Manufacturing Technology I

Lecture 10

„Cutting with geometrical undefined cutting edge:
Grinding tools and grinding wheel preparation“

Prof. Dr.-Ing. F. Klocke

➢ Structure and characteristics of grinding tools
➢ Effects of grinding wheel specifications on the process
➢ Wear mechanisms in grinding processes and their effects on the wheel topography
➢ Preparation of grinding wheels
Grinding and Honing Tools

Chip formation

source: Fachkunde Metall, Europa Lehrmittel © WZL
Grinding Wheel Structure

Composition of grinding wheels

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volume: \( V = V_1 + V_2 + V_3 \) [cm³]

(structure formula) 100 = \( V_1 \times V_2 \times V_3 \) [%]

mass: \( m = m_1 + m_2 = p_1 V_1 + p_2 V_2 \) [g]

100 = \( m_1 \times m_2 \) [%]

density: \( \rho = \frac{p_1 V_1 + p_2 V_2}{V_1 + V_2 + V_3} \times 100 \) [g/cm³]

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Conventional
CBN-abrasives
Hot pressed
### Specification codes of conventional grinding wheels

<table>
<thead>
<tr>
<th>Example</th>
<th>Abrasive</th>
<th>Grain Size</th>
<th>Hardness</th>
<th>Texture</th>
<th>Bonding Type</th>
<th>Special Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>60</td>
<td>L</td>
<td>S</td>
<td>B</td>
<td>P</td>
<td></td>
</tr>
</tbody>
</table>

- **Grain Size:**
  - Coarse: 6 30 70 220
  - Medium: 8 46 96 240
  - Fine: 10 46 96 240
  - Very Fine: 12 46 96 240
  - 14 150 500
  - 16 150 500
  - 20 180 600
  - 24 180 600
- **Hardness:**
  - A: Extremely soft
  - B: Soft
  - C: Medium
  - D: Hard
  - E: Extremely hard
- **Texture:**
  - Closed texture
  - Open texture
- **Bonding Type:**
  - Vitrified bonding
  - Silicate bonding
  - Rubber bonding
  - Resin bonding
  - Shellac bonding
  - Magnesit bonding

### Specification codes superabrasive wheels

<table>
<thead>
<tr>
<th>Example</th>
<th>Abrasive</th>
<th>Grain Size</th>
<th>Bonding</th>
<th>Hardness</th>
<th>Body Material</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>126</td>
<td>K</td>
<td>A</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Grain Size:**
  - Diamond: 1181, 213, 1001, 181
  - CBN: 711, 121
  - Other: 426, 76, 321, 54, 251, 46
- **Bonding:**
  - Resin bonding
  - Metal bonding
- **Hardness:**
  - A: Soft
  - B: Medium
  - C: Hard
  - D: Very hard
- **Body Material:**
  - Resin, Metal, Resin, Metal, Resin, Metal
- **Concentration:**
  - V: 10, 15, 20, 30, 40, 50

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Tasks and characteristics of grinding tools

Task

While cutting with geometrical undefined cutting edges the effect of material removal is caused by grains penetrating the workpiece material.

Required properties

<table>
<thead>
<tr>
<th>hardness and toughness</th>
<th>material removal from the workpiece</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>maintaining the sharpness</td>
</tr>
<tr>
<td>thermal stability</td>
<td>withstanding high machining temperatures</td>
</tr>
<tr>
<td></td>
<td>withstanding rapid temperature changes</td>
</tr>
<tr>
<td>chemical stability</td>
<td>avoiding chemical reactions at high temperatures and high pressures</td>
</tr>
</tbody>
</table>

Conventional Grains

<table>
<thead>
<tr>
<th>symbol</th>
<th>abrasive</th>
<th>Knoop-hardness [N/mm²]</th>
<th>thermal stability [°C]</th>
<th>thermal conductivity [W/(m°C)]</th>
<th>fields of application</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>corundum</td>
<td>1950 to 2200</td>
<td>2000</td>
<td>6</td>
<td>medium-tough to hard materials below 60 HRC (R_m &lt; 500 N/mm²) such as:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• steel</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• malleable cast iron</td>
</tr>
<tr>
<td></td>
<td>Sol-Gel-</td>
<td></td>
<td>2000</td>
<td>6</td>
<td>tough-hard steels over 60HRC, such as tool-steel</td>
</tr>
<tr>
<td></td>
<td>corundum</td>
<td></td>
<td></td>
<td></td>
<td>• grinding and polishing of glass</td>
</tr>
<tr>
<td>C</td>
<td>silicon</td>
<td>3000</td>
<td>1300</td>
<td>55</td>
<td>• surface grinding of HM, GG, ceramics, non-ferrous metals</td>
</tr>
<tr>
<td></td>
<td>carbide</td>
<td></td>
<td></td>
<td></td>
<td>• dressing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• manual grinding</td>
</tr>
</tbody>
</table>
Superabrasives

<table>
<thead>
<tr>
<th>symbol</th>
<th>abrasive</th>
<th>Knoop - hardness [N/mm²]</th>
<th>thermal stability [°C]</th>
<th>thermal conductivity [W/(m° C)]</th>
<th>fields of application</th>
</tr>
</thead>
</table>
| B      | cubic boron nitride (CBN) | 4700                     | 1370                   | 200-700                       | • hardened steel  
• low alloy steel  
• HSS                                                    |
| D      | diamond                 | 8000                     | 900                    | 600 - 2100                    | • carbon saturated steel  
• glass, stone, ceramics  
• tungsten carbide, cermets  
• glass-fibre re-inforced plastics (GRP)                  |

Tasks and characteristics of bonds

Task

The purpose of the bond is to retain the grinding grit in place until it is blunted by the cutting operation. The bond should then release the grain so that the next sharp grain can be used.

Required properties

- the bonding material must be firm enough
- formation of bond bridges with sufficiently large cross-sections
- a durable joint must be formed between bond and grit
### Grouping of bonds

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Bonding Type</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>vitrified bond</td>
<td>• brittle and thus sensitive to impact load</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• high modulus of elasticity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• high thermal stability, low resistance to thermal shock</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• chemical resistance against oil and water</td>
</tr>
<tr>
<td>D</td>
<td>resin bond</td>
<td>• high impact and shock resistance as well as side pressure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• application in parting-off and roughing wheels</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• high elasticity in fine-grinding wheels enables high surface qualities</td>
</tr>
<tr>
<td>M G</td>
<td>metal bond</td>
<td>• high wear resistance</td>
</tr>
<tr>
<td></td>
<td>galvanic bond</td>
<td>• difficult to dress</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• high thermal conductivity</td>
</tr>
</tbody>
</table>

- Structure and characteristics of grinding tools
- Effects of grinding wheel specifications on the process
- Wear mechanisms in grinding processes and their effects on the wheel topography
- Preparation of grinding wheels
Effect of the specification on $h_{cu}$ - grain size

- grain size
- grain concentration
- bonding hardness
- texture

- number of kinematic cutting edges $N_{kin}$
- number of current cutting edges $N_{mom}$
- distance between kinematic cutting edges $l_{kin}$
- chip thickness $h_{cu}$

Effect of the specification on $h_{cu}$ - grain concentration

- grain size
- grain concentration
- bonding hardness
- texture

- number of kinematic cutting edges $N_{kin}$
- number of current cutting edges $N_{mom}$
- distance between kinematic cutting edges $l_{kin}$
- chip thickness $h_{cu}$
Effect of bonding hardness

- Grain size
- Grain concentration
- Bonding hardness
- Vol. bond

Const:
- Number of kinematic cutting edges \( N_{\text{kin}} \)
- Number of current cutting edges \( N_{\text{mom}} \)
- Distance between kinematic cutting edges \( l_{\text{kin}} \)
- Chip thickness \( h_{\text{cu}} \)

Effect of vol. bond content

- Grain size
- Grain concentration
- Bonding hardness
- Vol. bond

Const:
- Number of kinematic cutting edges \( N_{\text{kin}} \)
- Number of current cutting edges \( N_{\text{mom}} \)
- Distance between kinematic cutting edges \( l_{\text{kin}} \)
- Chip thickness \( h_{\text{cu}} \)
Structure and characteristics of grinding tools

Effects of grinding wheel specifications on the process

Wear mechanisms in grinding processes and their effects on the wheel topography

Preparation of grinding wheels

Change of grinding wheel topography with material removal rate

<table>
<thead>
<tr>
<th>Variation of grinding wheel topography with material removal rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 µm</td>
</tr>
<tr>
<td>500 µm</td>
</tr>
<tr>
<td>Before process start</td>
</tr>
</tbody>
</table>

| 100 µm |
| 500 µm |
| $Q_{w} = 4 \ \text{mm}^{3}/\text{mmns}$ |
| $V_{c} = 500 \ \text{mm}/\text{mm}$ |

| 100 µm |
| 500 µm |
| $Q_{w} = 4 \ \text{mm}^{3}/\text{mmns}$ |
| $V_{c} = 1000 \ \text{mm}/\text{mm}$ |
Wear characteristics

Examples of grain wear

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The chip thickness $h_{cu}$ determines wear behaviour and wear speed

Motivation for grinding wheel dressing

<table>
<thead>
<tr>
<th>Macroscopic wear</th>
<th>Microscopic wear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial wear</td>
<td>Edge wear</td>
</tr>
<tr>
<td>Grain breakage</td>
<td>Abrasion</td>
</tr>
</tbody>
</table>

Consequence

- Profile lost
- Off-size condition
- Blunted grit-cutting-edges
- Increase of grinding forces
- Damage of the workpiece structure in the external zone

Tool conditioning
Increase of edge wear with increasing material removal rate and decreasing cutting speed

Structure and characteristics of grinding tools

Effects of grinding wheel specifications on the process

Wear mechanisms in grinding processes and their effects on the wheel topography

Preparation of grinding wheels
### Kinematics of common dressing processes

<table>
<thead>
<tr>
<th>Standing dressing tools</th>
<th>Rotating dressing tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-grit dressing tool</td>
<td>Profile dressing roll</td>
</tr>
<tr>
<td>Dressing tile</td>
<td>Form dressing roll</td>
</tr>
<tr>
<td>Multi-grit dressing tool</td>
<td>Pot dressing wheel</td>
</tr>
</tbody>
</table>

### Dressing tools

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<td>Form dressing roll</td>
</tr>
<tr>
<td>Multi-grit dressing tool</td>
<td>Pot dressing wheel</td>
</tr>
</tbody>
</table>
Wheel-topography due to dressings cinematics

Standing dressing tool

Rotating dressing tool

Profile-roll

Form-roll

Similar to:

turning

Similar to external cylindrical grinding

Plunge grinding

Traverse grinding

Creation of a “thread”

Overlapping of grit engagement paths

“thread” + Overlapping of grit engagement paths

Standing dressing tools: kinematic roughness (turning)

\[ R_t = r_t \sqrt{d_-^2 - d_+^2 - \frac{d_-^2}{4}} \]

oder

\[ R_t = \frac{d_-}{2T_b} \]

Ortlinie terrestrial \( f < 2r_t \cos(w_p + \phi) < 90^\circ \) und \( w_p < \phi < 180^\circ \)
Standing dressing tools: kinematic roughness

\[ R_t = \frac{f_{ad}}{b_d} \]

Grinding wheel periphery

\[ U_d = \frac{b_d}{f_{ad}} \]

Grinding forces

Change of the effective cutting width at the single grain diamond (according to R. Völler)

- Effective cutting width of a single grain diamond for \( V_d = 0 \) cm³
- Effective cutting width of the dressing tool
- Cutting speed at dressing: \( v_{cd} = 60 \) m/s
- Dressing capacity \( V_d \)

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Rotating dressing tools: influence of the depth of dressing cut

Influence of speed ratio and dressing in-feed on peak-to-valley height (wheel roughness, acc. to E. Saljé)

- Grinding wheel: A 60 K - 8V
- Diamond roller (D 700/7,5)

Peripheral speed at dressing: $v_{sd} = 30 \text{ m/s}$

<table>
<thead>
<tr>
<th>q_d</th>
<th>$a_{ad}$</th>
<th>$h_{cu}$</th>
<th>$R_{pa}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>0.7µm</td>
<td>15µm</td>
<td>5µm</td>
</tr>
<tr>
<td>0.5</td>
<td>0.5µm</td>
<td>10µm</td>
<td>3µm</td>
</tr>
<tr>
<td>0.0</td>
<td>0.3µm</td>
<td>7µm</td>
<td>2µm</td>
</tr>
<tr>
<td>-0.5</td>
<td>0.2µm</td>
<td>6µm</td>
<td>1µm</td>
</tr>
<tr>
<td>-1.0</td>
<td>0.1µm</td>
<td>5µm</td>
<td>0.5µm</td>
</tr>
</tbody>
</table>
Influence of dressing speed ratio $q_d$ on wheel roughness

Cycloid path of a dressing grain: down dressing, i.e. $q_d$ positive

$\begin{align*}
q_d &= +1.5 \\
q_d &= +1.2 \\
q_d &= +1 \\
q_d &= +0.5
\end{align*}$

grinding wheel surface

Influence of the ratio of dressing speeds $q_d$

Cycloid path of a dressing grain: up dressing, i.e. $q_d$ negative

$\begin{align*}
q_d &= -0.2 \\
q_d &= -0.4 \\
q_d &= -0.8
\end{align*}$

grinding wheel surface
Influence of dressing overlap factor on work result

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grinding wheel</td>
<td>A 60 K - 8 V</td>
</tr>
<tr>
<td>Workpiece material</td>
<td>Ck 45 N</td>
</tr>
<tr>
<td>Spec. material removal rate</td>
<td>$Q'_w = 1 \text{ mm}^3/\text{mm}$</td>
</tr>
<tr>
<td>Spec. material removal</td>
<td>$V'_w = 400 \text{ mm}^3/\text{mm}$</td>
</tr>
<tr>
<td>Cutting speed</td>
<td>$v_c = 45 \text{ m/s}$</td>
</tr>
<tr>
<td>Speed ratio</td>
<td>$q = 60$</td>
</tr>
<tr>
<td>Spark out time</td>
<td>$t_s = 10 \text{ s}$</td>
</tr>
<tr>
<td>Dressing tool</td>
<td>tile</td>
</tr>
<tr>
<td>Dressing in-feed</td>
<td>$a_{ud} = 30 \mu m$</td>
</tr>
</tbody>
</table>

**Graphs:**
- Spec. tangential force $F'_t$ vs. dressing overlap factor $U_d$
- Spec. normal force $F'_n$ vs. dressing overlap factor $U_d$
- Radial wheel wear vs. dressing overlap factor $U_d$
- Air gap peak-to-valley height $R_z$ vs. dressing overlap factor $U_d$

**Equations:**
- Effective profile of the dressing tool $b = 105 \mu m$
- Effective cutting width $b_d$
- Dressing overlap factor $U_d$ related to dressing infeed $f_{ud}$

Process preparation of CBN-grinding wheels

1. **Profiling**
   - Generating the grinding wheel shape
   - Wheel topography after profiling

2. **Sharpening**
   - Generation of the cutting edge space structure
   - Wheel topography after sharpening
Sharpening superabrasive grinding wheels

Grinding wheel: B 252 KSS 10JA V240
Dressing tool: Diamond roller
Sharpening block height: $h_{SB} = 25$ mm
Cutting speed: $v_c = 90$ m/s
Dressing feed: $a_d = 8$ µm
Dressing speed ratio: $q_d = 0.375$

$Q_{Sb}' = 400$ mm³/mms
$a_{Sb} = 70$ mm

$Q_{Sb}' = 710$ mm³/mms
$a_{Sb} = 240$ mm

Dressing of vitrified superabrasive wheels

1. dressing CBN-grain
2. sharpening / in-grinding

grinding procedure: external plunge grinding
workpiece material: S 6-3-2 (64 HRC)
cutting speed: $v_c = 90$ m/s
spec. material removal rate: $Q_{w}' = 23$ mm³/mms
grinding wheel diameter: $d_s = 400$ mm
Touch-Dressing of electroplated CBN Grinding Wheels

Projection of all static cutting edges in a galvanic bonded grinding coating on the layer of a steel plate

Standard grit size B151 after FEPA

Dressing in-feed at continuous dressing

radial feed rate \( f_d \) of the grinding wheel for the compensation of the dressing amount