Workpiece shape deviations in face milling of workpiece compounds

14th Materials Forum, Hannover Messe

Prof. Dr. B. Denkena, E. Hasselberg

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Production engineering at Leibniz University Hannover

university associated research centers:

Laser Zentrum Hannover e.V.

Institut für integrierte Produktion gGmbH
Infrastructure of Hannover Center for Production Technology

**employees**
- ca. 250 research assistants
- ca. 110 technicians and administrations
- ca. 520 student assistants
- ca. 1000 students

**machines and appliances**
- high-quality machine tools and installations
- latest measuring equipments, SEM, laboratories
- cleanroom (350 sq. m., class 100)
- total value ca. 50 million €

**building**
- ca. 22.000 sq. m. effective surface for office buildings, proving grounds, lecture and seminar rooms, library, cafeteria etc.
<table>
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<th>Research areas at IFW</th>
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<tr>
<td><strong>manufacturing processes</strong></td>
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<td>Dr.-Ing. Jens Köhler</td>
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<td>cutting processes</td>
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<td>abrasive processes</td>
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Agenda

Introduction

Shape deviations

Material height deviation

Transition deviation at material joint

Surface roughness deviation

Surface defects

Conclusions
Application

cylinder crankcase - top surface

Aston Martin Vantage
4,3 l - V8 - 385 hp

[source: KS Kolbenschmidt Pierburg]

cylinder crankcase - crankshaft bore

Audi A8 - 4,2 l - V8 - 301 hp

[source: Hackerodt-Unternehmensgruppe]

cylinder crankcase - bedplate

BMW M5/M6 - 5,0 l - V10 - 507 hp

[source: Rautenbach AG]

Hb/61716 © IFW
Process strategy

- **drilling**
- **turning**
- **milling**

**sequential**
- Material 1
- Material 2

**parallel (alternating)**
Experimental Setup

machine tool: 4-axis machining center Heller H5000
face mill: 32 mm diameter, 4 indexable inserts, coated cemented carbide
workpiece fixation: screws and alignment pins
process: dry machining, material ratio: 50:50

machining direction: from low strength into high strength material

<table>
<thead>
<tr>
<th>Material</th>
<th>AW2030</th>
<th>GJS600</th>
<th>Obomodulan®1400</th>
</tr>
</thead>
<tbody>
<tr>
<td>density [g/cm³]</td>
<td>2.85</td>
<td>7.2</td>
<td>1.2</td>
</tr>
<tr>
<td>hardness [HBW]</td>
<td>110</td>
<td>212</td>
<td>84 Shore-D</td>
</tr>
<tr>
<td>tensile strength [MPa]</td>
<td>410</td>
<td>749</td>
<td>94 (compressive strength)</td>
</tr>
<tr>
<td>Young's modulus [GPa]</td>
<td>75</td>
<td>174</td>
<td></td>
</tr>
<tr>
<td>thermal expansion coefficient [$10^{-6}$ K⁻¹]</td>
<td>23.0</td>
<td>12.5</td>
<td>76.0</td>
</tr>
<tr>
<td>thermal conductivity [W/mK]</td>
<td>130-160</td>
<td>39</td>
<td>&lt; 1</td>
</tr>
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</table>
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- Introduction
- Shape deviations
  - Material height deviation
  - Transition deviation at material joint
  - Surface roughness deviation
  - Surface defects
- Conclusions
Material height deviation

![Material height deviation diagram]

Compliance of cutting tool & workpiece

- Tool-diameter: \( d = 32 \text{ mm} \)
- No. of teeth: \( z = 1 \)
- Cutting inserts: coated carbide
- Cooling: none

Machining setup & process forces

- Cutting speed: \( v_c = 200 \text{ m/min} \)
- Feed per tooth: \( f_z = 0.1 \text{ mm} \)
- Axial depth of cut: \( a_p = 1.0 \text{ mm} \)
- Width of cut: \( a_e = 32 \text{ mm} \)
Material height deviation

![Graph showing process forces F against rotation angle ψ for AW2030 and GJS600.](image)

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<th>Parameter</th>
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<th>GJS600</th>
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<tr>
<td>Tool diameter</td>
<td>d = 32 mm</td>
<td></td>
</tr>
<tr>
<td>Number of teeth</td>
<td>z = 1</td>
<td></td>
</tr>
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<td></td>
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<tr>
<td>Axial depth of cut</td>
<td>a_p = 1.0 mm</td>
<td></td>
</tr>
<tr>
<td>Radial depth of cut</td>
<td>a_e = 32 mm</td>
<td></td>
</tr>
</tbody>
</table>

- **AW2030**:
  - K_{rc} = 486 N/mm²
  - K_{tc} = -1021 N/mm²
  - K_{ac} = 282 N/mm²
  - K_{re} = 10 N/mm
  - K_{te} = -11 N/mm
  - K_{ae} = 23 N/mm

- **GJS600**:  
  - K_{rc} = 632 N/mm²
  - K_{tc} = -1487 N/mm²
  - K_{ac} = 250 N/mm²
  - K_{re} = 118 N/mm
  - K_{te} = -123 N/mm
  - K_{ae} = 160 N/mm

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Transition deviation at material joint

polyurethane Obomodulan®1400

V_f

v_c

cast iron GJS 600

measured surface: 30 mm x 3 mm

profile in cutting direction X_c

height profile z

µm

0

-3

-6

19

25

38

mm

Ob®1400

GJS600

height difference

vibration

equation of motion:
m ẍ = -c ẍ - k x + F(t)

τ_d = \frac{2\pi}{\omega_d}

ξ = \frac{1}{4} \ln \frac{x_1}{x_4}

tool-diameter: d = 32 mm

no. of teeth: z = 1

cutting inserts: coated carbide

cooling: none

cutting speed: v_c = 200 m/min

feed per tooth: f_z = 0.1 mm

axial depth of cut: a_p = 1.0 mm

width of cut: a_e = 32 mm

m: mass

k: spring constant

c: damping constant

F(t): external force

Hb/68933 © IFW
Transition deviation at material joint

2D orthogonal cutting process (FE-simulation)

- tool substrate: cemented carbide
- tool coating: TiCN + Al₂O₃
- cooling: none

- cutting speed: \( v_c = 400 \text{ m/min} \)
- undeformed chip thickness: \( b = 0.07 \text{ mm} \)
- width of undeformed chip: \( h = 1.0 \text{ mm} \)

Hb/68934 © IFW
Surface roughness deviation

Influence of the chip formation on the workpiece surface

- Material 1
  - Ideal profile
  - Real profile
  - Feed per tooth $f_z$

- Material 2
  - Ideal profile
  - Real profile
  - Feed per tooth $f_z$
Surface roughness deviation

**Graph:**

- **x-axis:** Width of cut \(a_e\)
- **y-axis:** Average surface roughness \(R_z\)
- **Lines:**
  - AW2030 - GJS600
  - GJS600

**Key Values:**

- \(R_{z,GJS} \text{ max} = 2.4 \ \mu m\)
- \(R_{z,Al} \text{ max} = 3.3 \ \mu m\)
- \(R_{z,Al-GJS} \text{ max} = 4.2 \ \mu m\)
- \(R_{z,GJS-Al} \text{ max} = 5.4 \ \mu m\)

**Specifications:**

- Tool diameter: \(d = 32 \ \text{mm}\)
- Number of teeth: \(z = 1\)
- Cutting inserts: Coated carbide
- Cooling: None
- Cutting speed: \(v_c = 200 \ \text{m/min}\)
- Feed per tooth: \(f_z = 0.1 \ \text{mm}\)
- Axial depth of cut: \(a_p = 1.0 \ \text{mm}\)
- Width of cut: \(a_e = 32 \ \text{mm}\)
Surface defects

GJS 600 „high strength“

Obomodulan® 1400 „low strength“

scratch depth: 20 µm

Surface defects (scratches) ➤ transport of chips and fractures from one material into the other

tool-diameter: \( d = 32 \text{ mm} \)

no. of teeth: \( z = 1 \)

cutting inserts: coated carbide

cooling: none

cutting speed: \( v_c = 200 \text{ m/min} \)

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Shape deviations

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Conclusions
Conclusions

Four significant shape deviations occur in machining of parallel workpiece compounds mainly influenced by:

- **Material height deviation**
  - -> compliance of cutting tool and workpiece
  - -> process forces

- **Transition deviation at material joint**
  - -> process dynamics
  - -> machining direction

- **Surface roughness deviation**
  - -> material specific chip formation mechanisms
  - -> cutting tool kinematics

- **Surface defects (scratches)**
  - -> transport of chips and fractures from one material into the other

**Outlook:** generation of a comprehensive model
Acknowledgements

This research is supported by the German Research Foundation (DFG) within the project:

Modellierung des Stirnplanfräsprozesses von parallel angeordneten Werkstoffverbunden (DE 447/113-1)

Modeling of the face milling process of parallel arranged workpiece compounds (DE 447/113-1)
If you have any questions to the presented or further topics do not hesitate to contact us.

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