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

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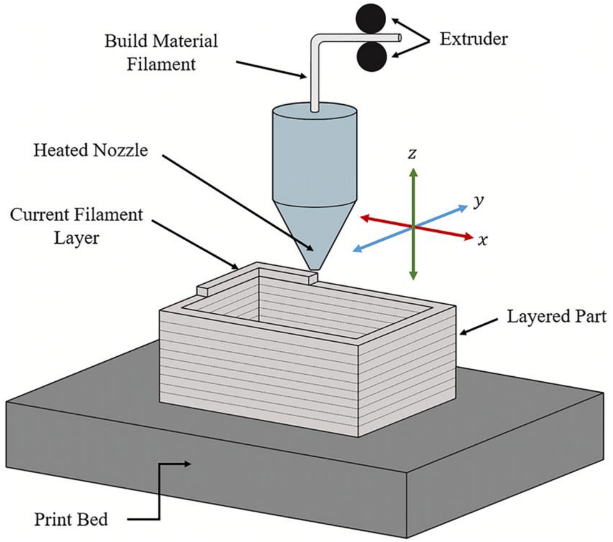
Simulation of 3D polymer printing

- Additive extrusion processes enables quick manufacturing of complex structures without moulds

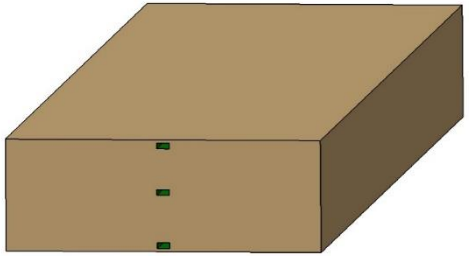
- Many process parameters influence the final properties

- Process simulations can help to predict the properties and evaluate the process parameters

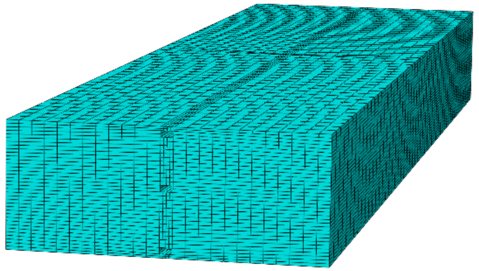


Thermal process simulation - Principle

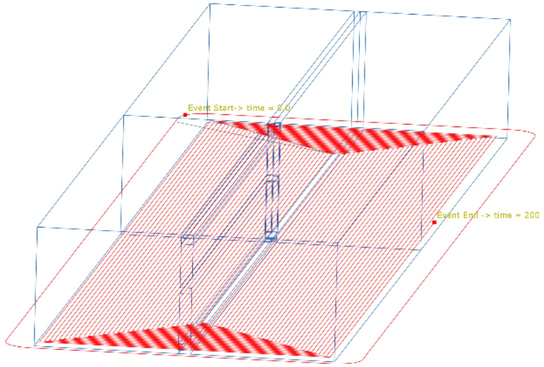
CAD



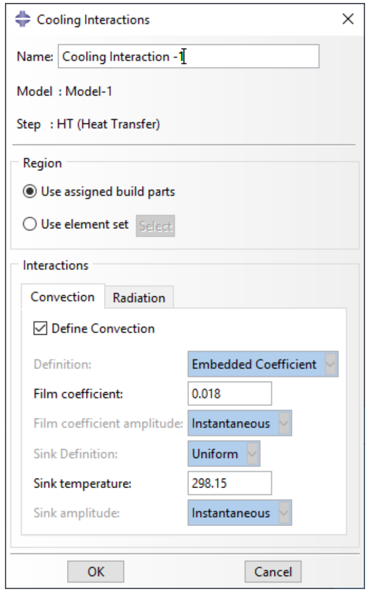
Meshing



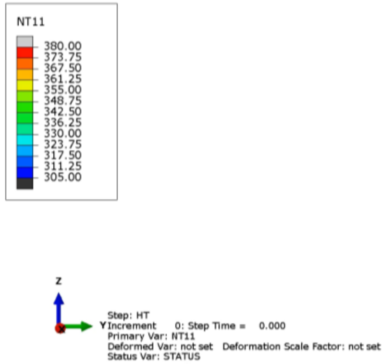
ToolPath Conversation G-Code->EventSeries



Thermal boundary conditions



Analysis



Influence of the bonding quality on part properties

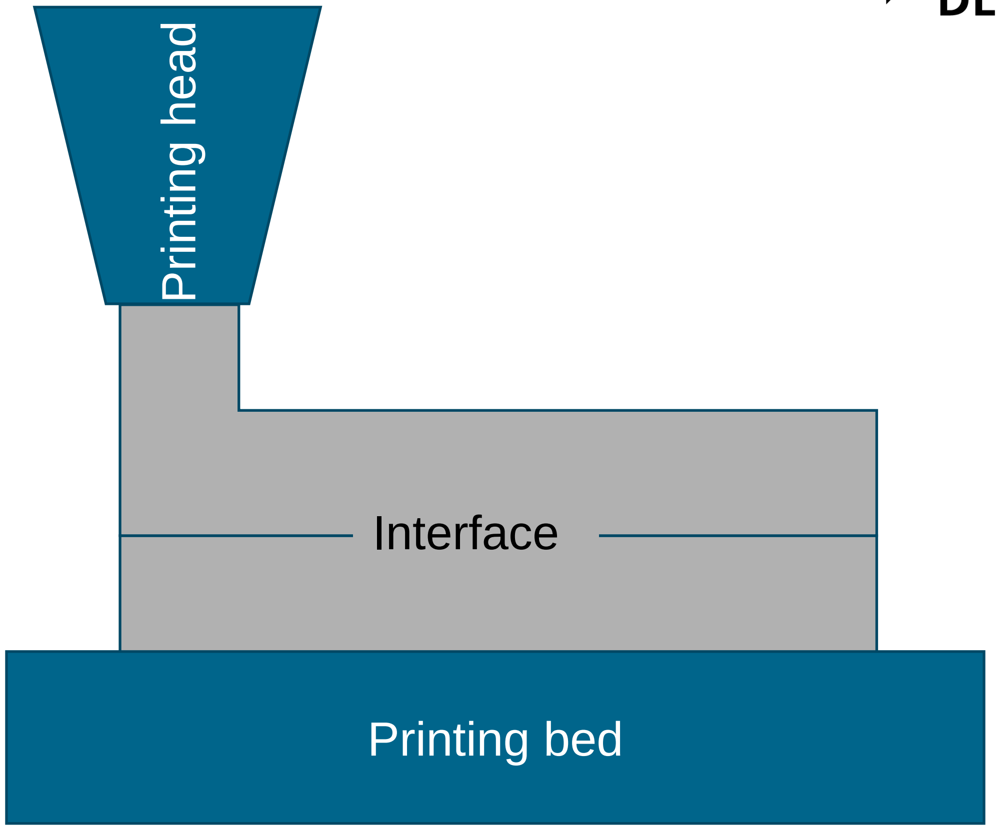
- Bonding defines the strength properties perpendicular to the deposition direction
  - Reason for anisotropic mechanic properties

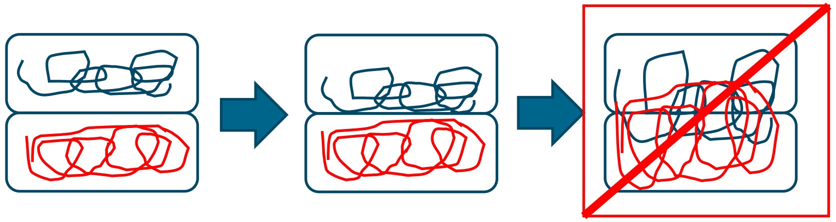
- For most materials strength in bonding direction is lowered compared to deposition direction

- 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



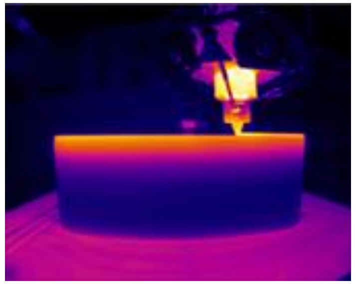


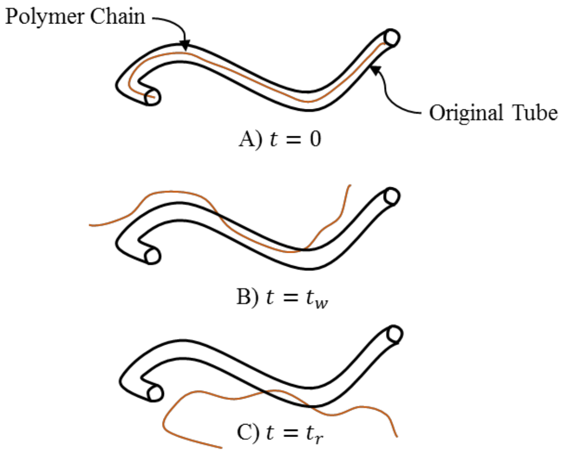
Calculation background of the bonding evaluation

- Modellation 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





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

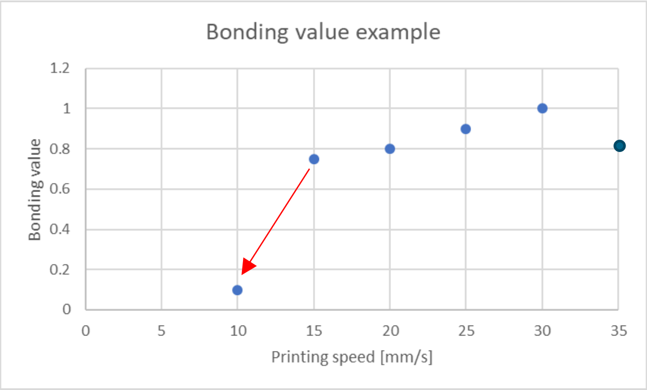
$$D_b = \left(\frac{\sigma(t)}{\sigma_\infty}\right)^{\frac{1}{4}} = \left[\int_0^{t_c} \frac{1}{t_w(T(\tau))}\, d\tau\right]^{\frac{1}{4}}$$

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

Modification of the model formulation

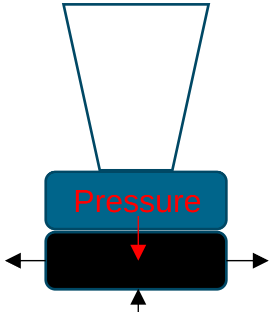
First modification

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



Second modification

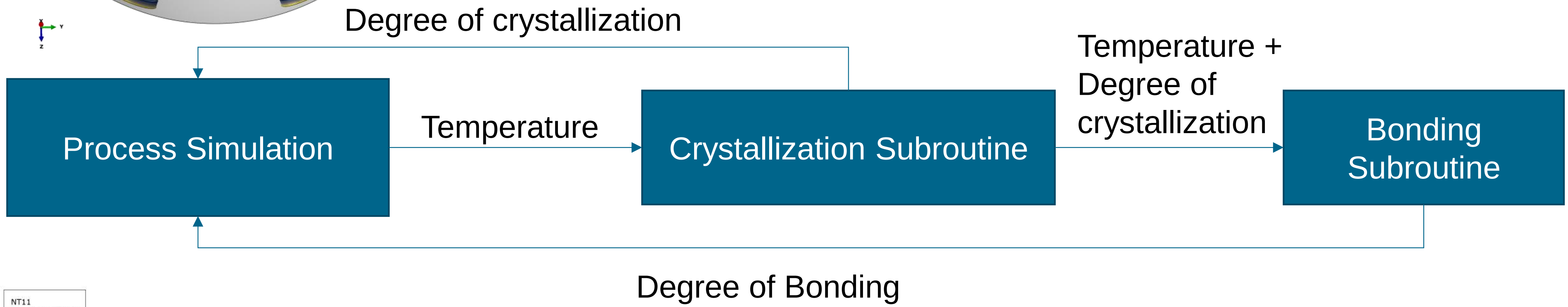
- High overprinting temperatures lead to less pressure in the bonding zone
- Numerical modification with temperature trigger at the softening temperature

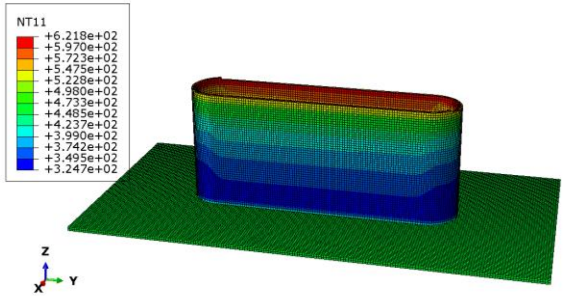


Final formulation

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

Implementation and linked subroutines





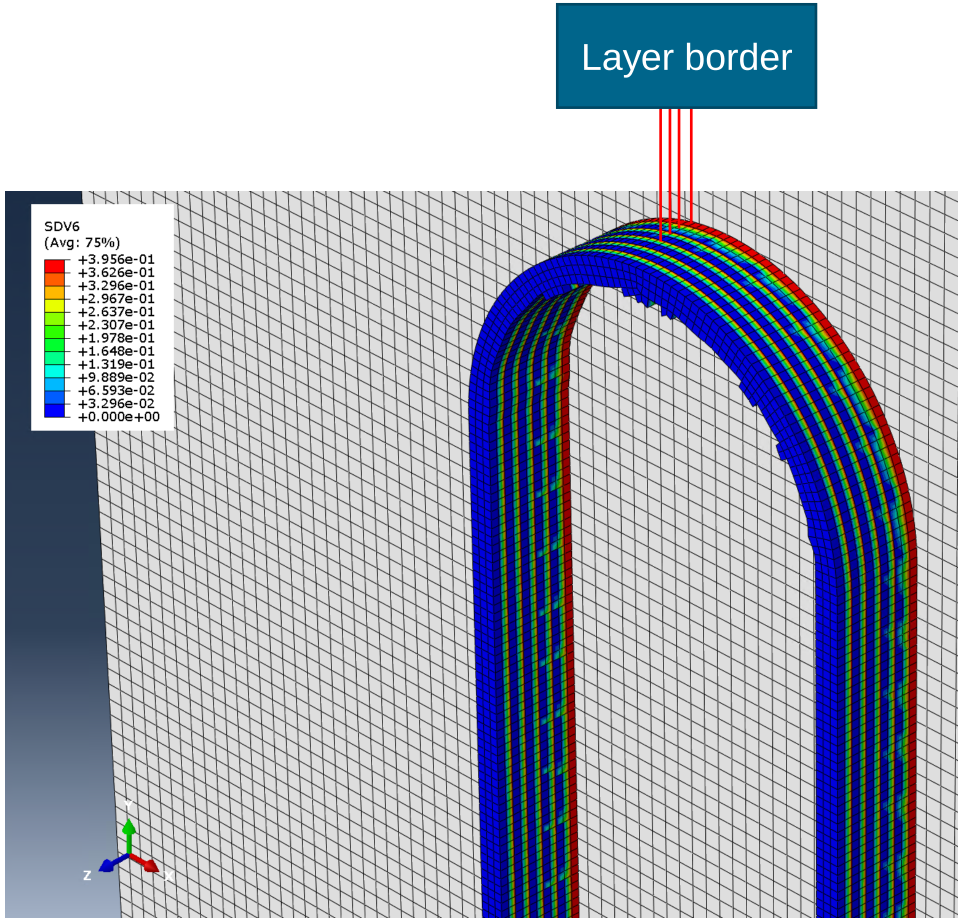
Integration in (process) simulation

- 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



Outlook

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

THANK YOU FOR YOUR ATTENTION

DLR

Quellen

- [1] FUSION BONDING OF FIBER REINFORCED SEMI-CRYSTALLINE POLYMERS IN EXTRUSION DEPOSITION ADDITIVE MANUFACTURING