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LMP LASER MATERIAL PROCESSING

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Thermo-Mechanical Modeling of Quasi-Simultaneous Laser Transmission Welding using LS-DYNA with Focus on Accuracy of Heat Input Calculation

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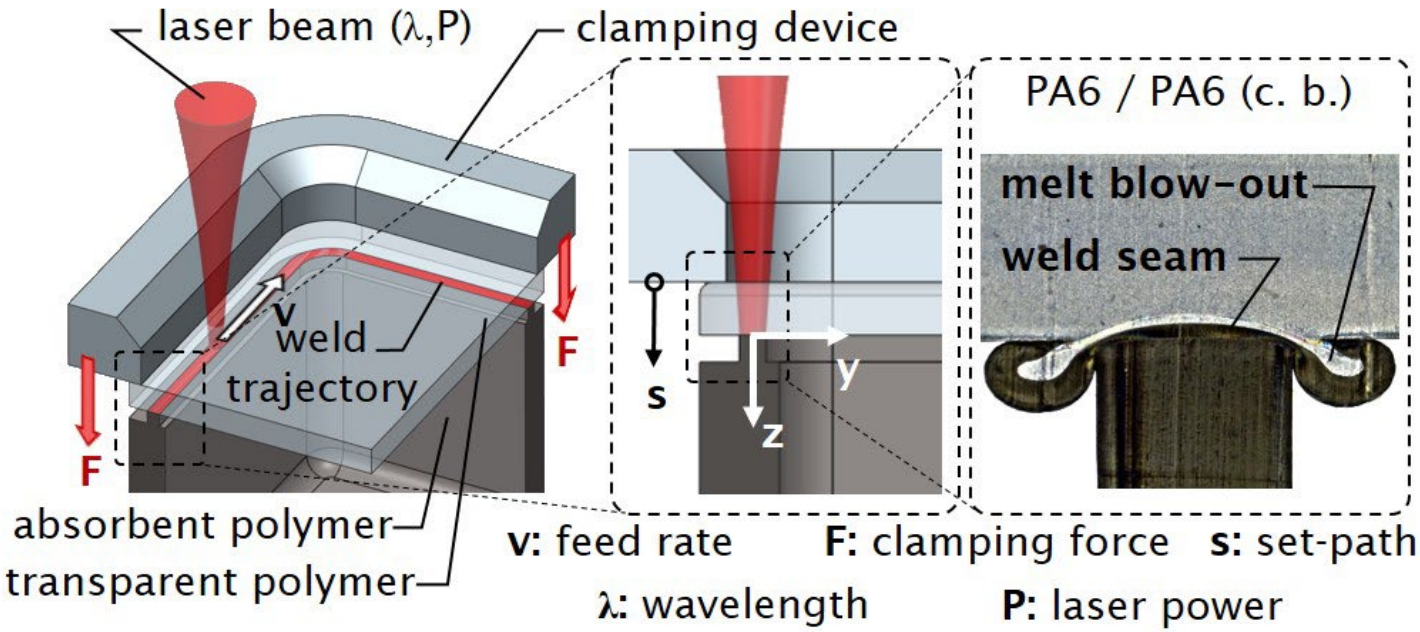
Agenda

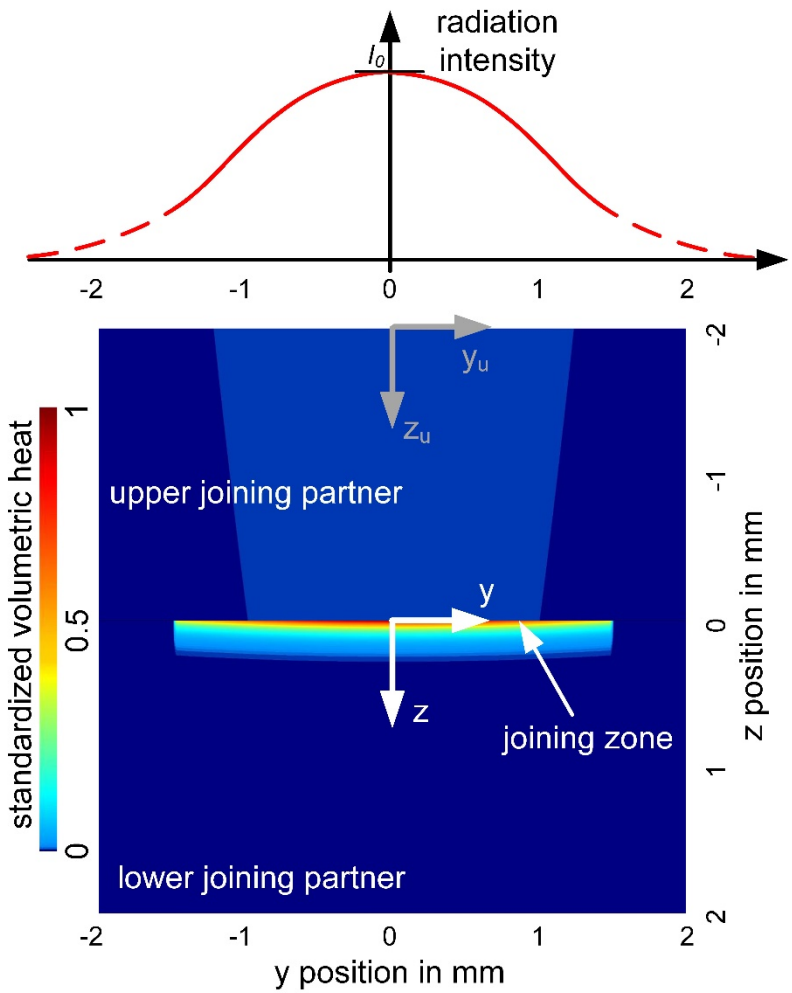
1. Principle of Quasi-Simultaneous Laser Transmission Welding
2. Simulation Model
   a. Overlap Configuration
   b. T-Joint Configuration
3. Calculation of Heat Input
4. Overlap Configuration Weldings of PA6
5. T-Joint Configuration
   a. Recent Issues
   b. Improvement
6. Conclusion and Outlook

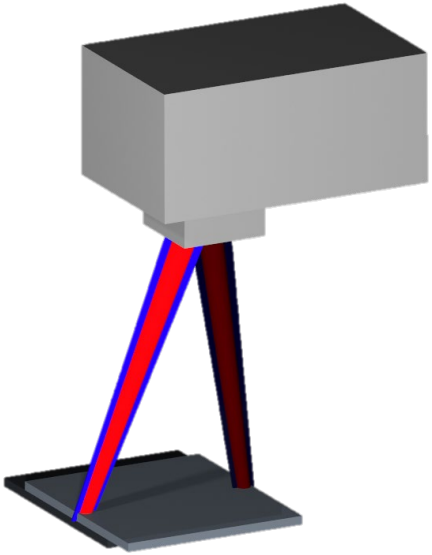
1. Principle of Quasi-Simultaneous Laser Transmission Welding



- laser radiation mainly transmitted by upper polymer and absorbed in lower one
- high feed rate (v > 0,5 m/s) causes nearly simultaneous melting of entire weld contour
- melt continuously squeezed out of joining zone

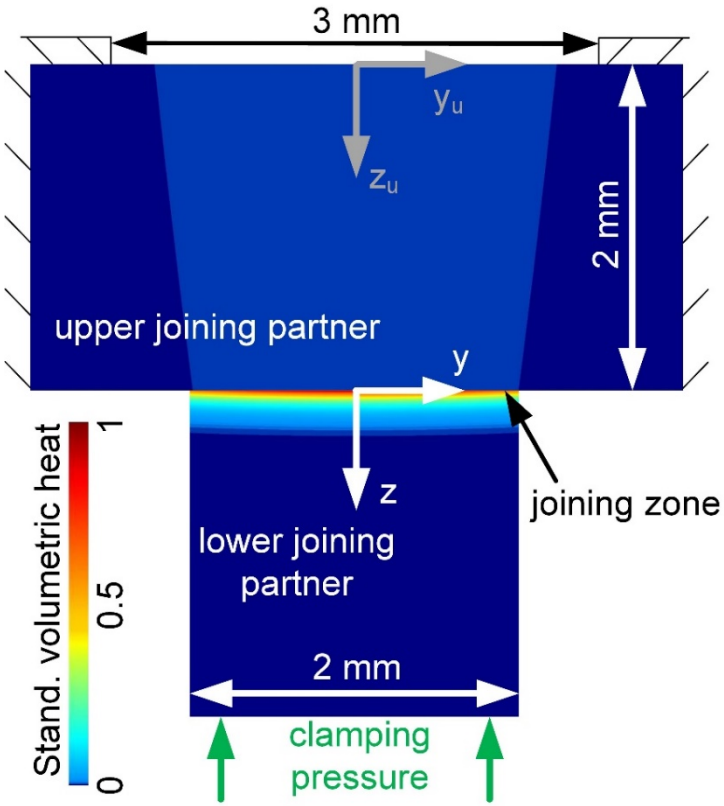
2. Simulation Model
a. Overlap Configuration



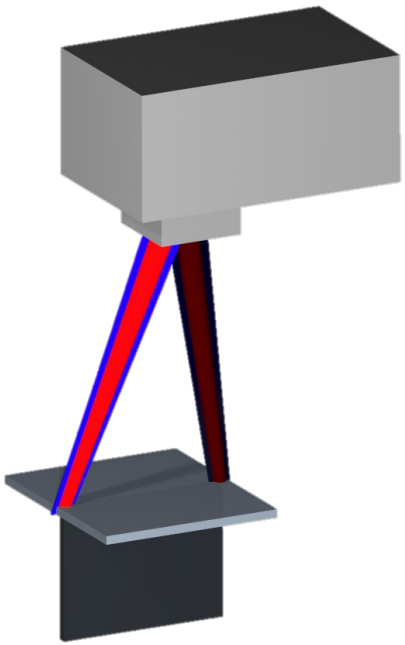


- negligibly small deformations of polymers → thermal simulation model
- 2D geometry
- temperature dependent specific heat and thermal conductivity
- material: PA 6

2. Simulation Model
b. T-Joint Configuration



- thermo-mechanical simulation model
- element formulation: plane strain EFG
- 2D contact between joining partners; allowing gaps
- thermo-elasto-viscoplastic material model
  - parametrized using tensile tests from 20 ˚C to 140 ˚C
  - parametrization beyond 140 ˚C based on assumptions



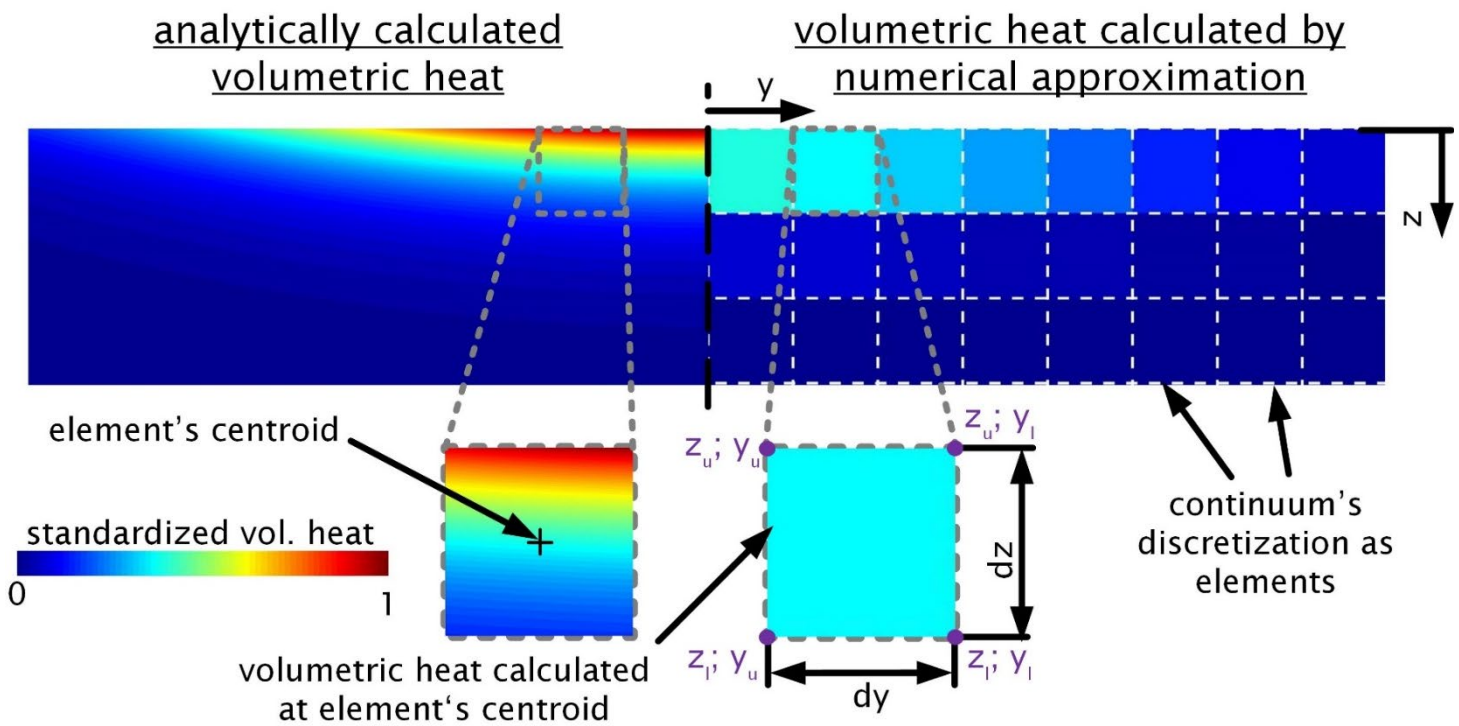
3. Calculation of Heat Input

Analytical equation [1]:

$$Q_l(y,z) = \frac{8 \cdot \alpha_l \cdot P}{\pi \cdot d^2} \cdot e^{\left(-\alpha_l \cdot z - 8 \cdot \frac{y^2}{d^2} - \alpha_u \cdot t_u\right)} \cdot \frac{1}{t_P} \cdot \int_0^{t_P} e^{\left(-8 \cdot \frac{(v \cdot t)^2}{d^2}\right)} dt$$

Q_l: heat input in lower polymer; d: beam diameter; P: laser power; v: feed rate;
t_u: thickness of upper polymer; α_l, α_u: absorption coefficient; t_P: duration of scan repetition

Implementation in LS-DYNA: calculation of element's heat input according to centroid coordinates



3. Calculation of Heat Input

Numerically calculated energy input:

$$E_{num}(y = y_c, z = z_c) = \int_{z_l}^{z_u} \int_{y_l}^{y_u} Q_l(y = y_c, z = z_c) dy\, dz$$

Analytically calculated energy input:

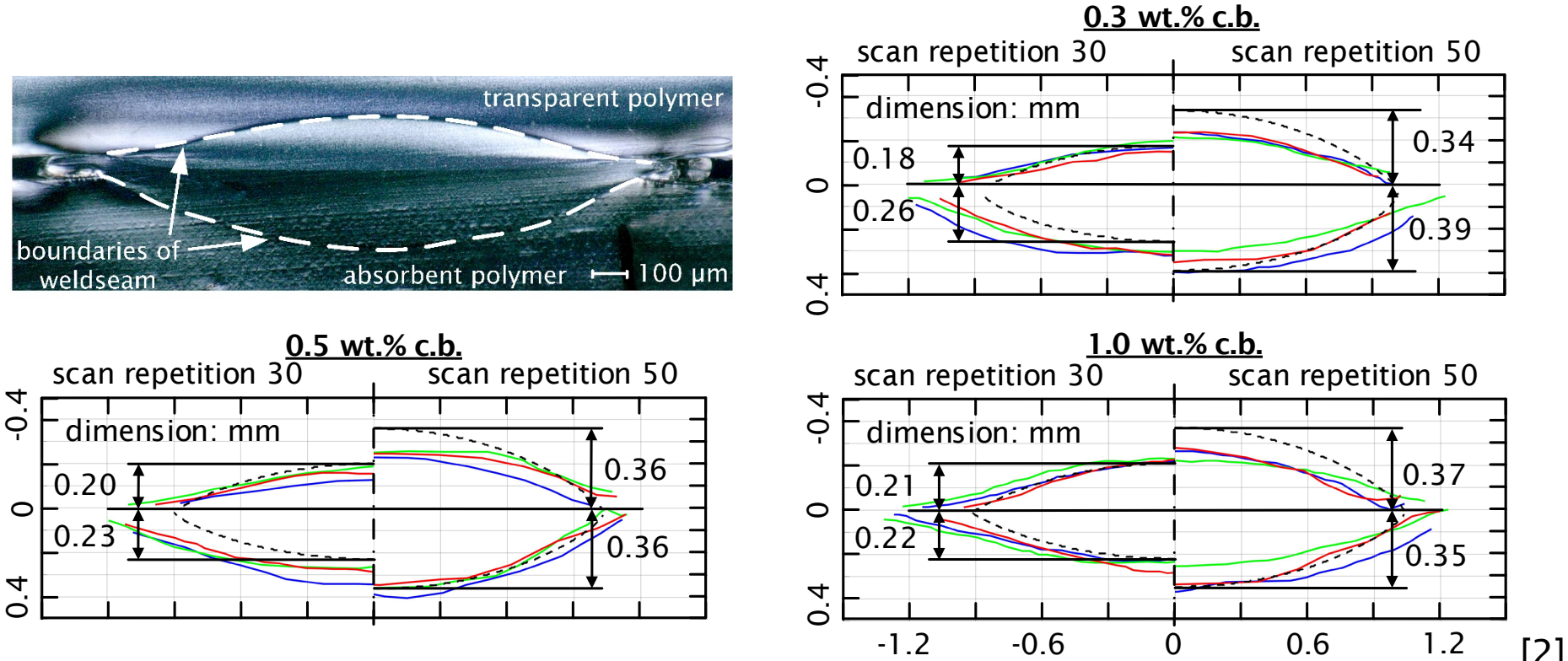
$$E_{analytic}(y, z) = \int_{z_l}^{z_u} \int_{y_l}^{y_u} Q_l(y, z) dy\, dz$$

Deviation of energy input calculation in one element:

$$Dev(y, z) = \frac{E_{analytic} - E_{num}}{E_{num}}$$

carbon black content *c. b.*	absorption coefficient α	beam diameter *d*	element edge length z_l-z_u; y_l-y_u	minimum deviation min $(Dev(y,z))$
[wt.%]	*[mm^{-1}]*	*[mm]*		*[%]*
0.3	20	4.5	0.025	1.0
0.5	43			4.9
1.0	94			24.6

4. Overlap Configuration Weldings of PA6

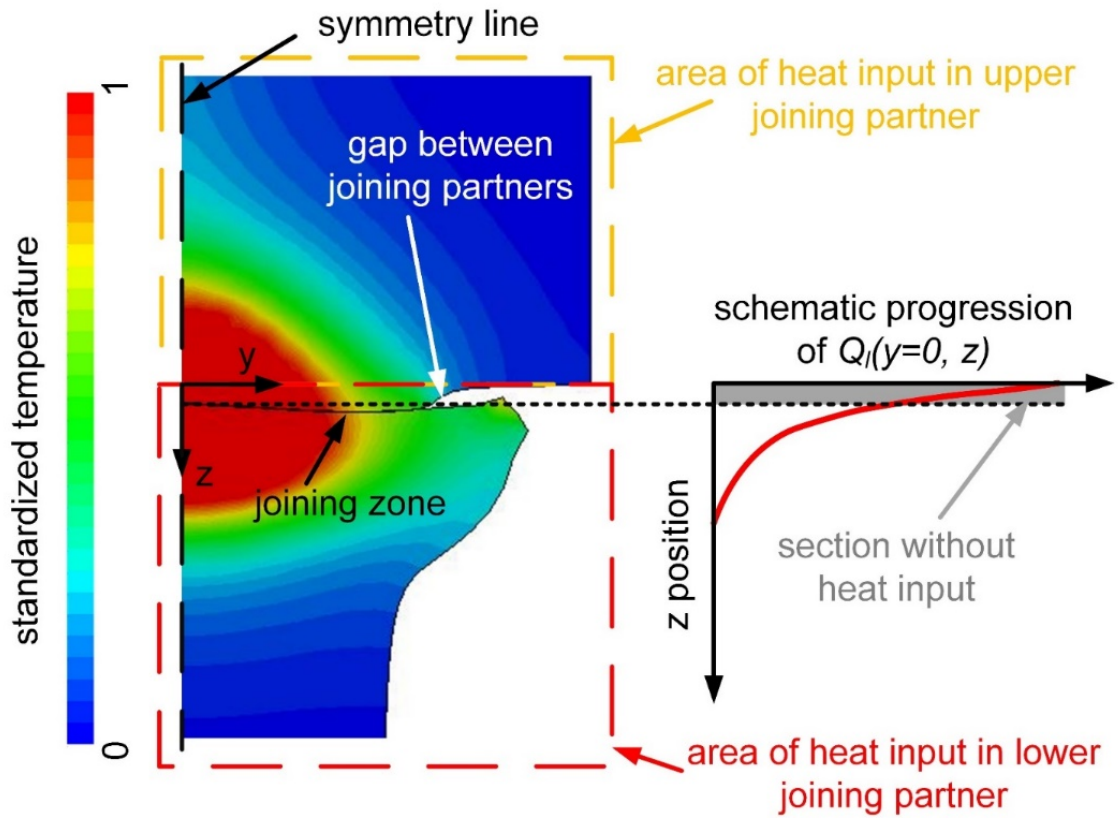


[2]

computed isotherm at melt temperature 228 °C
experimentally measured weld seam

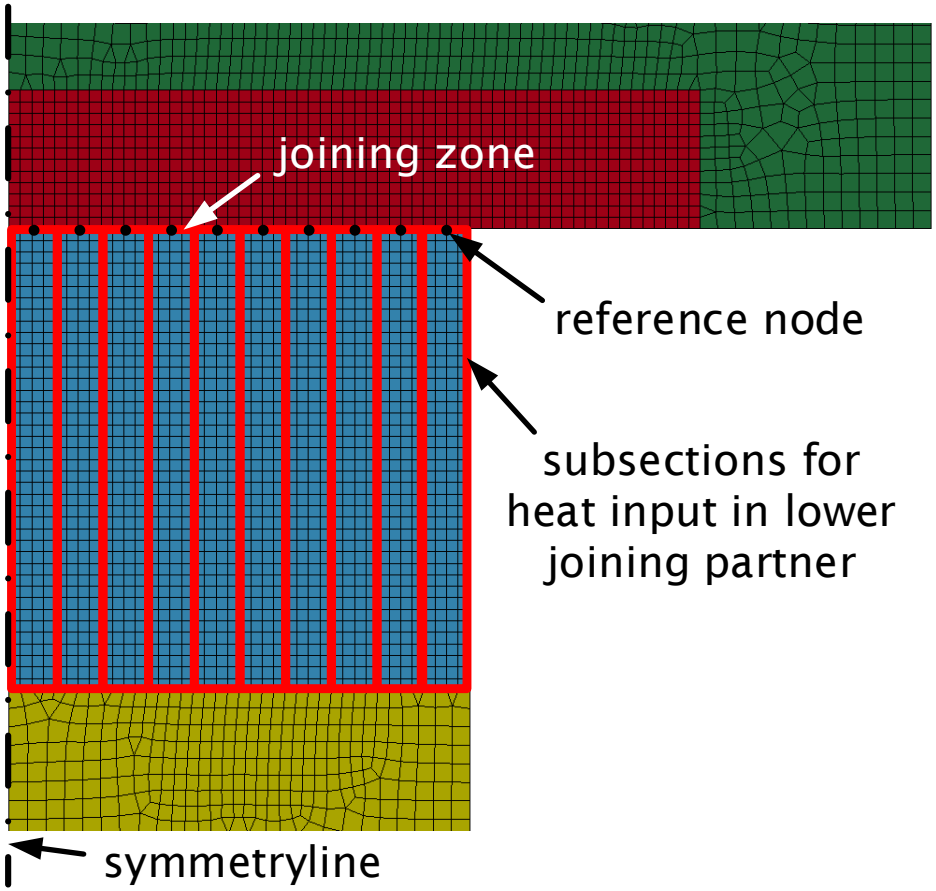
- relatively small deviations between weld seam dimensions in experiment and simulation
- temperature field is calculated accurately

5. T-Joint Configuration
a. Recent Issues

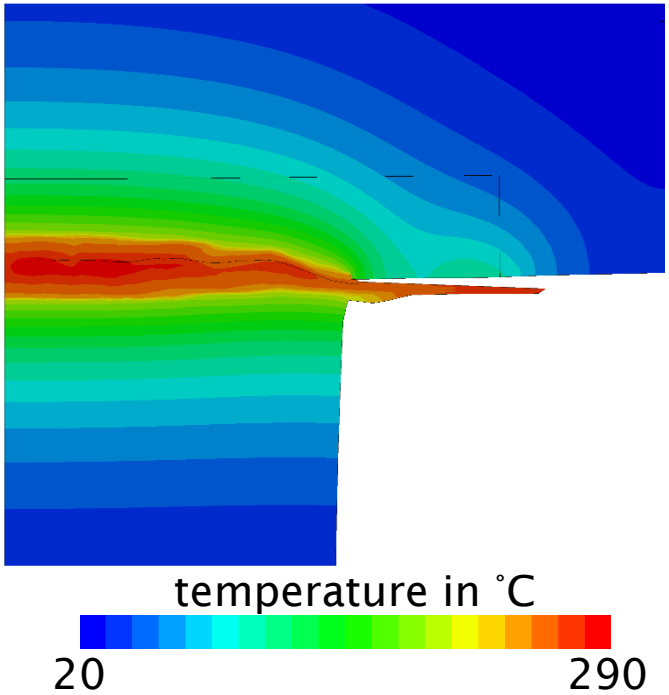


- calculation of heat input with respect to global coordinate system
- vertical movement of joining zone could not be taken into account in heat input calculation
- loss of heat input in lower joining partner

5. T-Joint Configuration
b. Improvement



- calculation of heat input in multiple subsections
- definition of reference nodes for each subsection
- calculation of heat input according to reference node‘s coordinates



6. Conclusion and Outlook

Conclusion:

- Deviations of heat input calculation are strongly dependent on polymer‘s absorption properties and element size.
- Recent issues concerning the deviations of heat input calculation as a consequence of deformations are bypassed using the new reference node feature.

Outlook:

- application for other thermoplastics
- implementation of scattering phenomena in heat input calculation

References

[1] Schmailzl, A.; Hüntelmann, S.; Loose, T.; Käsbauer, J.; Maiwald, F.; Hierl, S.: Potentials of the ALE-Method for Modeling Plastics Welding Processes, in Particular for the Quasi-Simultaneous Laser Transmission Welding. In: Numerical Analysis of Weldability. Graz 2018

[2] Schmailzl, A.; Käsbauer, J.; Martan, J.; Honnerová, P.; Schäfer, F.; Fichtl, M.; Lehrer, T.; Prušáková, L.; Tesar, J.; Skála, J.; Honner, M.; Hierl, S.: Measurement of Core Temperature through Semi-Transparent Polyamide 6 using Scanner-Integrated Pyrometer in Laser Welding. In: International Journal of Heat and Mass Transfer 146, 2019

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