Development of Cutting Tool Geometry for Hard-Milling-Operations

B. Denkena, J. Köhler, B. Bergmann

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challenges for hard milling operations

hard milling places high demands on:
♦ machine tool, clamping system and cutting tool

♦ high material strength and carbides
♦ high thermo-mechanical load
♦ dynamical load

♦ high wear rates
♦ cutting edge chipping
approach: undercut of the flank face

- how can the tools be designed?
- how high is the potential of the flank face undercut on tool life time in hard milling operations?
approach: undercut of the flank face

- how can the tools be designed?
- how high is the potential of the flank face undercut on tool life time in hard milling operations?
method for the undercut construction

finite element simulations for analyzing the tool stresses with various undercut geometries

regression analysis for calculating the minimal principle stresses \( \sigma_{\text{min}} \)

selection and manufacturing of suitable geometries

investigation and verification of tool life in cutting experiments

verification with cutting experiment
finite element simulation – process forces

\[ U_x = U_y = 0 \quad T = 20 \, ^\circ C \]

\[ q = h \cdot (T - T_0) \]

\[ \gamma_0 = -4^\circ \quad \alpha_0 = 14^\circ \]

FEM-orthogonal turning

Deform-2D 10.2.1 ®

process parameters:
\[ v_c = 120 \, \text{m/min} \]
\[ b = 1 \, \text{mm} \]
\[ f = h_m \]

workpiece: AISI H13 (Umbrello's equation, plastic)
tool substrate: WC (elastisch)
coating: non
friction: shear \( m = 0.6 \)
\[ h = 1000 \, \text{kW/m}^2\text{K} \]
regression analysis

\[ \sigma_{\text{min}} = f(S_b, S_t, r, p) = a \cdot S_b + b \cdot S_t + c \cdot p + d \cdot r + e \cdot S_b \cdot S_t + f \cdot S_b \cdot p + g \cdot S_b \cdot r + h \cdot S_t \cdot p + i \cdot S_t \cdot r + j \cdot p \cdot r + k \cdot S_b^2 + l \cdot S_t^2 + m \cdot p^2 + n \cdot r^2 \]

input:
- finite element simulation with \( f = h_{\text{max}} \)
- geometrical limits for the undercut preparation
- compressive strength for the cemented carbide \( \sigma_{\text{dB}} \approx 6300 \text{ MPa} \)

verification:
- in 13/14 the cutting edge chipping was predicted

\[ \sigma_{\text{min}} = 5712 \text{ MPa} \]
\[ S_b = 70 \mu m \]
\[ S_t = 78 \mu m \]
\[ r = 33 \mu m \]
\[ p = 53^\circ \]

\[ \sigma_{\text{min}} = 7635 \text{ MPa} \]
\[ S_b = 71 \mu m \]
\[ S_t = 99 \mu m \]
\[ r = 40 \mu m \]
\[ p = 40^\circ \]
enhanced tool life

width of flank wear land \( VB_m \)

μm

material removal \( V_W \) (tool life)

cm\(^3\) (min)

0 50 (46,5) 100 (93) 150 (140) 250 (233)

○ = cutting edge chipping

reference

wear criterion

0

Table:

<table>
<thead>
<tr>
<th>tool type</th>
<th>RPHW1204M0T cemented carbide TiAIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fase</td>
<td>0.2 x 20° -4° -3° 25°</td>
</tr>
<tr>
<td>engagement parameter</td>
<td>cutting speed ( v_c = 120 \text{ m/min} )</td>
</tr>
<tr>
<td></td>
<td>cutting depth ( a_p = 0.5 \text{ mm} )</td>
</tr>
<tr>
<td></td>
<td>feed per tooth ( f_z = 0.2 \text{ mm} )</td>
</tr>
<tr>
<td></td>
<td>width of cut ( a_e = 5 \text{ mm} )</td>
</tr>
<tr>
<td></td>
<td>tooth ( z = 1 \text{ mm} )</td>
</tr>
<tr>
<td></td>
<td>cooling none</td>
</tr>
</tbody>
</table>

material

AISI H13 (56 HRC)

process

face milling

Bg/72965 © IFW
chosen undercut geometries

tool 1

flank face modification over the active cutting edge
chosen undercut geometries

width of flank wear land VB

μm

0
50 (46,5)
100 (93)
150 (140)
200
250 (233)

material removal V_W (tool life)

tool

= cutting edge chipping

reference

wear criterion

material

AISI H13 (56 HRC)

process

face milling

tool type

RPHW1204M0T
cemented carbide

TiAIN

coating

engagement parameter

Fase

γ_a

γ_r

κ_r

0,2 x 20°

-4°

-3°

25°

= cutting speed

v_c = 120 m/min

cutting depth

a_p = 0,5 mm

feed per tooth

f_z = 0,2 mm

width of cut

a_e = 5 mm

tooth

z = 1 mm

cooling

none

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Seite 10
chosen undercut geometries

- flank face modification over the active cutting edge
- undercut over the active cutting edge with a rounding and a chamfer in the undercut
enhanced tool life

The graph shows the relationship between material removal rate ($V_W$) and tool life. The width of flank wear land ($V_{B_m}$) is plotted against the material removal rate ($V_W$) for different tools.

- **Tool 1** shows a higher tool life compared to **tool 2**.
- The reference line indicates the wear criterion.

### Tool Parameters
- **Type**: RPHW1204M0T
- **Substrate**: cemented carbide
- **Coating**: TiAlN

### Engagement Parameters
- **Cutting Speed** ($v_c$): 120 m/min
- **Cutting Depth** ($a_p$): 0.5 mm
- **Feed per Tooth** ($f_z$): 0.2 mm
- **Width of Cut** ($a_e$): 5 mm
- **Tooth**: 1 mm
- **Cooling**: None

### Material
- **AISI H13 (56 HRC)**

**Process**: Face milling

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Seite 12
enhanced tool life

![Graph showing tool life and material removal.](image)

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<tbody>
<tr>
<td>substrate</td>
<td>cemented carbide</td>
<td>cutting speed $v_c = 120$ m/min</td>
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<tr>
<td>coating</td>
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| material | AISI H13 (56 HRC) |
| process  | face milling |

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Seite 13
chosen undercut geometries

**tool 1**
- rake face
- flank face
- $S_b = 120 \mu m$
- $S_t = 100 \mu m$
- $r = 100 \mu m$
- $p = 30^\circ$

**tool 2 +3**
- rake face
- flank face
- $S_{b1} = 130 \mu m$
- $S_{b2} = 100 \mu m$
- $S_t = 100 \mu m$
- $r = 30 \mu m$
- $p = 51^\circ$

**tool 4**
- rake face
- flank face
- modification
- flank face
- $S_b = 100 \mu m$
- $S_t = 140 \mu m$
- $r = 100 \mu m$
- $p = 30^\circ$

- flank face modification over the active cutting edge
- undercut over the active cutting edge with a rounding and a chamfer in the undercut
- undercut over the surface generating cutting edge

Bg/70471 © IFW
enhanced tool life

width of flank wear land $V_{B_m}$

<table>
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<tr>
<th>tool</th>
<th>RPHW1204M0T</th>
<th>cemented carbide</th>
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<tr>
<td>type</td>
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<tr>
<th>$Fase$</th>
<th>$\gamma_a$</th>
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<th>$\kappa_r$</th>
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<tbody>
<tr>
<td>0.2 $\times$ 20$^\circ$</td>
<td>-4$^\circ$</td>
<td>-3$^\circ$</td>
<td>25$^\circ$</td>
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Engagement parameter
- cutting speed $v_c = 120$ m/min
- cutting depth $a_p = 0.5$ mm
- feed per tooth $f_z = 0.2$ mm
- width of cut $a_e = 5$ mm
- tooth $z = 1$ mm
- cooling none

Material
- AISI H13 (56 HRC)

Process
- face milling

Reference tool
- tool 2
- tool 3
- tool 4

Tool life $T \min$
- tool 2: 150 (140) cm$^3$ (min)
- tool 3: 250 (233) cm$^3$ (min)

$\odot =$ cutting edge chipping

Material removal $V_W$ (tool life)
end of tool life - reference and developed tool

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summary and outlook

summary:

- The potential of the undercut will be analyzed in milling operations with increased cutting speed and feed per tooth.

outlook:

- The potential of the undercut will be analyzed in milling operations with increased cutting speed and feed per tooth.

- The influence of the undercut on residual stresses and process forces will be investigated.
thanks for your attention

Entrance of the Hannover Centre for Production Technology (PZH) with buildings of the IFW

Institut für Fertigungstechnik und Werkzeugmaschinen (IFW)
Centre for Production Technology, Leibniz Universität Hannover
An der Universität 2
30823 Garbsen
Germany
www.ifw.uni-hannover.de

If you have any questions to the presented or further topics do not hesitate to contact us.

Contact details
B. Denkena
tel. +49 511 762-2533
info@ifw.uni-hannover.de

J. Köhler
tel. +49 511 762-2563
koehler@ifw.uni-hannover.de
gain of tool life

$S_b = 100 \ \mu m, \ S_t = 138 \ \mu m$

$S_b = 100 \ \mu m, \ S_t = 142 \ \mu m$

$S_b = 98 \ \mu m, \ S_t = 144 \ \mu m$

width of flank wear land $V_{B_m}$

reference

wear criterion

$\bigcirc = \text{cutting edge chipping}$

material removal $V_W$ (tool life)

RPHW1204M0T

cemented carbide

TiAIN

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engagement parameter

- cutting speed $v_c = 120 \text{ m/min}$
- cutting depth $a_p = 0,5 \text{ mm}$
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- width of cut $a_e = 5 \text{ mm}$
- tooth $z = 1 \text{ mm}$
- cooling none

material

AISI H13 (56 HRC)

process

face milling

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regression analysis

\[ \sigma_{\text{min}} = f(S_b, S_t, r, p) = a \cdot S_b + b \cdot S_t + c \cdot p + d \cdot r + e \cdot S_b \cdot S_t + f \cdot S_b \cdot p + g \cdot S_b \cdot r + h \cdot S_t \cdot p + i \cdot S_t \cdot r + j \cdot p \cdot r + k \cdot S_b^2 + l \cdot S_t^2 + m \cdot p^2 + n \cdot r^2 \]

coefficients:
- \( a = 9.42 \)
- \( h = -1.22 \)
- \( b = 208.76 \)
- \( i = -0.15 \)
- \( c = 4.27 \)
- \( j = 0.69 \)
- \( d = -60.63 \)
- \( k = 0.11 \)
- \( e = -1.15 \)
- \( l = -0.03 \)
- \( f = 0.50 \)
- \( m = -0.57 \)
- \( g = 0.16 \)
- \( n = 0.08 \)

calc. min. principal stresses \( \sigma_{\text{min}} \)

sim. min. principal stresses \( \sigma_{\text{min}} \)

ideal correlation \( R^2 = 0.98 \)

rake face

GPa

GPa

0

4

6

8

10

0

4

6

8

10

9

ideal correlation

R² = 0.98

cutting edge chipping

flank face

H

200 \( \mu \text{m} \)

\( \sigma_{\text{min}} = 5712 \text{ MPa} \)

\( S_b = 70 \text{ \( \mu \text{m} \)} \)

\( S_t = 78 \text{ \( \mu \text{m} \)} \)

\( r = 33 \text{ \( \mu \text{m} \)} \)

\( p = 53 ^\circ \)

flank face

H

200 \( \mu \text{m} \)

\( \sigma_{\text{min}} = 7635 \text{ MPa} \)

\( S_b = 71 \text{ \( \mu \text{m} \)} \)

\( S_t = 99 \text{ \( \mu \text{m} \)} \)

\( r = 40 \text{ \( \mu \text{m} \)} \)

\( p = 40 ^\circ \)