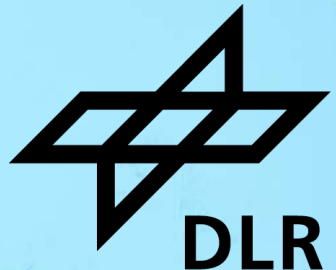


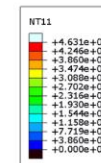
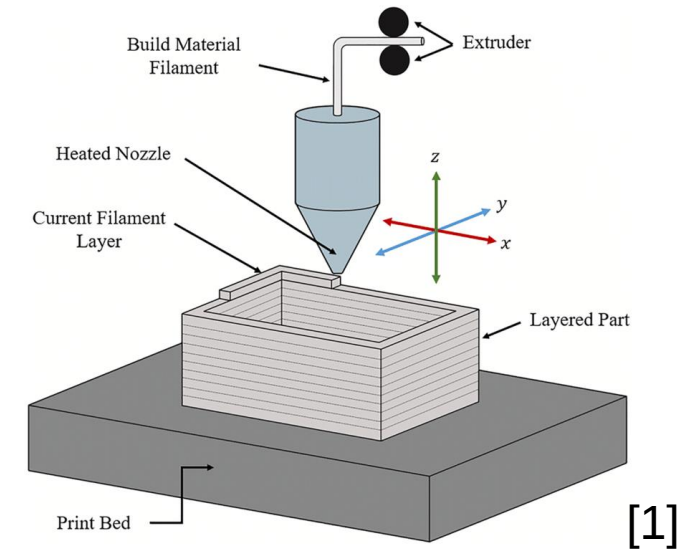
FURTHER DEVELOPMENT OF A BONDING MODEL FOR 3D PRINTED CARBON FIBRE REINFORCED HIGH PERFORMANCE POLYMERS

Felix Winkelmann, Robert Hein

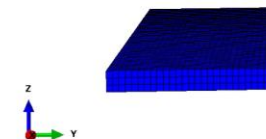


Simulation of 3D polymer printing

- Additive extrusion processes enables quick manufacturing of complex structures without moulds
- Many process parameters influence the final properties
- Process simulations can help to predict the properties and evaluate the process parameters

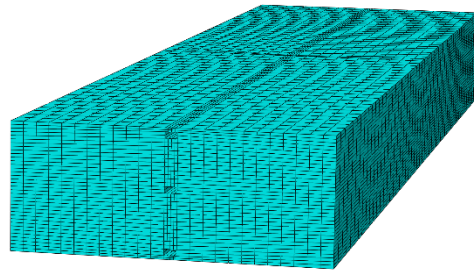


Step: Step-1 Frames: 0
Total Time: 0.000000

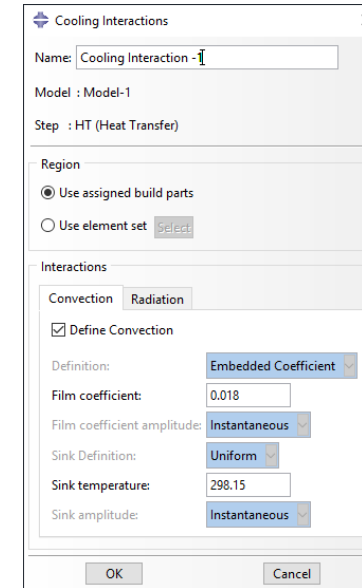


Thermal process simulation - Principle

CAD

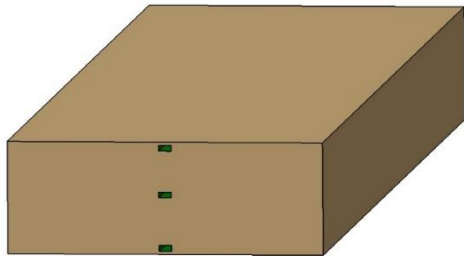


ToolPath
Conversation
G-Code-
>EventSeries

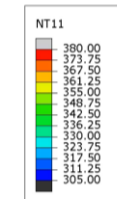
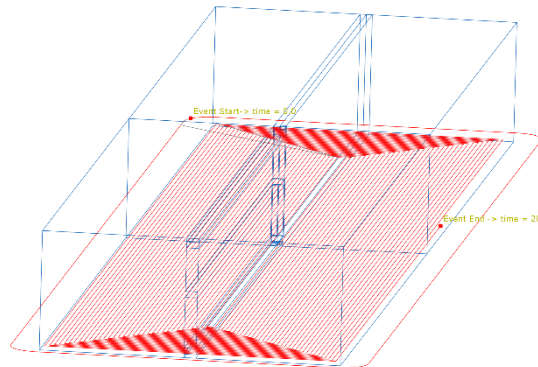


Analysis

Meshing



Thermal boundary
conditions



z
Step: HT
Y Increment: 0: Step Time = 0.000
Primary Var: NT11
Deformed Var: not set Deformation Scale Factor: not set
Status Var: STATUS

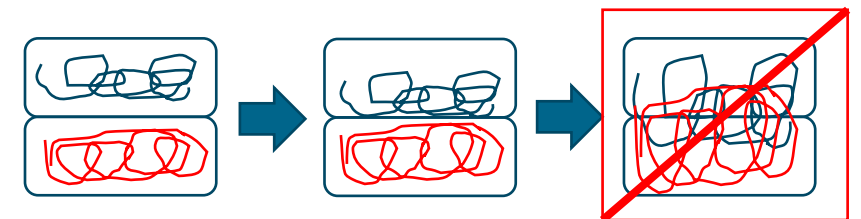
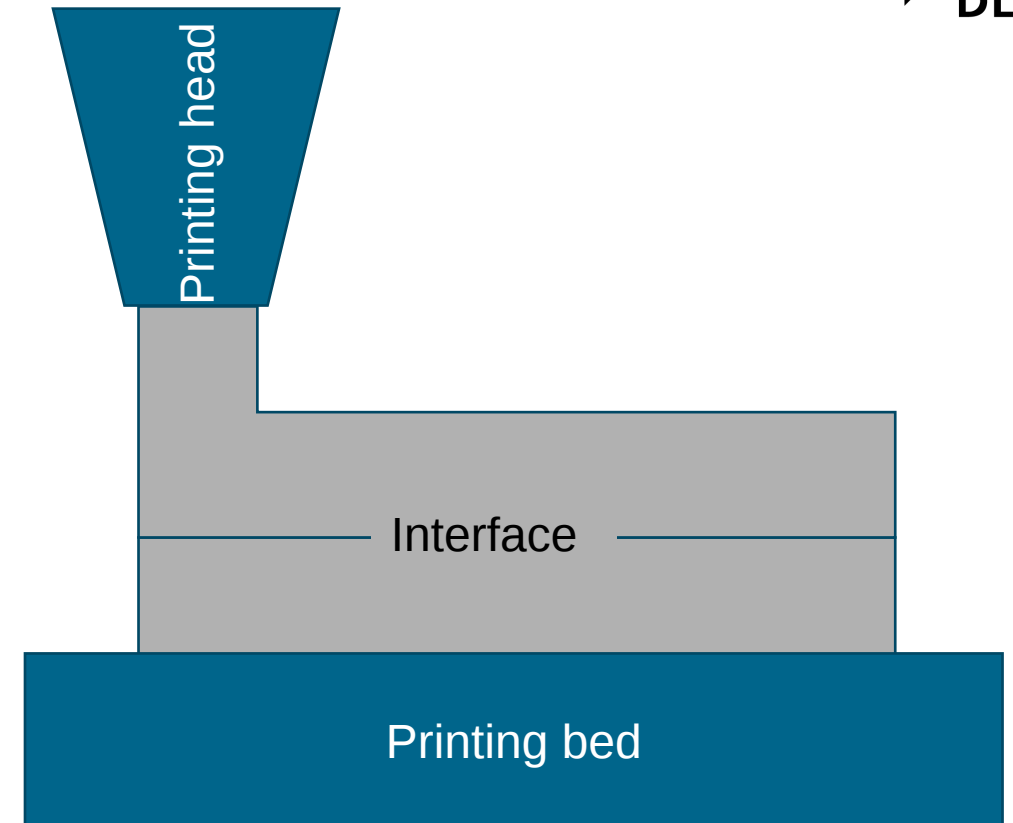
Influence of the bonding quality on part properties

- Bonding defines the strength properties perpendicular to the deposition direction
 - Reason for anisotropic mechanic properties
- For most materials strength in bonding direction is lowered compared to deposition direction
- Evaluation of bonding quality is needed to analyze process parameters



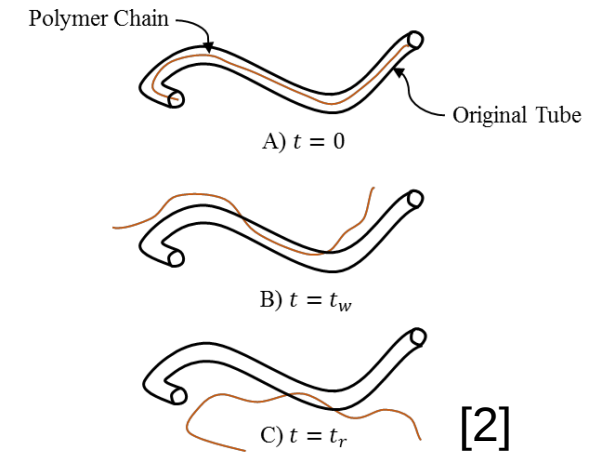
Bonding Theory

- Highly temperature dependent diffusion based process
- Polymer molecules move through interface and entangle
- Crystallization lowers bonding time through more stiff polymer chains



Calculation background of the bonding evaluation

- Modelling of the bonding behavior based on reptation theory
- Modification to take crystallization into account made by Barocio
- Fitting approach with parameters calculated based on bonding tests under different temperature conditions

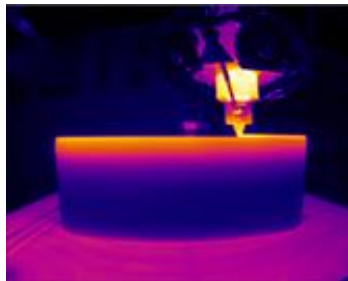


$$t_r \approx \frac{\langle L \rangle^2}{D_c}$$

$$D_b = \left(\frac{\sigma(t)}{\sigma_\infty} \right)^{\frac{1}{4}} = \left[\int_0^{t_c} \frac{1}{t_w(T(\tau))} d\tau \right]^{\frac{1}{4}}$$

$$t_w(T) = A \cdot \exp \left(\frac{E_A}{RT} \right)$$

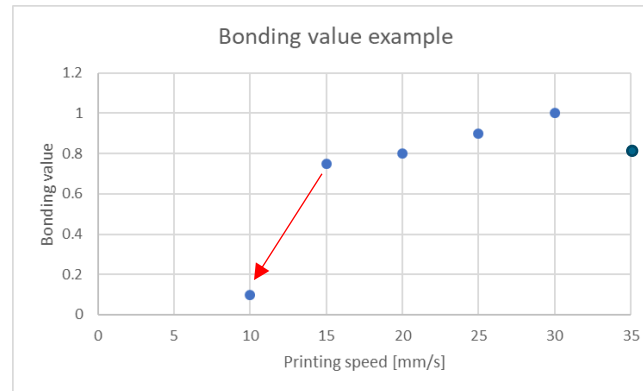
[2]



Modification of the model formulation

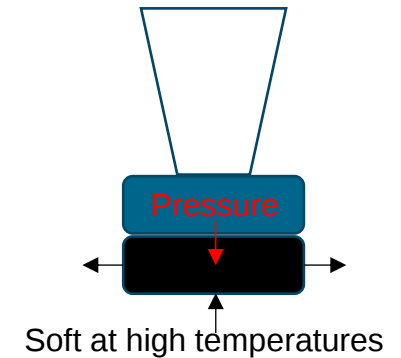
First modification

- Further development for higher precision at lower bonding
- Correction term for integration for steep fall in bonding



Second modification

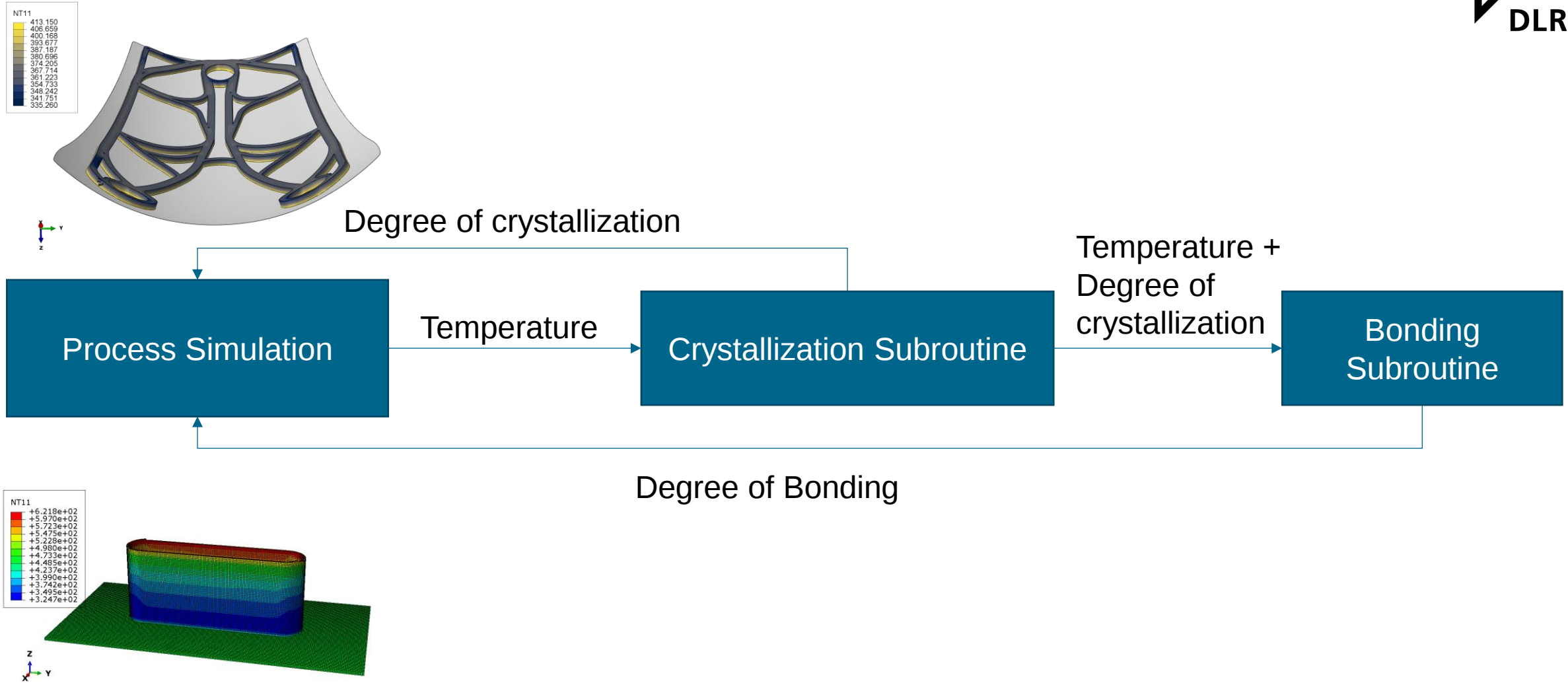
- High overprinting temperatures lead to less pressure in the bonding zone
- Numerical modification with temperature trigger at the softening temperature



Final formulation

$$D = \left[\int_0^{t_c} (B * t + C) * \frac{1}{A * e^{\left(\frac{E_A}{RT(t)}\right)}} - \max(0, T - T_{EW}) * D + E dt \right]^{\frac{1}{4}}, t_c \in \{t \text{ s.t. } X_{vc} < X_{vc}^{crit}\}$$

Implementation and linked subroutines

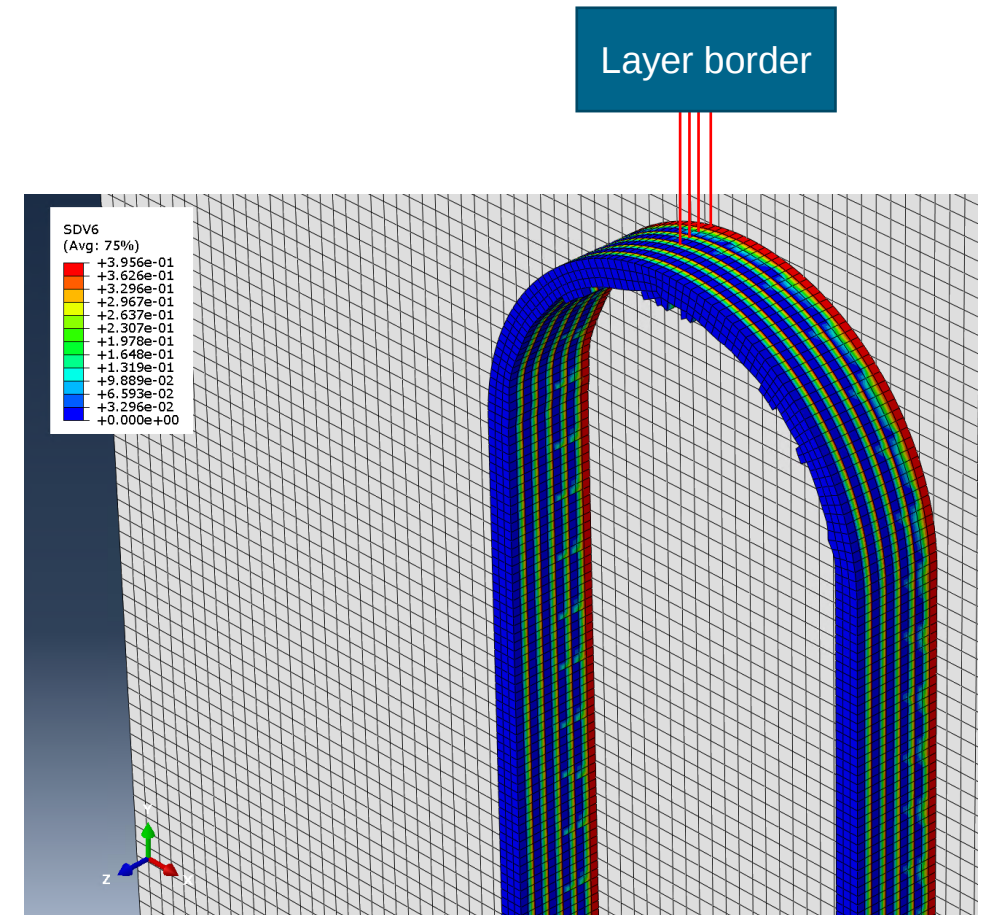


Integration in (process) simulation

- Per increment temperature, degree of crystallization and degree of bonding is calculated
- Implementation on minimal model was successful

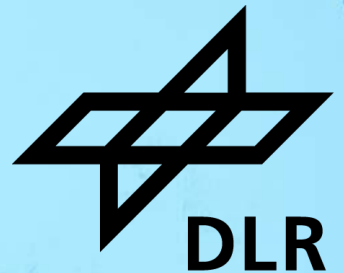
Implementation in process simulation is work in progress

- Influence of printing bed is visible
 - Higher bonding values at the layer next to the printing bed



- Finalize the implementation
- Validation for different printing conditions
- Integrate the bonding evaluation in frame work to evaluate parts

THANK YOU FOR YOUR ATTENTION



- [1] Shah, J., Snider, B., Clarke, T. et al. Large-scale 3D printers for additive manufacturing: design considerations and challenges. Int J Adv Manuf Technol 104, 3679–3693 (2019). <https://doi.org/10.1007/s00170-019-04074-6>
- [2] Barocio, Eduardo. “FUSION BONDING OF FIBER REINFORCED SEMI-CRYSTALLINE POLYMERS IN EXTRUSION DEPOSITION ADDITIVE MANUFACTURING.” (2020).