

# Additive Manufacturing @ IWF – inspire

## *Research topics and applications*



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- Part I Additive manufacturing at inspire
- Part II Research focus in SLM
- Part III Research focus in DMD
- Part IV Applications & outlook / Summary



# *Part I*

## *Additive manufacturing at inspire*







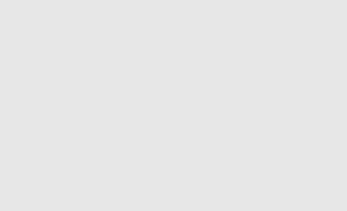
# Additive Manufacturing processes

## ■ AM processes

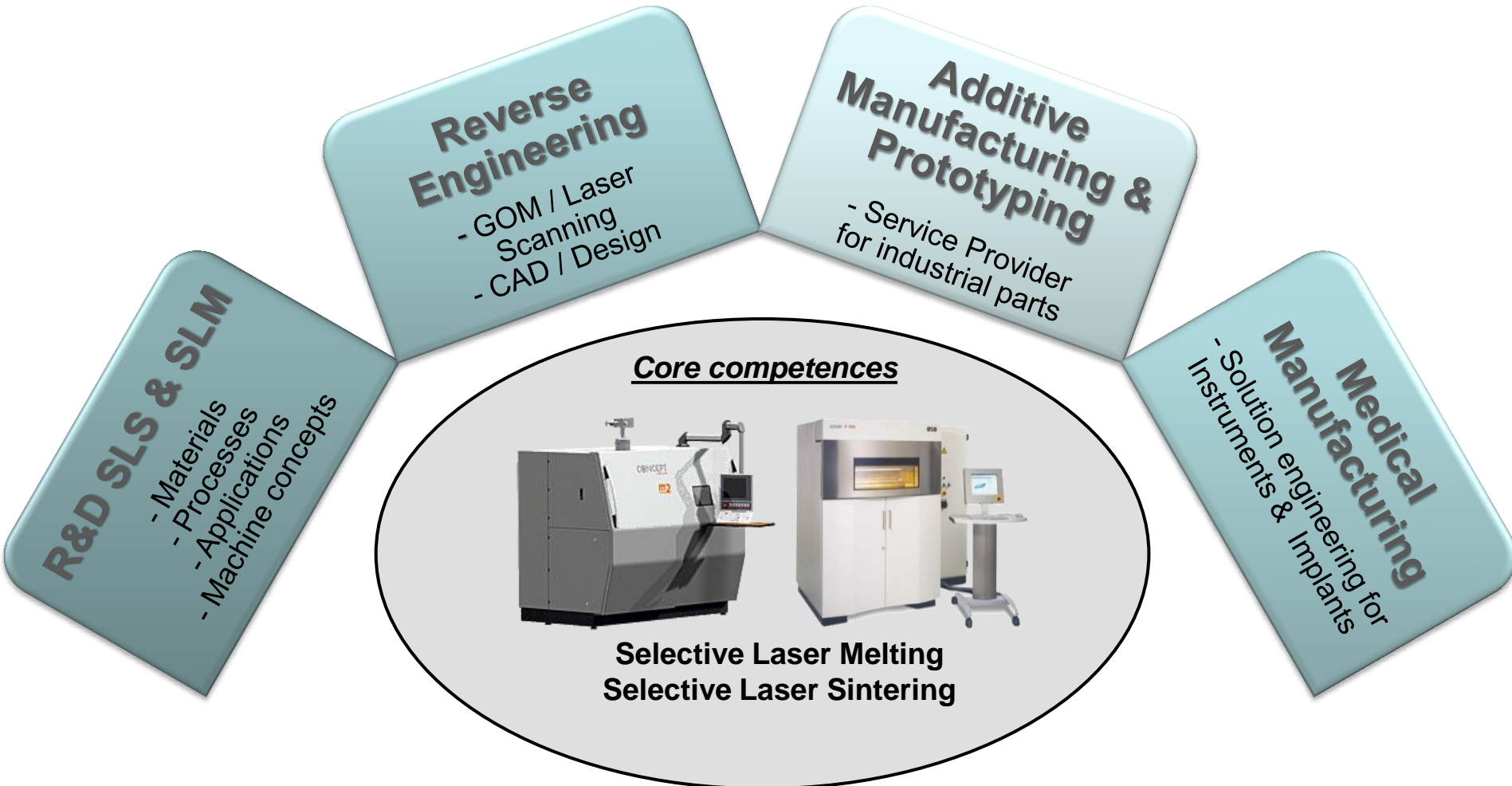
	<b>Selective Laser Melting SLM</b>	<b>Electron Beam Melting EBM</b>	<b>Direct Metal Deposition DMD</b>	<b>Selective Laser Sintering SLS</b>
Materials	<b>Metals:</b> basis Fe, Ni, Ti, Al,...	<b>Metals</b> Mainly <b>Ti</b> , also Fe, Ni	<b>Metals:</b> basis Fe, Ni, Ti	<b>Plastics</b> PA, PP, and others (PEEK)
Material density	<100%	< 100%	< 100%	<100%
<b>Typ. part sizes</b>	Some mm up to ≈ 300mm	Until 300 x 200mm (∅ / H)	Some cm up to meter-range	Some cm up to typ. ≈ 0.7m
<b>Part complexity</b>	Very high	high	High, but limited	Very high
<b>Typ. Build trate (*)</b>	1 up to ≈ 50 cm <sup>3</sup> /h	≈ 30 - 80 cm <sup>3</sup> /h	5 up to >100 cm <sup>3</sup> /h possible	Some cm <sup>3</sup> /h

(\*) material-, part- and machine dependent

■ AM processes

	<b>Selective Laser Melting SLM</b>	<b>Electron Beam Melting EBM</b>	<b>Direct Metal Deposition DMD</b>	<b>Selective Laser Sintering SLS</b>
Machines				
Process	Powder bed / Laser 	Powder bed / e-beam 	Nozzle / laser 	Powder bed / Laser 

- Powder based processes
- Aiming at high quality industrial production



## *Part II*

### *Research focus in SLM*



## Materials

- Powder requirements
- Materials for AM
  - AM-adapted alloys
  - Hybride materials
- Material characterization
  - Microstructure
  - Mechanical properties
  - ...

## AM-Processes

- Processing windows for materials
- SLM- / SLS- Process Simulation
  - Internal stresses
  - Process effects
  - ...
- Process productivity

## Applications

- Lightweight structures
- Structurally optimised parts
- Tooling
- Production of industrial parts

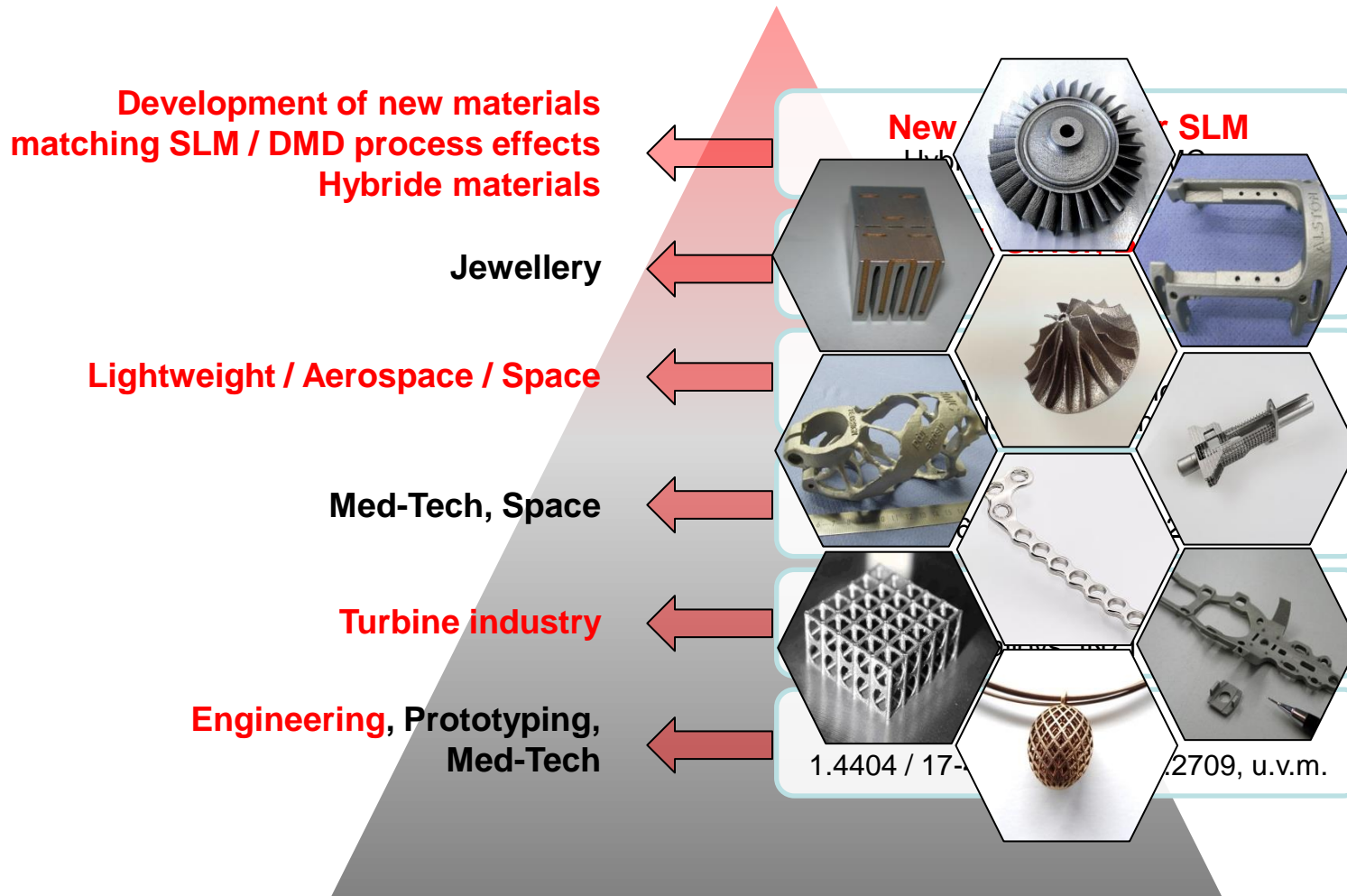
## Machine

- Investigations into future machine concepts
- Optimization of machine components
- Optimization of the overall-productivity
- QS for AM

Standardisation (ASTM-ISO, VDI)



■ Overview (examples @ inspire)

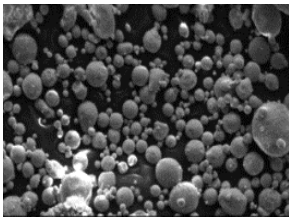
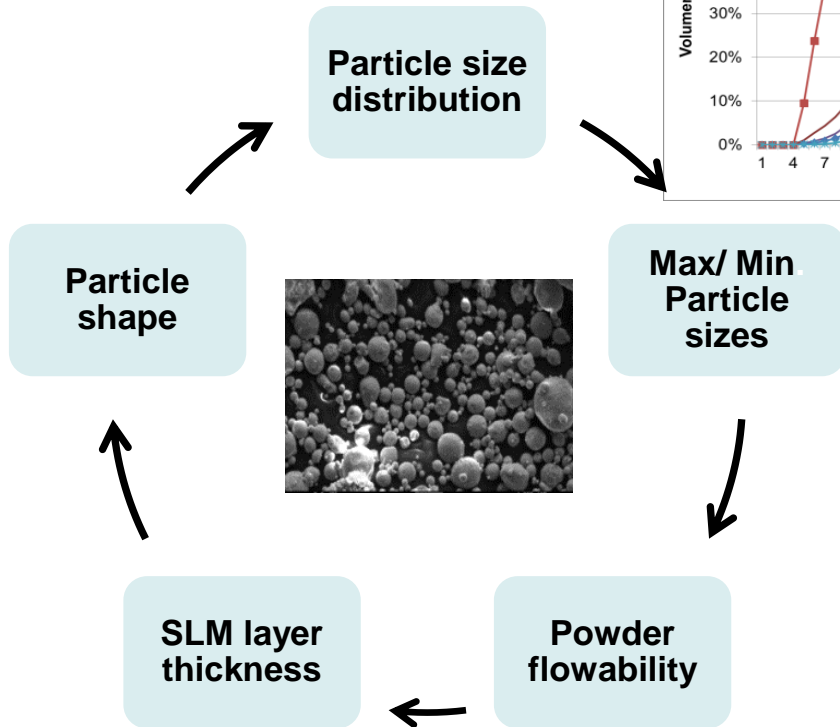
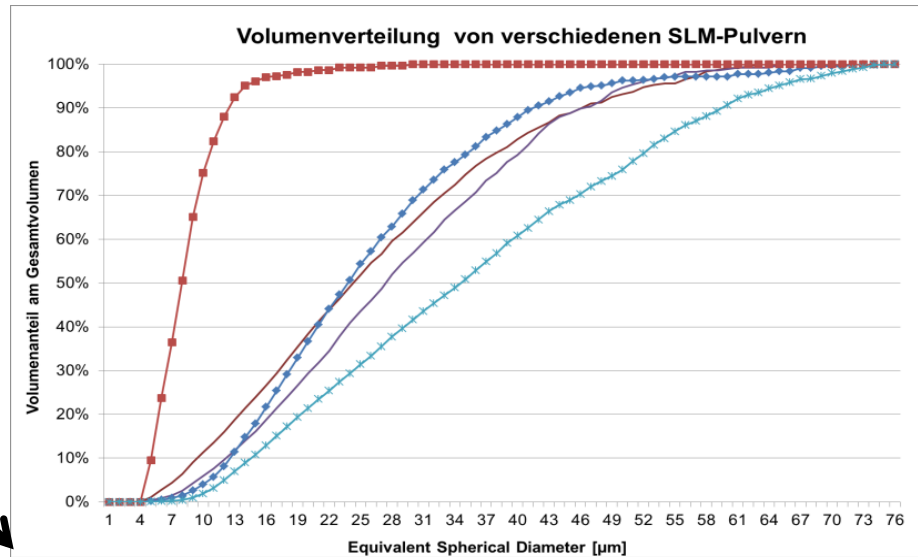


**Materials**

- Powder requirements
- Materials for AM
  - AM-adapted alloys
  - Hybride materials
- Material characterization
  - Microstructure
  - Mechanical properties
  - ...

# Material characterization

- Powder properties and requirements



- Qualification of powders
- Definition of requirements
- QS & Standardisation



### Materials

- Powder requirements
- Materials for AM
  - AM-adapted alloys
  - Hybride materials
- Material characterization
  - Microstructure
  - Mechanical properties
  - ...

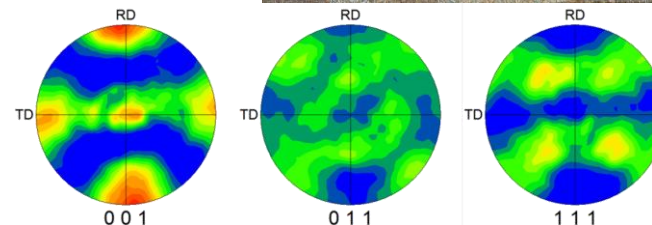
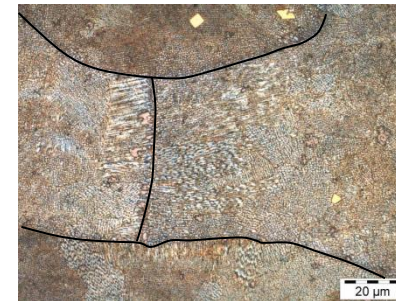
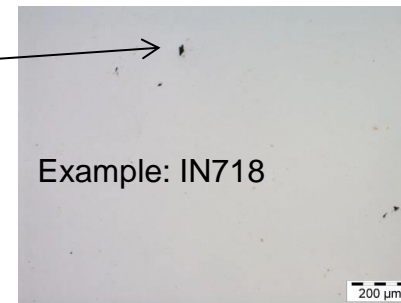
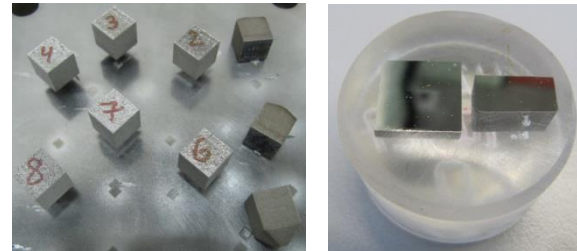
## ■ Selective Laser Melting

### — Material & Microstructure

- Remaining pores are hard to avoid!  
 → ev. post processing / HIP required  
 Density increase of up to 3% is possible

- Fine grained microstructure  
 → very high cooling gradient  
 → affecting mechanical properties /  
 Anisotropy

- Material dependent:  
 Preferential grain orientation



#### Materials

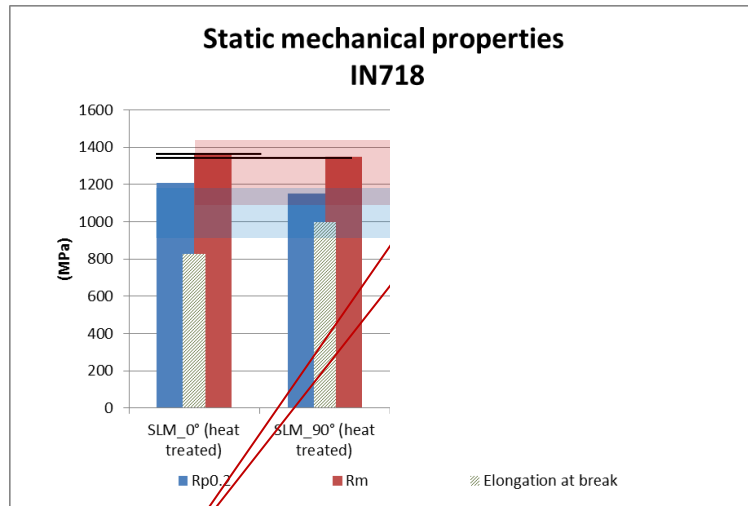
- Powder requirements
- Materials for AM
  - AM-adapted alloys
  - Hybrid materials
- Material characterization
  - Microstructure
  - Mechanical properties
  - ...

## ■ Selective Laser Melting

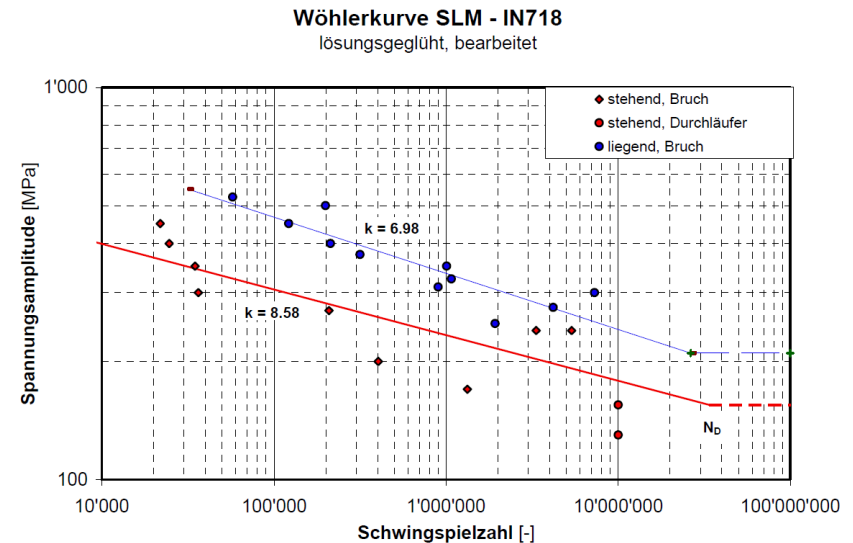
There are differences to «conventional» materials



### – Static mechanical properties



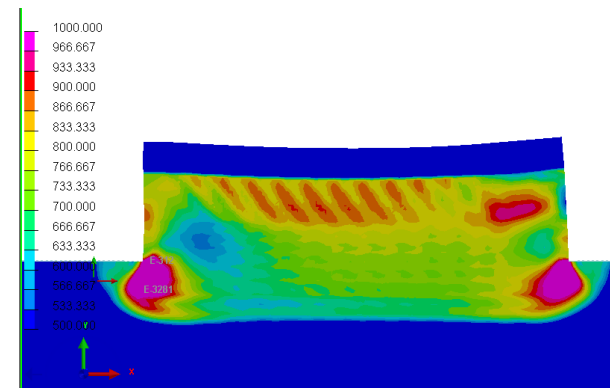
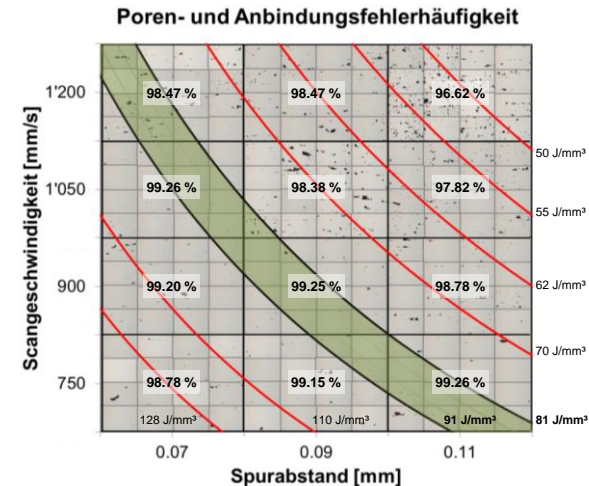
### Dynamic mechanical properties




- **Anisotropy** horizontal – vertical build orientation (Rule of thumb: typ. 5% – 15%)
- Static mechanical properties in the range of cast and forged
- Significant differences for dynamic mechanical properties

## ■ Selective Laser Melting

- Evaluation of the processability of materials for SLM / DMD
- Development of SLM-processing windows
  - New alloys
  - Hybride materials
  - ...
- Process effects
  - Internal stresses
  - Crack susceptibility
  - Pores





**AM-Processes**

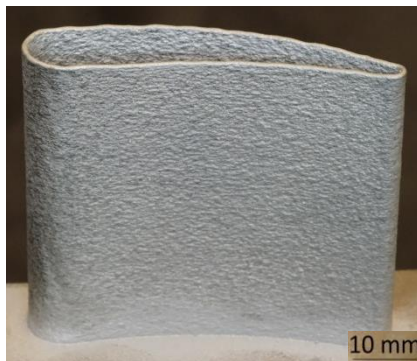
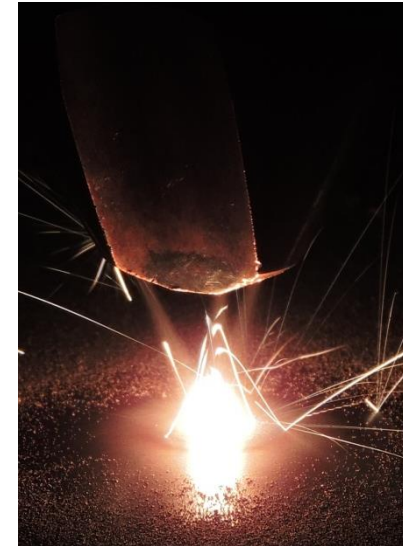
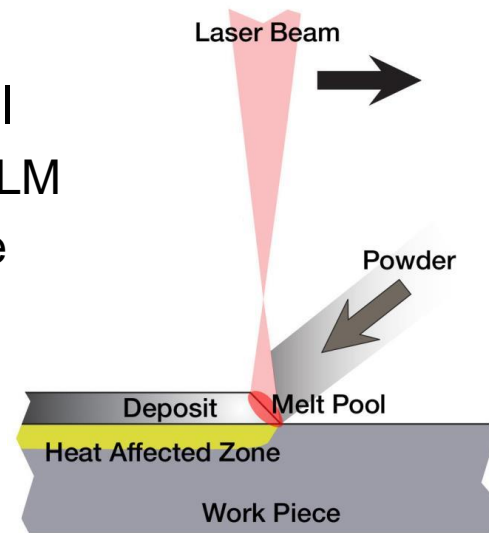
- Processing windows for materials
- SLM- / SLS- Process Simulation
  - Internal stresses
  - Process effects
  - ...
- Process productivity

# *Part III*

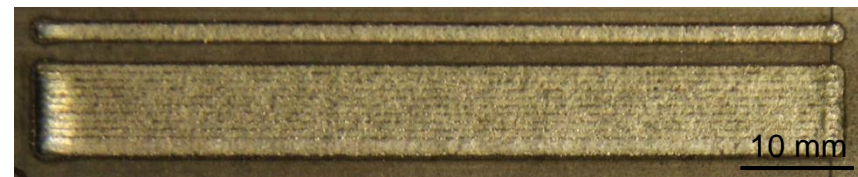
## *Research focus in DMD*

# Laser Cladding / Direct Metal Deposition (DMD) – Process Principle

- Local melting by laser beam
- Powder is blown into the melt pool
  - Compare: Preplaced powder in SLM
  - Repair of damaged parts possible
- Production of ...
  - Layer/coating: Track by track
  - 3D-Parts: Layer by layer

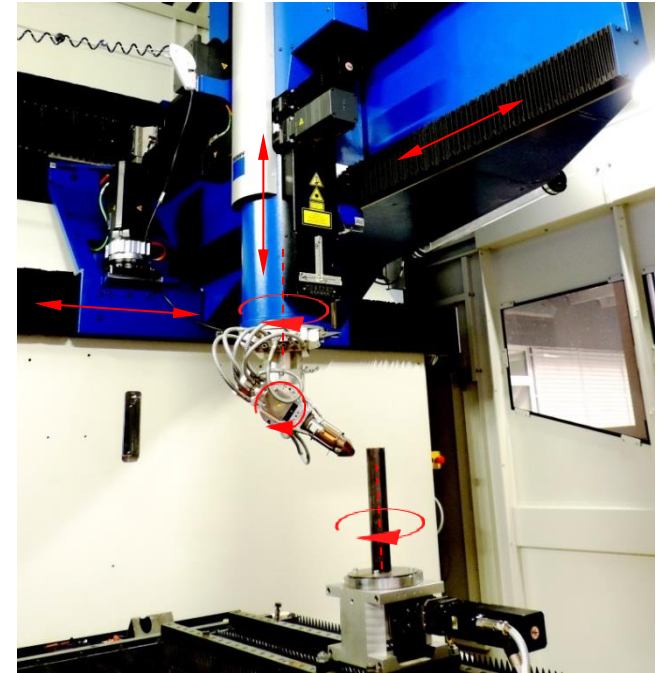


Turbine blade crown



Coating

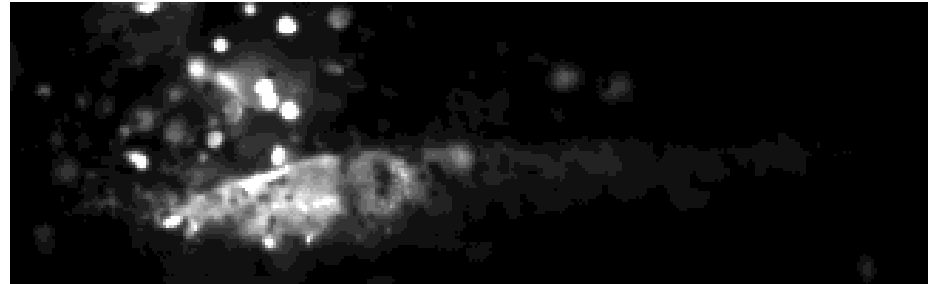
- Trumpf TruLaser Cell 7020
  - 5-axis
  - Additional rotatory axis
- 5 kW CO<sub>2</sub>-Laser (cw)
- Coaxial powder nozzle
  - 3 Discrete powder gas streams)
- Powder feeder:
  - Trumpf DepositionLine
  - Max.  $\approx$  35 g/min  
(@ inspire/IWF)



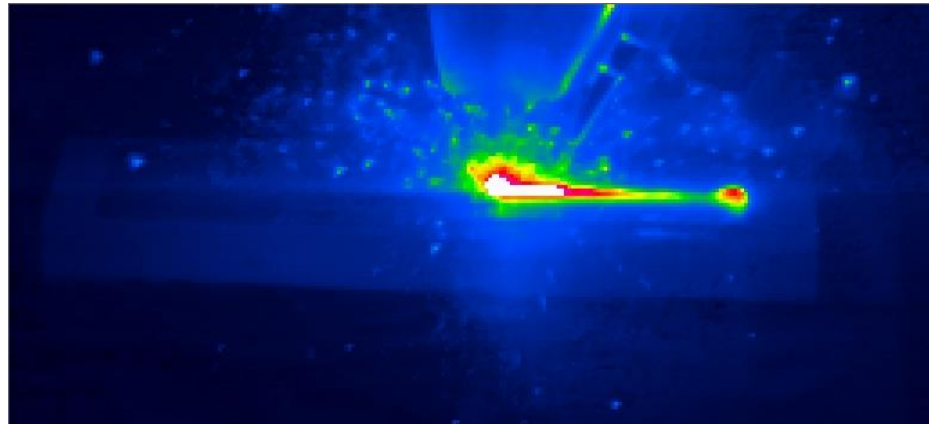


# Laser Cladding / DMD - Experimental

- High speed camera images

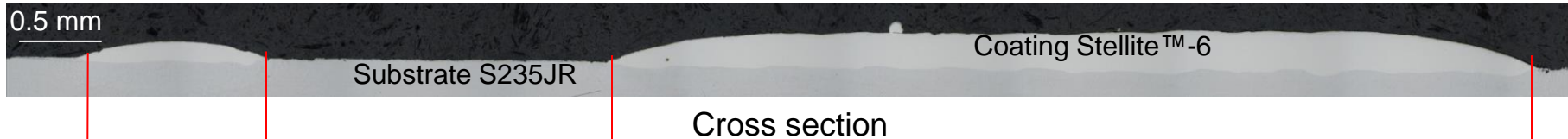


- Temperature measurement
  - 2-color pyrometer, thermography

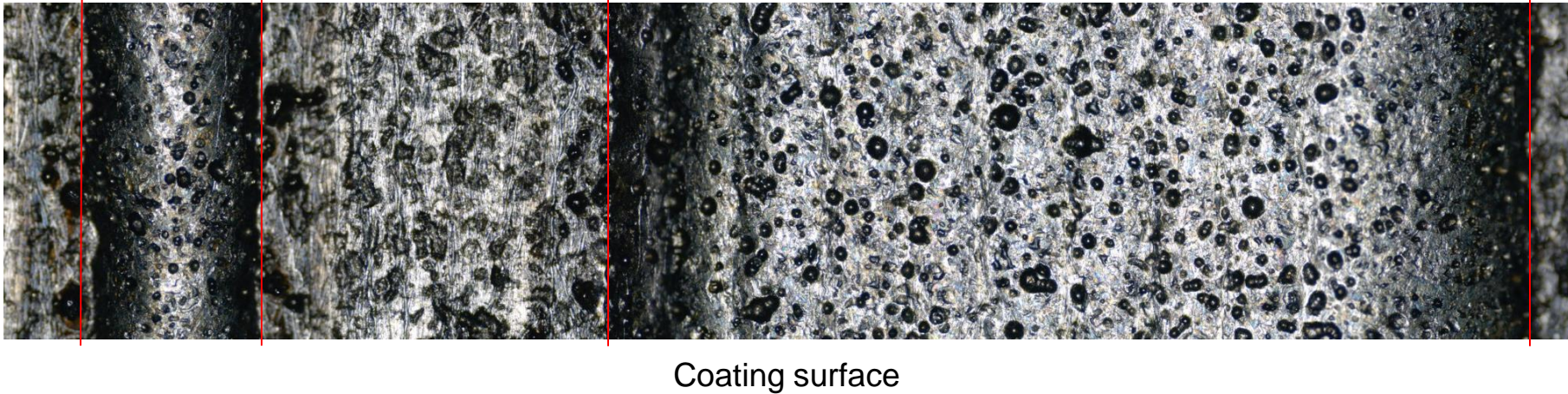


- Design of Experiments (**DOE**)
  - Empirical/quantitative models
  - Process optimization

- Metallography (→ cracks, pores, dilution)

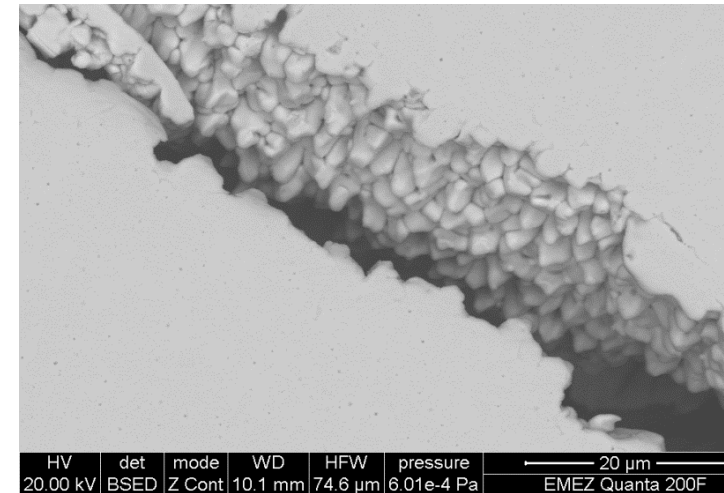


- 3D Light microscopy (→ cracks)

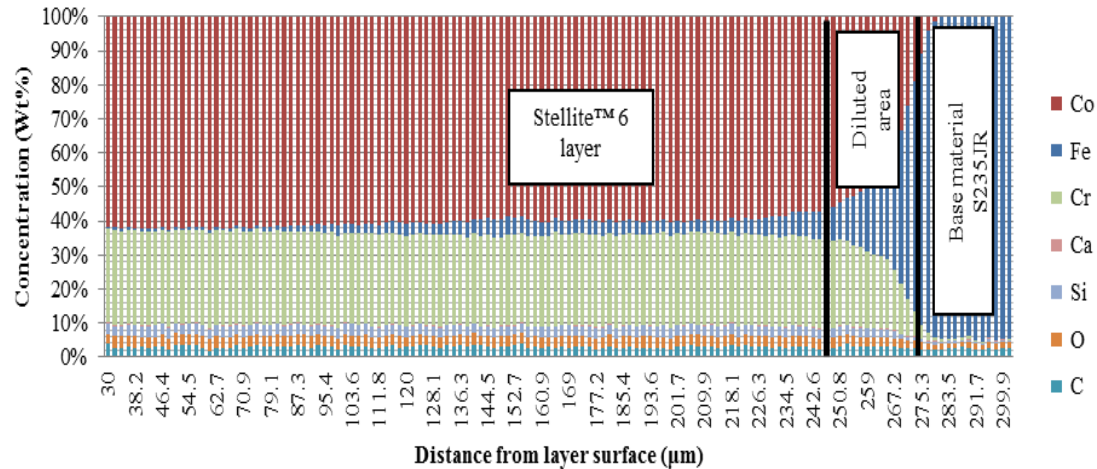


- Cross section is only a small cut-out
  - High standard deviation of crack density between micrographs
  - Crack density is measured from surface image of a large area

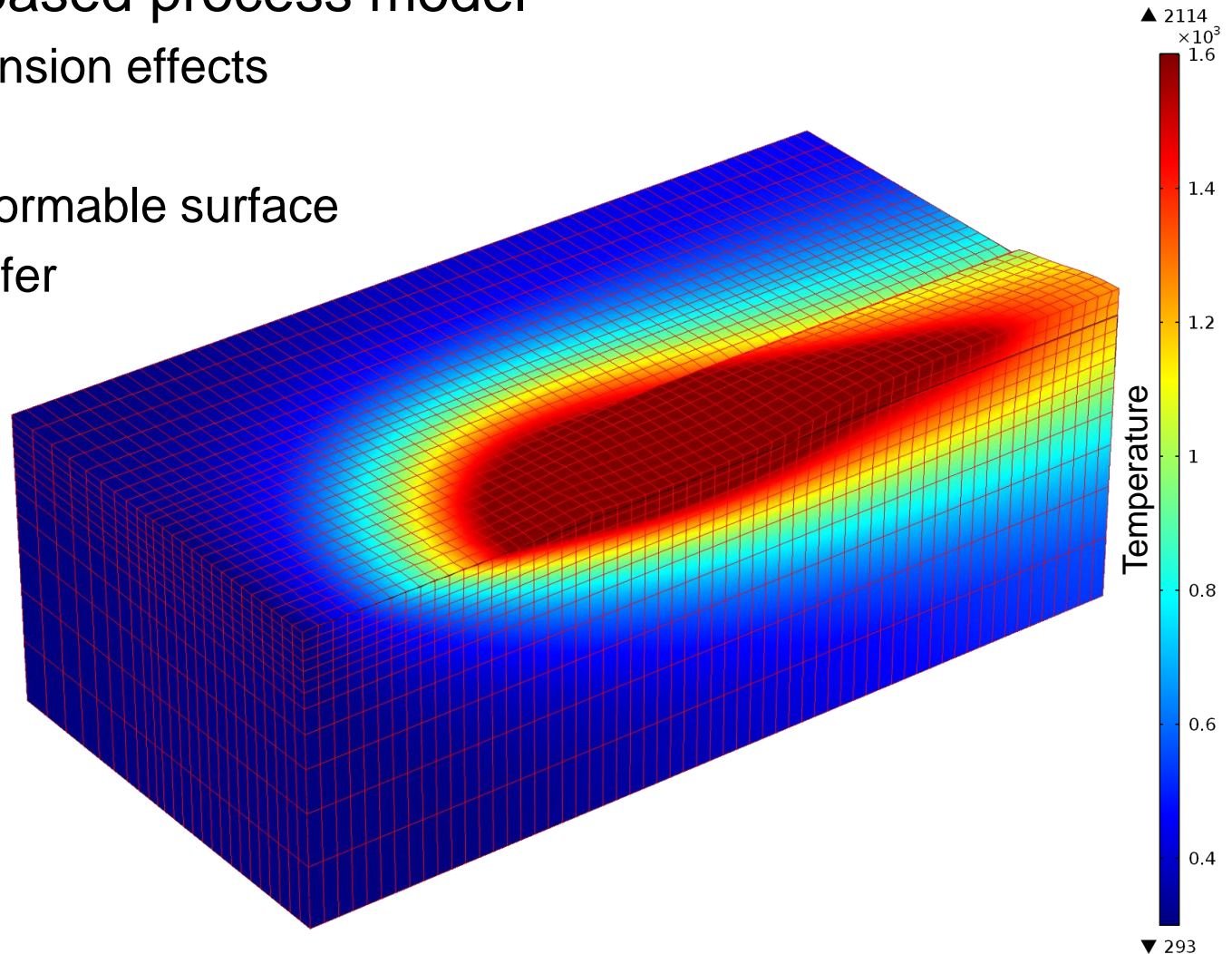
- Scanning Electron Microscopy (**SEM**)
  - Spherical dendrite tips visible
  - Hot cracking



- Energy Dispersive X-ray Spectroscopy (**EDX**)
  - Concentration profile along depth of layer
  - Only low dilution of coating with base material



- Physically based process model
  - Surface tension effects
  - Fluid flow
  - Freely deformable surface
  - Heat transfer



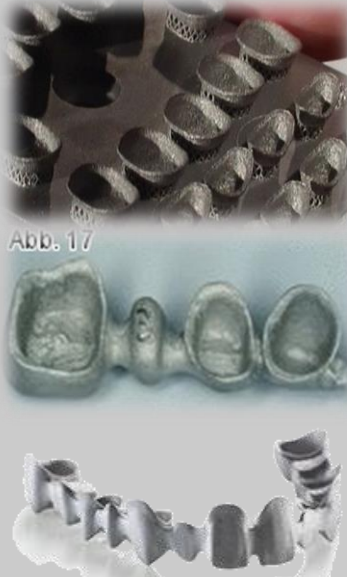
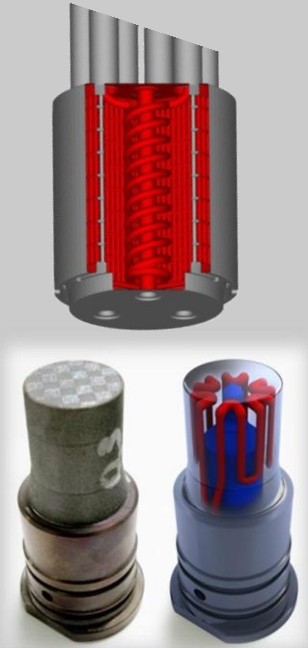


# *Part IV*

## *Applications & outlook*

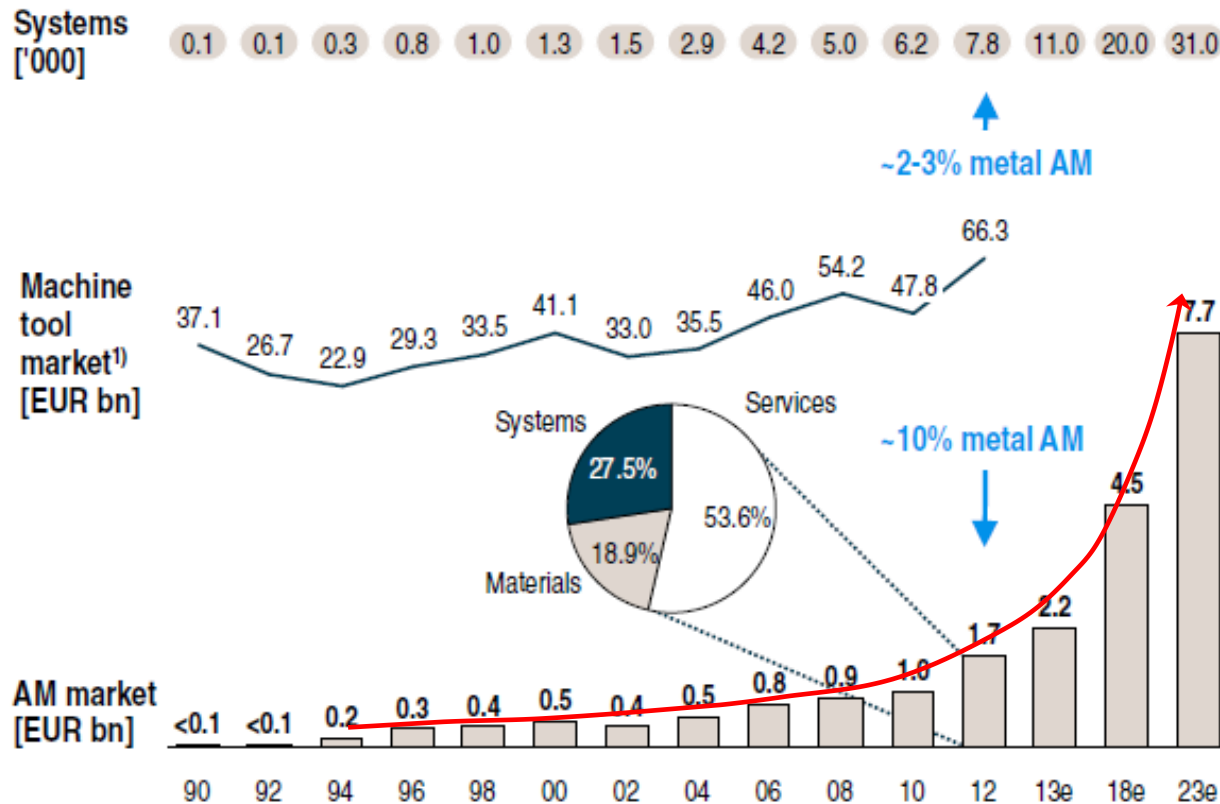
### *Summary*

- ... industrially implemented **Business-Cases** (SLM)

Turbine componentes	Jewellery	Dental products	Tooling
Injection nozzle	«Nice, complex» parts	Crowns / bridges	Conformal cooling
 <p>GE-Einspritzdüse</p>		 <p>Abb. 17</p>	

# Summary

- AM Business world-wide
  - Machines, Parts, Materials, Services



- > Primary AM market includes AM systems, materials, services as well as service provider revenues
- > Commercialization of AM started in 1987 with the SLA-1 stereo-lithography system from 3D Systems
- > Since then, the AM industry has reached a volume of nearly EUR 2 bn
- > EOS introduced the first metal AM system (EOSINT M250) in 1995
- > AM market will see double-digit growth and quadruple within the next 10 years

Roland Berger Consultants 2014

- Big expectations in additive manufacturing...

## But

- Expectations only can be fulfilled, if significant developments are done !
  - Not «Prototypen-machines», but real **Production environment**
  - Application-specific **machine concepts**
  - **Hybrid-Manufacturing**
  - **Produktivität**
  - Automatisierung der ganzen **process chain**
  - **Standardisation**





# Summary

2009

2010

2011

2012

2013

2014

2015

2016

ASTM F42  
start 2009



ISO/TC261  
start 2011



ISO-ASTM  
PSDO agreement  
Oct. 2011

**ASTM-F42**  
**ISO-TC 261**



ASTM-ISO  
joint standards  
development plan  
Jul. 2013

Cen-CENELEC  
STAIR-AM, 2012-....



**STAIR-AM**



**SASAM:**  
FP7 Project, 2012-2014



**FP7**



**TC ?**  
CEN/TC?  
2015?

**ASTM-ISO-  
CEN  
Standardisation ?**





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