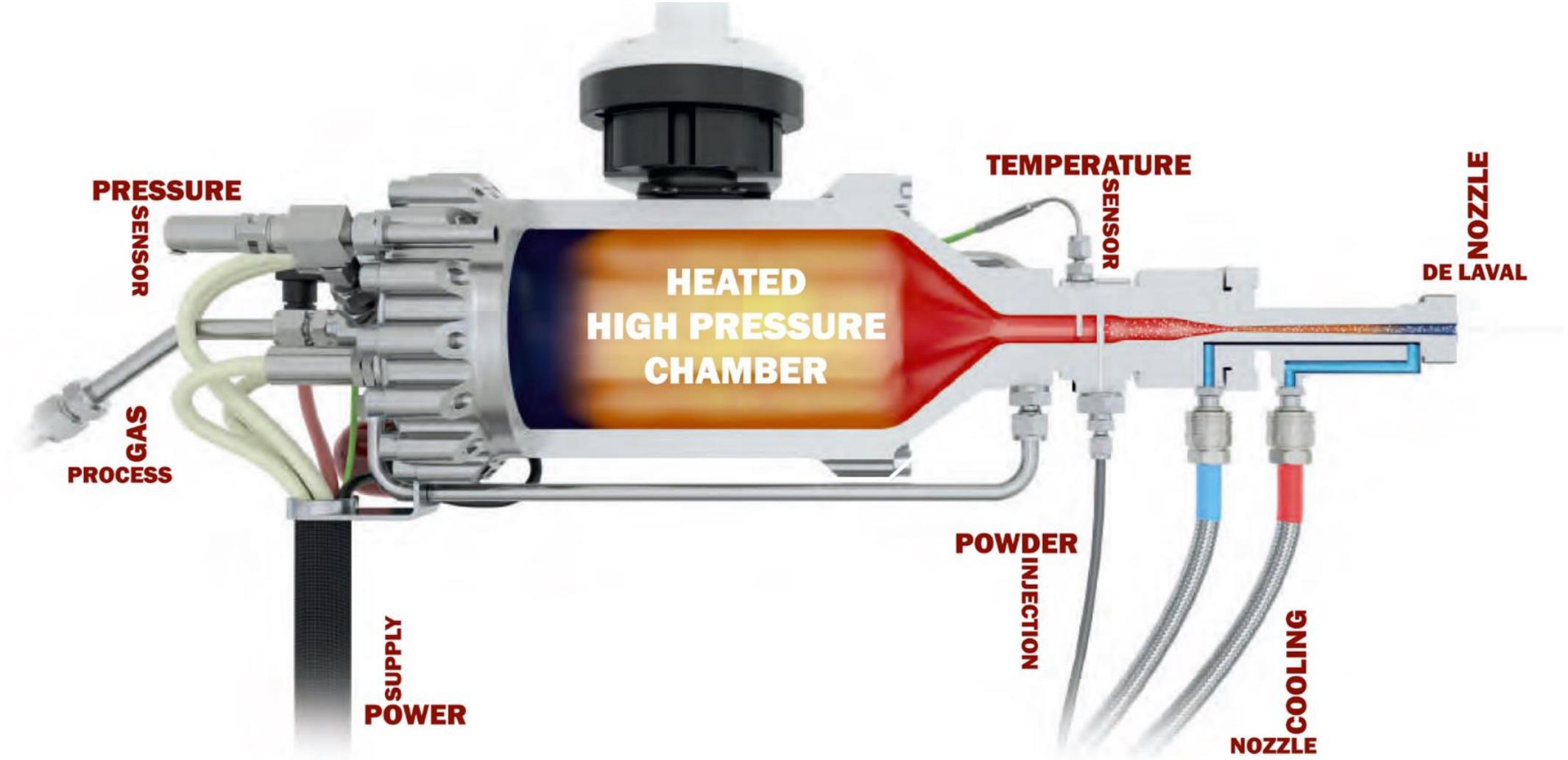




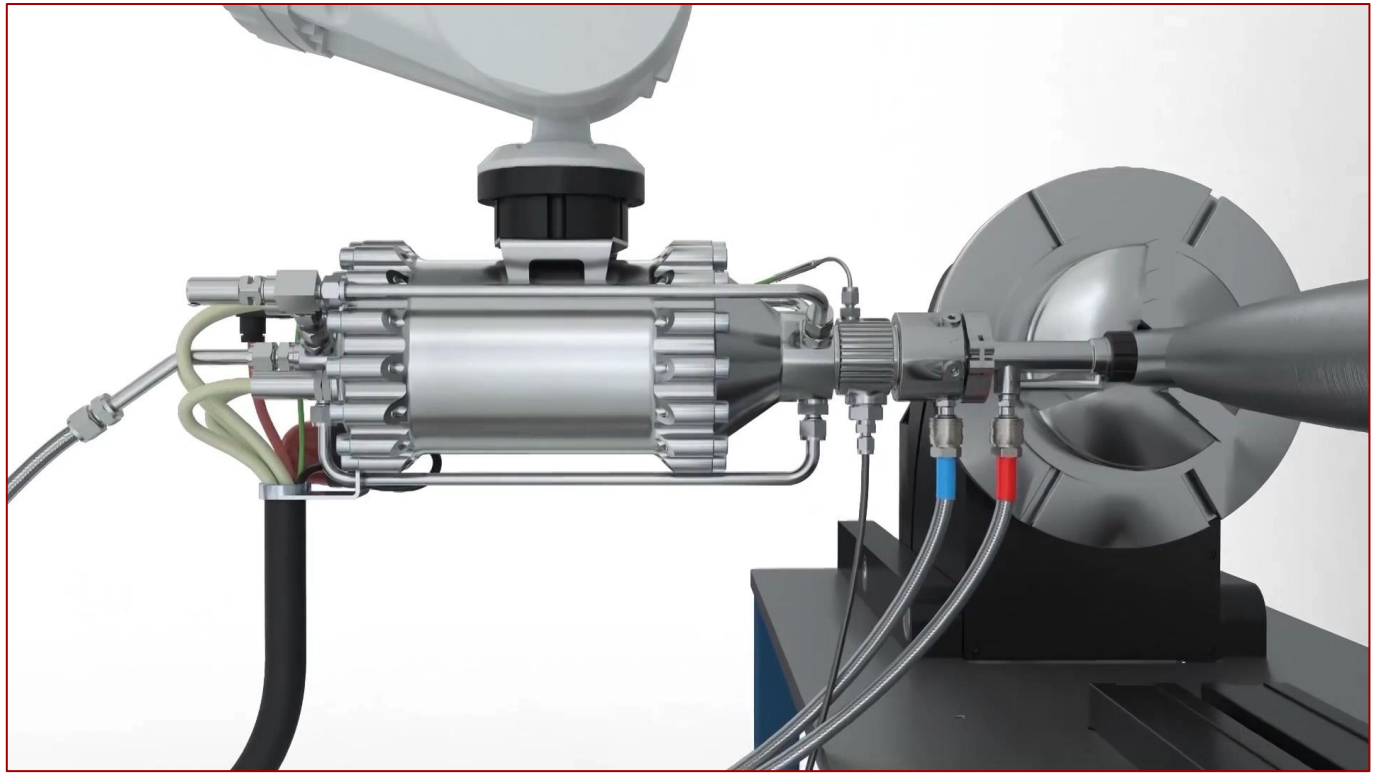




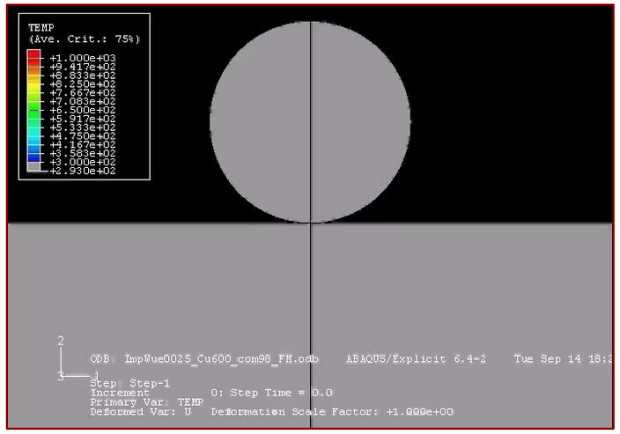
Core component - Cold Spray Gun



Solid-state process



- Feed stock material is not melted
- Minimal thermal influence on the feed stock and substrate material
- Production of homogeneous and very dense coatings, due to the high kinetic energy of the particles and a high degree of deformation on particle impact



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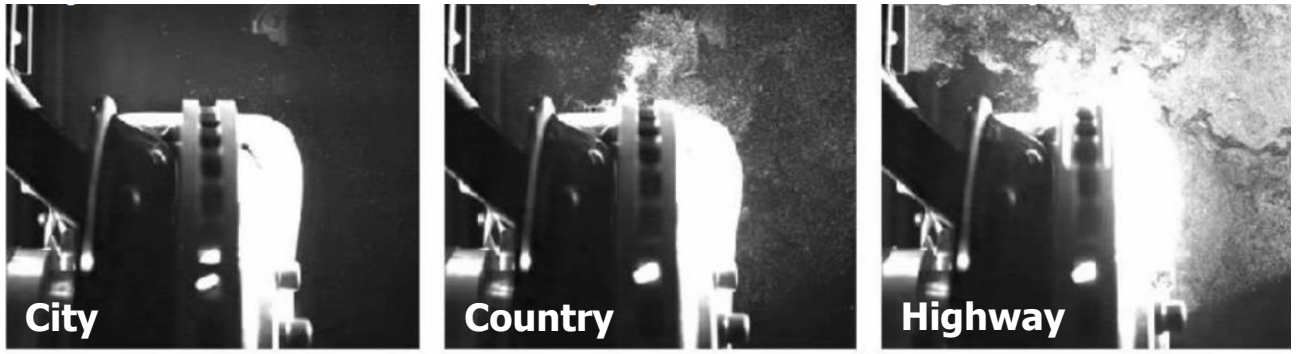
Motivation for the Development

- **Euro-7 regulation for the reduction of particle emission of passenger car brake systems starting in 2025**

Particle emission after 3.2 s



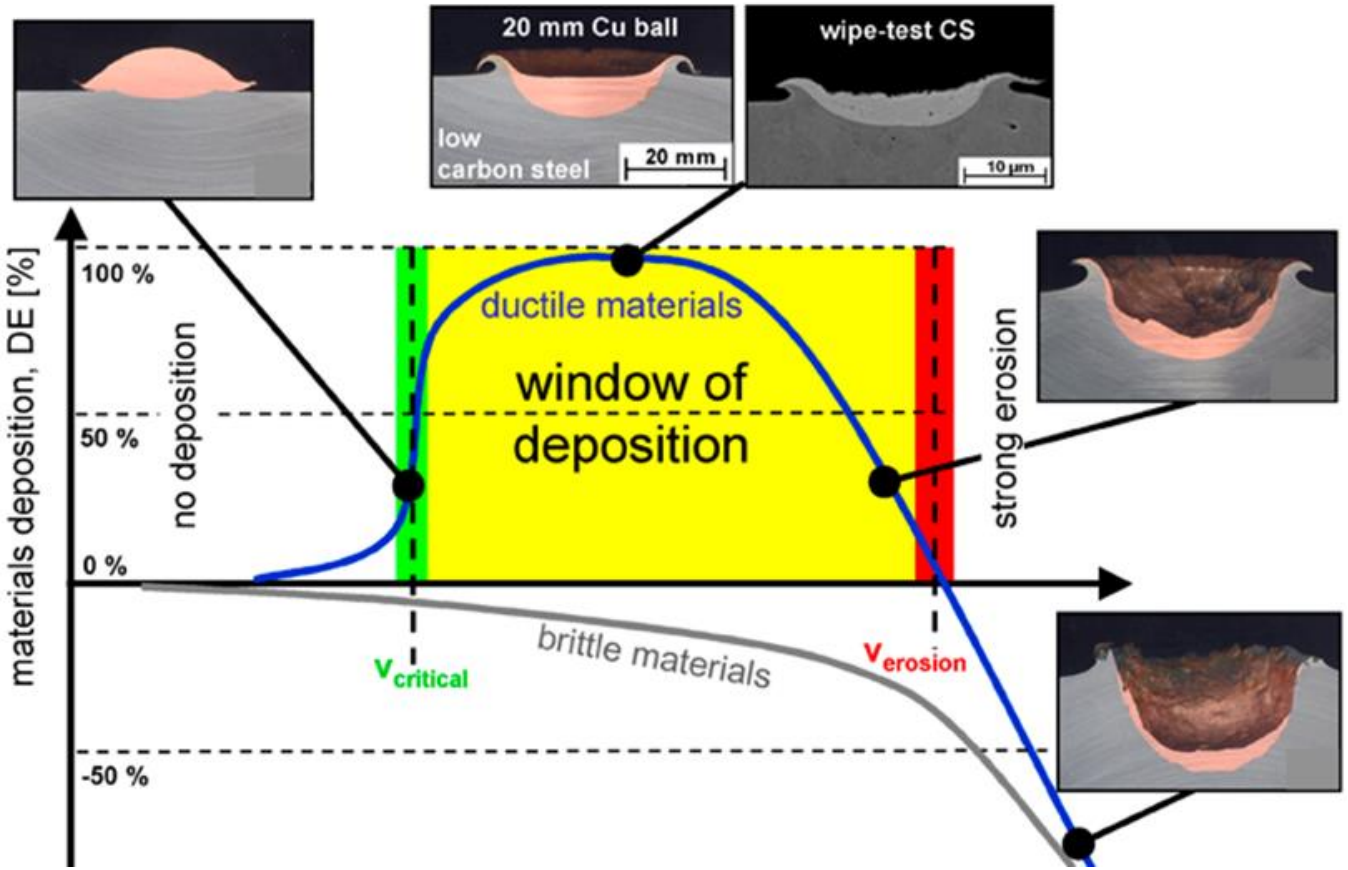
Source: HORIBA
Source: K. Augsburg, H. Sachse, R. Horn, S. Gramstat, 15th ETH conference on Combustion Generated Nanoparticles, June 26th - 29th 2011

- The necessity of corrosion resistance for electric-driven cars
- Growing aesthetic requirement, reduced rust formation and dust deposit on the rims
- Reduction of wear and maintenance costs

Requirements

- **Reduction of particle emission**
  Up to over 90% compared to the standard brake system
- **Brake performance**
  The tribological performance between the brake disc and the brake pad must be ensured at all conditions
- **Mechanical performance**
  The coating must withstand the applied braking forces at all conditions
- **Corrosion protection**
  Up to 720 hours in a salt spray chamber
- **Low cost**
  Different coating solutions for different requirements
- **Use of standard materials**
  High availability and safe sources

Coating materials

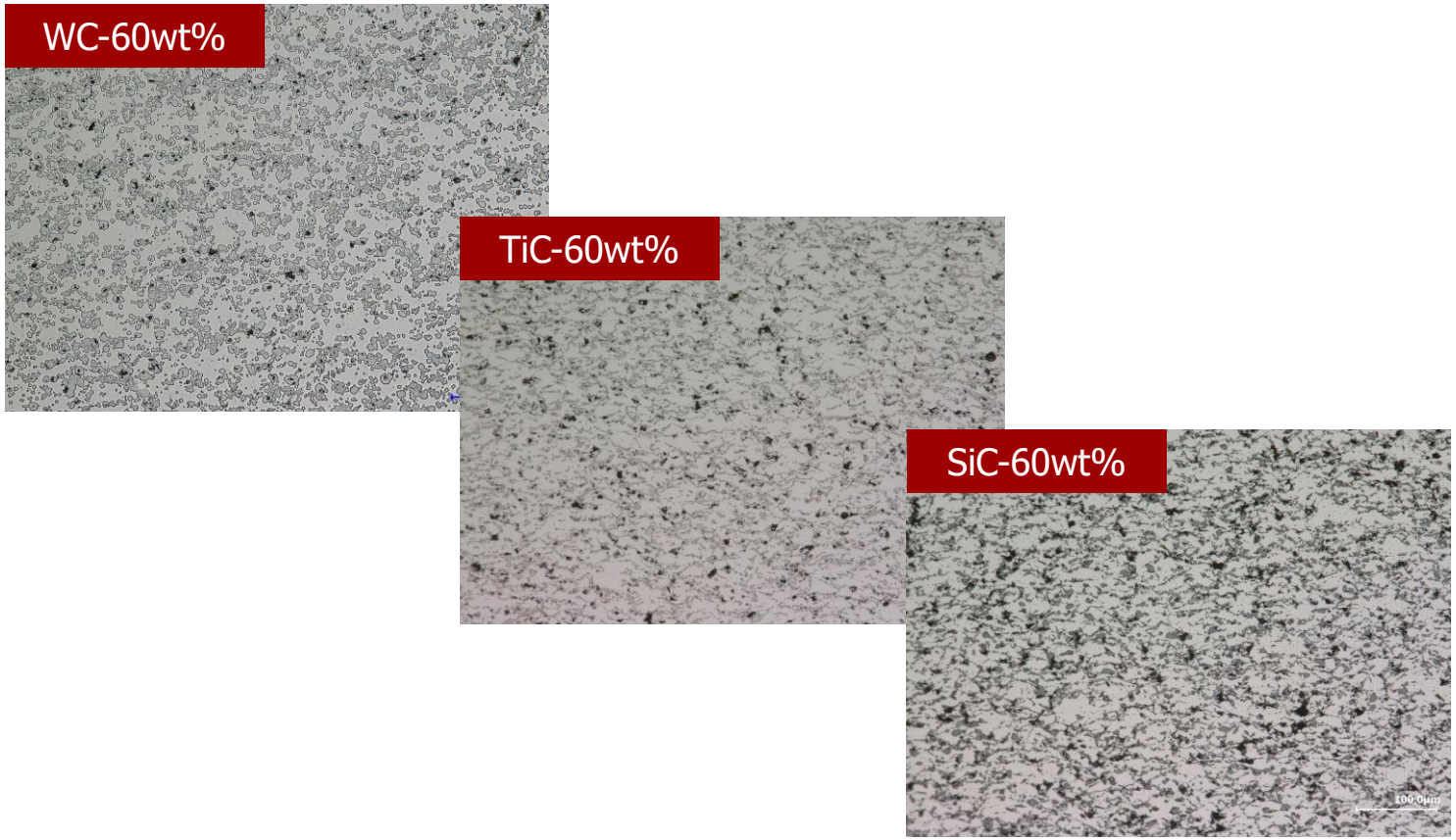


Composite coating

- **Matrix materials**
  - Ti-6Al-4V
  - 430L
- **Hard materials**
  - WC
  - SiC
  - TiC

Deposition efficiency and cross section analysis

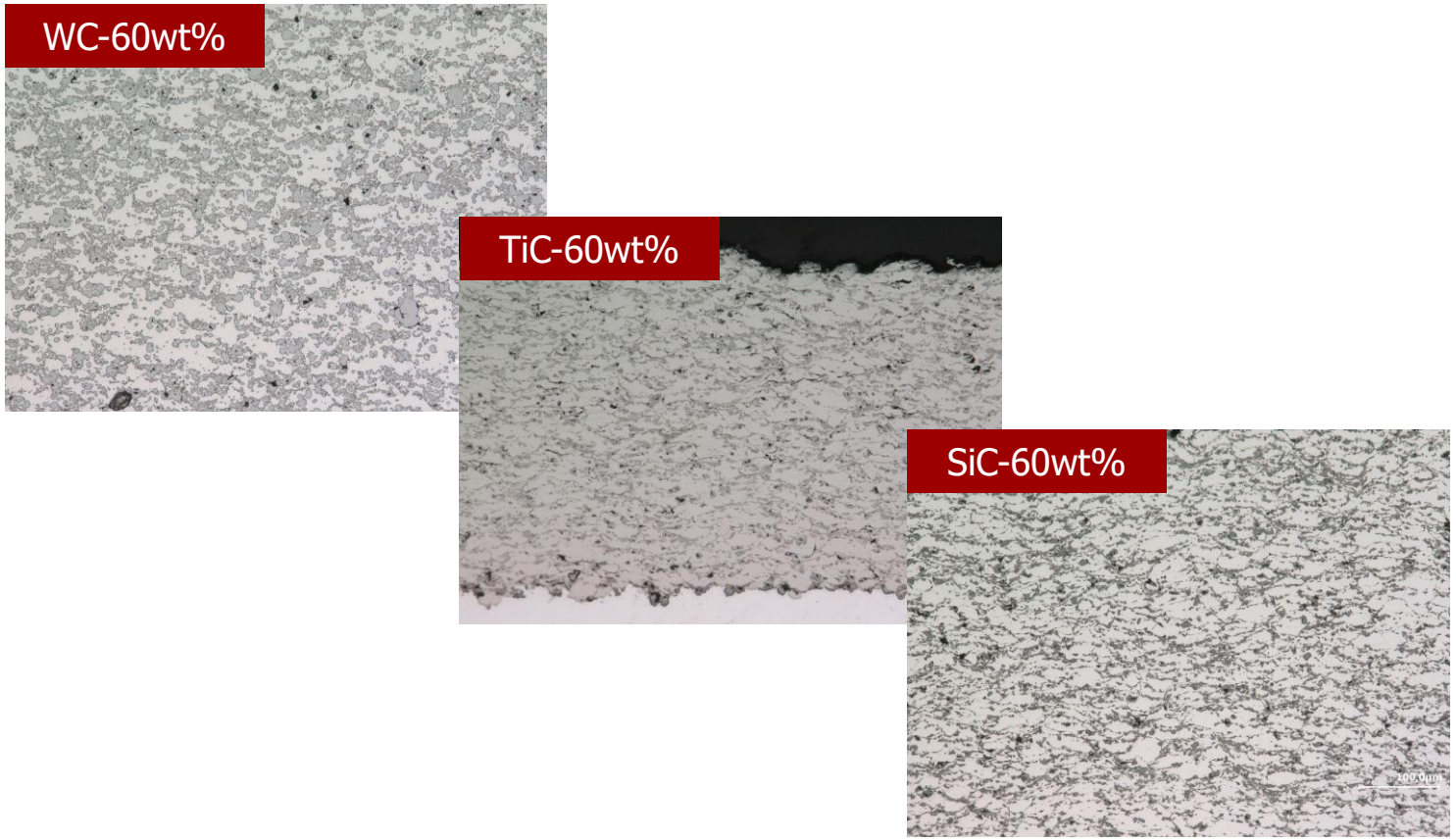
Ti-6Al-4V + Hard materials



- Uniform carbide distribution
- Overall porosity <1.5 %
- Deposition efficiency
  - Ti-6Al-4V+WC-60 ~ 88 %
  - Ti-6Al-4V+TiC-60 ~ 50 %
  - Ti-6Al-4V+SiC-60 ~ 50 %
- All three mixtures are potential candidates for the brake discs application

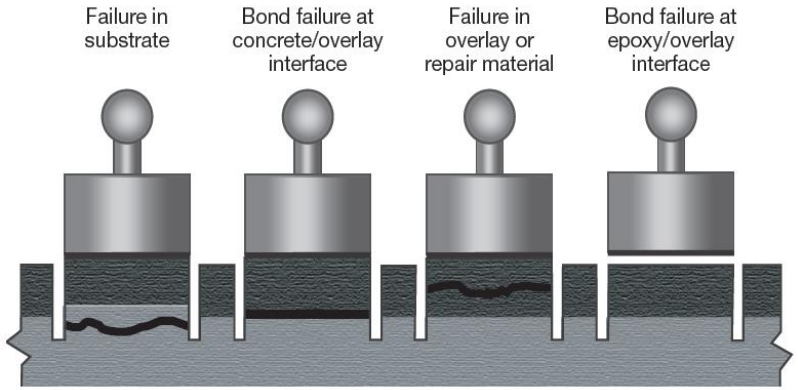
Deposition efficiency and cross section analysis

430L + Hard materials



- Uniform carbide distribution
- Overall porosity <2 %
- Deposition efficiency
  - 430L+WC-60 ~ 70 %
  - 430L+TiC-60 ~ 38 %
  - 430L+SiC-60 ~ 36 %
- 430L+WC60 is a potential candidate for the brake discs application

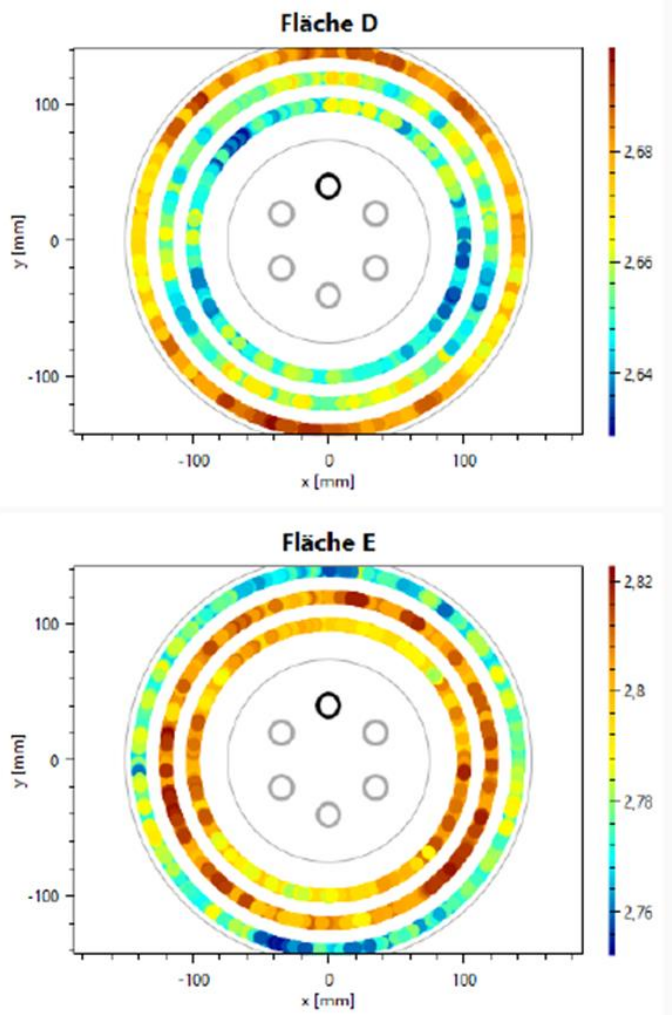
Bonding strength

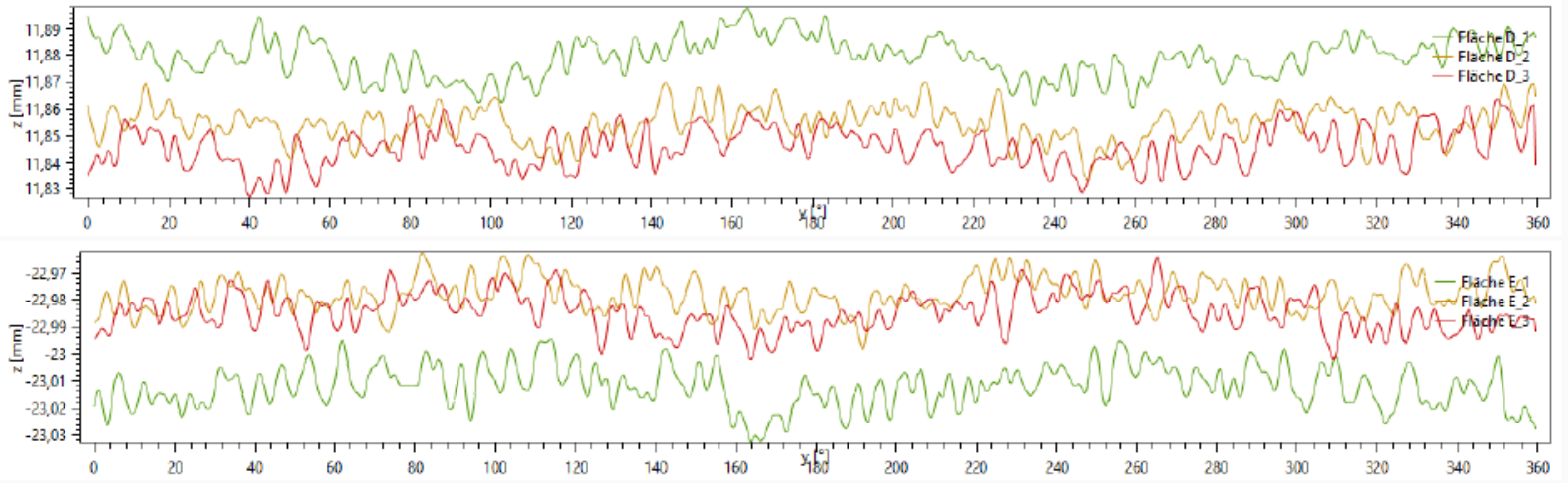


Adhesion Strength

- Ti-6Al-4V+WC-60 ~ 90 ± MPa
- 430L+WC-60 ~ 90 ± 5 MPa

Thermal distortion





Measuring circle 1 (green) outside at 280 mm
Measuring circle 2 (orange) in the middle at 240 mm
Measuring circle 3 (red) inside at 200 mm

- **20-30µm maximum measured distortion after coating process**
- Reduced distortion and uniform coating layers leads to
  - Reduced coating costs
  - Reduced grinding costs

Brake performance / AK-Master test

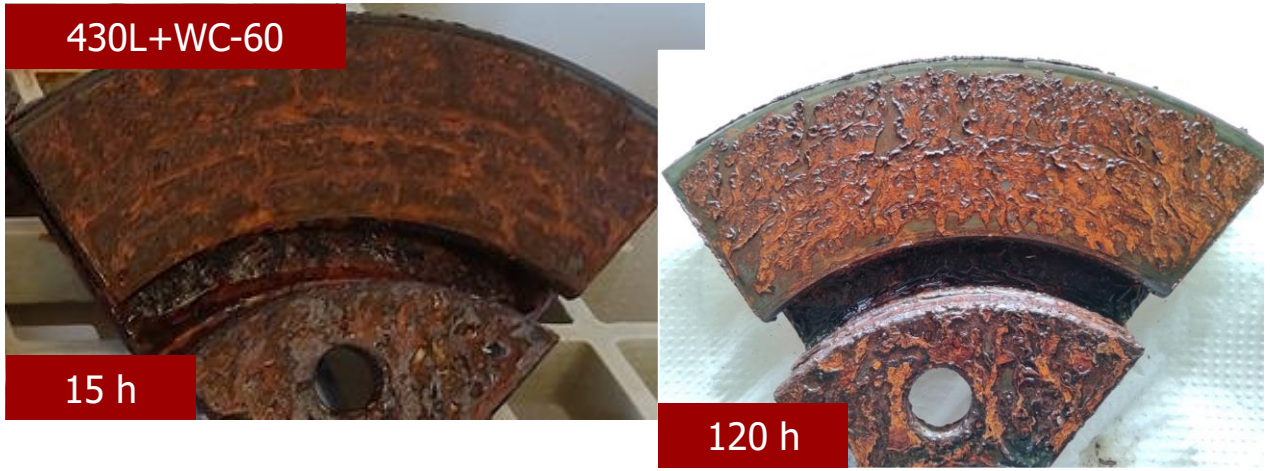
Ti-6Al-4V+WC-60

430L+WC-60

- No wear on brake disc
- Very low wear on brake pads
- No visible cracks on brake disc surface
- Braking behavior can be improved by choosing adapted brake pad material

Coating material	Disc (g)	Inboard Pad (g)	Outboard Pad (g)	μ_{min}	μ_{nom}
Ti-6Al-4V+WC-60	0	8.49	8.98	0.23	0.25
430L+WC-60	-0.1	6.99	7.33	0.24	0.28
Uncoated disc (Reference)	6.3	8.89	9.80	0.31	0.38

Corrosion performance



- Salt Spray Test (5% NaCl)
- Standard - ISO 9227
- Performed after AK-Master test

- Ti-6Al-4V+WC-60
  No corrosion was observed after 720 h
- 430L+WC-60
  Corrosion was observed after 15 h

Mechanical performance / Crack formation test

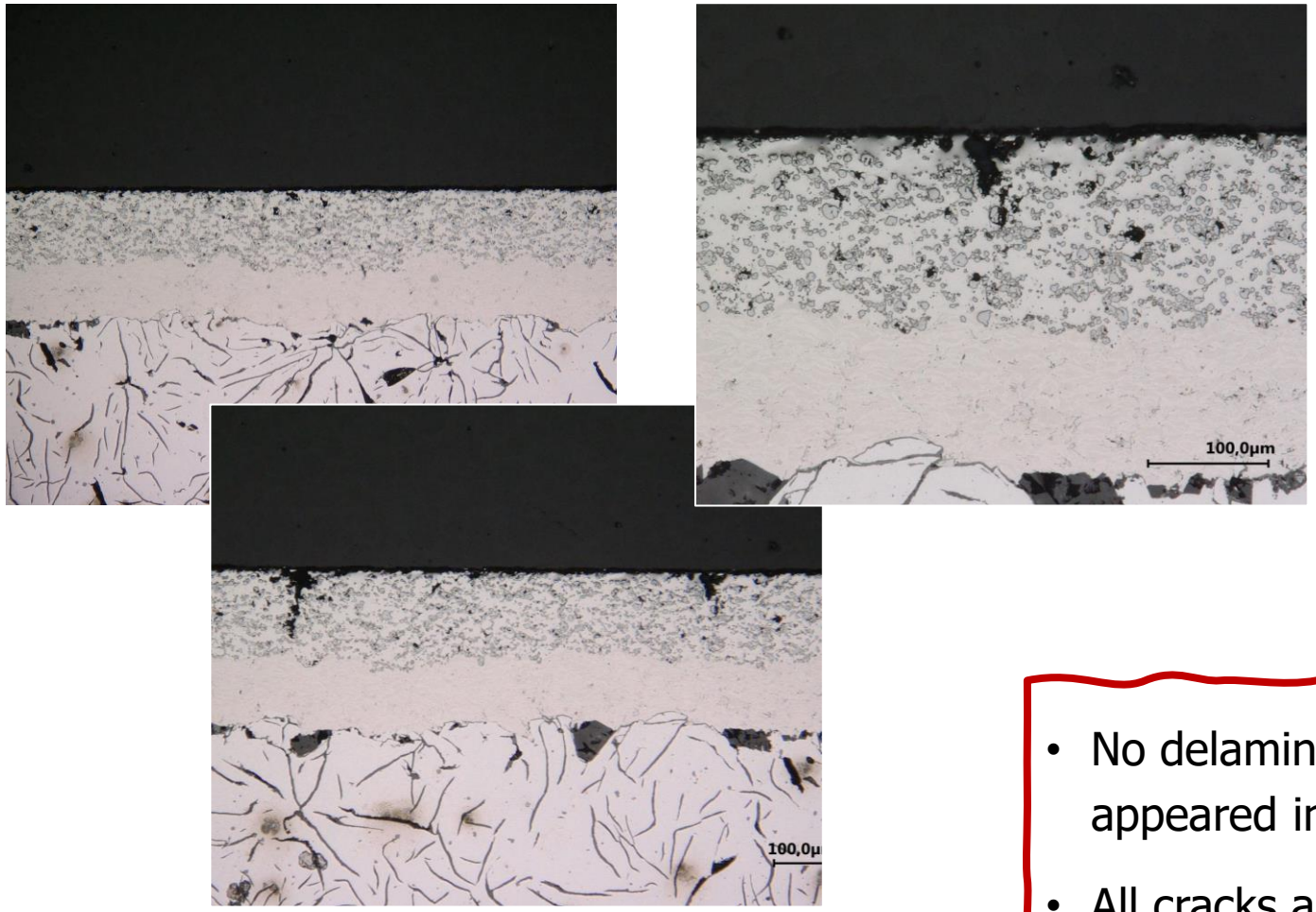
Before testing

After testing

- Intermediate layer - Ti
  - Layer thickness ~ 120 µm
- Top layer - Ti-6Al-4V+WC-60
  - Layer thickness ~ 250 µm (after coating)
  - Layer thickness ~ 150 µm (after grinding)
- Crack formation test
  - 15 brake cycles of 10 shock brakes
  - From maximum speed to 5 km/h with maximum brake deceleration

- No delamination and only very few minor cracks appeared in the coating of the brake disc
- Only slight wear on brake pads are visible

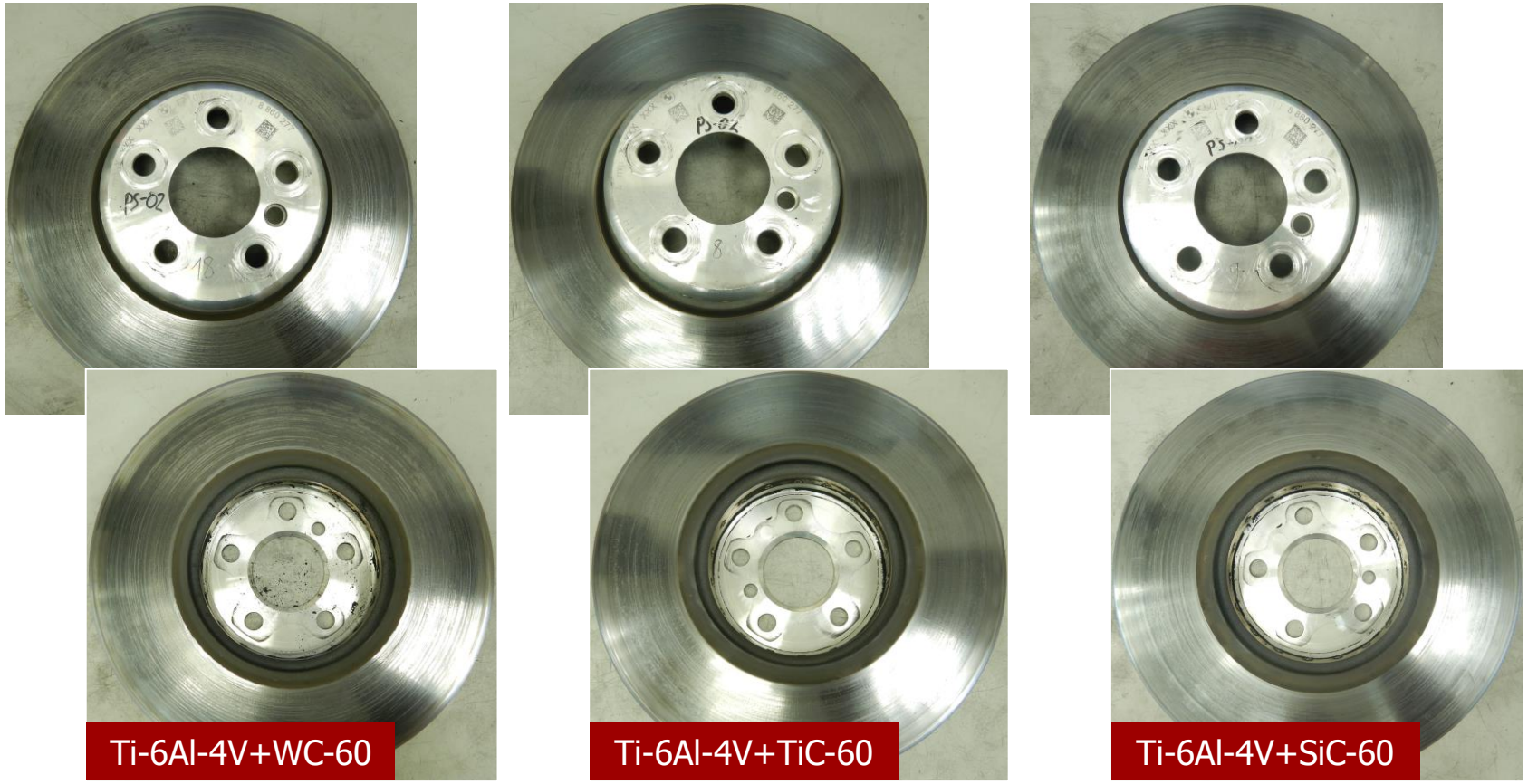
Mechanical performance / Crack formation test



- Intermediate layer - Ti
  - Layer thickness ~ 120 µm
- Top layer - Ti-6Al-4V+WC-60
  - Layer thickness ~ 250 µm (after coating)
  - Layer thickness ~ 150 µm (after grinding)
- Crack formation test
  - 15 brake cycles of 10 shock brakes
  - From maximum speed to 5 km/h with maximum brake deceleration

- No delamination and only very few minor cracks appeared in the coating of the brake disc
- All cracks are limited to the top layer

Reduction of particle emission



- Comparable performance results for all three hard materials
- Particle emission tests shows a saving of >85 % compared to the standard brake system

Cost comparison

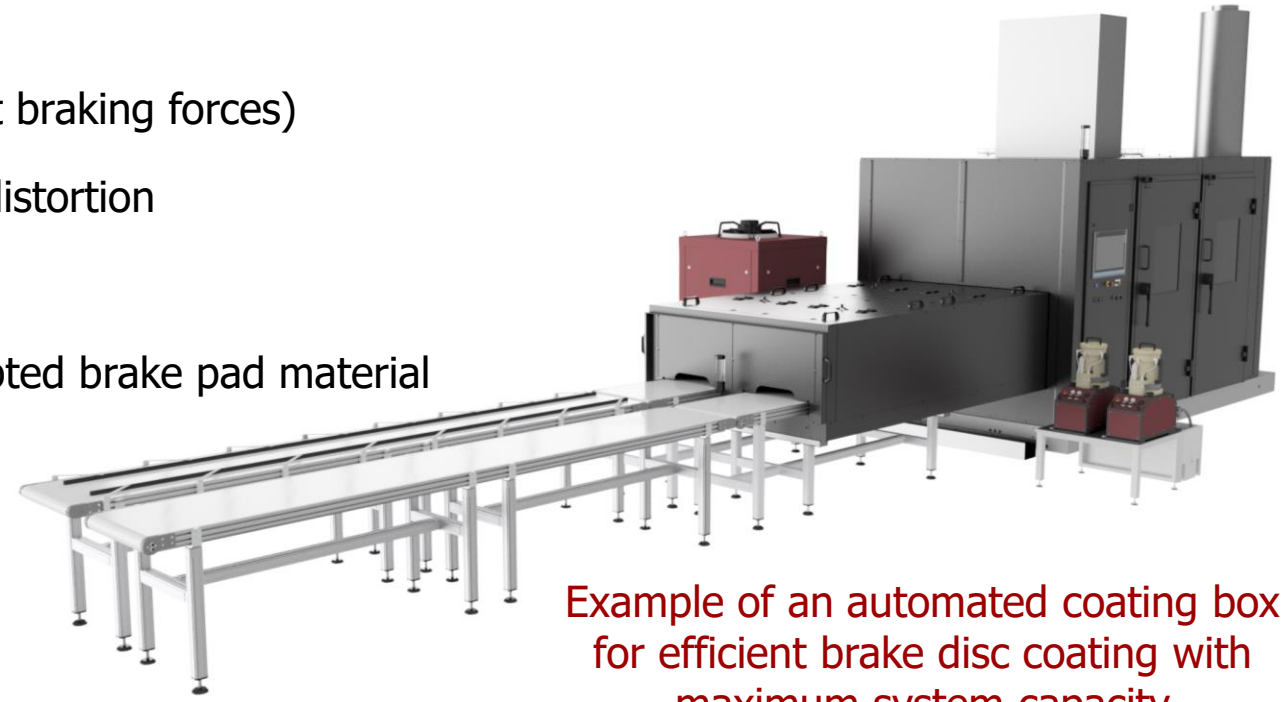
Coating material	Ti-6Al-4V+WC-60	Ti-6Al-4V+TiC-60	Ti-6Al-4V+SiC-60	Ti
Layer	Top	Top	Top	Intermediate
Deposition rate per Gun	12 kg/h	8 kg/h	5 kg/h	7 kg/h
Coating thickness after coating	200-300 µm	200-300 µm	200-300 µm	100-130 µm
Coating weight	107-160 g	64-96 g	50-74 g	33-42 g
Coating thickness after grinding	125-200 µm	125-200 µm	125-200 µm	---
Coating cost per disc	11-16 €	9-13 €	6-9 €	3,50-4,50 €

Further cost reduction is under development

- Reduction of layer thicknesses
- Use of other materials
- Single-layer coating

Summary and outlook

- ✓ Low porosity and uniform coating layer
- ✓ High bonding strength (No delamination even at highest braking forces)
- ✓ Very low thermal impact to the brake disc and thus no distortion
- ✓ Wear reduction of >95 %
- ✓ Coefficient of friction can be improved by choosing adapted brake pad material
- ✓ High corrosion resistance up to 720 h
- ✓ Grinding cost can be significantly reduced
- ✓ Particle emission reduction >85 %
- ✓ Further development with single-layer coating is in progress to increase the performance and reduce the cost
- ✓ Very robust technology with very high throughput
- ✓ Always the same process parameters regardless of brake disc size and shape



Example of an automated coating box for efficient brake disc coating with maximum system capacity

Technical qualification status

- IMPACT Cold Spray coatings for brake discs are technical qualified by BMW Group and other OEM’s
- Cold Spray coatings for brake discs under evaluation for series production by BMW Group

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Thank you for your attention!