

---

# CUTTING TECHNOLOGIES FOR DIFFICULT-TO-MACHINE MATERIALS

Koriath H.-J., Hochmuth, C.; Busch, K.

Bogachev Y.P., Sakharova O.P.

---



---

© Fraunhofer IWU

## Cutting Technologies for Difficult-to-Machine Materials

### AGENDA

1 Introduction

2 Material and Components Trends

3 Hybrid Processes

3.1 Characteristics

3.2 Technologies and Applications

3.2.1 Vibration-Superimposed Machining

3.2.2 Media-Superimposed Machining

3.2.3 Machining with Superimposed Movement of the Axis

4 Summary and outlook

---

© Fraunhofer IWU  
2



## Cutting Technologies for Difficult-to-Machine Materials

### AGENDA

#### 1 Introduction

#### 2 Material and Components Trends

#### 3 Hybrid Processes

##### 3.1 Characteristics

##### 3.2 Technologies and Applications

##### 3.2.1 Vibration-Superimposed Machining

##### 3.2.2 Media-Superimposed Machining

##### 3.2.3 Machining with Superimposed Movement of the Axis

#### 4 Summary and outlook

© Fraunhofer IWU  
3

 Fraunhofer  
IWU

### 1 Introduction

## New Competitive Factors

- **Availability of resources + cost of resources = preconditions for success in the economic competition**
- **Business success = f (quality, productivity, flexibility)**
- **Resource efficiency is required in production and in the utilization phase**
- **Efficient technologies result in sustainable competitive advantages**



## Challenges for cutting processes!

© Fraunhofer IWU  
4

 Fraunhofer  
IWU

## Cutting Technologies for Difficult-to-Machine Materials

### AGENDA

1 Introduction

2 Material and Components Trends

3 Hybrid Processes

3.1 Characteristics

3.2 Technologies and Applications

3.2.1 Vibration-Superimposed Machining

3.2.2 Media-Superimposed Machining

3.2.3 Machining with Superimposed Movement of the Axis

4 Summary and outlook

© Fraunhofer IWU  
5



### 2 Material and Components Trends

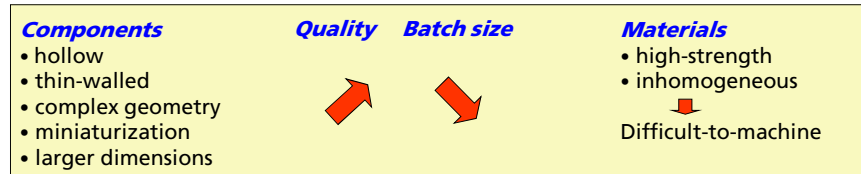
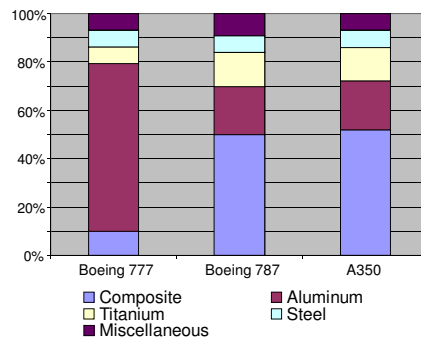
#### IWU-analysis

##### Sectors

- Automotive
- Aviation
- Energy
- Tool making
- Medical engineering

##### Properties

- Geometry
- Quality
- Overall size
- Materials



© Fraunhofer IWU  
6



## Cutting Technologies for Difficult-to-Machine Materials

### AGENDA

- 1 Introduction
- 2 Material and Components Trends
- 3 Hybrid Processes
  - 3.1 Characteristics
  - 3.2 Technologies and Applications
    - 3.2.1 Vibration-Superimposed Machining
    - 3.2.2 Media-Superimposed Machining
    - 3.2.3 Machining with Superimposed Movement of the Axis
- 4 Summary and outlook

### 3.1 Characteristics

#### Principle, Process Variation, Motivation for Application

*Hybrid processes are defined in this presentation as a combination of additional forms of energy in existing conventional machining processes.*

#### Objectives:

- Increased quality and productivity
- Improvement of chip breaking
- Reduction of thermomechanical tool loads

=> **Shift of existing technological process limits**

Principle	Process Variants	Motivation for Application
Vibration-superimposed machining	drilling	improvement of chip breaking
	turning	
	grinding	improvement of quality, productivity
	EDM	
ECM		
Media-superimposed machining	high pressure cooling	improvement of chip breaking
	cryogenic cooling	increase in material removal rate
Laser-assisted machining	turning	improvement of machinability
	milling	
Machining with superimposed movement of the axis	scissors kinematics	increase in dynamics in die and mold making
	EDM	improvement of the operating properties of engines
	out-of-round machining by adaptronic form honing and form boring	

Application of hybrid processes

## Cutting Technologies for Difficult-to-Machine Materials

### AGENDA

1 Introduction

2 Material and Components Trends

3 Hybrid Processes

3.1 Characteristics

3.2 Technologies and Applications

3.2.1 Vibration-Superimposed Machining

3.2.2 Media-Superimposed Machining

3.2.3 Machining with Superimposed Movement of the Axis

4 Summary and outlook

© Fraunhofer IWU  
9

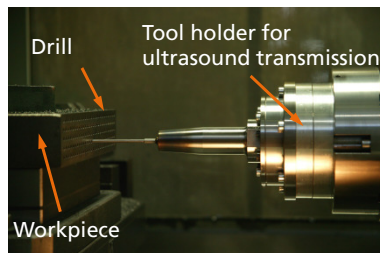
Fraunhofer  
IWU

### 3.2.1 Vibration-Superimposed Machining

#### Deep hole drilling with ultrasonic support – Process principle

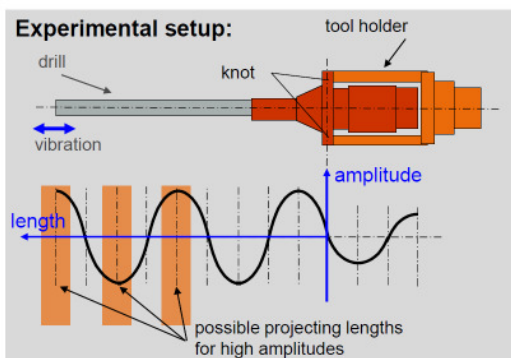
##### Objectives:

- Chip control
- Reduction of tool wear
- Process reliability
- Substitution of emulsions with MQL
- Increasing of productivity



© Fraunhofer IWU  
10

##### Experimental setup:



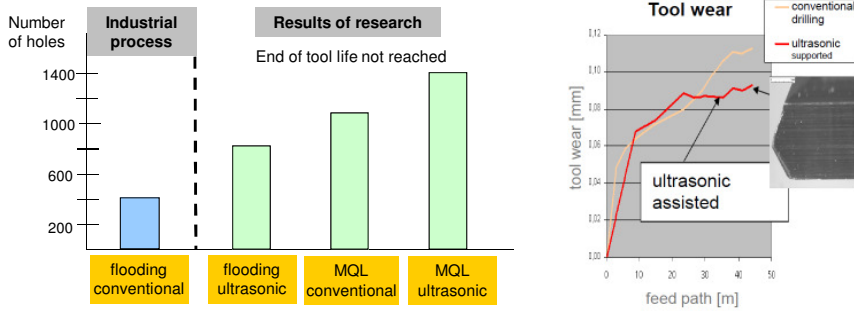
- Superimpose of the conventional deep hole drilling process with supersonic vibrations  
→ frequency 25 kHz, amplitudes up to 10  $\mu\text{m}$

Fraunhofer  
IWU

### 3.2.1 Vibration-Superimposed Machining

## Deep hole drilling with ultrasonic support – Results

### Tool Life and Tool Wear



### Results:

- Increase in tool life with ultrasonic support
- Chip control
- **Increased process efficiency and reliability in deep hole drilling of cast iron**

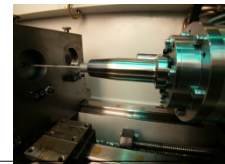
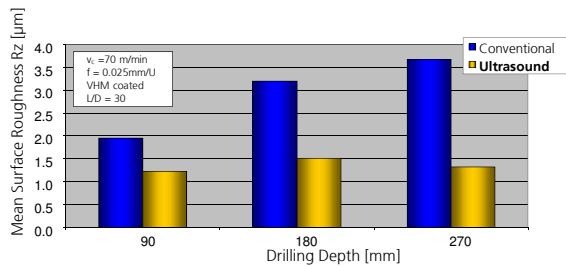
© Fraunhofer IWU  
11



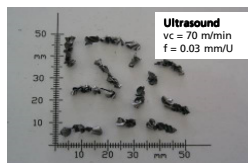
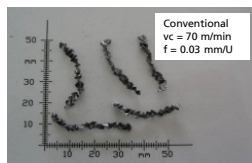
### 3.2.1 Vibration-Superimposed Machining

## Deep hole drilling with ultrasonic support – Results

### Influencing Surface Roughness and Chip Breaking



**Technological Parameters:**  
Material: X39CrMoV5-3  
Amplitude: 8 µm  
Frequency: 20 kHz



### Effects:

- Reduction of surface roughness
- Shortening of chip length

© Fraunhofer IWU  
Prof. Neugebauer  
12



## Cutting Technologies for Difficult-to-Machine Materials

### AGENDA

1 Introduction

2 Material and Components Trends

3 Hybrid Processes

3.1 Characteristics

3.2 Technologies and Applications

3.2.1 Vibration-Superimposed Machining

3.2.2 Media-Superimposed Machining

3.2.3 Machining with Superimposed Movement of the Axis

4 Summary and outlook

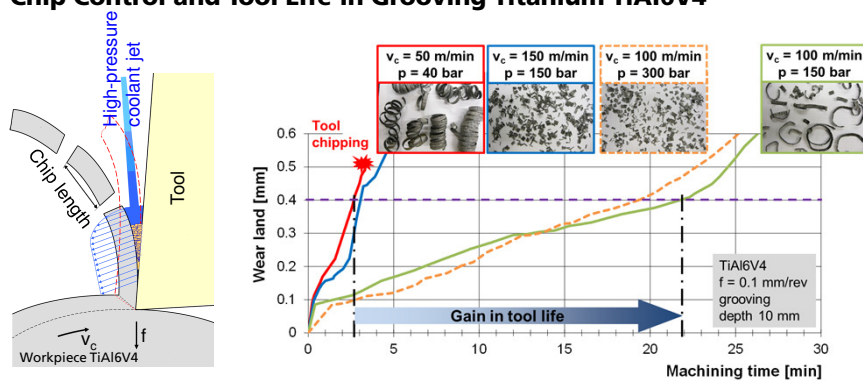
© Fraunhofer IWU  
13

Fraunhofer  
IWU

### 3.2.2 Media-Superimposed Machining

## Application of High-Pressure Cooling

### Chip Control and Tool Life in Grooving Titanium TiAl6V4



#### Effects

- High energy and resource efficiency, low cost, higher productivity
- higher cutting speeds and feeds
- Improved tool life, controlled chip breaking (chip length)

© Fraunhofer IWU  
Prof. Neugebauer  
14

IWP

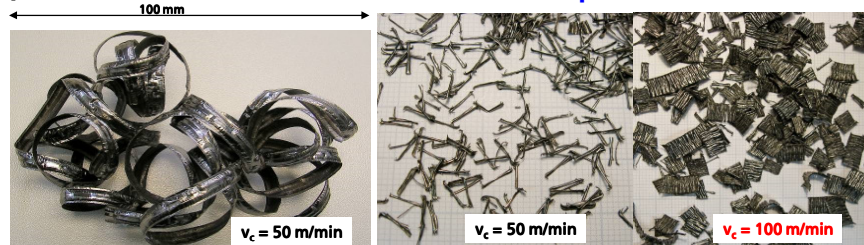
Fraunhofer  
IWU

### 3.2.2 Media-Superimposed Machining Application of High-Pressure Cooling

#### Chip Breaking in Grooving Titanium 5553

**p = 6 bar**

**p = 270 bar**



#### Effects of High Pressure Cooling:

- Excellent chip control (optimal chip break)
- Increased cutting speed and productivity
- Reduction of tool wear
- Very good cooling and flushing effect

Aktivierungssystem

© Fraunhofer IWU  
Prof. Neugebauer  
15



### 3.2.2 Media-Superimposed Machining Application of High-Pressure Cooling

#### Chip Breaking – Turning of difficult-to-cut sintered bronze

**p = 6 bar**

**p = 260 bar**



#### Effects of High Pressure Cooling:

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

Aktivierungssystem

© Fraunhofer IWU  
Prof. Neugebauer  
16



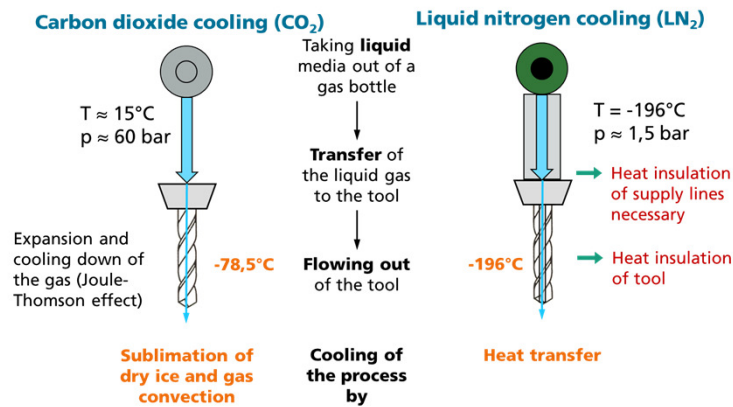
### 3.2.2 Media-Superimposed Machining

## Application of Cryogenic Cooling

### Process principles and cooling media

#### 2 types of coolants

→ Differences in **generation of cooling effect** and **handling**



© Fraunhofer IWU  
17

Fraunhofer  
IWU

### 3.2.2 Media-Superimposed Machining

## Application of Cryogenic Cooling

### Process principles and cooling media

#### Carbon dioxide cooling (CO<sub>2</sub>)

- Temperatures as low as  **$-78,5^\circ\text{C}$**
- **easy handling** and **integration in the machine tool**
- **No heat insulation** of the supply lines necessary
- **No special tools** necessary
- Generation of **low temperatures only at tool tip**

#### Liquid Nitrogen cooling (LN<sub>2</sub>)

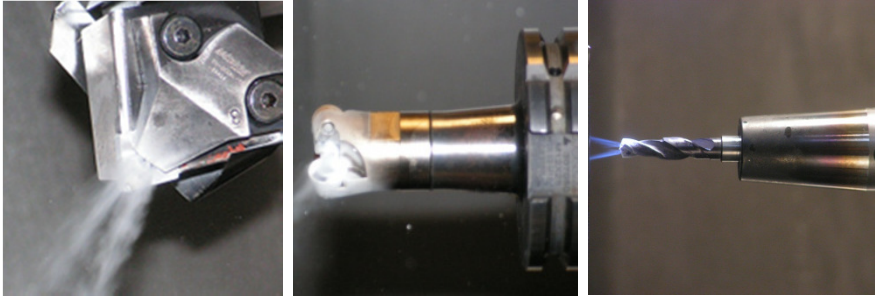
- Temperatures as low as  **$-196^\circ\text{C}$**
- **Heat insulation of the supply lines and machine components is necessary**
- **Special tools** with heat insulated coolant supplies are necessary
- **Long starting times of the cooling system**, because the supply lines first have to be cooled down by the medium

© Fraunhofer IWU  
18

Fraunhofer  
IWU

### 3.2.2 Media-Superimposed Machining Application of Cryogenic Cooling

#### Machining examples with cryogenic cooling (Carbon dioxide)



#### Turning

Supply through turning chisel

#### Milling

Supply through spindle of machine tool and milling tool

#### Drilling

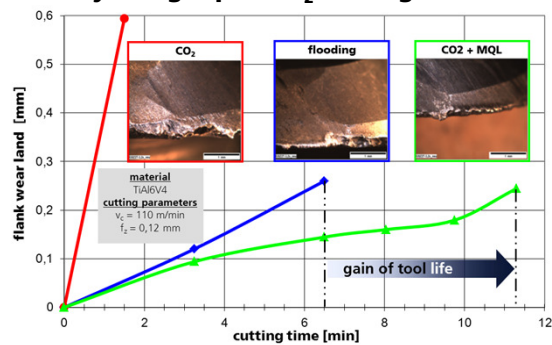
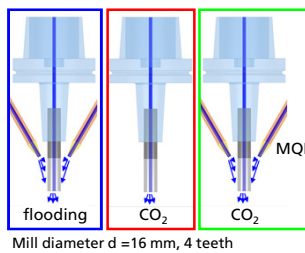
Supply through spindle of machine tool and drilling tool

© Fraunhofer IWU  
19



### 3.2.2 Media-Superimposed Machining Application of Cryogenic Cooling

#### Tool life in milling Titanium alloy using liquid CO<sub>2</sub>-cooling



#### Effects

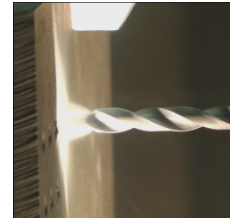
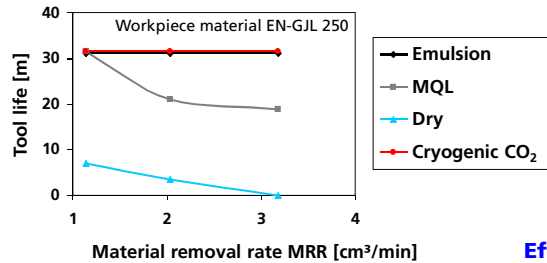
- Tool life x2
- reduced tool wear
- Nearly dry milling process

© Fraunhofer IWU  
20



### 3.2.2 Media-Superimposed Machining Application of Cryogenic Cooling

#### Material removal rate in drilling



Inner supply through tool

MRR [cm³/min]	Tool life [m]			
	Emulsion	MQL	Dry	Cryogenic
1.14 (75% $v_c, f_d$ )	>31.5	>31.5	7.1	>31.5
2.03 (100% $v_c, f_d$ )	>31.5	20.9	3.6	>31.5
3.18 (125% $v_c, f_d$ )	>31.5	18.9	0	>31.5

Tool life 31.5 m → 900 drilled holes (Ø 7mm, depth 35mm)

#### Effects

- Enormous potential for application verifiable
- Significant higher tool life than with MQL or dry cutting; analog emulsion cooling
- Low energy consumption compared to emulsion systems

© Fraunhofer IWU  
21

Fraunhofer  
IWU

## Cutting Technologies for Difficult-to-Machine Materials

### AGENDA

1 Introduction

2 Material and Components Trends

3 Hybrid Processes

3.1 Characteristics

3.2 Technologies and Applications

3.2.1 Vibration-Superimposed Machining

3.2.2 Media-Superimposed Machining

3.2.3 Machining with Superimposed Movement of the Axis

4 Summary and outlook

© Fraunhofer IWU  
22

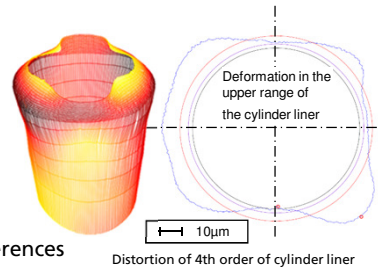
Fraunhofer  
IWU

### 3.2.3 Machining with Superimposed Movement of the Axis

## Tribological Optimization – Preventive Final Finishing

### Challenges

- **Cylinder form deviation influences** the **tribological system** piston – piston rings – cylinder liner
- **Reasons for cylinder form deviations:** static, semi-static and dynamic distortion resulting from head mounting, temperature differences in operation, variable thermal expansion and gas pressure
- **70 - 80% of oil consumption** originated from the piston system
- **Friction portion** of the piston system may amount **up to 50% of the overall engine friction**



**Motivation:** **Minimizing of cylinder form deviations** of bores in the cylinder block after mounting

**Solution options:** Design modification of the components and bore shape

**Preventive out-of-round machining**

© Fraunhofer IWU  
23



Fraunhofer  
IWU

### 3.2.3 Machining with Superimposed Movement of the Axis

## Tribological Optimization – Preventive Final Finishing

### Technical machining requirements:

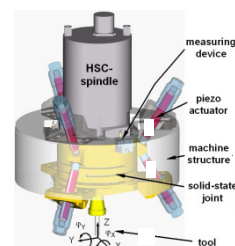
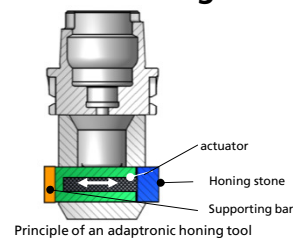
- Development of effective and flexible fine-finishing process ( $IT < 6$ ,  $Rz < 3\mu m$ )
- **High dynamic relative movement** between tool and workpiece ( $f > 50$  Hz,  $s = 10 \dots 100 \mu m$ )

### Solution options:

- Single-axis movement **"Adaptronic form honing"**
- Multi-axis movements **"Out-of-round drilling"** (magnetic spindle, **sub-kinematic-system**)

### Process preconditions:

- Integration of a process guiding system
- Development of measuring concepts and strategy (for **analyzing 3D shapes**)



Principle of a Hexapod sub-kinematics system

© Fraunhofer IWU  
24



Fraunhofer  
IWU

### 3.2.3 Machining with Superimposed Movement of the Axis

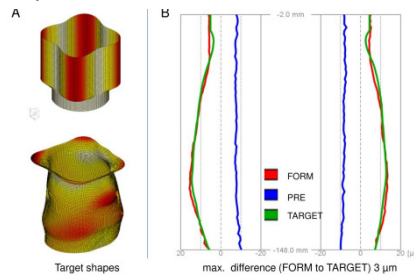
## Tribological Optimization – Preventive Final Finishing

### Results of Adaptronic Form Honing

- ✓ Realization of an adaptronic form honing tool
- ✓ Development of a specific form honing process and machining strategies
- ✓ Functioning of tool and process proven in experiments
  - Shape accuracy of **+3 μm/-3 μm**
  - Requirements on productivity were achieved ( $Q'w$  5...10 mm<sup>3</sup>/mm<sup>2</sup>/min)
  - Target surface structure and roughness values realized
  - Engine test successful: less oil consumption (test: **29 g/h** → target: <47 g/h)



The adaptronic form honing tool



© Fraunhofer IWU  
25

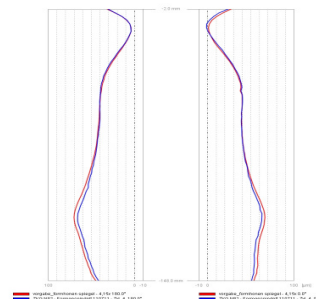
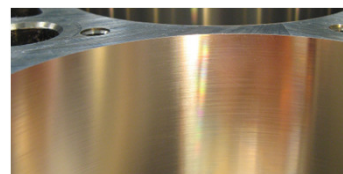


### 3.2.3 Machining with Superimposed Movement of the Axis

## Tribological Optimization – Preventive Final Finishing

### Results of Out-of-Round Drilling

- ✓ Realization of a Hexapod sub-kinematics system
- ✓ Development of a specific process and machining strategies
- ✓ Functioning of the process proven in experiments in crankcases made of aluminum alloys
  - Difference between target and drilled shape **<6 μm**
  - Roughness value  $R_z < 2 \mu m$  achievable
  - Rotation speed up to 6000 rpm



© Fraunhofer IWU  
26



### 3.2.3 Machining with Superimposed Movement of the Axis

## Tribological Optimization – Preventive Final Finishing

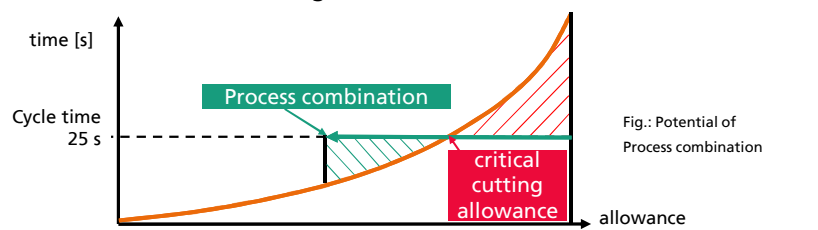
Combination of **Adaptronic Form Honing** and **Out-of-Round Drilling**

### Problem:

- Machining time depends on dimension of shape deviations (radial cutting allowance)

### Benefits of the process combination:

- Reduction of the radial cutting allowance in honing process
- Reduction of the machining time
- Constant thickness of coatings



© Fraunhofer IWU  
27



Fraunhofer  
IWU

## Cutting Technologies for Difficult-to-Machine Materials

### AGENDA

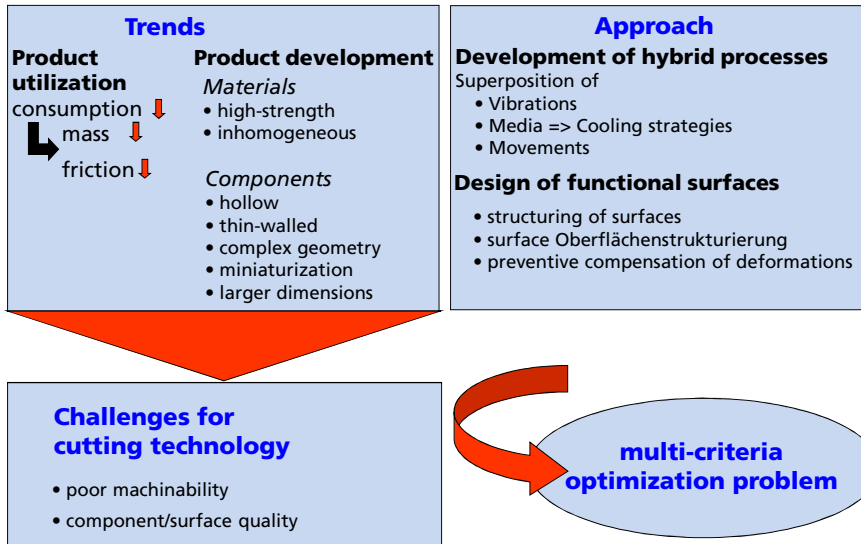
- 1 Introduction
- 2 Material and Components Trends
- 3 Hybrid Processes
  - 3.1 Characteristics
  - 3.2 Technologies and Applications
    - 3.2.1 Vibration-Superimposed Machining
    - 3.2.2 Media-Superimposed Machining
    - 3.2.3 Machining with Superimposed Movement of the Axis

### 4 Summary and outlook

© Fraunhofer IWU  
28

Fraunhofer  
IWU

#### 4 Summary and outlook



© Fraunhofer IWU  
29

Fraunhofer  
IWU

**РОССИЙКО-ГЕРМАНСКИЙ ИННОВАЦИОННЫЙ ПРОЕКТ ИНОКРТ IWUMASH-TITAN**

1.2. Пример заготовки детали из сплава титана

3. Приспособление для установки обрабатываемой заготовки

**РАЗРАБОТАНА ТЕХНОЛОГИЯ ОБРАБОТКИ ТОНКОСТЕННЫХ СЛОЖНОПРОФИЛЬНЫХ ДЕТАЛЕЙ ИЗ ТРУДНООБРАБАТЫВАЕМЫХ МАТЕРИАЛОВ**

**Основные направления**

Основная технология разработана с учетом особенностей обработки тонких деталей:

- сплавов с черными металлами и развитой литевой системой,
- тонкостенных, неважных и сложных и криволинейных в процессе обработки,
- малых глубины впадин.

Особенность обработки, соответствие поставленной задаче и выбранного инструмента и параметров обработки проверено в процессе экспериментальных исследований.

**Теоретические исследования и практические эксперименты**

- направлены на отработку основных принципов обработки для выбранных деталей из труднообрабатываемых материалов, включающие в себя разработку базовой технологии, выбор подсистем инструмента, доступные на рынке, а также анализ суточных ошибок, выявление основных системных ошибок при фиксации заготовки, с использованием метода конечных элементов и компьютерной модели;
- учитывают особенности деталей в аэрокосмической промышленности с требованием очень высокой точности работы.

В настоящее время опытные образцы детали при обработке труднообрабатываемых

ниже из-за высокой степени износа инструмента (в среднем от 40 до 80 мкм.) Низкая теплопроводность легированных сплавов с учетом пренебрежимой отвода тепла из зоны резания от инструмента и заготовки - требуются высокоэффективные охлаждения.

Некоторые варианты комбинированного охлаждения: воздушный, жидкостный, ультразвуковой и воздушный-жидкостный были анализированы и экспериментально проверены.

**Математическое моделирование**

- проведено с целью оптимизации условий фиксации заготовки и ее обработки с использованием методов конечных элементов для анализа деформации заготовки и инструмента.
- На этой основе была проведена оптимизация принципа фиксации и параметров обработки и разработаны методы коррекции и компенсации размеров ошубок.

**Развитие проекта**

Партнеры продолжают исследования и разработку в рамках инновационных проектов IWUMASH и MACROMASH в Самарской лаборатории СЭЛ ЭНИМС-ТИМ и в IWU Fraunhofer.

© Fraunhofer IWU  
30

Fraunhofer  
IWU

Ждем Вас на выставке  
в павильоне 2.2 В08  
вместе с ф-мой Микромат

*Thank you for your attention*