PROCESSES & INNOVATIVE TOOLS FOR HIGH PERFORMANCE GRINDING

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GRINDING CONFERENCE
1. Who is Saint-Gobain
2. Chip forming mechanism
3. Chip thickness, length, and contact time
4. New developments of grinding wheels
4. Summary
SAINT-GOBAIN

- one of the 100 industrial companies in the world
- More than 180000 employees
- Plants in 67 countries
- Turnover > 41 Mrd €

Many well known brands, such as:
SAINT-GOBAIN ABRASIVES

- Supplier for all product groups
  - Bonded Abrasives
  - Coated Abrasives
  - Superabrasives
  - Thin- and Cut-off Wheel
  - Construction Products
- ~ 11000 Employees
- 61 plants in 28 countries
- ~ 1,5 Mrd € turnover
Chip formation mechanism
THREE BASIC COMPONENTS FOR OPTIMAL SOLUTIONS

Grain
- Fused alumina (white, rose, monocrystalline)
- Seeded gels (SG, XG, NQ, …)
- Extruded alumina (TG, TGX, …)
- Diamond / cBN

Porosity
- The porosity is formed by a specific matrix technology or by artificial pore inducers

Bond
- Bonds show different hardness, wear resistance, grit retention capacity
THE VARIETY LEADS TO THE OPTIMUM

Why not only one single specification?

- Each abrasive grain/bond/porosity shows its strengths in certain areas
- The following points are influenced by specification:
  - Specific grinding energy $E_c$
  - Threshold power $P_{th}$
  - Aggressiveness / chip thickness
  - Surface roughness
  - Maximum metal removal rate $Q$
  - Wheel wear
  - Self-sharpening effect
  - Wheel life

- The grinding behavior can also be optimized by an adapted dressing strategy.
GRINDING PROCESS … INTERACTIONS

**SLIDING**
\( P_{th}, \text{lubrication}, \ldots \)

**PLOWING**
\( P_{th}, \text{material}, \ldots \)

**CHIP FORMATION**
\( E_c, \text{material}, \ldots \)

**SLIDING bond/workpiece**
Wheel structure, wear, …

**SLIDING chip/bond**
Wheel structure, cleaning, …

**SLIDING chip/workpiece**
Cleaning, chip removal, …
**CASE STUDY: CBN VERSUS SINTERED CORUNDUM**

**OD Plunge Grinding**

- **Wheels:** Vit-bond, 400 mm Ø  
  cBN B126, NQ 60, TQX 80  
- **Work piece:** 100Cr6, 60 HRC  
  130 – 90 mm Ø  
- **Machine:** Blohm, Emulsion

**Results:**

- Der extruded „longish“ TQX shows the lowest specific grinding energy, followed by the sintered corundum NQ and cBN.  
- The cBN wheel has the lowest threshold power… easiest chip formation!
The chip....

and its thickness and length
CHIP THICKNESS

The equivalent chip thickness $h_{ec}$ is an important indication for the process

$$h_{ec} = \frac{Q'_{w}}{v_c} = \frac{v_{w} \cdot a_e}{v_c}$$

For more accuracy the undeformed chip thickness $h_{cu}$ shows the influence of the abrasive concentration $c$, the abrasive shape $r$ and the wheel diameter $d_e$.

$$h_{cu} \approx \sqrt{\frac{v_{w}}{v_c \cdot c \cdot r}} \cdot \sqrt{\frac{a_e}{d_e}}$$

Polishing and finishing: $h_{ec} = 0.01 - 0.1 \, \mu m$
Precision grinding: $h_{ec} = 0.1 - 0.7 \, \mu m$
Rough and high performance grinding: $h_{ec} = 0.7 - 3.5 \, \mu m$

Practical impact of chip thickness:
- $h$ too small: burn, burrs, surface too fine … „wheel acts hard“
- $h$ too high: rough surface, noise, high wheel wear …. „wheel acts soft“

Acc. Malkin et al, & Shaw
CASE STUDY: CHIP THICKNESS AND ROUGHNESS

OD Plunge Grinding

Wheels: Vit bond, 300 mm Ø
        NQ 80 VS3

Work piece: 100Cr6, 60 HRC
            160 mm Ø

Q'w: 4, 6, and 8 mm³/mm·s

Machine: Studer, Emulsion
Only roughing…

Results:
- Direct relation between \( h_{ec} \) and \( R_a \)
- Other parameters like \( v_c \) show a significant influence on this relation
CASE STUDY: END MILL - FLUTEGRINDING

Starting point: Currently, the customer has issues with the process times and with burrs….. Significant optimization required

End mill 50 mm x 6.5 mm  Stainless steel 1.4028
Flute depth 2 mm  Rollomatic GrindSmart 628XS, Oil

Competition, tool and parameters:
$v_c = 55 \text{ m/s}, v_w = 50 \text{ mm/min}, a_e = 1 \text{ mm} \ (2 \text{ passes})$

>>> Surface too fine, squeezing, creation of burrs

$h_{ec} = 0.015 \mu m$ (Chip thickness too low, but more „aggressive“ parameters impossible due to wear)

Saint-Gobain: Q-Flute B64 EVO …. To realize a larger chip thickness!
$v_c = 35 \text{ m/s}, v_w = 120 \text{ mm/min}, a_e = 2 \text{ mm} \ (1 \text{ pass})$

$h_{ec} = 0.11 \mu m$

>>> and thus: 50% reduction of process time, no burrs!
Another important parameter in the grinding process is the length of contact / chip length $l_c$:

### Surface and Traverse Grinding

$$l_c = \sqrt{a_e \cdot d_e \cdot \left(1 + \frac{v_w}{v_c}\right)}$$

### Plunge Grinding

$$l_c = \sqrt{\frac{v_{fr} \cdot \pi \cdot d_w \cdot d_e \cdot \left(1 + \frac{v_w}{v_c}\right)}{v_w}}$$

#### Example:

Surface, OD and ID grinding with $Q'_{w}$ 6,7 mm³/mm·s

- $d_s$ 125 mm, $a_e$ 0,01 mm, $v_c$ 50 m/s, $v_w$ 40000 mm/min (.h$_{ec}$ 0,13 µm)

- **Surface grinding**
  - $l_c = 1.1$ mm

- **OD grinding ($d_w$ 20 mm)**
  - $l_c = 0.4$ mm

- **ID grinding ($d_w$ 170 mm)**
  - $l_c = 2.2$ mm
These large differences of the contact lengths influence the contact time $t_c$ (grit to work piece) accordingly:

$$t_c = \frac{l_c}{v_c}$$

**Example:**
Surface, OD and ID grinding with $Q'_w$ 6,7 mm³/mm·s

- Surface grinding
  - $d_s$ 125 mm, $a_e$ 0,01 mm, $v_c$ 50 m/s, $v_w$ 40000 mm/min ($h_{ec}$ 0,13 µm)
  - $l_c = 1.1$ mm, $t_c = 23$ µs

- OD grinding ($d_w$ 20 mm)
  - $l_c = 0.4$ mm, $t_c = 8.4$ µs

- ID grinding ($d_w$ 170 mm)
  - $l_c = 2.2$ mm, $t_c = 44$ µs

**Conclusion:** At the same material removal rate the variation of the contact times are significant (factor of $\sim$5) .... Consequently, there is a huge difference in the load on the grits !!!
NUMBER OF ACTIVE ABRASIVE GRAINS

Rough estimation for eg diamond tools:
Assumption of a mean grit size and a consistent average grit shape (between ball and cubus).
Grit shielding, shielding angles, different heights etc. are excluded from this estimation.

<table>
<thead>
<tr>
<th>Concentration</th>
<th>FEPA grit size</th>
<th>Mesh size</th>
<th>Grit size [µm]</th>
<th>Particles per ct</th>
<th>Particles per mm³ (volume)</th>
<th>Particles per mm² (area)</th>
<th>Particles per mm (line)</th>
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<tbody>
<tr>
<td></td>
<td>D181</td>
<td>80/100</td>
<td>167</td>
<td>16000</td>
<td>35</td>
<td>11</td>
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<tr>
<td>C50 = 2,2 ct/cm³</td>
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<td>140</td>
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<td>62</td>
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<td></td>
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<tr>
<td></td>
<td>D91</td>
<td>170/200</td>
<td>83</td>
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<td>297</td>
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Active grain concentration

The chip thickness and surface roughness are strongly influenced by the concentration of active abrasive grains at the surface.

This number can be modified by the total abrasive concentration, but also (and very importantly) by the grit size.

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Load on the grits / chip lengths

Based on our example with concentration C100 und D126, we see that 5.9 grits per mm are in action (= distance between the grits 0.17 mm).

- Surface-: \( l_c = 1.1 \text{ mm} \quad t_c = 23 \mu s \) mit 6.5 grits
- OD- \((d_w 20 \text{ mm})\) \( l_c = 0.4 \text{ mm} \quad t_c = 8.4 \mu s \) mit 2.5 grits
- ID- \((d_w 170 \text{ mm})\) \( l_c = 2.2 \text{ mm} \quad t_c = 44 \mu s \) mit 13 grits

With ID grinding the „work“ is done by 13 abrasive grits…. Larger time and length of contact, and lower chip thickness!

Risk
Grit polishing, burn, low surface roughness

On the opposite, with OD grinding it’s only 2.5 grits, in a small time and at a short length

Risk
High wear due to heavy load on the grit and the bond
CASE STUDY: CREEPFEED GRINDING

Starting point: Thermal damage at the surface (burn), when the grinding wheels wear down to a lower diameter.

Grinding wheel 300 – 180 mm Ø, NQ vit bond, 2 grade of hardness (hard = bond volume + 50%)
Inconel, oil, $v_c = 22$ m/s, $v_w = 500$ mm/min, $a_e = 1$ mm >> $Q'_w = 8,3$ mm³/mm·s, $h_{ec} = 0,38$ µm

Grinding results:
Large diameter (300 mm): Everything OK, no burn neither at soft nor at hard specification
Small diameter (180 mm): Burn with hard spec, but the soft spec is alright!

Calculations:
Length and time of contact:
- at 300 mm: $l_c = 17,3$ mm; $t_c = 0,78$ ms
- at 180 mm: $l_c = 13,4$ mm; $t_c = 0,61$ ms

With the small diameter the length and time of contact is 22% shorter, and therefore the load on the grit is much higher, leading to increased wear. As the bond at the hard spec can't cover this wear, it leads to friction and subsequently burn!
With the soft wheel (lower bond volume) this problem could be solved!
New developments of grinding tools
BASIC REQUIREMENTS FOR NEW DEVELOPMENTS:

• High porosity and low bond volume

• Low specific grinding energy and threshold power

• Low abrasive shape factor…. Elongated grain
CASE STUDY: CREEP FEED GRINDING

Starting point:
Process optimization required, as the customer suffered from problems with the competition tool such as low life time and partly thermal damages

Grinding wheel 300 mm Ø, TQX vit bond, high porosity
Ni based aloy, $v_c = 15\text{-}25\text{ m/s}$, $v_w = 250\text{-}600\text{ mm/min}$, $a_e = 3\text{-}0,3\text{ mm}$

Results:
- Burn free grinding
- High flexibility of parameters
- 10 times higher life time compared to competition
- Process times reduced by 40%
Properties of this diamond tool
- Highly porous metal bond, up to 46% porosity
- High thermal conductivity
- Very high grit retention due to chemically active components
- Homogeneous structure
- Easily dressable (profile- und CNC-dressing)

Benefits
- Combines the best properties of metal and vitrified bond
- Low grinding forces
- Avoids thermal damages
- High G-ratios
- Excellent process stability
- Low specific grinding energy
- Perfectly suitable for difficult-to-grind materials, such as TiAl, CMC, Carbide, …
Comparison between SiC und Paradigm (Diamant)
- Blohm Planomat HP
- Grinding of grooves
- Total infeed 4 mm, per cut 0,2 mm

Benefits of TiAl for the Turbine-Industry
- Low density (50% lower than Ni-Superalloys)
- High temperature stability
- High specific toughness

BUT:
- Difficult to grind
- Risk of burn and cracks

Results
- Grinding with SiC showed burn from the beginning
- With the Paradigm several cuts could be performed at a constant power and without burn and cracks.
- Dressing of the Paradigm was only necessary to keep the form, but not due to burn.
Summary
SUMMARY

- Selection of grain type
- Specific Grinding energy
- Threshold power
- Chip thickness
- Chip formation
- Deformation elastic / plastic
- Specific Grinding energy
- Porosity
- Cooling
- Direction of Grinding
- Speed ratio
- Specification
The performance of a grinding process can easily be optimized:

We just need...

✓ Some simple calculations
✓ Understanding of the microscopic mechanism
✓ and the properties of the grains, bonds, machine & workpiece

Grinding is simple... relatively!
Thanks for your attention