Grind-Hardening
Process Modelling
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What is Grind-Hardening?

Conventional Production Chain:
- Raw Material
- Material Removal Processes
- Transport
- Heat Treatment
- Transport
- Finishing
- Dispatch

- Turning
- Milling
- Drilling
- Forming
- Gear cutting
- Tempering
- Nitriding
- Case hardening
- Grinding
- Honing
- Super Finishing

Integrated Production Chain:
- Raw Material
- Material Removal Processes
- Grind-Hardening
- Dispatch

- Turning
- Milling
- Drilling
- Forming
- Gear cutting
- Grinding and Finishing

Production time and cost saving
What is Grind-Hardening?

Grind hardening is a process that combines material removal and surface hardening of the workpiece at the same time. The heat dissipated in the cutting area is used for the heat treatment of the workpiece.

Process Parameters
- Depth of cut: 0.2 – 1.2 mm
- Feed speed: 0.3 – 1.2 m/min
- Both CBN and Corundum wheels
- MGL or even dry

Grinding machine:
- Need for high stiffness
- Powerful spindles required

Workpiece material:
- C concentration > 0.3%
- 38 MnS 6, 42 CrMo 4, C42, Cf 53, 100 Cr 6
- Max HRC: ≈ 50 – 60
• Use of advanced modelling methods for the prediction of process performance and optimize the process parameters
**Grinding forces estimation**

Function of the process parameters, workpiece material and grinding wheel topography

**Estimation of the heat generated**

Function of process forces and grinding wheel rotational speed \( P = F_t \cdot u_s \)

**Estimation of the heat entering the workpiece**

Heat partition to the workpiece is a function of process parameters and grinding wheel grits material

40 – 60 % of generated energy is absorbed by the workpiece

**Estimation of the temperature field using FEA**

FEA of 2-D simple geometries

**Estimation of the Hardness Distribution**

Using “transformed” CCT diagrams as to account for the rapid heating of the material

- From the Hardness distribution
- From the austenitisation temperature depth

**Estimation of the HPD**
Theoretical Analysis – Analytical Modelling

Grinding Forces

Heat Generation

Heat Partition

\[ F_t = F_{t,sl} + F_{t,ch} + F_{t,pl} \]

Takes into consideration:
- Gr. Wheel topography
- Chip formation energy

\[ q_t = \frac{P}{b \cdot l_c} \]

\[ P = F_t \cdot (u_s \pm u_w) \]

\[ q_t = q_w + q_s + q_{ch} \]

\[ R_{ws} = \frac{q_w}{q_w + q_s} = \left(1 + \frac{\beta_s}{\beta_w} \cdot \sqrt{\frac{u_s}{u_w}}\right)^{-1} \]

\[ q_w = R_{ws} \cdot (q_t - q_{ch}) \]
Theoretical Analysis – 2-D FEA Modelling

- Triangular heat source distribution
- Quasi-stationary problem
- Explicit solution using ANSYS multiphysics

**Results**: Temperature field for various process parameters combinations
Theoretical Results – 2-D FEA Results

1. FEA Estimation of Temperature Distribution
2. Calculation of Metallurgical Transformations
3. Calculation of Micro-Hardness Distribution
4. Process maps – Process knowledge database
Industrial Application

- Workpiece material: 100 Cr 6
- Technical Specifications:
  - Surface hardness: 660 - 750 HV1
  - HPD = 0.3 – 0.5 mm
- Maximum allowable depth of cut: 3 mm
- Available grinding wheel: A 60 L7 V
### Industrial Application

**Process parameters from Process maps**

<table>
<thead>
<tr>
<th>$u_w$ (m/min)</th>
<th>$a_e$ (mm)</th>
<th>$u_s$ (m/s)</th>
<th>$Q_w$ (W/mm²)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>0.2</td>
<td>19</td>
<td>16.9</td>
<td>Rejected</td>
</tr>
<tr>
<td>0.6</td>
<td>0.2</td>
<td>34</td>
<td>25.5</td>
<td>Approved</td>
</tr>
<tr>
<td>0.9</td>
<td>0.2</td>
<td>41</td>
<td>32.0</td>
<td>Approved</td>
</tr>
<tr>
<td>1.2</td>
<td>0.2</td>
<td>-</td>
<td>-</td>
<td>Rejected</td>
</tr>
</tbody>
</table>

**Heat Flux (W/mm²)**

- $u_w = 0.3$ m/min
- $u_w = 0.6$ m/min
- $u_w = 0.9$ m/min

**Theoretical Heat Flux**

- Maximum HPD

**Theoretical Calibrated**

<table>
<thead>
<tr>
<th>de (mm)</th>
<th>ae (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>0.27</td>
</tr>
<tr>
<td>400</td>
<td>0.20</td>
</tr>
<tr>
<td>600</td>
<td>0.13</td>
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</table>
Industrial Application

Product requirements

Process parameters from Process maps

Verification

\[
\begin{align*}
u_w &= 0.6 \text{ m/min} \\
Q_w &= 25.5 \text{ W/mm}^2
\end{align*}
\]

\[
\begin{align*}
u_w &= 0.9 \text{ m/min} \\
Q_w &= 32.0 \text{ W/mm}^2
\end{align*}
\]
Industrial Application

**Experiments**

- Hardness (HV)
- Temperature (°C)
- HPD (mm)

**Technical Specifications**

- $a_s = 0.2 \text{ mm}$
- $A 60 \text{ L7 V}$
- $u_w = 0.6 \text{ m/min}$
- $u_w = 0.9 \text{ m/min}$

**Images**

- Coolant fluid supply
- Clamping device
- Grinding machine table

**Graphs**

- Temperature (°C) vs. $x$ (mm)
- Hardness (HV) vs. $x$ (mm)
- HPD (mm) vs. $x$ (mm)

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Thank you for your attention.

For more information:

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