Material Development for Additive Manufacturing

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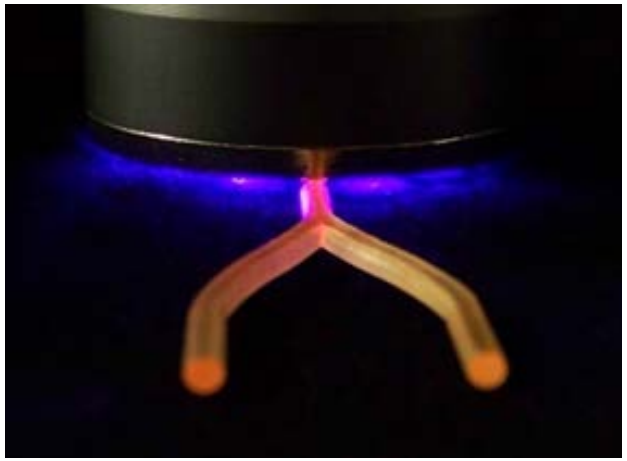
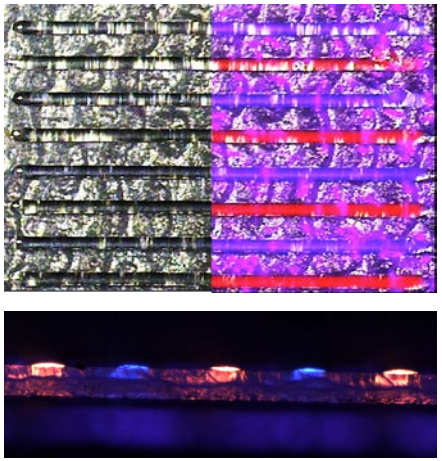
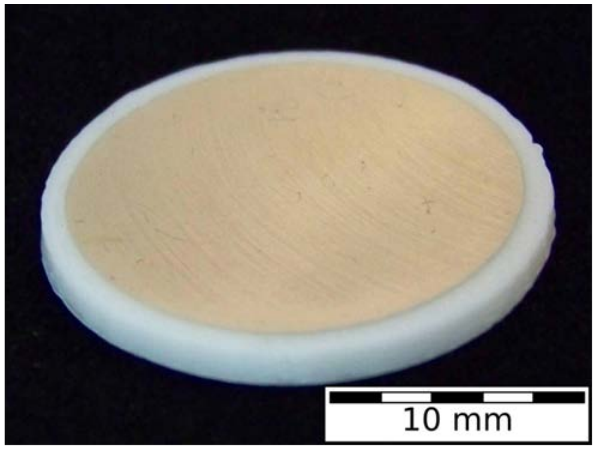
Overview

- Requirements for New Material Development
- Materials for Stereolithography
- Materials for InkJet Printing
- Materials for Fused Deposition Modelling







Requirements – Method Driven

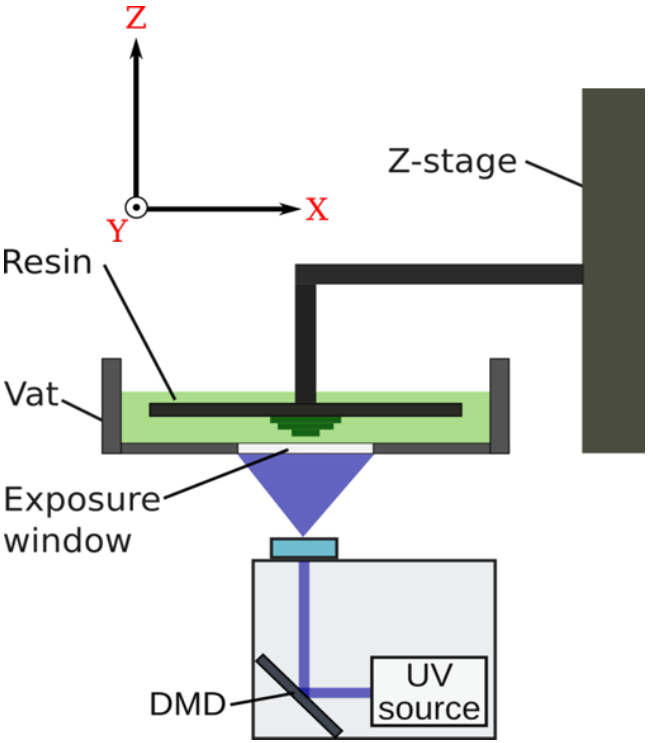
- Stereolithography
  - Viscosity < 200-300 mPas
  - UV-curable resin
  - Transparent resin, but filled systems possible
- InkJet Printing
  - Viscosity < 15 mPas@printing temperature
  - Adapted wetting behavior
  - Ideal case: solvent free plus UV-curing
- Materials for Fused Deposition Modelling
  - Viscosity <1000 Pas@printing temperature
  - Low filled composites commercial available
  - Highly filled composites under development

New Material Development requires enhanced process understanding and control

Stereolithography

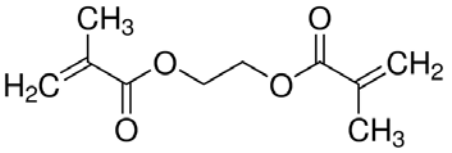
- Fundamental prerequisite
  - Open software for parameter adjustment
  - Own customized material possible
- Suitable machine with
  - powerful light source with broad bandwidth (365-405 nm)
  - high resolution (Full-HD DMD™ projector)
  - Minimum feature size: xyz: 30 x 30 x 10 µm³
  - Illumination from the bottom
    - no oxygen problem

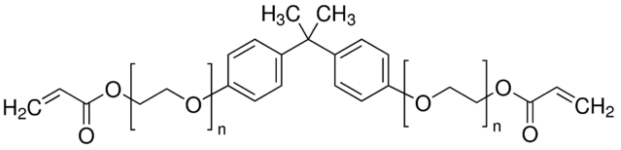
Source: B9Creator.com

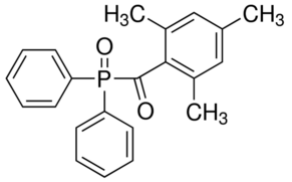


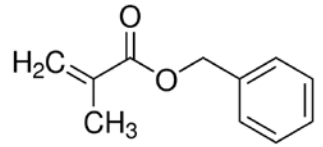
Stereolithography

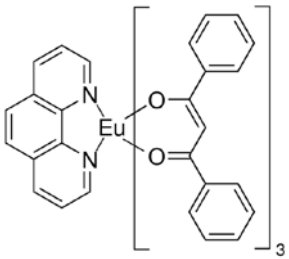
- Curable base material composition, e.g.
  - Ethylene glycol dimethacrylate
  - Bisphenol A ethoxylate diacrylate
  - Benzyl methacrylate
  - Photoinitiator DPO
- Organic dopants

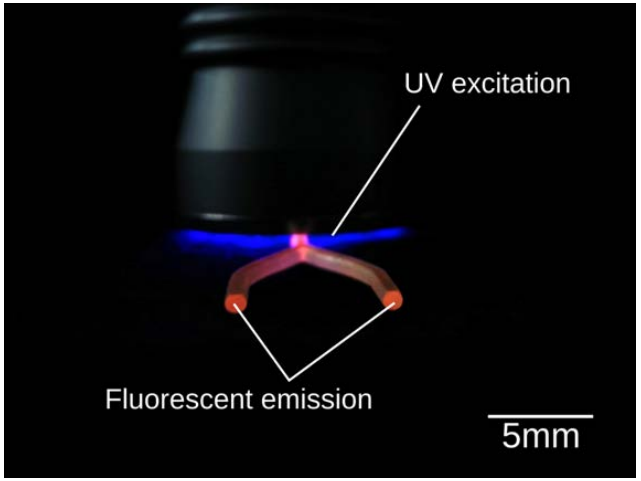


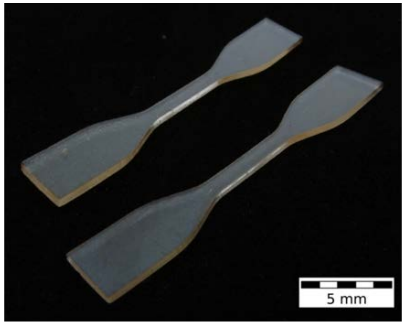


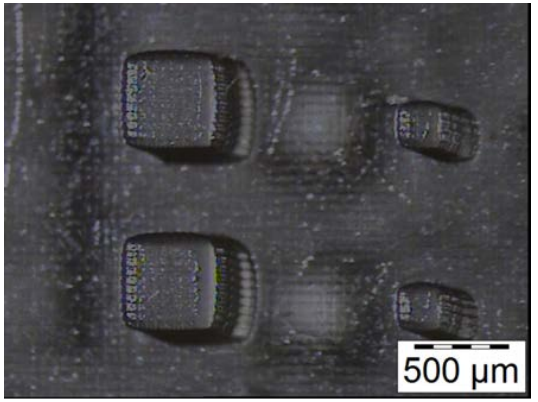








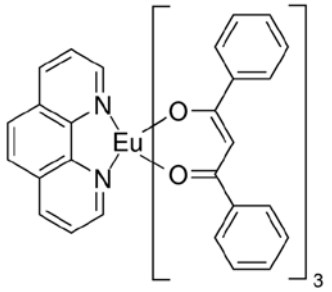


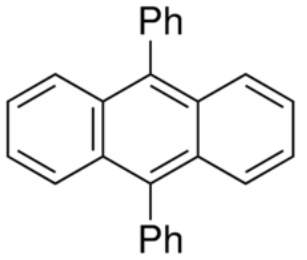


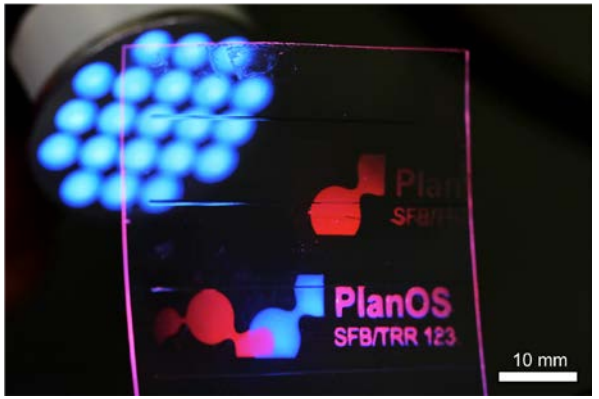
Gleißner et. al., Sensors & Actuators A: Physical 241, 2016

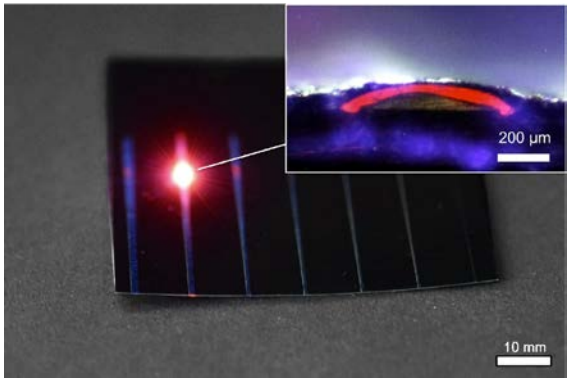
InkJet-Printing

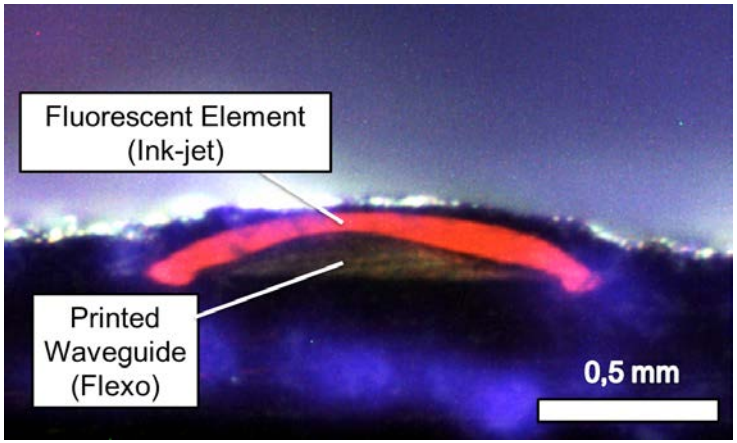
- Similar material as in stereolithography
- Multiple InkJetting: 5-20 layers
- Fluorescent dopants
- Combination with other printing techniques
- Key issues:
  - Viscosity
  - Wetting
  - Curing
  - Oxygen problem







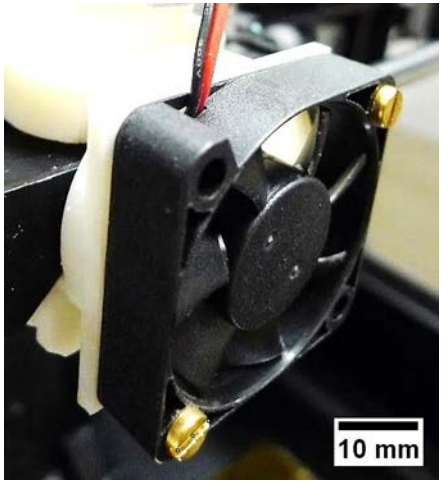


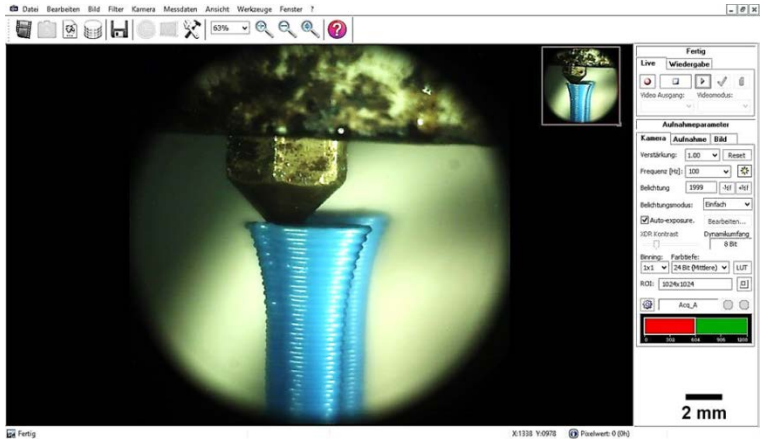


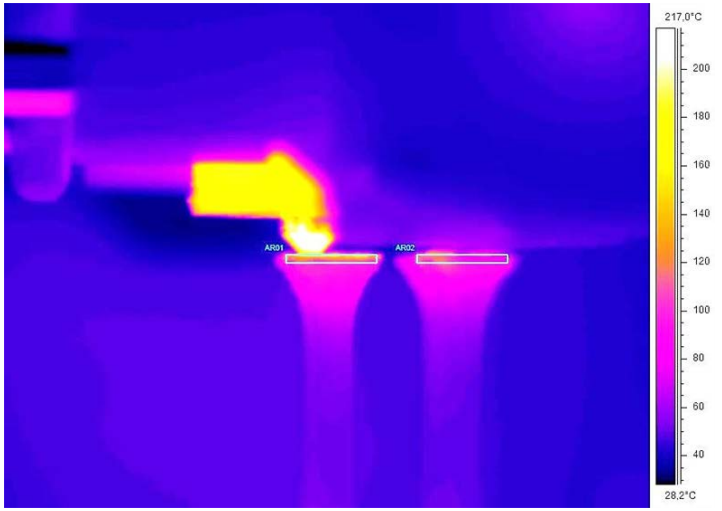
Dimatix DMP 2831
(Dimatix Fujifilm)

Fused Deposition Modeling Understanding

- Improvement of commercial open FDM printers (Makerbot Replicator 2X)
  - Filament feed
  - Temperature control
  - Built platform adjustment
- Process control
  - High speed camera
  - Infrared camera

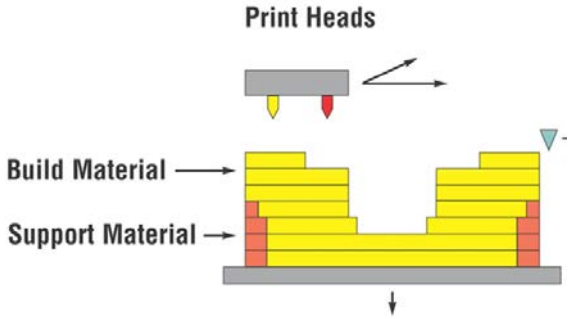


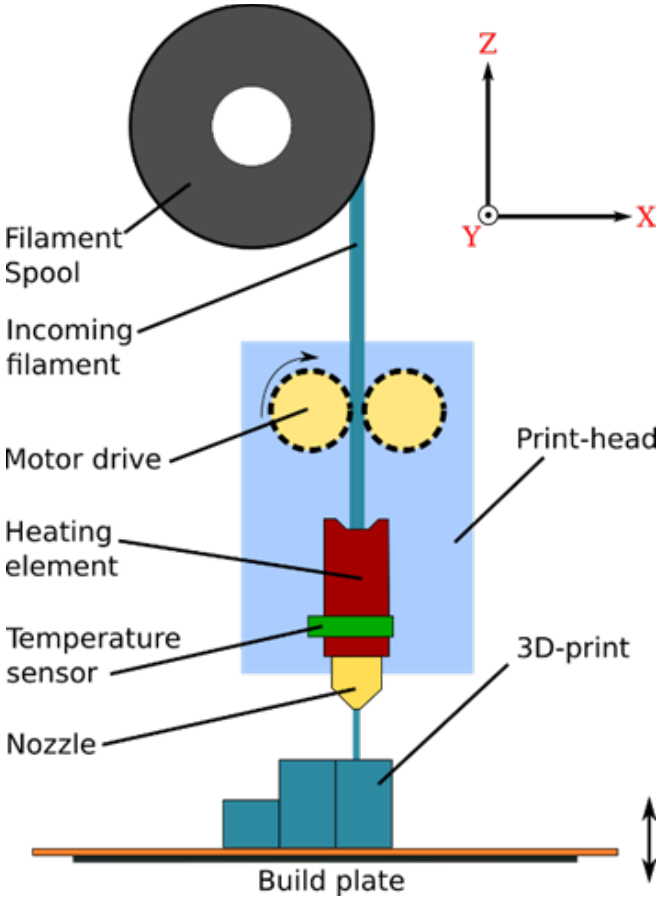




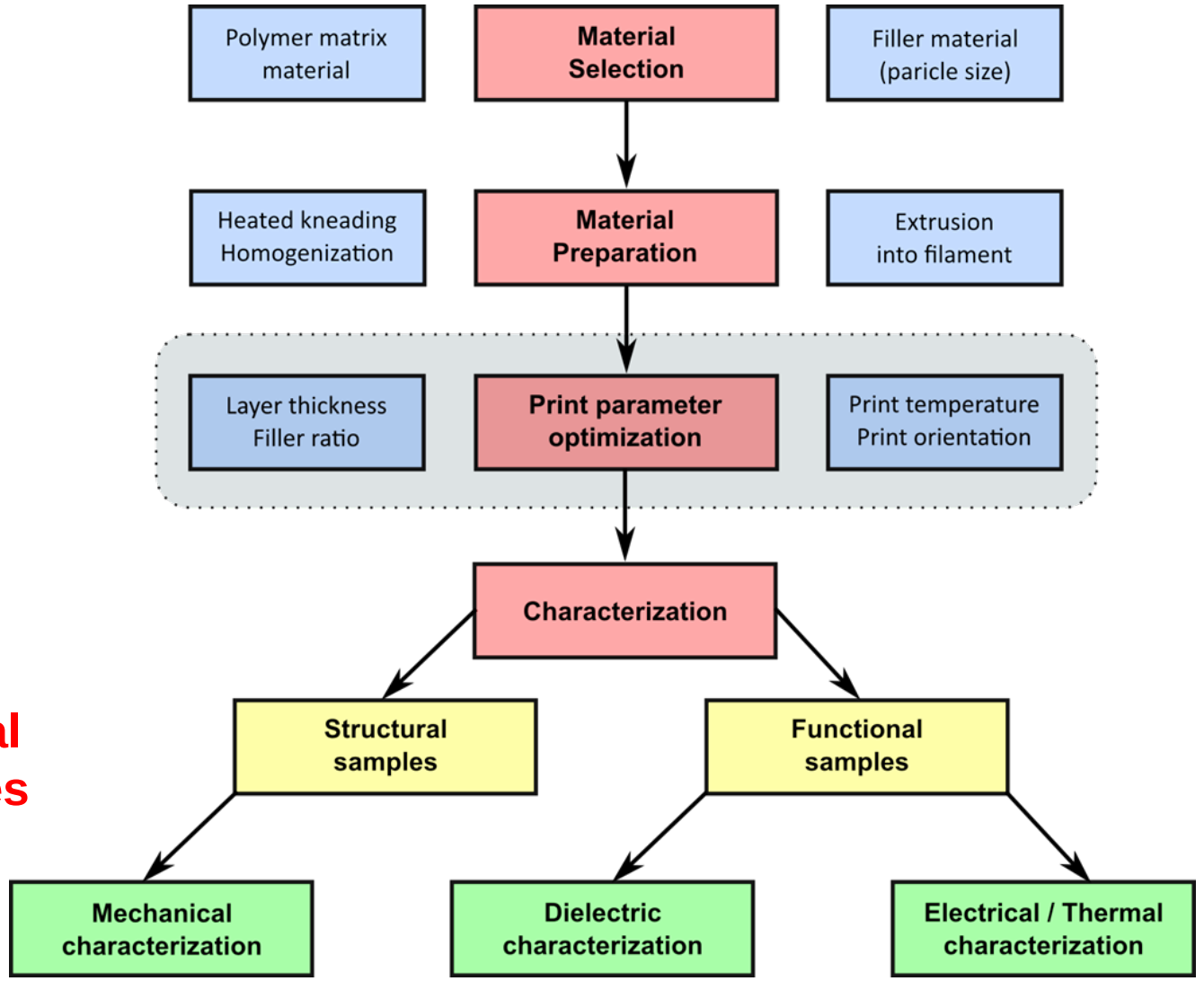
Fused Deposition Modeling of Composites

- Fundamental prerequisite
  - Open software for parameter adjustment
  - Own customized material possible
- Suitable machines with
  - Layer thickness <100 µm
  - Dual head
  - Broad nozzle temperature range up to 300°C
- Printing of composites/feedstocks: new process chain necessary





Fused Deposition Modeling of Composites

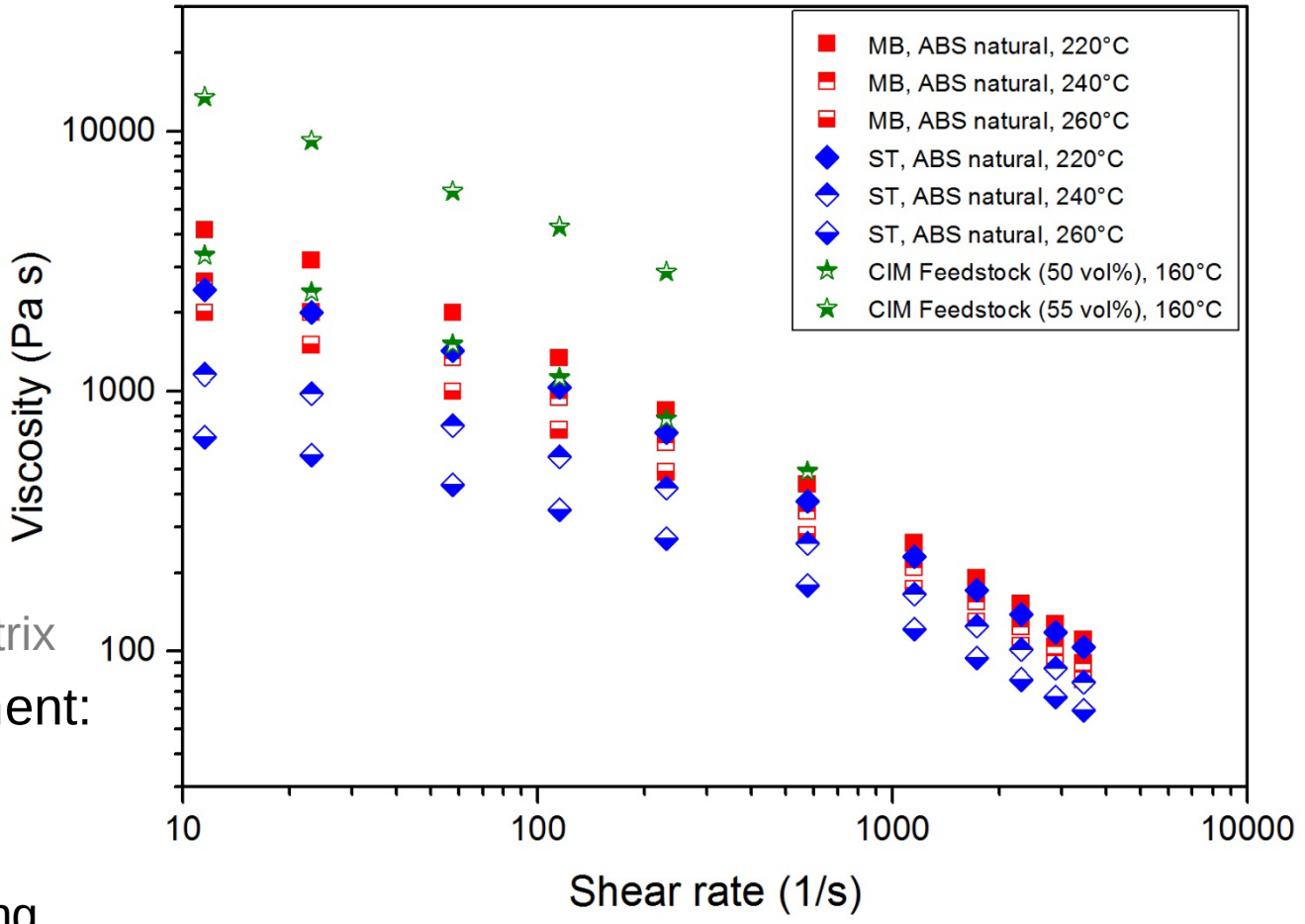


Structural properties

Functional properties

Fused Deposition Modeling of Composites

- Starting point:
  - Flow behavior of ABS
  - Influence of
    - Shear rate
    - Temperature
- Comparison:
  - CIM Feedstock
- Possible Approaches:
  - ABS as matrix
  - CIM Feedstock as matrix
- Process chain development:
  - Compounding
  - Printing
  - Thermal postprocessing



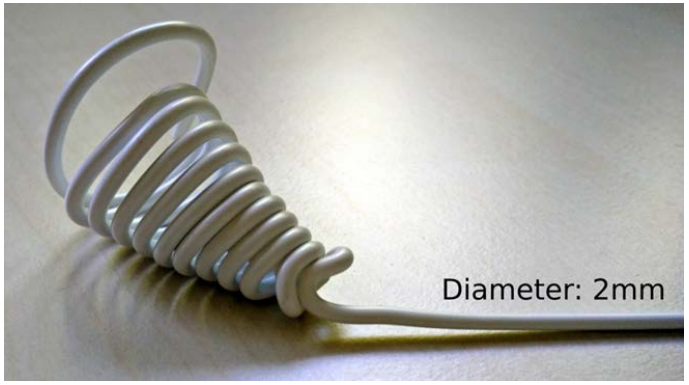
Fused Deposition Modeling of Composites

Mixer/Kneader

High pressure capillary rheometer

Granulator

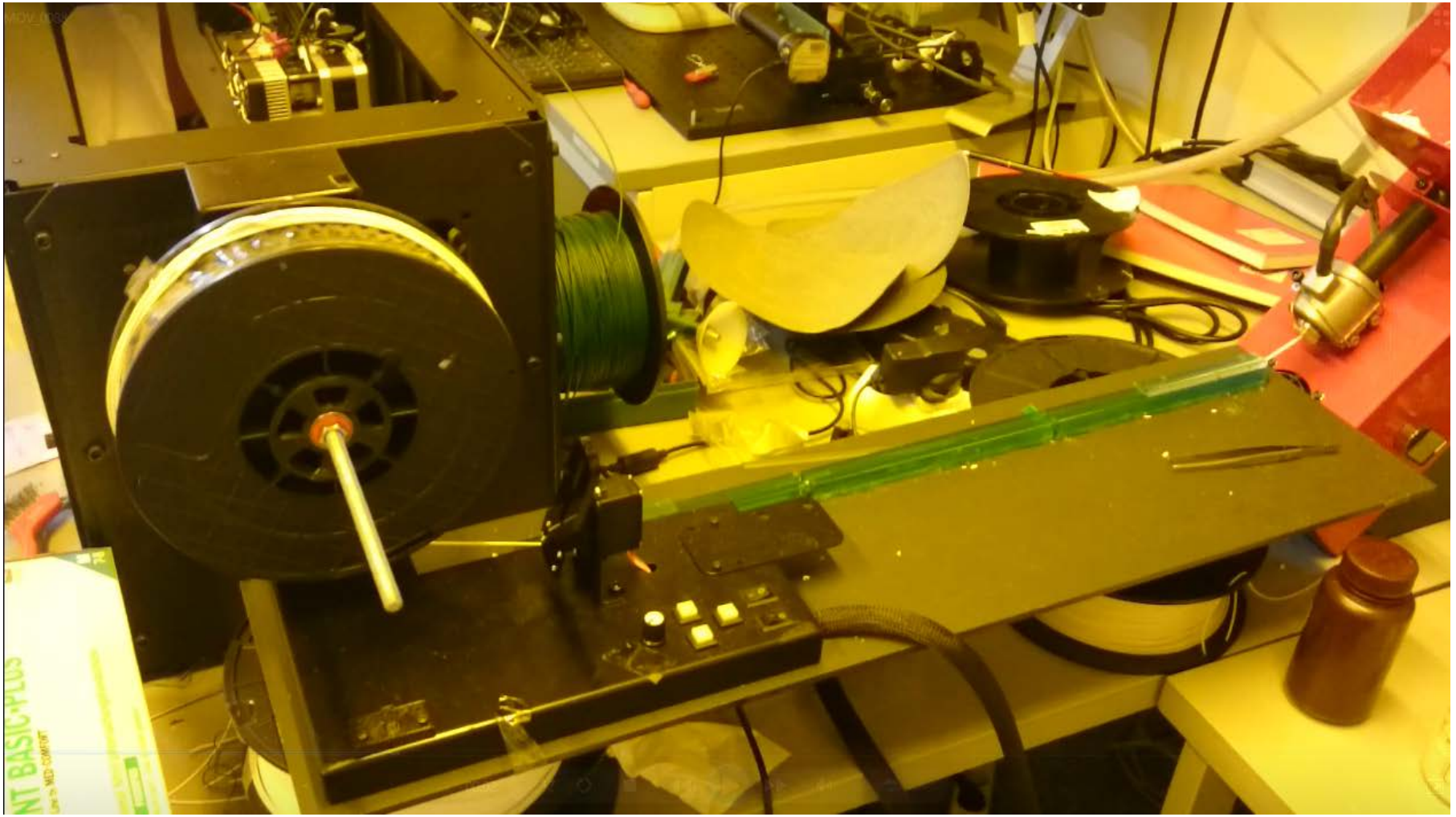
Granules



Filament

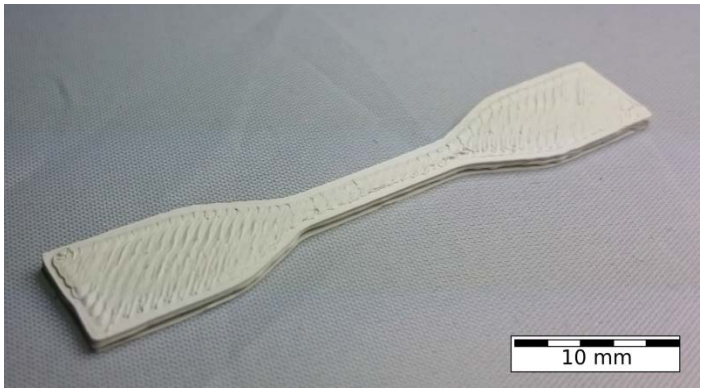
Filament extruder

Fused Deposition Modeling of Composites

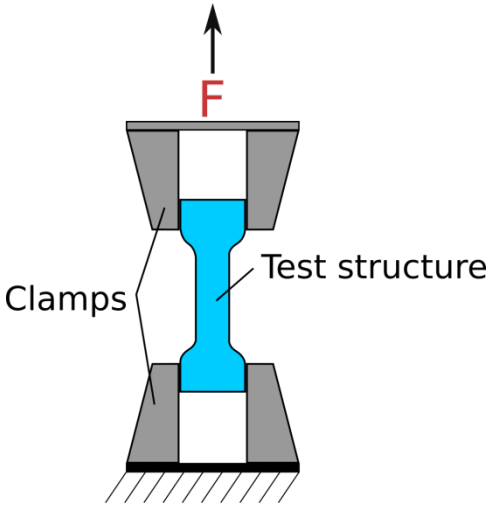


Fused Deposition Modeling of Composites

- Materials:
  - ABS
  - Filler: $BaTiO_3$ (d_{50} = ~3µm)
  - Filler content (10-, 20-, 30-, 35 vol. %)
  - Additives
- Printing modified Makerbot 2X:
  - Temperature
  - Printing orientation
- Tensile test specimen
  - ASTM D638 standard
  - Stress-Strain characteristics
  - Impact of filler content



ABS + 20-vol. % $BaTiO_3$ tensile test specimen



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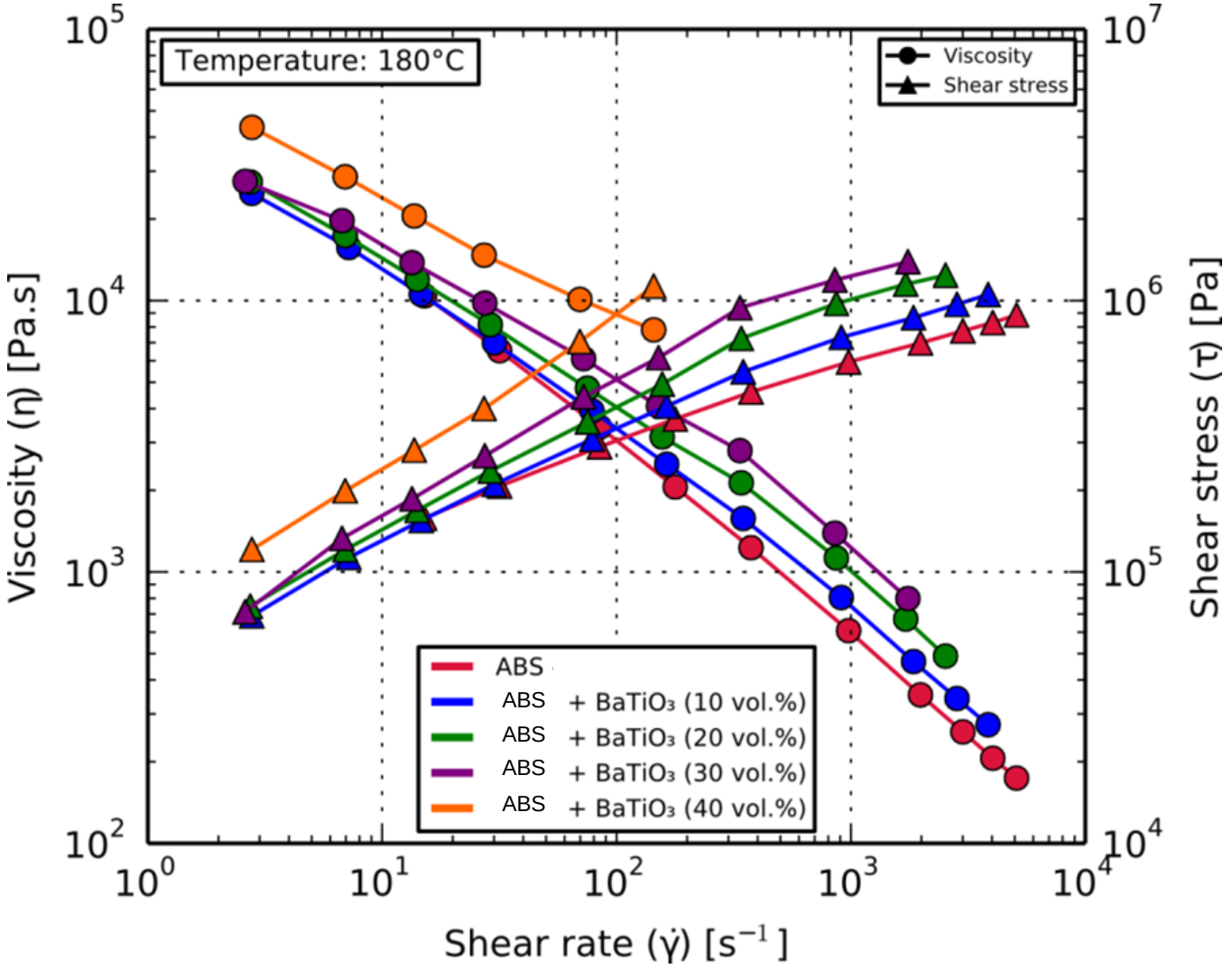
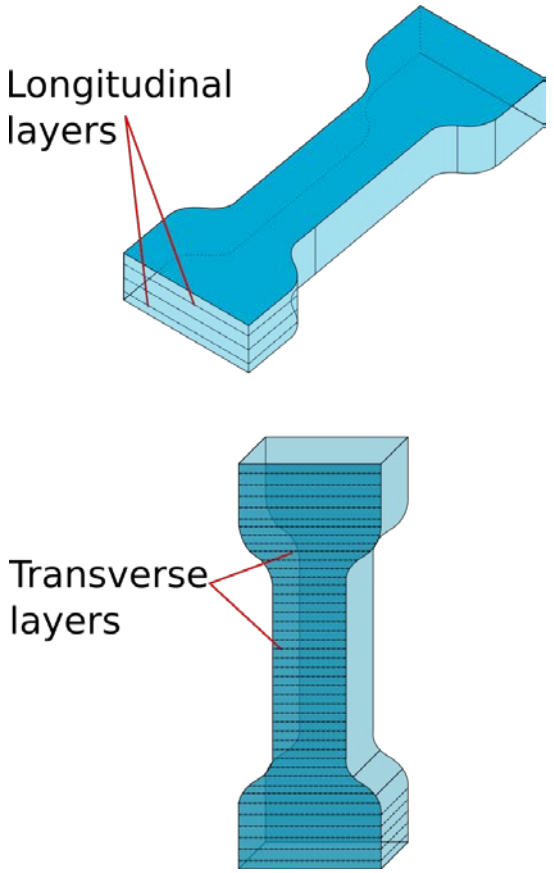


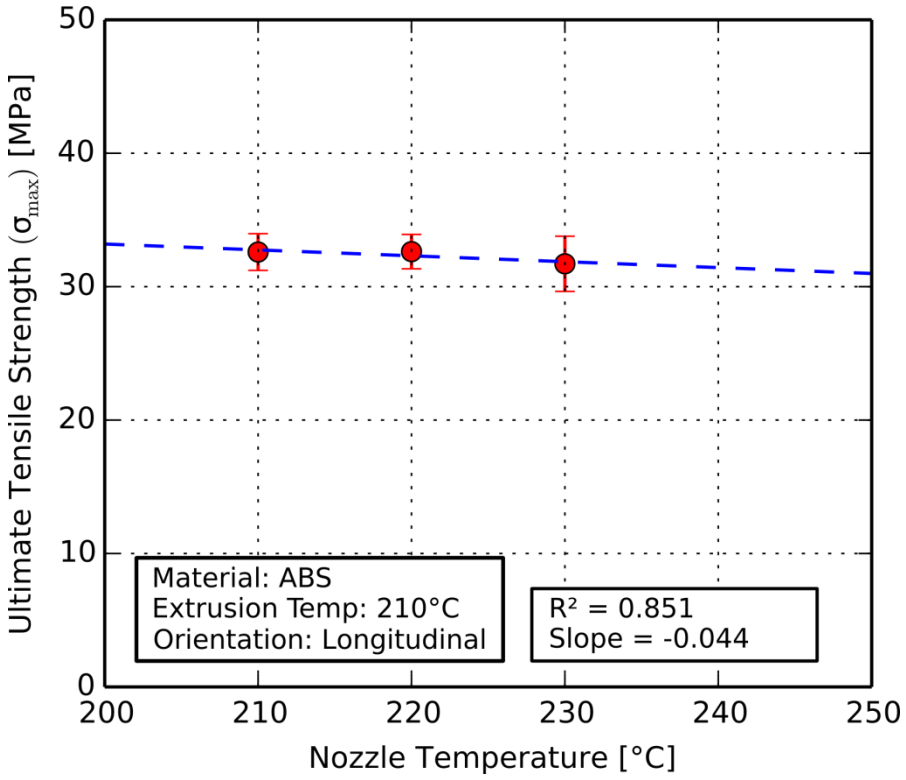
Fused Deposition Modeling of Composites

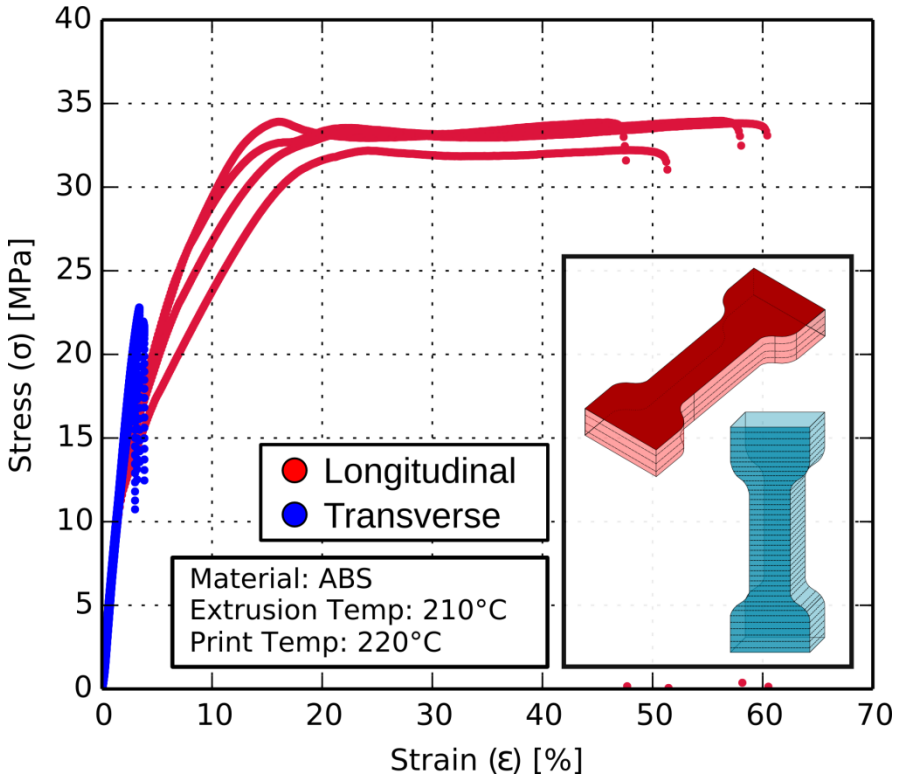
- Parameter optimization:
  - Extrusion temperature: 200 - 220°C
  - Print temperature: 210 - 230°C

- Printing probe orientation 200 µm layer thickness:
  - Longitudinal: Printed layers parallel to the long axis
  - Transverse: Perpendicular layers (upright)



Mechanical Characterization of Printed ABS





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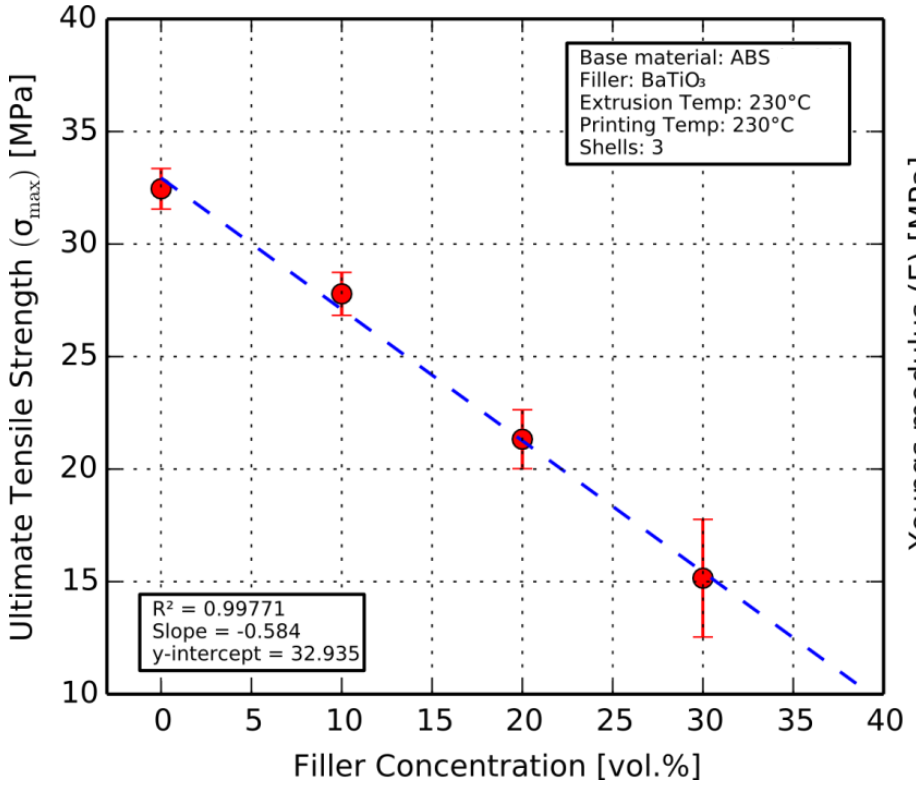
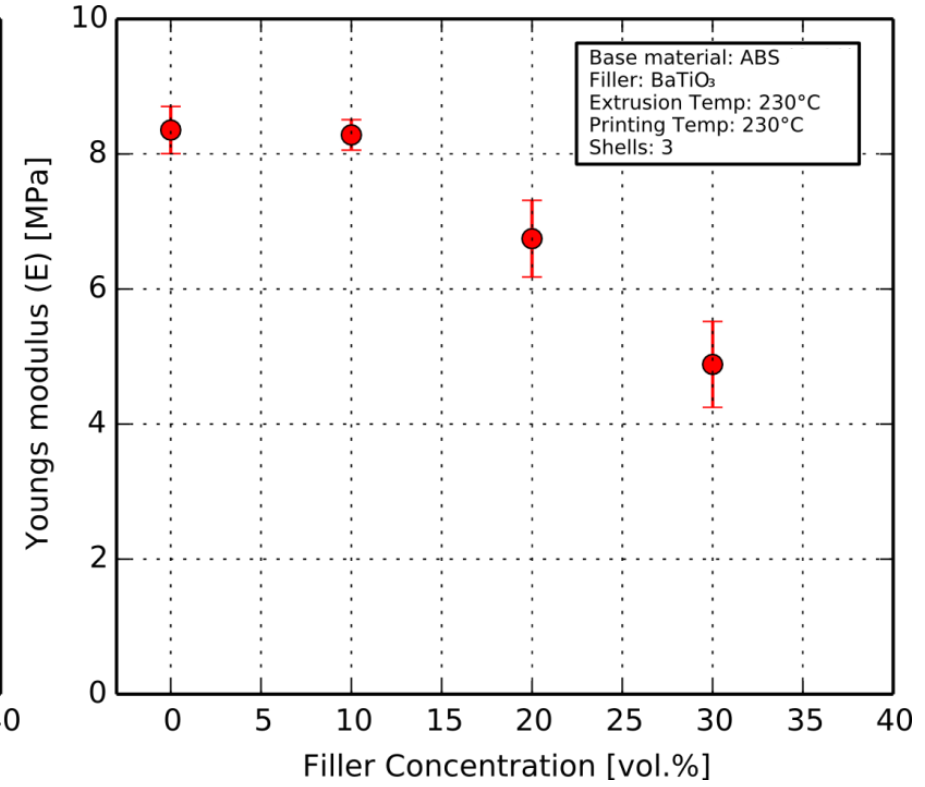
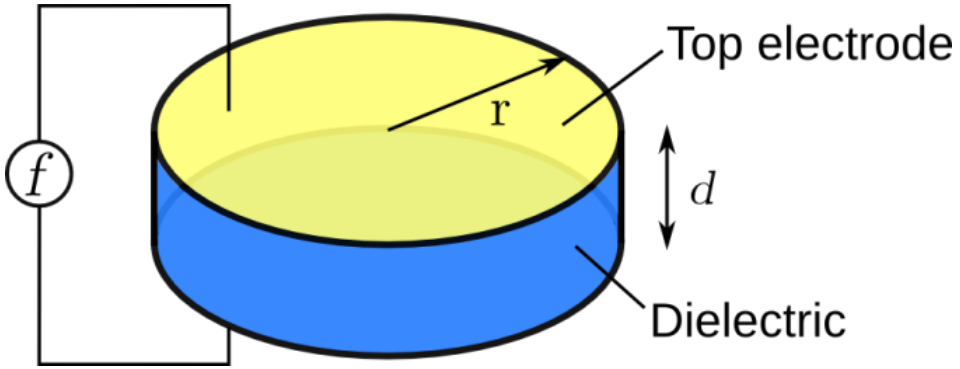


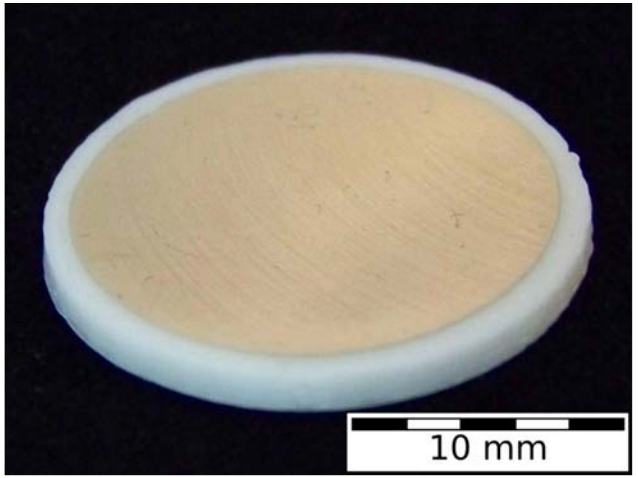


Functional Characterization of Printed Composites

- Used Material: Polymer- $BaTiO_3$-composite
- Test specimens: Disc-shaped (r = 12.5 mm, d = 2.0 mm)
- Electrodes: Sputtered Au (r = 11 mm, t = 40 nm)
- Capacitor: Parallel-plate model

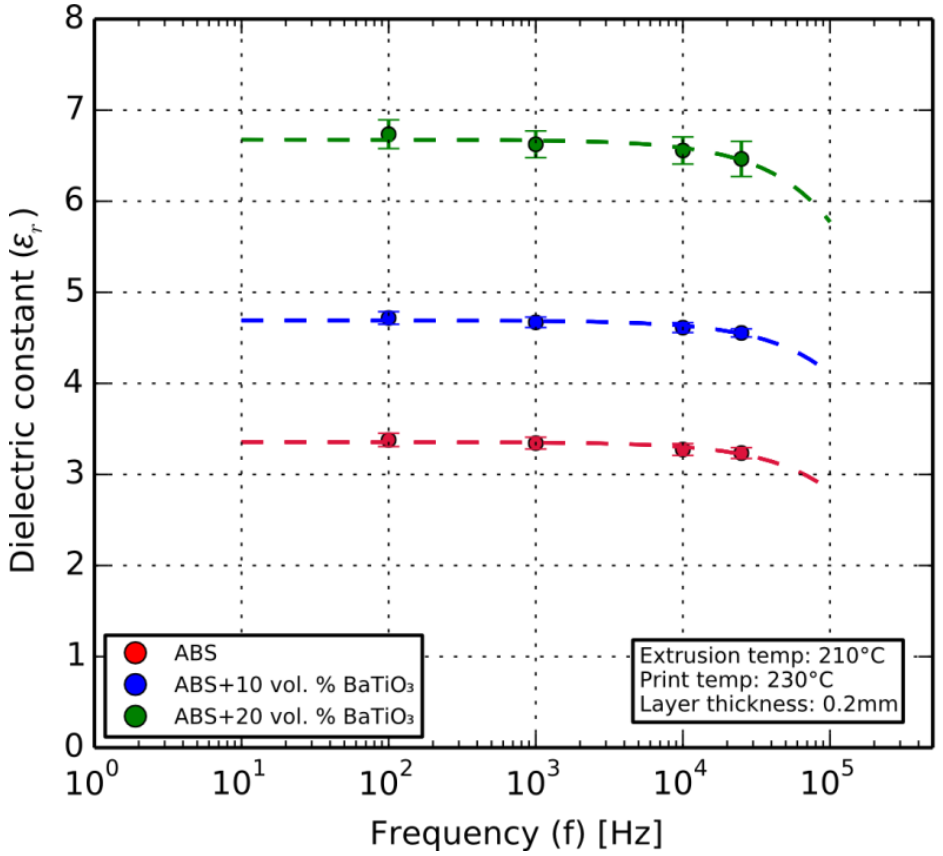
$$\varepsilon_r = \frac{C \cdot d}{\varepsilon_o \cdot A}$$

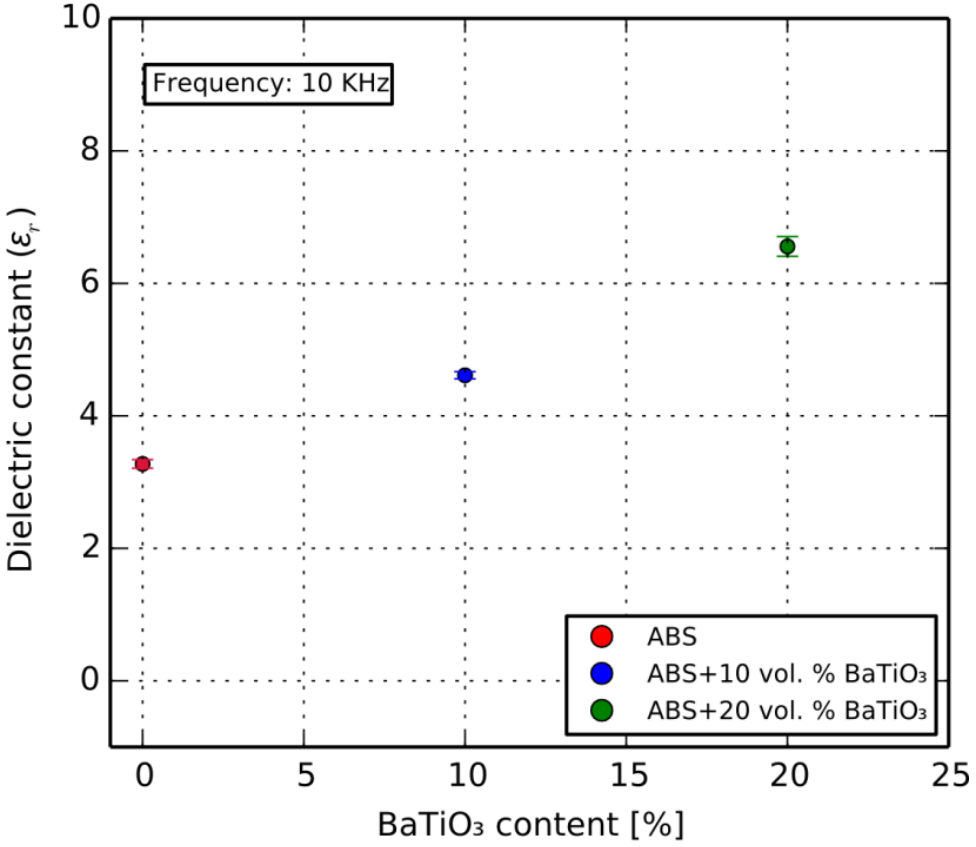




ABS + 20-vol. % $BaTiO_3$ dielectric test specimen

Functional Characterization of Printed Composites





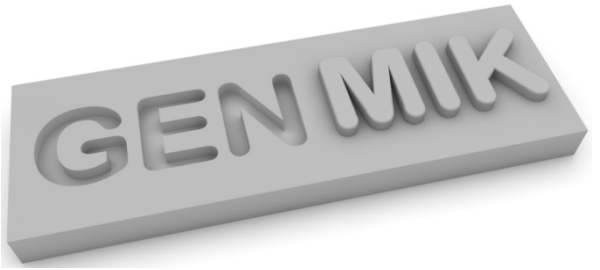
Conclusions

- For the future success of Additive Manufacturing a broadening of the material's base is essential
  - Curable resins
  - Meltable thermoplastics
  - Polymer matrix composites
  - Ceramics and metals
- All AM techniques should accept materials with higher viscosity
- Closer cooperation between machine developers and material scientists necessary
- Multi-Material-Printing is challenging but essential

Acknowledgement

DFG Deutsche Forschungsgemeinschaft

PlanOS
SFB/TRR 123



DiMAP
DIGITAL MATERIALS FOR 3D PRINTING

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