# Joining Sub-Platform

## Industrial trends and demands for Arc Welding in AM Technologies

Univ.-Prof. Dr.-Ing. habil. Jean Pierre Bergmann

Technical University of Ilmenau, Germany

November 16th 2017

# Agenda

1. Introduction
2. Motivation for AM
3. Study on industrial trends for Arc AM
4. Summary

# Technische Universität Ilmenau - Germany

facts and figures

- founded in 1894
- about 7000 students
- 5 faculties (<100 professors)


Production technology group

Team is consisting of 23 research assistants, 7 technical employes and 1 full professor

Research topics are

welding of light weight materials, laser material processing
solid state welding, cladding and chipping (milling and turning)
additive manufacturing (plastics as well as metals)

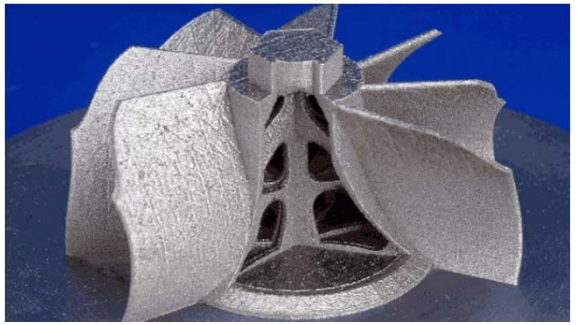
# Motivation for Additive Manufacturing

**Limits of conventional Production Technologies**

Complexity

[Autodesk]

Light weight construction



[Welt der Fertigung]

Undercuts

[RT Journal]

Individualization

[EOS]

**Additive Manufacturing as an enabling Technology**

JOINING

# Study on potentials and development

Technische Universität Ilmenau was appointed from German welding society (DVS e.V.) to perform a study and to depict potentials and research topics for arc based additiv manufacturing

Start in September 2017

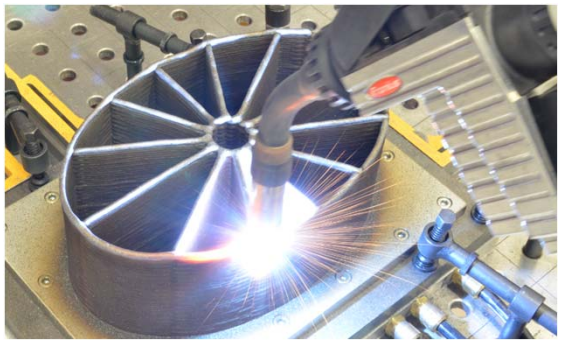
End in December 2017

Study is divided in

- a part regarding depicting of the development and state of the art (printed media, internet etc.)
- a part performing interviews with experts in Germany (20-25)

# Arc Technologies for AM

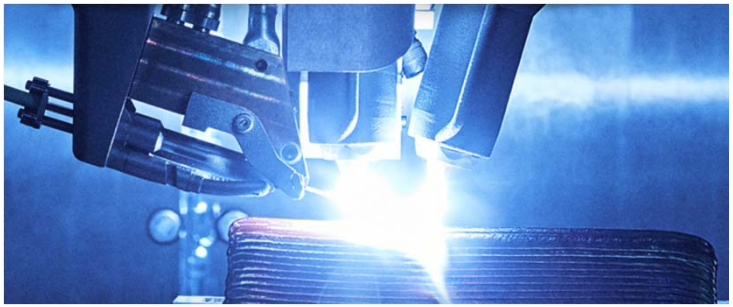
## Wire Arc Additive Manufacturing (WAAM)



[TU Ilmenau]

- GMAW and TIG processes
- feeding of wire
- low priced technical setup
- Deposition rates up to 5 kg/h and over
- little material loss compared to powder based technologies

## Plasma Deposition Manufacturing (PDM)

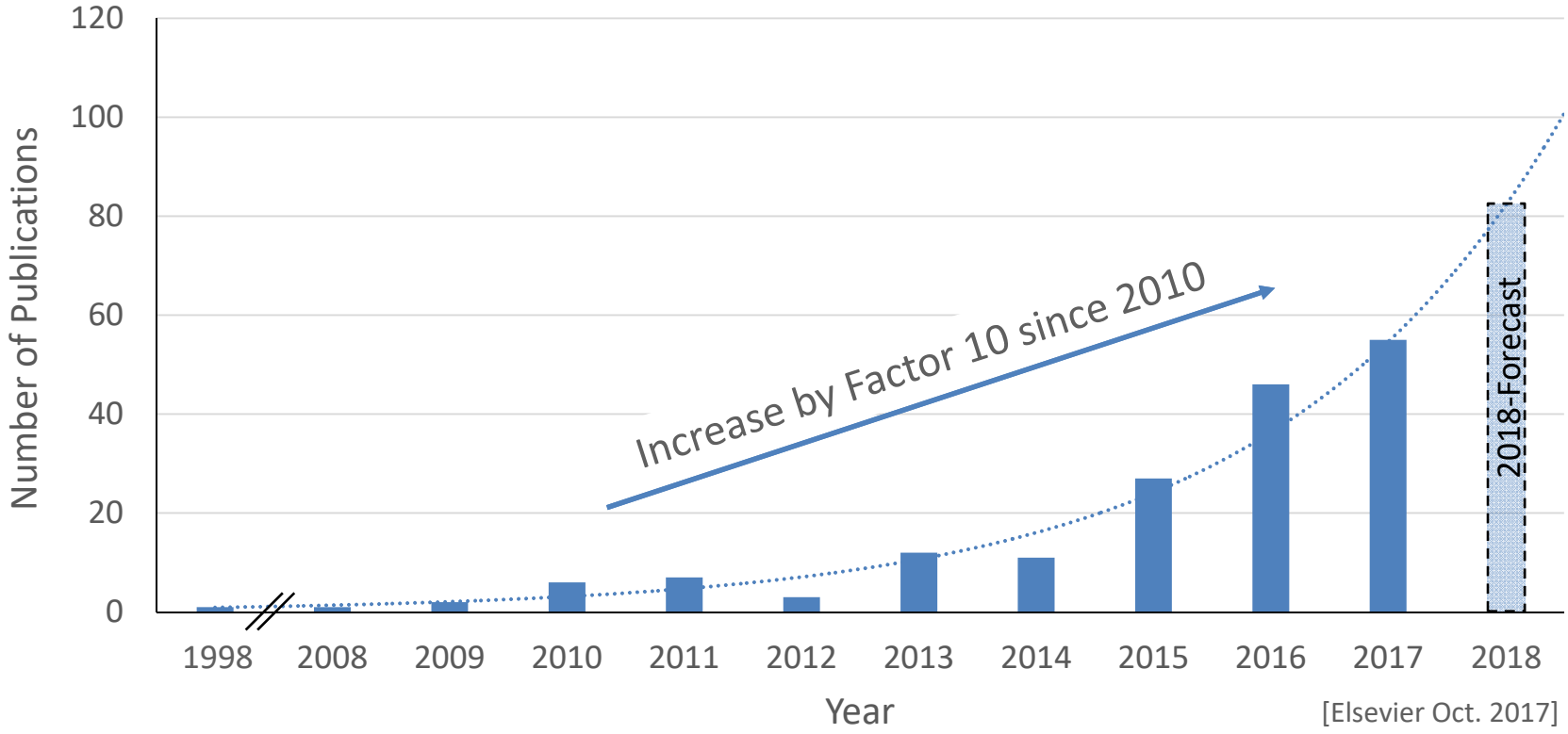


[Norsk Titanium]

- Plasma and µ-Plasma processes
- feeding of powder or wire
- Deposition rates up to 10 kg/h
- Powder availability and over spray

# Arc Technologies for AM

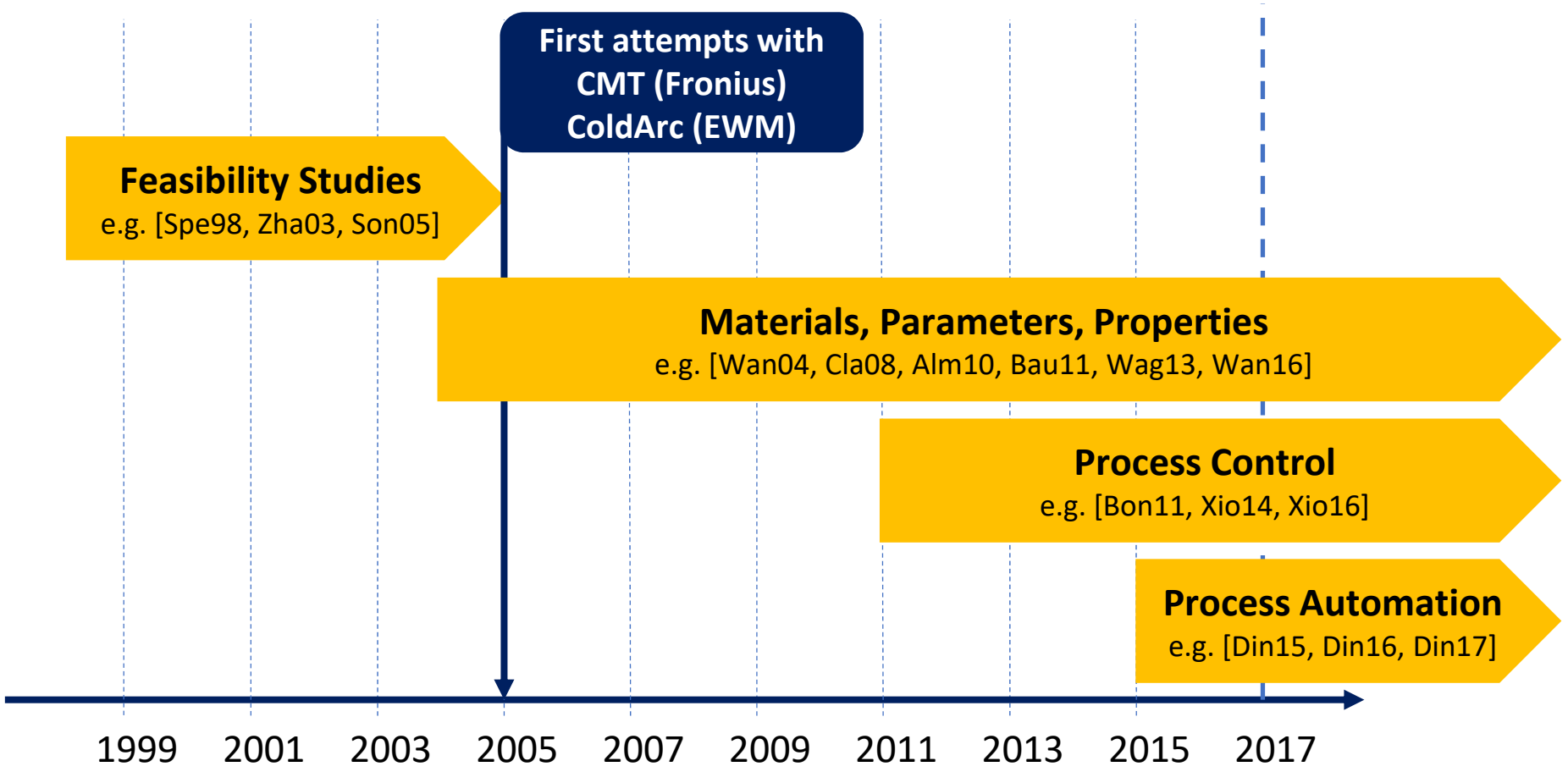
Number of Publications for Arc AM
(Database Elsevier / ScienceDirect)




[Elsevier Oct. 2017]

# Arc Technologies for AM

Content of Publications for Arc AM



# Arc Technologies for AM

Examples of ongoing Projects for Arc AM within the EU

| University / Coordinator | Project / Runtime | Content |
|---|---|---|
| ESA (European Space Agency) and 26 Academic and Industrial Partners | Project AMAZE 2013 - 2017 | AM aiming towards Zero Waste & Efficient Production - New approaches to design, materials, automation, finishing |
| Cranfield University, UK | Various Projects since 20xx | RUAM (2007-2011)<br>CAM Software Development (2014-2017)<br>Active Cooling for WAAM (2014-2017)<br>Cost Analysis Tool for WAAM (2015-2018)<br>Mixed Material Pipe Structures (2016-2019) |
| TU Ilmenau, Germany | Various Projects since 2011 | Direct industrial support<br>Temperature adjustable large Tools (2016 – 2019)<br>Composite Material Fabrication (2016 – 2018)<br>3D printed Knots for Bionic Structures (2017 – 2019) |
| University Delft / MX3D, Netherlands | Various projects since 2015 | 3D printing of various structures and materials with WAAM (bridges, sculptures etc.) |
| etc. | | |

# Arc Technologies for AM

Commercially available systems for Arc AM


[Mutoh Industries]

Mutoh Value Arc MA5000-S1 (2015)
working space - 0,125 m³
Additional subtractive Manufacturing

[GEFERTEC]

GEFERTEC GTarc 800-5 (2017)
working space - 0,8 m³
Additional subtractive Manufacturing

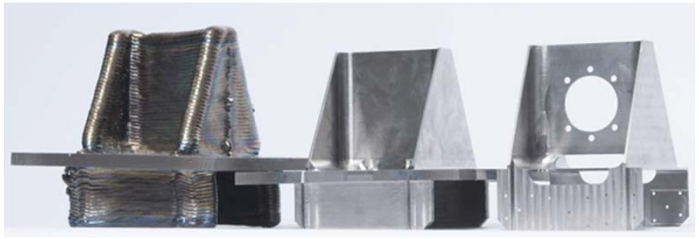
# Arc Technologies for AM

Industrial applications and markets of Arc AM

„Norsk Titanium to build world‘s first industrial-scale aerospace Additive Manufacturing plant in New York“

## Aerospace Industry

[Airbus]



[Norsk Titanium]

*Ti6-4 support for Aerospace Applications*

## Energy Industry

[TU Ilmenau]

*G19 9 L Si Impeller for Energy Applications*

## Oceanic / Offshore Industry

[GEFERTEC]

*CuAl8 Propeller for Oceanic Applications*

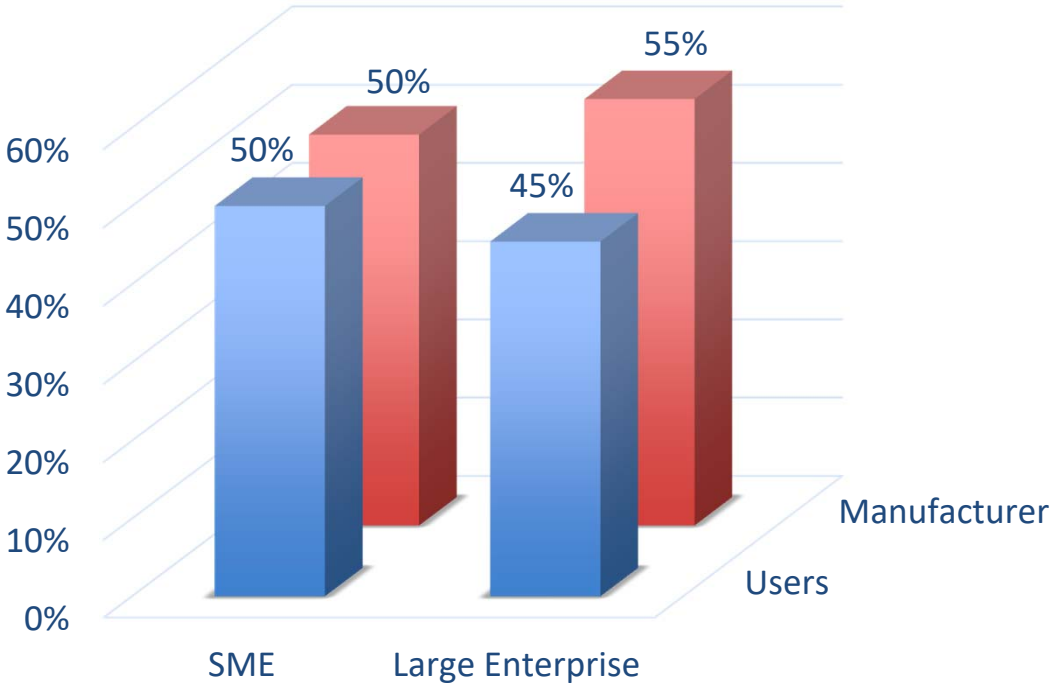
„Norsk Titanium wins award for ist Rapid Plasma Deposition 3D printing technology“

JOINING

# Interview on Industrial Trends for Arc AM

Survey based on analytic pattern concerning the following topics:

- Potentials of Arc AM
- Industrial Requirements for Arc AM Structures
- Software Integration
- Standardization
- Network Integration in context of Industry 4.0



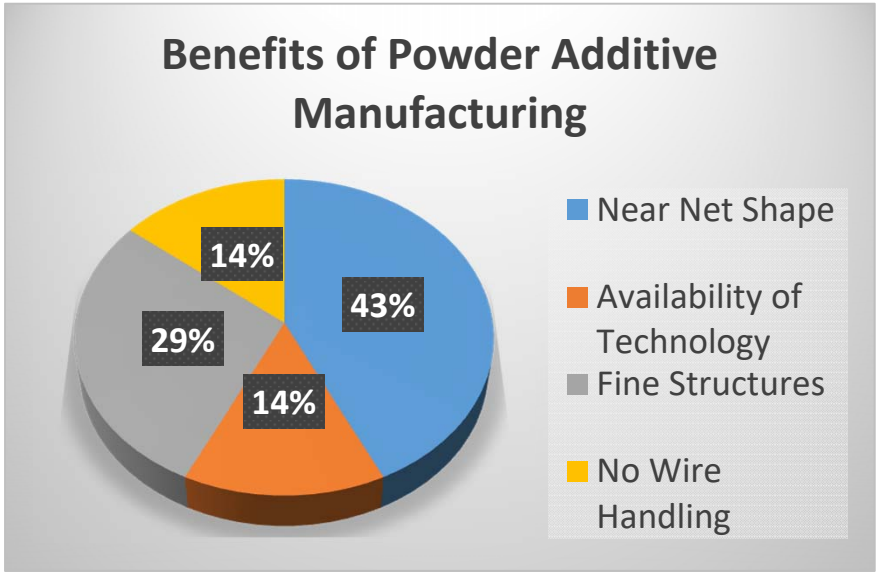

Classification and Structure of the participating Companies

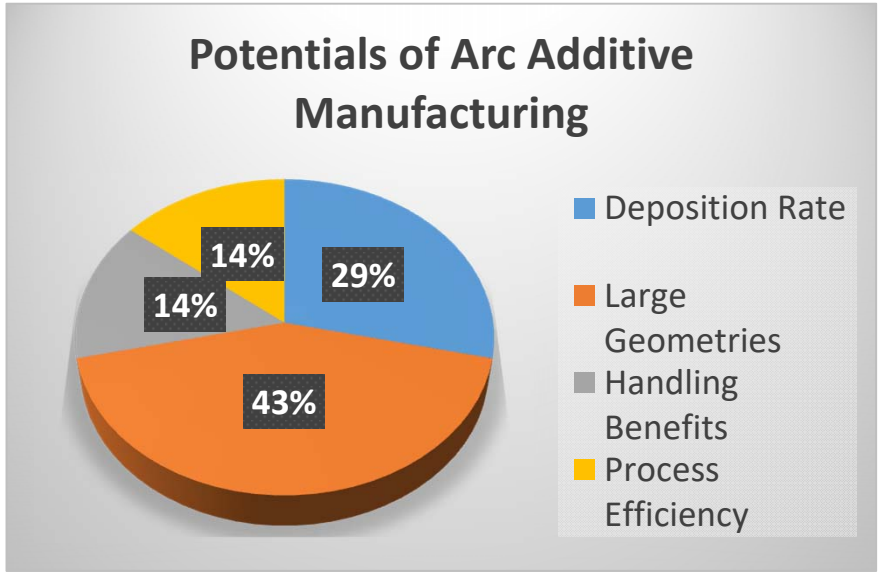
# Interviews on Industrial Trends for Arc AM

Preliminary eesults of the study (ongoing interviews)

„Why do powder based AM process have a higher popularity compared to Arc AM processes?“

„What are the main potentials of Arc Additive Manufacturing processes?“

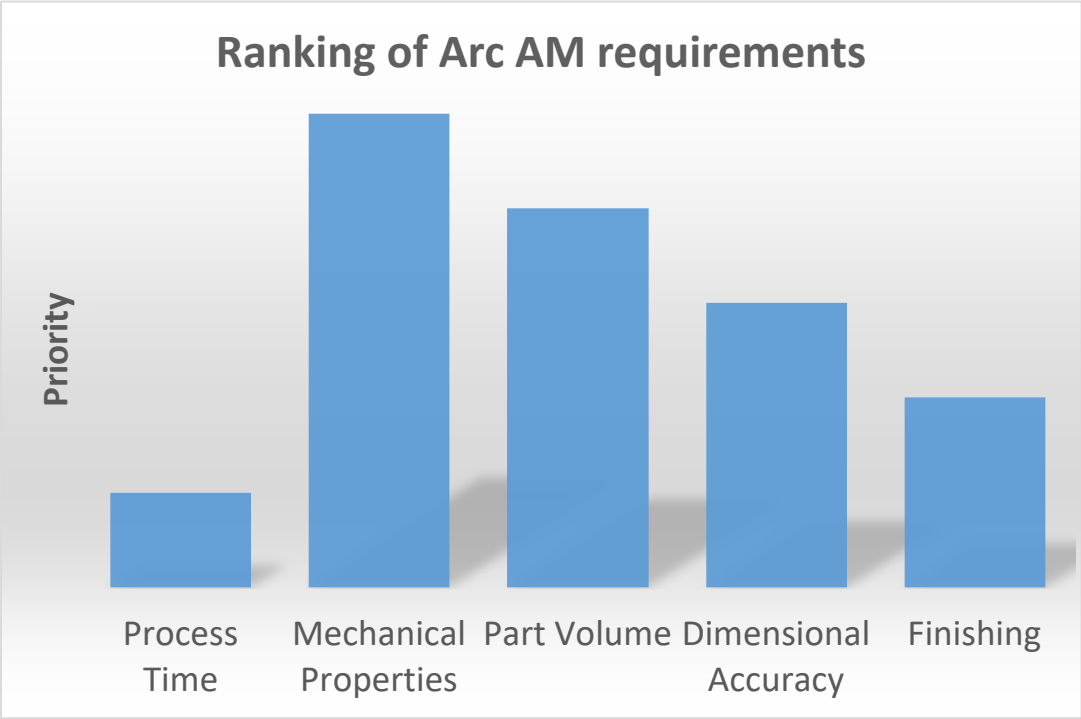


# Interviews on Industrial Trends for Arc AM

Preliminary Results of the Study (ongoing interviews)

„Please rank the following criterias for Arc AM“




Statements of the interviewed companies:

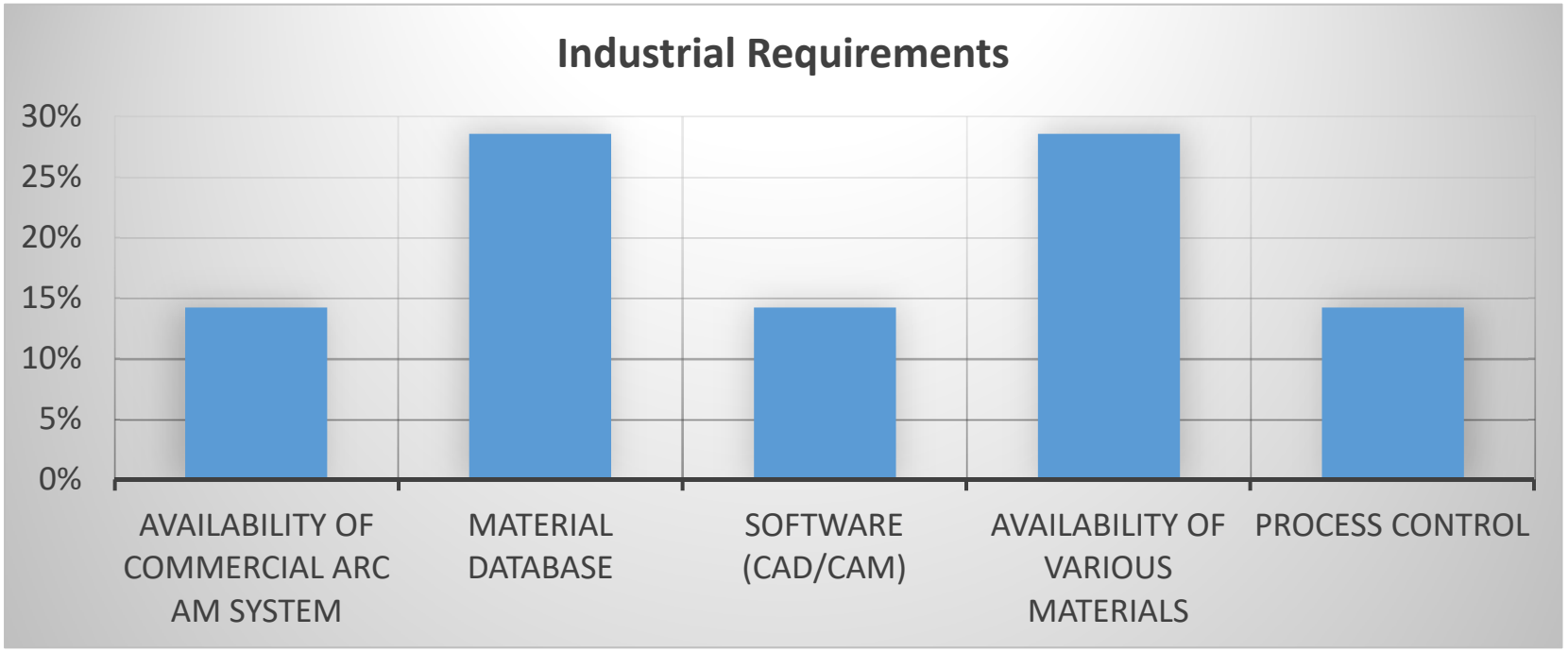
„…process time is not important due to large parts“

„The most important criteria for Arc AM is the realization of homogeneous mechanical properties.“

# Interviews on Industrial Trends for Arc AM

Preliminary Results of the Study (ongoing interviews)

„Which requirements need to be conformed in order to apply Arc AM in your company?“



# Preliminary conclusions

Topics

- Part volume is a benefit

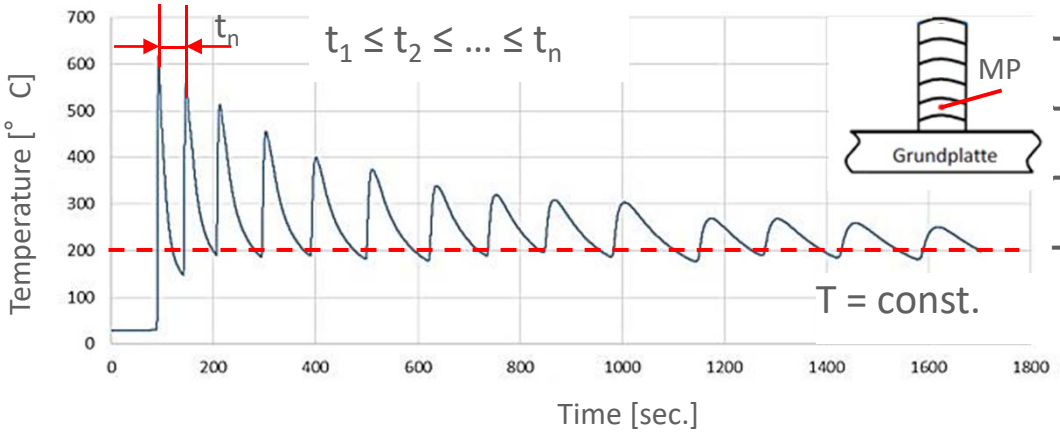
→ *machinery / process control*

- *Material properties and homogeneity of the parts*
- *Distortion*

→ *high heat input (compared to laser)*

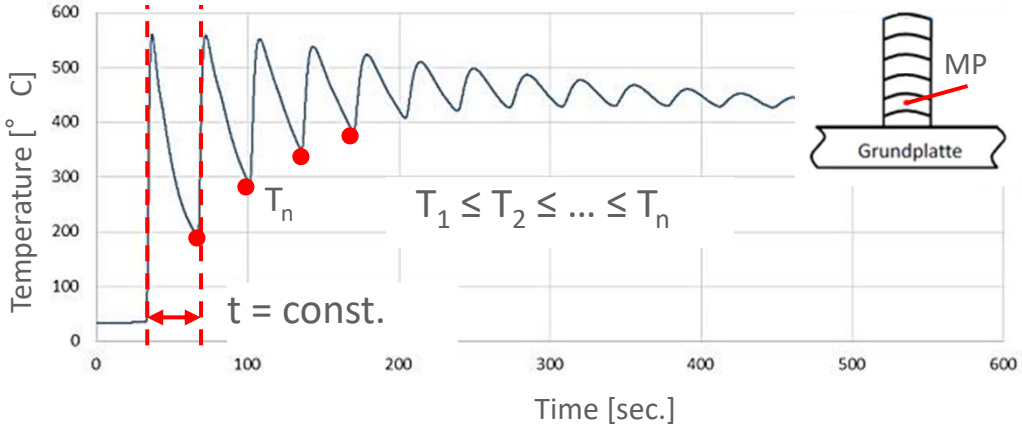
# Preliminary conclusions

Way 1: temperature controlled process




- → Defined interlayer temperatur
- → Total time is depending on cooling time
- → Higher total processing time
- → Microstructure can be modelled over the part

Way 2: time controlled process




- → Defined interlayer holding time
- → Total time is depending from holding time
- → Shorter total processing time
- → Microstructure

# Arc Technologies for AM

***Cooling or heating?***

***Material (summarised from literature)***

Unalloyed steels
High alloyed steels
Tool steels
…
Ni-Alloys
Ti-Alloys
Al-Alloys
Cu-Alloys

…can be processed, but:

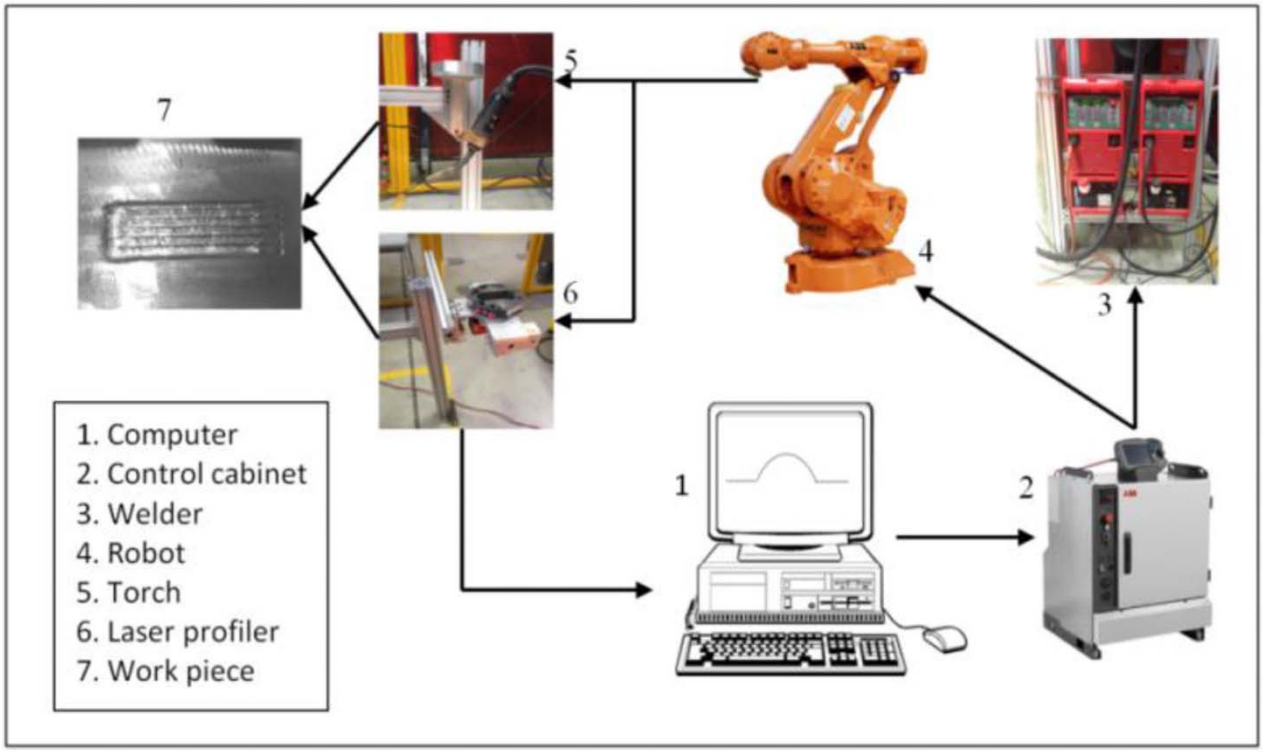
→ size effects (wall thickness, part volume)
→ mass distribution effects

are not fully described!

[TU Ilmenau]

GMAW processing „tower“
Deposition Rate: 4 kg/h
Material: unalloyed steel (G4Si1)

# Preliminary conclusions




Ding et al., (2015), Int. Journal of advanced manufacturing technologies

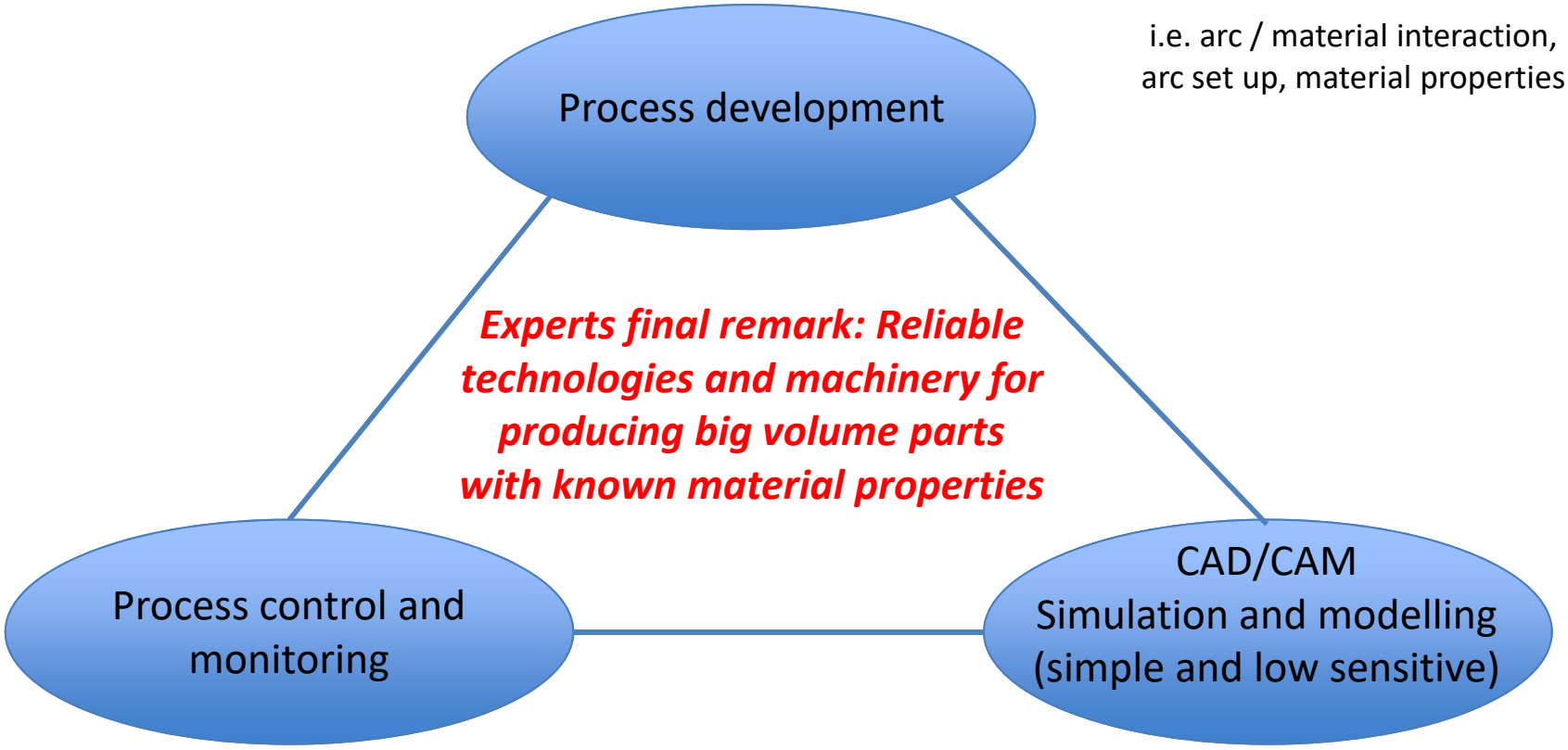
Distortion prediction and control

Microstructure prediction

Robot path

CAD/CAM

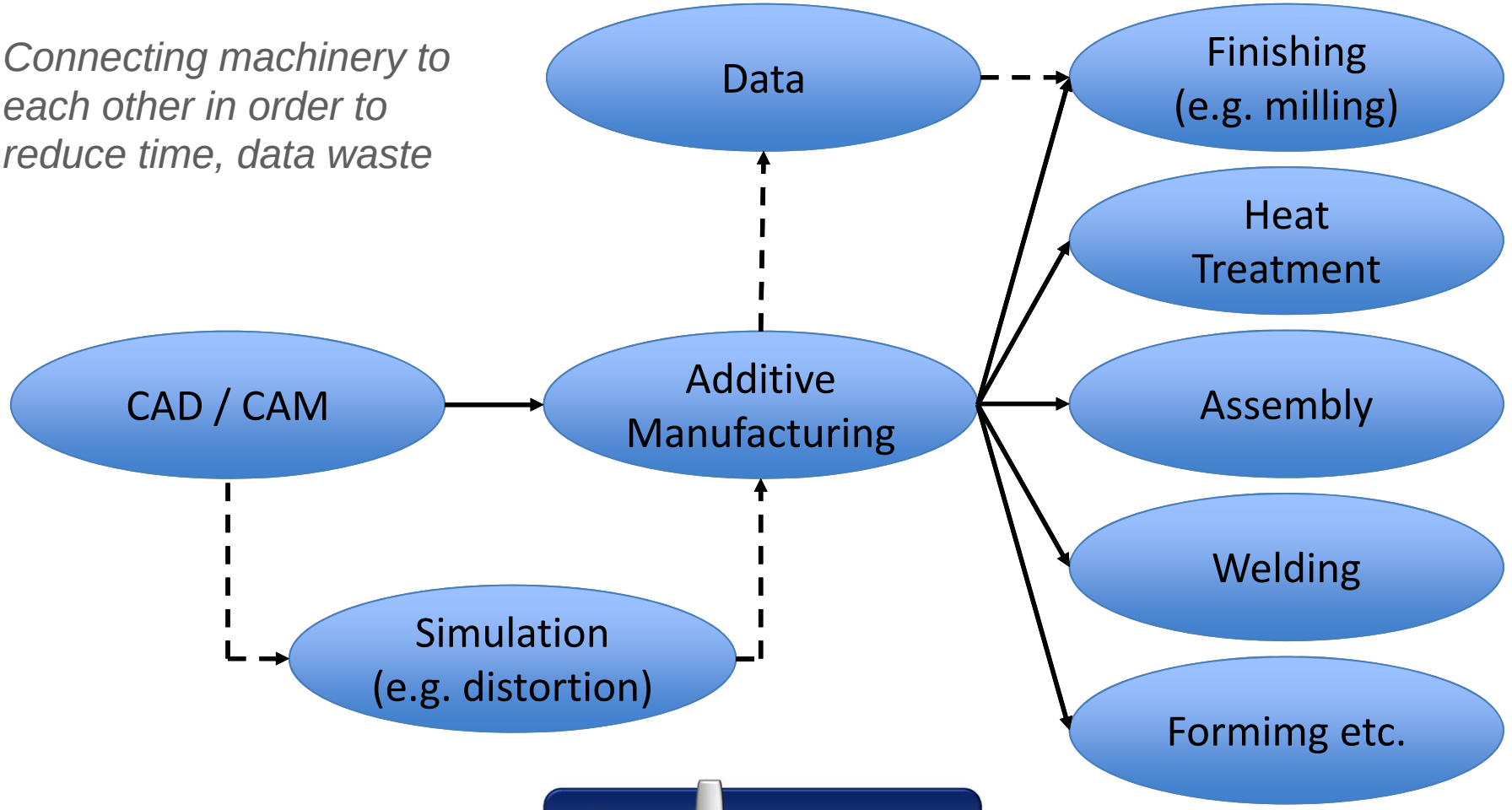
# Summary


Process development
i.e. arc / material interaction,
arc set up, material properties
Experts final remark: Reliable technologies and machinery for producing big volume parts with known material properties
Process control and monitoring
CAD/CAM
Simulation and modelling
(simple and low sensitive)
i.e. temperature, geometry…
i.e. distortion …

# Outlook

Processing Chain of future industrial Additive Manufacturing

*Connecting machinery to each other in order to reduce time, data waste*



# Thanks for your attention

**Univ.-Prof. Dr.-Ing. habil. Jean Pierre Bergmann**

**Production Technology Group**
**Faculty of Mechanical Engineering**
**Technische Universität Ilmenau**

**Tel: +49 3677 692981**
**Mail: jeanpierre.bergmann@tu-ilmenau.de**

# Literature


| | |
|---|---|
| Alm10 | Almeida, P.; Williams, S. (2010): Innovative process model of TI-6Al-4V additive layer manufacturing using cold metal transfer (CMT). In: Proceedings of the Twenty-first Annual International Solid Freeform Fabrication Symposium. |
| Bau11 | Baufeld, B., et al. (2011): Manufacturing TI-6Al-4V Components by Shaped Metal Deposition: Microstructures and Mechanical Properties. IOP Conference Series: Materials Science and Engineering, Vol. 26, Conference 1. |
| Bon11 | Bonaccorso, F.; Cantelli, L.; Muscato, G. (2011): Arc welding Control for Shaped Metal Deposition Process. 18th IFAC World Congress Milano (Italy). |
| Cla08 | Clark, D.; Bache, M.R.; Whittaker, M.T (2008): Shaped metal deposition of a nickel alloy for aero engine applications. In: In Journal of Materials Processing Technology, Volume 203, Issues 1–3, pp. 439-448. |
| Din15 | Ding, D., et al. (2015): A practical path planning methodology for wire and arc additive manufacturing of thin-walled structures. In: Robotics and Computer-Integrated Manufacturing, Vol. 34, pp. 8-19. |
| Din16 | Ding, D., et al. (2016): Bead modelling and implementation of adaptive MAT path in wire and arc additive manufacturing. In: Robotics and Computer-Integrated Manufacturing, Vol. 39, pp. 32-42. |
| Din17 | Ding, Y.; Akbari, M.; Kovacevic, R. (2017): Process planning for wire-feed metal additive manufacturing system. In: The International Journal of Advanced Manufacturing Technology, https://doi.org/10.1007/s00170-017-1179-z, last access: 10-09-2017 at 3 p.m. |
| Son05 | Song, Y.; Park, S.; Choi, D.; Jee, H. (2005): 3D welding and milling: Part I–a direct approach for freeform fabrication of metallic prototypes. In: International Journal of Machine Tools, Vol. 45, pp. 1057-1062. |

# Literature


| | |
|---|---|
| Spe98 | Spencer, J. D.; Dickens, P. M.; Wykes, C. M. (1998): Rapid prototyping of metal parts by three-dimensional welding. Proceedings of the Institution of Mechanical Engineers, Part B. In: Journal of Engineering Manufacture, Vol. 212(3), pp. 175-182. |
| Wag13 | Wagiman, A.; et al. (2013): Effect of GMAW-CMT Heat Input on Weld Bead Profile Geometry for Freeform Fabrication of Aluminium Parts. In: Applied Mechanics and Materials, Vol. 465, pp. 1370-1374. |
| Wan04 | Wang, H.; Jiang, W.; Ouyang, J.; Kovacevic, R. (2004): Rapid prototyping of 4043 Al-alloy parts by VP-GTAW. In: Journal of Materials Processing Technology, Vol. 148, pp. 93-102. |
| Wan16 | Wang, J.F., et al. (2016): Effect of location on microstructures and mechanical properties of additive layer manufactured Inconel 625 using gas tungsten arc welding. In: Materials Science and Engineering: A, Vol. 676, pp. 395-405. |
| Xio14 | Xiong, J.; Zhang, G. (2014): Adaptive control of deposited height in GMAW-based layer additive manufacturing. In: Journal of Materials Processing Technology, Vol. 214, No. 4, pp. 962-968. |
| Xio16 | Xiong, J.; Ying, Z.; Zhang, W. (2016) :Forming appearance control of arc striking and extinguishing area in multi-layer single pass GMAW based additive manufacturing. In: The International Journal of Advanced Manufacturing Technology, pp. 1-8. |
| Zha03 | Zhang, H.; Xu, J.; Wang, G. (2003) : Fundamental study on plasma deposition manufacturing. In: Surface and Coatings Technology, Vol. 171, pp. 112–118. |