Development of tribofunctional coatings for automotive applications using thermal spray and combined polymer lacquer techniques

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engineexpo2011

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MESSE STUTTGART, GERMANY

DAY 3 THURSDAY 19 MAY

ALTERNATIVE MATERIALS AND GRADES TO IMPROVE POWERTRAIN CHARACTERISTICS

Outline

- Motivation
- Coatings in automotive
- Activities at IFKB
- Combined coatings for dry sliding applications
- Cylinder liner coating via HVOF and HVSFS
- Experimental results
- Conclusion

Technologie Transfer Initiative

IFKB Universität Stuttgart

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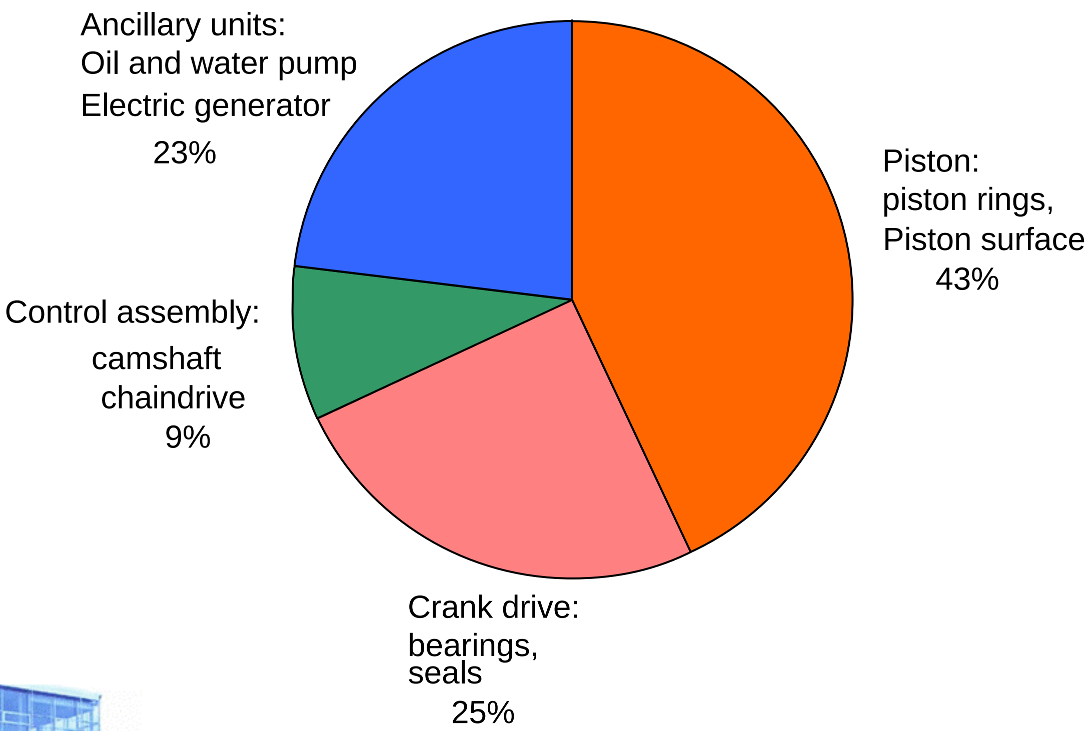
Motivation

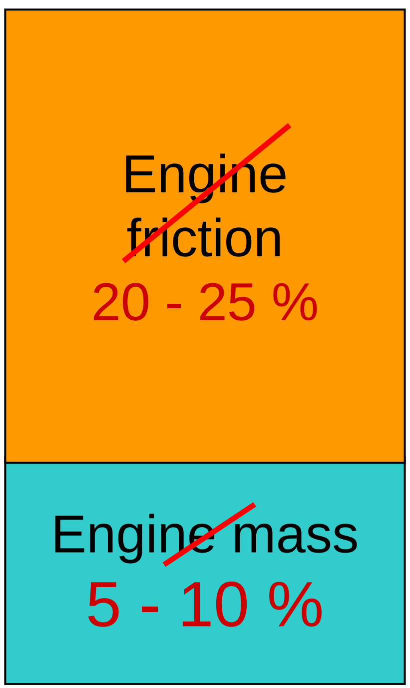
Reduction of friction and wear is essential for energy and cost saving

35 Billions EUR loss per anno in Germany due to friction

According to VW: 10% reduce in engine friction means 2g CO_2 saving / km !



Cost saving potentials:



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Approaches to reduce friction

Classical approach:
Lubrication by oil film

- ❖ Very low friction coefficients can be achieved
- ❖ No coatings necessary

- ❖ Some applications do not allow oil or grease
- ❖ Tribosystem needs to be encapsulated
- ❖ Oil loss is an environmental problem

New approach:
Coatings with dry lubrication ability

- ❖ No oil or grease
- ❖ No encapsulation necessary
- ❖ Lacquer based coatings

- ❖ Systems still show limited lifetimes
- ❖ Elaborate coatings for high performance systems
- ❖ Costs

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Coatings in automotive (examples)

Lacquer technologies

\+ … see next slide

Thermal spraying

Bearings

Cylinder liner

pistons

Synchron rings

Disk breaks

Surface conversion and treatment
case hardening
plasma treatment
(C, N, B, C+N)

Crank shaft

Gear wheels

Gear wheels

PVD / CVD processes

Gear wheels

Piston rings

Emblems

Fuel injection

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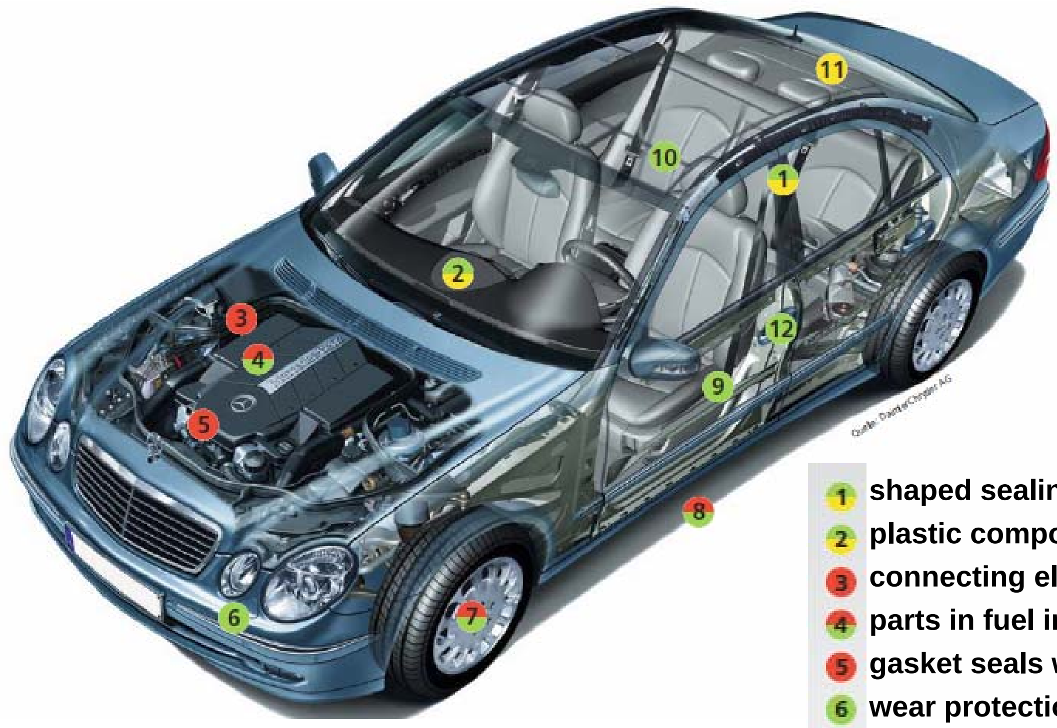
Application Areas of Functional Polymer and Polymer Composite Coatings in Automotive Engineering



1 shaped sealing
2 plastic components (interior)
3 connecting elements in the engine compartment (cylinder head screws …)
4 parts in fuel injection systems
5 gasket seals with reduced friction coefficient
6 wear protection of sealing
7 functional coatings of wheel bolts
8 sliding lacquers for exhaust systems
9 wear protection of seat adjustment components
10 coatings on locking devices for safety belts
11 sliding elements for luggage covers
12 components for door locking systems

- assembly lubrication / optimized running-in period (red)
- life-time lubrication (green)
- noise minimization (yellow)

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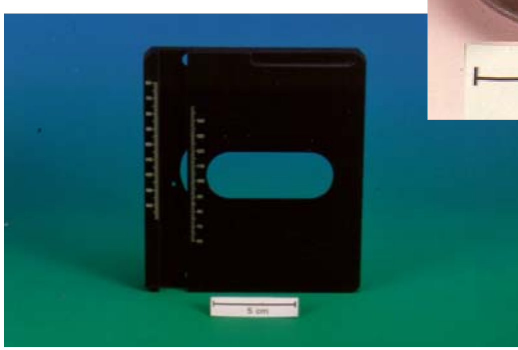
Activities at IFKB University of Stuttgart

Development of combined Hardphase – polymer coatings with dry lubrication ability for industrial applications



Development of cylinder liner coatings using thermal spray methods (HVOF and HVSFS)

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Concept of Polymer Hardphase Composite Coatings (type-1)

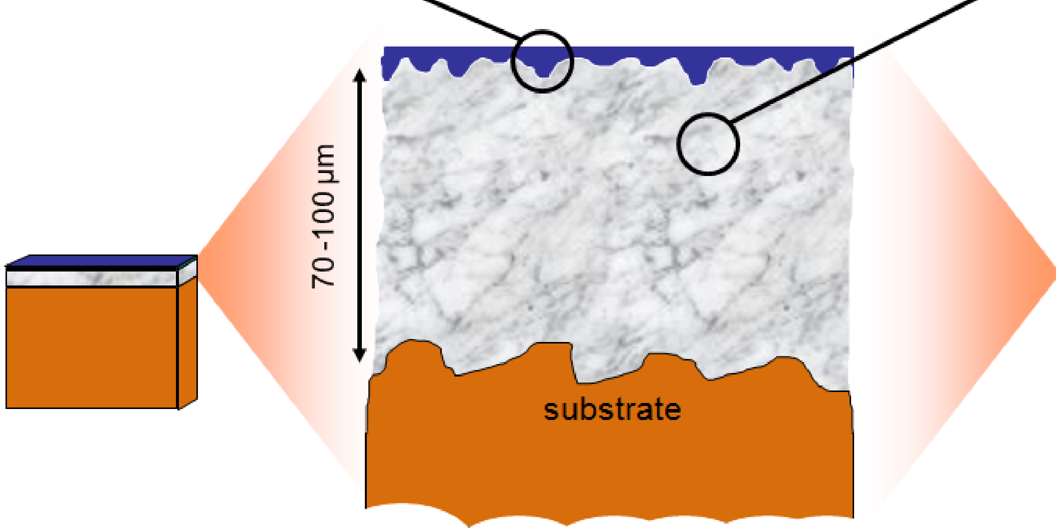
sliding lacquer (single or multilayers)
organic / anorganic binder with
dissolved solid lubricants

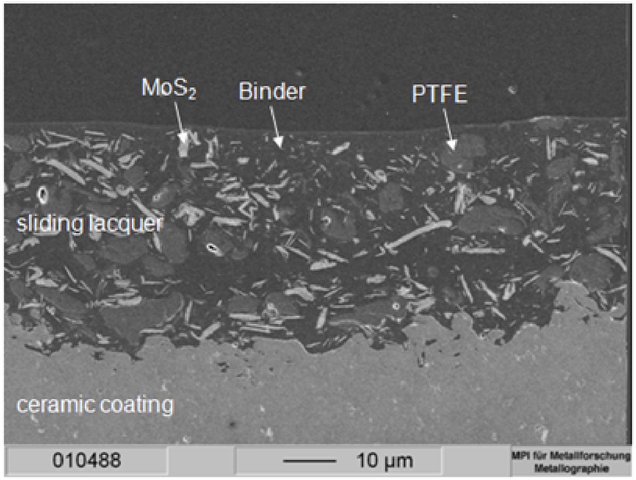
low wettability
- low shear strength
- low coefficient of friction

solid lubricants:
PTFE, MoS_2, Graphit, BN_{hex} ……

thermally sprayed coatings
- wear resistant
- high hardness
- defined surface roughness

coating materials:
metals, metal alloys, oxide ceramics
or cermets





Dietmar Scherer,
Herstellung und Charakterisierung von trockenschmierfähigen
und verschleißfesten Kombinationsschichten auf Leichtmetallen
Dissertation, Universität Stuttgart, 2002

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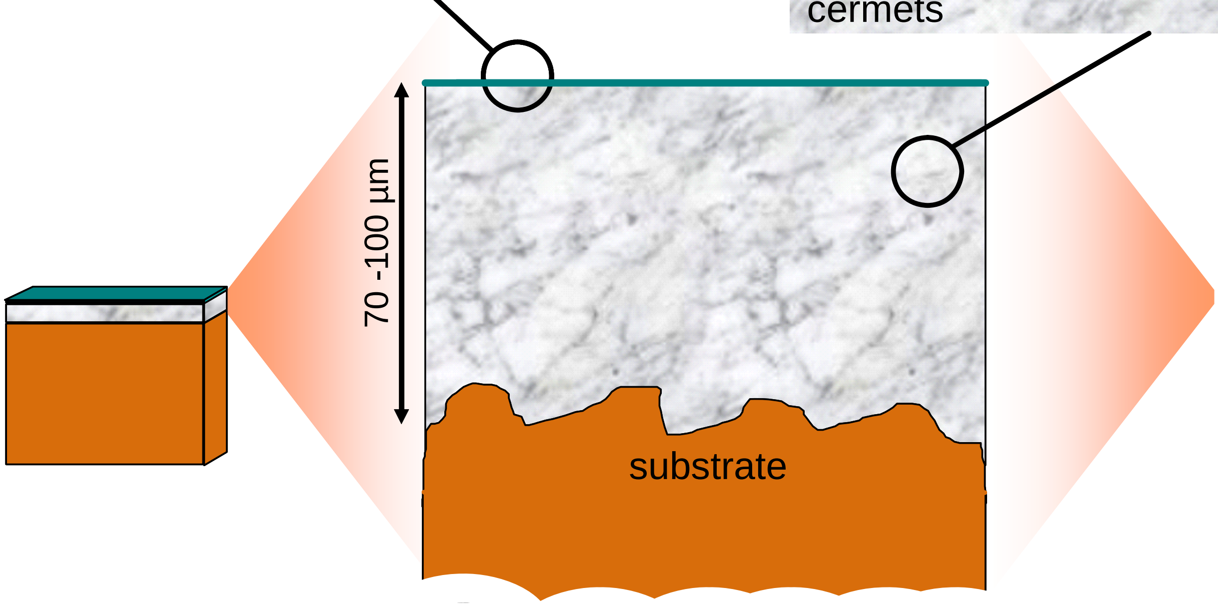
Concept of Polymer Hardphase Composite Coatings (type-2)

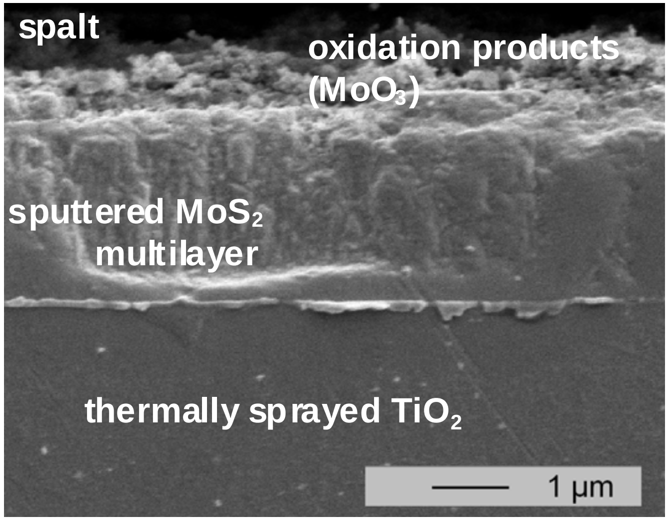
PVD coating
- low wettability
- high hardness
- low coefficients of friction

DLC; MoS_2

thermally sprayed coatings
- wear resistant
- high hardness
- defined surface roughness

coating materials:
metals, metal alloys, oxide ceramics or cermets





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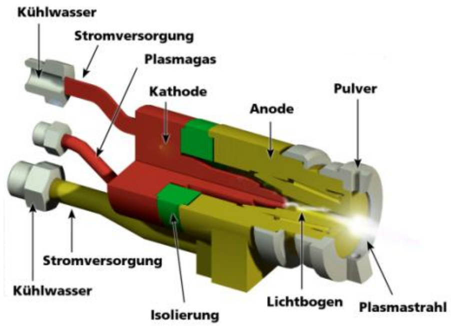
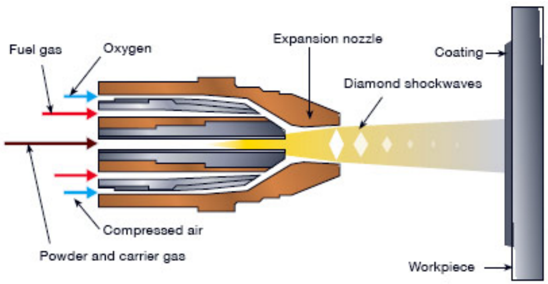
Manufacturing Route of Polymer Hardphase Composite Coatings (PHCC)

Manufacturing of Thermally Sprayed Coating

- cleaning and degreasing
- surface activation (grid-blasting, etching, …)
- coating application via APS or HVOF
- mechanical post-treatment: grinding, polishing or lapping



APS
Atmospheric Plasma Spraying



HVOF
High Velocity Oxy Fuel Flame Spraying

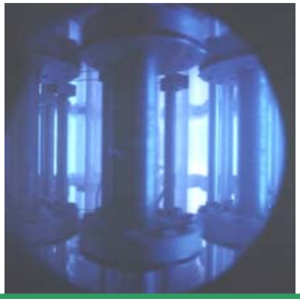
Manufacturing of Polymer Coating

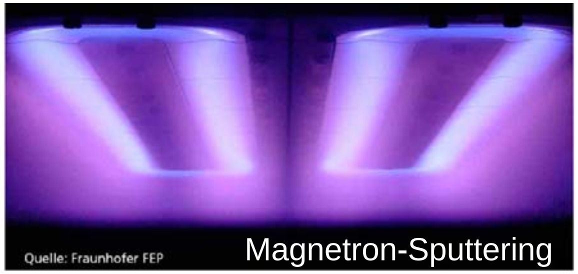
- cleaning and degreasing
- air spraying
- curing

Manufacturing of PVD Coating

- cleaning and degreasing
- Plasma etching
- sputtering / vapor deposition

Paint-Gun





Magnetron-Sputtering

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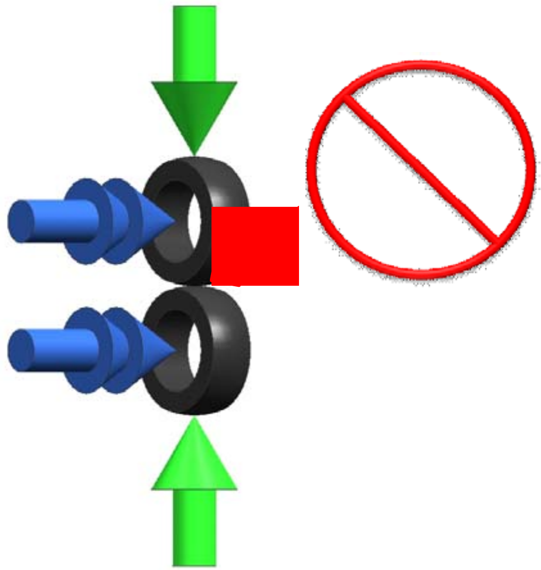
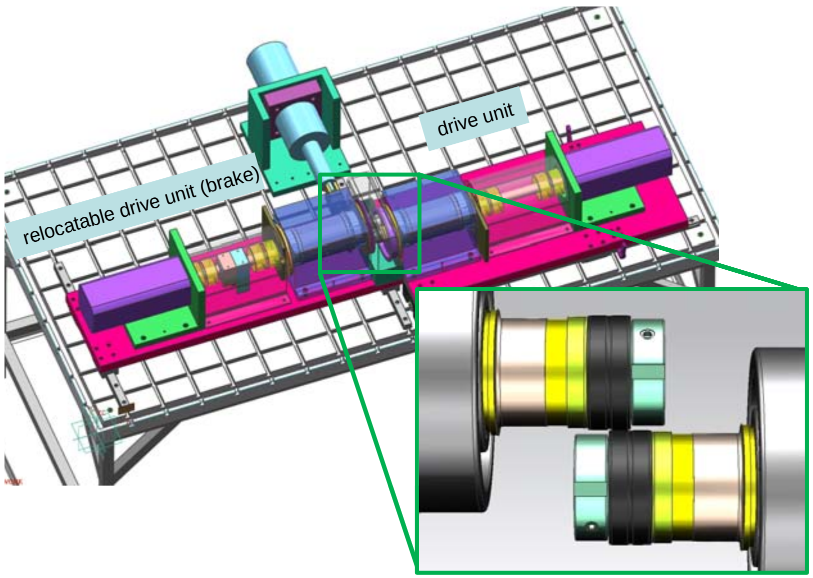
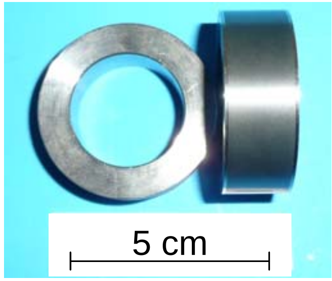
Development of a Tribosystem with Dry Sliding Ability



dry-sliding system under rolling and sliding load



Twin-Disc-Tester



test samples

Test Conditions:

Disc-Diameter	42 mm
Disc-Width	15 mm
Slip	22 %
Axial Force	1000 N

Measured Values:

- Life-Time (brake drive)
- Coefficient of Friction μ
- Axial Force

ZIM
impulse für wachstum
Zentrales Innovationsprogramm Mittelstand

Bundesministerium für Wirtschaft und Technologie

AiF
Ideen eine Zukunft geben

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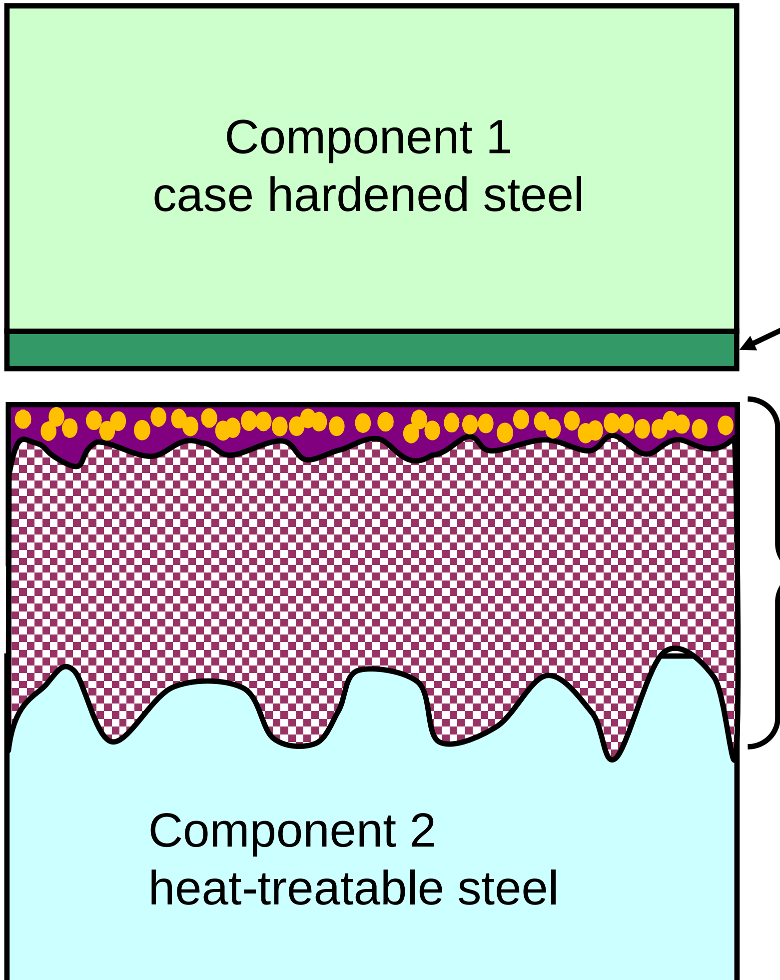
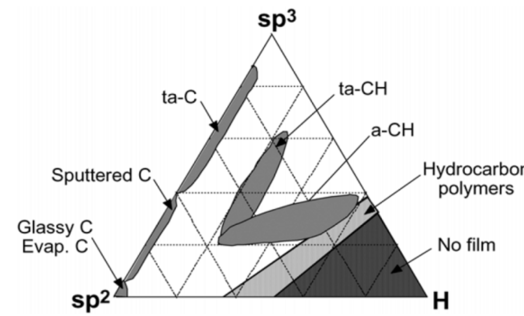
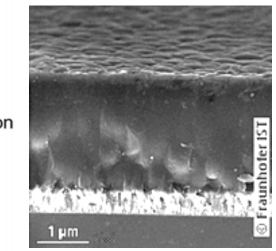
Basic Structure of the Tribosystem



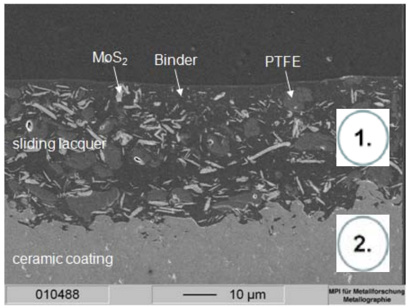
amorphous carbon layer :
hard and smooth surfaces





Quelle: Robertson, J. 1992, 'Properties of diamond-like carbon'

PHCC: adjustable surface properties



1. **sliding lacquer with solid lubricants**
2. **APS or HVOF sprayed hard phase coatings**

State of the Art: DLC vs. DLC Coating!

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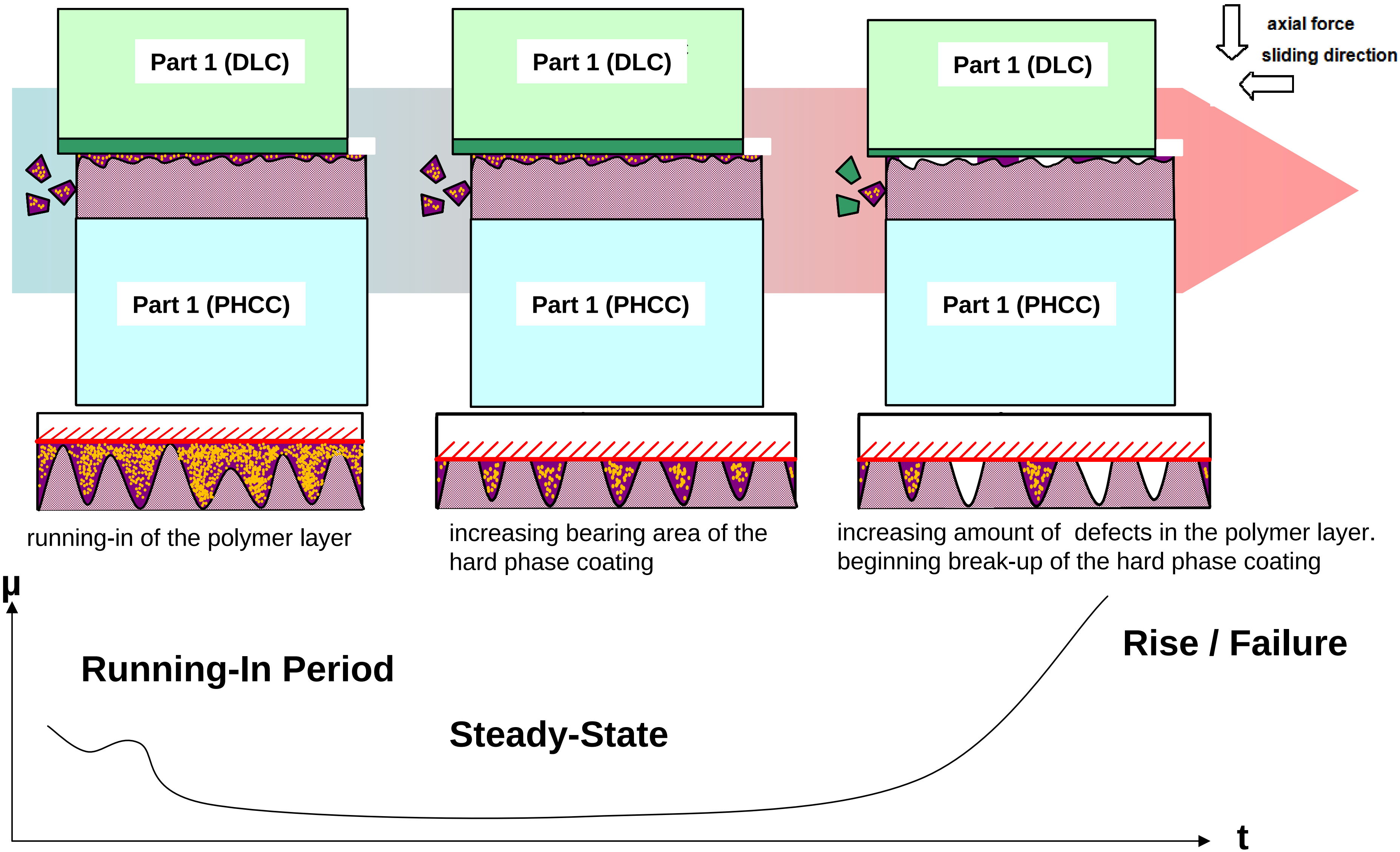
Model of a Dry Sliding System



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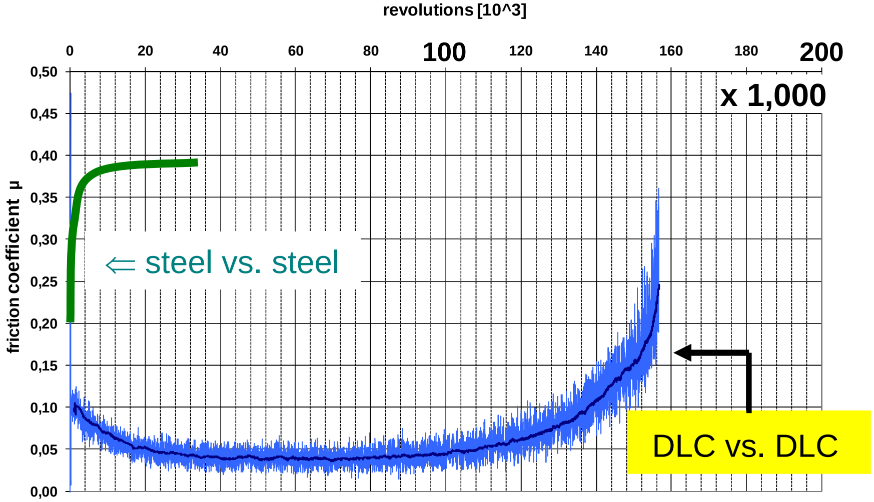
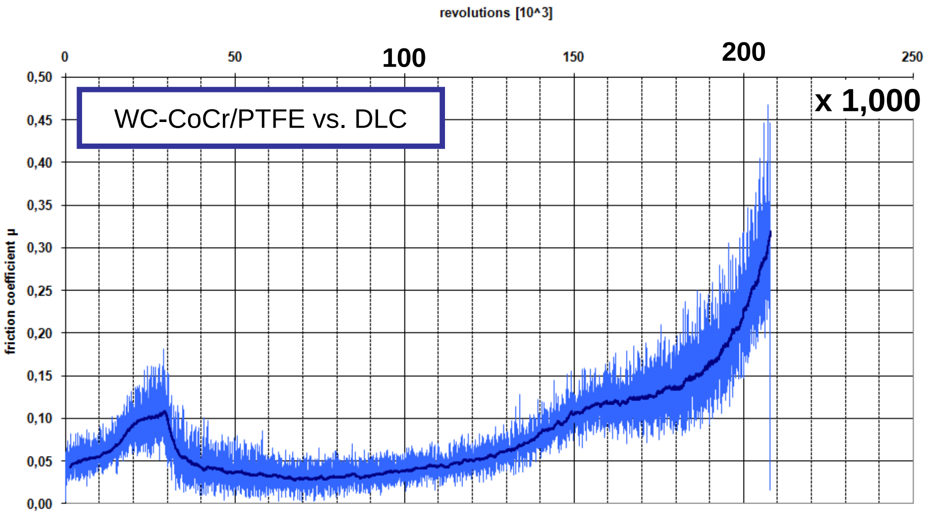
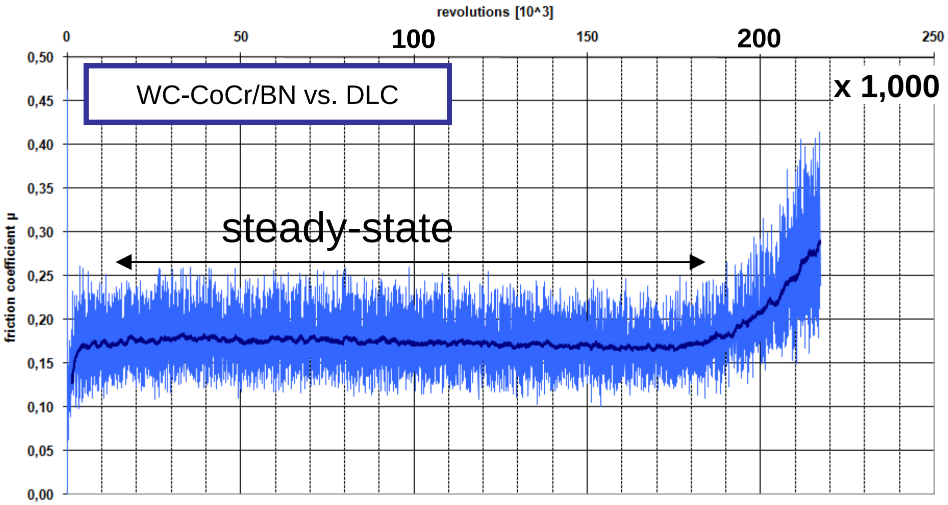
PHCC: WC-CoCr / PTFE and WC-CoCr BN
Test-Results Combined coating type 1 vs. State-of-the-Art DLC



Summary:

- ❖ Composition WC-CoCr / BN reaches high Life-time values
- ❖ Composition WC-CoCr / PTFE reaches friction coefficients comparable to DLC
- ❖ DLC offers very low friction coefficients





AiF Ideen eine Zukunft geben

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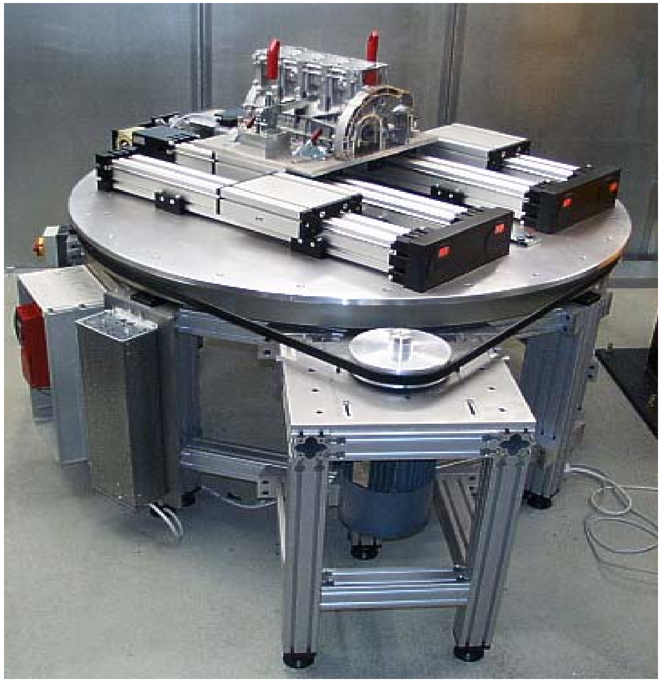
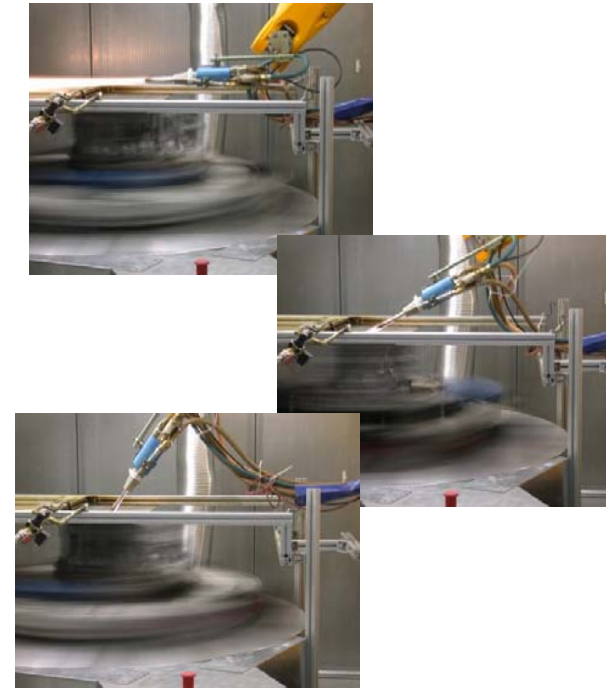
Cylinder liner coatings via High Velocity Flame Spraying





Handling for cylinder liner coating with externally driven HVOF spray torch and rotating engine block.

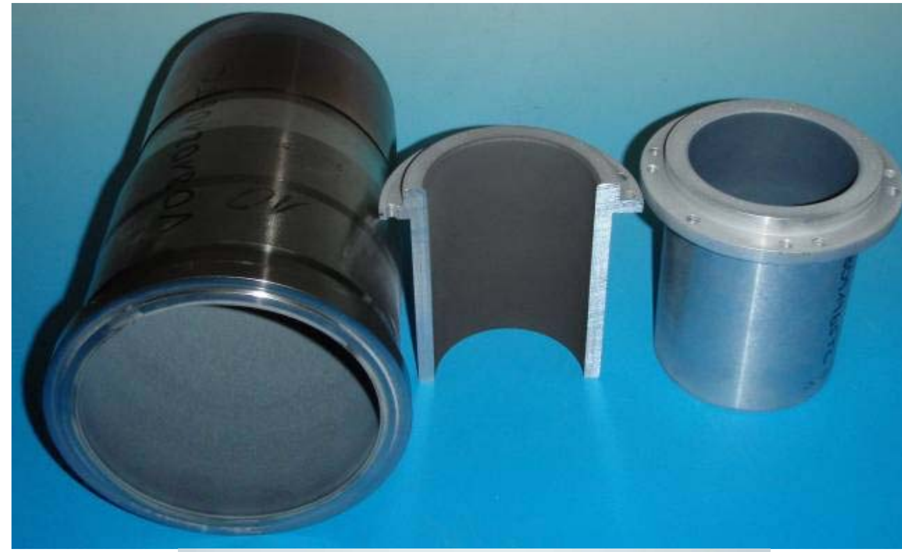
Concept developed at IFKB.

Coated geometries

– **Gray cast iron liner:**
  - For commercial vehicle inline-6 diesel engine
  - 2.1 Liter displacement per cylinder
  - 131 mm bore, 260 mm height
  - 200 mm coating depth, coated surface: 82.3 cm²

– **AlSi9Cu3 test liner:**
  - For process run-in & tribological testing
  - 82.5 mm bore, 125 mm height
  - Coated surface: 32.5 cm²

– **AlSi9Cu3 engine block:**
  - Passenger car inline-4 gasoline engine
  - 2.0 Liter total displacement
  - Integral coated cylinder surface, 32.5cm²
  - Weight: 20 kg



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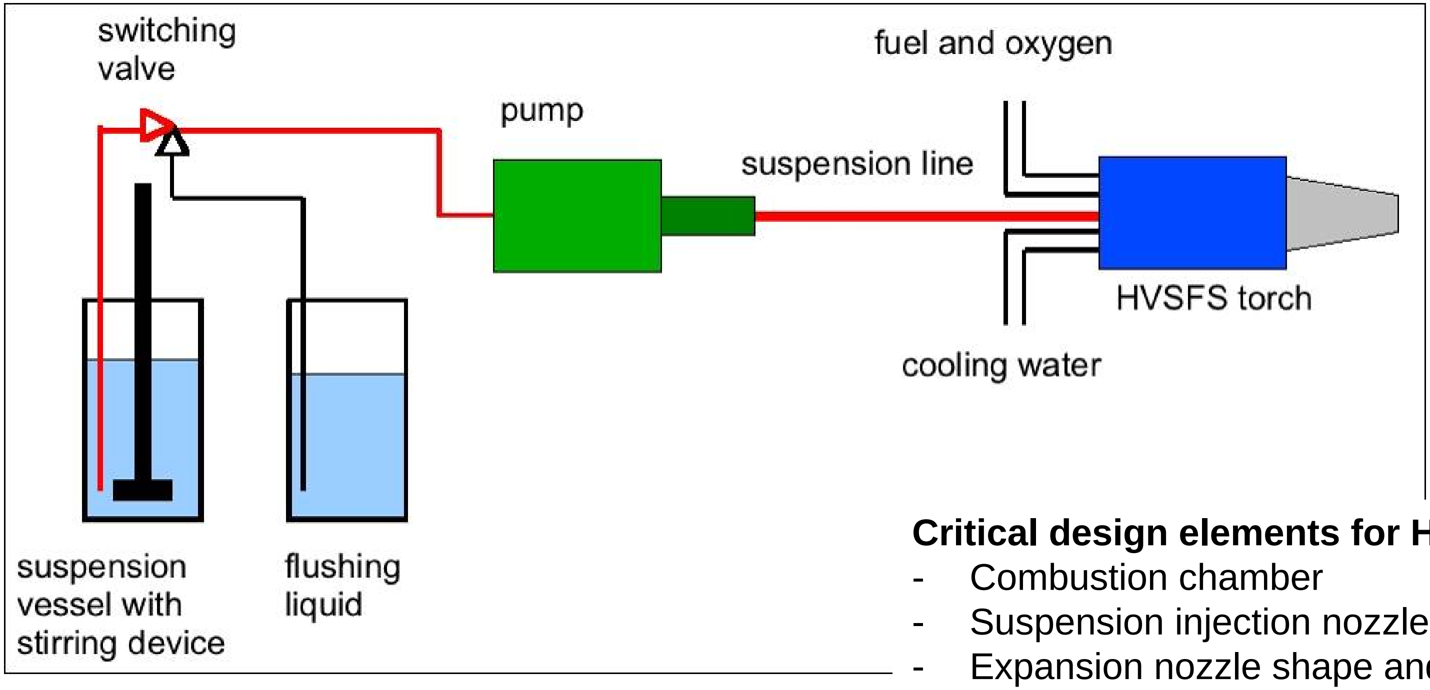
HVSFS
(High Velocity Suspension Flame Spraying)

- novel approach for direct processing of nanoscaled powder particles
- i. e. with n-TiO_2/TiC in a water-isopropanol suspension
- process temperature: ~ 2,500 - 3,200 °C
- particle velocity: ~ 700 - 1300 m/s



Critical design elements for HVSFS:

- Combustion chamber
- Suspension injection nozzle
- Expansion nozzle shape and length
- Radial & axial injection

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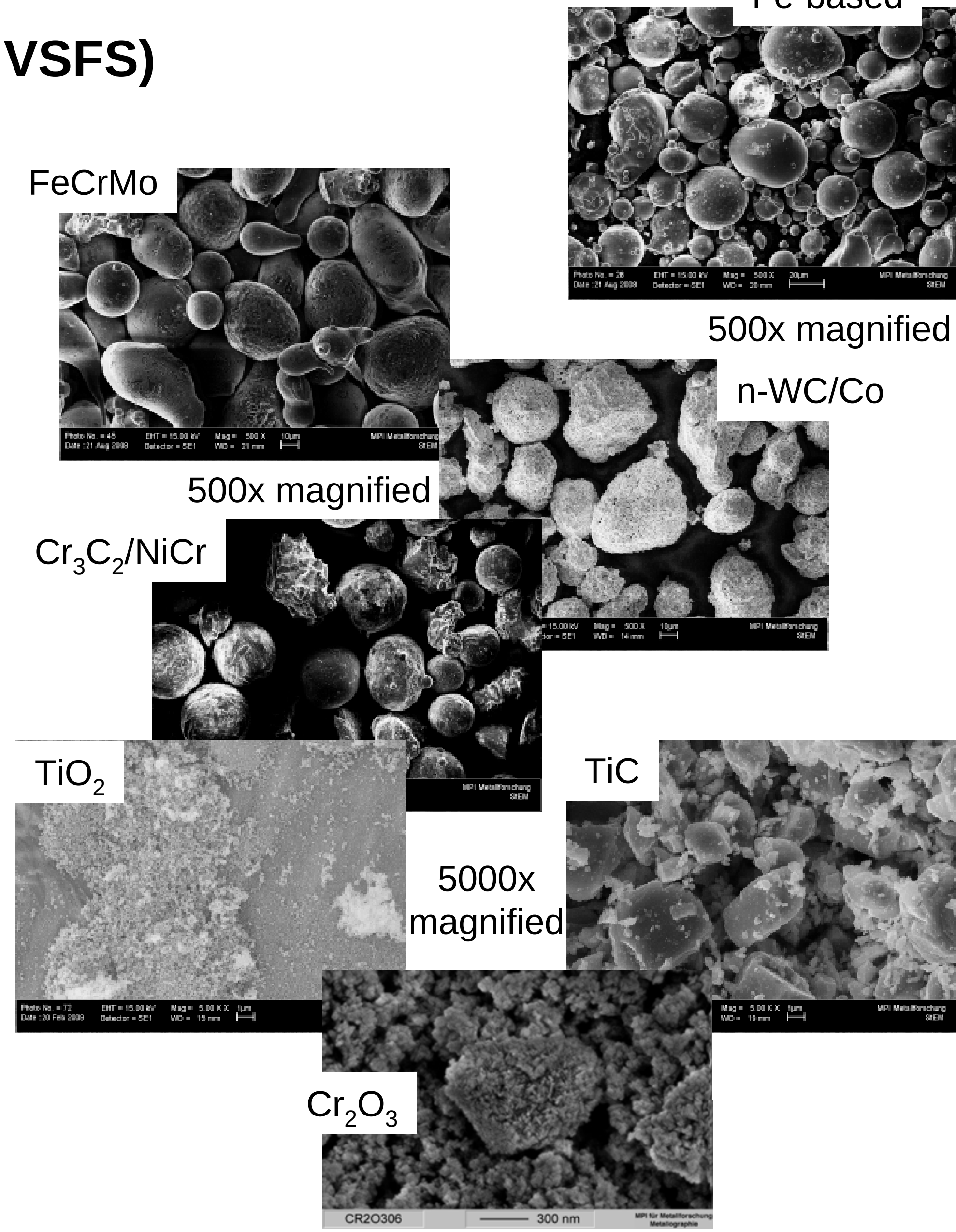
Applied spray materials:
Powders (HVOF) and nanooxides (HVSFS)

- **Durum Nano 3:**
  - Fe-based, high alloyed
  - blend powder, gas atomized
  - processed by HVOF
- **Sulzer-Metco Diamalloy 1008:**
  - Fe17Cr11Mo
  - gas atomized powder
  - processed by HVOF
- **Inframat Infralloy S7412:**
  - nanostructured WC/Co 88/12
  - agglomerated, sintered powder
  - processed by HVOF
- **GTV 80.15.1:**
  - Cr_3C_2/Ni20Cr 75/25
  - agglomerated, sintered powder
  - processed by HVOF

For suspension spraying

- **Titania based suspension:**
  - nanoscale TiO_2/TiC 80/20
  - water based solvent
  - IFKB composition
  - processed by HVSFS
- **Chromia based suspension:**
  - nanoscale Cr_2O_3
  - isopropanol based solvent
  - IFKB composition
  - processed by HVSFS



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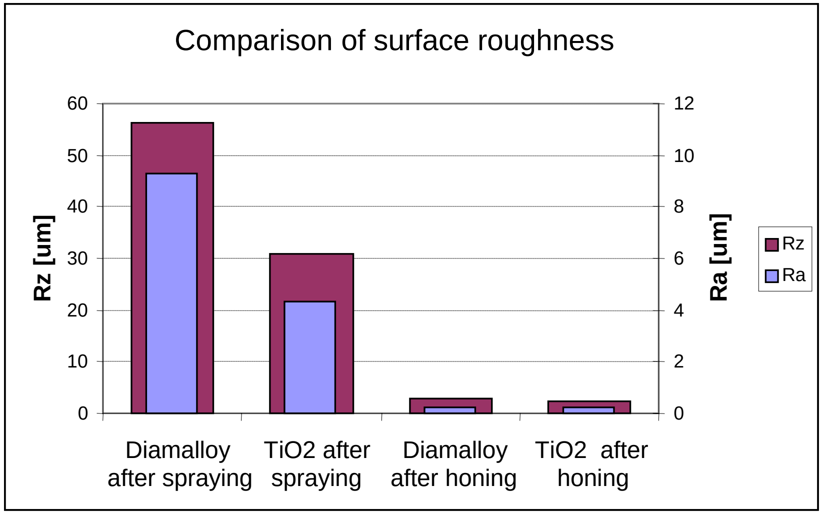
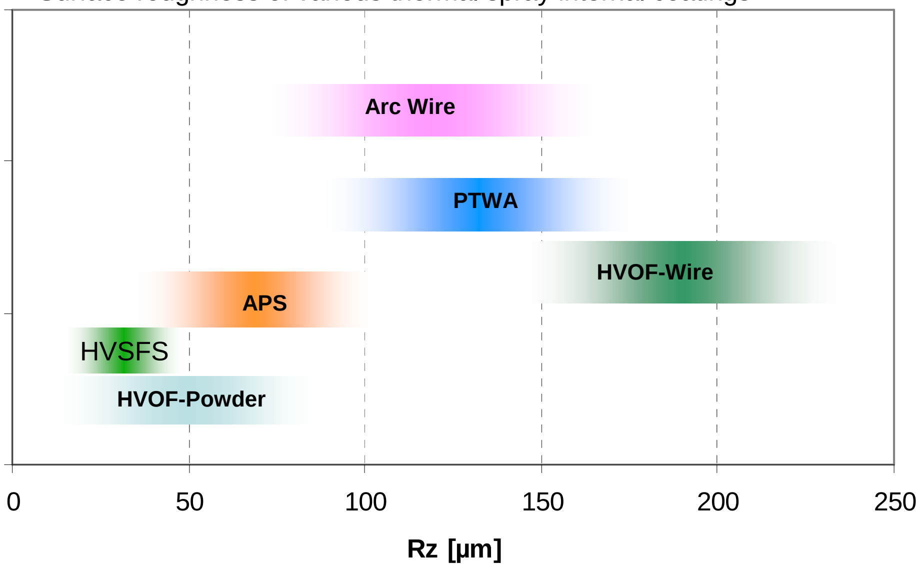
Cylinder liner coating surface characteristics

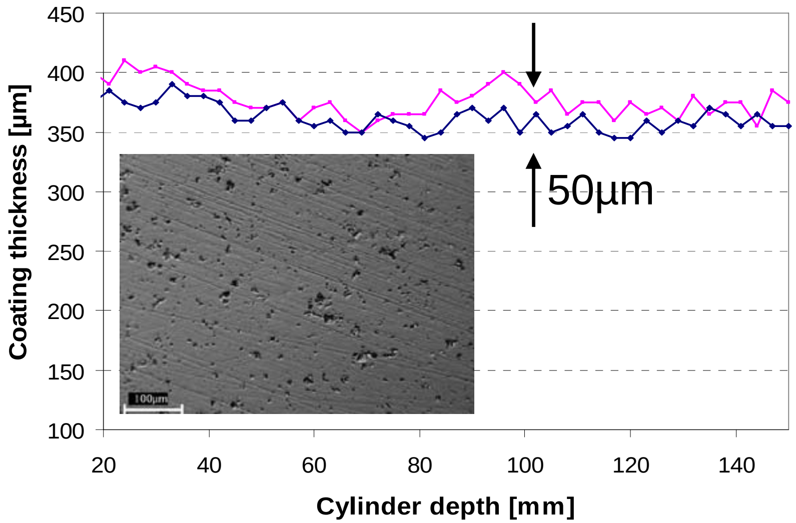
- net shape, low dimensional tolerances of the coated component
- low surface roughness obtained by HVOF coating technique
- no machining or grinding operations necessary before honing. Minimization of the first honing step



Surface roughness of various thermal spray internal coatings



Coating profile along the cylinder depth and honed surface of a Cr_3C_2/NiCr coating (TopGun®)



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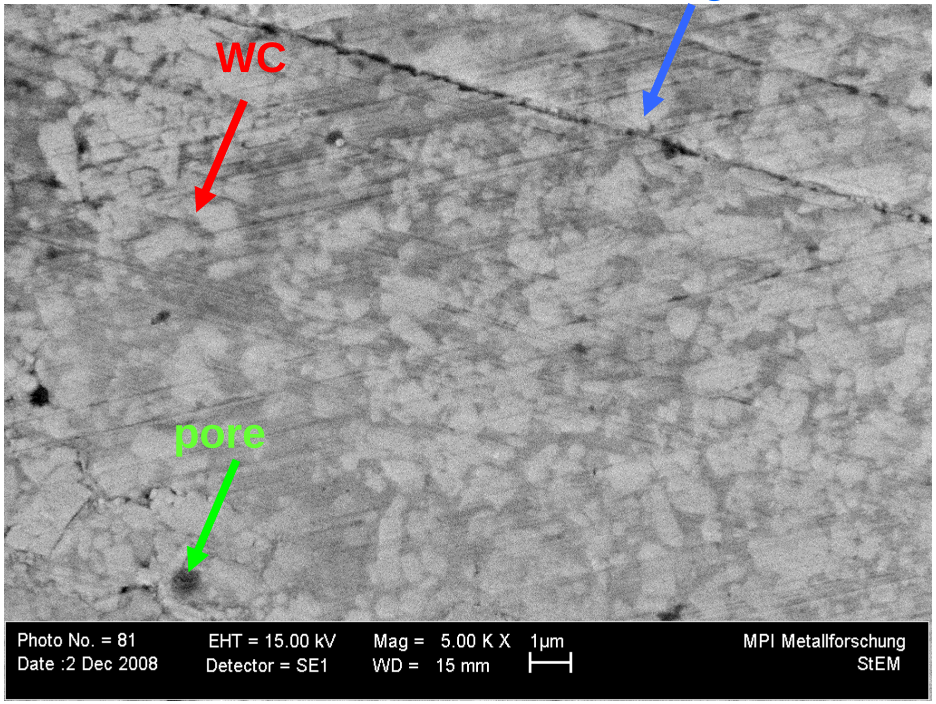
Coating Characterization
Honed liner surface with nanostructured coatings

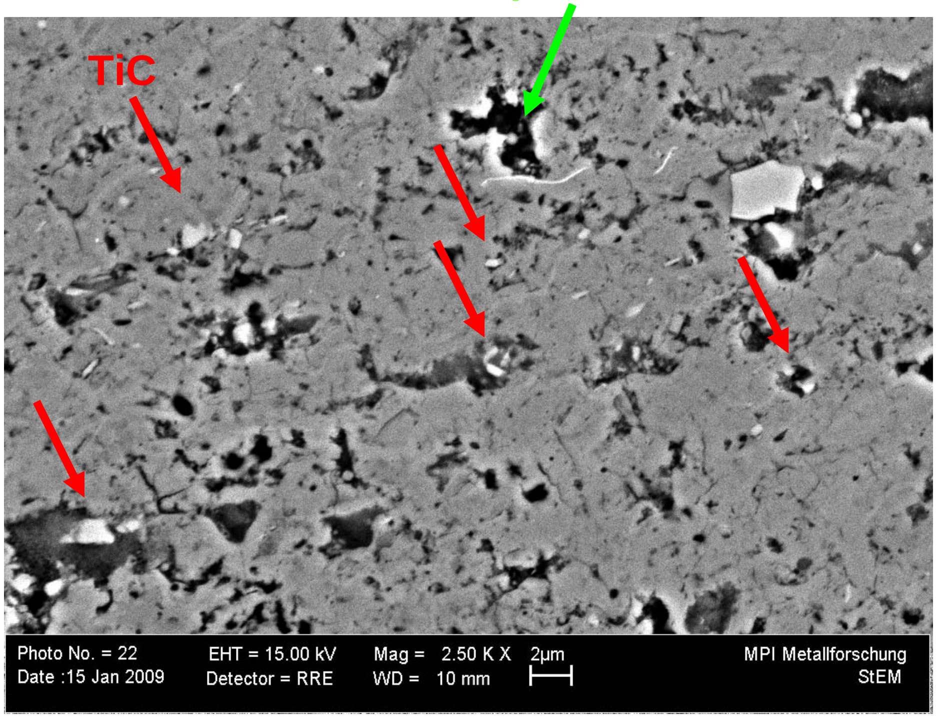
Nano WC/Co



SEM image of honed nano WC/Co surface with WC nano particles and hone grooves

Open porosity after honing: 0,1 %

Nano TiO_2/TiC



BSE cross section image of n-TiO_2/TiC coating

Bright spots: TiC; partially reacting with TiO_2 and forming Ti_nO_{2n-1} (Magnéli Phases)

Open porosity after honing: 1,4 %

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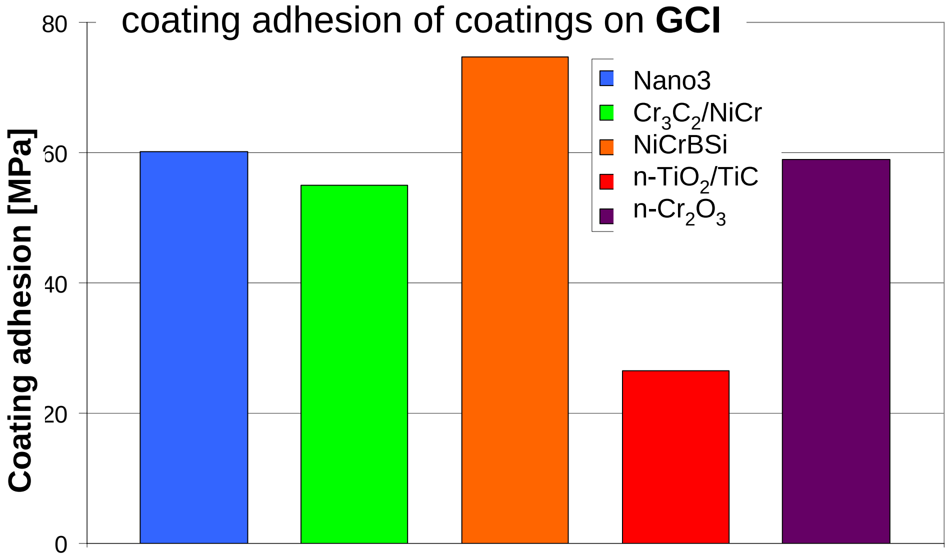
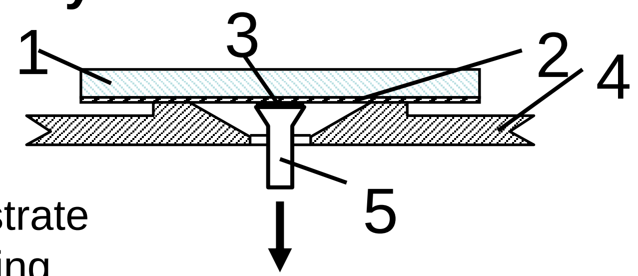
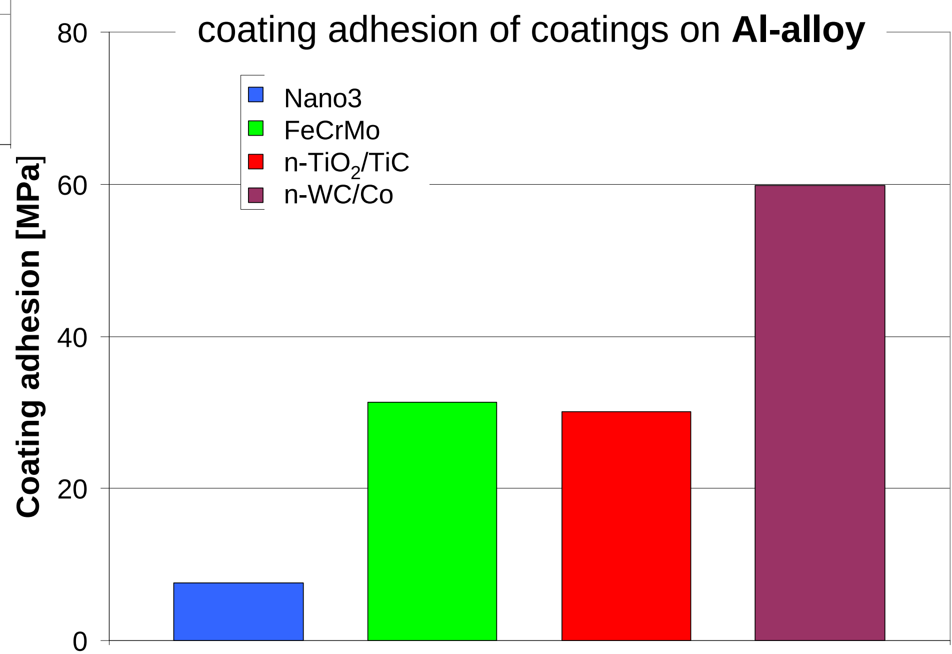
Coating Characterization

Coating adhesion on Al-alloy and GCI cylinder liners





1: substrate
2: coating
3: glue
4: substrate seat (cardanic suspension)
5: tension rod



→ **no coating delamination during post-treatment and engine run**

bonding strength: $\sigma = \dfrac{\text{pulling force F}}{\text{contact area A}}$

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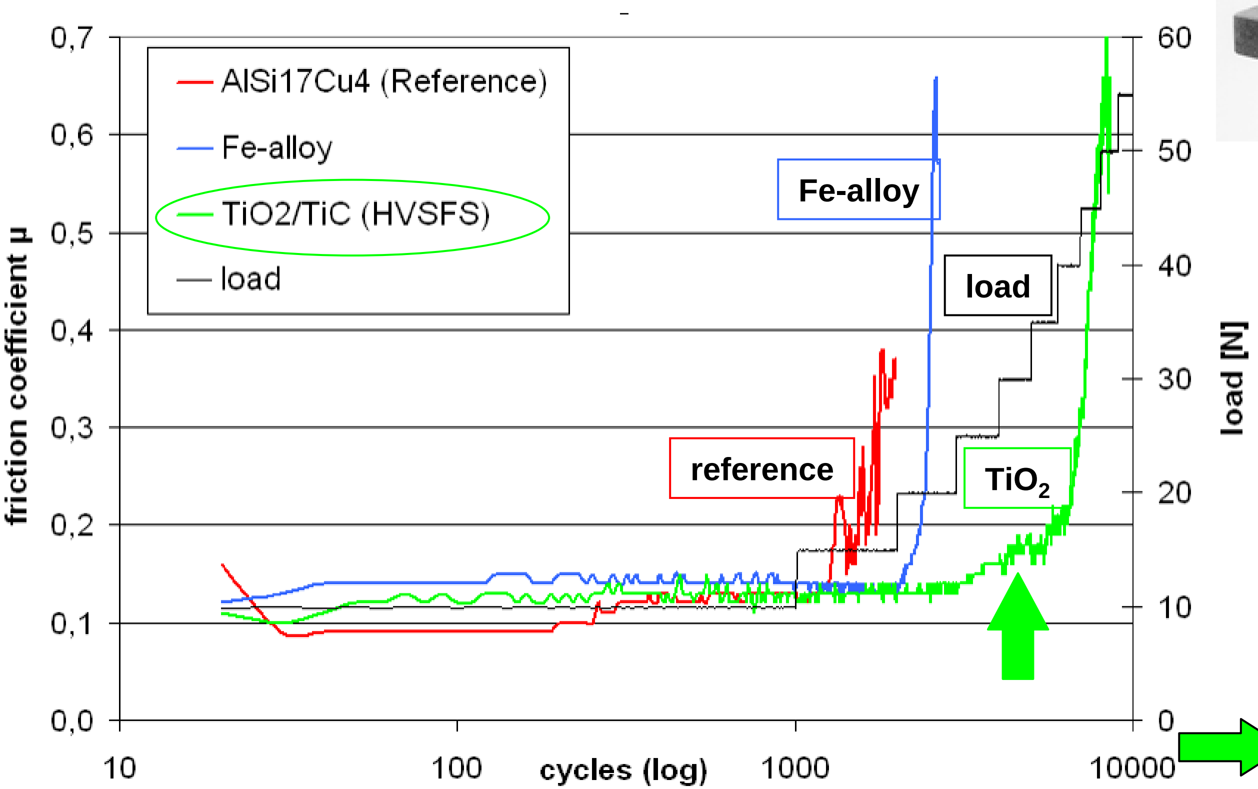
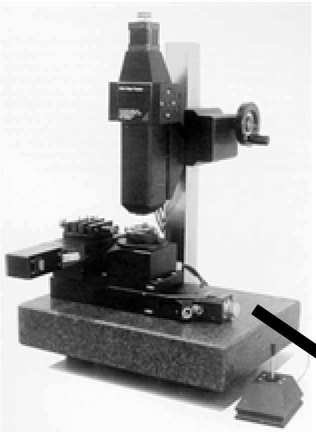
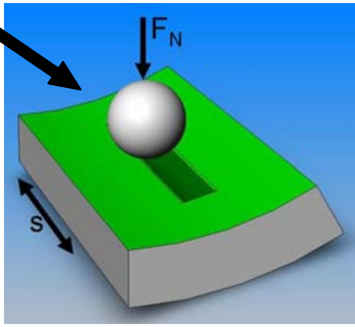
HVSFS Coatings for Cylinder Liners and Engines

Fretting tests after single shot lubrication:

- state-of-the-art AlSi17Cu4 and Gray Cast Iron with cross honing as reference measurements
- simulates operating states of deficient lubrication







Testing conditions (lubricated):

- oscillating motion, 5 mm stroke
- load force F_N from 10 to 55 N
- ambient temperature
- single shot lubrication

HVSFS coatings shows lowest friction coefficient and good wetting behavior

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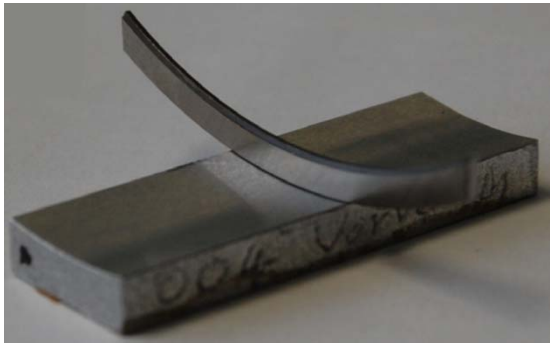
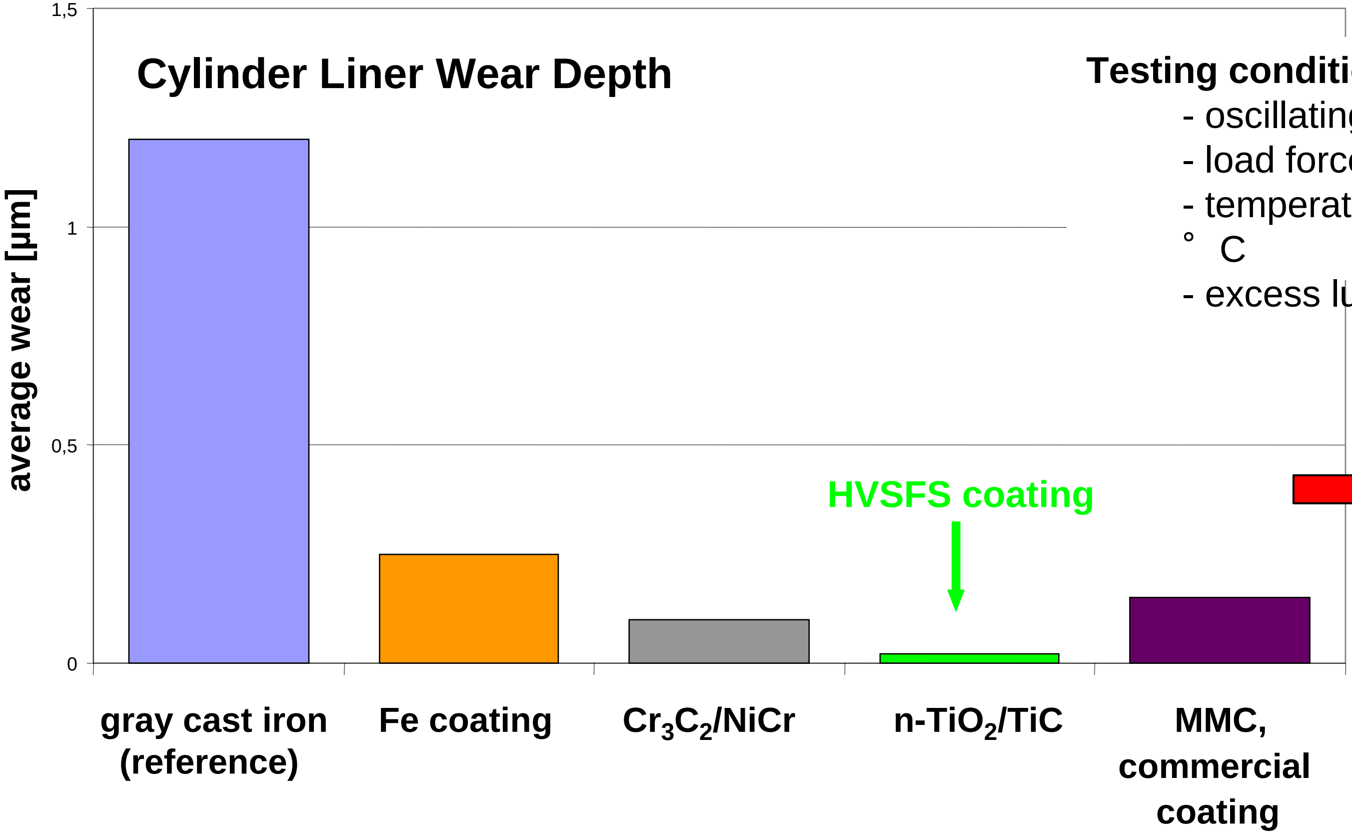
Wear test results: Comparison of wear tests of HVOF, HVSFS and commercial (APS) coatings

- piston ring on cylinder liner segment
- frictional wear occurred during segment test
  (gray cast iron and commercial APS coating as reference)





Testing conditions:
- oscillating motion, 30 mm
- load force F_N from 150 to 473 N
- temperature from 91 to 112 °C
- excess lubrication

HVSFS coatings show significantly lower wear

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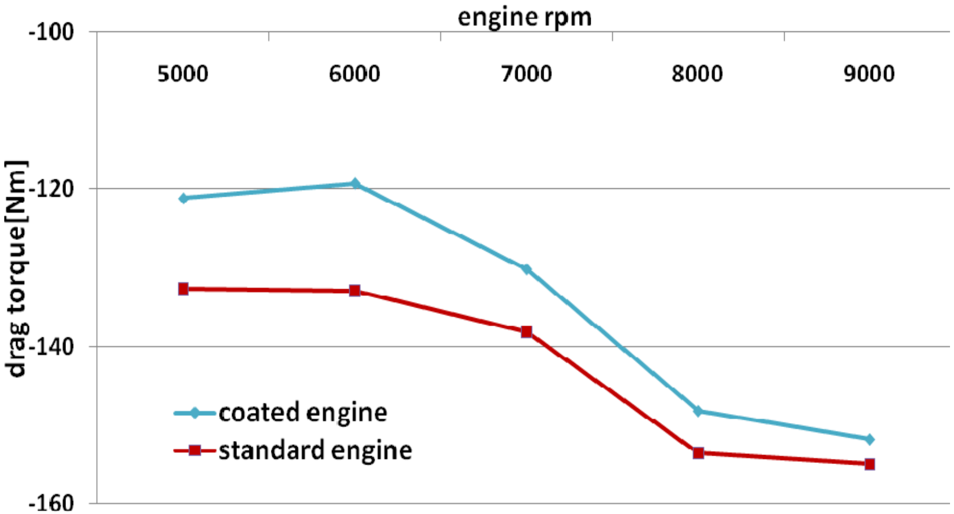
Results in first engine tests

Drag Torque Measurement:

- inline-4-cylinder (600 cm³), engine
- WC/Co-coated
- Formula Student race car engine
- Comparison to series production
- Nikasil® coating



Fired/Externally driven Single-Cylinder Test Engine:

- Formula 1 test engine setup
- Comparison to state-of-the-art Nikasil® coating

Coating	friction pressure reduction [bar] fired engine	friction pressure reduction [bar] externally driven engine
Cr_3C_2/NiCr	0.05	0.05
Mo	0.1	0.02
Mo_2C/Mo	0.02 … 0.09	n/a

➡ **significantly reduced frictional losses with all thermal spray coatings**

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Conclusions

- Combination of ceramic or cermet based TS coatings with polymers has potential for dry sliding application with increased lifetime compared to pure polymer coating
- Evaluation of combined coatings under rolling / sliding conditions show better performance than standard DLC systems
- Cylinder liner coating is performed using HVOF and HVSFS with rotating crankcase
- Thermal spray coatings show beneficial pore structure on surface (oil retention)
- High performance coatings with high wear and corrosion resistance
- HVOF / HVSFS can be of interest for liners in trucks ⇨ corrosion and wear resistance

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