TECHNISCHE UNIVERSITÄT CHEMNITZ

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Kunststofftechnik Chemnitz

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AiF

DVS FORSCHUNG

Heated Tool Welding of Thick-Walled Components

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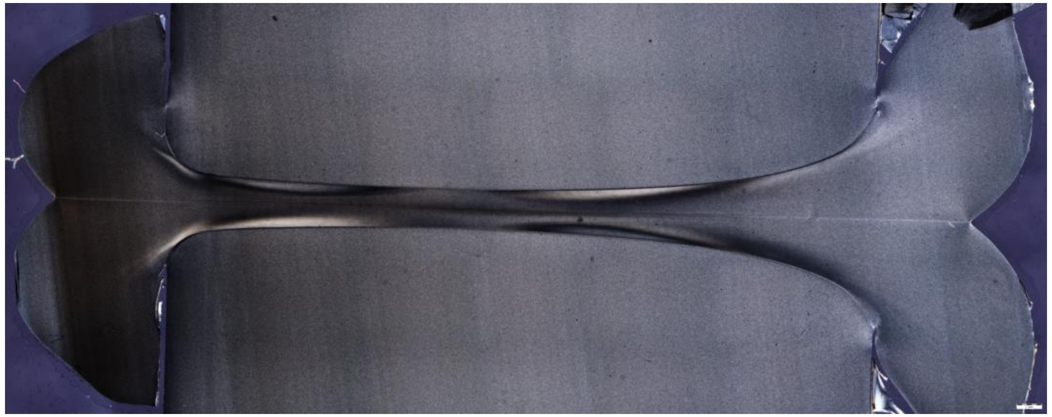
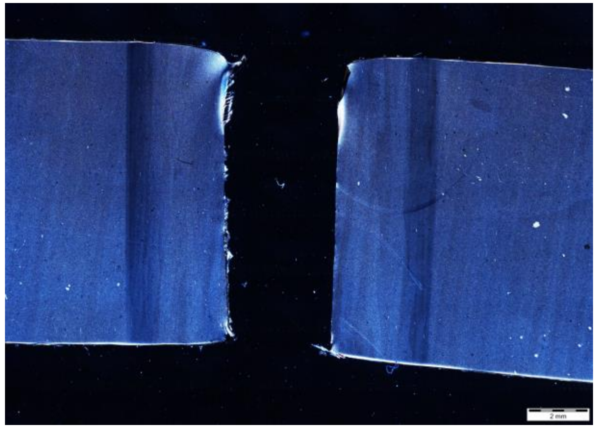


Outline

1. Motivation at TU Chemnitz
2. Experimental
3. Results
4. Overview of further planned research activities
5. Conclusion



Motivation at TU Chemnitz

State of the art

- Reports from users about problems with heated tool welding of components with large wall thicknesses

- Experimental scientific work carried out only with wall thicknesses up to 20 mm
  → Linearly extrapolated parameter sets for high wall thicknesses in the DVS guideline

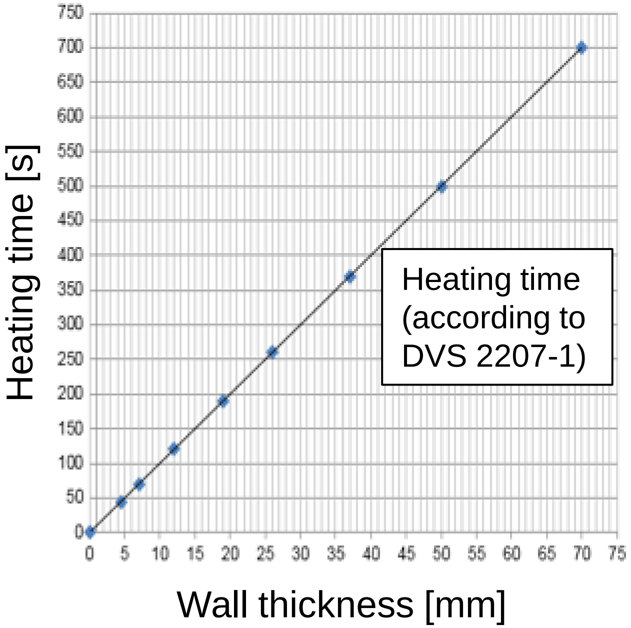
Comparison between usual laboratory dimensions (10 mm) and higher wall thicknesses (100 mm)

➢ Issues arising:
  – Larger shear and strain flow ranges?
  – Inhomogeneous cooling conditions?
  – Unexplored weld seam morphology?
  – Unknown residual stress?

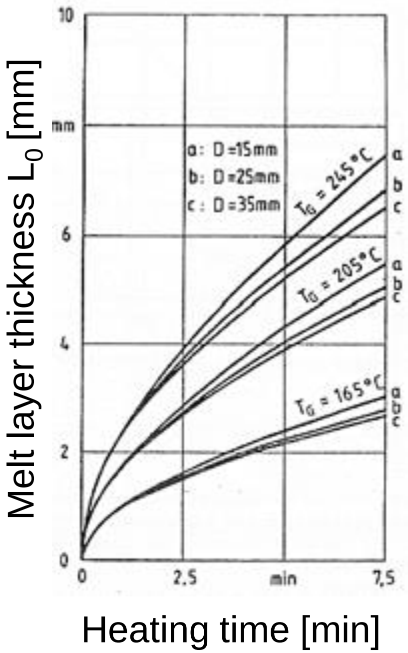
Influence on mechanical properties?

Motivation at TU Chemnitz

- Linear increase of the heating time as a function of the wall thickness according to DVS
  → Degressive increase in the melt layer thickness



Specification for the heating time as a function of the wall thickness according to DVS



Achievable melt layer thickness as a function of the heating time*

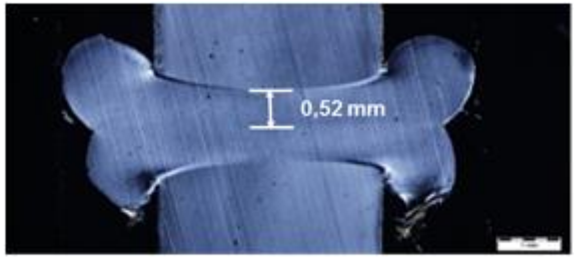
→ Linear relationship between heating time and wall thickness neither theoretically justified nor experimentally verified

*Source: P. Tappe; Modellgesetze beim Heizelementstumpfschweißen teilkristalliner Thermoplaste

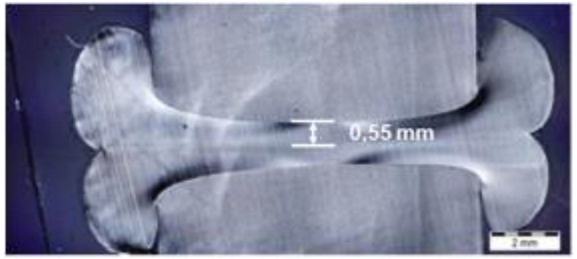
Motivation at TU Chemnitz

- Heating element butt welds made of polyethylene of different wall thickness, welded according to DVS 2207-1:

L: Residual melt layer thickness
d: Wall thickness



d: 4 mm



d: 10 mm

d: 35 mm

L/d	0.13	0.055	0.035

Disproportionate increase in residual melt layer thickness

→ Change in rheological behaviour depending on wall thickness
→ Influence on morphological seam formation (and mechanical properties?)

➢ Two IGF projects on heated tool welding of thick-walled components at Chemnitz University of Technology, Professorship of Plastics Technology:

- „Quality-compliant heated tool butt welding of thick-walled semi-finished products made of polyethylene“
  - Duration: 01.09.2017 – 31.08.2019

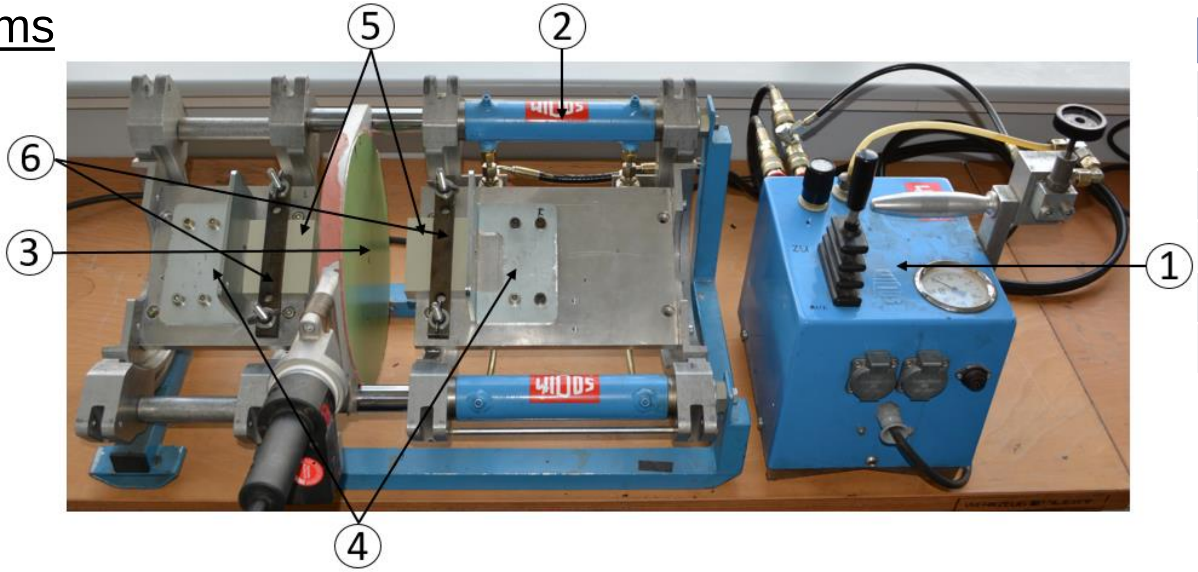
⇒

- „Strength gradient of thick-walled, heated tool welded semi-finished products“
  - Duration: 01.04.2023 – 31.03.2025

Experimental

Welding systems

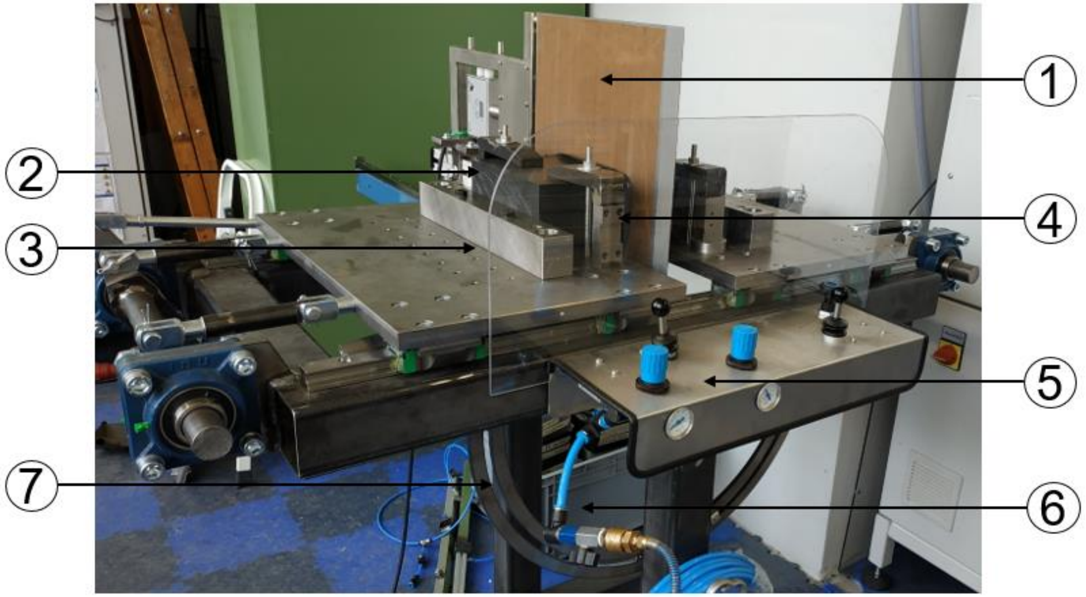
1.



Number	Machine element
1	Hydraulic unit
2	Hydraulic cylinder
3	Heating element
4	Tools
5	Welding parts
6	Clamping elements

Machine data	
Force	50 N – 5.000 N
Working width	210 mm

2.



Number	Machine element
1	Heating element
2	Welding part
3	Tools
4	Clamping elements
5	Operating unit
6	Pneumatic supply
7	Tilting device

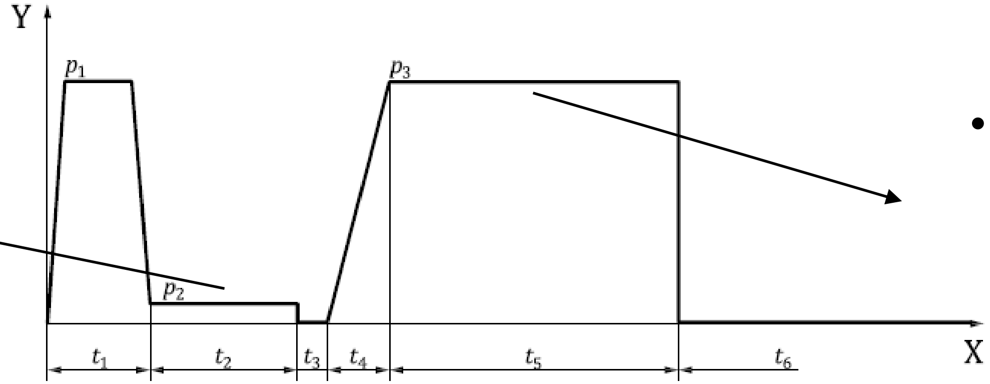
Machine data	
Force	50 N – 20.000 N (different operating cylinders)
Working width	400 mm

Experimental

Overview of examinations and test methods

DVS 2207-1 ← Production of heated tool welded parts → Varying parameters and process control

- Material: PE100 / PE100 RC
- Wall thickness: 30 / 70 / 100 mm



- Heating phase:
  - ➢ Examination of the melt layer formation

- Joining/Cooling phase:
  - ➢ Investigation of the joining path and of the material solidification

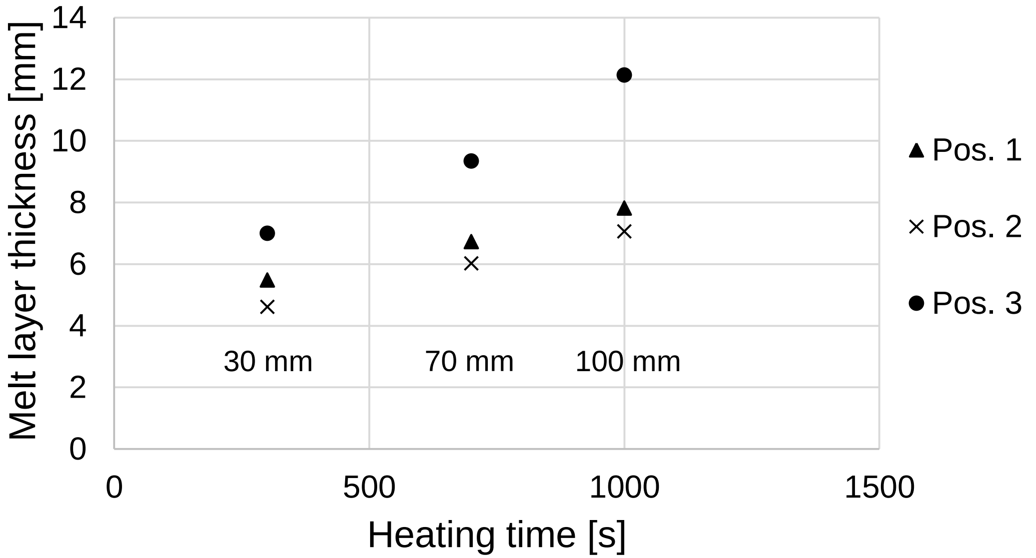
➢ Does the wall thickness affect the weld formation in a non-linear way?

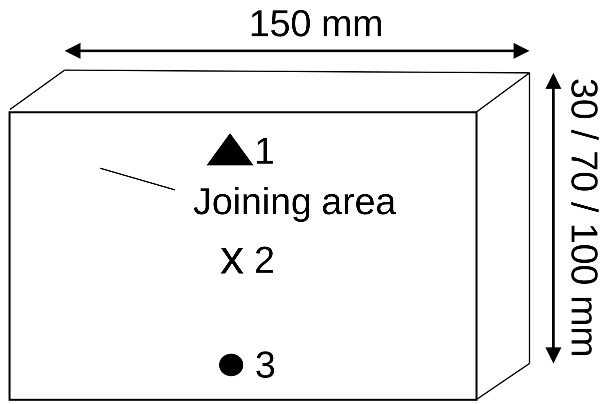
➢ Are there any local differences in the joining area?

- Thermal, optical and mechanical investigations
  - Tensile test, Technological bending test, Impact bending test, Long-term tensile creep test
  - Local sample analysis
  - Partial lack of specifications for large wall thicknesses in the guidelines

Results

Examination of the melt layer formation of PE100 – Wall thickness 30 / 70 / 100 mm





Measuring positions on the joining area (Pos. 1, 2 und 3)

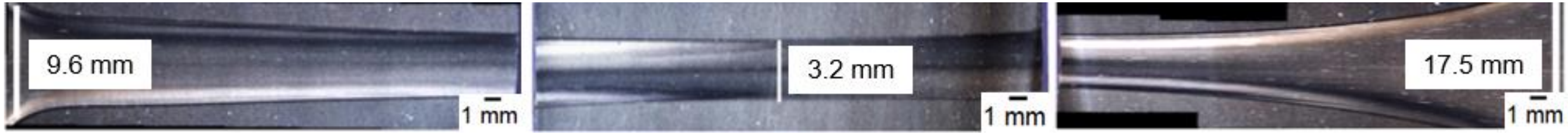
Wall thickness [mm]	Melt layer thickness centre [mm]	Melt layer thickness bottom [mm]	Difference [mm]
30 mm	4.6 mm	7.0 mm	2.4 mm
70 mm	6.0 mm	9.4 mm	3.4 mm
100 mm	7.1 mm	12.1 mm	5.0 mm

- Curvature / Extension of the melt layer at the edge
- Increasing curvature as a function of the wall thickness

Results

Microscopic examination of the weld seam thickness

Top

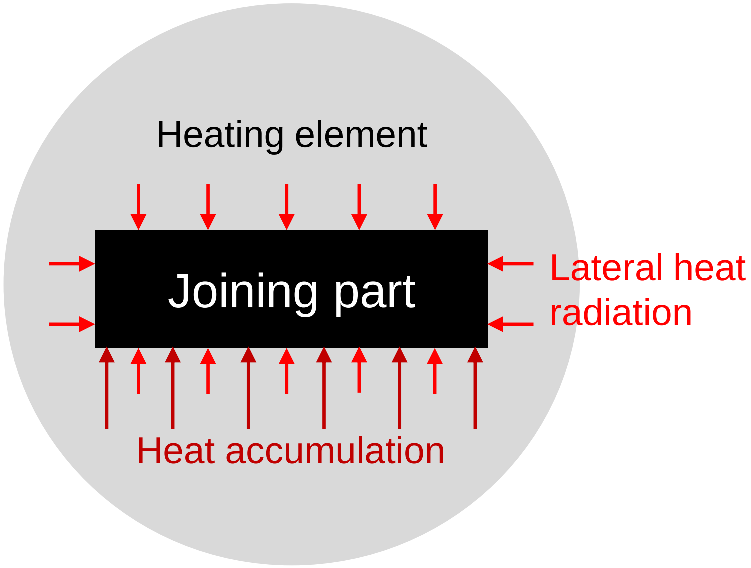


Bottom

Microscopic image of PE100 RC, wall thickness 100 mm (polarised transmitted-light), welding parameters according to DVS

➢ Asymmetric curvature of the weld seam / High weld thickness at the edge of the weld seam

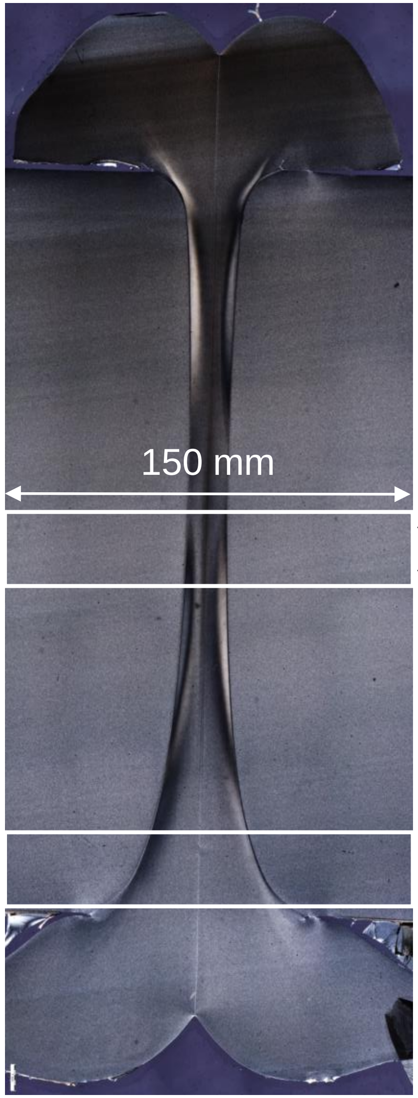
- Reason for asymmetrically curved melt layer and resulting weld seam profile:
  - Lateral heat radiation and heat accumulation during heating phase
    - ➢ Increasing curvature as a function of the wall thickness and heating time
    - ➢ Local difference in resulting mechanical properties?



Schematic illustration of heat accumulation / lateral heat radiation

Results

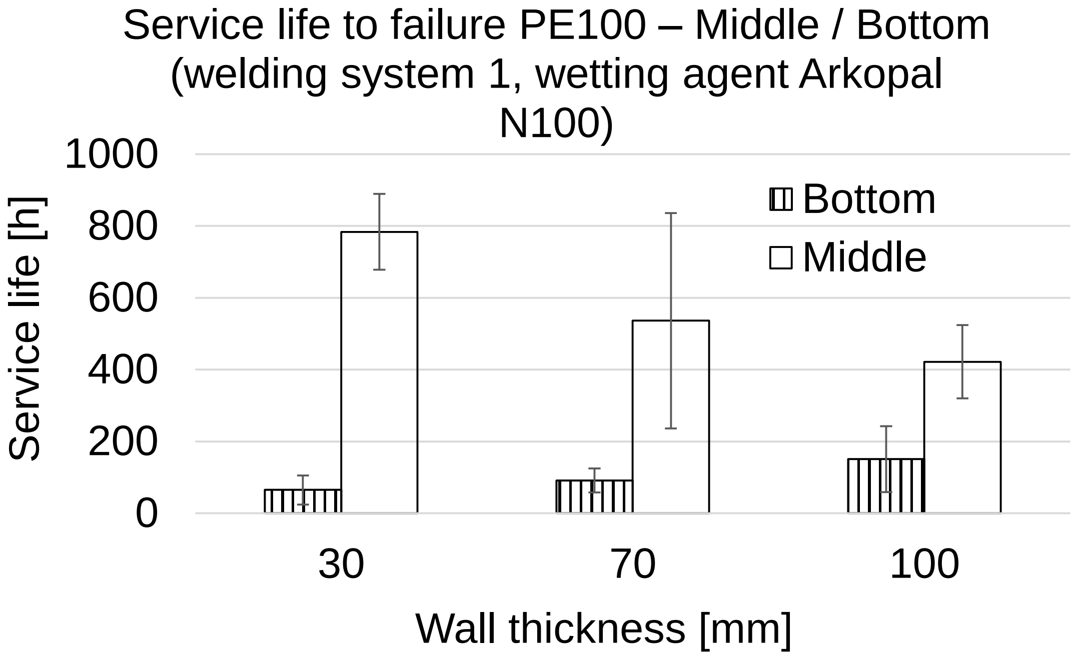
Tensile creep test of PE100, wall thickness 30 – 100 mm (parameters according to DVS)

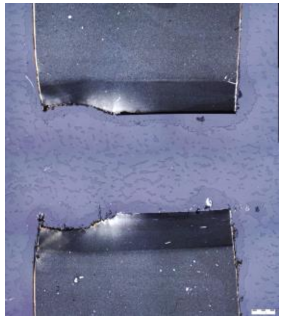


10 mm

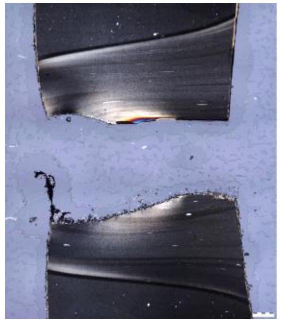
Test conditions	
Guideline	DVS 2203-4
Temperature	95 °C
Test load	4 MPa
Sample dimensions	150 mm x 10 mm x 10 mm

- Test specimens from the middle and the bottom of the weld seam
- Removal of the welding bead notch





100 mm, middle, 538 h



100 mm, bottom, 26 h

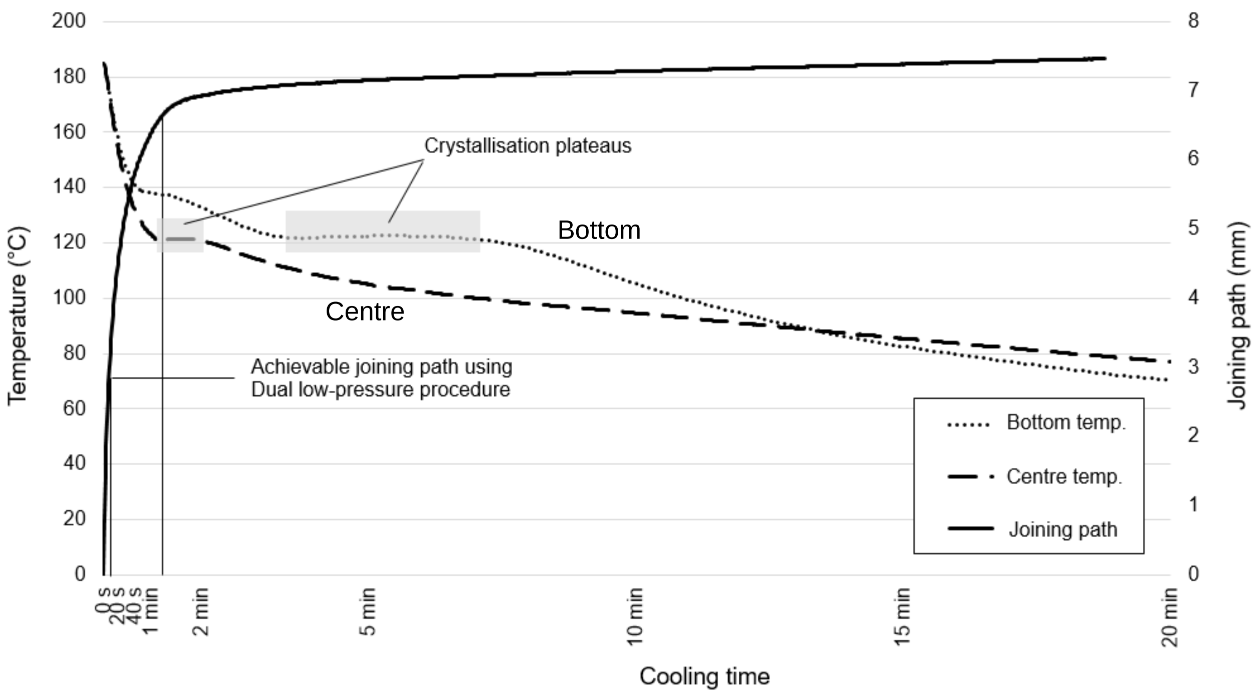
➢ Fracture initiation and progression completely in the joining area

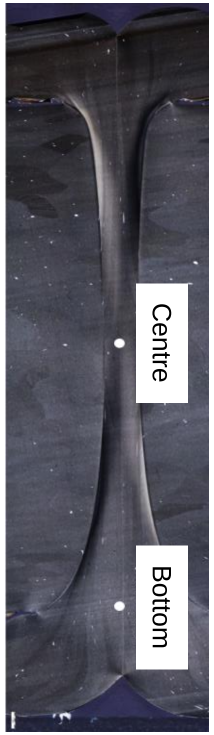
- Short service life to failure in the strongly curved, lower edge area of the welds for all wall thicknesses (30 mm, 70 mm, 100 mm)

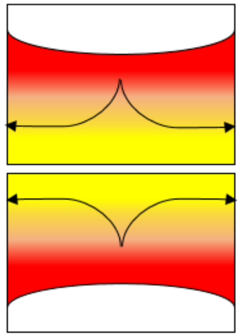
Results

Cooling curve and joining path as a function of time, PE100, wall thickness 30 mm, parameters according to DVS

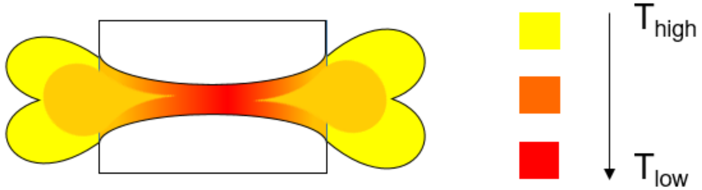
- Temperature measurement by means of thermocouples at different positions in the joining area during cooling phase
- Measurement of joining path by means of laser measurement system







1.Before / during joining



2. After joining

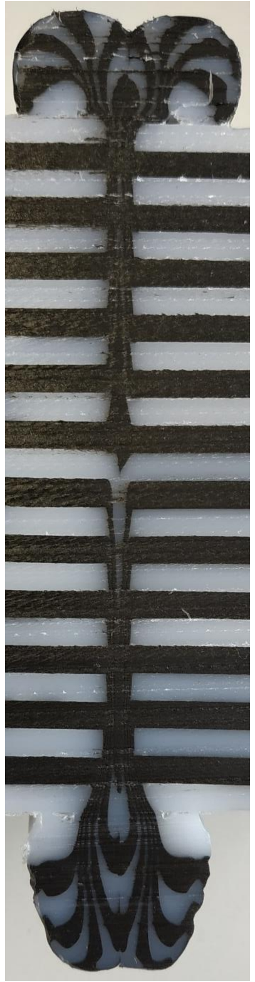
- Thermal rearrangement during the melt flow process
- In addition: higher amount of melt volume in the edge area due to curvature

- Significantly longer and later starting crystallisation time at the bottom of the weld / No uniform cooling conditions
- Significant increase in joining path still after start of crystallisation / Flow movements in solidifying material

➢ High resulting residual stress state / Compressive stress (centre) and tensile stress (edge)

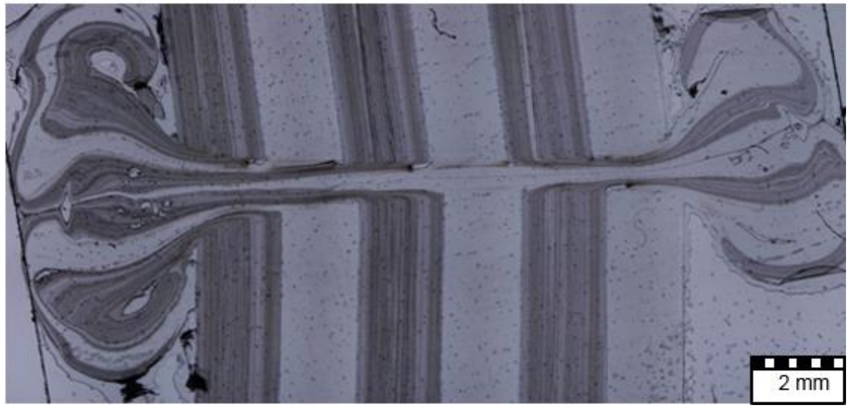
Results

Visualisation of the squeeze flow



PE
(wall thickness100 mm)

PP
(wall thickness 66 mm)



Microscopic image of flow processes during heated tool butt welding of PP-H (soot-filled and natural-colored 2 mm plates alternately layered)

➡ Outermost layer of the weld bead from the middle area of the joining part

- Melt flow from the centre to the bead area
- Melt flow volume increasing towards the edge
- Flow lines of different lengths

➢ Local flow velocities in the melt channel vary

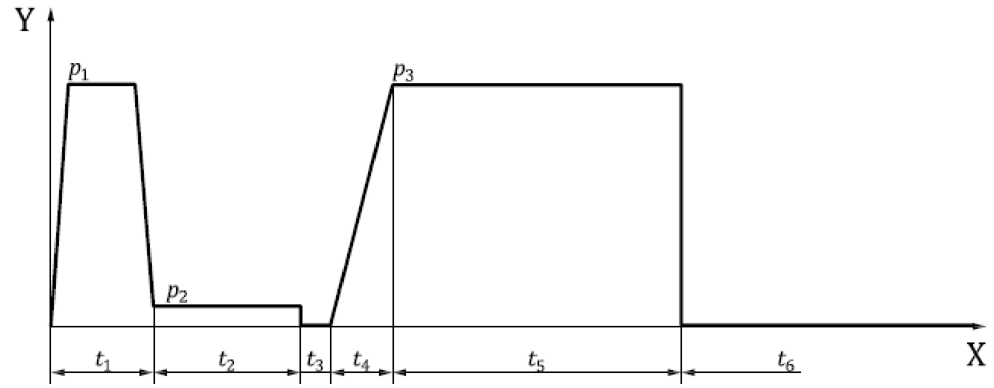
Results

ISO 21307: Plastics pipes and fittings – Butt fusion jointing procedures for polyethylene (PE) piping systems

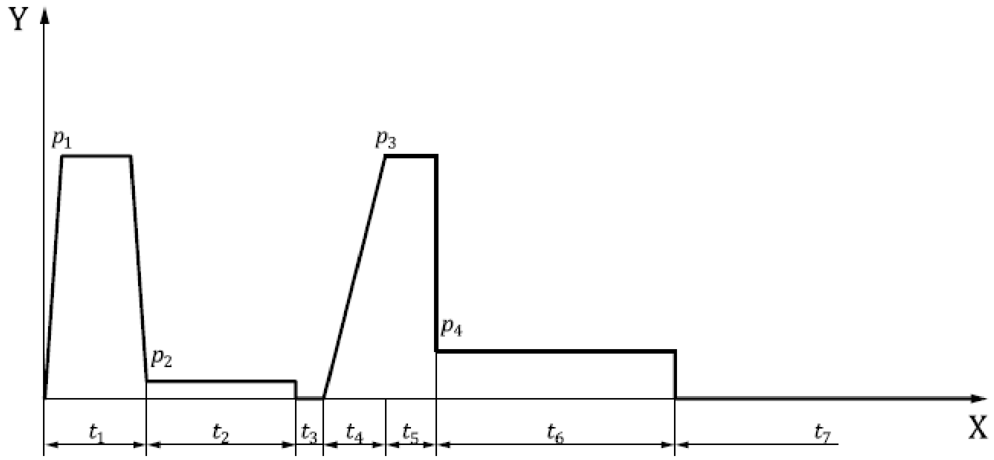
1. Single low-pressure procedure:
   - Joining pressure 0.15 MPa over entire joining and cooling time
   - Procedure according to DVS

2. Single high-pressure procedure:
   - Joining pressure 0.5 MPa
   - Shorter cooling time (0,5x DVS)

3. Dual low-pressure procedure:
   - Joining pressure 0.15 MPa (10 s)
   - After 10 seconds: 0.025 MPa



Schematic figure of the Single low-pressure and the Single high-pressure procedures



Schematic figure of the Dual low-pressure procedure

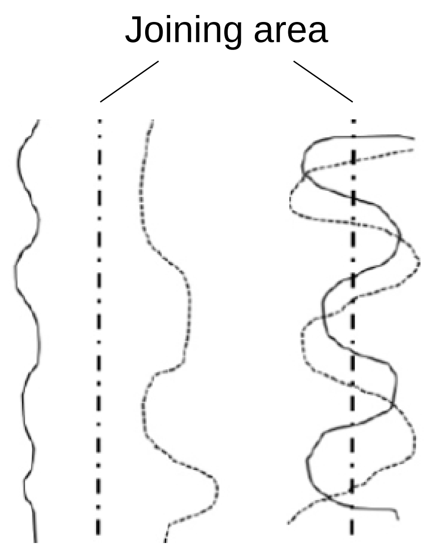
Overview of further planned research activities

Definition of a switch-off criterion for the joining path

- State of the art:
  - Further rheological stress on the cooling system due to constantly increasing joining path
  - Suppression of the relaxation phase of the strain-flow-induced orientation in the area of the joining plane

- First approaches for improvement:
  - Dual low-pressure procedure + single high-pressure procedure
  - No observation of improved creep behaviour due to generally selected joining pressures and process times

- Goal:
  - Improvement of creep behaviour through logically selected joining pressure-process time-relationship

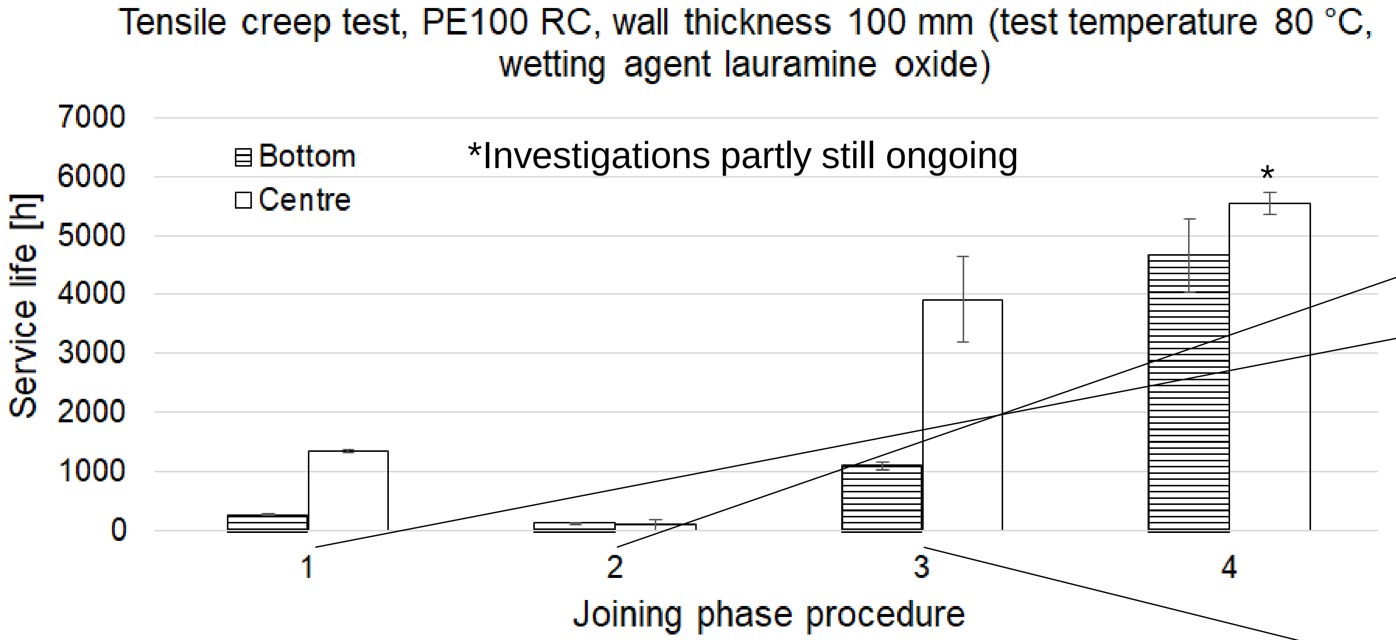


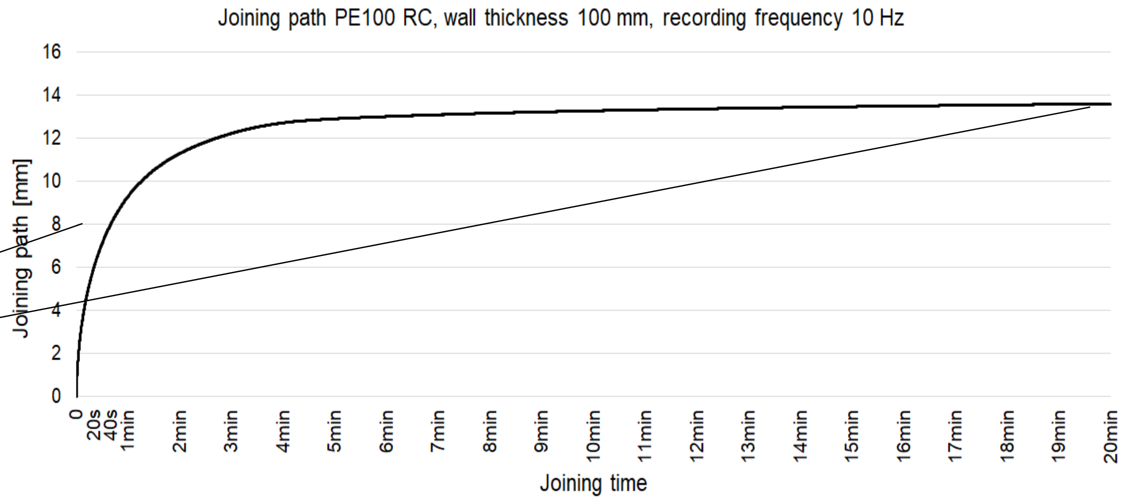
Left: stretched molecular chains during joining; right: relaxation of molecular chains after joining

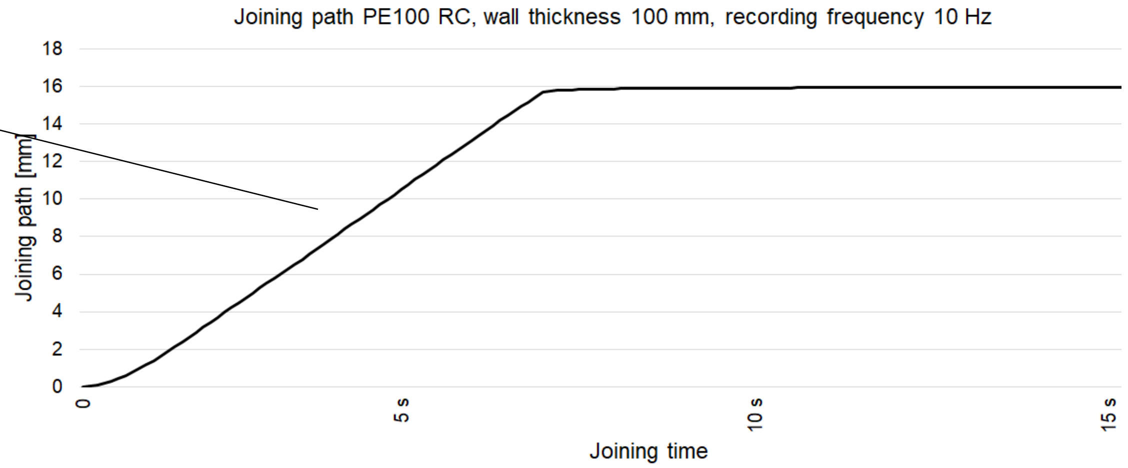
Overview of further planned research activities

Definition of a switch-off criterion for the joining path

(Investigations carried out with welding system 2)







Joining phase procedure	Joining pressure	Joining time under pressure	Joining path
1	DVS (0.15 MPa)	DVS (120 min)	14 mm
2	DVS	1 min	8 mm
3	~ 2 MPa	15 s	16 mm
4	0.6 MPa	1.5 min	16 mm

→ Goal: Correlation between joining path and cooling temperature!

Conclusion

- DVS 2207-1: Long heating and cooling times due to extrapolated parameters for high wall thicknesses

- Locally non-uniform properties within the weld seam

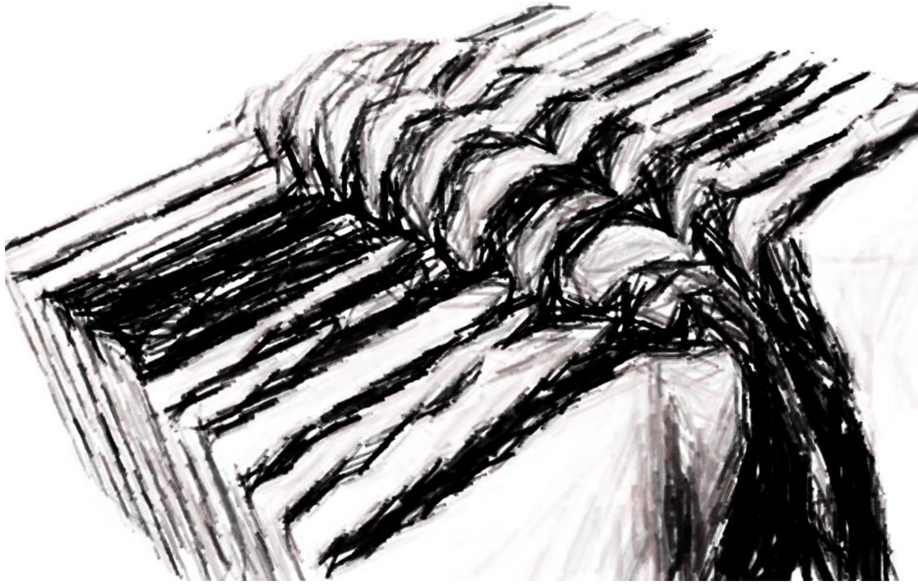
  – Weld seam geometry
  – Heating and cooling behaviour
  – Melt flow behaviour
  – Internal stresses

Strength gradient
+
Mechanical weakening of the edge area

➢ Further studies on strength gradient necessary

  - Avoidance of further rheological stress on the already solidifying system
  - Allowing the relaxation phase necessary for the formation of strength

Thank you for your attention!



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