Components and DLC-coatings:
A performance boost!

Greger Håkansson
Product and Services Overview

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A comprehensive portfolio of coating services and coating equipment
# Wear Mechanisms and Coatings

<table>
<thead>
<tr>
<th>Phenomenon</th>
<th>Required coating property</th>
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<tbody>
<tr>
<td>Adhesive wear (galling or scuffing)</td>
<td>Low surface energy, No mutual solubility, Differences in hardness</td>
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<tr>
<td>Abrasive wear</td>
<td>High hardness, Low friction (C.O.F.), Low surface roughness</td>
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<tr>
<td>Fatigue wear</td>
<td>High compressive stress, High elasticity, Hardness match</td>
</tr>
<tr>
<td>Surface/sub-surface cracks</td>
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<td>Crack propagation</td>
<td></td>
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<tr>
<td>Corrosive wear</td>
<td>Corrosion barrier</td>
</tr>
<tr>
<td>Fretting wear</td>
<td>Combination of adhesive and abrasive wear</td>
</tr>
<tr>
<td>Erosive wear</td>
<td>High hardness, High elasticity</td>
</tr>
</tbody>
</table>

*Rarely 1 mechanism only!!*
Advantages with DLC Coatings

• Carbon-based coatings "doped" with metal(s)
  • Hardness ranges between 900-8000 H\textsubscript{V}!!!
  • 1-5 µm = Normally within tolerance limits.
• Deposition temperature typically below 200°C.
  • Reduced friction (typically 0,03-0,15).
  • Increased abrasive wear resistance
    • Anti-scuffing / Anti-galling
      • High fretting resistance
      • High pitting resistance
  • Noise reduction
Engine Components

Increased wear resistance and/or decreased friction!

- Camshaft
- Tappets
- Valves
- Piston
- Piston ring
- Piston pin
- Con rod
- Crankshaft
## Classification of DLC Coatings

<table>
<thead>
<tr>
<th>Doping elements</th>
<th>Hydrogen free</th>
<th>Hydrogen containing</th>
<th>Kristalline C-Schichten</th>
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</thead>
<tbody>
<tr>
<td>Structure</td>
<td>sp²</td>
<td>sp³</td>
<td>sp² / sp³</td>
</tr>
<tr>
<td>Shortcut</td>
<td>a-C</td>
<td>ta-C</td>
<td>a-C:Me</td>
</tr>
<tr>
<td>Other designations</td>
<td>DLC</td>
<td>DLC i-C</td>
<td>DLC</td>
</tr>
<tr>
<td>Deposition process</td>
<td>PVD</td>
<td>PVD</td>
<td>PA-CVD</td>
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</tbody>
</table>

- **Metal**: Metallic elements
- **Non-metal**: Non-metallic elements
- **Hydrogen free**
- **Hydrogen containing**
- **Undoped**: Not doped with additional elements
- **Doped**: Doped with additional elements

**Diamond-like-carbon (DLC) films**

**VDI standard 2840**
Tribobond 40: a-C:H:W
Tribobond 41: a-C:H:W + a-C:H
Tribobond 42: CrN + a-C:H
Tribobond 43: CrN + a-C:H:W
Tribobond 44: a-C:Cr
Tribobond 45: a-C (Tetrabond)
Tribobond 46: a-C:H (ADLC)
Tribobond 47: a-C:Cr + a-C:H
## Properties of DLC Coatings

<table>
<thead>
<tr>
<th>Coating</th>
<th>Abrasive Wear Resistance</th>
<th>Impact Fatigue Resistance</th>
<th>Load Carrying Capability</th>
<th>Running-in Behaviour</th>
</tr>
</thead>
<tbody>
<tr>
<td>a-C:H:W (40)</td>
<td>Medium abrasive wear resistance</td>
<td>Good impact fatigue resistance</td>
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</tr>
<tr>
<td>a-C:H:W + a-C:H (41/47)</td>
<td>High abrasive wear resistance</td>
<td>Low impact fatigue resistance (42/43=High)</td>
<td>Medium to high load carrying capability (42/43=High)</td>
<td></td>
</tr>
<tr>
<td>a-C:Cr (44)</td>
<td>Medium to high abrasive wear resistance</td>
<td>Good load carrying capability</td>
<td>Medium to high abrasive wear resistance</td>
<td></td>
</tr>
<tr>
<td>a-C (45)</td>
<td>High impact fatigue resistance</td>
<td>Good load carrying capability</td>
<td>Medium abrasive wear resistance</td>
<td>Good running-in behaviour</td>
</tr>
<tr>
<td>a-C:H (46)</td>
<td>Low load carrying capability</td>
<td>High abrasive wear resistance</td>
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</table>
Despite Only a Couple of μm!

Carbon/metal multi-layer

Metallic interlayer

Silicon substrate

~3 nm per layer!!
~350 layers per μm!!
Comparison: Load Carrying Capability

Load carrying capability [%].

- a-C:H (ADLC): 65
- Cr + a-C:H: 100
- Cr + a-C:H:W + a-C:H: 138
- Cr + CrN + a-C:H: 180
Behaviour of DLC-Coatings

Coated part

Counterpart

Separation of part and counterpart by an inert coating

Reduction of friction, transfer of coating from part to counterpart (polishing effect)

Low Friction = Low Wear
Before coating $R_z \leq 1 \, \mu$m is desired!

Wear on the summits
Industrial Coating Equipment

HTC 1200
Batch Coater
PVD/PACVD (MF)

Coating volume:
- 650 mm in diameter
- 850 mm in height

Coatings:
- a-C:H
- a-C:H:W
- CrN
- Cr$_2$N
PVD Equipment

HTC - 1200

Cr
WC

Cr
WC

ionbond
SEM and SIMS analysis

a-C:H:W + a-C:H (TB 41)

Fracture

Depth profile (SIMS)
Quality Control

a-C:H:W + a-C:H (41)

Plunger DDS:
a-C:H:W thickness: 1.0 µm
a-C:H thickness: 0.9 µm

HF-Test: HF 1

=474.09 µm
=392.22 µm
=277.20 µm
=246.69 µm

100 µm
Automotive components

- Piston pins, con rods, cam followers, bearings, valves, bushings, tappets, cam shafts, compressor shafts, valve guides, gears...
- Increasing wear resistance
- Decreasing friction

**Targets:**
- Reduce energy consumption
  ⇒ Improved fuel efficiency
  ⇒ Reduction of the CO$_2$-emission
- Power amplification (Racing)
  ⇒ Improved acceleration
Precision Components

Unit injector VW diesel engine

Source: Volkswagen
Door Lock System
Thank you for your attention

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