Trends in the development of cutting materials and coatings for hard machining applications
What is hard turning?

- Single point cutting of work pieces that have hardness values over 45 HRc, however it is more typically 55-68 HRc.
- Traditionally, hardened steel was machined by grinding.
Cutting material properties

- Oxide ceramics
- Mixed ceramics
- Nitride ceramics

- Al₂O₃
- Si₃N₄
- PCD
- Coated CC
- Micro-grained CC
- Superfine grained CC
- Cermet
- Coated CC
- Cemented carbide (CC)
- HSS

Ideal cutting tool material
”The northeast passage”
Hard turning choices in hardened steel

- **TH1000 (PVD)**
  - (60-120 m/min)
- **TH1500 (CVD)**
  - (80-140 m/min)
- **Secomax™ CBN**
  - (150-300 m/min)
What is PCBN?

<table>
<thead>
<tr>
<th></th>
<th>SECOMAX low cBN</th>
<th>SECOMAX high cBN</th>
</tr>
</thead>
<tbody>
<tr>
<td>cBN Content (50%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cBN Content (90%)</td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Property</th>
<th>SECOMAX low cBN</th>
<th>SECOMAX high cBN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knoop’s Hardness [Gpa]</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>Fracture Toughness [MPa/m²]</td>
<td>4.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Thermal Conductivity [W/mK] (20°C)</td>
<td>38</td>
<td>160</td>
</tr>
</tbody>
</table>
Synthesis Conditions for cBN and PCBN

- **Cubic lattice - cBN**
- **Hexagonal lattice - hBN**
- **Equilibrium line cBN/hBN**

1. cBN synthesis
2. PCBN synthesis
Production route PCBN

hBN Powders → HPHT Pressing → cBN Powders

Binder Powders + cBN Powders → Admixed

Capsule Assembly → HPHT Pressing → PCBN Disc → Finished Disc

Tool Fabrication → Cut Pieces → EDM / Laser Cutting → Processing

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PCBN Cutting Material

Hard Materials

1. Hot hardness

Soft/Abrasive Materials

2. Hot hardness

Difficult to Machine Materials


Exploitation of PCBN’s hardness and abrasion resistance at high temperature
Workpiece Material as a Function of Temperature in dry machining

80% of generated heat into chip
10% into cutting edge
10% into workpiece
SECOMAX Machining bearing steel (60HRc)

SECOMAX High cBN content

SECOMAX Low cBN content

\[ v_c = 150 \text{ m/min}, \ f = 0.1 \text{ mm/rev}, \ a = 0.25 \text{ mm} \]
Coated PCBN for hard turning

- Patented nanolaminate multi layer coating, (Ti,Al, Si)N.
- PVD coating specifically developed for PCBN inserts
- Improved wear resistance compared to uncoated
  = Prolonged and consistent tool life.
- Reduced crater wear development
  = Possible to use higher cutting speed.
Secomax PCBN chipbreaker inserts

Secomax™ chipbreaker is machined into the inserts using laser technology. Laser technology enables machining of complex three-dimensional geometries which had been impossible to produce with any other production technology. Laser machining provides several benefits over conventional production technologies such as grinding.
Short description of TH1000 and TH1500

- Better toughness compared to ceramics
- Innovative Solution
  - PVD Nanolayer
  - Substrate with maximum hardness
  - Oxidation resistance

Offer possibilities where ceramic and CBN are unsuitable because of too low process stability
Raw Materials for Cemented Carbides

WO₃

Reduction

1000 C

H₂

W

Carburization

2000 C

W+C

WC
Process technology - inserts

**T250M:**
- WC 88 wt%
- TaC 1.5 wt%
- NbC 0.5 wt%
- Co 10 wt%

1. **Weighing up**
2. **Milling**
3. **Spray drying**
4. **Pressing**
5. **Sintering**
6. **Grinding**
7. **Coating**

**N₂ 200°C**

**1500°C**

**PEG**
- Water
- Ethanol

**Weighing up**

**Coating**

**SECO**
Facing of 34CrNiMo6 (AISI 4340), 43 HRC, through hardened with Coolant, \( ap = 2.0 \text{ mm} \), \( f = 0.3 \text{ mm/rev} \)

Tool Life, \( V_c = 160 \text{ m/min} \)

<table>
<thead>
<tr>
<th>Tool Life, ( V_c = 160 \text{ m/min} )</th>
</tr>
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<tbody>
<tr>
<td>TK1000</td>
</tr>
<tr>
<td>TP1500</td>
</tr>
<tr>
<td>TH1500</td>
</tr>
</tbody>
</table>

No. of Facings | Tool Life, \( V_c = 160 \text{ m/min} \) |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>TK1000, 0.15 mm</td>
</tr>
<tr>
<td>70</td>
<td>TK1000, 0.20 mm</td>
</tr>
<tr>
<td>120</td>
<td>TK1000, 0.25 mm</td>
</tr>
<tr>
<td></td>
<td>TP1500, 0.30 mm</td>
</tr>
<tr>
<td></td>
<td>TH1500, 0.35 mm</td>
</tr>
</tbody>
</table>

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Microstructure of the compared grades

TP1500: Medium grained, 5.6% Co
Co-enriched surface zone
HV = 1550

TK1000: Fine grained, 5.5% Co
HV = 1700

TH1500: Superfine grained, 5.0% Co
HV = 2200
Influence of Texture of the Alumina

Facing of peeled bar, 34CrNiMo6 (AISI 4340), 43 HRC with Coolant
Vc = 150 m/min, dp = 2.5 mm, f = 0.3 mm/rev

Fine grained cemented carbide: 5.5% Co, HV = 1700
DurAtomic™

alpha-Al$_2$O$_3$
DurAtomic™
When to use what grade?

TH1500 (CVD-Duratonic)–Long times in cut and high MRR

Work piece condition

- Stable
- Semi-stable
- Unstable

Hardness [HRC]

<table>
<thead>
<tr>
<th>Work piece condition</th>
<th>55</th>
<th>50</th>
<th>45</th>
</tr>
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<tbody>
<tr>
<td>Stable</td>
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<td></td>
<td></td>
</tr>
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<td></td>
</tr>
<tr>
<td>Unstable</td>
<td></td>
<td></td>
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</tr>
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a_p [mm]

- Fine
- Medium
- Semi rough
When to use what grade?

TH1000 (PVD Coated)—Short times in cut and toughness

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<th>Hardness [HRC]</th>
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<td>Unstable</td>
<td>45</td>
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<tr>
<th>Work piece condition</th>
<th>a₀ [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stable</td>
<td>0,25</td>
</tr>
<tr>
<td>Semi-stable</td>
<td>1,5</td>
</tr>
<tr>
<td>Unstable</td>
<td>3,0</td>
</tr>
</tbody>
</table>

Fine | Medium | Semi rough
Crown wheel – PCBN vs carbide

PCBN, low cBN
- Tool life: 250 pcs/edge, total 83 min, 20 s/piece
- $v_c = 160 \text{ m/min}$
- $a_p = 1.3 \text{ mm}$
- $f_{\text{dia}} = 0.12 \text{ mm/rev}$
- $f_{\text{faceing}} = 0.12$

Carbide TH1000
- Tool life: 52 pcs/edge, total 33 min, 38 s/piece
- $v_c = 70 \text{ m/min}$
- $a_p = 1.3 \text{ mm}$
- $f_{\text{dia}} = \text{entry} = 0.12$, then 0.15 mm/rev
- $f_{\text{faceing}} = 0.12$

63 HRc surface hardness, hardening depth $\sim 1.2\text{mm}$

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Crown wheel – PCBN vs carbide

Carbide TH1000
+ Great tool life for carbide in 63 HRc
+ Low cost per insert.
+ More forgiving for unstable conditions
- 5 cutting edges to manufacture 250 pcs.
- Longer cutting times

PCBN, low cBN
+ High productivity
+ Short cycle time
+ High usage of machine capacity
- Sensitive to unstable conditions
- High cost per insert
- Usually not suitable for small production volumes

63 HRc surface hardness, hardening depth ~1.2mm
**Summary**

Window of application:

- **TK1000**
- **"TH1500"** (CVD)
- **"TH1000"** (PVD)

**HRC**

PCBN/Ceramics:
- No or reduced chip breaking when softer than ~56 HRc
- Use PCBN with chip breakers.
Short description of TH1000 and TH1500

- Better toughness compared to ceramics
- Innovative Solution
  - PVD Nanolayer
  - Substrate with maximum hardness
  - Oxidation resistance

  offer possibilities where ceramic and CBN are unsuitable because of too low process stability

- Reference:
  TP0500: ca 1600 HV10
63HRC surface hardness, hardening depth ~1,2mm

+1/5 of the parts/edge, 1/10 of the cost

-Longer cycle time

Geometry: CNMG120608-MF5
Coating: PVD TiSiN+TiAlN

\[ v_c = 70 \text{m/min} \]
\[ a_p = 1,3\text{mm} \]
\[ f_{\text{dia}} = \] -entry = 0,12 then 0,15
\[ f_{\text{faceing}} = 0,12 \]

TH1000: Time in cut / piece: 38s
Number of work pieces: 52
Tool life = 33min
Cost: ~2,5Euro/edge

CBN: \[ v_c = 160\text{m/min} \] TIC=20
\[ a_p = 1,3\text{mm} \] \[ f = 0,12 \]
Number of work pieces: 250
Cost: ~25Euro/edge
Summary

Window of application:

CBN/Ceramics: No chip breaking when softer than ~56HRC
Chemical Vapour Deposition (CVD)

\[ H_2 + CH_4 + TiCl_4 \rightarrow TiC + HCl + H_2 \]

T = 1000°
Growth rate
~1 μm/h
Physical Vapour Deposition (PVD)

Gas inlet
(N₂, CH₄, Ar)

Evaporation source
(cathode of Ti, (Ti,Al))

Inserts

T=500°C
P=2 Pa
Growth rate ~3 μm/h
CVD vs PVD

CVD
(Chemical Vapour Deposition)

- Thick wear-resistant coating
- Easy to get good adhesion
- Uniform coating thickness
- Coatings of Al₂O₃
- Tensile stresses

- For high wear resistance
- Medium to big chip thickness

PVD
(Physical Vapour Deposition)

- Sharp edges
- Compressive stresses
- No reaction with substrate
- Careful cleaning for good adhesion
- Single-sided coating

- For edge sharpness and toughness
- Small chip thickness
- Short engagement
SECOMAX™

Hard turning
Kurzvorstellung TH1000 und TH1500

- Zähigkeitsvorteile von Hartmetall im Vergleich zu Keramik nutzen
- Innovative Lösung
  = PVD-Nanolayer
  = Substrat maximaler Härte
  = Oxidationsbeständigke

bietet Möglichkeiten, wo Keramik und CBN wegen zu geringer Prozesssicherheit nicht geeignet sind

- Referenz: TP0500: ca. 1600 HV10
Short description of TH1000 and TH1500

TH1500
- Better toughness compared to ceramics
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  - PVD Nanolayer
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  offer possibilities where ceramic and CBN are unsuitable because of too low process stability
- Reference:
  TP0500: ca 1600 HV10

TH1000
- (Ti,Al)N/TiSiN Nanolayer
- MT-CVD Ti(C,N)
- 2200 HV Feinkorn 5% Co
Secomax PCBN chipbreaker inserts

Conventional PCBN insert

PCBN chipbreaker inserts

Secomax PCBN chipbreaker inserts are recommended in applications where improved chip control is demanded e.g.:

- When removing a case hardened layer
- When machining from hard to soft material
- Internal machining where chip evacuation is a problem
Secomax PCBN chipbreaker inserts

Results from tests in soft material SS1672 (C45) ~ 200 HB:
- Depth of cut 0.10 mm
- Feed rate 0.10 mm/rev
- Speed 160 m/min

PCBN standard insert
CNGA120408S-01525-L1-B

PCBN chipbreaker insert
CNGM120408S-01525-L1-B
Production route

1. hBN Powders
2. HPHT Pressing
3. cBN Powders
4. Binder Powders
5. Admixed
6. Capsule Assembly
7. HPHT Pressing
8. PCBN Disc
9. Processing
10. Finished Disc
11. EDM / Laser Cutting
12. Cut Pieces
13. Tool Fabrication
Production route

hBN Powders ➔ HPHT Pressing ➔ cBN Powders

Binder Powders

Admixed

Capsule Assembly ➔ HPHT Pressing ➔ PCBN Disc ➔ Processing

Tool Fabrication ➔ Cut Pieces ➔ EDM / Laser Cutting ➔ Finished Disc
Production route

1. hBN Powders → HPHT Pressing
2. cBN Powders → Binder Powders → Admixed
3. Capsule Assembly → HPHT Pressing → PCBN Disc
4. Finished Disc → Processing
5. Cut Pieces → EDM / Laser Cutting
6. Tool Fabrication

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Production route

- hBN Powders
- HPHT Pressing
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- Tool Fabrication

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Production route

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Production route

hBN Powders → HPHT Pressing → cBN Powders → cBN Powders → Binder Powders -> Admixed → Capsule Assembly → HPHT Pressing → PCBN Disc

Tool Fabrication → Cut Pieces → EDM / Laser Cutting → Finished Disc → Processing
Production route

- hBN Powders
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Production route

1. **hBN Powders**
2. **HPHT Pressing**
3. **cBN Powders**
4. **Admixed**
   - **Capsule Assembly**
   - **HPHT Pressing**
   - **PCBN Disc**
5. **Processing**
6. **Tool Fabrication**
7. **Cut Pieces**
8. **EDM / Laser Cutting**
9. **Finished Disc**
Production route

hBN Powders → HPHT Pressing → cBN Powders

Binder Powders → Admixed → Capsule Assembly

HPHT Pressing → PCBN Disc

Processing → EDM / Laser Cutting → Finished Disc

Cut Pieces → Tool Fabrication