Micro Milling of Additive Manufactured Metals

A Machinability Analysis

- Prof. Dr.-Ing. habil Dr.-Ing. E.h. E. Brinksmeier[1]
- Dr.-Ing. O. Riemer[1]
- M.Sc. K. Kempen[2]
- Dipl.-Ing. C. Brandao[1]

[1] Uni Bremen, Laboratory for Precision Machining LFM, Germany

[2] KU Leuven, Dept. of Mechanical Engineering, Belgium

IWT
Stiftung Institut
für Werkstofftechnik
Bremen

ECO Centrum

LFM
Labor für
Mikrozerspanung

Hi-Micro Project – Main Goals

- Innovative process chain for micro injection moulding parts
- Monolithic tool inserts with cooling channels using additive manufacturing
- Post processing of tool insert features (i.e. by micro milling)
- Micro parts for various applications:

micro fluidics

consumer goods

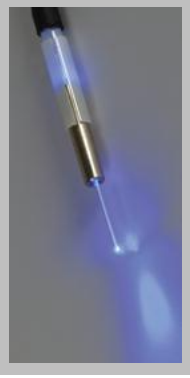
biomedics

mechanical parts

consumer goods

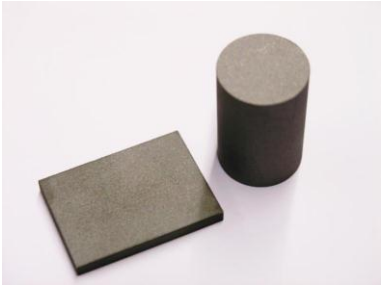
optical parts

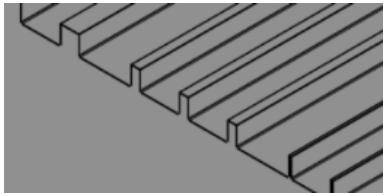
biomedics

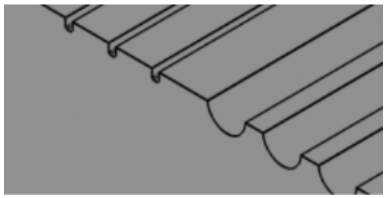


Source: kurzweil, sophion, officine panerai, optogenetics

Outline



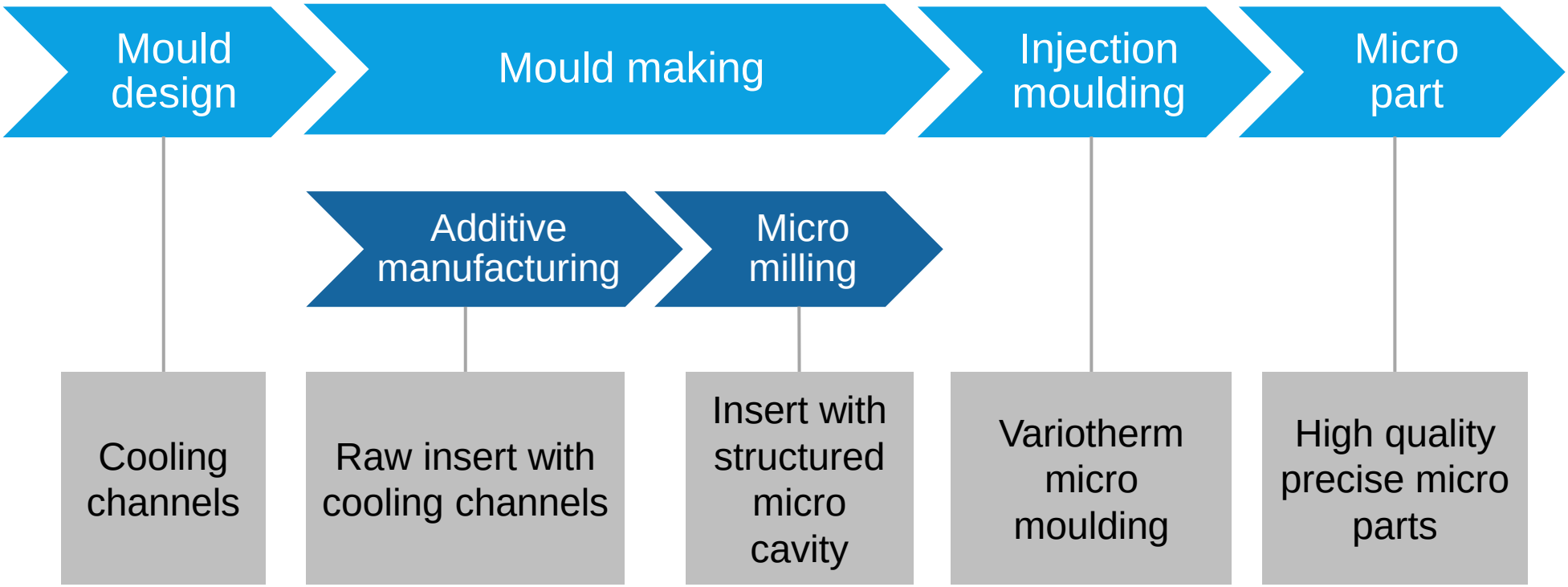




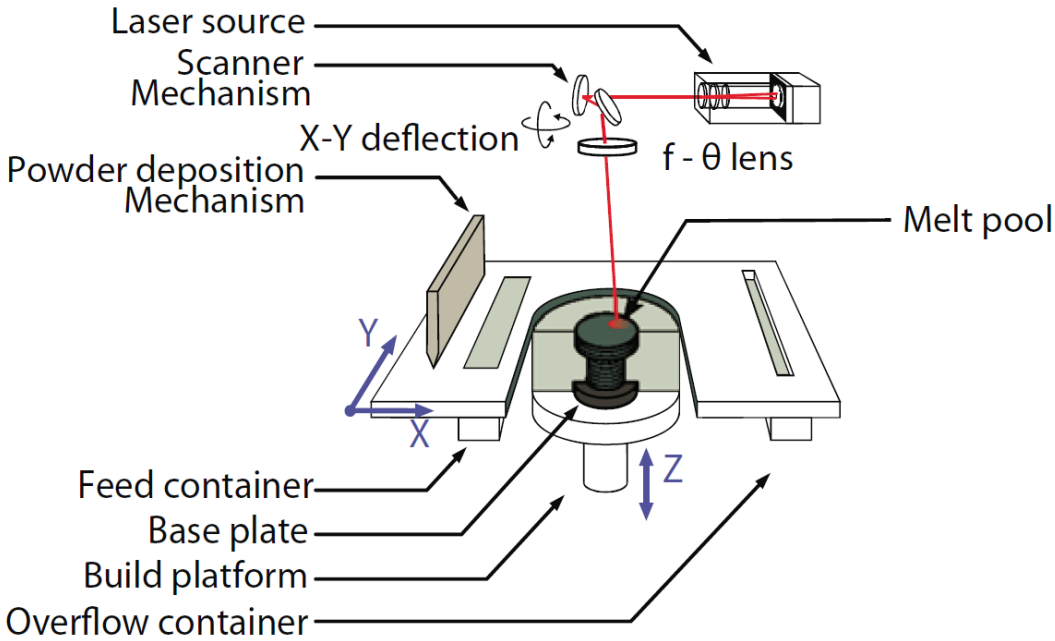
- Novel process chain for injection mould manufacturing with internal cooling channels
- Additive manufactured materials
- Micro milling
  - Machined features
  - Milling Parameters
- Results
  - Surface quality
  - Shape accuracy
- Conclusion

Process Chain for Mould Manufacturing

for Moulds with Cooling Channels



Additive Manufacturing: Selective Laser Melting

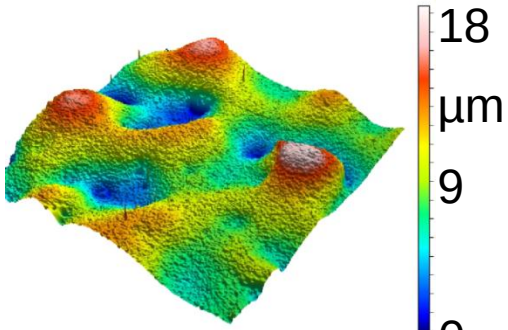


Additive manufacturing :

by layer-wise addition of material,

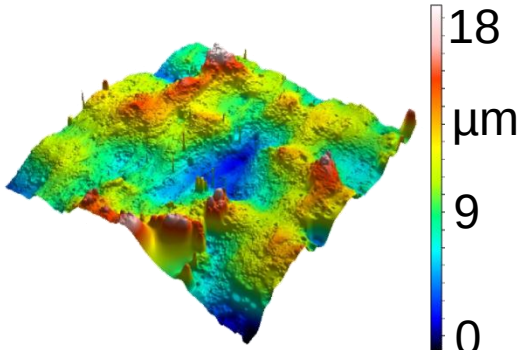
rather than by material removal (e.g. drilling, milling, grinding, EDM …) or forming (e.g. forging, deep drawing, moulding,...)

Additive Manufactured Metals



330 x 300 µm²

- Maraging steel X3NiCoMoTi 18-9-5 (1.2709)
  - Density ≈ 100%
  - Hardness 33 – 37 HRC (330 – 370 HV)[1]
  - Tensile strength 1100 MPa (conv.: 950 – 1100 MPa)
  - Surface roughness Sa 4 – 6.5 µm

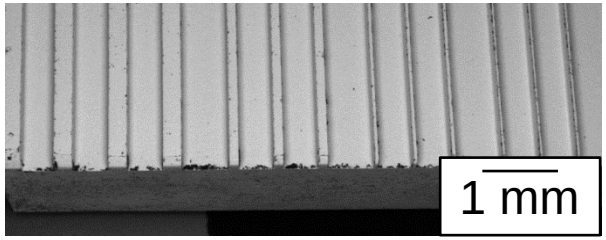


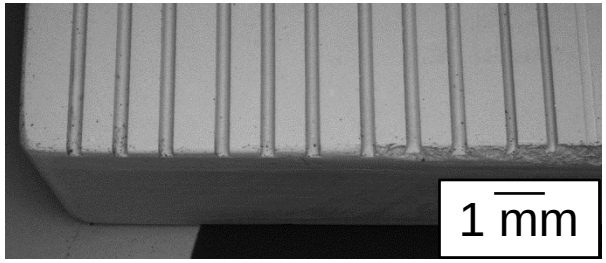
330 x 330 µm²

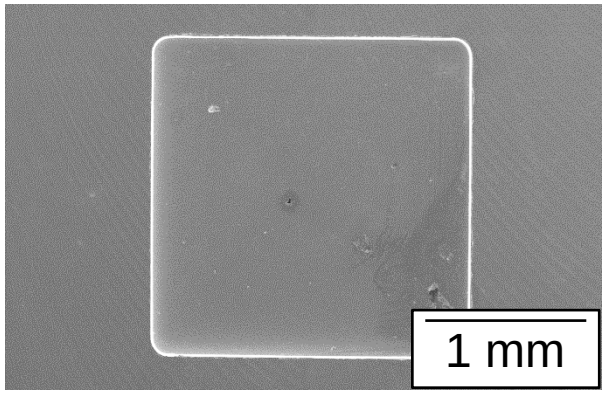
- Aluminium alloy AlSi10Mg (3.2381)[2]
  - Density 98 – 99%
  - Hardness ≈ 127 HV (conv.: 86 HV)
  - Tensile strength ≈ 390 MPa (conv.: 310 MPa)
  - Surface roughness Sa 7 – 10 µm

[1] DIN EN ISO 18265:2002
[2] K. Kempen et al. Mechanical properties of AlSi10Mg Produced by Selective Laser Melting, Physics Procedia 39 (2012)

Micro Milled Features





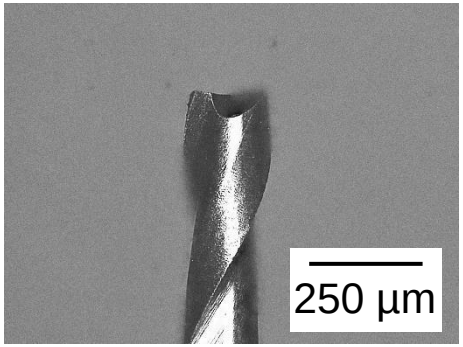


- Ribs / thin walls (continuous)
  - Aspect ratio: 1 – 10
  - Constant height: 0.3 mm
  - Variable width: 0.3, 0.15, 0.05, 0.03 mm
- Grooves (continuous)
  - Aspect ratio: 1 – 1.5
  - Variable depth: 0.3, 0.2, 0.15 mm
  - Variable width: 0.3, 0.2, 0.1 mm
- Pocket (discontinuous)
  - Aspect ratio: 0.05
  - Constant width (2 mm) and depth (0.1 mm)

Milling Conditions

Standard Cutting Parameters and Feed Rate Variation

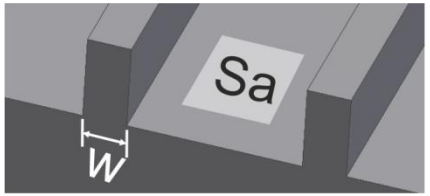
DMG Sauer US 20 linear

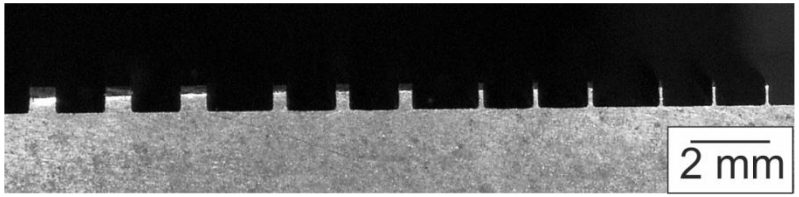


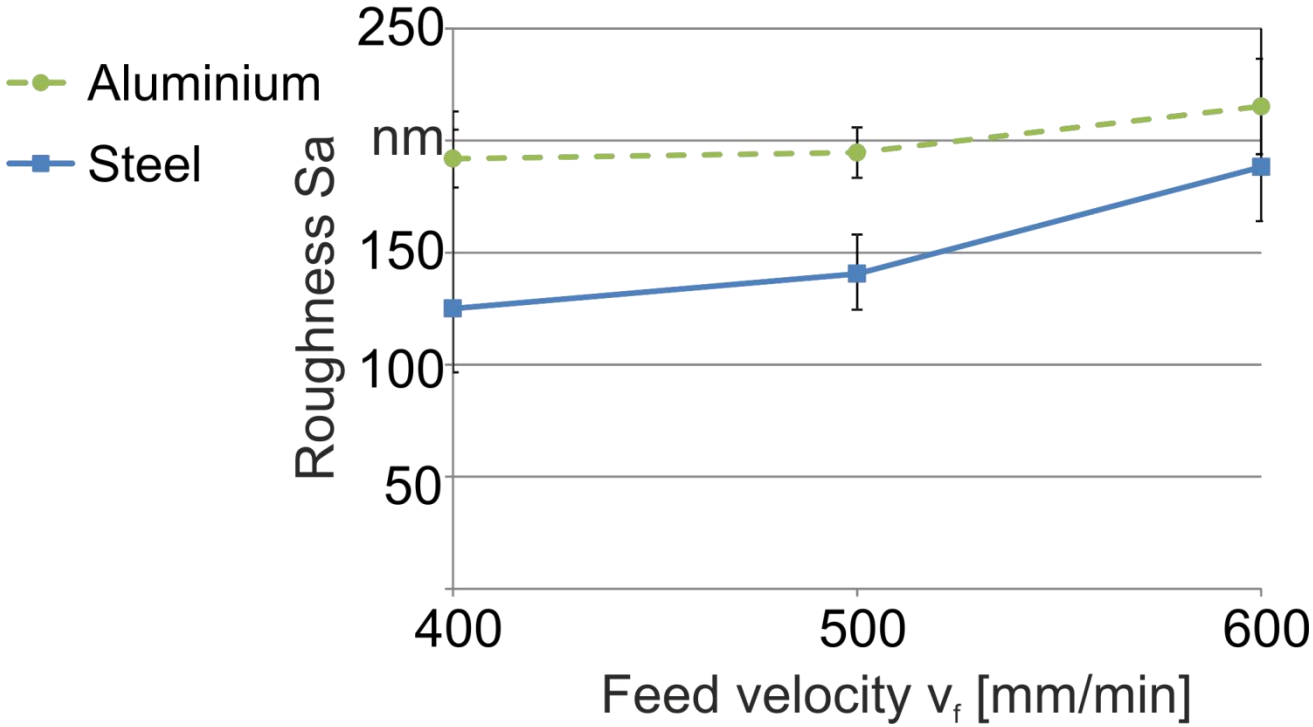
Micro flat-end mill (d0.2 mm)

- Micro end mills
  - Torus / WC, TiAlN coated / d = 0.5 mm
  - Flat-end / WC / d = 0.2, 0.1 and 0.08 mm
  - Ball-end / WC, TiAlN coated / d = 0.5 mm
- Cutting parameters (as recommended)
  - Width of cut a_e: 5 – 50 µm
  - Depth of cut a_p: 5 – 50 µm
  - Feed velocity v_f: 60 – 80 mm/min
    400 – 1,000 mm/min
  - Cutting velocity v_c: 10 – 26 m/min
    65 m/min

Thin Walls – Surface Analysis







Process
Down milling

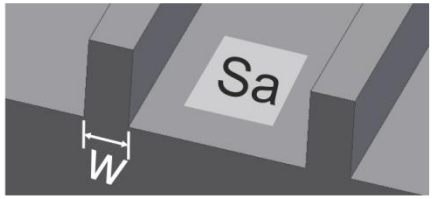
Material
Steel (1.2709)
Aluminium (3.2381)

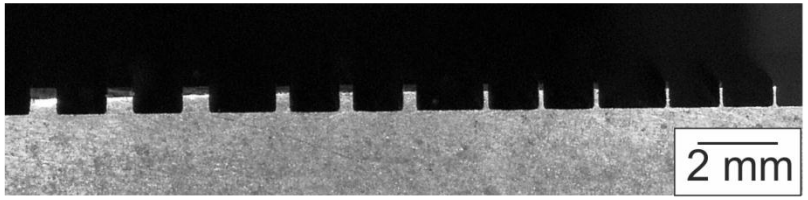
Tool
Torus-end mill,
WC, TiAlN, d0.5 mm

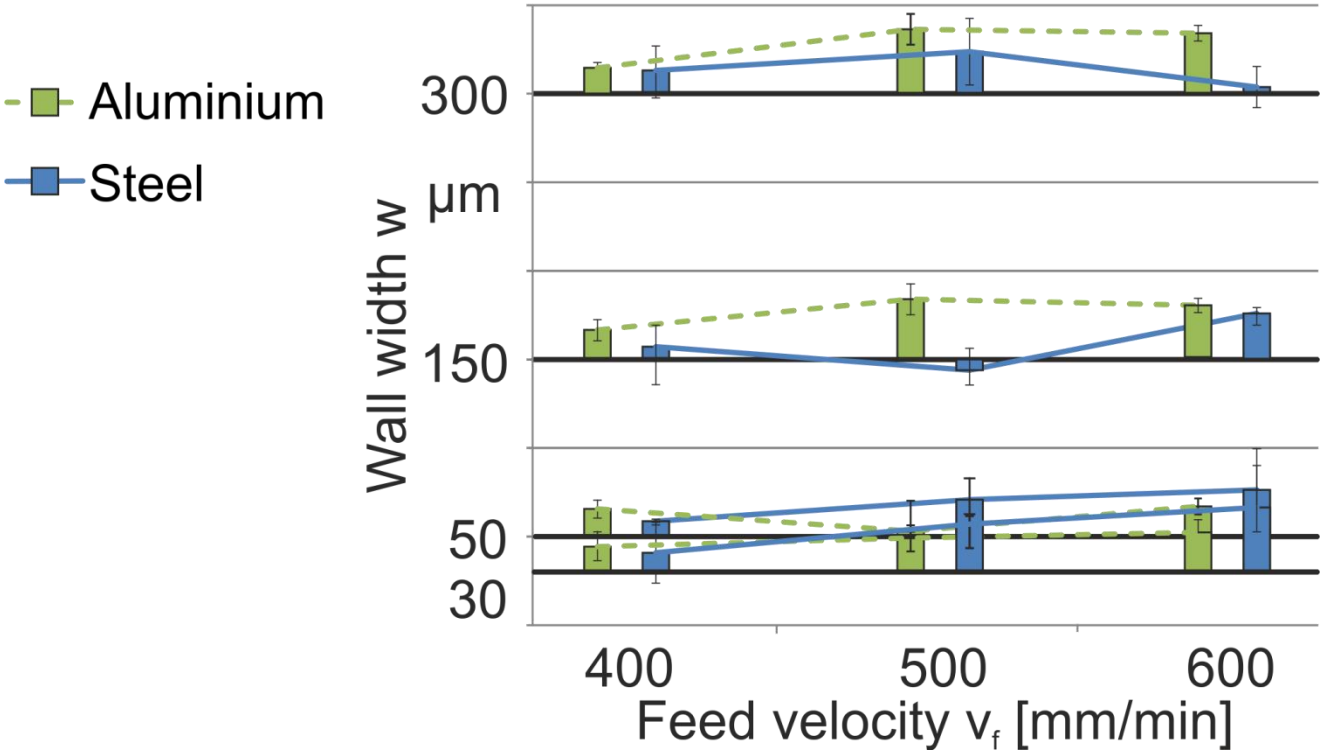
Parameters
a_e = 50 µm
a_p = 50 µm
v_c = 20.5 m/min

Metrology
White light interferometry

Thin Walls - Shape Analysis







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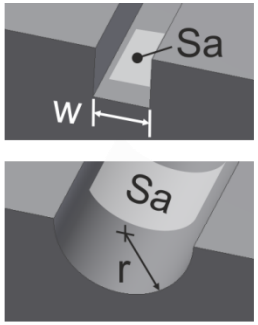
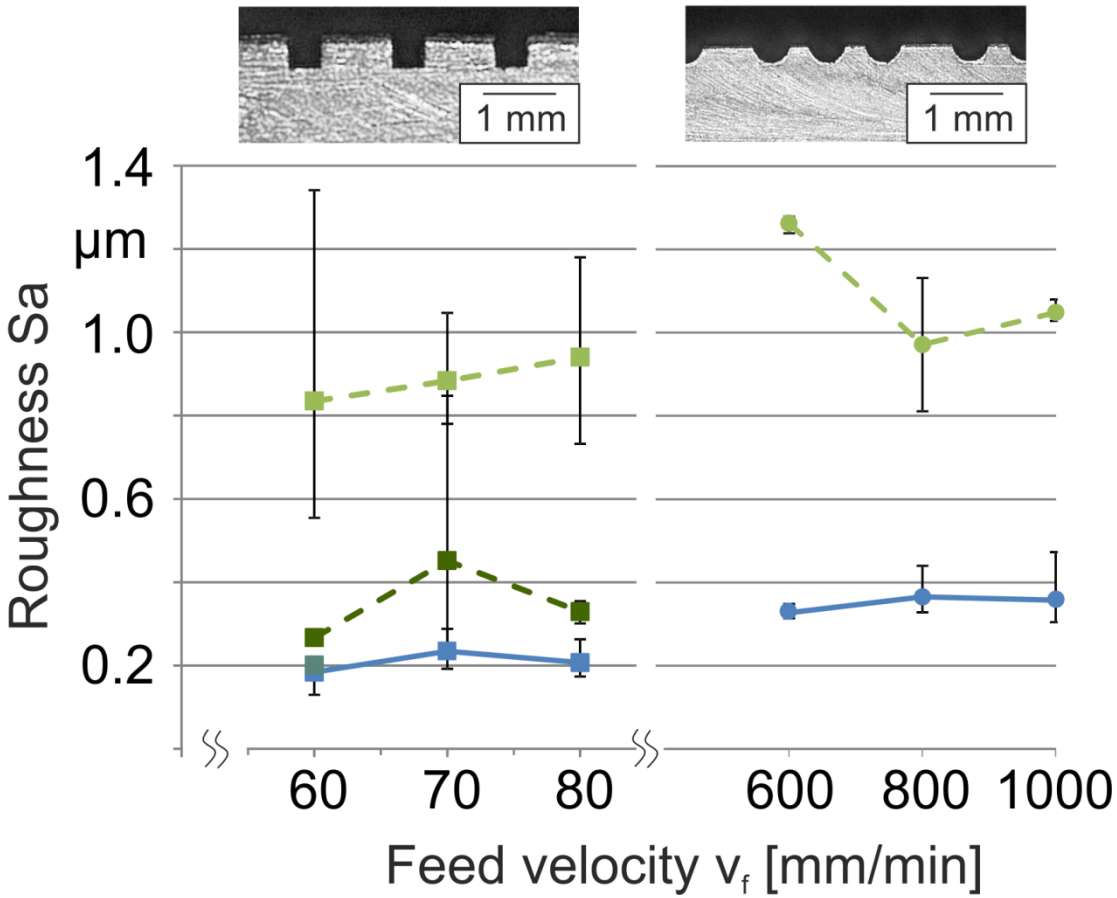
Metrology
Confocal Microscopy

Grooves – Surface Analysis





Process
Down milling

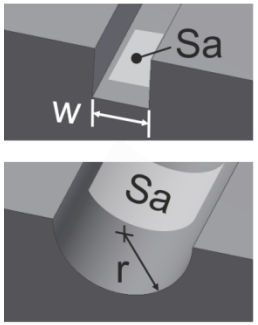
Material
Steel (1.2709)
Aluminium (3.2381)

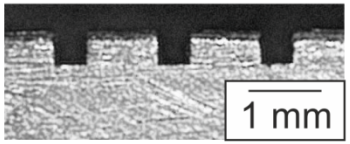
Tool
Flat-end mill,
d0.2, 0.1, 0.08 mm
Ball-end mill, d0.5 mm

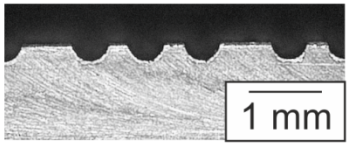
Parameters
a_e = 5 µm
a_p = 5, 20 µm
v_c = 10 – 63 m/min

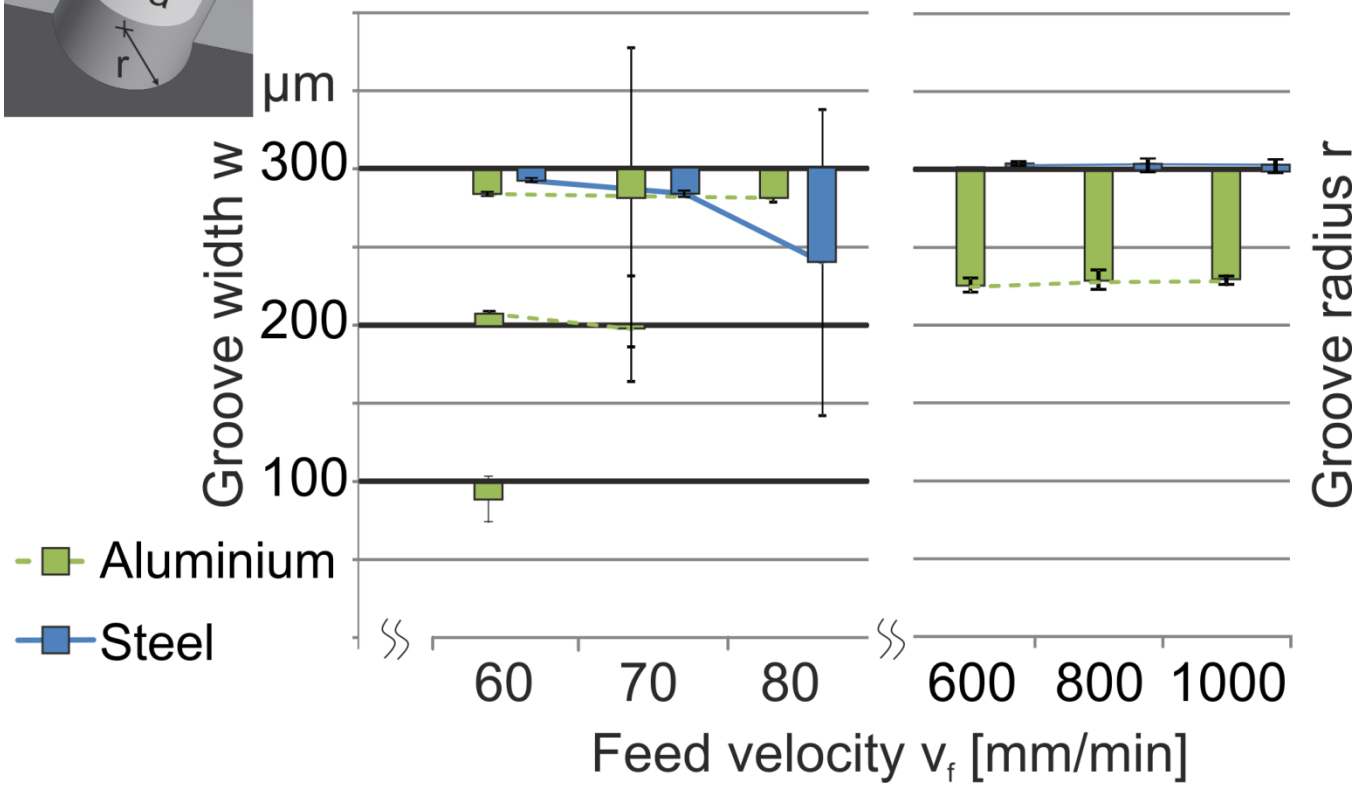
Metrology
White light interfer.

Grooves – Shape Analysis









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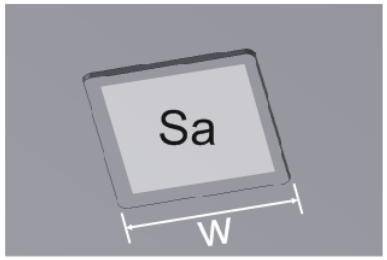
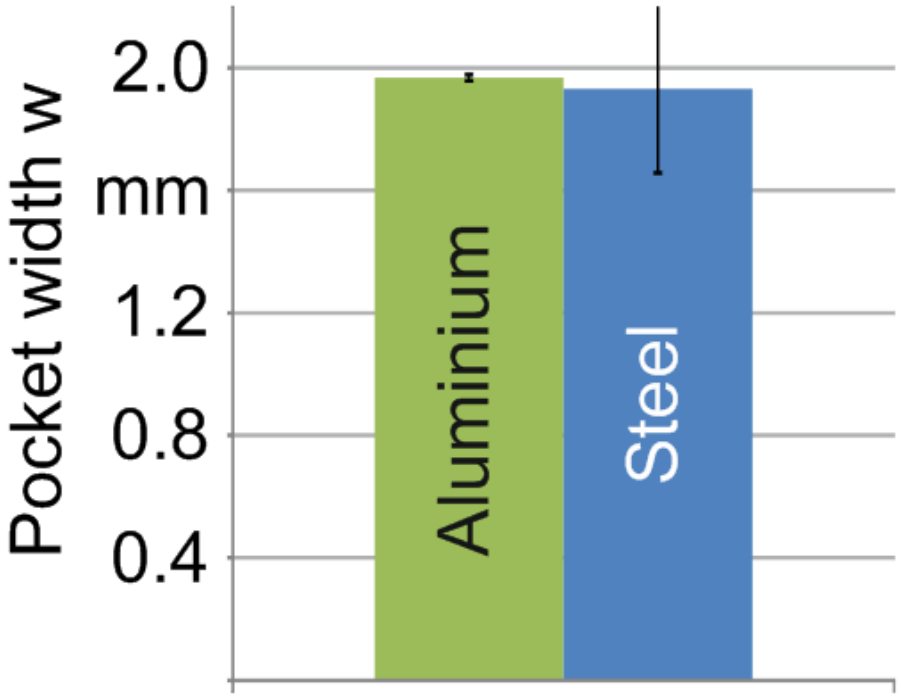
Metrology
Confocal microscopy

Pocket – Shape Analysis





Process
Down milling

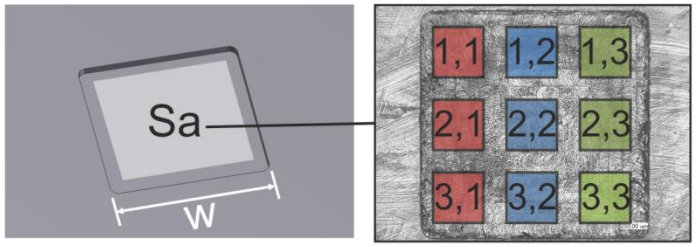
Material
Steel (1.2709)
Aluminium (3.2381)

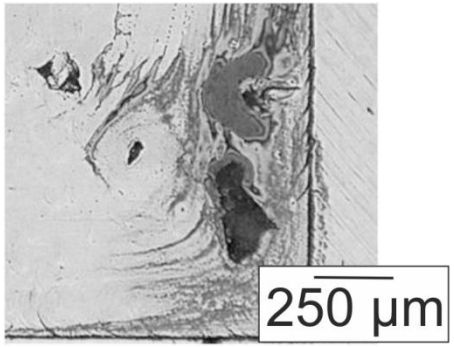
Tool
Flat-end mill,
WC, TiAlN, d0.2 mm

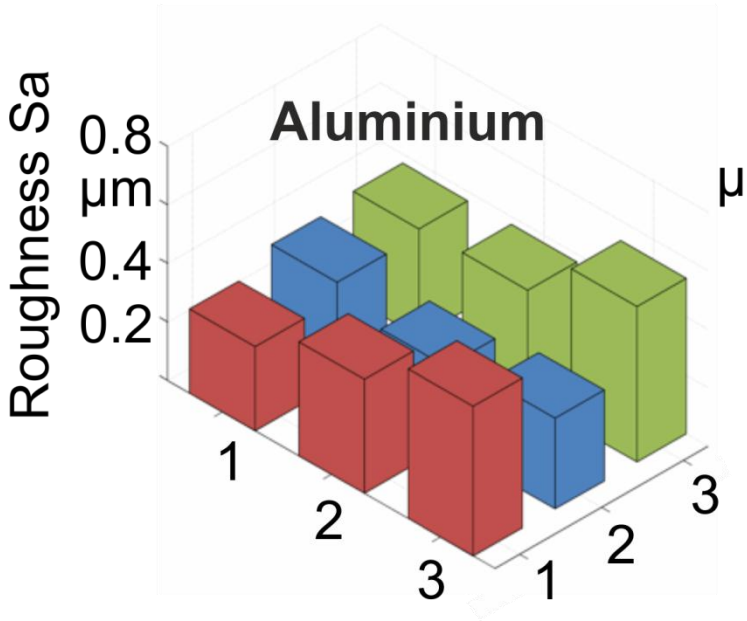
Parameters
a_e = 5 µm
a_p = 5, 20 µm
v_c = 10 – 63 m/min
v_f = 80 mm/min

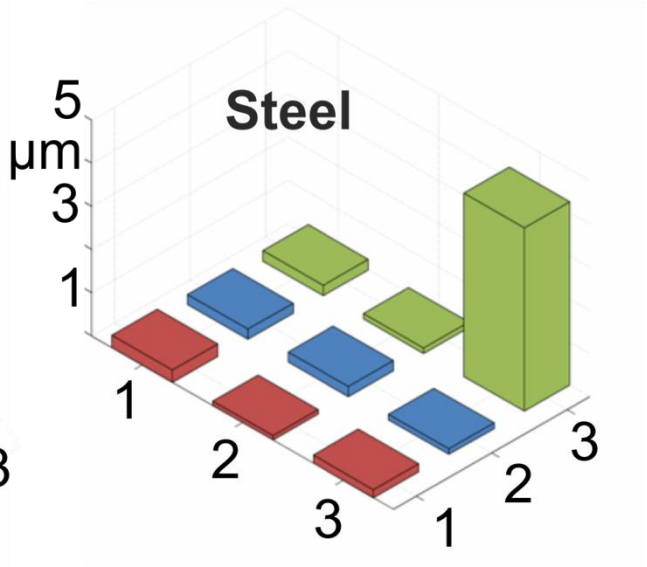
Metrology
Confocal microscopy

Pocket – Surface Analysis









<u>Process</u>
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<u>Parameters</u>
a_e = 5 µm
a_p = 5, 20 µm
v_c = 10 – 63 m/min
v_f = 80 mm/min

<u>Metrology</u>
White light interfer.

Conclusion

- Surface roughness down to Sa120 nm achievable, but single defects lead to scrap
- Reduction of tool and material deflection by low feed rate
- Maraging steel
  - Lower surface roughness
  - Higher density
  - Higher shape accuracy (general)

Acknowledgement

The authors wish to thank

SEVENTH FRAMEWORK PROGRAMME

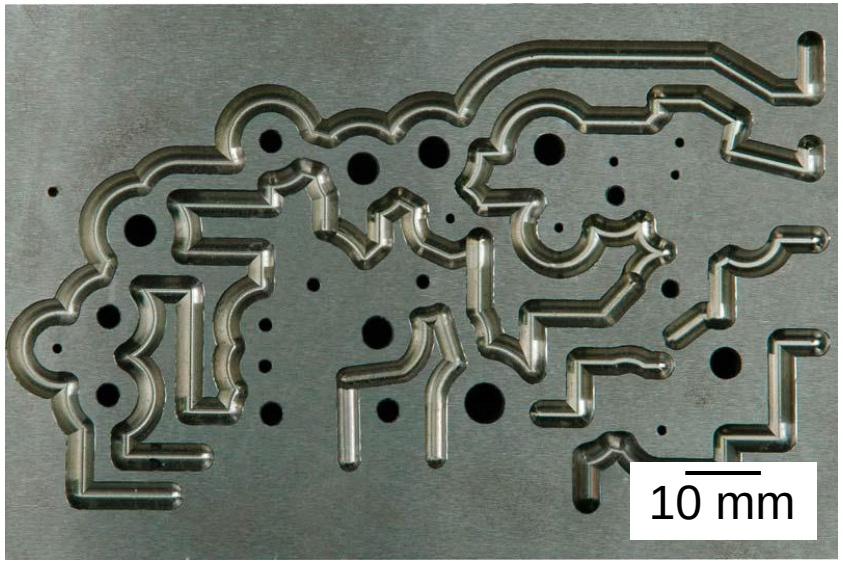
For funding this work under the project „High Precision Micro Production Technologies“ (Hi-Micro)

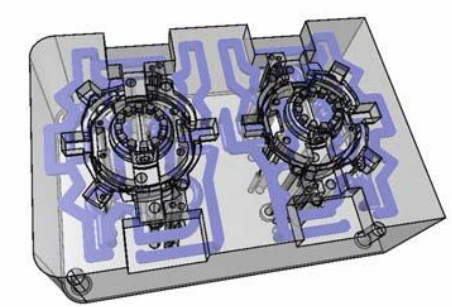
LayerWise

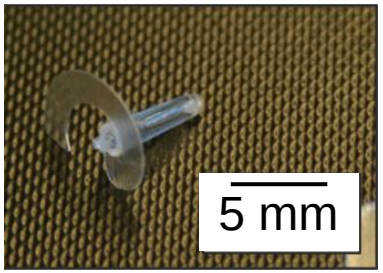
For providing selective laser melted steel workpieces

Cooling Channels in Injection Moulds

State of the Art in Variotherm Processes







- Injection moulds with cooling channels:
  - Faster cooling
  - Shorter cycle time
  - Less warpage
- Micro injection moulds with cooling channels:
  - More accurate micro features
  - Longer melt flow
  - Less warpage

Source: gwk