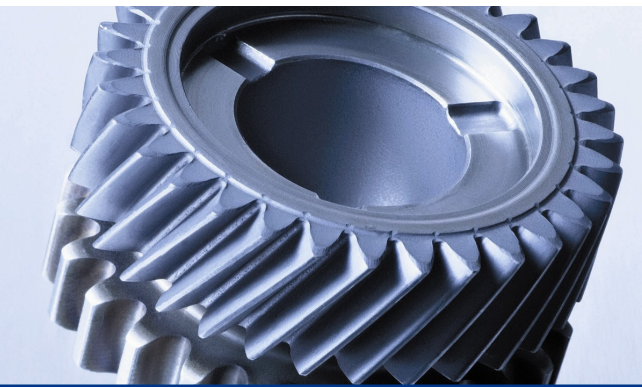
Innovation in Music


Reduced friction, weight and size of mechanical systems by tailor made coatings and lubrication

Guenter Eitzinger, Katrin Zorn, Oliver Jantschner, Christian Mitterer-18.05.2012
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htc@miba.com

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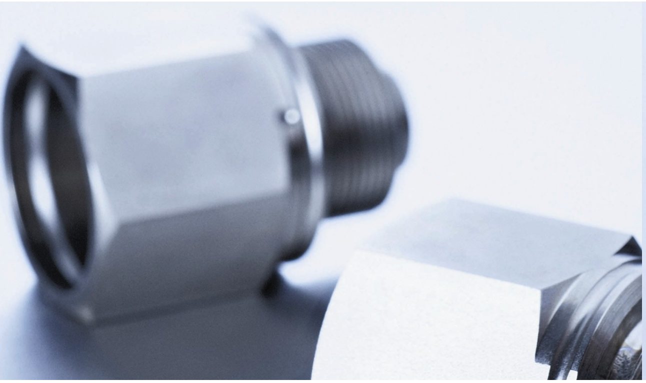
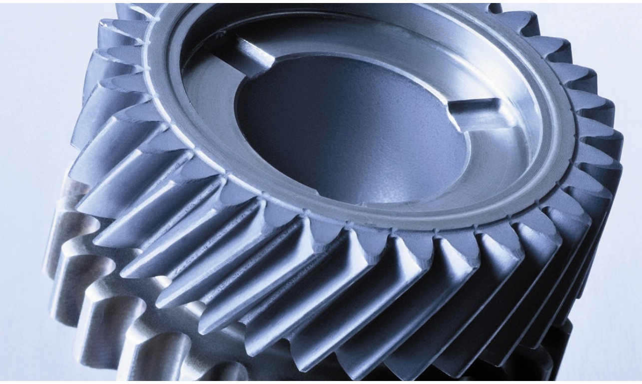
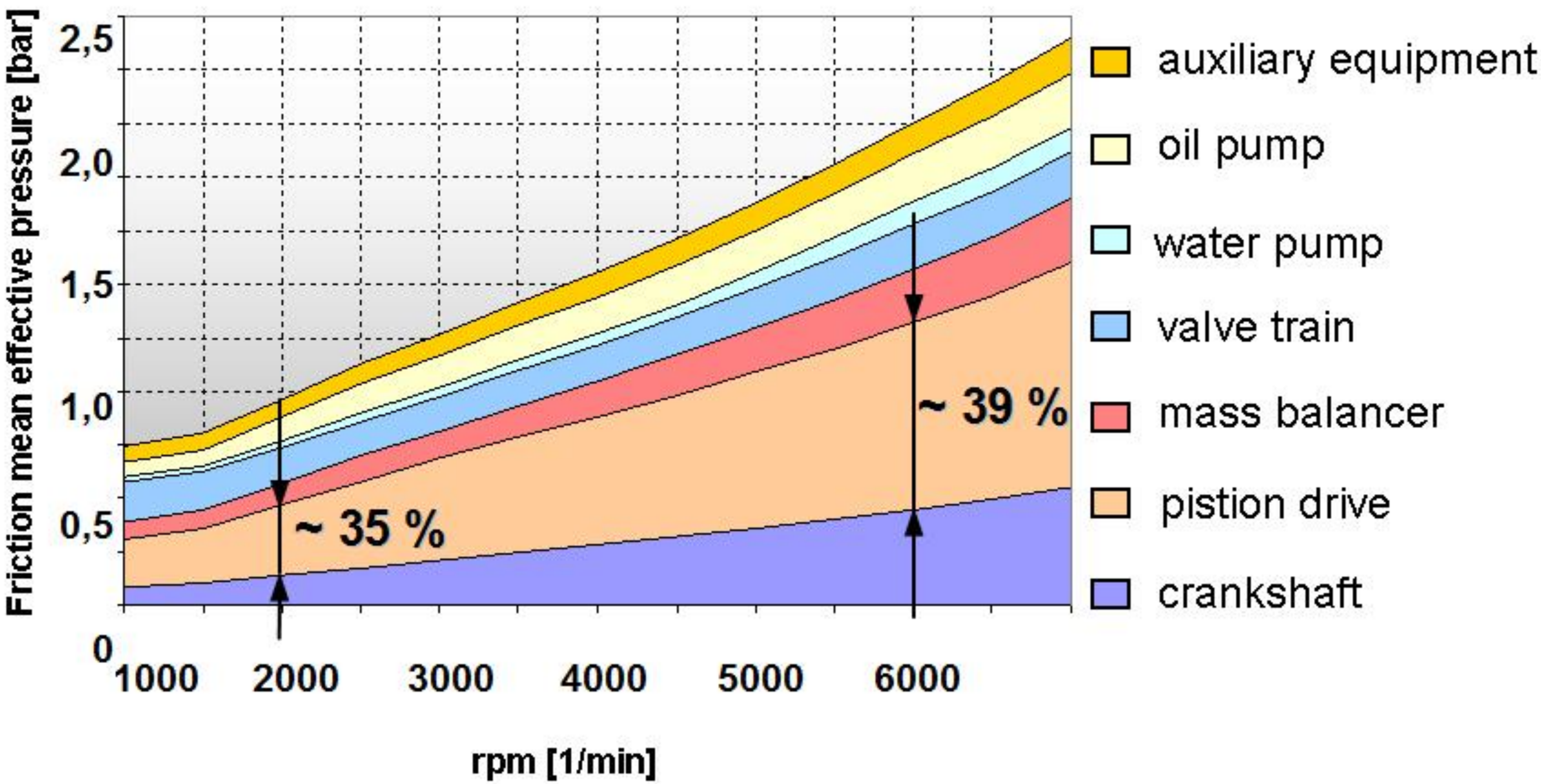
Agenda

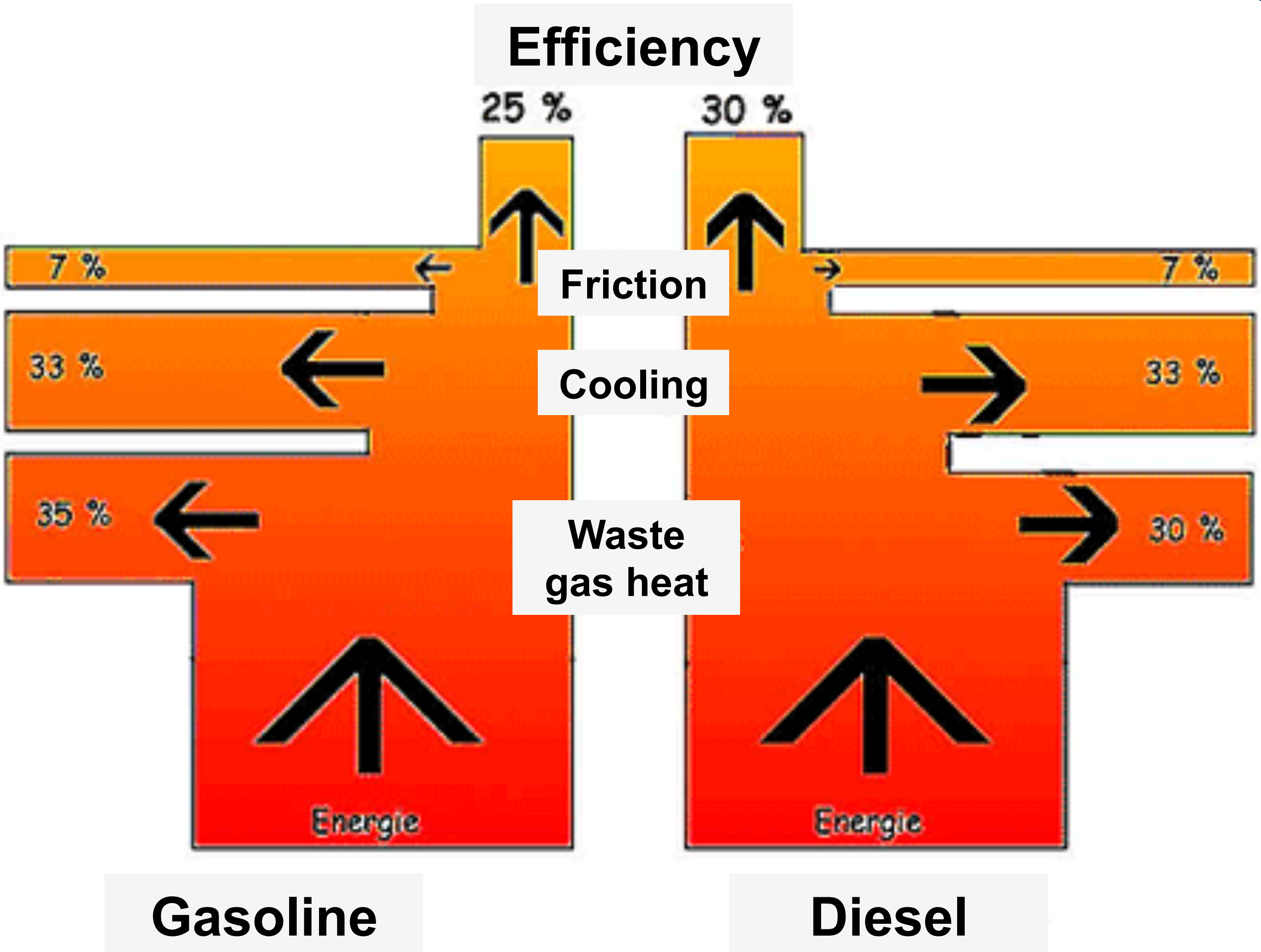

- Motivation
- High Temperature DLC
- Lightweight pump body (Al - Alloy) coated with ENiP
- Sliding lacquer on a sintered net shape part
- Summary

Motivation

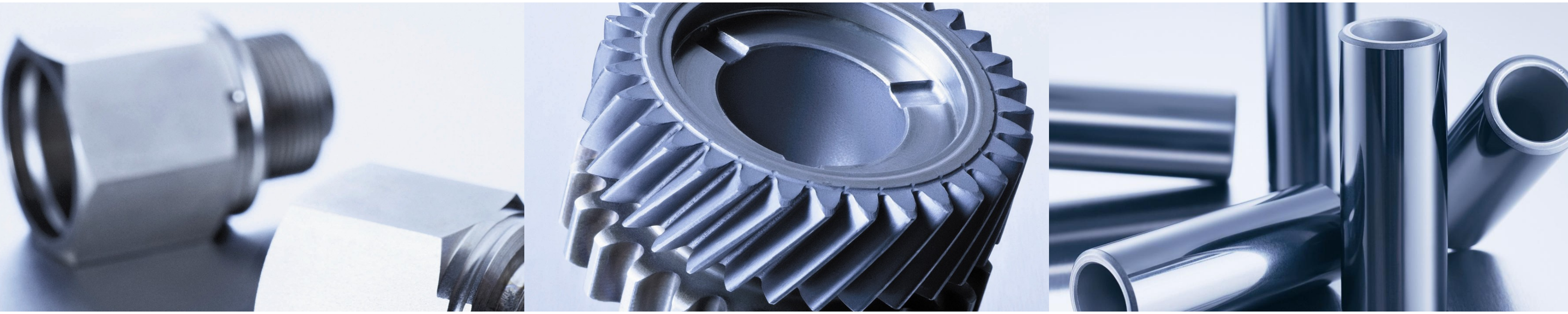


Source: A.Merkle, M.Werner, Technical University of Munich, Institute of Combustion engines ©2008-2009

Efficiency Combustion Engine



Agenda



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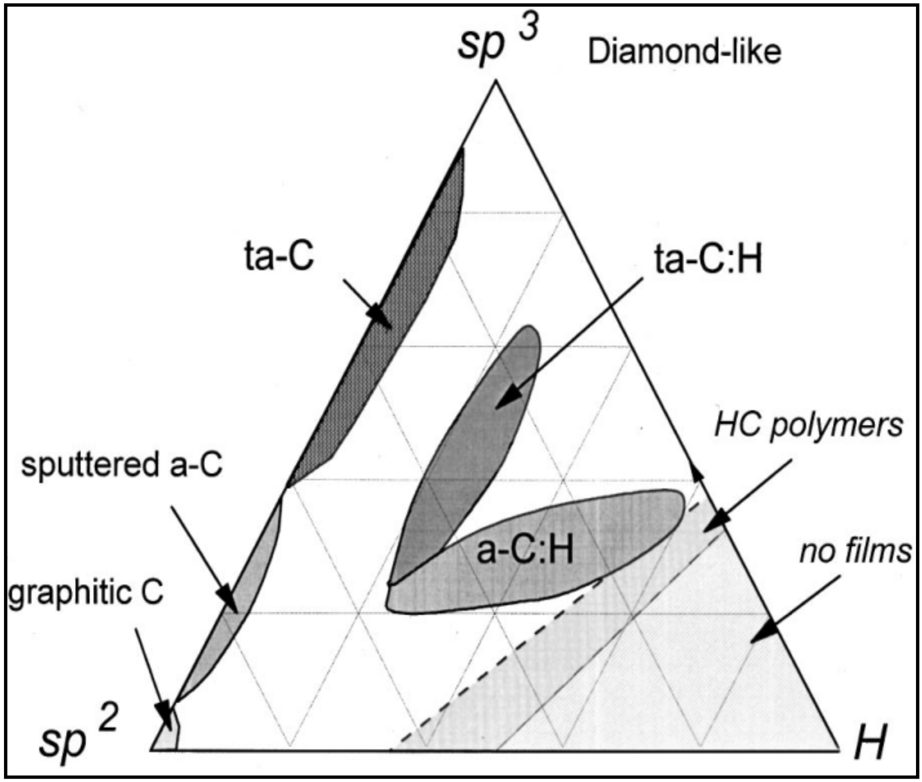
Diamond like carbon (DLC) How to tune?

- Deposition Temperature:
  - Higher sp3-content, above 300°C up to 80%
  - Higher hardness
  - Higher intrinsic stresses
- Bias Voltage:
  - Higher sp3-content
  - Higher hardness
  - Higher intrinsic stresses
- Addition of metallic species:
  - Effects oxidation resistance
  - Is able to stabilize sp^3
- Addition of H, N, O



Diamond like carbon (DLC) Classification

Table 1. Classification of carbon films; see also explanatory material in the text

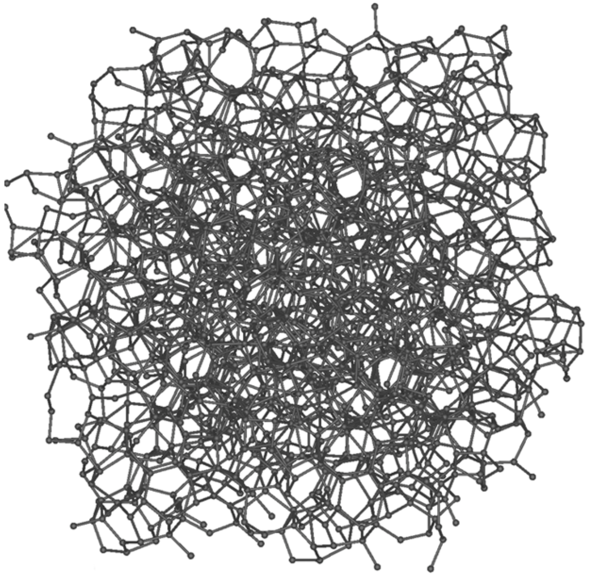
	Carbon films													
Designation	1 Plasma polymer films	2 Amorphous carbon films (diamond-like carbon films/DLC)							3 Crystalline carbon films					
									Diamond films					Graphite films
Thin film/ thick film	Thin film	Thin film							Thin film			Thick film (freestanding)		Thin film
Doping, Additional elements		hydrogen-free		modified with metal	hydrogenated		modified		undoped		doped	undoped	doped	undoped
							with metal	with non-metal						
Crystal size on the growth side		(amorphous)							1 nm to 500 nm, nanocrystalline	0,5 µm to 10 µm, microcrystalline	0,1 µm to 5 µm	(5 µm to) 80 µm to 500 µm	80 µm to 500 µm	
Predominating C-C bond type	sp^2 or sp^3, linear bond	sp^2	sp^3	sp^2	sp^2 or sp^3	sp^3	sp^2	sp^2	sp^3	sp^3	sp^3	sp^3	sp^3	sp^2
Film no.	1	2.1	2.2	2.3	2.4	2.5	2.6	2.7	3.1	3.2	3.3	3.4	3.5	3.6
Designation	Plasma polymer film	Hydrogen-free amorphous carbon film	Tetrahedral hydrogen-free amorphous carbon film	Metal-containing hydrogen-free amorphous carbon film	Hydrogenated amorphous carbon film	Tetrahedral hydrogenated amorphous carbon film	Metal-containing hydrogenated amorphous carbon film	Modified hydrogenated amorphous carbon film	Nanocrystalline CVD diamond film	Microcrystalline CVD diamond film	Doped CVD diamond film	CVD diamond	Doped CVD diamond	Graphite film
Recommended abbreviation	–	a-C	ta-C	a-C:Me (Me = W, Ti ...)	a-C:H	ta-C:H	a-C:H:Me (Me = W, Ti ...)	a-C:H:X (X = Si, O, N, F, B ...)	–	–	–	–	–	–
Other designations commonly encountered but which should no longer be used		DLC, graphite-like carbon	DLC, i-C, diamond, amorphous diamond	Me-DLC, DLC	DLC, a-DLC, hard carbon	DLC	DLC, Me-DLC, Me-C:H, MeC:H, metal-carbon	DLC	PCD, PD, NCD	PCD, PD	PCD, PD	Diamond ceramic, TFD	Diamond ceramic	
Deposition methods	PA-CVD	PVD	PVD	PVD	PVD, PA-CVD	PVD, PA-CVD	PVD + PA-CVD, PA-CVD	PVD + PA-CVD, PA-CVD	Activated CVD	Activated CVD	Activated CVD	Activated CVD	Activated CVD	CVD, PVD

Diamond like carbon (DLC) Structure

Amorphous carbon

is a random network of covalently

bonded sp2 (trigonal) clusters linked by sp3 (tetrahedral) bonds.



Element	C	Si	Cr
Radius	73 pm	111 pm	128 pm
Electron-configuration	[He] $2s^2\,2p^2$	[Ne] $3s^2\,3p^2$	[Ar] $3d^5\,4s^1$
Crystal structure	hex, cubic, tetrahedral	Diamond-cubic	Bcc (body centered cubic)

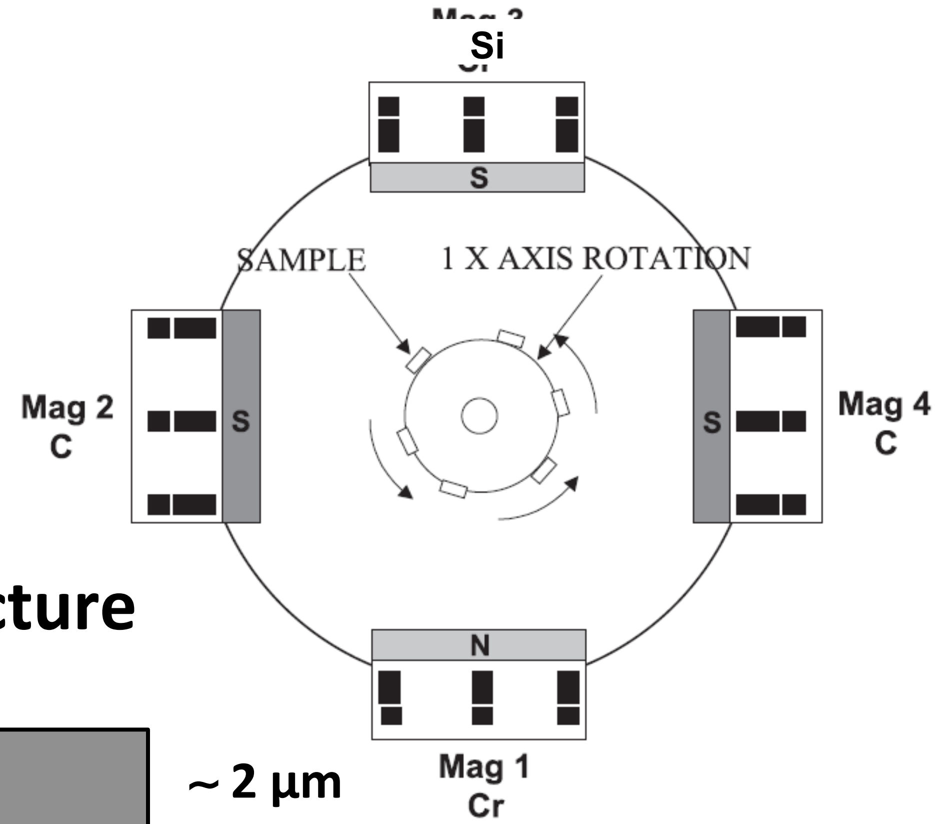
Addition of Cr and Si

- Lower sp3 hybridization energy → increased sp3/sp2 hybridization ratio
- Increased thermal stability
- Carbide formation at elevated temperatures
- Increased tribological performance at high temperatures

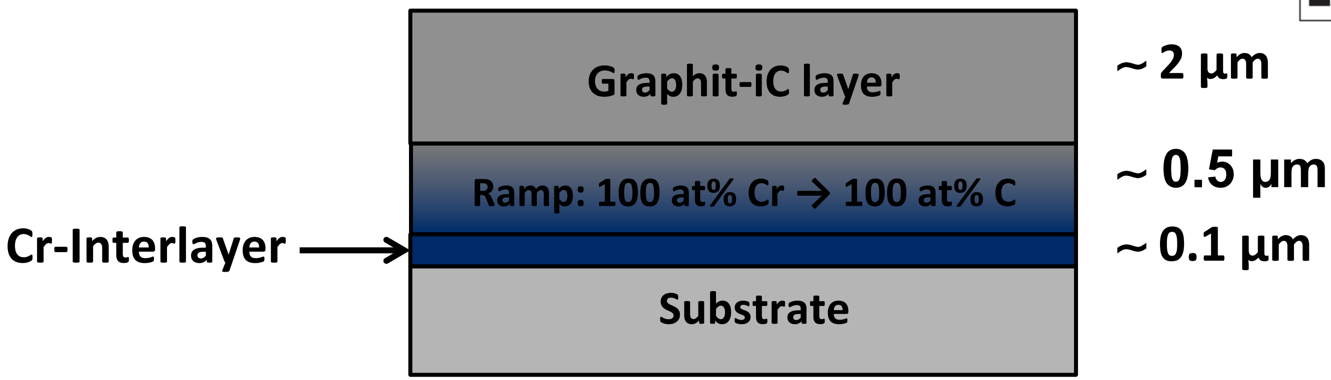
High Temperature DLC Deposition

Deposition parameters:

- Unbalanced magnetron sputtering
- Ar-plasma
- Temperature: < 200°C
- Rotation: 8-10 rpm
- Bias: - 60 V / pulsed 50 kHz
- Deposition Pressure: 0.3-0.4 Pa
- Substrates: M42 tool steel, Si (100)



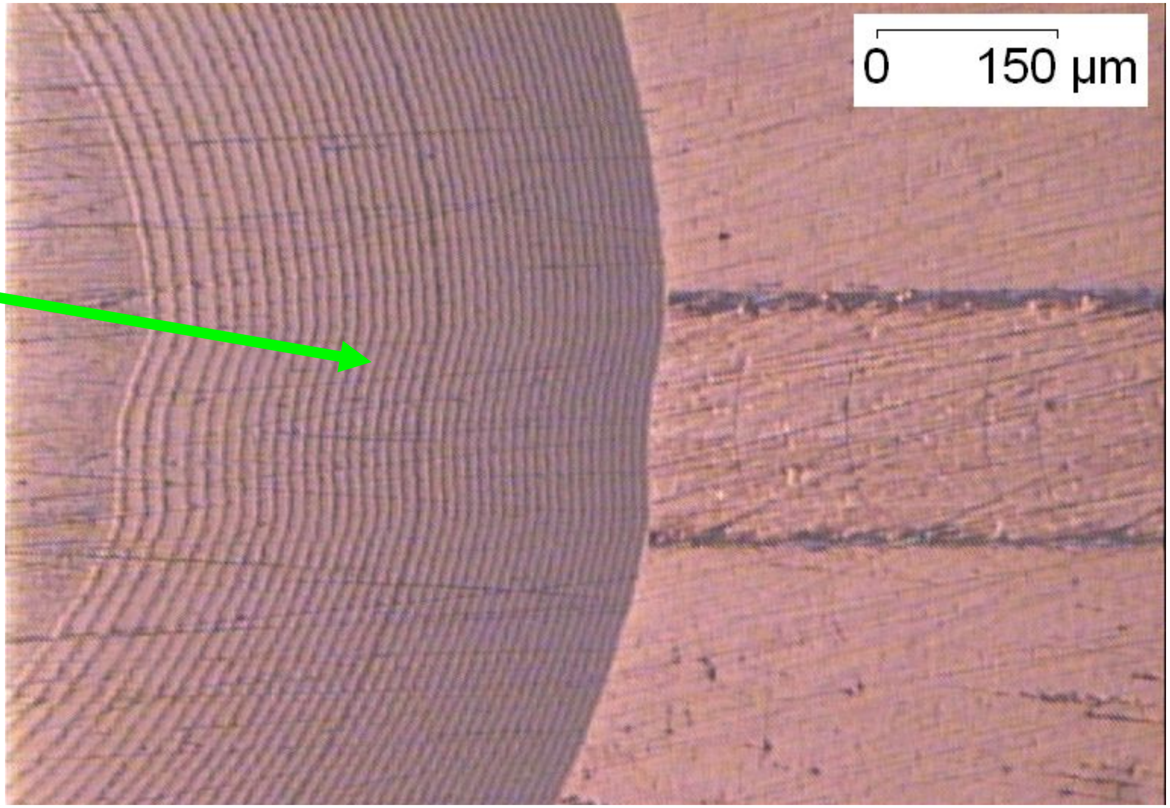
Coating architecture



Increase of loadability with Multilayer

Example of a multilayer structure

- Multilayer structure



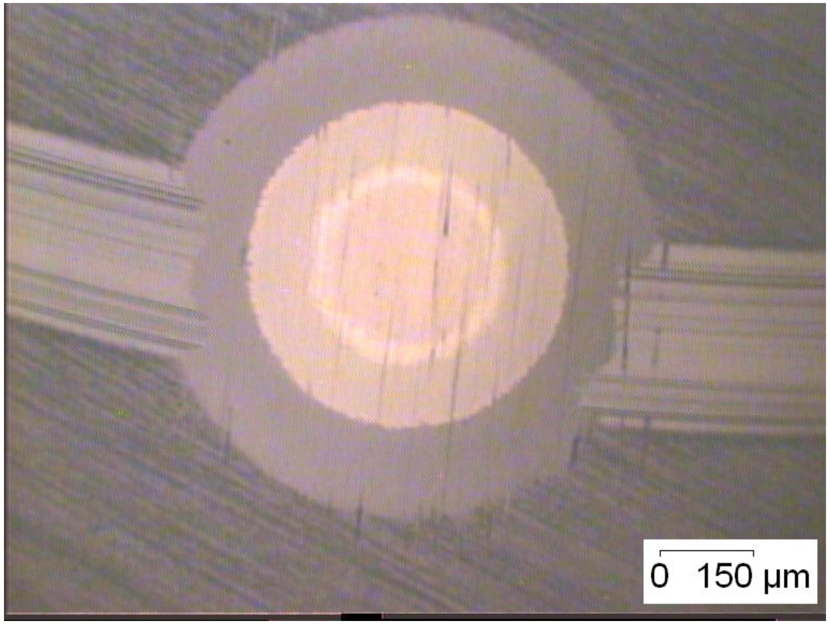
- Crack stops in the ductile multilayer

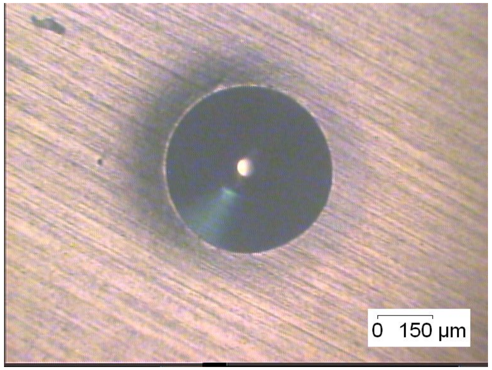
HT DLC Pin on disc - Rockwell

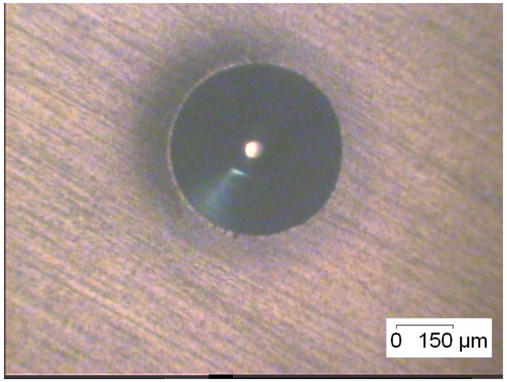
CrN =1.51µm, Gr-iC =3.30µm   Total = 4.81µm

POD at 80N Spec Wear rate = 4.26 x10^{-17} m^3/Nm

Hardness : 2080 HV (Calculated)

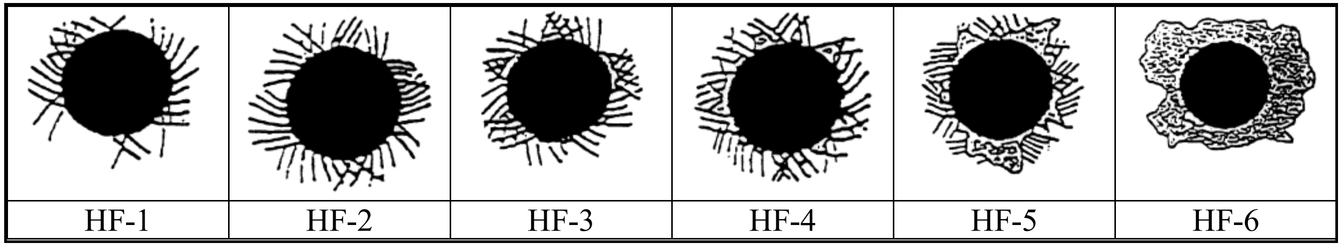


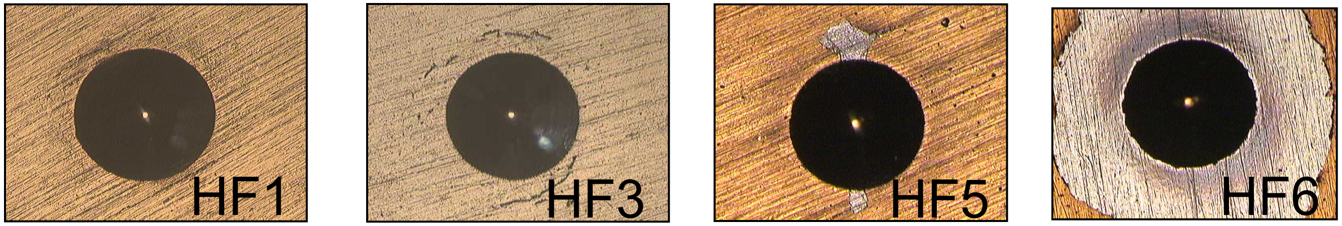




Rockwell C Adhesion Test

- Adhesion criteria developed by the Union of German Engineers (VDI)





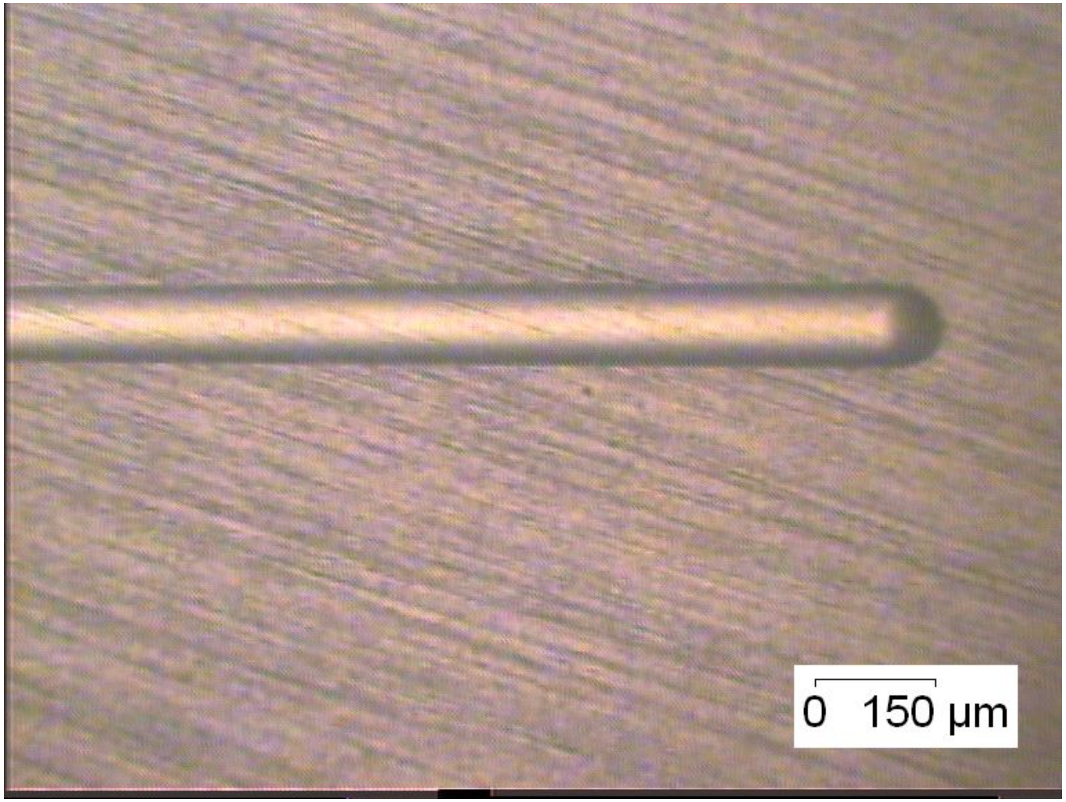
Test parameters:

- Substrate hardness min. 54HRC
- Coating thickness max. 5µm
- Magnification x100

HT DLC – Scratch Test

CrN =1.51µm, Graphitic_iC_HT =3.30µm Total = 4.81µm

Scratch to 80N



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HT DLC – Different Media

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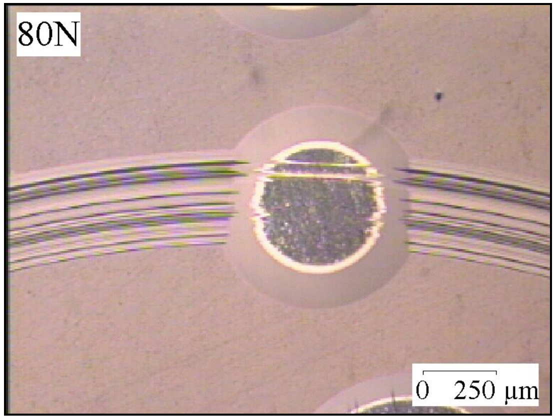
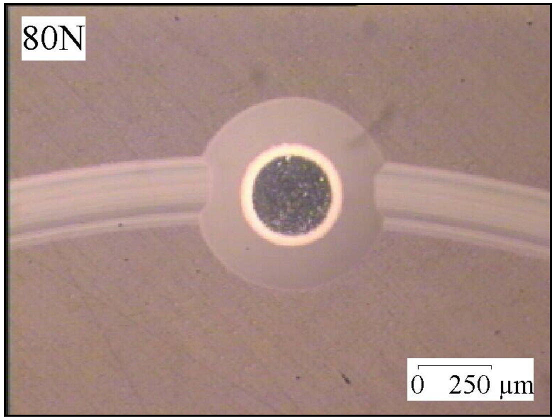
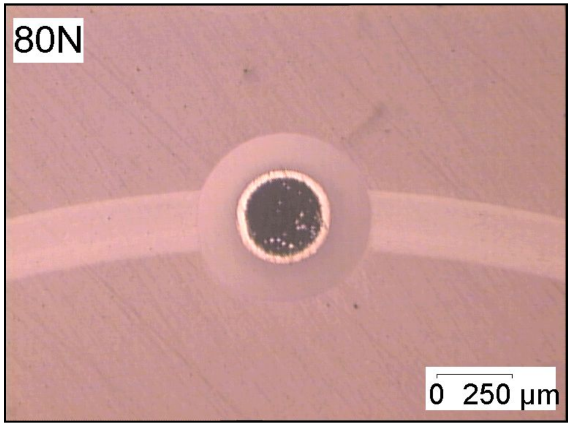
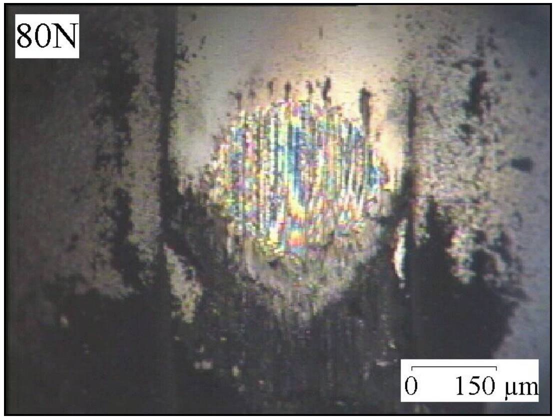
Pin on Disk Test Resultate bei 80N gegen WC-Co Pin

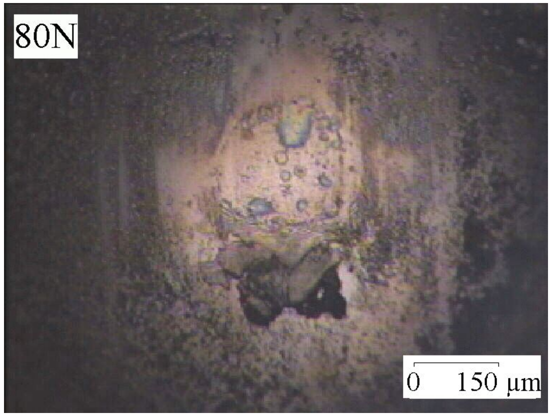
Air | **Water** | **Oil**

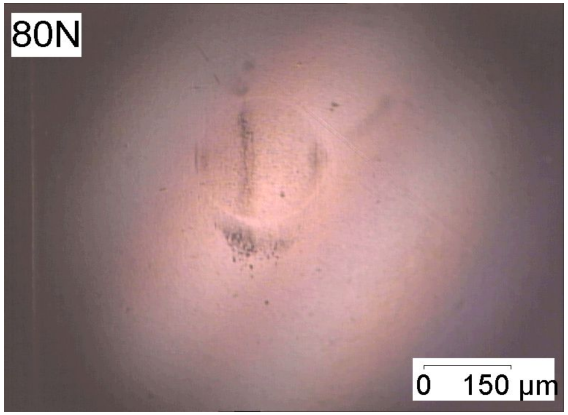










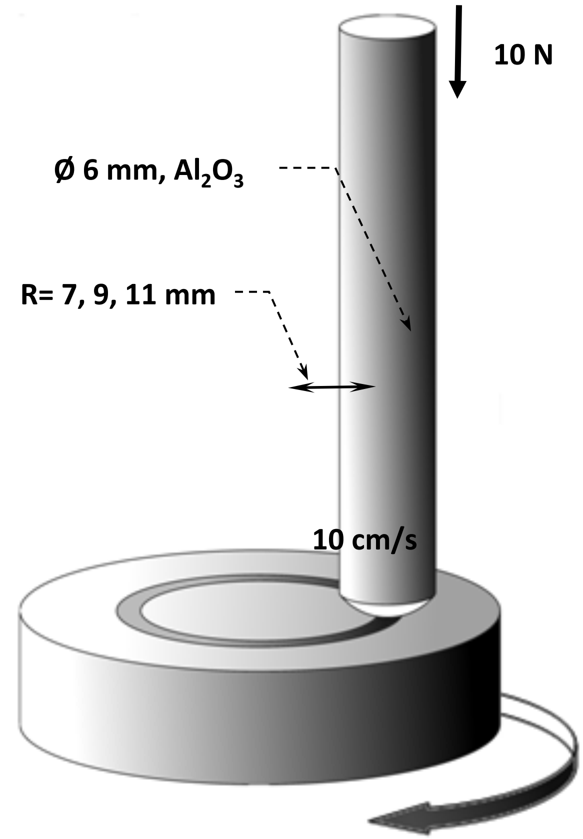


High Temperature DLC – Wear test

CSM Tribometer, Ball-on-disk configuration

Ball: $Al2O3$, 6 mm Ø
Load: 10 N
Temperature: RT, 250, 325, 400°C
Sliding distance:
    1000 m (RT)
    100 m (250, 325, 400°C)
Linear speed: 10 cm/s
Wear track radius:
    R = 7 mm (RT)
    R = 9 mm (250°C)
    R = 11 mm (325°C)

    R = 13 mm (400°C)
Acquisition rate: 10 Hz



Profilometer for wear track analysis

Veeco white light profiler
Calculation of the Wear Rate

Metal content versus COF and Wear

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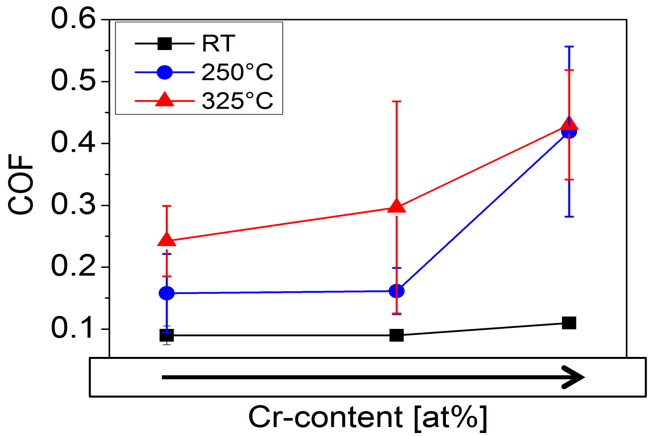
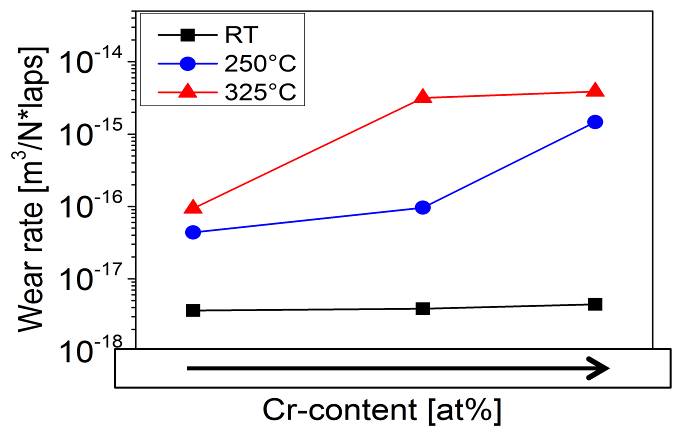
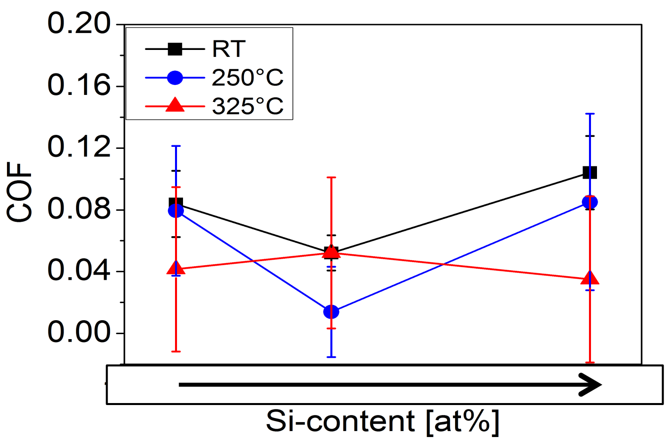
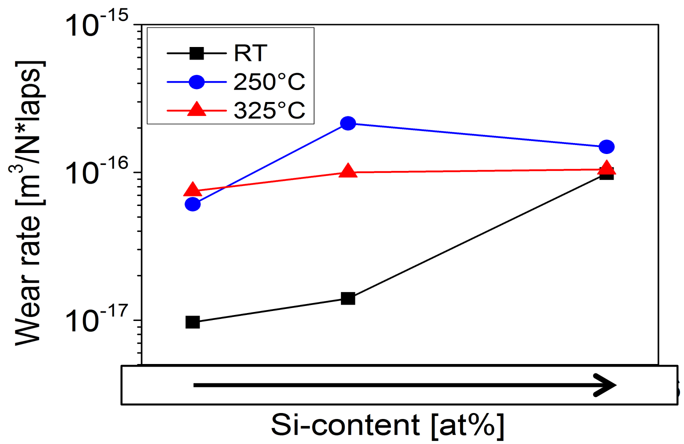
Depending on the Cr-content



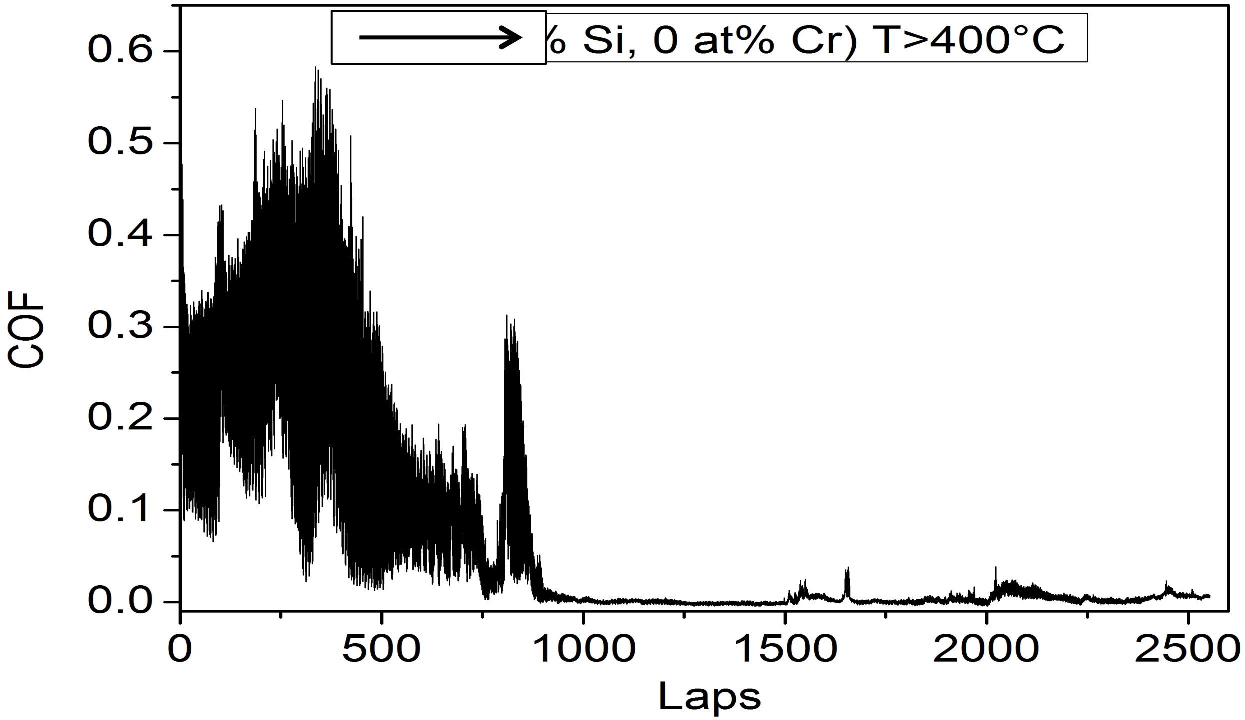


Depending on the Si-content



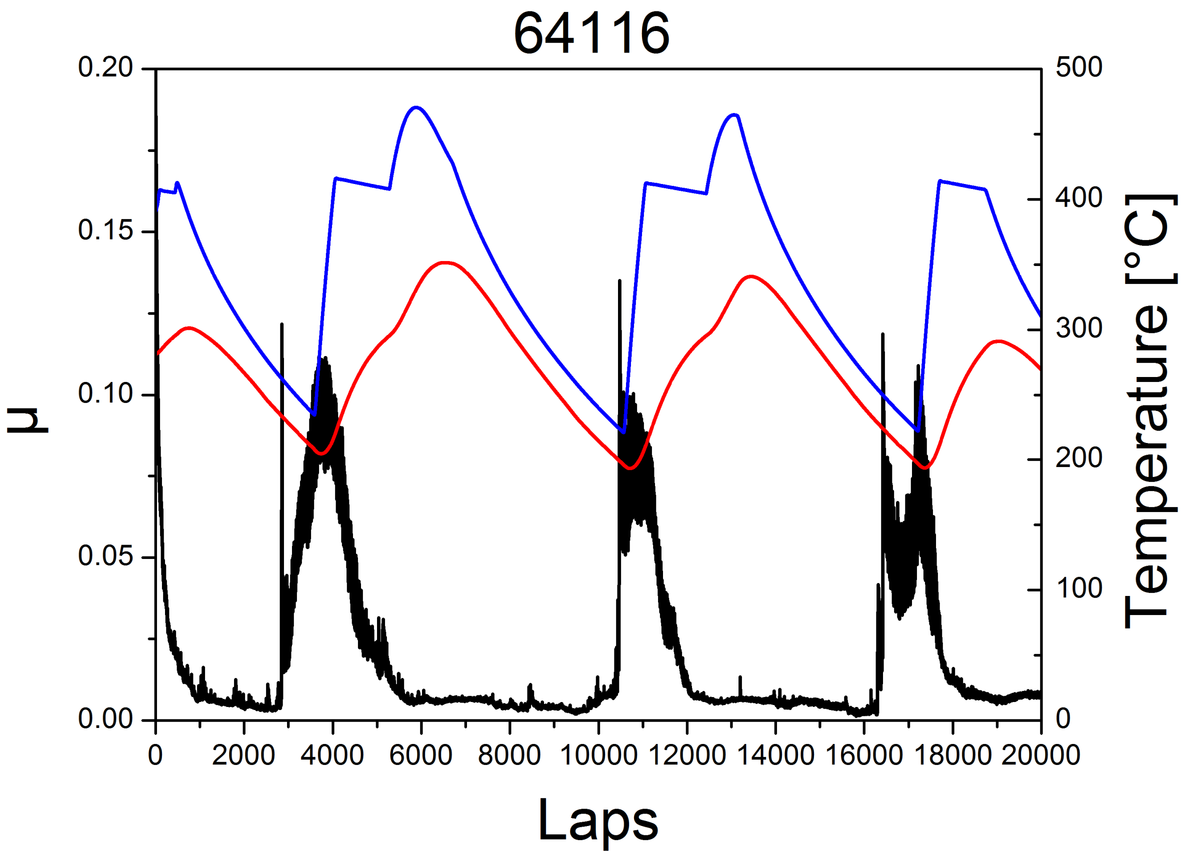


HT_DLC Temperature > 400°C



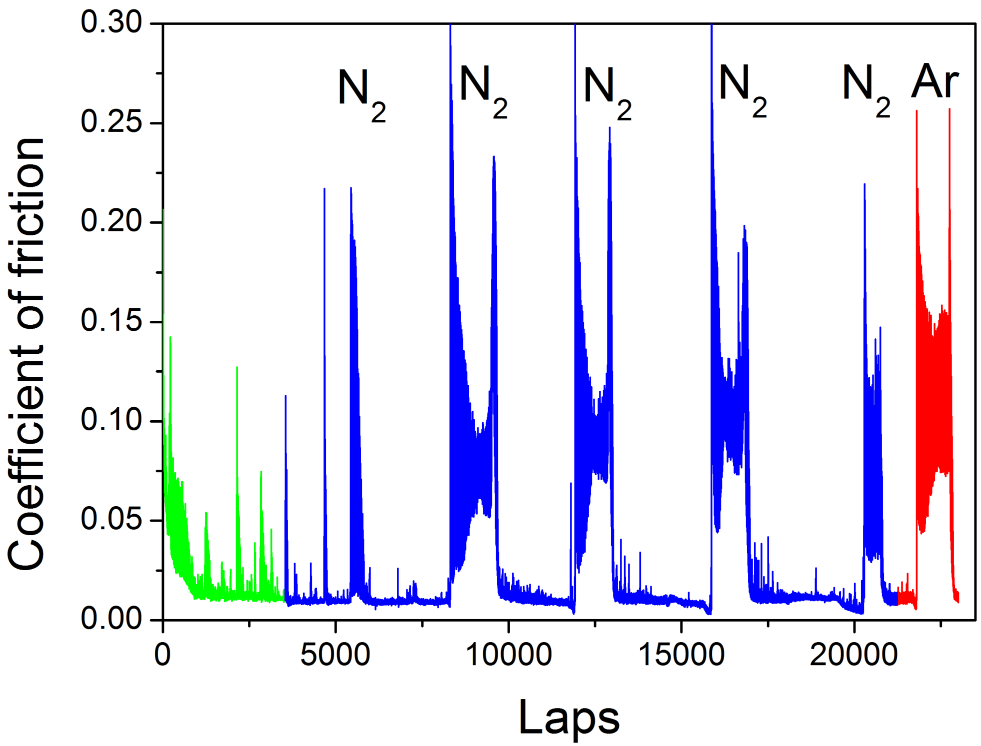
- Si addition leads to very low friction especially at T>250°C
- Si-O-C sliding film formation in oxygen containing environments
- Low friction effect is stable up to 450°C

HT_DLC – Temperature versus COF



- Si-O-C sliding film formation is thermally activated
- Increasing Si-Content → higher Tmin
- Temperature range of sliding film formation between 220 and 240°C

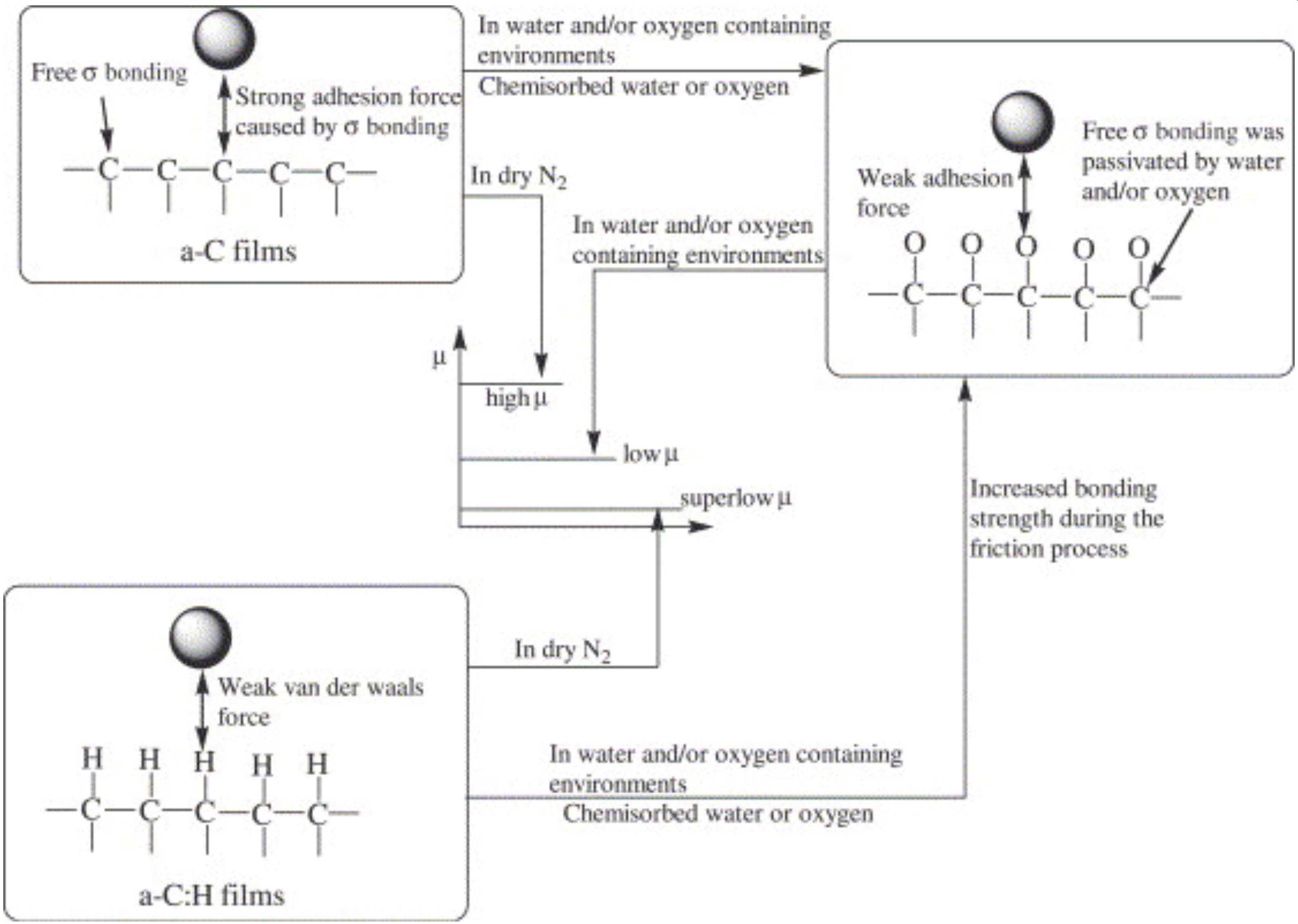
HT_DLC – Different gases versus COF



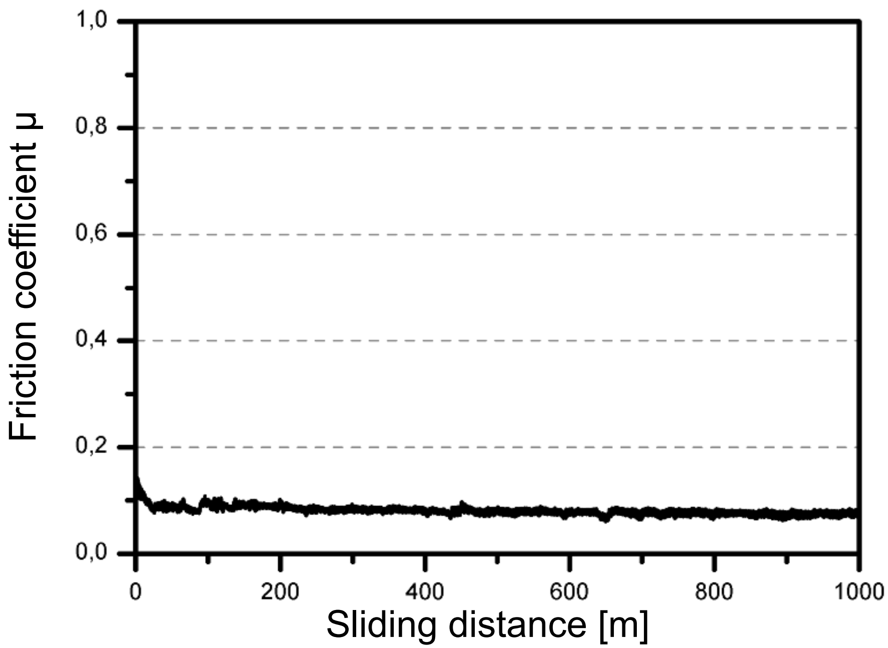
T=250°C

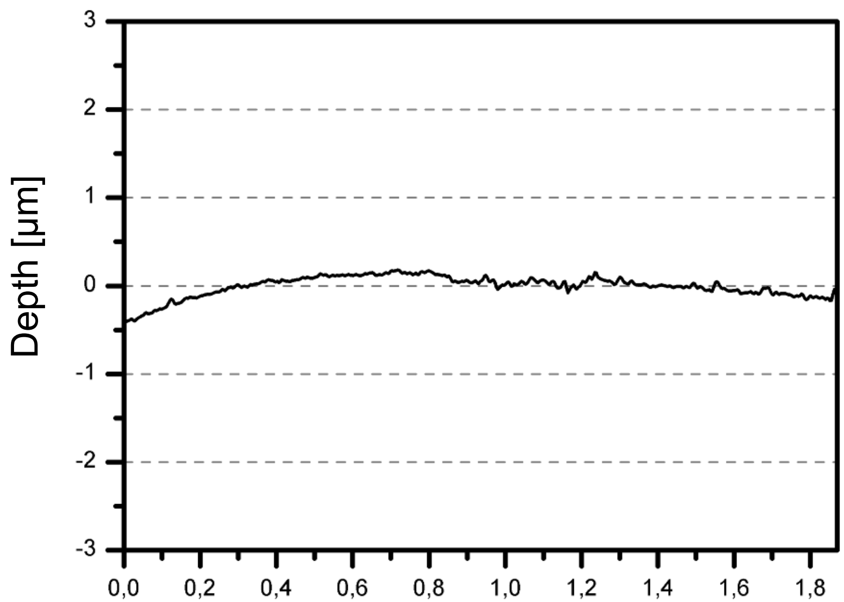
- COF in non-oxygen environments seems to be graphite-shearing dominated

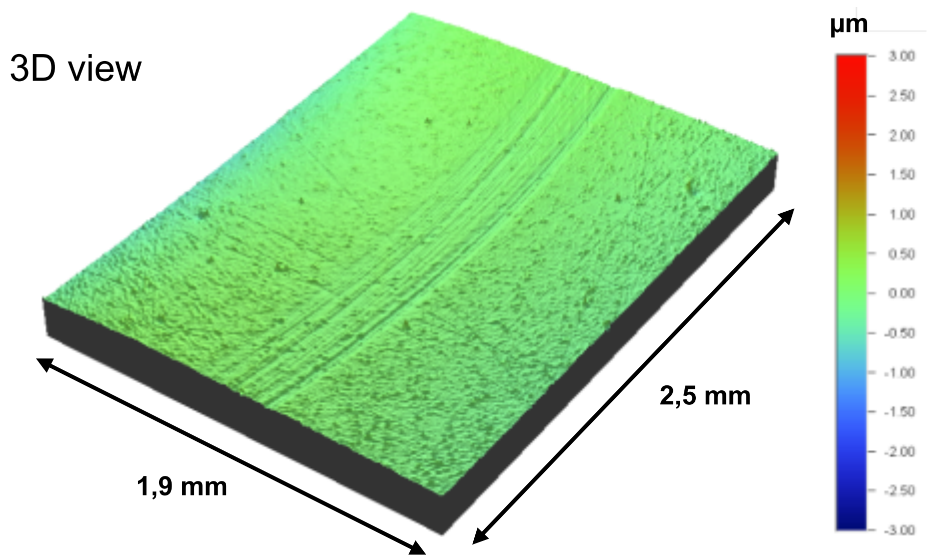
Work Principles of different DLC coatings



Graphit-iC™ (Hardness ~1600 HV)



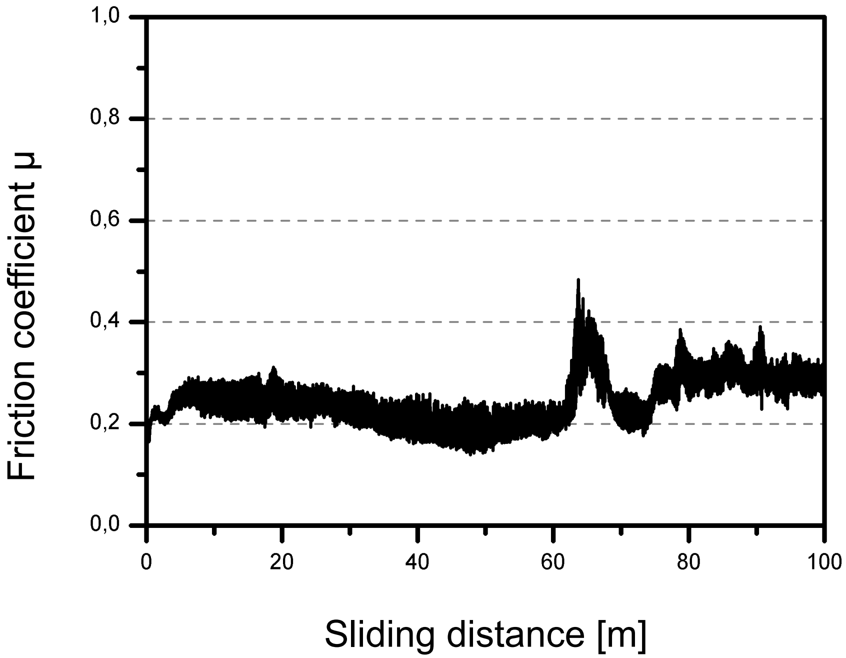


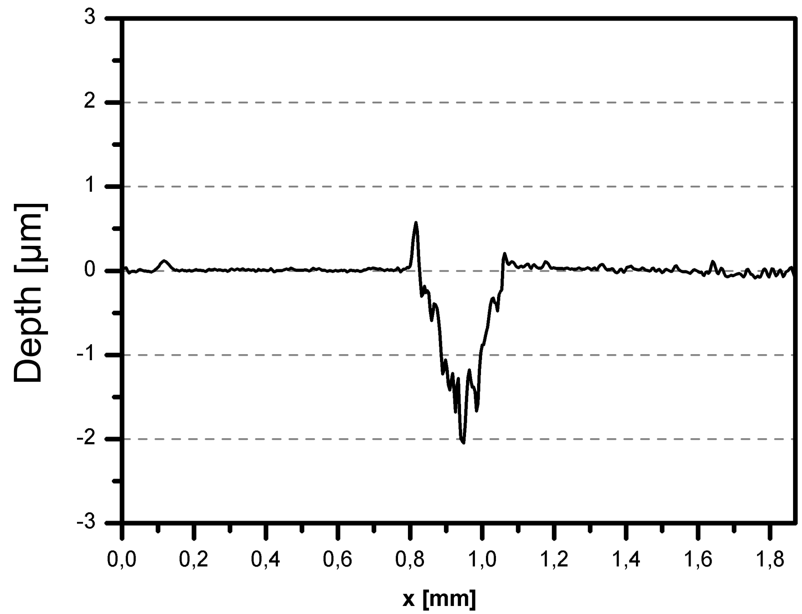


Ball-on-Disc Test:

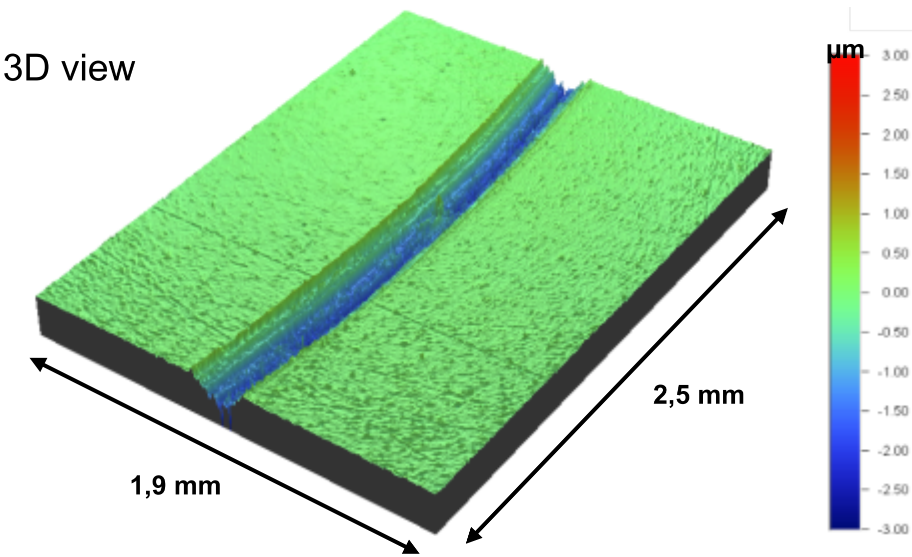
- Applied Load: 10N @ RT
- Friction coefficient ~ 0,08
- Low specific wear

Graphit-iC™ (Hardness ~1600HV)





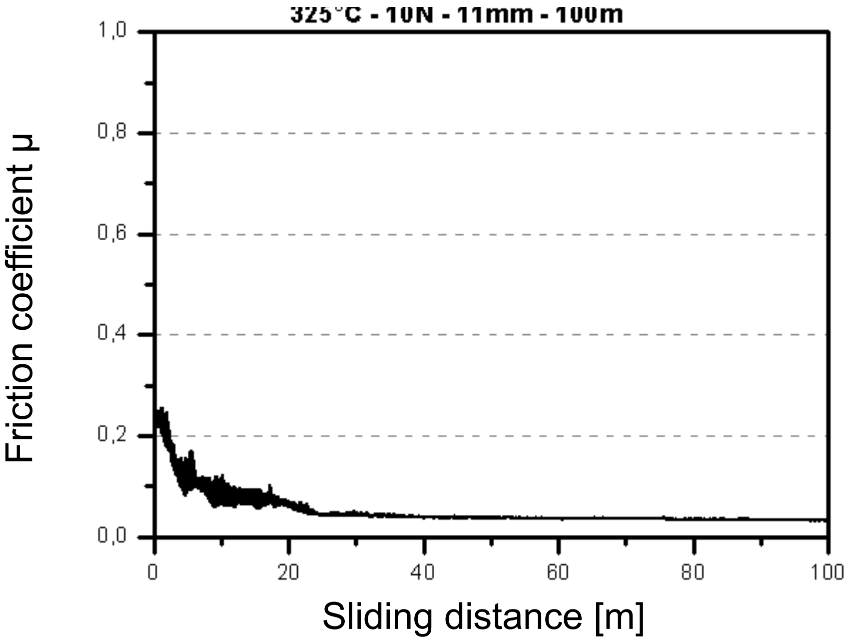
3D view

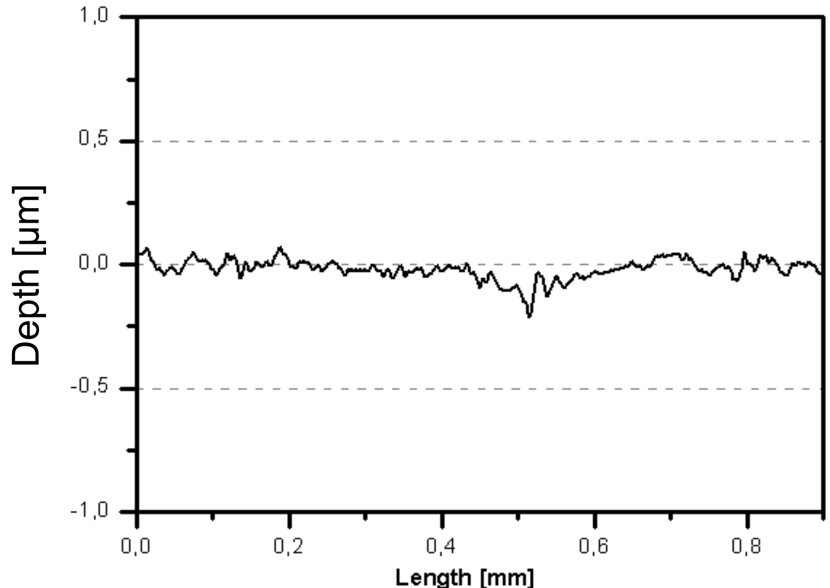


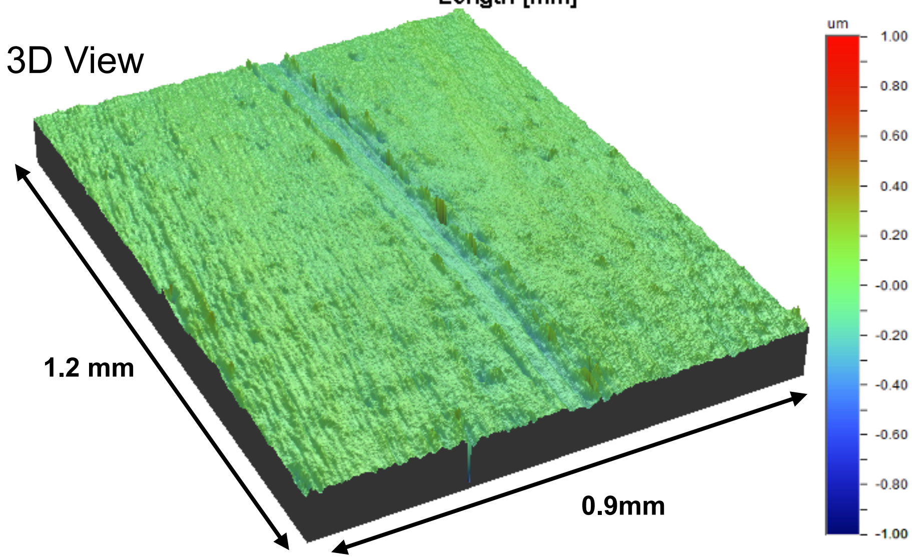
Ball-on-Disc Test:

- Applied Load: 10N @ 250°C
- Friction coefficient ~ 0,2
- Coating failure

Graphit-iC™ HT (Hardness ~1900HV)



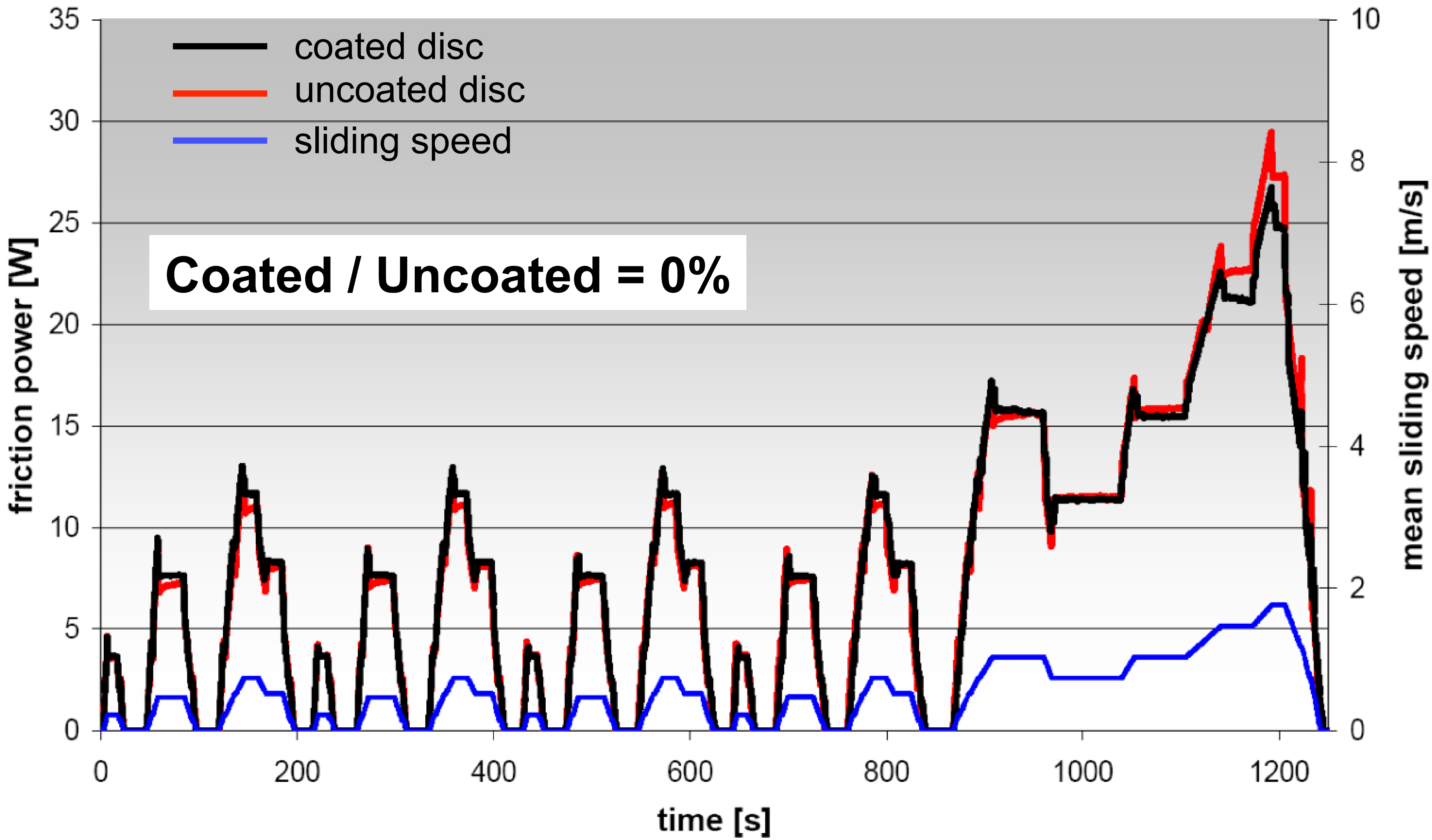




Ball-on-Disc Test:
- Applied Load: 10N @ 325°C
- Friction coefficient ~ 0,05
- Very low specific wear

100Cr6 Ring-on-Disc, 2MPa, 25°C

Oil: Shell Helix Ultra (5W30)



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100Cr6 Ring-on-Disc, 2MPa, 120°C

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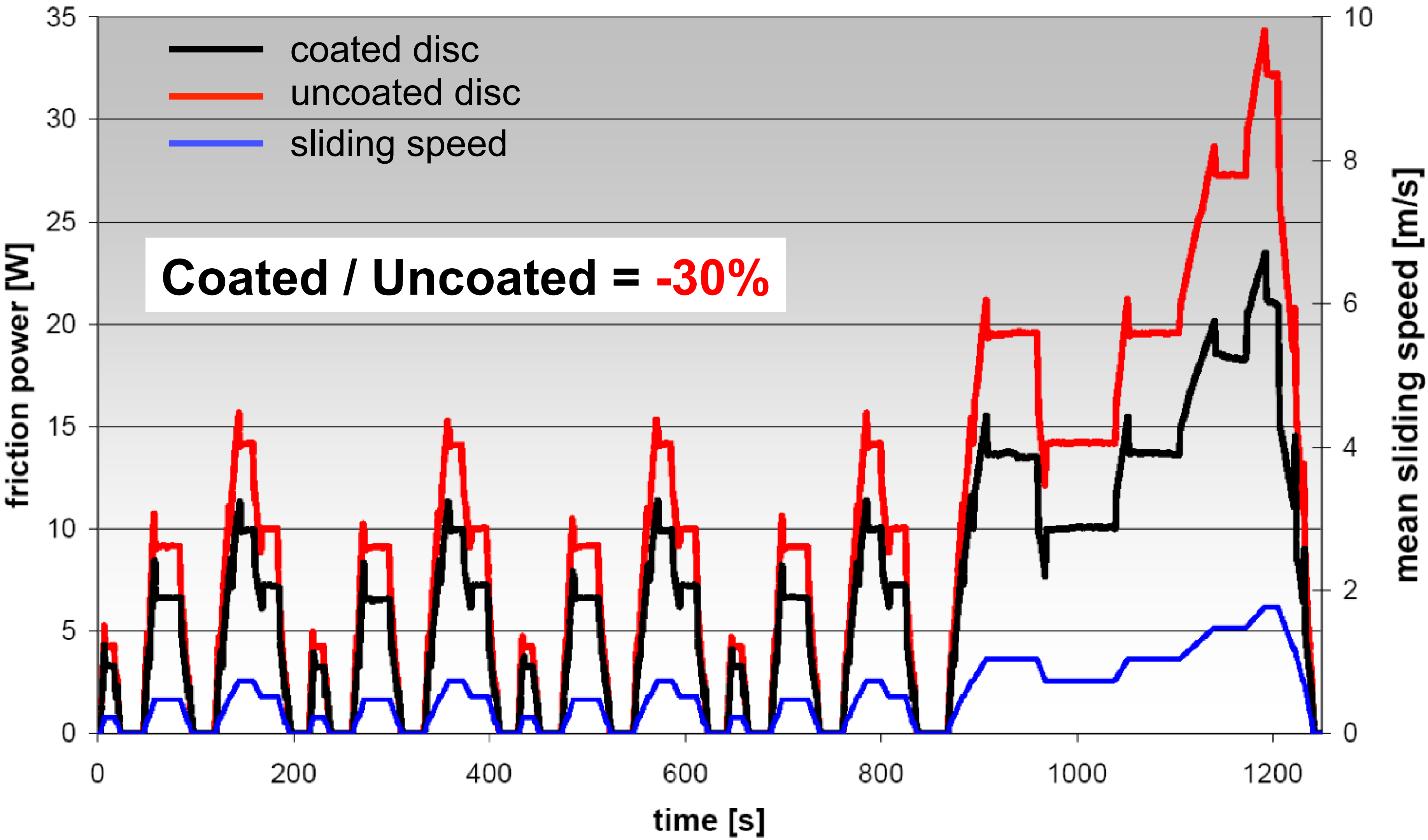
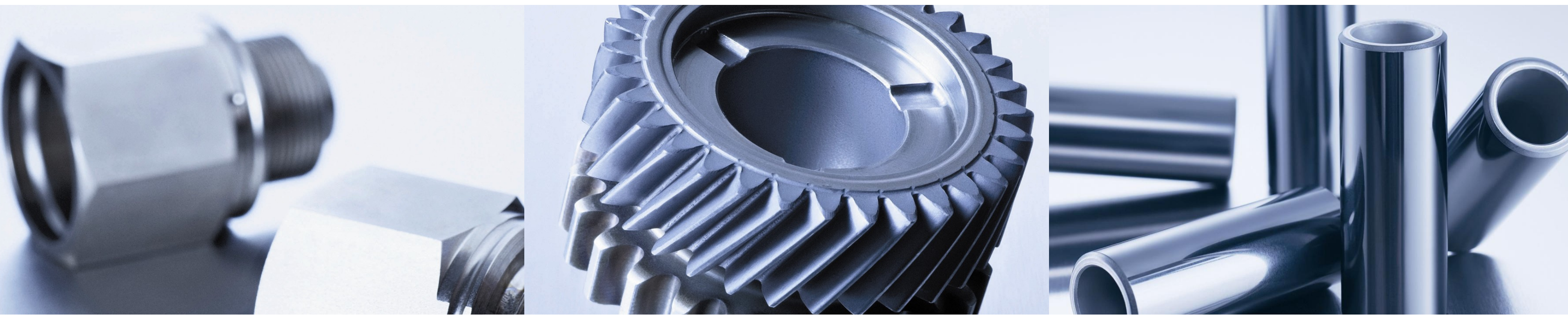
Oil: Shell Helix Ultra (5W30)



Possible application

- Piston Pins
- Piston skirt
- Liner
- Tappets
- Valves
- Cam
- Conrod
- Camshafts
- Turbocharger cmponents

Agenda



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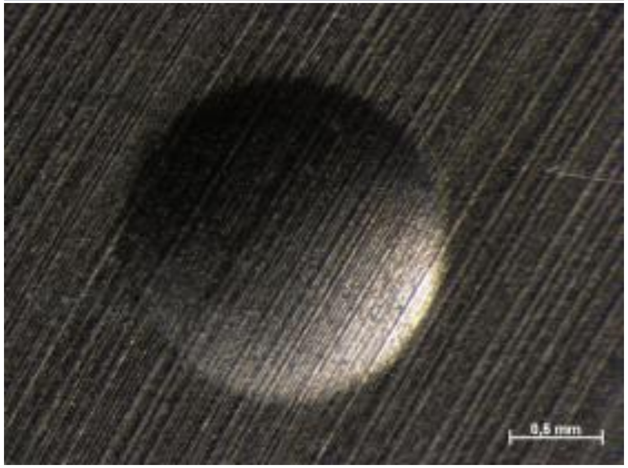
Pump housing Al-NiP- Technology



Pumphousing
Gasoline Engine

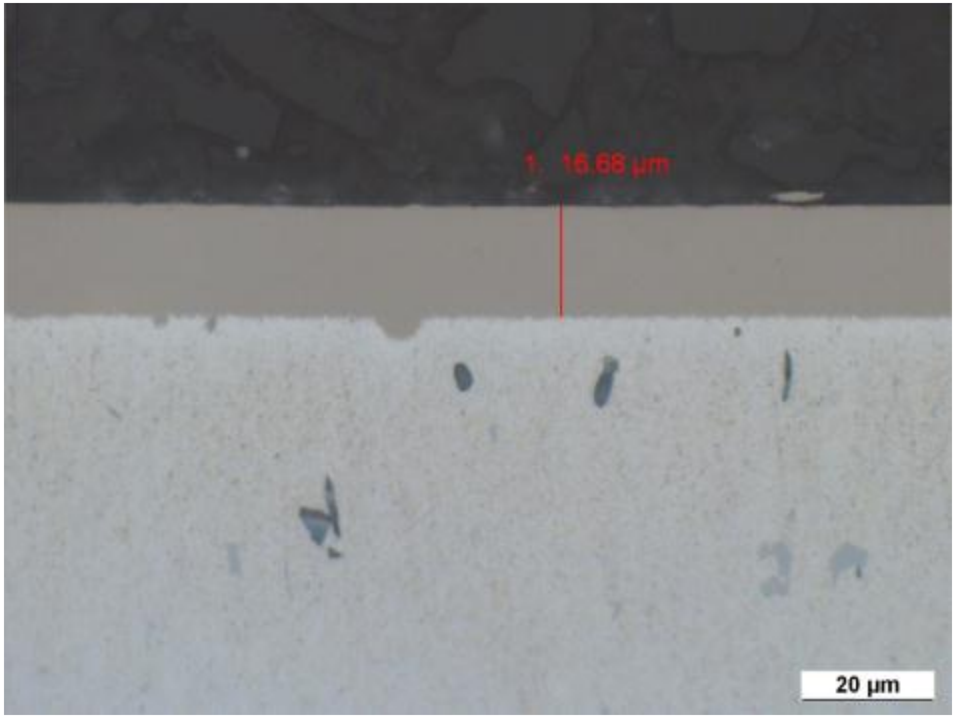
Bonding test with Brinell

Coating Requirements

	✓Coating NiP overall
	✓No visible contact points are allowed or contact marks
	✓Coating thickness 17µm +/-2µm
	✓Visual appearance :- without stains - homogenous visual appearance
	✓Adhesion bonding test ✓O.K. after heat treatment acc. Product specification
	✓Hardness test of coating 580+/- 50 HV Measured hardness 603 HV(0,05)

Pump housing Al-NiP- Technology

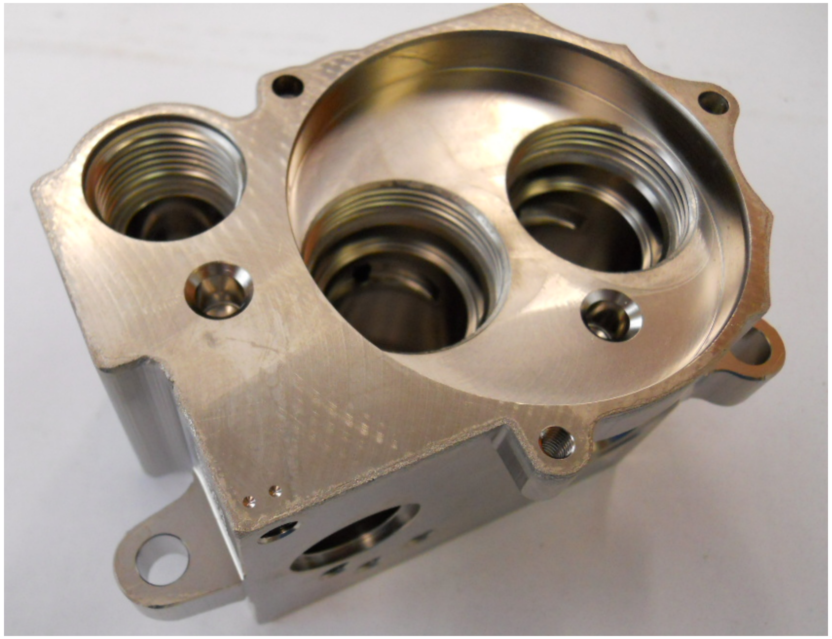
Coating thickness 17µm +/- 2



Longitudial bore coating thickness 17 µm

Possible application

- Fuel pumps
- Vacuum pump
- VVT parts
- Turbocharger parts
- ….



Advantages:

- Excellent corrosion behavior
- Excellent wear behavior
- Weight saving

Agenda

- Motivation
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- Lightweight pump body (Al - Alloy) coated with ENiP
- **Sliding lacquer on a sintered net shape part**
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Sliding lacquers: Synthec™ Pro

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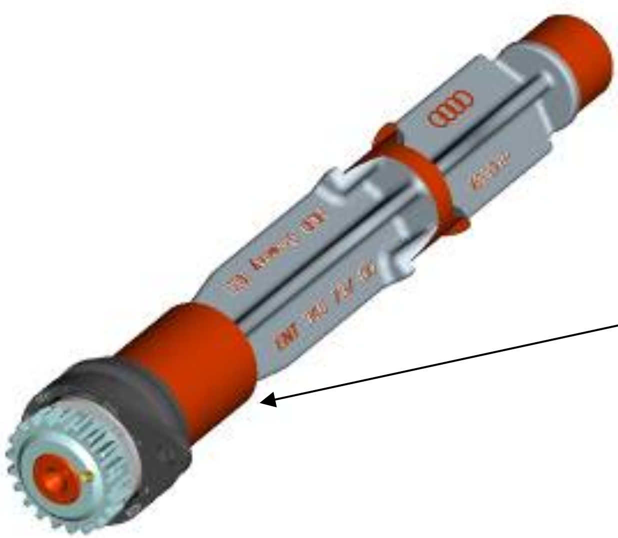
Engine : EA 888 Audi 4 Cylinder Gasoline (World engine)
Integrated Mass Balancer System

Reason: Engine Start Stop –coating reduce friction and increase emergency behaviour of the system

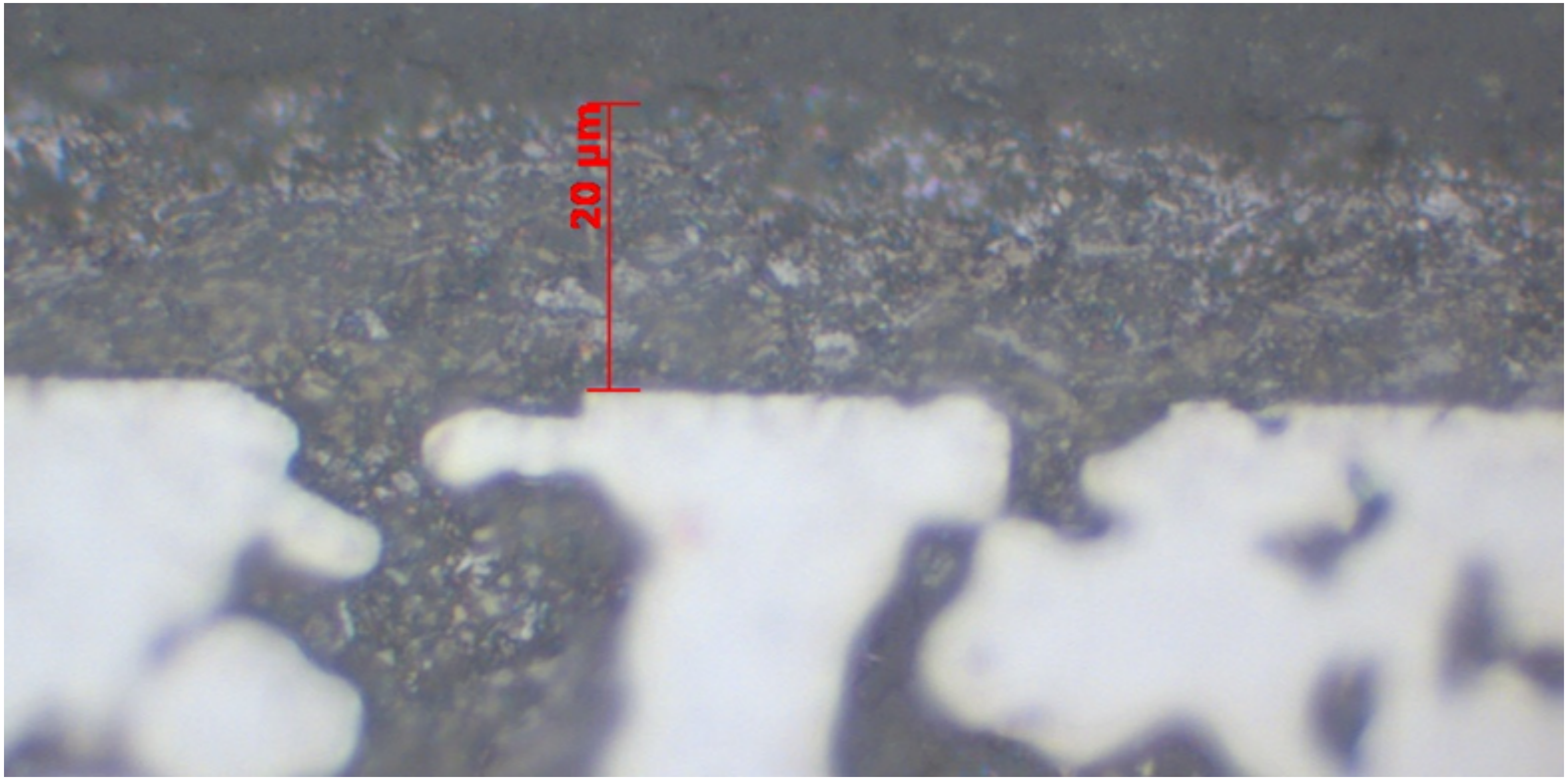


Rotational speed : max. 14000 rpm

Max. Torque: max. 60 Nm

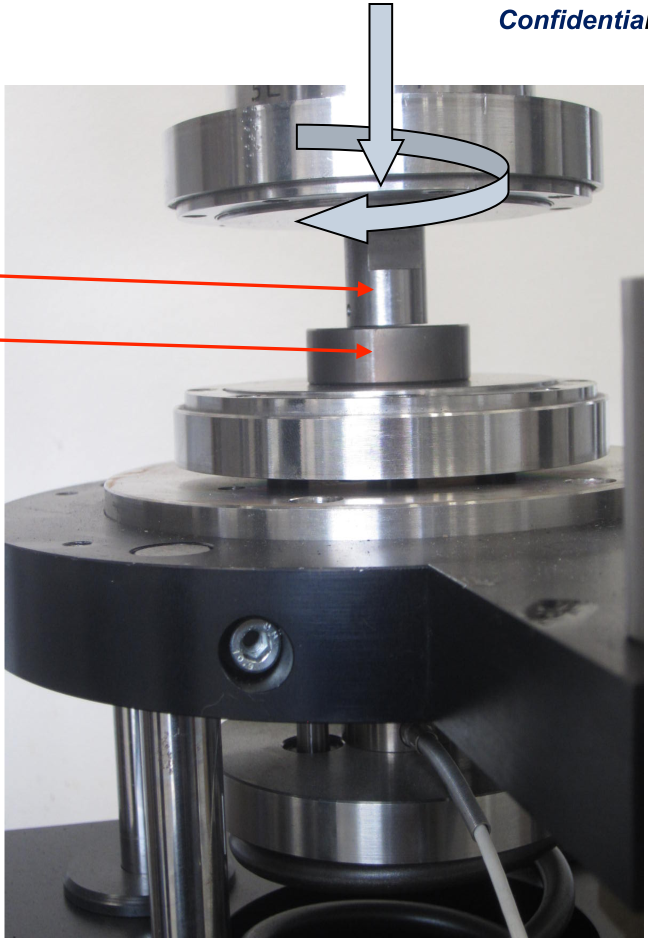
One Radial- and two integrated axial bearings on a net shape sintered part

Detail Synthec®Pro on Sintermaterial

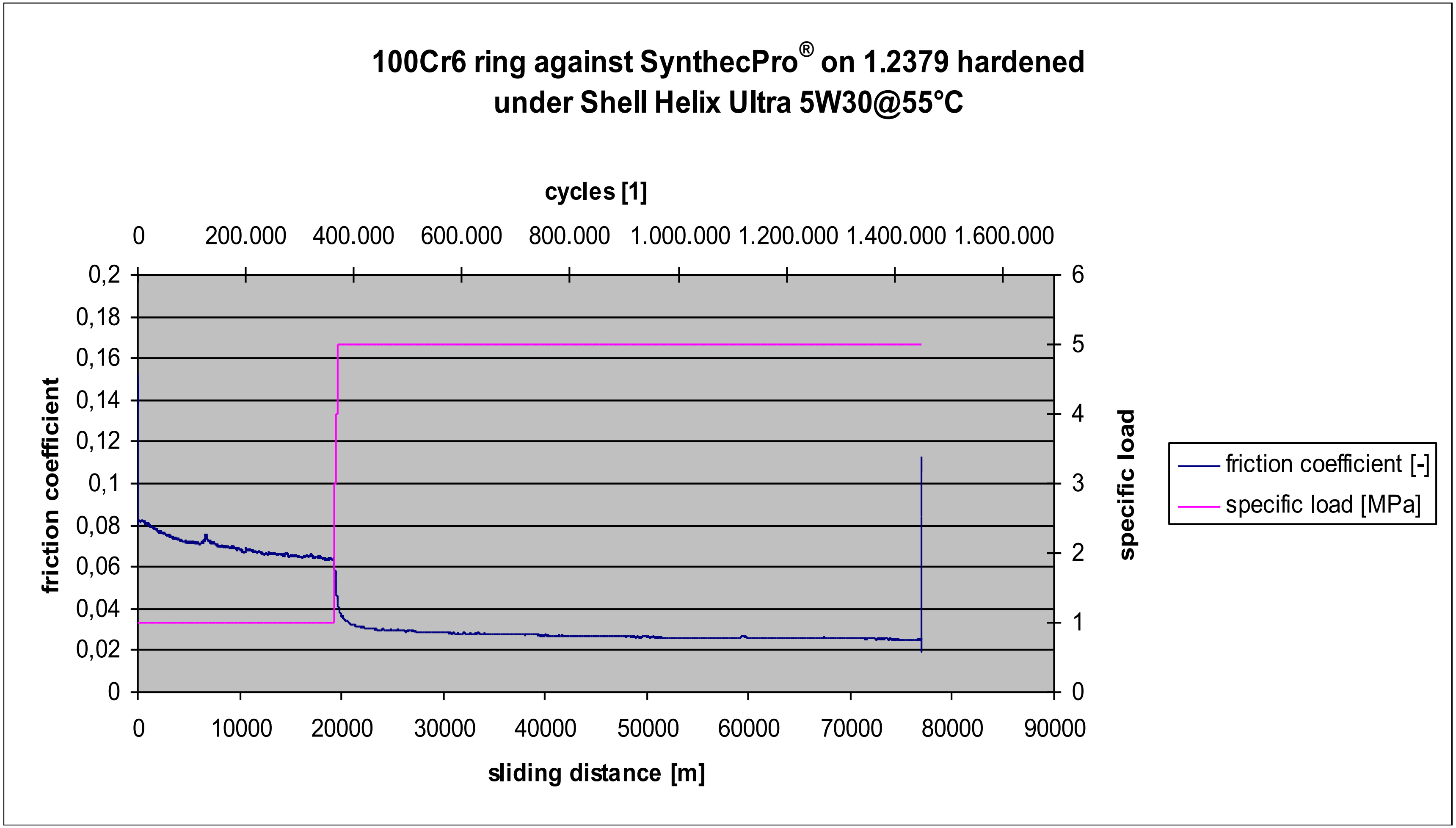


Test arrangement

- Ring on disc tests SynthecPro®
  (oil jar not shown)
- 100Cr6 Ring
- 1.2379 disc Ø40mm 58+2HRC coated
- submerged in Shell Helix Ultra 5W30
- Specific load 1-3-5MPa
- Temperature: 55°C



COF versus Load of Synthec Pro



Application examples of Synthec Pro

sliding bearings

split gears

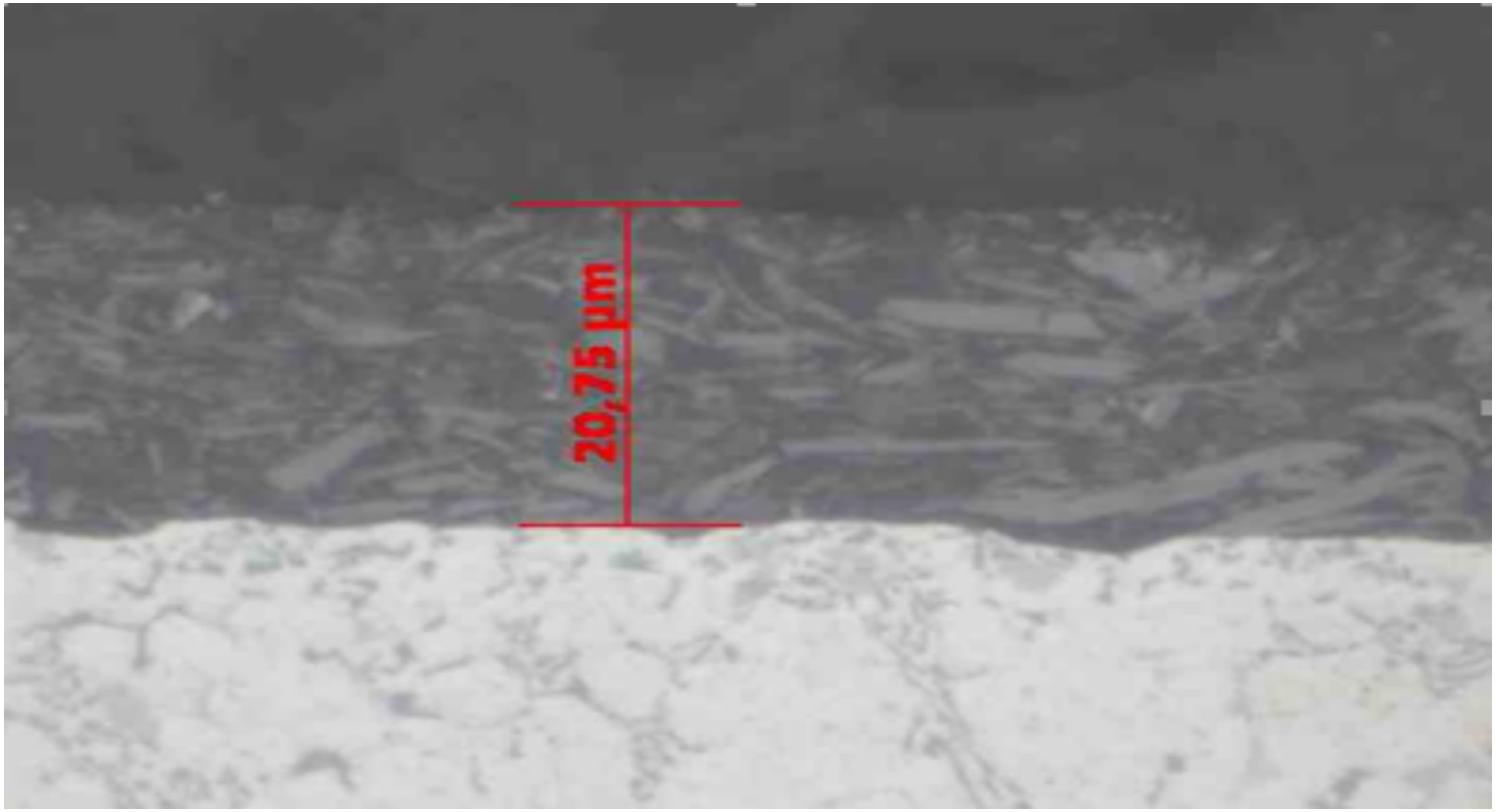
piston skirt

sprockets

bearing block

intermediate gears

Synthec®Pro on AlSi9Cu3 Alloy



Synthec Pro Properties

Performance Attributes

- Very wide temperature range in applications (-50 up to 300° C)
- Superior wear resistance
- Life-time lubrication
- Corrosion resistance
- Reduction of stick-slip effects
- Avoidance of frictional corrosion
- Resistance against vacuum and radiation
- Environmental friendly
- Potential for weight reduction
- Potential for cost reduction

Summary

- Reducing CO_2 emission is one of the top priorities for the automotive industry and us
- Coatings technology is a key for reduction of friction
- Tailor made coatings are promising candidates for reducing weight, friction and wear

Thank you for your attention. Questions ?

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