Next generation PVD coatings for tools and components

Dr. auf dem Brinke | June 2010

The Secret of Staying Ahead
Our tools
Classification of Key Surface Treatments

Graph for illustration purposes only, not scientifically exhaustive.

- Chemical Vapor Deposition (CVD)
- Welding (PTA)
- Thermal Spray
- IONIT OX
- Physical Vapor Deposition (PVD)
- Plasma Nitriding
- Electroplating
- Ion Implant
Effective mass: MAXIT® coatings

Without coating

We need for 100,000 holes
1,000 drills -
equals 60 kg

With coating

We need for 100,000 holes
250 drills -
equals 15 kg + 7.5 g

PVD-hard coating: 7.5 g TiN
Driving high technology

Introduction

Dry cutting

High speed cutting
Driving High Technology
Engine – Surface Treatments

- Nitriding
- Nitriding + Oxidation
- PVD
Driving High Technology
efficiency in coating architecture and design

<table>
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</table>

- Metallic hard materials
- Covalent hard materials
- Ionic hard materials

- Metallic bindings
- Covalent bindings
- Ionic bindings

**All-round properties**

**Metallic hard materials**

**Covalent hard materials**

**Ionic hard materials**

**Heteropolar bindings**

- + toughness
- + chemical resistance
- + hardness
- + less chemical interaction
- + adhesion
- - brittleness
- - hardness
- - adhesion

**Driving High Technology excellence in coating architecture and design**

Sulzer Metco
Schematic illustration of various possibilities to design advanced high performance coatings
Driving High Technology
PVD ARC Technology

Arc evaporators e.g. AlTi
segmented targets

PRINCIPLE

Me++
Me++

Electrons (30V, 100 A)

Minipool
Solid Target

S

Sulzer Metco
How does it work?
low friction and anti sticking coatings MAXIT®W-C:H

Working principle

Counterpart

Separation of substrate and counterpart by a chemical inert coating
reduction of the roughness
Coating transformation

Low friction

Substrate
Application W-C:H - Coating of gears

uncoated
gear MAXIT® W-C:H coated
counter-gear uncoated

1500 N/mm²
1.35 x 10⁶ cycles
20% grey spots
1900 N/mm²
5.4 x 10⁷ cycles

W-C:H coated gears give an efficient protection
against grey spotting and also pitting. ⇝ weight reduction
Application – clutch actuator pistons

**low friction coating W-C:H** for noise and vibration free clutch operation extremely thin walled app. 0.5 mm

- for components with high tribological stress
- gear, bearing and hydraulic components

<table>
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<tr>
<th>Property</th>
<th>Value</th>
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<tr>
<td>Deposition temperature</td>
<td>150 – 250 °C</td>
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<tr>
<td>Color</td>
<td>grey-black</td>
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<tr>
<td>Coating morphology</td>
<td>multi-layer</td>
</tr>
<tr>
<td>Thickness</td>
<td>1 - 5 µm</td>
</tr>
<tr>
<td>Hardness HK0.05</td>
<td>1000 - 1300</td>
</tr>
<tr>
<td>Friction against 100Cr6</td>
<td>0.15 - 0.30 dry running</td>
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Coating design from bond layer to function

Tailored coatings

function layer a-C:H

W-C:H

bond system Cr - CrN
Application Tappet on Nitrided Camshaft

advantages:

- improving fuel efficiency
- improving engine power (+3-4%)
- improving dry-running properties
- minimum oil lubrication in field test

⇒ reduction of weight and size of engine

<table>
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<tr>
<th>Property</th>
<th>Value</th>
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<tr>
<td>W:C-H-mod</td>
<td></td>
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<tr>
<td>Thickness</td>
<td>3.0 ± 0.5 μm</td>
</tr>
<tr>
<td>Hardness</td>
<td>1750 ± 150 HV</td>
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<tr>
<td>Friction coeff. μ</td>
<td>0.15</td>
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<tr>
<td>Elastic modulus</td>
<td>200 GPa</td>
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</table>
advantages:

- improving fuel efficiency
- less maintenance
- improving dry-running properties
- cavitation resistance by trampoline effect (elasticity of coating)

<table>
<thead>
<tr>
<th>properties</th>
<th>TiN</th>
<th>Hardchrome</th>
<th>Me-C:H</th>
<th>MAXIT® W-C:H\text{mod}</th>
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<tr>
<td>hardness [HV]</td>
<td>ca. 2500</td>
<td>800 - 1100</td>
<td>ca. 1200</td>
<td>ca. 1750</td>
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<tr>
<td>Dry friction coeff. $\mu$</td>
<td>0,65 ± 0,05</td>
<td>0,6 - 0,65</td>
<td>0,20 ± 0,05</td>
<td>0,15 ± 0,05</td>
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<tr>
<td>Abrasion resistance</td>
<td>++</td>
<td>+</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Cavitation resistance</td>
<td>++</td>
<td>−/+</td>
<td>+</td>
<td>+ ++</td>
</tr>
<tr>
<td>Running-in behavior</td>
<td>−</td>
<td>−/+</td>
<td>++</td>
<td>+++</td>
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Combination treatment of nitriding and PVD
Support for hard PVD layer – no eggshell effect

High scratch resistance at the surface also for “soft” materials (smaller 40 HRC) caused by nitriding and coating
Influence of polishing on surface roughness divided or integrated combination process

\[
\begin{array}{c|cc|c|c|c}
\text{Polishing Method} & \text{PN} & \text{CrN} & \text{Polished} \\
\hline
\text{Roughness (Rz)} & 0.5 & 1.0 & 1.5 & 2.0 & 2.5 & 3.0 & 3.5 \\
\end{array}
\]
metal forming – combi treatment

- 3-4 times longer lifetime
- rework possible
- combi treatment PN + PVD
Calender roll Ø 180 x 850 mm CrN-mod. coated

**Threads**
- deposits
- adhesion

**Polish + CrN-mod coating**
- Prevention of deposits
- Reduced adhesion

Die plate / CrN-mod. coated
Where can PVD coatings boost the performance?

- Wear protection by high hardness
- Reduction of penetration by f.e. glass fibers using combination processes of nitriding plus PVD
- Reduction of deposits by chemical unreactive coatings
- Reduction of sticking tendency by non-reactive coatings
- Reduction of friction by low friction coatings on f.e. ejector pins
- Endurable surface quality
Driving high technology
The innovative APA evaporator technology

Arc cathode with extended magnetic field

APA cathode (Sulzer Metaplas GmbH)

see: WO002008125397A1
Demands on coatings for modern precision tools

- Hot hardness combined with sufficient toughness
- Thermal shock resistance
- Oxidation resistance
- Minimum chemical/physical interaction with work piece material to reduce sticking and tribooxidation

Possible combination:

Nanocrystalline morphology → optimum hardness - toughness

Nanostructured multilayers → increase of fracture toughness
Driving high technology
Coating optimization by "micro alloying"

Nano-composite states: alloying - phases

- Doped coatings
  - CrN plus some atoms e.g. Si
  - "micro alloyed"

- Grain boundary segregation
  - e.g. AlTiNC/C

- Two or more phases
  - hcp AlN + fcc AlTiN
  - hcp (CrTi)$_2$N + fcc TiCrN
  - starting at 17 at% Cr
Driving high technology
Micro alloyed coatings: How does it work?

- A significant amount of 0.1 – 3 at% of an additional element

- The element is incorporated into the crystal leading to higher stability, higher oxidation resistance, etc.

- The element is accumulated at the grain boundaries leading to an amorphisation and thus forcing the formation of a nano-composite.

- Influencing the nucleation towards smaller grain sizes and thus forming nano-crystalline structures, e.g. nano-columns
Driving high technology
MAC: \( M_{\text{power}} \) (TiSiXN)

\( M_{\text{power}} \) from the METAPLAS machining Series

Micro alloyed MeSiXN based nano-composite
hardness 42 +/- 3 GPa, load 10mN

Optimized structure of AITiN
hardness 29 +/- 2 GPa, load 10 mN
Dry rough milling of X210Cr12, 200 HB annealed

\( v_c = 150 \text{ m/min}, \quad f = 0.15 \text{ mm/tooth}, \quad a_p \times a_e = 3 \times 10\text{mm} \)
Driving high technology
Multilayer structure design: tailored $M_{\text{power}}$

- AlTiN
- TiSiXN

3000 nm
100 nm
Driving high technology
Cutting test $M^{powerNano}$

finishing, material: 1.2767 (52-54 HRC)

- $V_c$ (m/min): $\approx 250$
- $V_f$ (mm/min): 2200
- $n$ (min$^{-1}$): 13500
- $f_z$ (mm/Zahn): 0.086
- $a_p$ (mm): 0.1
- $a_e$ (mm): 0.1

VB (μm)

<table>
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<th>time (min)</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
<th>100</th>
<th>120</th>
<th>140</th>
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<td>VB (μm)</td>
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Mpower Nano
Hard milling, smoothing, Material 1.2379 60-62 HRC

dry, \( v_c = 115\text{m/min} \), \( f_z = 0.05\text{mm} \), \( a_p = 0.1 \), \( a_e = 0.2 \)
Driving high technology

MAC: \( F_{\text{fusion}} \)

- cold pressing: working temperature is around 200°C (not 600°C!)
- sheet material: high tensile steel (SAPH400: JIS), thickness of 2-3mm
- pressing force: 3,000 ton.
- the tested die is for a part of the most critical area.

\( \text{Fusion} \) coated tool is still working, 7,200 shots as for today

- TiC (U.T.T.E CVD): 3,000 shots
- CrN: 1,000 shots
- M: 1,000 shots
- No coating: never tried
HIPAC: a new evolution of HPPMS

HIPAC results in a highly ionized metal and gas plasma and allows control over the deposition process.

- HPPMS
  - Power is applied to the magnetron in pulses of a few tens of µs at a low frequency (< 2 kHz).
  - Peak target current ~ 1000 A (at 800 V), i.e. 1 MW.
  - Plasma density ~ $10^{19}$ m$^{-3}$.
  - Ionization of the sputtered material: up to 90% for Ti and Al.

HIPAC coating blind hole L:D 2:1
Standard L:D 1:2

HIPAC (High Ionization Plasma for Advanced Coatings) results in a highly ionized metal and gas plasma and allows control over the deposition process.
Driving High Technology
Hybrid processes (AIP & HIPAC)

Smooth and dense sputtered insulating top coat

HIPAC: insulating nano crystalline top layer

Arc: crystalline (Al,Ti)N

1μm

2μm
Driving high technology
Conclusions

- PVD coatings ensure high quality in component production
- New developments open up economic machining of new materials
- Lower coating temperatures allow even direct coating of plastics
- Overcoming line-of-sight coating using HIPAC
- New options for component design using PVD coatings
- DLC coatings represent a group of their own and can be adapted to existing components lowering friction losses and raising lifetime
- Combination of ionitriding and PVD can help substituting expensive materials and protect aftermarket
- Combination treatment can make PVD coatings affordable for mass production
Thank you for your attention!