6th International Conference on Additive Technologies iCAT 2016

FACHHOCHSCHULE KÄRNTEN

iCAT 2016

Nürnberg, Germany, 29. - 30. November 2016

International Conference on Additive Technologies


# Additive Manufacturing with coated Materials

## – First experimental Investigations and Design Considerations

Bernhard Heiden, Ulrich Leitner

*Nürnberg, ICAT 2016, 30th November 2016, 10:40-11:00 Room 2, Session Chair: Jochen Schmidt*

Organised by:

FH-Prof. Mag. phil. Dipl-Ing. Dr. techn. Bernhard Heiden, MBA
Wirtschaftsingenieurwesen (WING) & Engineering and Management (IEM)
www.fh-kaernten.at/wing

2016

# The Team of the Studiengang Wirtschaftsingenieurwesen (WING) and Industrial Engineering and Management (IEM)

***„Menschen, die miteinander arbeiten, addieren ihre Potenziale. Menschen, die füreinander arbeiten, multiplizieren ihre Potenziale“***

*Steffen Kirchner*

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**FH-Prof. Mag. DI Dr. Bernhard Heiden, MBA**
*Professur für Produktionstechnik*

**FH-Prof. DI Dr. Erich Hartlieb**
*Studiengangsleiter Wirtschaftsingenieurwesen*
*Professur für Innovations- und Technologiemanagement*

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**Monika Decleva, BSc**
*Wissenschaftliche Mitarbeiterin*

**Alexandra Reithofer**
*Administration*

**Teamerweiterung ab 2015/2016**
Unterstützung im Smart Lab Carinthia
- DI Reinhard Tober
- Stephan Wölcher
- Dominik Pototschnig

# Von der Idee zur erfolgreichen Marktumsetzung

InnovationsWerkstatt
KÄRNTEN

Impuls

Analyse und Zieldefinition

Ideenentwicklung und -verdichtung

Konzept-entwicklung und Geschäftsmodell

Leistungs-entwicklung und Markttest

Umsetzung und Markteinführung

smart lab
CARINTHIA
Prototyping & Industrie 4.0

- CNC
- LASER CUTTER
- SCHNEIDPLOTTER
- 3D-DRUCK / SCANNING
- ELEKTRONIK
- DESIGN / KONSTRUKTION

Konstruktion und Entwicklung

Prototypen-fertigung

Prototypen-validierung

# The FH-intradisciplinary Team for Additive Manufacturing (AM)

**FH-Prof. DI Dr. Robert Hauser**

*Professor for Physics*
*Head of Mechanical Engineering & Light Weight Construction Studiengang*
*Focus: Sensors*

**FH-Prof. Mag. DI Dr. Bernhard Heiden, MBA**

*Professor for Production Engineering*
*Focus: Manufacturing*

**FH-Prof. DI Dr. Franz Riemelmoser, MBA**

*Professor for Mechanical Engineering*
*Focus: Light Weight Materials*

**FH-Prof. DI Dr. Javad Zharbakhsh**

*Professor for FEM and Computational Engineering*
*Focus: Numerical Simulation*

**Extended Team 11-12/2016**
- Hannes Oberlercher, BSc MSc (FH)
- Thomas Martinz, Bs (FH)

**Actual Projects:**
- MMO3D – Development of a Robot Cell for AM, Interreg
- 3DDruck-FD – Development of a dental AM-application
- GENFEROS 4.0 – Qualifizierungsnetz FFG – Spreading of AM-technoligy knowledge for the industry

# Overview

- Introduction
  - System-Analysis AM → What is essential?
  - Project Background for this work
- Additive Manufacturing with Coated Materials
  - Overview
  - Triz
  - Pi-Theorem
  - Experiments
  - Results
  - Outlook

# Asymmetry AM vs. SM

AM: - Everything that can be digitalised can be produced

- Everything that as material can be
  - „extruded & be molten“
  - „pulverised & be molten“
  - „made single & is to be glued“ is suitable for an AM method

SM: - Only a small part of model materials, that can be digitalised, is producible with a SM Maschine

- The limitation of the machine lies in the outer room from the perspective of the production process (outer surface of the workpiece, outer room of the production machine)
- Everything that can be free cutted, can be manu-factured

SM = Subtractive Manufacturing AM = Additive Manufacturing

# Asymmetry AM vs. SM (I)

Conclusion:

AM: → controllable standardized phase transformation (phase change of starting material)

→ controlled standardized binding (phase change of locking agent)

→ approximation to the form coming from inside (as a production process)

SM: → controlled unstandardized cutting process (partitioning) with constant phase

→ approximation to the workpiece form from the outer side

AM = Additive Manufacturing
SM = Subtractive Manufacturing

# Asymmetry AM vs. SM (II)

Conclusion:

AM: → Phase change & inside → outside
SM: → Phase constant & outer → inner side

manufacturing

AM = Additive Manufacturing
SM = Subtractive Manufacturing

# Project Background for this work
# Project MMO3D

## Project Partner:

- Carinthia University of Science - Studiengänge Mechanical Engineering, Systems Engineering and Industrial Engineering and Management (Austria)
- Oprema Ravne (Slowenja, Leadpartner)
- Holzkompetenzzentrum W3C, (Austria)
- University Ljubljana (Slowenja, Institut of Robotiks)
- Roboteh (Slowenja)

Schematic fig. of the faser manipulation process*

## Goal of Innovation:

- adaptation of a 6-axis robot with a molding technology and a faser manipulator.
- production of geometrically complex products with high strength lightweight materials

  → applications in E-mobility and medical technology.

* http://www.fh-kaernten.at/unser-studienangebot/engineering-it/aktuelles/news-archiv/news-archiv-list/news-archiv-details/entwicklung-von-roboterzellen-fuer-den-3d-druck/ 30.11.2016

FACHHOCHSCHULE KÄRNTEN

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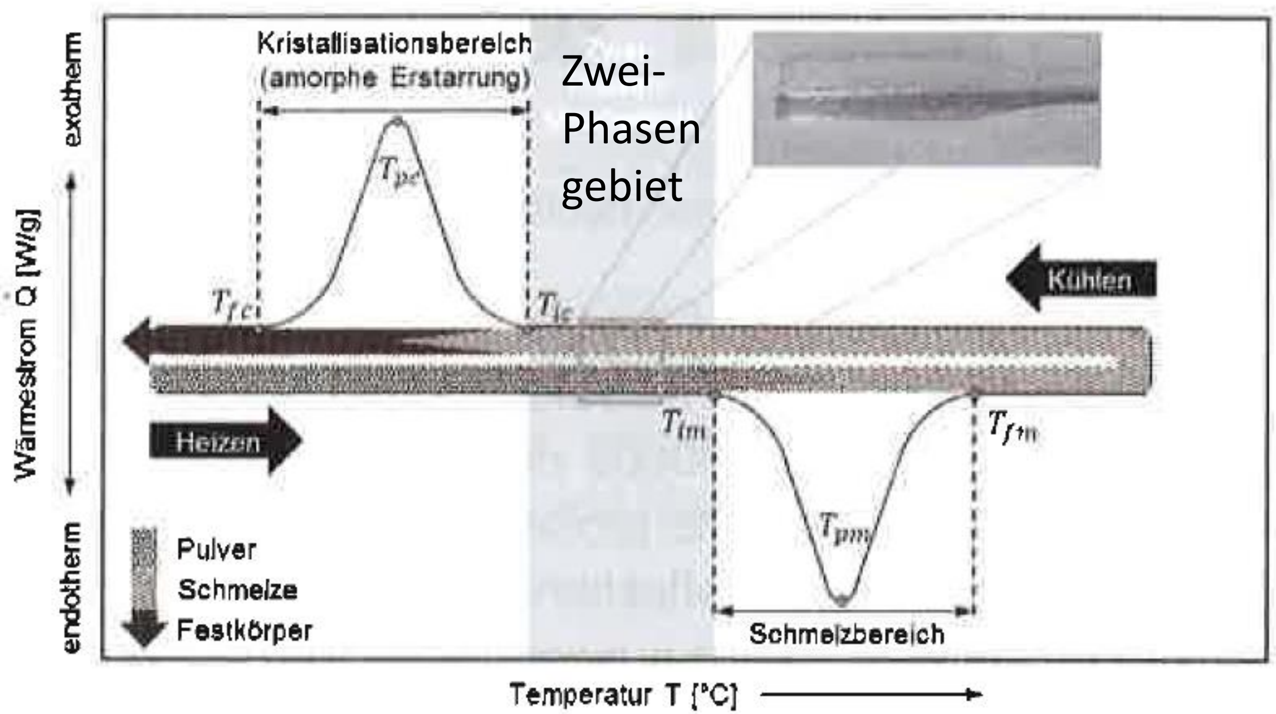



Abb. 7.4 Schematischer Verlauf einer DSC-Kurve eines teilkristallinen Thermoplasten

*[WiG15]

# EVOLUTIVE STEPS (Bifurkations)



| i3.0 | i4.0 | i5.0 |
|---|---|---|
| SM:<br>*Phasenkonstanz<br>*außen → innen<br>*außen control CNC | AM:<br>* Phasenänderung<br>* innen → außen<br>* außen control CNC | AMSO(1):<br>* Phasenänderung<br>* innen → außen<br>* innen control SOC * |
| | | AMSO(2):<br>* Phasenkonstanz<br>* innen → außen<br>* innen control SOC |
| | | AMSO(3):<br>* Phasenänderung<br>* außen → innen<br>* innen control SOC |

Legende:

AMSO = Additive Manufacturing Self Organized
AM = Additive Manufacturing
SM = Subtractive Manufacturing
CNC = Computer Numerical Control
SOC= Self Organized Control

# Additive Manufacturing with Coated Materials

–

# First experimental Investigations and Design Considerations

# Digitalisation of a line

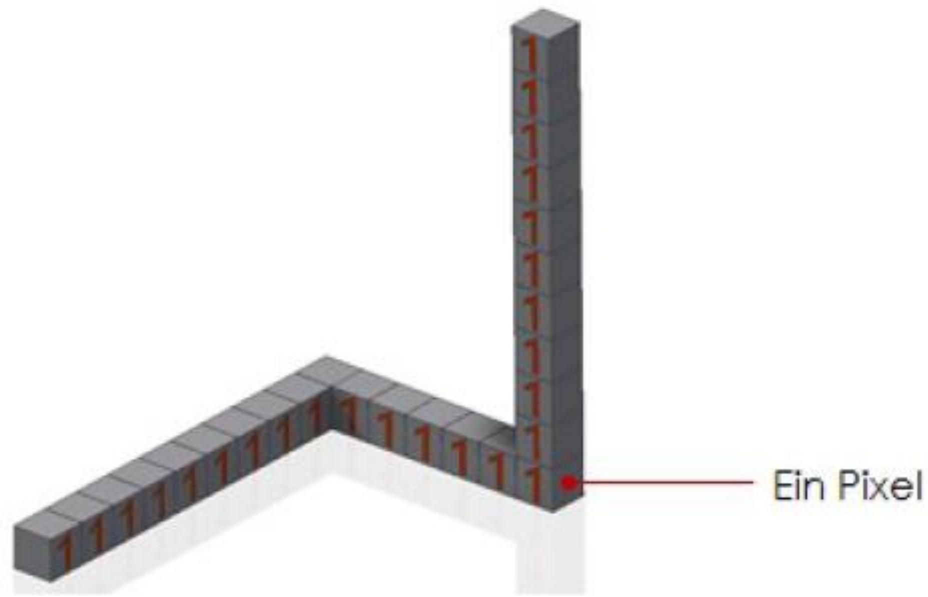



**Abbildung 1: Räumliche Materialisierung von Pixelpunkten**

*

[LeU16]

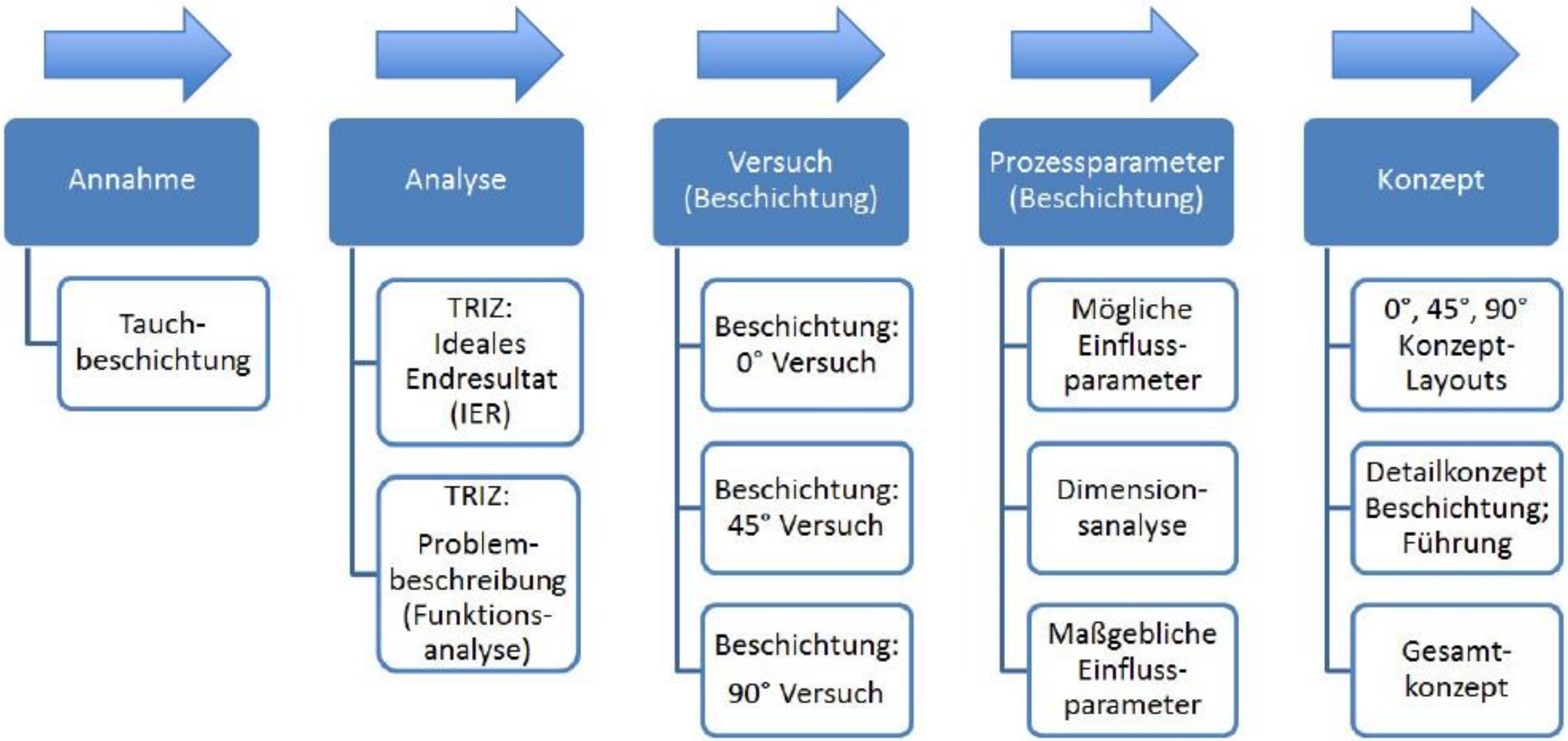
# Overview of the proposed coating process

Konzepterstellung für einen Prototypen eines 3D Druckers

- Herstellung des Verbund Werkstoffs (ausgewählte Materialien)
- Beförderung und Führung des Verbundwerkstoffes
- Konzept einer Anordnung von Druckerkomponenten


[LeU16]

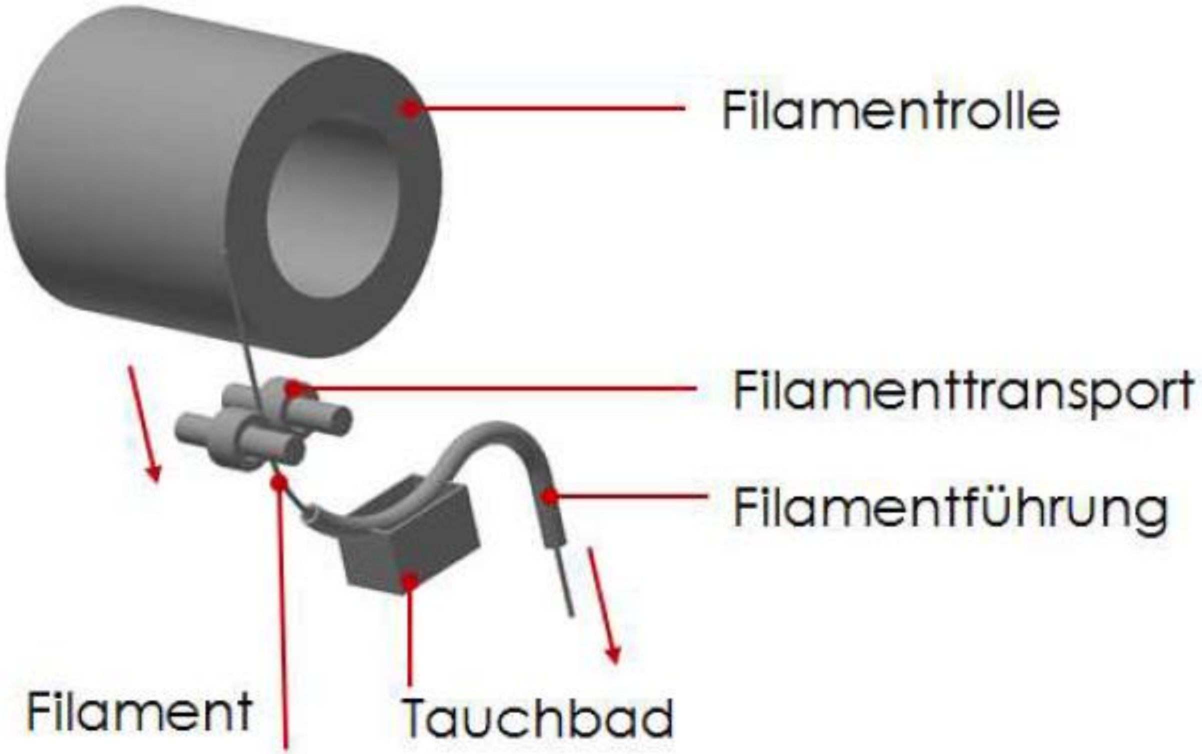
# Design and experimental method




[LeU16]

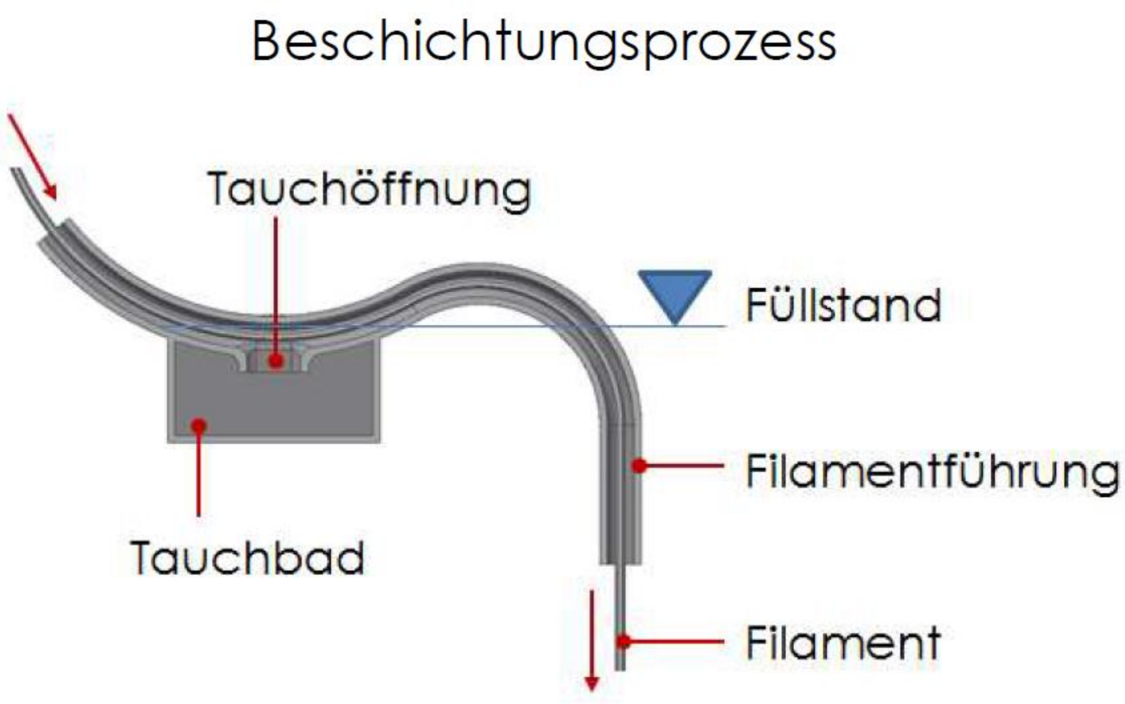
# Coating process – first idea (I)

- Beschichtung des GF-Filaments im Tauchbad
- Filamenttransport durch angetriebene Rollen
- Filamentführung nach der Beschichtung berührungslos




[LeU16]

# Coating process – first idea (II)




[LeU16]

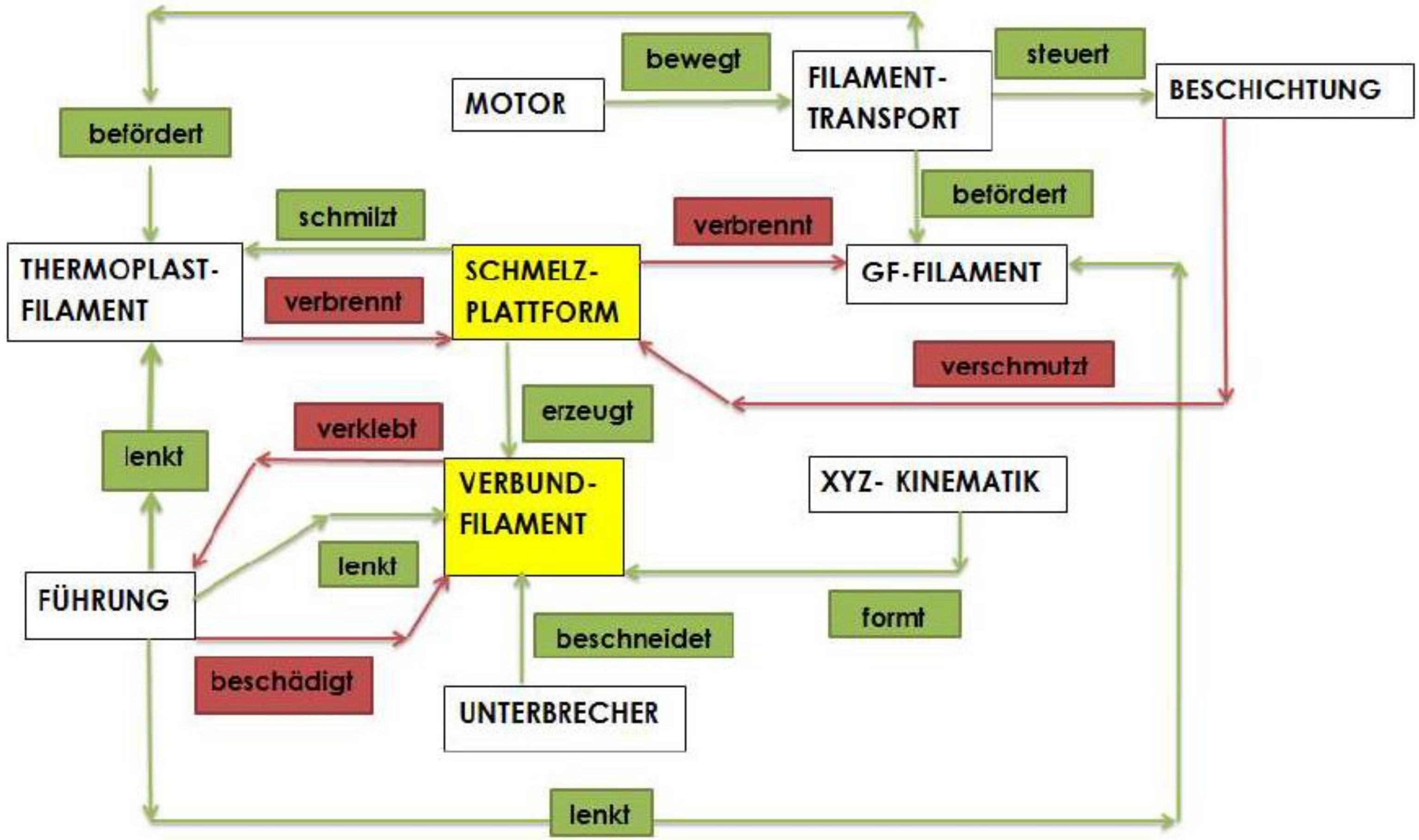
# Ideal final result with TRIZ

- Bester denkbarer Zielzustand
- Bewusst überzeichnete Formulierung des Systems
- Ausbruch aus gewohnten Denkmustern
- Motivation für neue Orientierungen

  - Kernfilament mit Beschichtung – Verbundfilament
  - Verschiedene Beschichtungsdicken
  - Berührungslose 3D Beförderung des Verbundfilaments

[LeU16]

# Functional analysis with TRIZ




[LeU16]

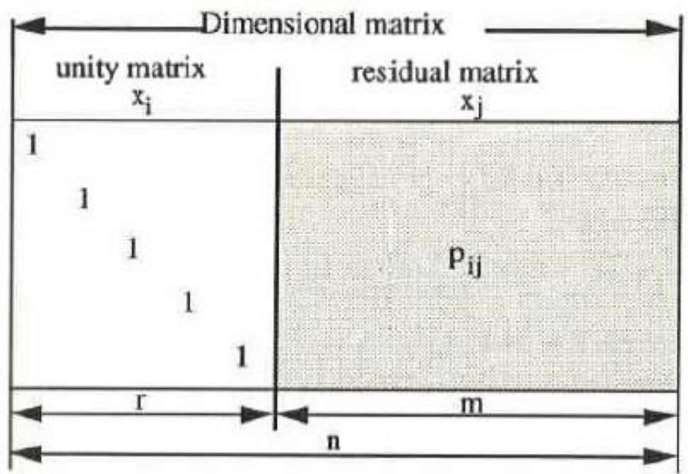
# Dimensionsanalyse [1]

**Parameter** Temperatur, Viskosität...

(Mögliche)

**Dimensions-matrix**

(m=n-r)




**PI-Zahlen**

(Dimensionslos)

$$\pi(1) = \frac{d}{\Delta T^0 * vD^{-1} * vF^1 * g^0} = \frac{d * vD}{vF} \quad \left[\frac{m * \frac{m}{s}}{\frac{m^2}{s}}\right]$$

**Dimensionslose Kennzahlen (Reynolds...); Einfluss-parameter; Zähigkeit (Viskosität)**

[ZIM91]

# Dimensional Matrix

| | ΔT [K] | vD [m/s] | vF [m²/s] | g [kg/ms²] | d [m] | ρF [kg/m³] | ρD [kg/m³] | βL [1/K] | θ [K] | vF [m/s] | σF [kg/s²] | vD [m²/s] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperatur [K] | 1 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 1 | 0 | 0 | 0 |
| Länge[m] | 0 | 1 | 2 | -1 | 1 | -3 | -3 | 0 | 0 | 1 | 0 | 2 |
| Zeit[s] | 0 | -1 | -1 | -2 | 0 | 0 | 0 | 0 | 0 | -1 | -2 | -1 |
| Masse[kg] | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 |

| | | | | | PI 1 | PI 2 | PI 3 | PI 4 | PI 5 | PI 6 | PI 7 | PI 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ΔT [K] | vD [m/s] | vF [m²/s] | g [kg/ms²] | d [m] | ρF [kg/m³] | ρD [kg/m³] | βL [1/K] | θ [K] | vF [m/s] | σF [kg/s²] | vD [m²/s] |
| Temperatur [K] | **1** | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 1 | 0 | 0 | 0 |
| Länge[m] | 0 | **1** | 0 | 0 | -1 | -2 | -2 | 0 | 0 | 1 | -1 | 0 |
| Zeit[s] | 0 | 0 | **1** | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| Masse[kg] | 0 | 0 | 0 | **1** | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 |

[LeU16]

# 11 influence Parameters → 8 Pi-Numbers

$$\pi(1) = \frac{d}{\Delta T^0 * vD^{-1} * vF^1 * g^0} = \frac{d * vD}{vF} \quad \left[\frac{m * \frac{m}{s}}{\frac{m^2}{s}}\right]$$ Reynoldszahl

$$\pi(2) = \frac{\rho F}{\Delta T^0 * vD^{-2} * vF^0 * g^1} = \frac{\rho F * vD^2}{g} \quad \left[\frac{\frac{Kg}{m^3} * \frac{m^2}{s^2}}{\frac{Kg}{m * s^2}}\right]$$

$$\pi(3) = \frac{\rho D}{\Delta T^0 * vD^{-2} * vF^0 * g^1} = \frac{\rho D * vD^2}{g} \quad \left[\frac{\frac{Kg}{m^3} * \frac{m^2}{s^2}}{\frac{Kg}{m * s^2}}\right]$$

$$\pi(4) = \frac{\beta L}{\Delta T^{-1} * vD^0 * vF^0 * g^0} = \beta L * \Delta T^1 \quad \left[\frac{1}{K} * K\right]$$

$$\pi(5) = \frac{\theta}{\Delta T^1 * vD^0 * vF^0 * g^0} = \frac{\theta}{\Delta T} \quad \left[\frac{K}{K}\right]$$

$$\pi(6) = \frac{vF}{\Delta T^0 * vD^1 * vF^0 * g^0} = \frac{vF}{vD} \quad \left[\frac{\frac{m}{s}}{\frac{m}{s}}\right]$$

$$\pi(7) = \frac{\sigma F}{\Delta T^0 * vD^{-1} * vF^1 * g^1} = \frac{\sigma F * vD}{vF * g} \quad \left[\frac{\frac{Kg}{s^2} * \frac{m}{s}}{\frac{m^2}{s} * \frac{Kg}{m * s^2}}\right]$$

$$\pi(8) = \frac{vD}{\Delta T^0 * vD^0 * vF^1 * g^0} = \frac{vD}{vF} \quad \left[\frac{\frac{m^2}{s}}{\frac{m^2}{s}}\right]$$

[LeU16]

# Oh vs. Re

$$1 \leq PI = \frac{\mathrm{Re}}{\sqrt{We}} = \frac{\sqrt{\rho r \gamma}}{\mu} \leq 10^{*}$$

$$Oh = \frac{\sqrt{\mathrm{We}}}{\mathrm{Re}} = PI^{-1}$$

$$Oh = \frac{\sqrt{\mathrm{We}}}{\mathrm{Re}} = \frac{Z\ddot{a}higkeitskraft}{\sqrt{Oberfl\ddot{a}chenkraft}}$$

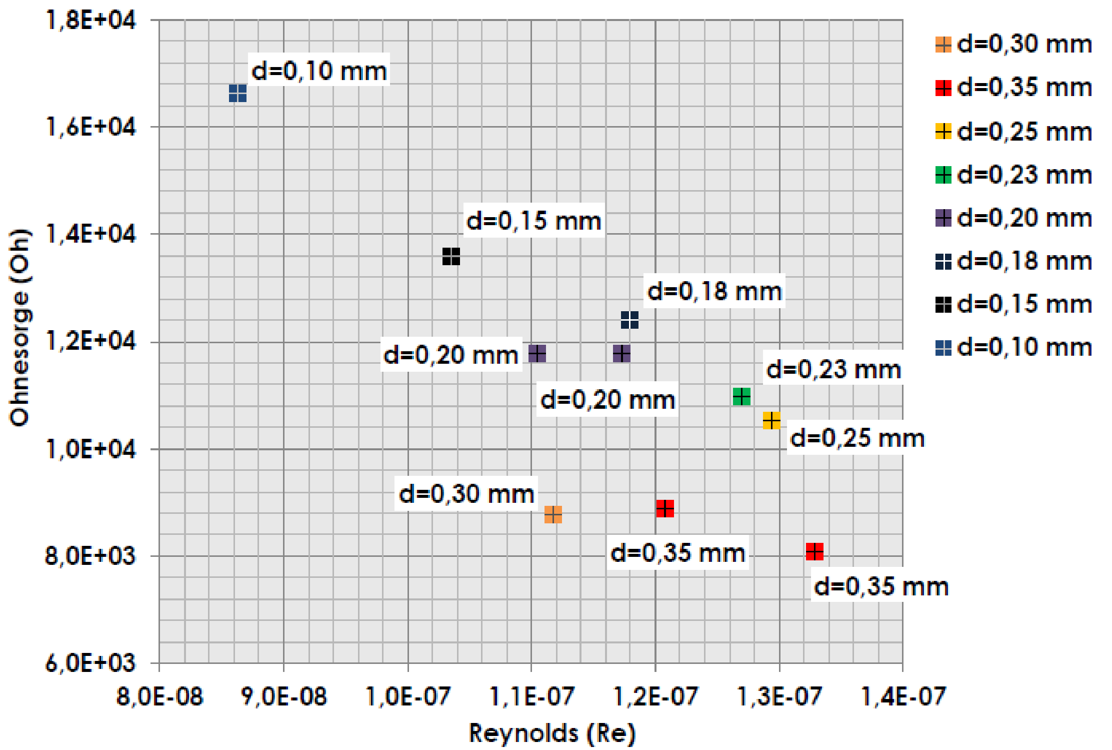



Figure 1: Oh vs. Re with the fiber coating thickness d as a parameter according to [1]

[LeU16], *for inks [Gil15]

PI …Printing indicator

# Experimental Setup (1)

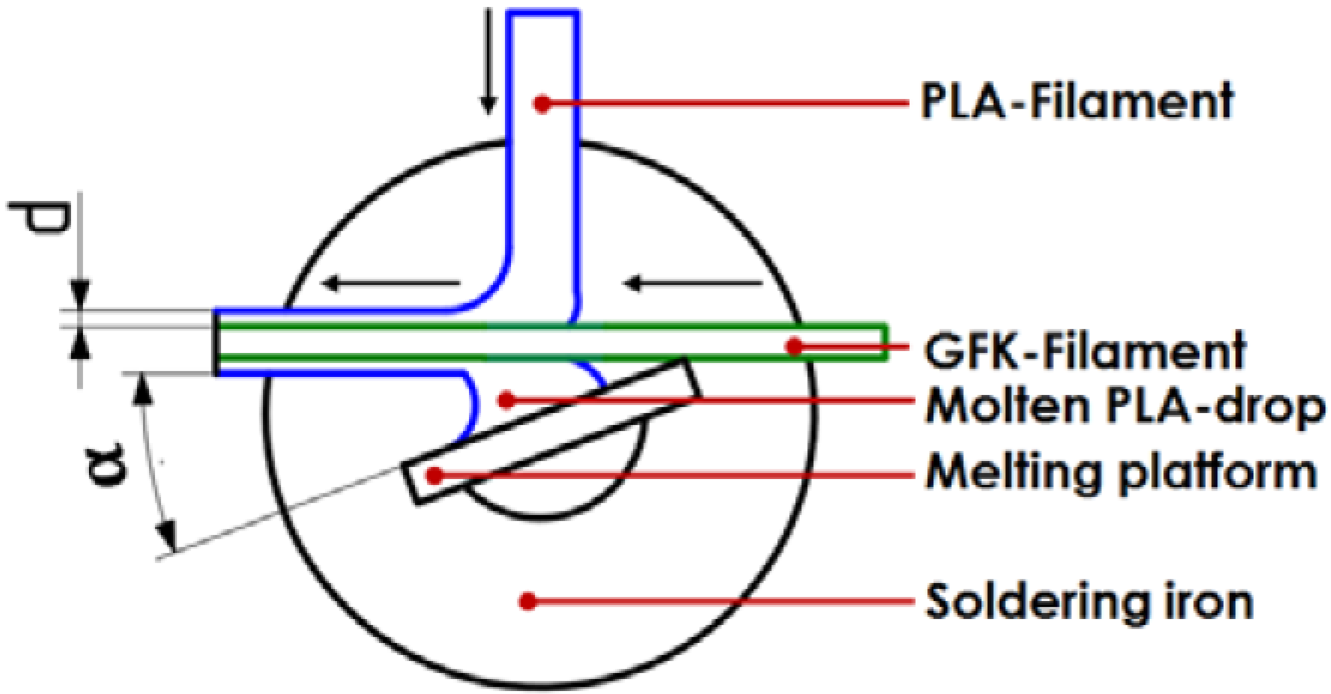
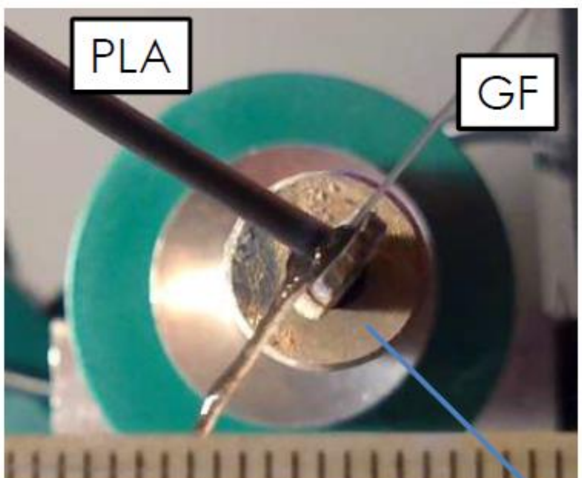
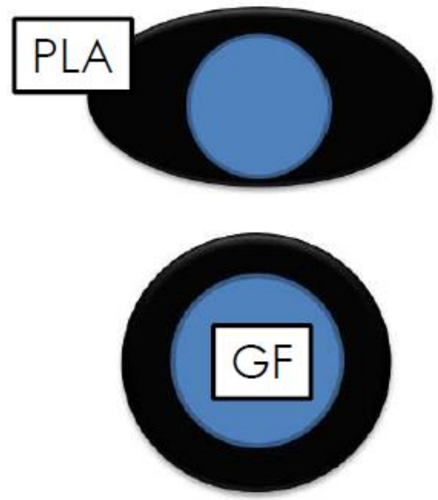



Figure 3: coating concept – principal process layout [1]; the GFK-fiber is coated with the PLA-filament with coating thickness d

# Experimental Setup (2)

- Schmelzplattform mittels Lötkolben
- GF-Filament mit PLA-Beschichtung
- Geometrisch verschiedene Versuchsaufbauten (Anstellung der Lötkolbenspitze unter 0°, 45° und 90° zur Horizontalen
- Unterschiedliche Beschichtungsgeometrien




0; 45°
Elliptisch

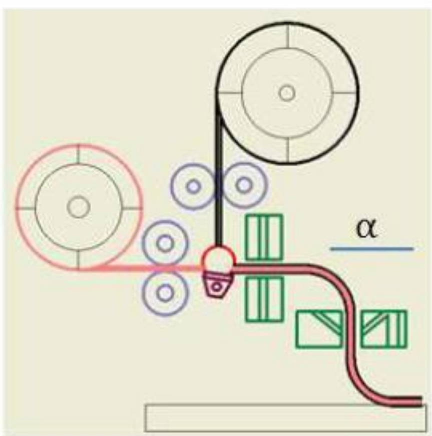
90°
Rund

Lötkolben; Schmelzplattform

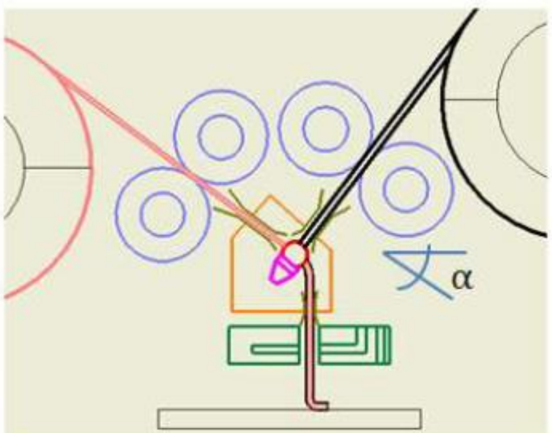
[LeU16]

# 3 Concepts

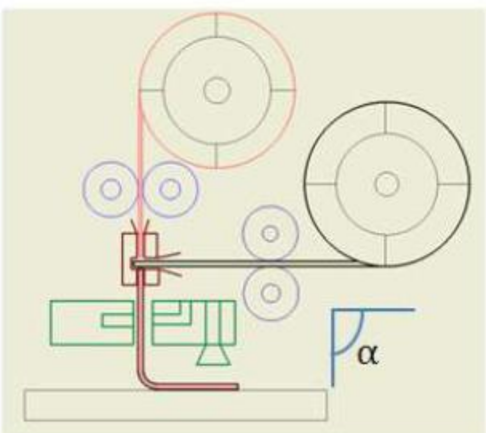
- Drei Konzepte
- Abgeleitet aus den Versuchen
- Filamentbeschichtung, -beförderung, -führung




Horizontal (α 0°)




Schief (α 45°)




Vertikal (α 90°)

[LeU16]

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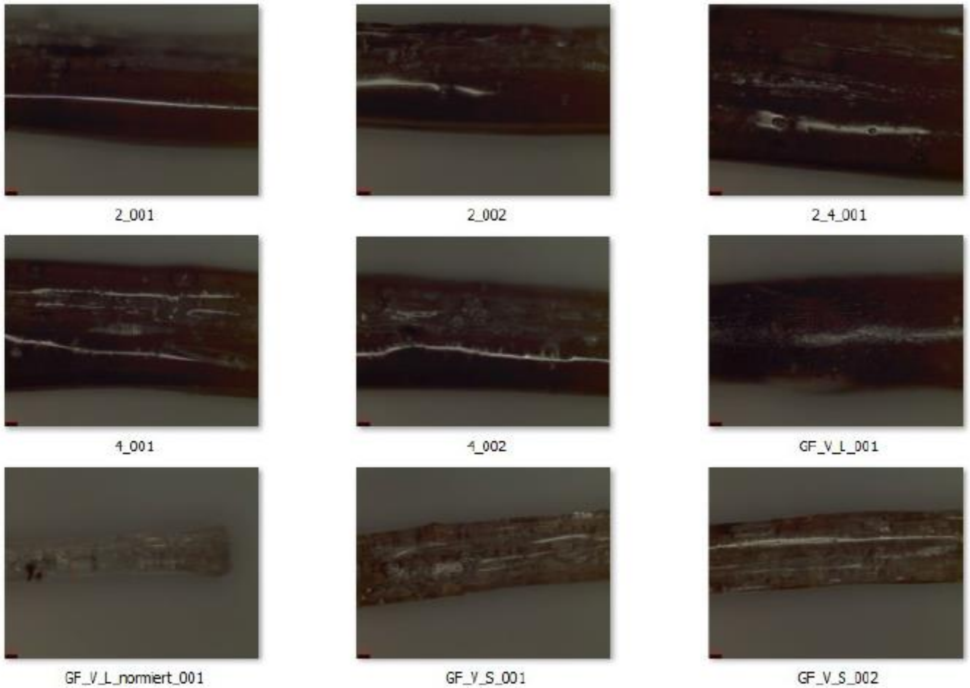


**Abbildung 23: Auszug der Mokroskopaufnahmen der ersten Versuchsreihe**

Beschichtungsdicke GF | V | L: (1 mm – 0,3 mm)/2 **=** 0,35 mm

Beschichtungsdicke GF | V | S: (0,6 mm – 0,3 mm)/2 **=** 0,15 mm

2 mm / 1 sec - *Probe GF | V | S (Glasfaser | Vorschub | Schnell)*

1 mm / 1 sec – *Probe GF | V | L (Glasfaser | Vorschub | Langsam)*

[LeU16]

# Best working concept

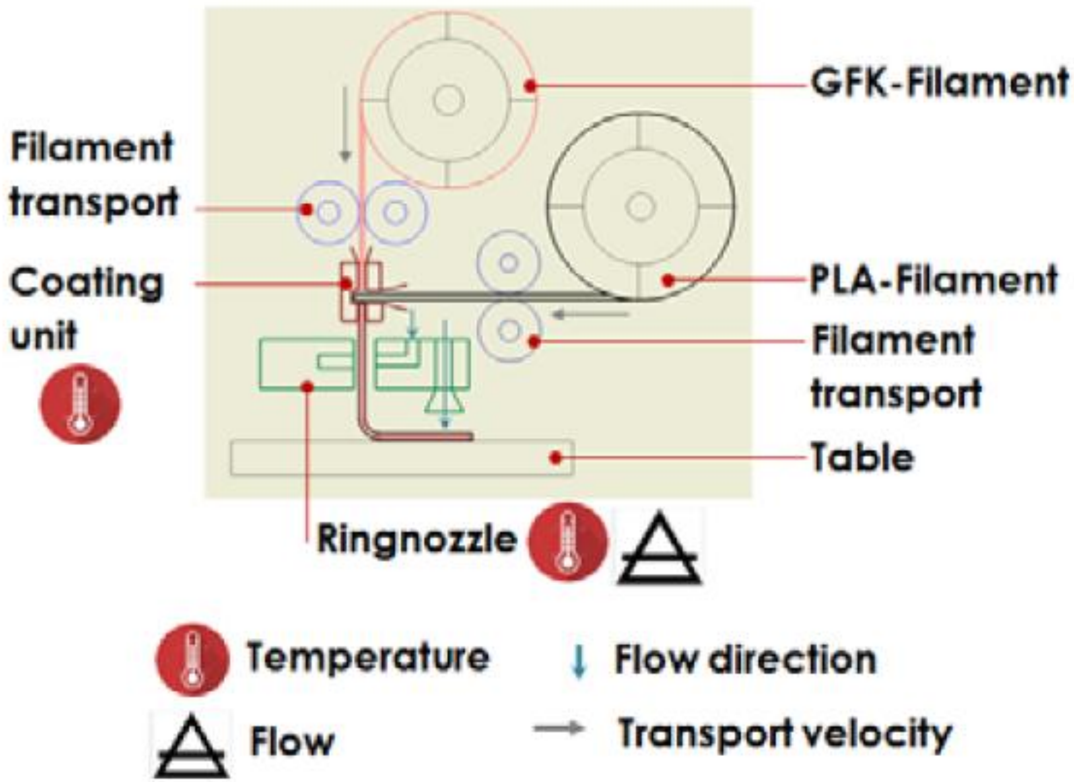


Figure 2: Additive manufacturing concept for coated fibers - vertical layout [1]

[LeU16]

# Experiment with soldering iron and fiber

Der Versuch – Beschichtung eines Glasfaser-Filament

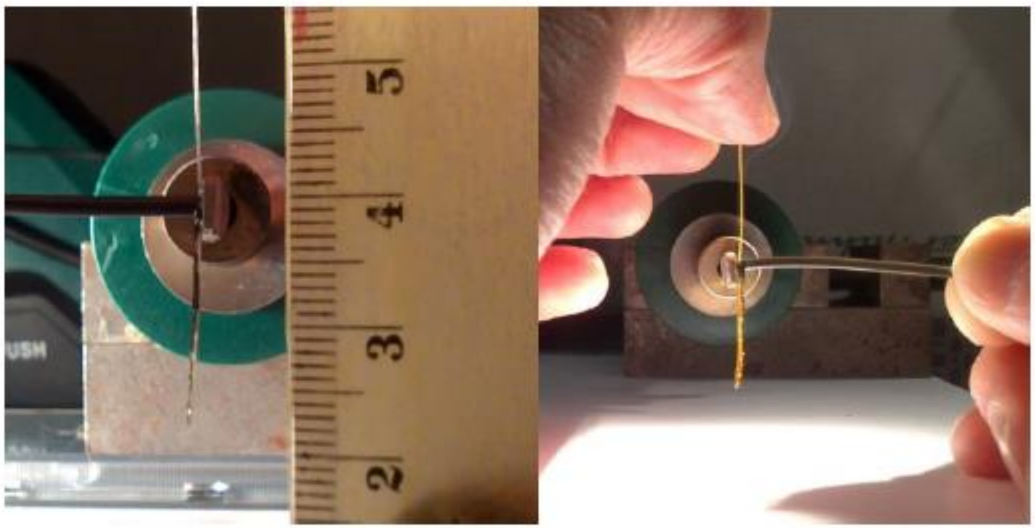


**Abbildung 15: Vertikale Versuchsanordnung – Beschichtetes Filament**

[LeU16]

# Coating Thickness - velocity

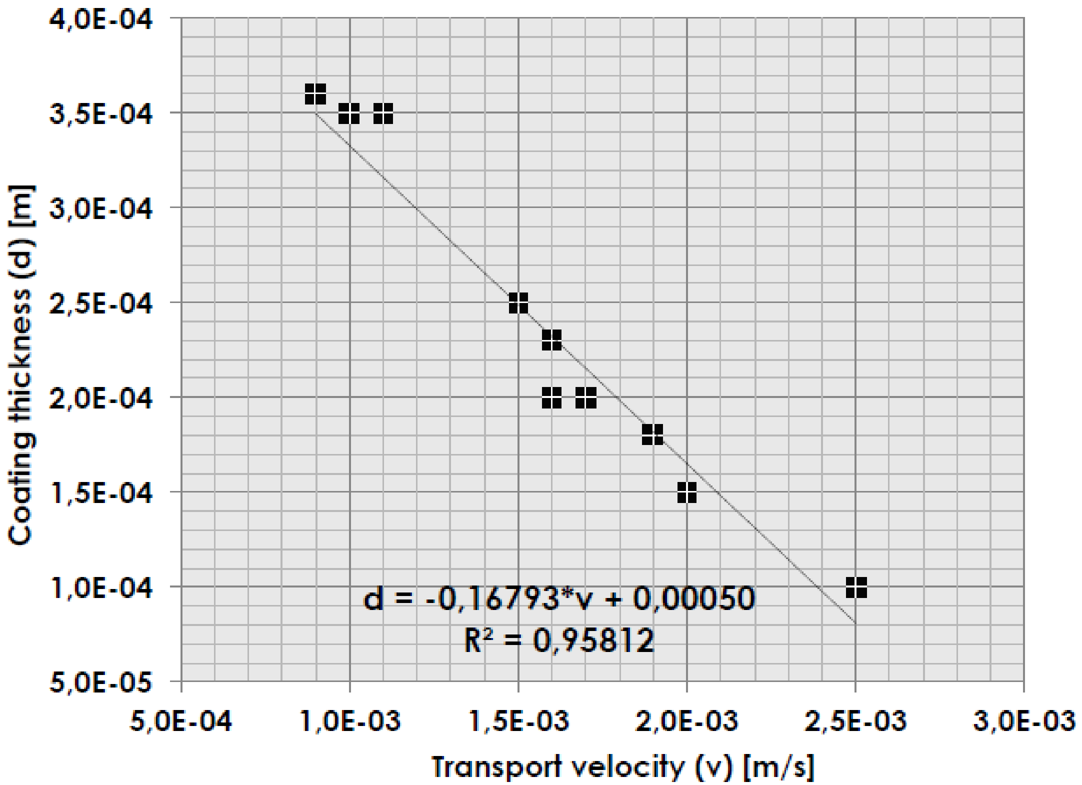


Figure 4: coating thickness d over fiber transport velocity v according to [1]

[LeU16]

# Outlook

- Implementation of the Coating Process in a detailed and automated 3D-Printing Prototype of the Nozzle head
- Prototype Testing of the Ring-Nozzle
- Prototype Production of 3D-Printed Structures for the Project MMO3D

# Herzlichen Dank für die Aufmerksamkeit!

**FH-Prof. Mag. DI Dr. Bernhard Heiden MBA**

*Professur für Produktionstechnik*

PS.: The presentation you will find soon also at:
http://www.dr-heiden.com/Vortraege.htm

# Literature


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