Challenges in Mechanical Machining of Metal-CFRP-Stacks

'Polymer Meets Aerospace' – Innovative Polymers in Aerospace Industries

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Challenges in Mechanical Machining of Metal-CFRP-Stacks

- The Fraunhofer Institute for Machine Tools and Forming Technology
- Motivation
- Occurring problems when machining Titanium and Metal-CFRP-stacks
- Approaches and results
  - Tool development
  - Process development
- Conclusions and summary

The Fraunhofer IWU

Locations in Germany

- founded on July 1st, 1991
- about 510 employees
- 29 million euro budget
- Project Group in Augsburg since January 2009
- Project Group in Zittau since October 2011

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Structure and Regional Networks

Innovation Cluster Mechatronic Mechanical Engineering

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Institutional Network Production Engineering Chemnitz – Dresden

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Forming Technology Cutting Technique Production Systems Joining and Assembling Production Management	Mechatronics Joining Technology Additive Manufacturing Technologies	Virtual Reality Machine Tool Design Forming Technology Process Control Engineering
about 510 employees 29 million euro budget		about 189 employees 5 million euro budget

Kompetenzzentrum Maschinenbau

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MAINE

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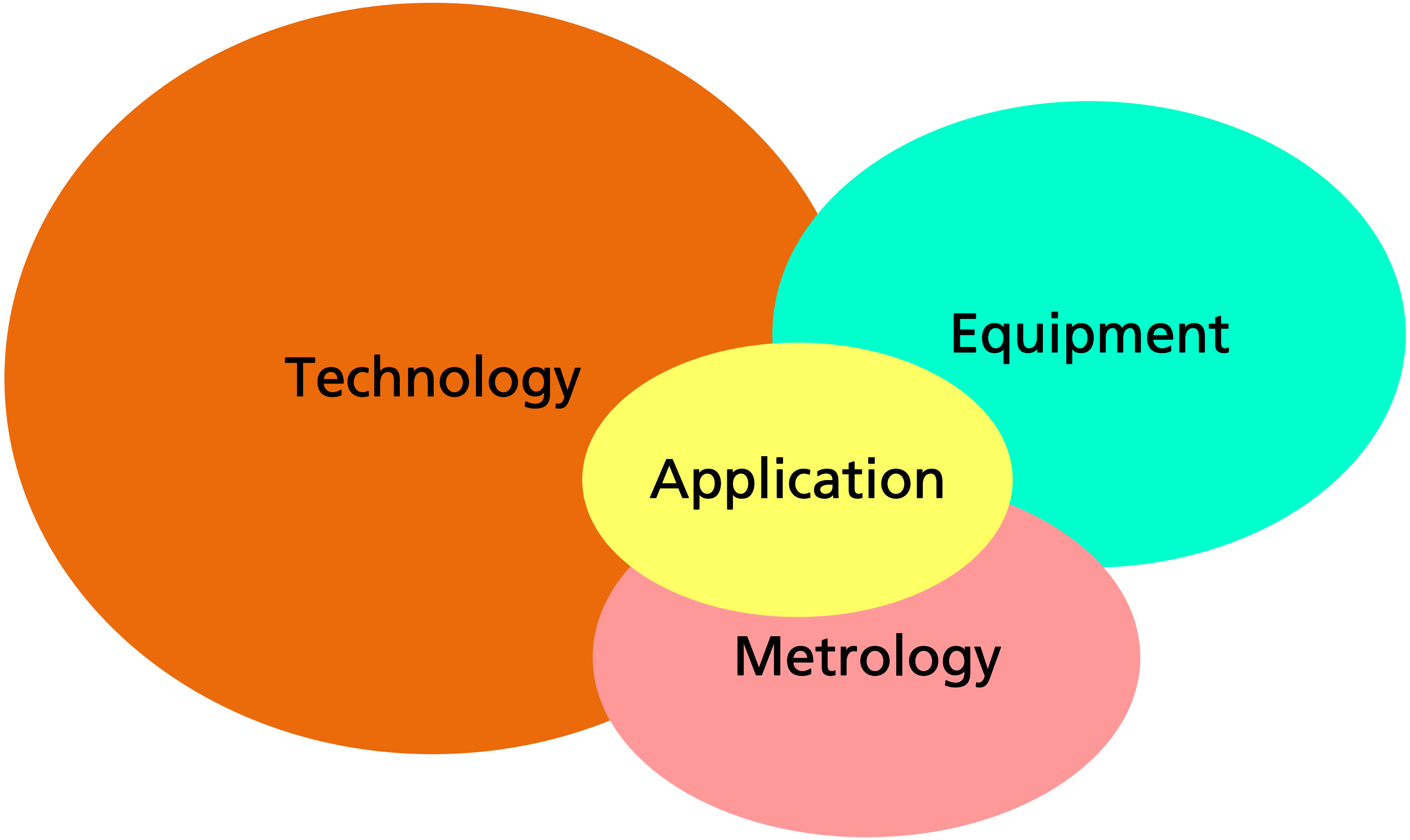
Technology Development



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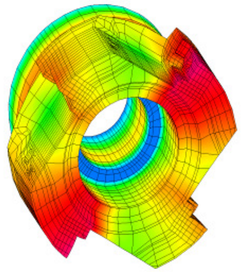
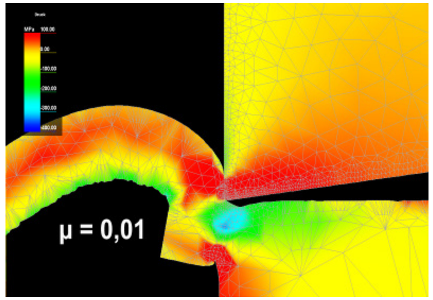
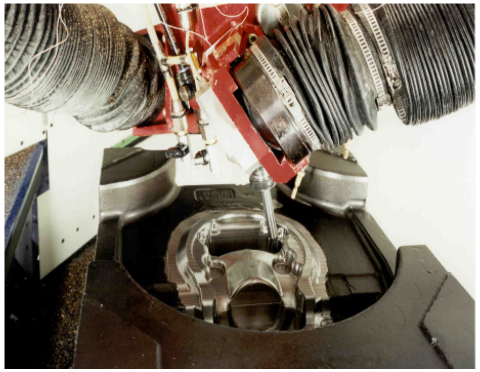
Cutting Technologies

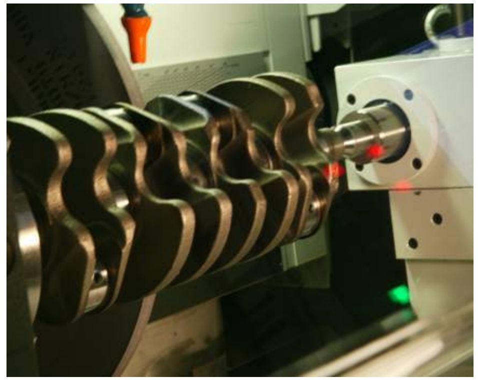
Process basis

- Modeling and simulation of cutting processes / optimization of cutting tools
- Design of modular tool systems
- Optimization of coating-substrate-systems
- Clamping of thinwalled workpieces



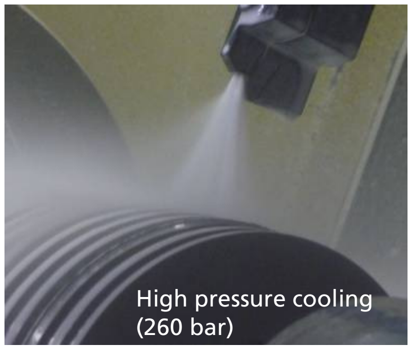


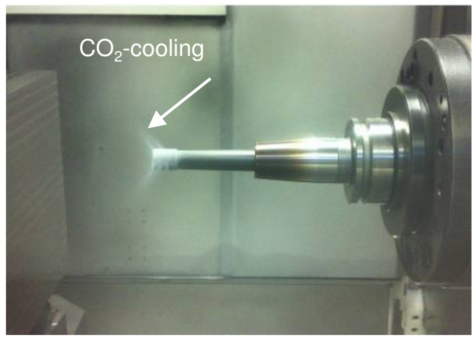




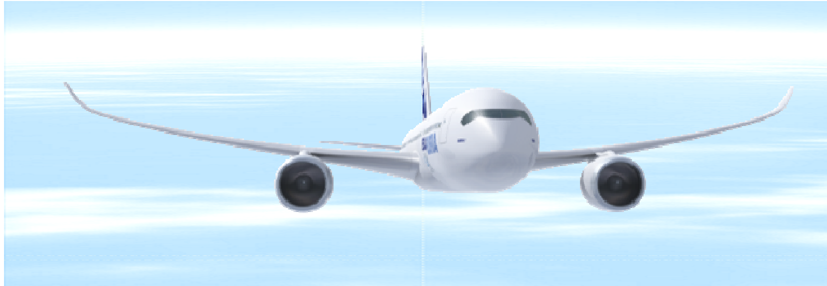
Process development

- Hybrid processes
  (High pressure or Cryogenic cooling,
  Ultrasonic oscillations)
- High Alternative Cooling Strategies
  (Dry cutting, MQL, High pressure or
  Cryogenic cooling)
- 5 axis milling, hard machining
- Process chain optimization
- Process combinations / integration





Motivation



- For the assembly of the components of an aircraft **up to 1,000,000 rivet holes are necessary**
- **Joining of different lightweight construction materials is required**, such as CFRP and titanium oder CFRP and aluminum
- Process-reliable manufacturing of rivet holes in an appropriate quality in **one process step with one tool**
  - → Prevention of stresses in the components
  - → Reduction of process steps
  - → Prevention of refinishing operations
  - → Cost minimization due to shorter process times and reduced tool costs

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➡ **Adequate tools and manufacturing technologies are required**

Occurring Problems when Machining Metal-CFRP-Stacks

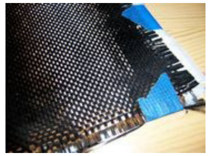
Material properties influencing machining

Titanium

- **Low thermal conductivity** (high temperatures)
- **High reactivity** with the cutting materials at high temperatures
- High strength at high and low temperatures
- **High tool wear**

Aluminium

- **High thermal conductivity**
- **Generally easily cutting**
- High tendency to **built-up edge**
- Often **long chips**
- Abrasive behavior of the cutting process at higher Si content



CFRP

- **High thermal conductivity** of the fibers
- **Matrix is thermally sensitive**
- High strength and stiffness
- Low thermal expansion
- Extremely high strength under changing loads
- **Dust formation** when machining CFRP (fracture of fiber)
- **Abrasive properties** in the cutting process

CONCLUSION **Completely different requirements** on the machining process

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Occurring Problems when Machining Metal-CFRP-Stacks

Tool and process requirements

	Titanium	Aluminium	CFRP
Cutting edge	▪ High-temperature resistant and ductile substrate heat-resistant coating ▪ Sharp cutting edge ▪ positive rake angle	▪ PCD-cutting edge ▪ neutral rake angle	▪ PCD-cutting edge or cemented carbide with diamond coating against abrasion ▪ Sharp cutting edge
Chip flutes	▪ ***helical*** chip space	▪ ***helical*** chip space	▪ ***Straight*** , deep chip space
Cooling	▪ ***Internal cooling*** with MQL	▪ ***Internal cooling*** with MQL	▪ ***Dry machining*** perhaps compressed air
Parameters	▪ ***Low*** rotation speed ▪ ***High*** feed rate	▪ ***High*** rotation speed ▪ ***middle*** feed rate	▪ ***High*** rotation speed ▪ ***Low*** feed rate

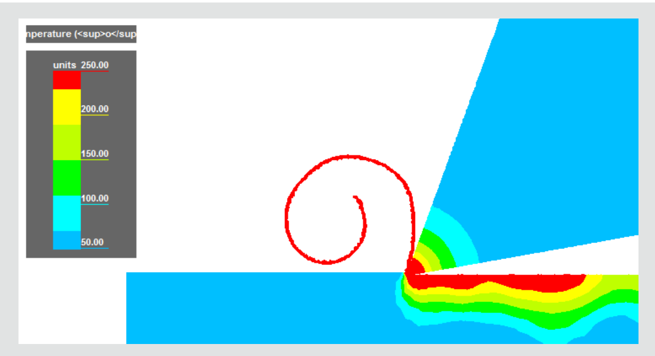
Metal-CFRP-Stracks → Diversification of ideal machining approaches

Approaches

Process-reliable manufacturing of high-quality rivet holes

Tool development

- Geometry
  (numerical simulation FEM,
  process studies)
- Coatings

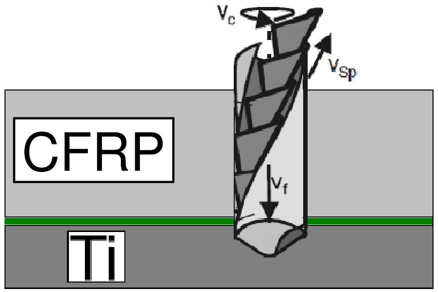


Process development

- Machining strategy
- Cutting parameters
- Hybrid processes
  (superposition of vibrations)
- Cooling lubricant strategy
  (for example High pressure or
  cryogenic)

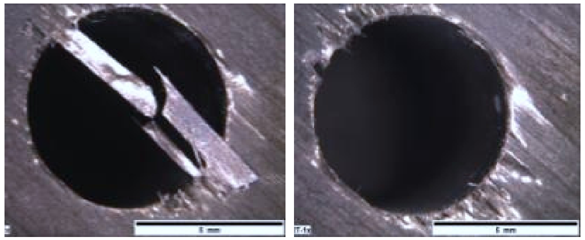
Machining of Titanium-CFRP-Stacks

Main problems



- **Drilling direction CFRP → titanium**
  - **Damaging of the CFRP** by hot and sharp titanium chips
  - **Burr formation** in titanium

- **Drilling direction titanium → CFRP**
  - **Delamination und fiber projection** at hole exit



  - **Flutes blocked** by molten CFRP-chips
  - **Burning of the CFRP-matrix** because of high tool temperatures

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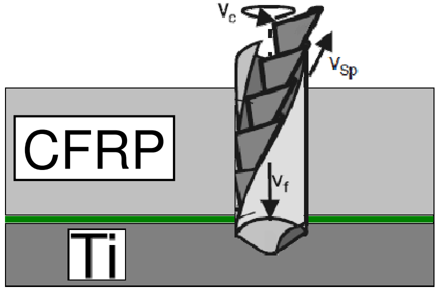
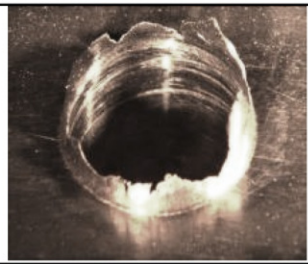
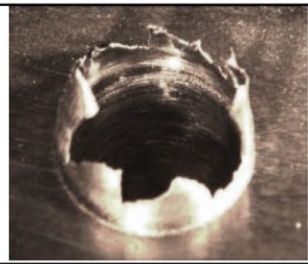
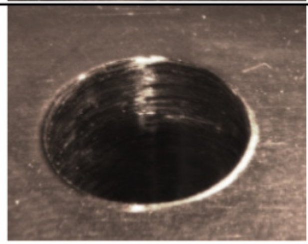
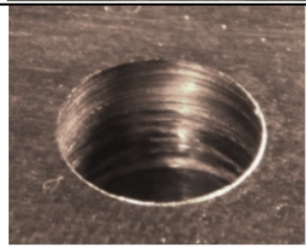
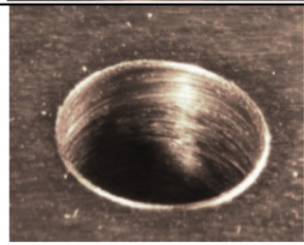
Approaches and Results

Tool Development



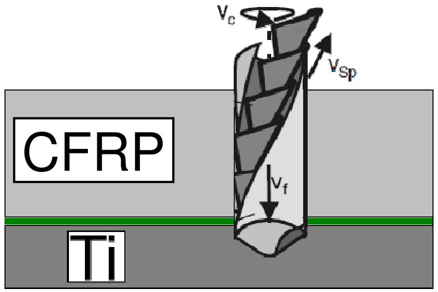
- Deriving different tool geometries from FEM-simulations
- Process studies for machining the single materials (Ti, CFRP) and the stack

	Hole exit V4	Hole exit V5	Hole exit V13
Stack (CFRP→Titanium)			
Titanium			

CONCLUSION **Different machining conditions between titanium and CFRP-titanium-stacks**

Approaches and Results

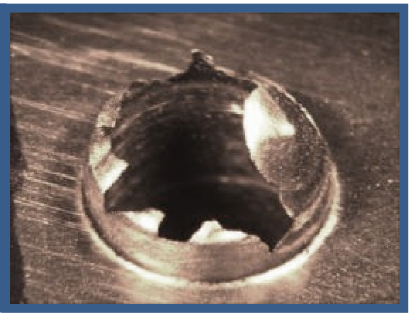
Tool Development



Hole exits in titanium

variation of tool geometry

V4

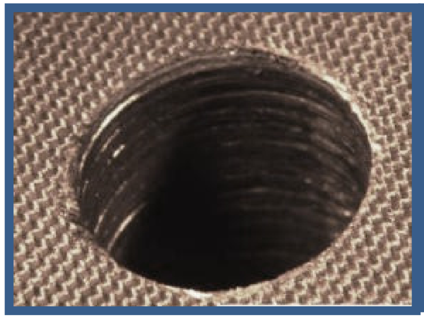


V24

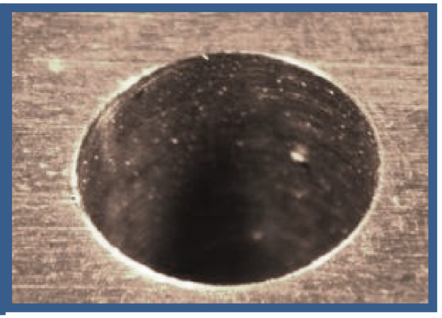
- **Severe burr formation** of the titanium at hole exit
- Poor removal of the titanium chips

→ Need for improvement

Material transition CFRP-titanium



CFRP



Ti6Al4V

Quality of transition between materials unproblematic

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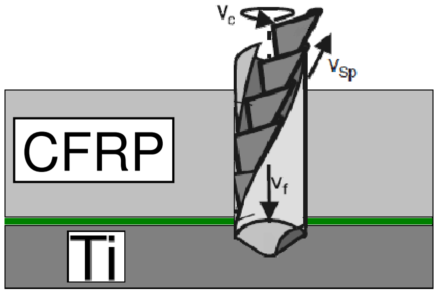
Approaches and Results

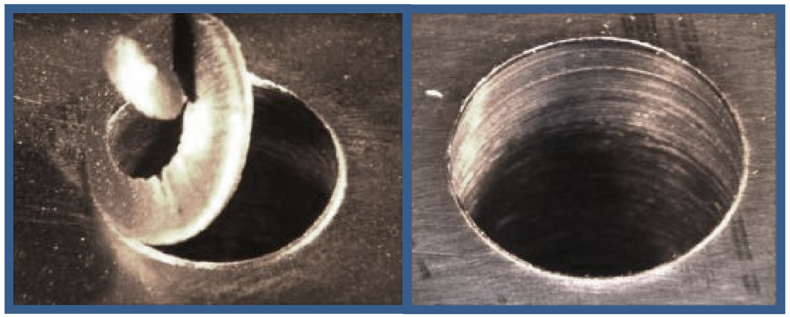
Tool Development



- Modification of tool geometry and optimization of tool surface

Hole exits in titanium

tool optimization



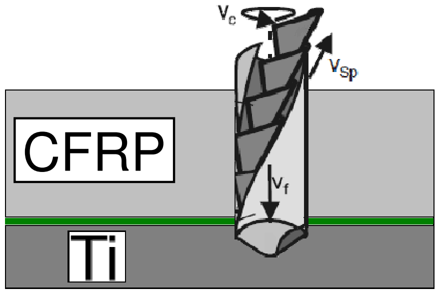
V4 V4-2

Optimized tool leads to:

- Reduced burr formation at the hole exits
- Better chip removal

Approaches and Results

Process Development



Process influenced by cryogenic cooling with carbondioxide snow

Problem:

- High process temperatures in machining titanium
  → Damaging of the CFRP
  → Blocked flutes by molten CFRP-chips
- For safety reasons **application of oily coolants is not possible**

Solution:

- Realization of dry machining
  by cryogenic process cooling

Result:

- **Trouble-free removal of the CFRP-chips**
- **Prevention of scorching hot titanium chips**

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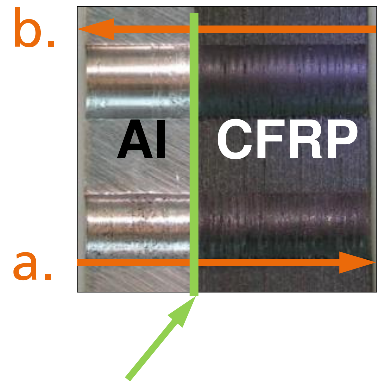
Machining of Aluminium-CFRP-Stacks

Process Development

Application of acoustic emission sensors for determining drill position

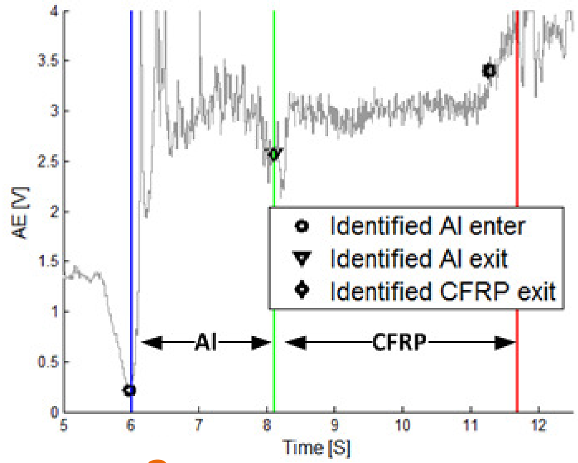
Objective: Adjusting the cutting parameters to the layer material during the drilling process of CFPR-Al-stacks

Approach: Indentification of the material transition by using acoustic emission sensors

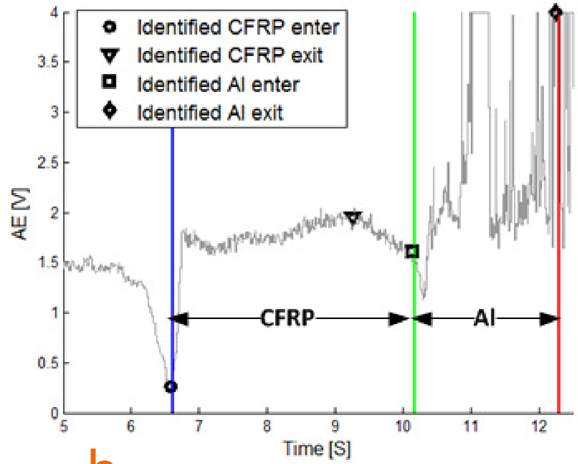


material transition (shim-layer)

Result:



a.



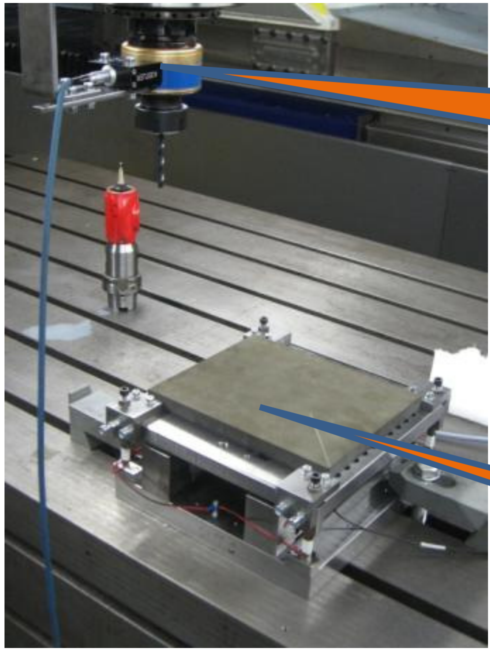
b.

Development of an algorithm to identify the material transition

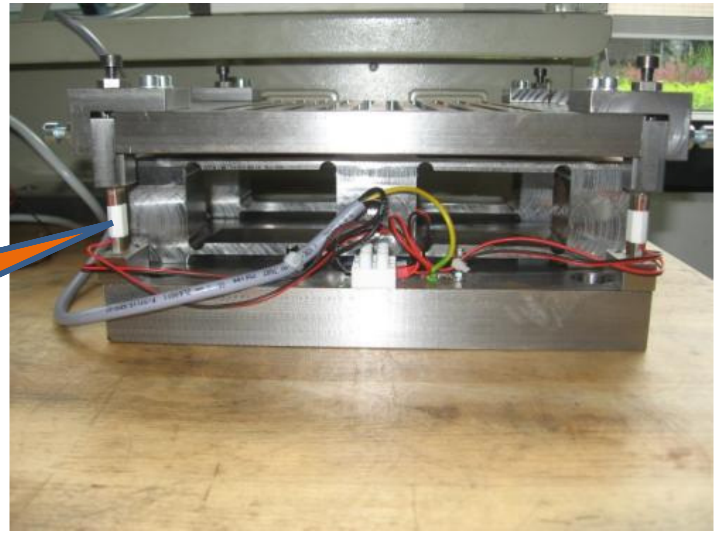
Machining of Aluminium-CFRP-Stacks

Process Development

Process influenced by low-frequency vibrations



experimental set-up



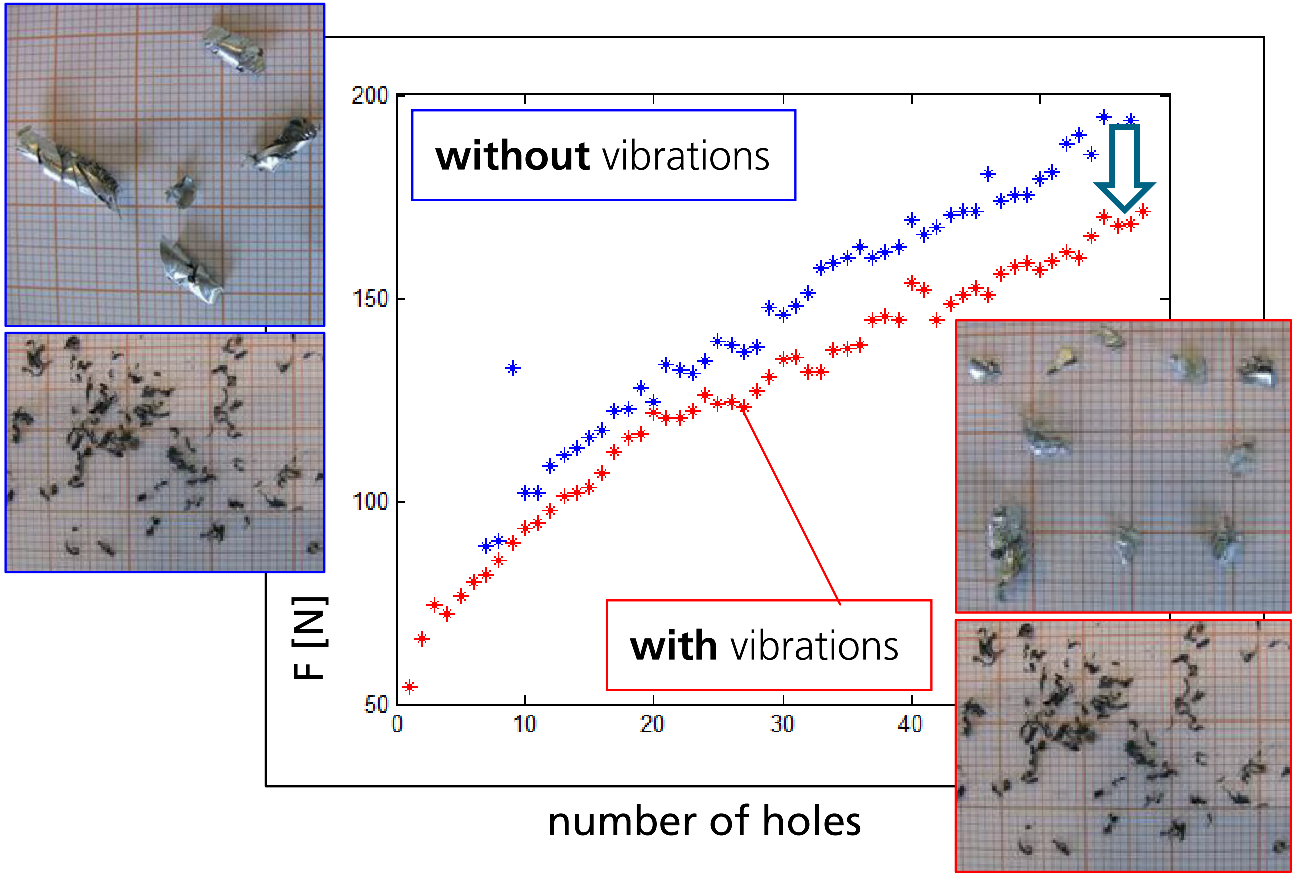
vibration equipment

Objective: **Reduction of the feed forces** when drilling Al-CFRP-Stracks

Machining of Aluminium-CFRP-Stacks

Process Development

Process influenced by low-frequency vibrations



Parameters:

- f = 200 Hz,
  A = 12 µm
- v_c = 57 m/min,
  f = 0.06 mm/rev

Result:

- Lower feed forces
- Reduced tool wear
- Better chip removal

Machining of Titanium

Process Development

High Pressure Cooling for Improved Chip Control

Technology:

- Supply of the coolant at high pressure (up to 260 bar)
- targeted delivery of the active medium directly on the cutting edge

Insert holder with internal coolant supply

Nozzles for high pressure jet

Fields of application:

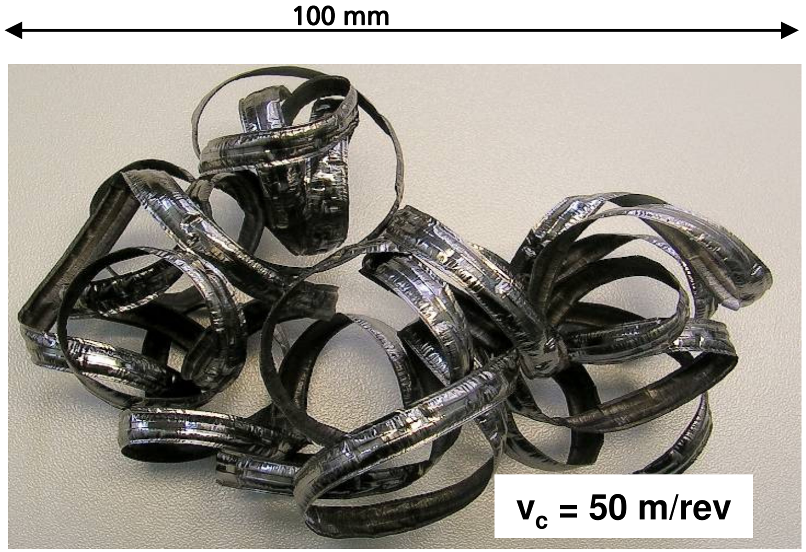
- difficult cutting materials
- Chip breaking problems / long chipping materials
- productivity gains

Machining of Titanium

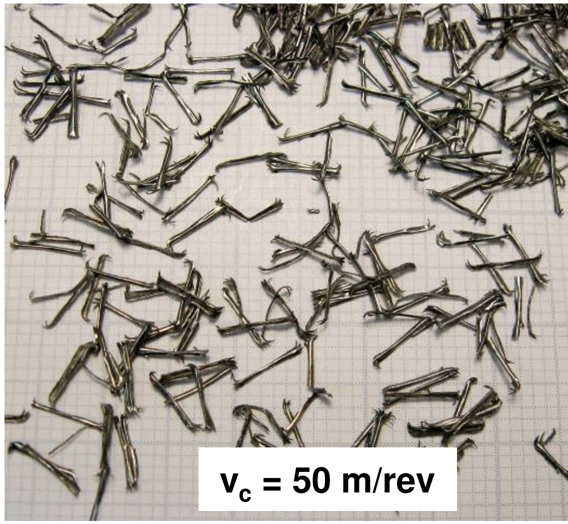
Process Development

High Pressure Cooling for Improved Chip Control

p = 6 bar



p = 260 bar



p = 120 - 150 bar

Grooving in Ti 5-5-5-3

Effects of high pressure coolant:

- Excellent chip control (optimum chip breaking)
- Increased cutting speed and productivity
- Reduction of tool wear
- Very good cooling and flushing

Conclusions and Summary

- In order to avoid burr and delamination the **drilling direction** has to be **considered** (CFRP→Metal or Metal→CFRP) when developing the **tool design** for drilling of composite stacks.

- **Internal cooling** is mandatory in order to reduce the temperature and to improve chip removal.

- The **AE signal** can be used for **online-monitoring of the drill position** in the composite stack. When drilling a stack of different materials, it is possible to determine the drill positions at the points of entrance, exit and transition between the different layers. Thus, **material-specific cutting parameters** can be realized in composite stacks.

- Machining of difficult to machine materials can be influenced **efficiently** by using **hybrid processes** and **cooling strategies**.

- The specific supply of **cooling lubricant under high pressure** allows for an improved cutting process. Potential options of **energy-efficient manufacturing** can be realized, above all, by using **higher cutting speeds**.

Thank you for your attention !

Die Ergebnisse entstanden in gemeinsamen Forschungsarbeiten mit

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Dr. Gühring KG, Chemnitz und Gühring oHG, Sigmaringen-Laiz
NILES-SIMMONS Industrieanlagen GmbH, Chemnitz

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