# JoinTec:

## Innovative and competitive new joining technology for steel pipes using adhesive bonding


**University of Paderborn, Germany**

Laboratory for Materials and Joining Technology (LWF)

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# Agenda

**TOP 1: Welcome and introduction**

**TOP 2: Research results of project partners**

- **LWF**
- **Salzgitter Mannesmann Forschung GmbH**
- **Mannesmann Fuchs Rohr GmbH**
- **Sika Danmark A/S**
- **CSM SPA**
- **AGFW e.V.**
- **Gas de France**
- **Bohlen & Doyen Polska Sp. Z o.o.**

**TOP 3: Presentation of Bayer MaterialScience**

**TOP 4: Discussion regarding tests, types of specimens**

**TOP 5: Administration of the project (deliverables to the European Commission, financial statements, schedule for technical reporting)**

**TOP 6: Next steps / Miscellaneous**

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# Welcome and Introduction

**JoinTec**

**–**

**Innovative and competitive new joining technology for steel pipes using adhesive bonding**

Main objectives/ tasks:

§ Elaborating an efficient, integrated and easy-to-use joining technique for adhesive bonding of steel pipes.

§ Development of guidelines, design calculation methods and non-destructive testing methods including a repair concept for adhesively bonded steel pipes.

# Welcome and Introduction

## Programme bar chart (tasks, deliverables, milestones)

| Work packages | Work packages' title | Deliverables | 1st year | 2nd year | 3rd year |
|---|---|---|---|---|---|
| **WP 1** | **Joining Fundamentals** | | | | |
| Task 1.1 | Survey of requirements | Working points | | | |
| Task 1.2 | Optimisation joint design | Joint geometry | | | |
| Task 1.3 | Adhesive Development | Adequate adhesive | | | |
| Task 1.4 | Selection of surface treatment | Surface treatment | | | |
| Task 1.5 | Development of application method | Application method | | | |
| **WP 2** | **Process Quality Control** | | | | |
| Task 2.1 | Quality control system | Control system | | | |
| Task 2.2 | Repair procedure | Repair procedure | | | |
| Task 2.3 | Transfer to field conditions | Suitability | | | |
| **WP 3** | **Full scale testing** | | | | |
| Task 3.1 | Full scale tests | Stress strain curves | | | |
| Task 3.2 | Defect tolerance criteria | Tolerance criteria | | | |
| Task 3.3 | FEM-model | Calc. model | | | |
| **WP 4** | **Adhesive bonding concept** | | | | |
| Task 4.1 | Pipe laying test at site | Verification | | | |
| Task 4.2 | Comparison with welding | Cost calculation | | | |
| Task 4.3 | Guidelines, design criteria | Design criteria | | | |
| **WP 5** | **Co-ordination** | | | | |
| Task 5.1 | Co-ordination | Teamwork | | | |
| Task 5.2 | Reports | Reports | | | |

project start

24.01.2008

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# WP1: Proposed adhesives

**Structural polyurethane solution adhesives**

**PU154:**
High-performance thixotropic structural adhesive for rotor blades

**PU155:**
Two component polyurethane solution adhesive for structural bonding and sandwich components

**PU156:**
Two component high strength adhesive for bonding of metal to wood constructions

| | PU154 | PU155 | PU156 |
|---|---|---|---|
| **Curing mechanism** | Polyaddition | Polyaddition | Polyaddition |
| **Density mixed** | 1.2 g/cm$^3$ | 1.3 g/cm$^3$ | 1.5 g/cm$^3$ |
| **Viscosity mixed** | a little pasty | pasty | 3,200 mPa*s (CQP 538-2) |
| **E-Modulus** | 3,070 MPa (ISO 527) | (n/a) | 2,239 MPa (ASTM D 790) |
| **Tensile strength** | 36.5 MPa (ISO 527) | 13.0 MPa (ISO 527) | 18.0 MPa (ISO 527) |
| **Elongation at break** | 3.1 % (ISO 527) | 25.0 % (ISO 527) | 4.0 % (ISO 527) |

Source: Sika

# WP1: Differential Scanning Calorimetry (DSC)

→ **Determination of the time and temperature depending chemical und physical effects of the adhesive's curing reaction**

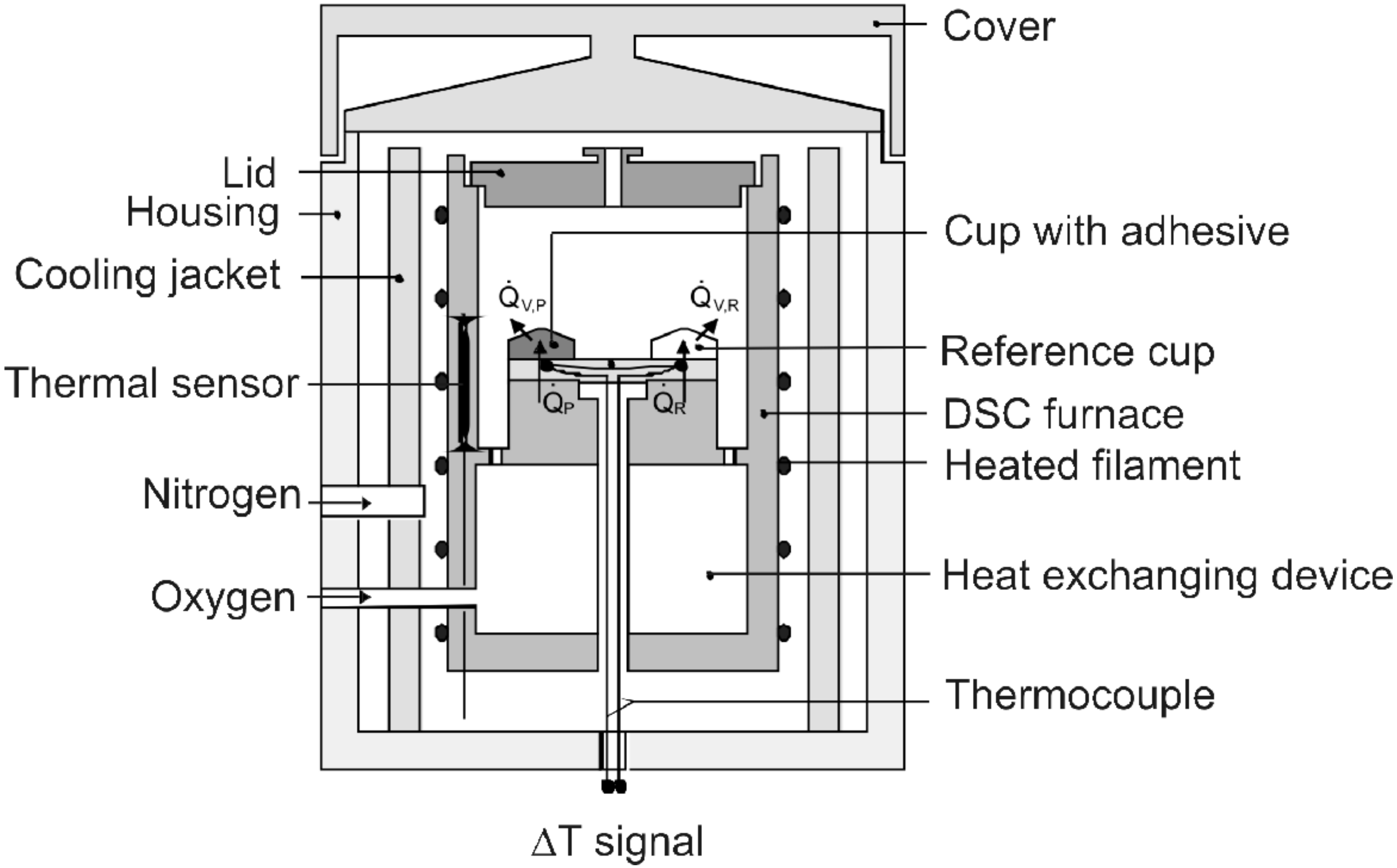
- **Testing device:** Mettler DSC30

- **Testing method:** measurement of the temperature differences of an adhesive filled cup and an empty cup that are exposed to the same temperature profile and determination of the standardised heat flux

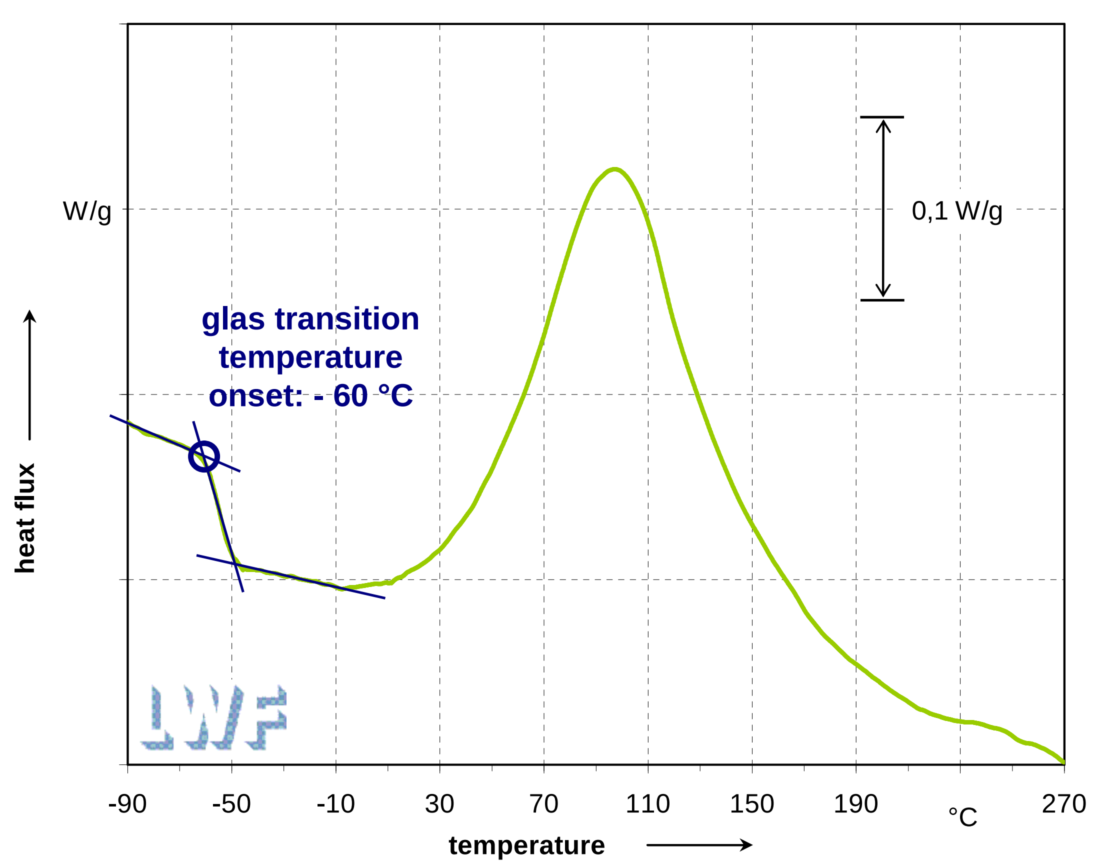
- **Results:**
  - reaction kinetics of the curing reaction (temperature- and time-relating)
  - specific enthalpy of the reaction
  - glas transition temperature

# WP1: Differential Scanning Calorimetry (DSC)

→ **schematic test setup of DSC testing device**



# WP1: DSC analysis on PU154

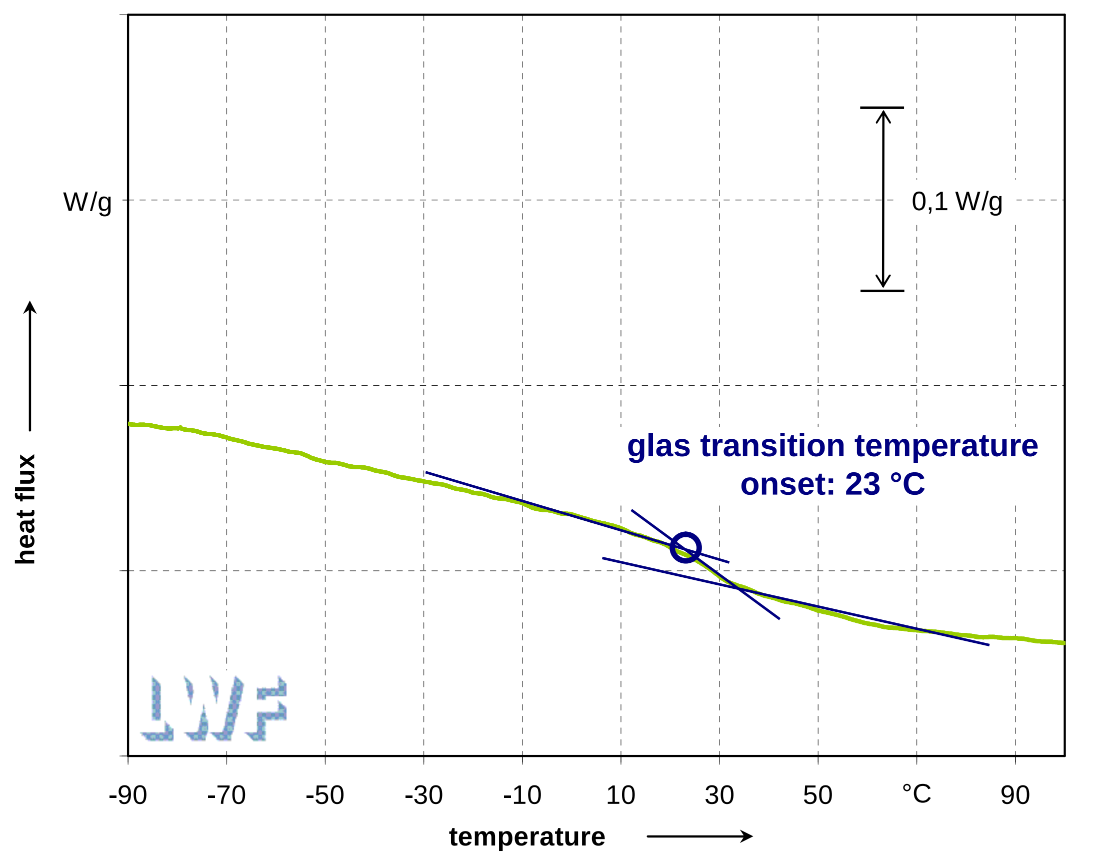



| |
|---|
| **Adhesive**<br>PU154 |
| **Testing device**<br>Mettler DSC30 S |
| **Test method**<br>DSC analysis (DIN 53765) |
| **Heating rate**<br>8K/min |
| **Displayed**<br>standardised heat flux |
| **Mass of adhesive sample**<br>19.98 mg |
| **Specimen**<br>Al-cup (20µl)<br>sample of adhesive |



normalised reaction enthalpy: 158.57 J/g (linear baseline)

# WP1: DSC analysis on cured PU154




**Adhesive**
PU154

**Testing device**
Mettler DSC30 S

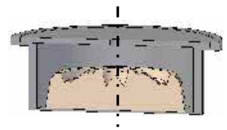
**Test method**
DSC analysis (DIN 53765)

**Heating rate**
8K/min

**Displayed**
standardised heat flux

**Mass of adhesive sample**
19.98 mg

**Specimen**
Al-cup (20µl)
sample of cured adhesive



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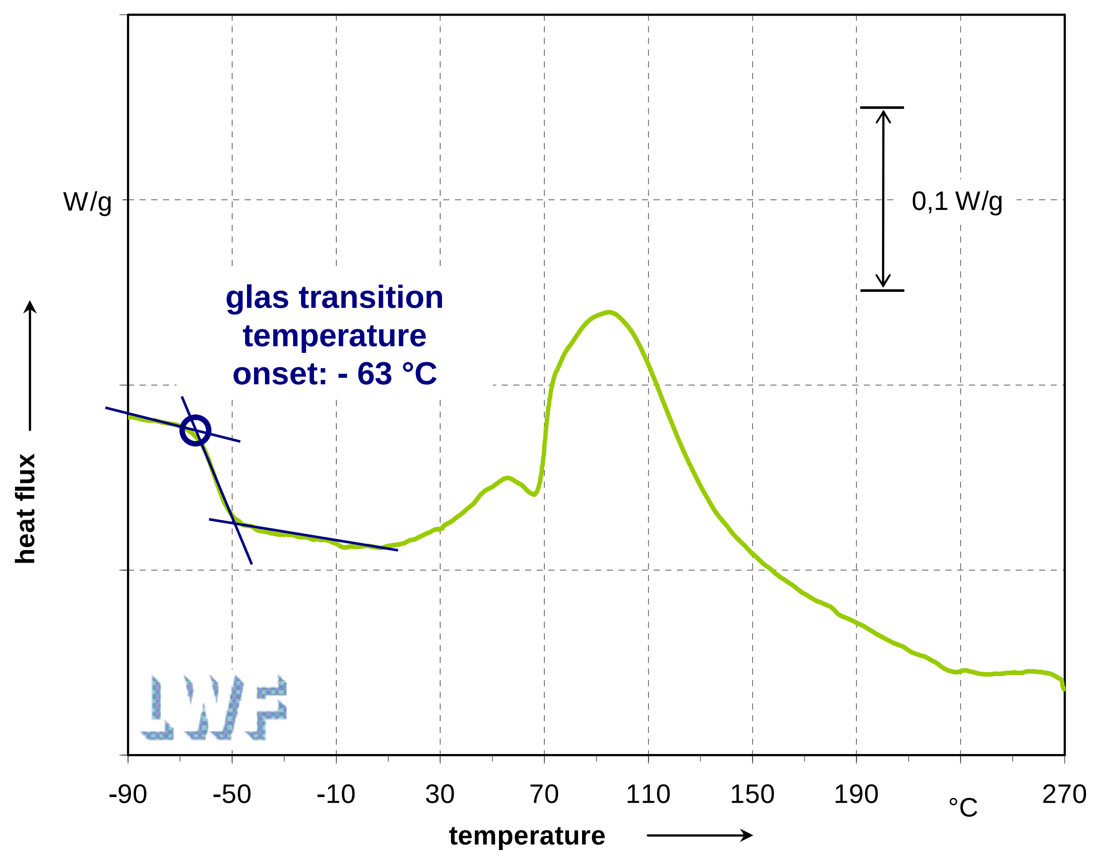
# WP1: DSC analysis on PU155




| | |
|---|---|
| **Adhesive** | PU155 |
| **Testing device** | Mettler DSC30 S |
| **Test method** | DSC analysis (DIN 53765) |
| **Heating rate** | 8K/min |
| **Displayed** | standardised heat flux |
| **Mass of adhesive sample** | 19.96 mg |
| **Specimen** | Al-cup (20µl)<br>sample of adhesive |

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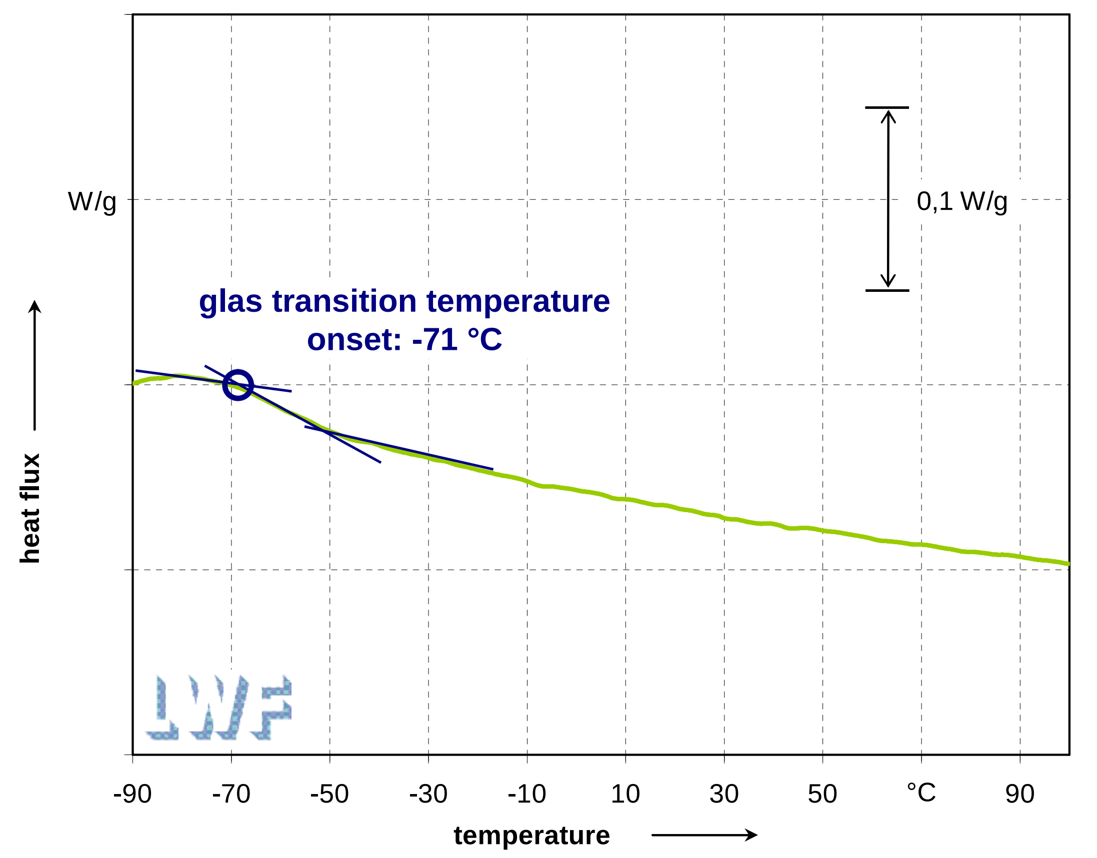
normalised reaction enthalpy: 91.17 J/g (linear baseline)

# WP1: DSC analysis on cured PU155




**Adhesive**
PU155

**Testing device**
Mettler DSC30 S

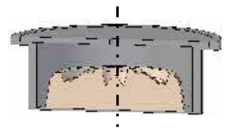
**Test method**
DSC analysis (DIN 53765)

**Heating rate**
8K/min

**Displayed**
standardised heat flux

**Mass of adhesive sample**
19.96 mg

**Specimen**
Al-cup (20µl)
sample of cured adhesive



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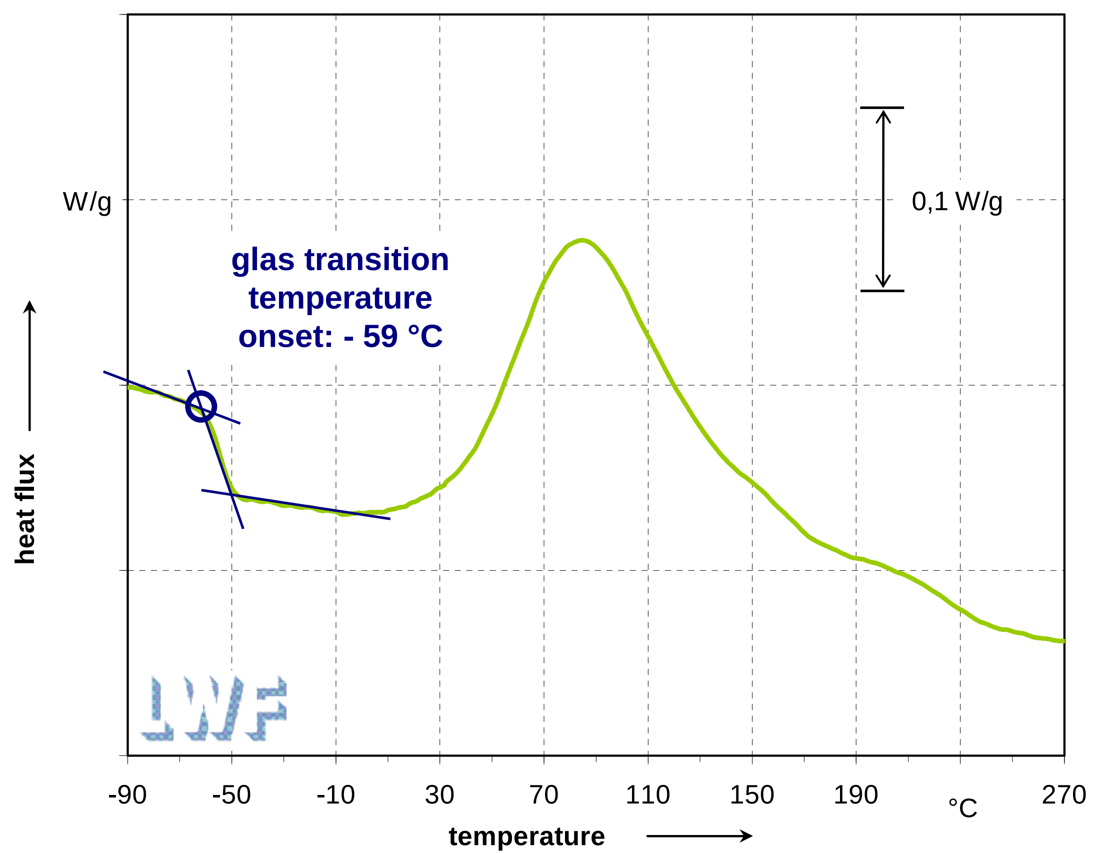
# WP1: DSC analysis on PU156




**Adhesive**
PU156

**Testing device**
Mettler DSC30 S

**Test method**
DSC analysis (DIN 53765)

**Heating rate**
8K/min

**Displayed**
standardised heat flux

**Mass of adhesive sample**
19.95 mg

**Specimen**
Al-cup (20µl)
sample of adhesive

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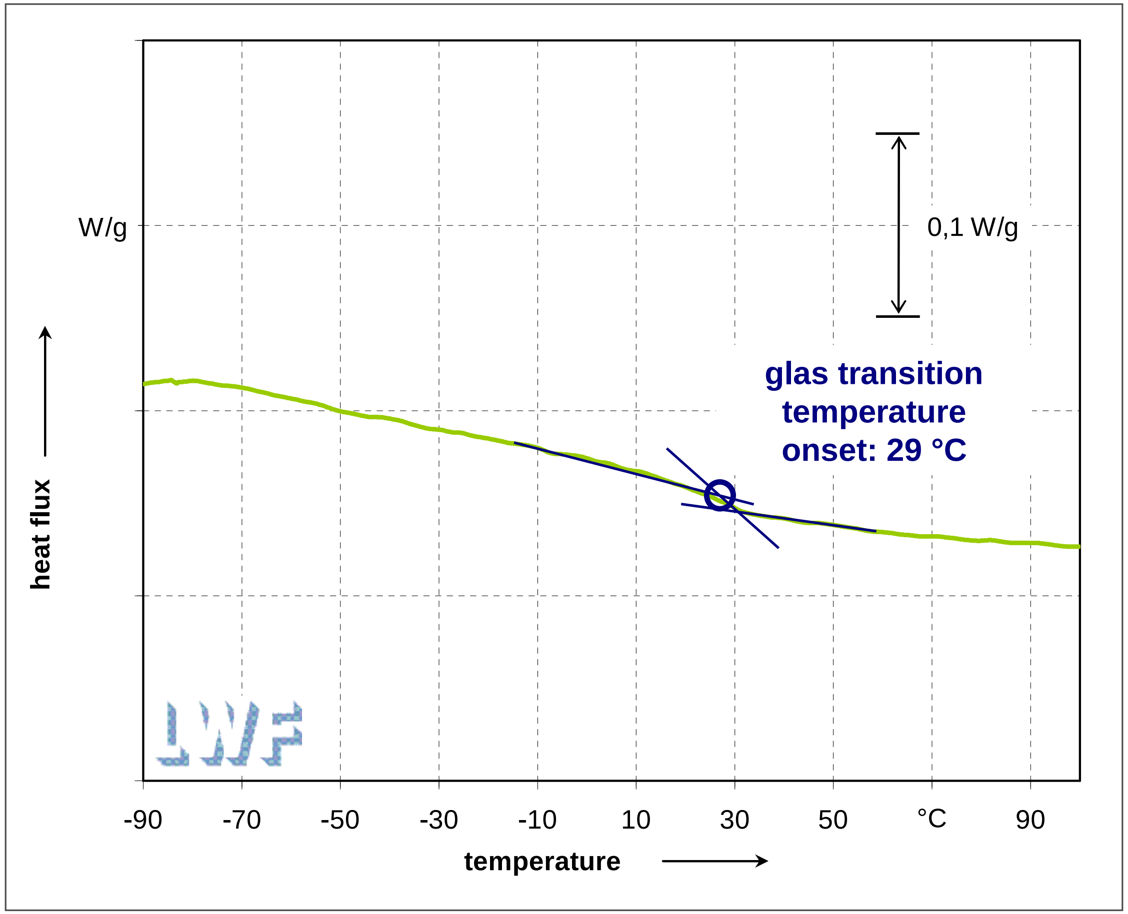
normalised reaction enthalpy: 114.72 J/g (linear baseline)

**University of Paderborn, Germany**
Laboratory for Materials and Joining Technology (LWF)
Prof. Dr.-Ing. Ortwin Hahn

Dipl.-Ing. T. Boeddeker

# WP1: DSC analysis on cured PU156




| |
|---|
| **Adhesive**<br>PU156 |
| **Testing device**<br>Mettler DSC30 S |
| **Test method**<br>DSC analyses (DIN 53765) |
| **Heating rate**<br>8K/min |
| **Displayed**<br>standardised heat flux |
| **Mass of adhesive sample**<br>19.96 mg |
| **Specimen**<br>Al-cup (20µl)<br>sample of cured adhesive |

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# WP1: $\tau$ - $\gamma$ tests on thick tensile specimens

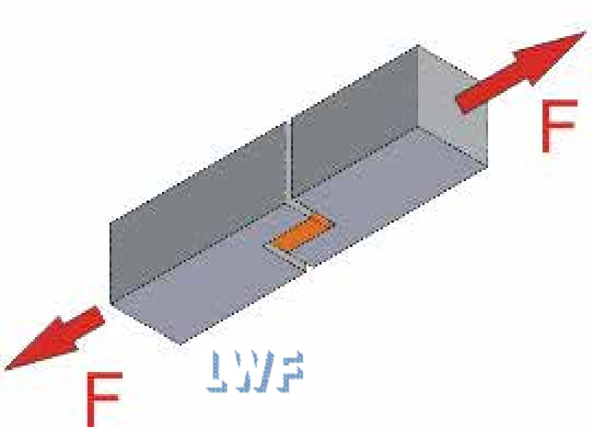
**$\tau$ - $\gamma$ tests: Tests performed in dependence on DIN ISO 11003-2**

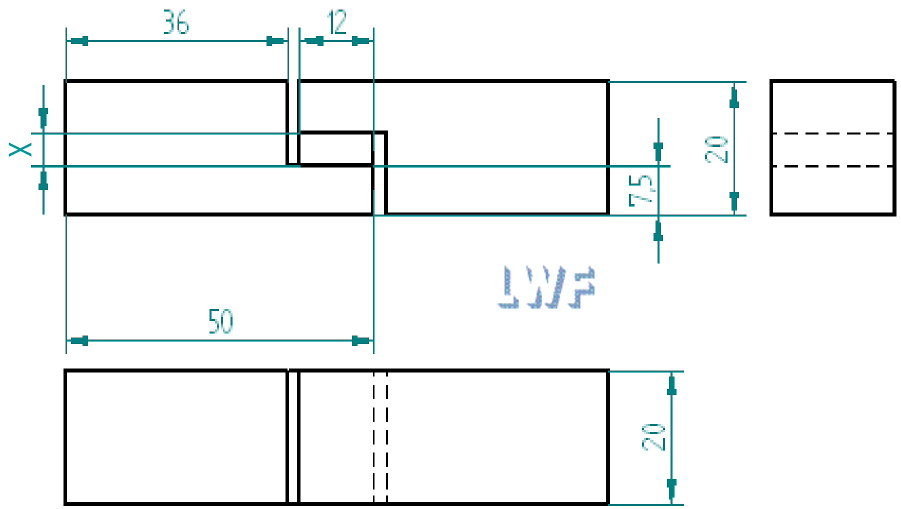
→ Determination of shear stress and shear strain behaviour of the adhesives

§ used specimen: thick tensile specimen in dependence on DIN ISO 11003-2 (adhesive thickness x = 0.5 mm, 3 mm & 5 mm)

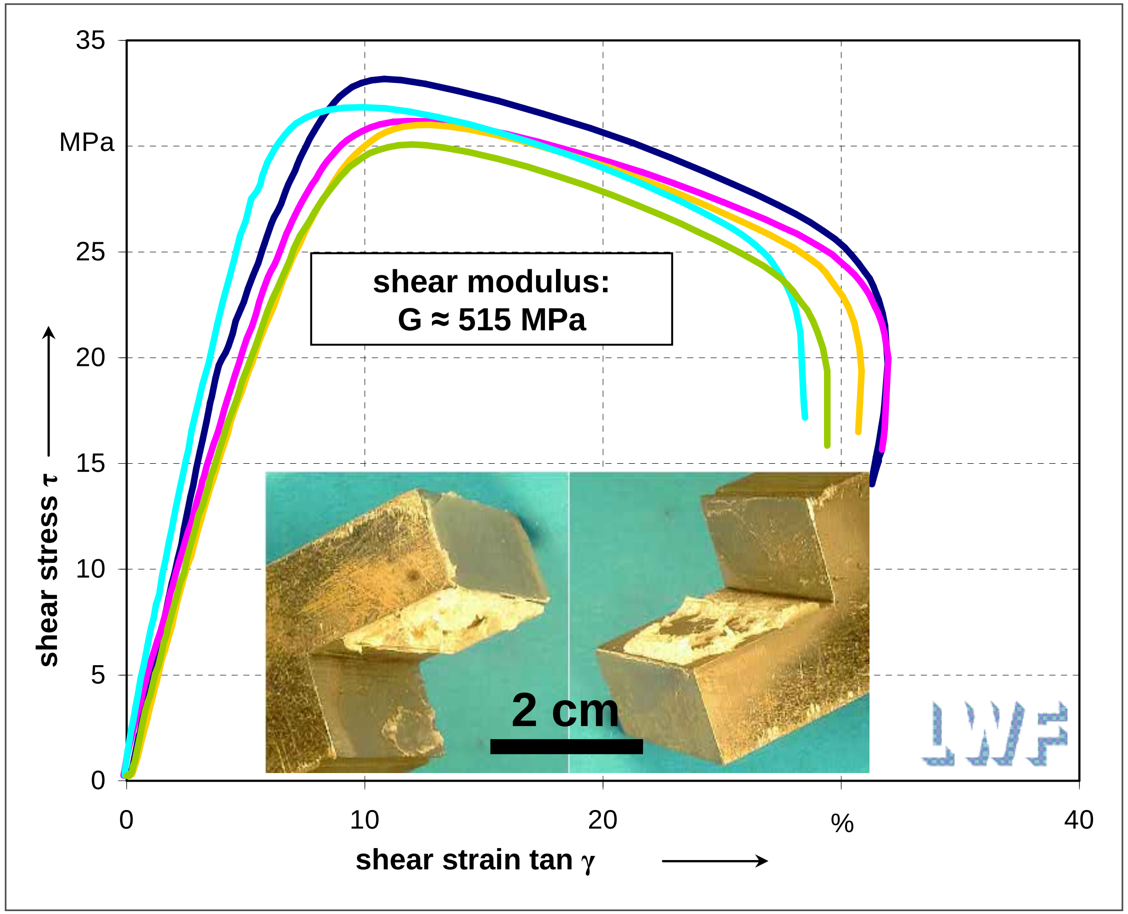
§ testing velocity depending on the thickness of the adhesive layer:
$\dot{\gamma}$ = 0.001 1/s; 0.006 1/s; 0.01 1/s

§ dimensions of the used thick tensile specimen:

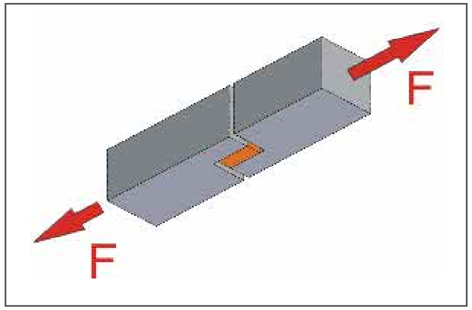


# WP1: $\tau$ - $\gamma$ tests on thick tensile specimens: PU154




| | |
|---|---|
| **Adhesive** | PU154 |
| **Curing** | 10 d at room temperature |
| **Testing device** | Zwick Z100 |
| **Testing velocity** | depending on thickness of adhesive layer, $\dot{\gamma} \approx 0.01$ 1/s |
| **Specimen** | thick tensile specimen |
| **Thickness of adhesive layer** | 0.5 mm |

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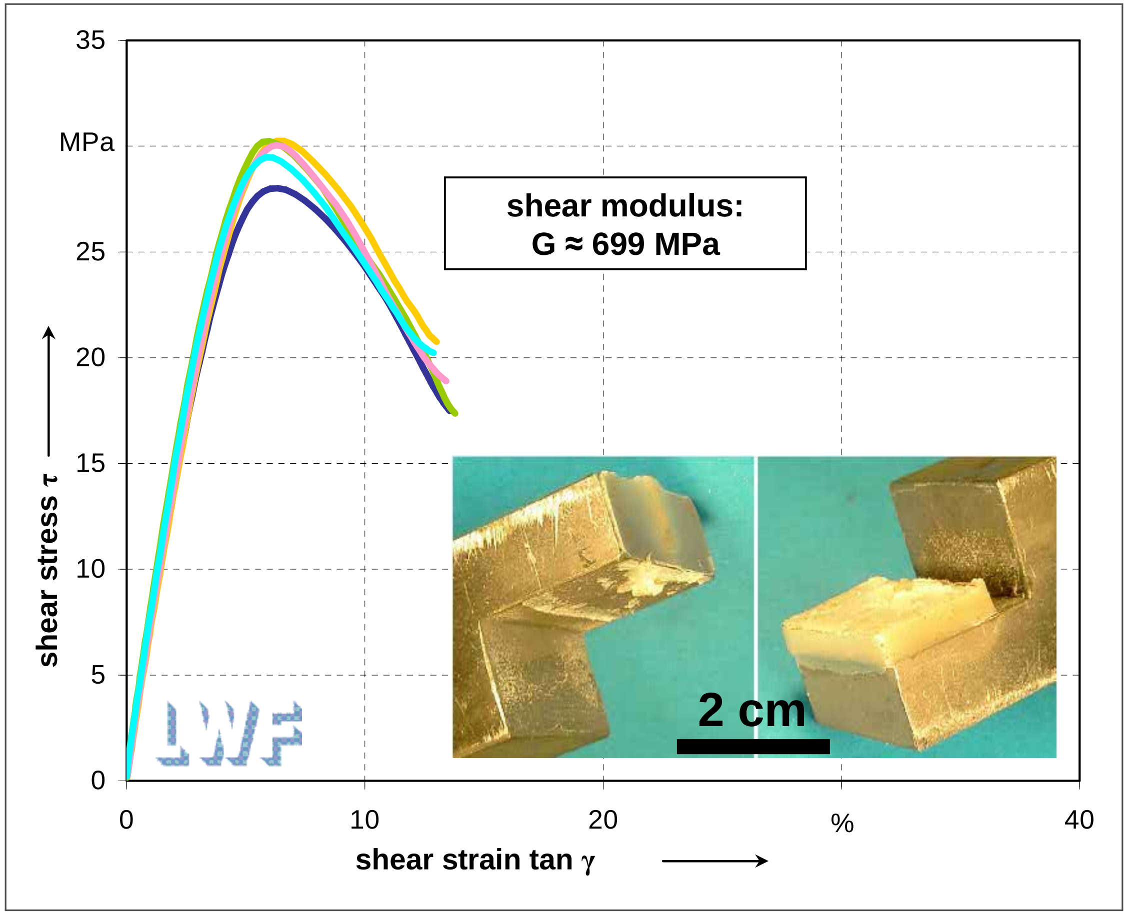
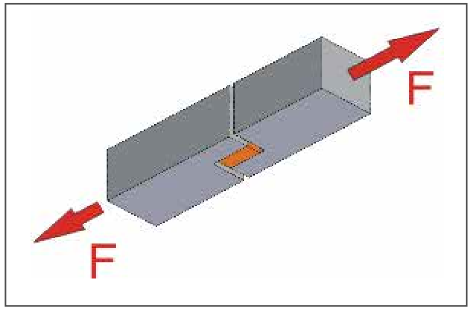
Average displacement at maximum shear stresses: 0.061 mm

# WP1: τ - γ tests on thick tensile specimens: PU154




| Adhesive |
|---|
| PU154 |
| **Curing** |
| 10 d at room temperature |
| **Testing device** |
| Zwick Z100 |
| **Testing velocity** |
| depending on thickness of adhesive layer, $\dot{\gamma} \approx 0.006$ 1/s |
| **Specimen** |
| thick tensile specimen |
| **Thickness of adhesive layer** |
| 3 mm |

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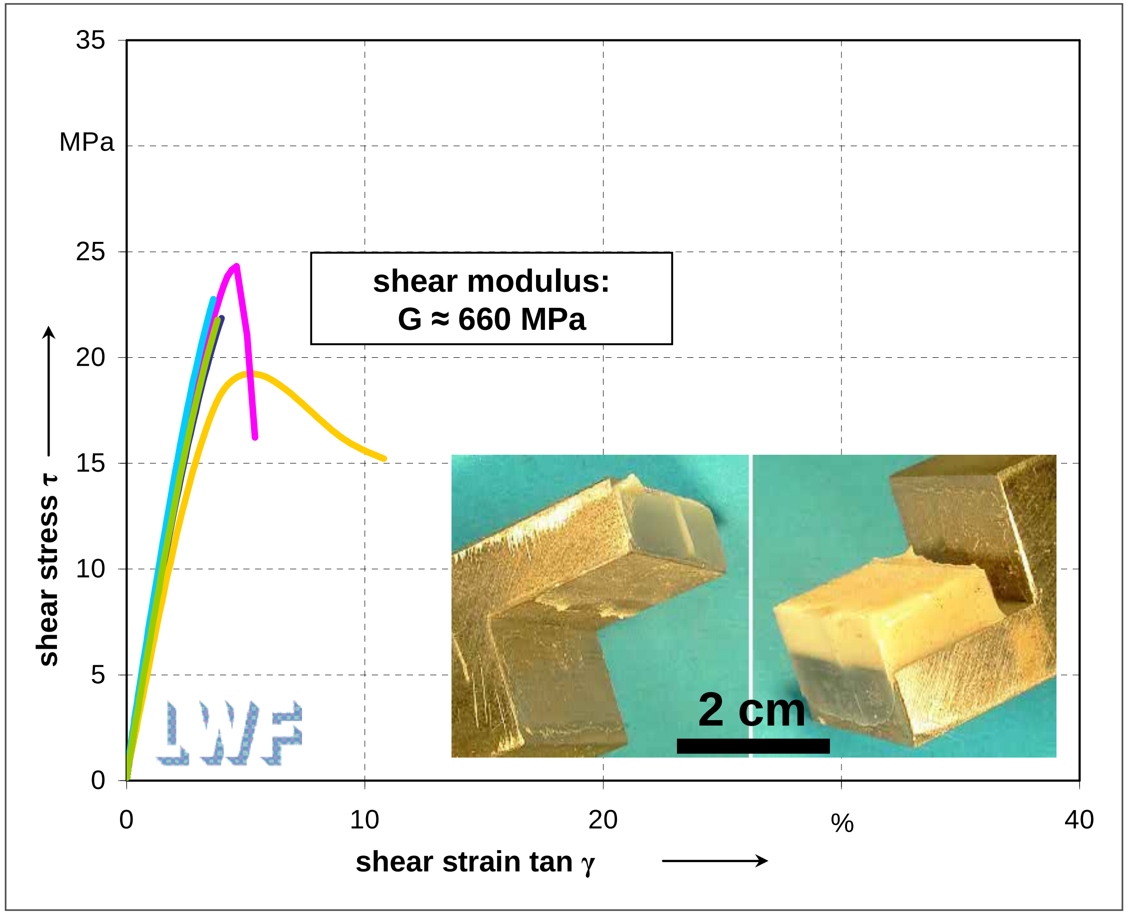
Average displacement at maximum shear stresses: 0.177 mm

# WP1: τ - γ tests on thick tensile specimens: PU154




**Adhesive**
PU154

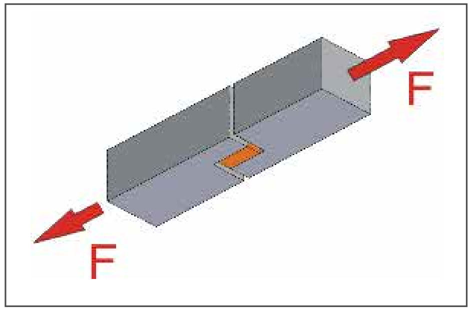
**Curing**
10 d at room temperature

**Testing device**
Zwick Z100

**Testing velocity**
depending on thickness of adhesive layer, $\dot{\gamma} \approx 0.001$ 1/s

**Specimen**
thick tensile specimen

**Thickness of adhesive layer**
5 mm

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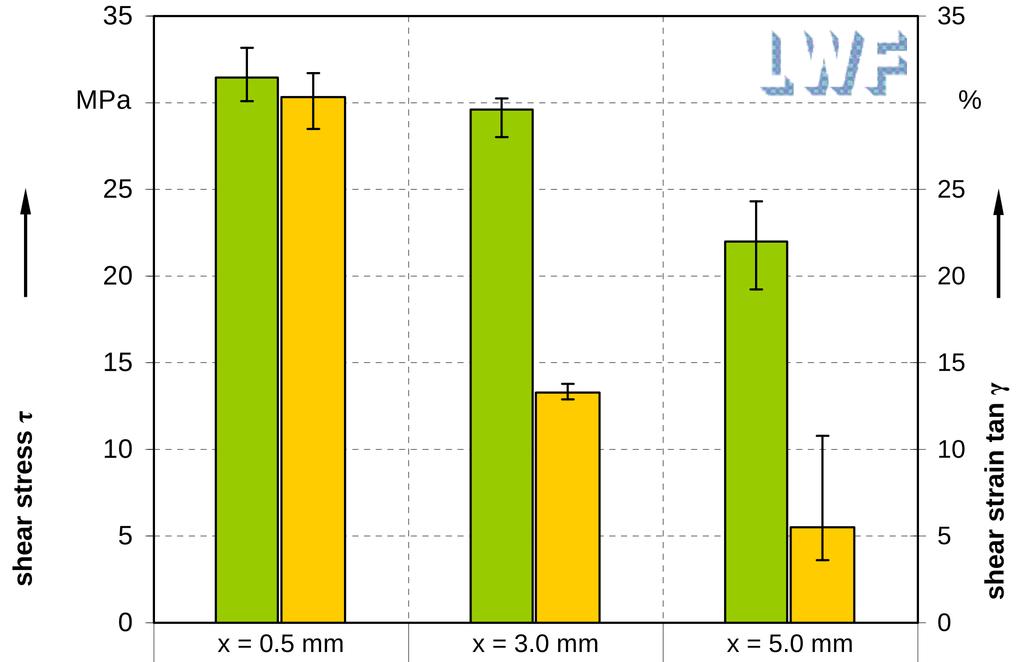
Average displacement at maximum shear stresses: 0.212 mm

# WP1: $\tau$ - $\gamma$ tests on thick tensile specimens: PU154




| | x = 0.5 mm | x = 3.0 mm | x = 5.0 mm |
|---|---|---|---|
| τ-max | 31,46 | 29,606 | 21,99 |
| + | 1,71 | 0,644 | 2,32 |
| - | 1,38 | 1,586 | 2,76 |
| tan γ-max | 30,32 | 13,276 | 5,516 |

**Adhesive**
PU154

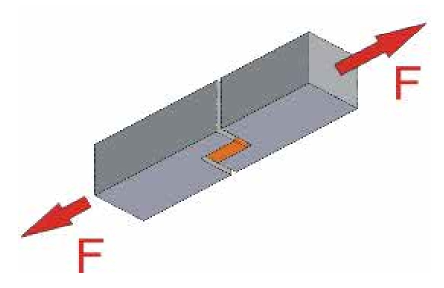
**Curing**
10 d at room temperature

**Testing device**
Zwick Z100

**Testing velocity**
depending on thickness of adhesive layer

**Specimen**
thick tensile specimen

**Thickness of adhesive layer**
x = see diagramm

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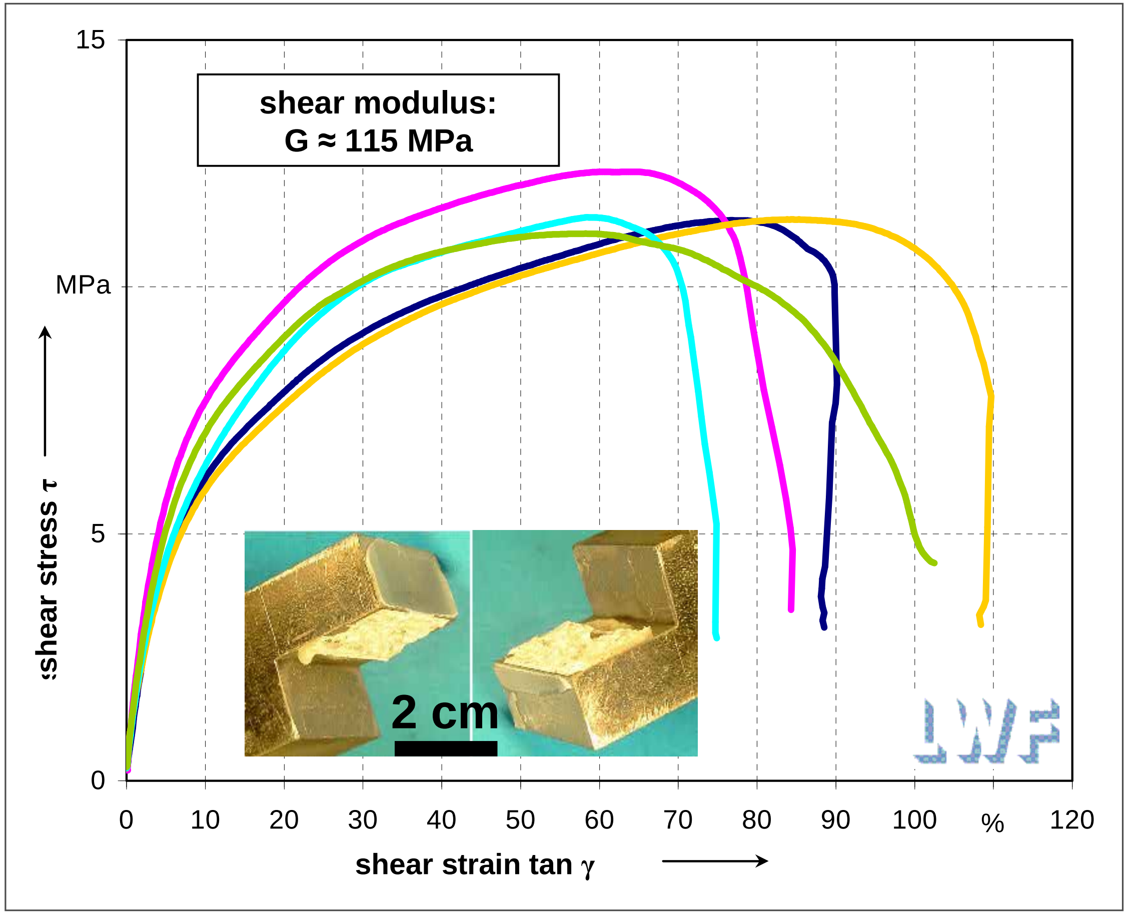
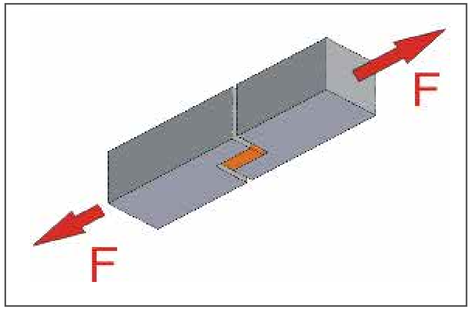
# WP1: τ - γ tests on thick tensile specimens: PU155




| Adhesive |
| --- |
| PU155 |
| **Curing** |
| 10 d at room temperature |
| **Testing device** |
| Zwick Z100 |
| **Testing velocity** |
| depending on thickness of adhesive layer, $\dot{\gamma} \approx 0.001$ 1/s |
| **Specimen** |
| thick tensile specimen |
| **Thickness of adhesive layer** |
| 0.5 mm |

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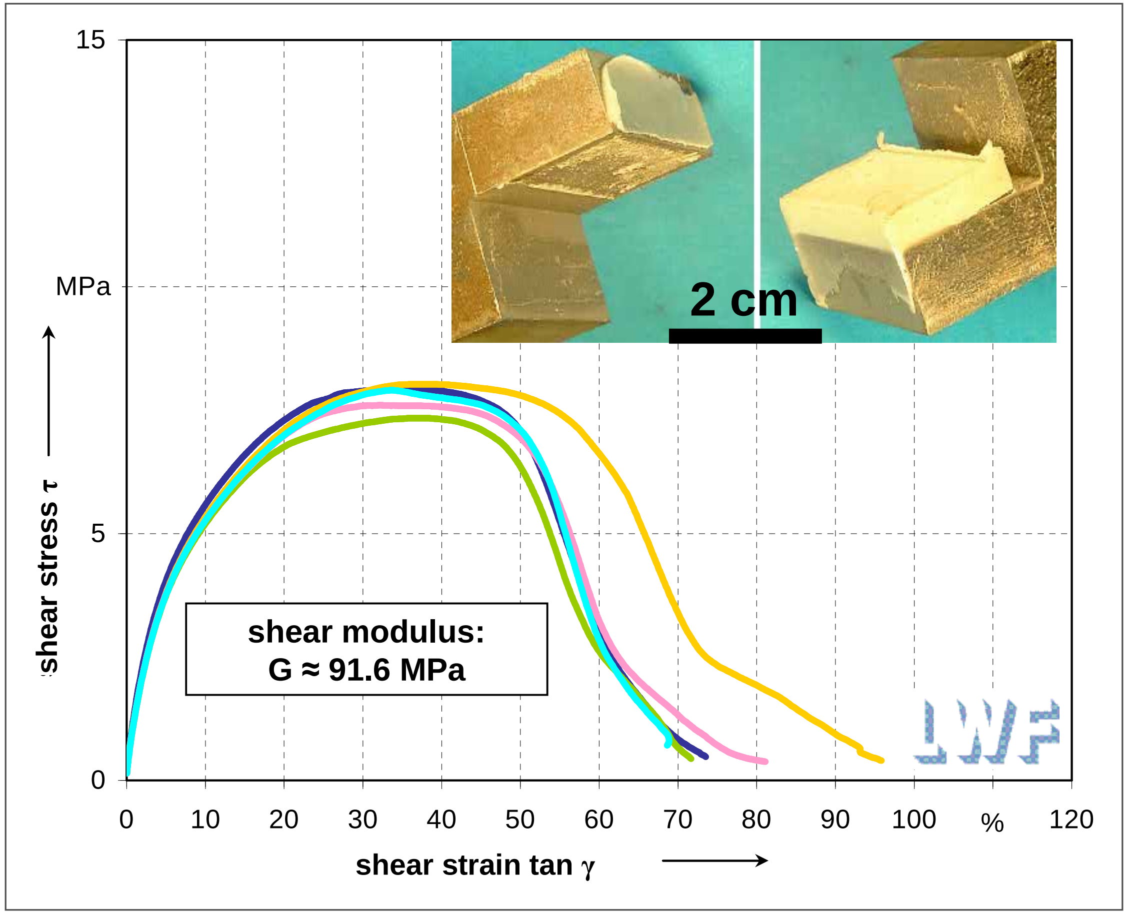
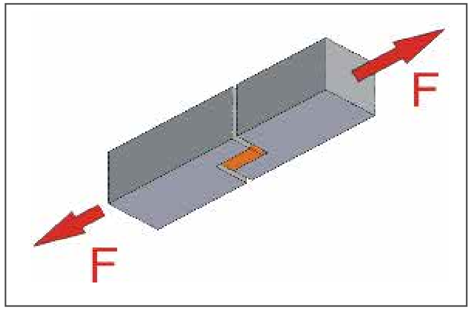
Average displacement at maximum shear stresses: 0.448 mm

# WP1: τ - γ tests on thick tensile specimens: PU155




| |
|---|
| **Adhesive**<br>PU155 |
| **Curing**<br>10 d at room temperature |
| **Testing device**<br>Zwick Z100 |
| **Testing velocity**<br>depending on thickness of adhesive layer; $\dot{\gamma} \approx 0.006$ 1/s |
| **Specimen**<br>thick tensile specimen |
| **Thickness of adhesive layer**<br>3 mm |

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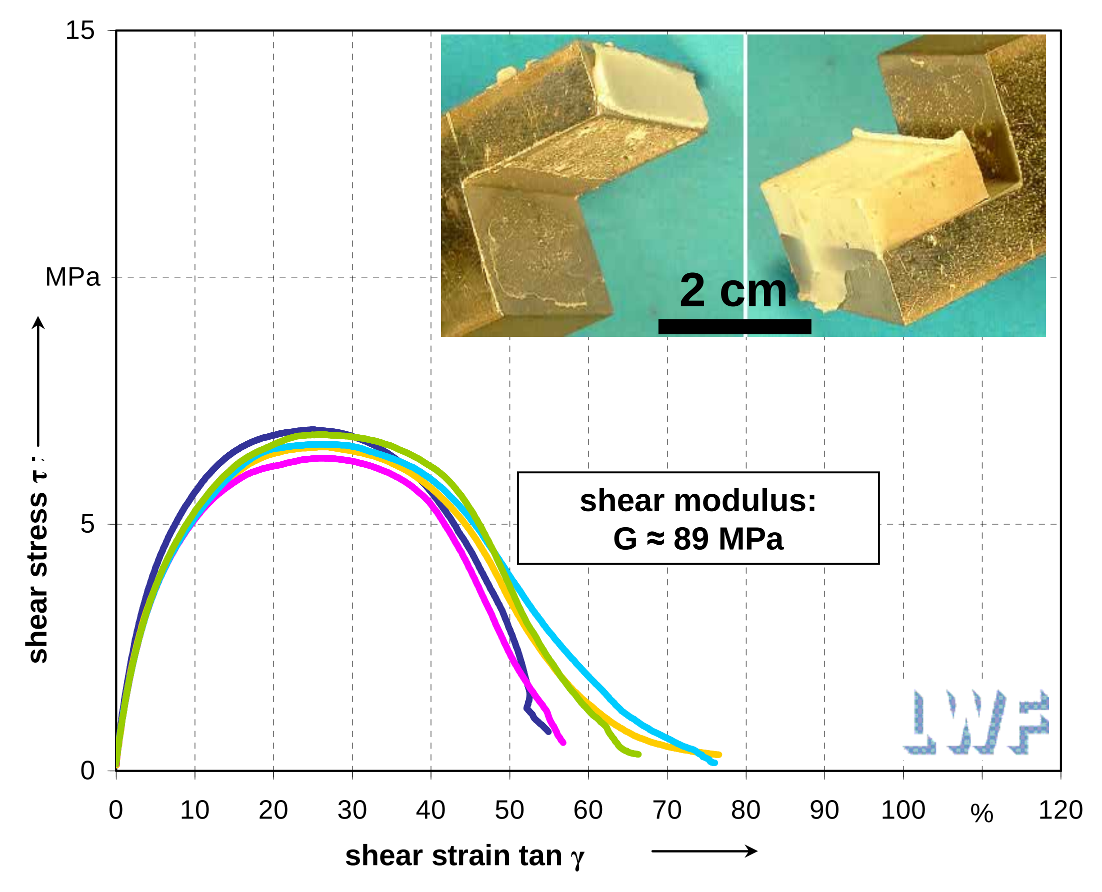
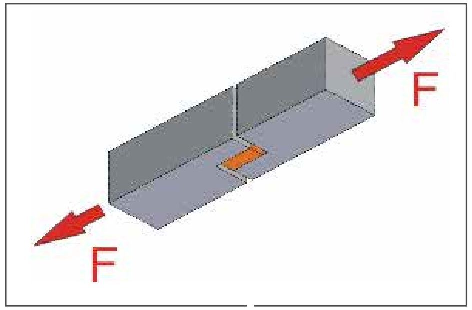
Average displacement at maximum shear stresses: 1.145 mm

# WP1: τ - γ tests on thick tensile specimens: PU155




| Adhesive |
|---|
| PU155 |
| **Curing** |
| 10 d at room temperature |
| **Testing device** |
| Zwick Z100 |
| **Testing velocity** |
| depending on thickness of adhesive layer; $\dot{\gamma} \approx 0.01$ 1/s |
| **Specimen** |
| thick tensile specimen |
| **Thickness of adhesive layer** |
| 5 mm |

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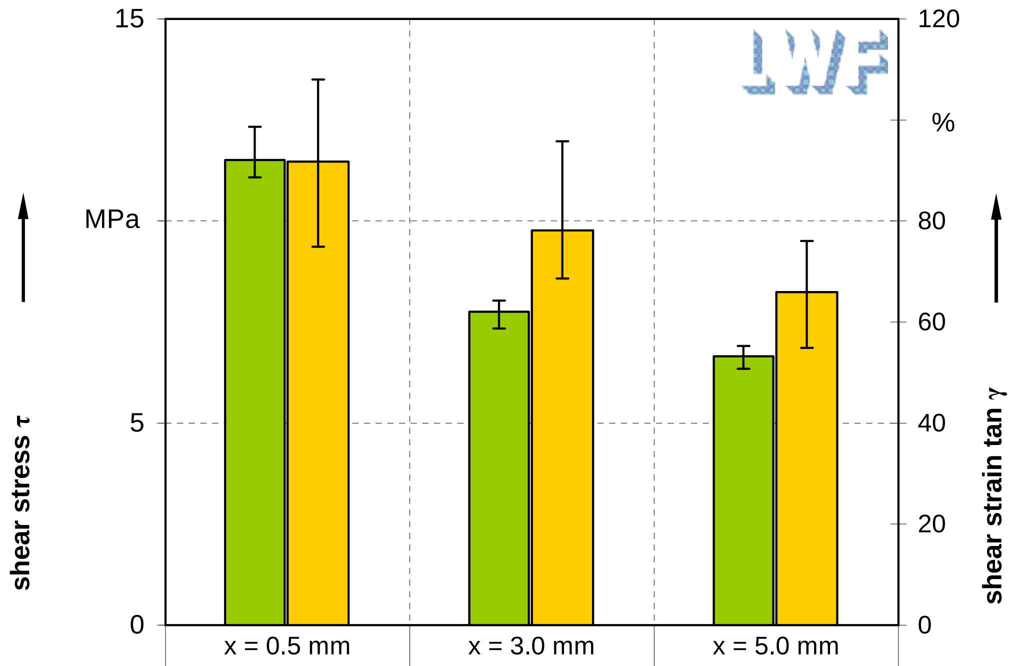
Average displacement at maximum shear stresses: 1.339 mm

# WP1: $\tau$ - $\gamma$ tests on thick tensile specimens: PU155




| | x = 0.5 mm | x = 3.0 mm | x = 5.0 mm |
|---|---|---|---|
| τ-max | 11,508 | 7,758 | 6,65 |
| + | 0,822 | 0,272 | 0,26 |
| - | 0,428 | 0,418 | 0,31 |
| tan γ-max | 91,746 | 78,148 | 65,918 |

**Adhesive**
PU155

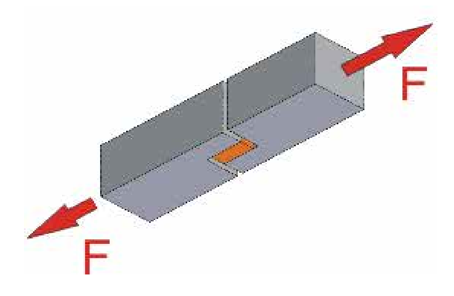
**Curing**
10 d at room temperature

**Testing device**
Zwick Z100

**Testing velocity**
depending on thickness of adhesive layer

**Specimen**
thick tensile specimen

**Thickness of adhesive layer**
x = see diagramm

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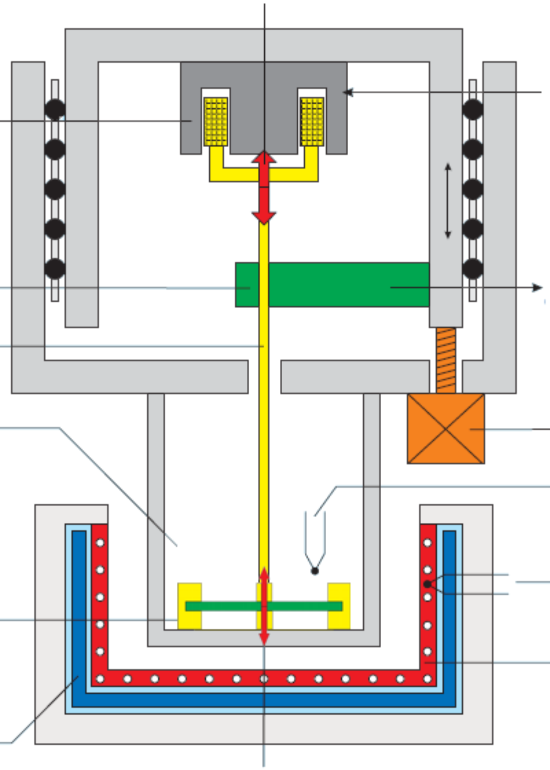
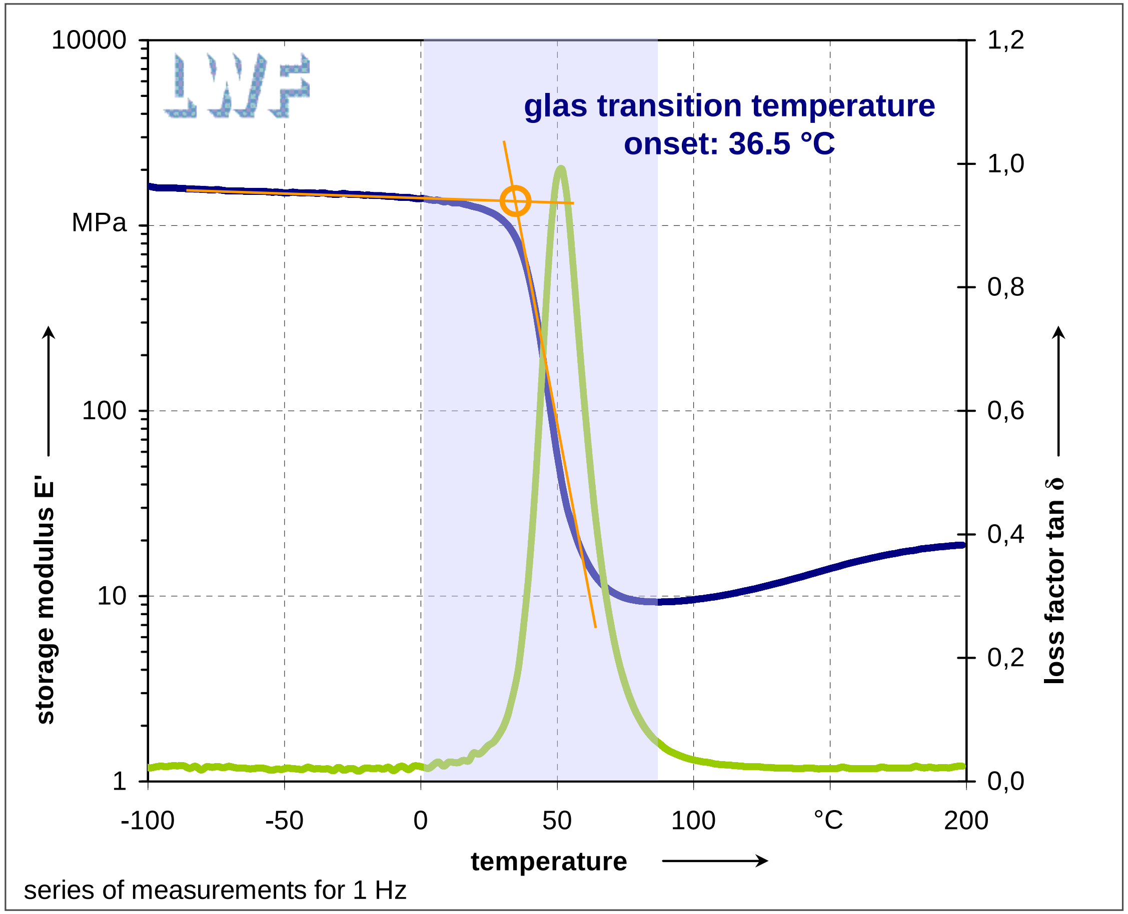
# WP1: Dynamic Mechanical Analysis (DMA)




§ Applying an oscillating force to a sample and measurement of the material's reaction to that force

§ Measurands: dynamic storage modulus E', dynamic loss modulus E'' and loss factor tan $\delta$

# WP1: DMA: PU154




**Adhesive**
PU154

**Curing**
10 d at room temperature

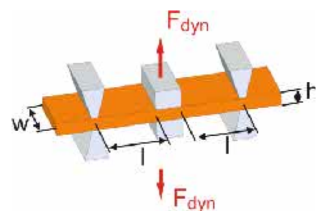
**Testing device**
Netzsch DMA 242

**Testing frequency**
1 Hz / 5 Hz / 10 Hz

**Temperature sequence**
-100°C - +200°C

**Heating rate**
3 K/min

**Specimen**
dual cantilever bending
l = 5 mm; h = 2 mm; w = 10 mm

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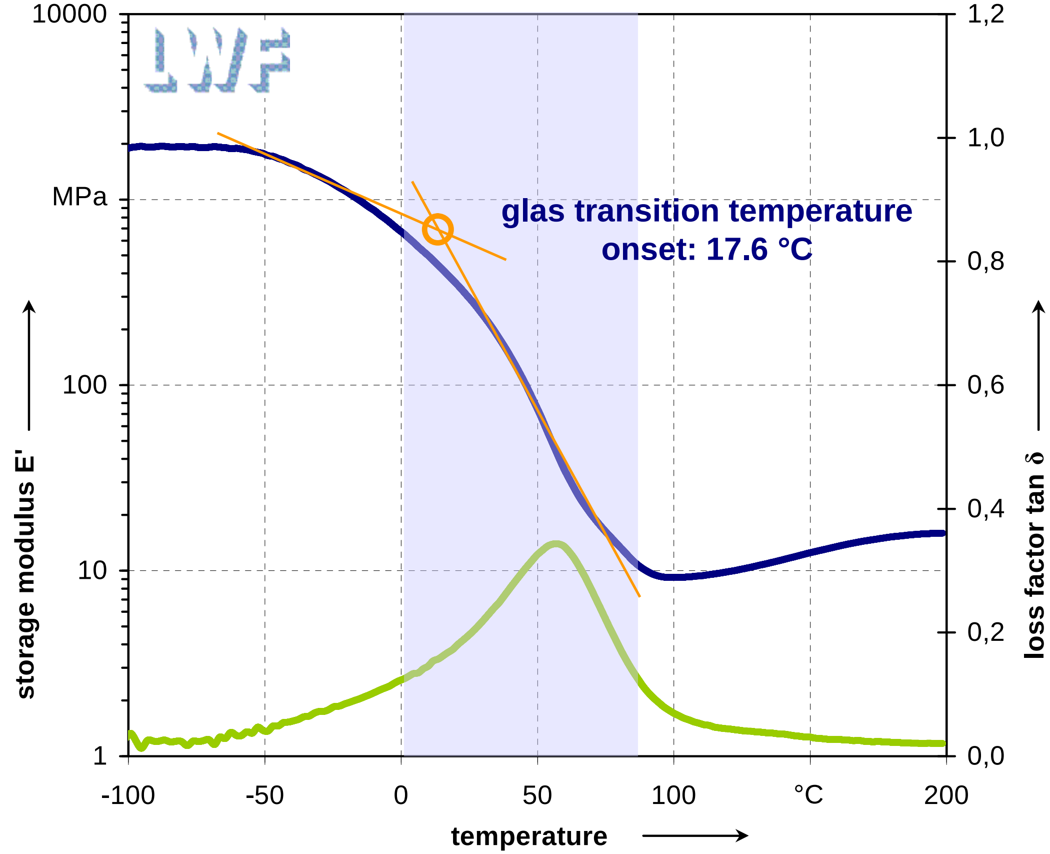
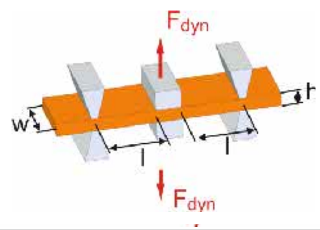
Stiffness reduces from 1398 MPa (0°C) to 9.42 MPa (80°C) in the relevant temperature interval

# WP1: DMA: PU154




series of measurements for 1 Hz

| |
|---|
| **Adhesive**<br>PU155 |
| **Curing**<br>10 d at room temperature |
| **Testing device**<br>Netzsch DMA 242 |
| **Testing frequency**<br>1 Hz / 5 Hz / 10 Hz |
| **Temperature sequence**<br>-100°C - +200°C |
| **Heating rate**<br>3 K/min |
| **Specimen**<br>dual cantilever bending<br>l = 5 mm; h = 2 mm; w = 10 mm<br> |
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Stiffness reduces from 669 MPa (0°C) to 13.5 MPa (80°C) in the relevant temperature interval

# WP1: Conclusion of first fundamental tests

**Conclusion:**

§ decreasing of maximum shear stresses with increasing of adhesive layer thicknesses

§ decreasing of shear modulus with increasing of adhesive layer thicknesses

§ only small displacements at maximum shear stresses with increasing of adhesive layer thicknesses

§ adherence changes by using larger adhesive layer thicknesses:

- § cohesive failure at 0.5 mm adhesive layer thickness
- § failure near to the interface at 5.0 mm adhesive layer thickness

§ intense loss of stiffness in the relevant temperature interval

# WP1: Joint design

**Development of joint geometry:**

§ identification of joint principles regarding pipe joining

§ benchmarking:

criteria:

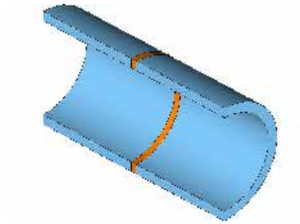
- § mechanical properties of bonded pipes (first evalutions using FEM)
- § complexity for producer of the steel pipes in preparing pipes for adhesive bonding
- § joining at the construction site
- § application of the adhesive
- § corrosion

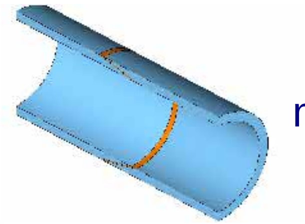
→ Choice of the most suitable joint principle

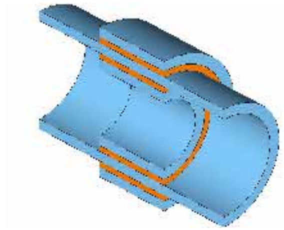
§ working on details of the joint design (pipe treating, spacer, sealings, filling of joint, etc.)

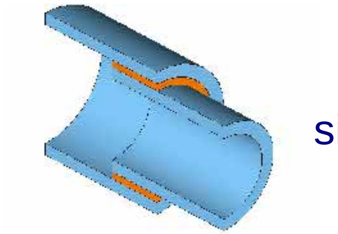
§ tests on small scaled pipes

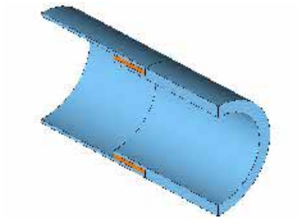
# WP1: Geometries for pipe joining in principle

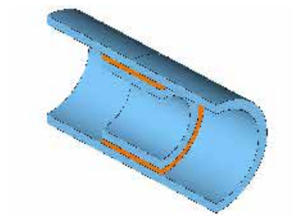

butt joint

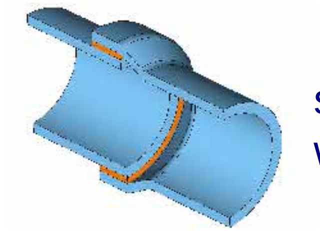

mounting

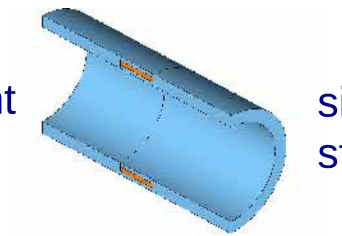

brackets - double-lap

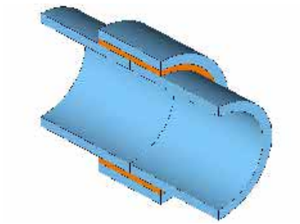

single-lap joint


single-lap joint stepped with arrester


internal brackets - single-lap


single-lap joint widened


single-lap joint stepped


external brackets – single-lap

→ implemented as FEM-models

**University of Paderborn, Germany**
Laboratory for Materials and Joining Technology (LWF)
Prof. Dr.-Ing. Ortwin Hahn

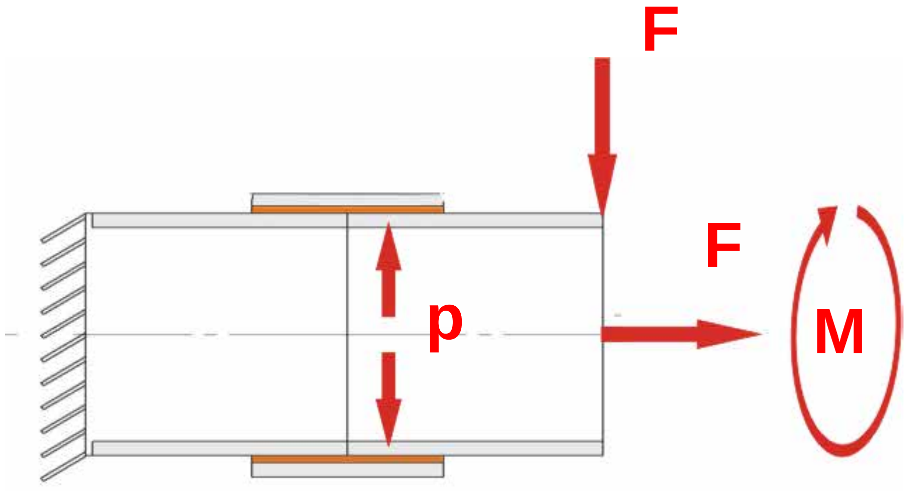
Dipl.-Ing. T. Boeddeker

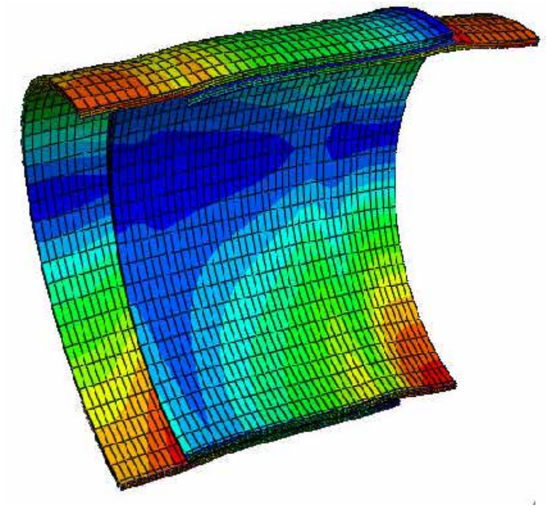
# WP1; WP3: Distribution of tension in joint geometry

**Implemented FEM-Model:**

§ model of steel tubes and different joint geometries
§ linear-elastic material model of used steel and adhesive
§ connection of the adhesive with pipe and brackets established using tied contacts
§ loads were applied using coupling constraints
§ loads, moments and applied pressures have a value of 1

→ identifying the joint geometry which will be most suitable to resist the applied loads on pipe connections regarding to adhesive bonding



e.g. pipe joint under bending loads

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- **AGFW e.V.**
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- **Bohlen & Doyen Polska Sp. Z o.o.**

**TOP 3: Presentation of Bayer MaterialScience**

**TOP 4: Discussion regarding tests, types of specimens**

**TOP 5: Administration of the project (deliverables to the European Commission, financial statements, schedule for technical reporting)**

**TOP 6: Next steps / Miscellaneous**

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# Tests to be performed, types of specimens

**Material: hot-rolled steel, epoxy coated (t = 5.5 mm up to t = 8.8 mm)**

§ direct bonding on the epoxy layer applied on the pipes

→ Is the layer appropriate for adhesive bonding (delaminating of the epoxy under stress)?

§ Plastics are often unpolar materials

- § surface treatment to raise the polarity is necessary
- § it has to be determined whether adhesive bonding directly on the steel or on the epoxy leads to a better performance of the connection

**Material: sheet metal samples (coated / uncoated)**

§ sheet metal samples

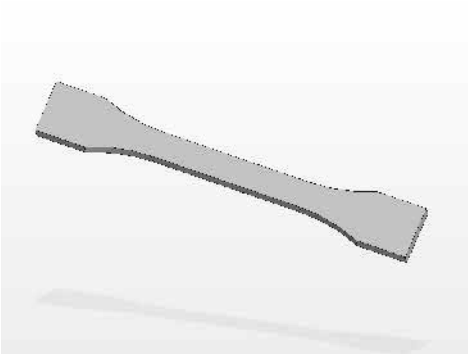
§ pipe samples, which were reverse bended to a sheet

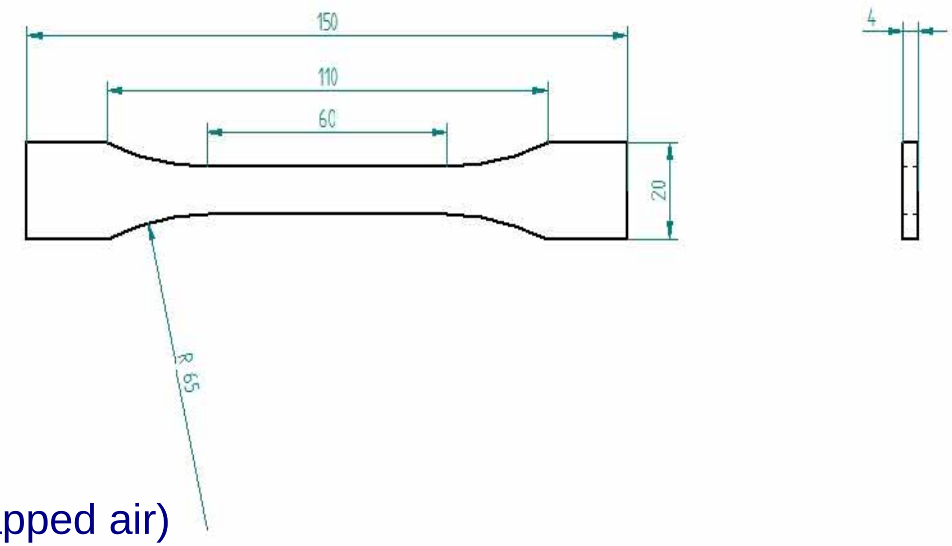
- § strain hardening?
- § changes of the surface conditions?

# Tests to be performed, types of specimens

**σ-ε tests: Tests will be performed according to DIN ISO 527 Plastics – Determination of tensile properties**

§ **Specimen:** tensile specimen made of proposed adhesives DIN ISO 527 type B






§ **Problem:** imperfections in the adhesive (trapped air)

§ **Proposal:** usage of a smaller specimen, not according to DIN ISO 527 type B
(quadratic square section, small measurement range)

**University of Paderborn, Germany**
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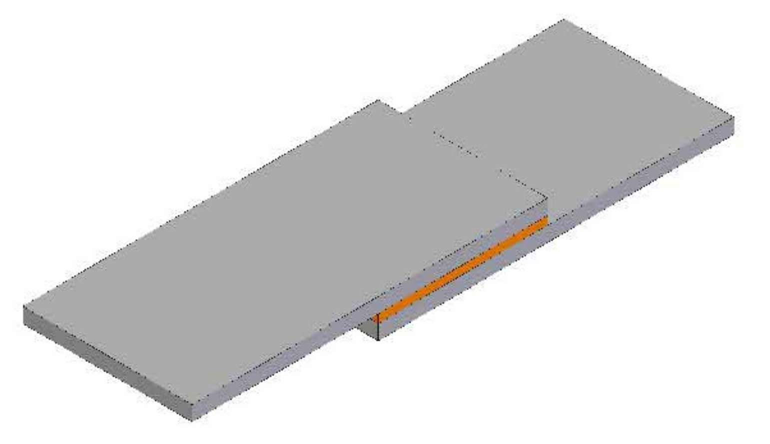
Dipl.-Ing. T. Boeddeker

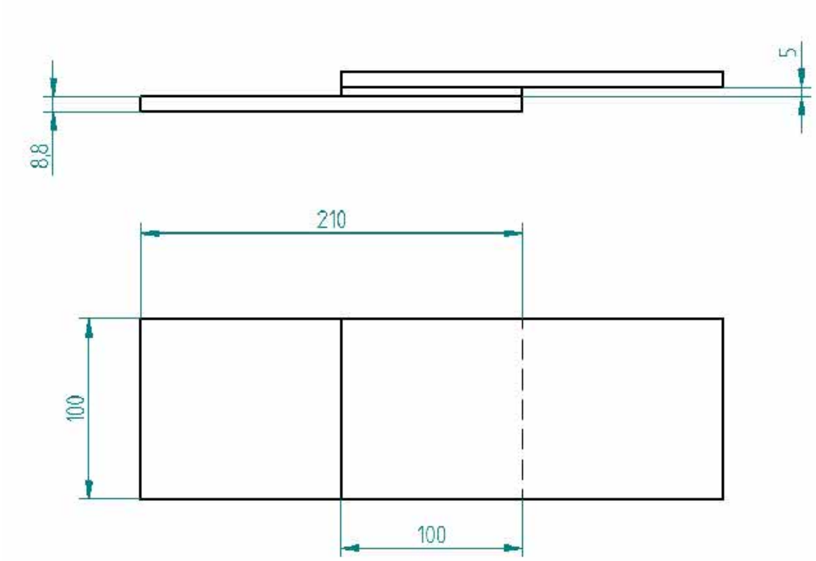
# Tests to be performed, types of specimens

**Determination of the mechanical behaviour of adhesive bonded hot-rolled steel**

§ **Specimen:** simple overlapped tensile specimen according to DIN EN ISO 14273

§ **Expected properties (using the proposed adhesives):** tensile strength up to **370 kN**





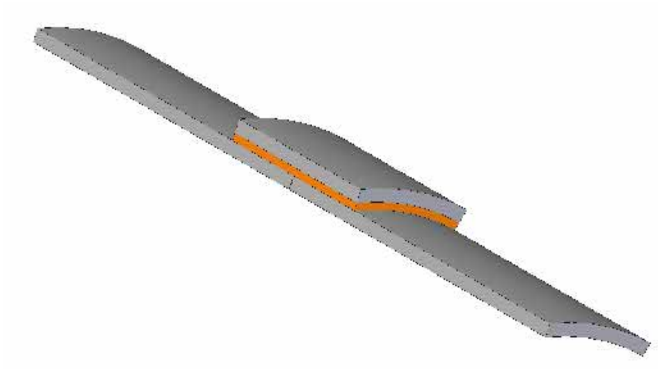

→ testing is currently not possible at LWF (but at Salzgitter Mannesmann Forschung)

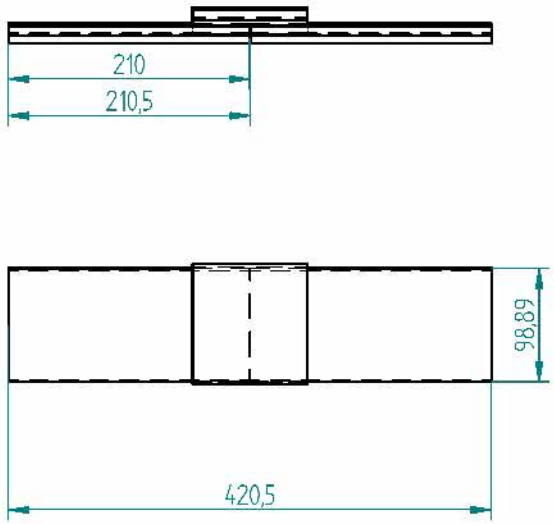
§ **Proposal:** specimens according to DIN EN ISO 14273, but with dimensions for sheet metal thicknesses up to 1.5 mm ($l$ = 105 mm; $w$ = 45 mm; overlapping $l_o$ = 35 mm)

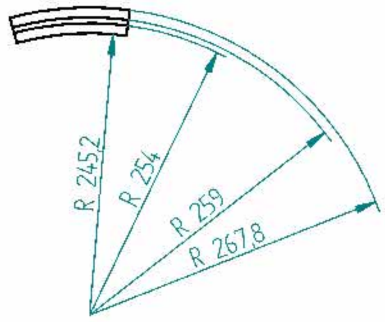
# Tests to be performed, types of specimens

**Determination of the mechanical behaviour of adhesive bonded pipe-samples**

**Proposed specimen:** butt-jointed pipe sample with bracket






→ Special clamping support necessary  (glimbal clamping)

# Tests to be performed, types of specimens

**Aging:** Performance of the tests according to (VDA 621-415) and (P-VW 1200)

Determination of the adhesives behaviour and the behaviour of the joint depending on environmental influences

**Proposed specimen:** thick tensile specimen and tensile specimens as well as small scaled pipes

**Comments:**

§ tests for the automotive industry

§ climate conditions used in this tests are not the same as the conditions the layed pipes are exposed to

→ Are there specific tests for aging of pipe joints?

# Tests to be performed, types of specimens

**Fatigue:** determination of the behaviour of simple overlapped specimens under dynamic loads

**Proposed specimen:** tensile specimens as well as small scaled pipes specimens (Can this tests be performed with the same geometry proposed for the static tensile tests at SZMF?)

**Comments:** It has to be taken into account that according to DIN 13491 only a small number of load cycles are necessary as the following table shows:

| | Load cycles |
|---|---|
| main pipes | 100 |
| distribution pipes | 250 |
| house service connection pipes | 1,000 |

→ Warming of the adhesive during the fatigue tests has to be avoided!
Proposed conditions:

| | |
|---|---|
| frequency: | f = 1 Hz |
| load cycles: | N = 10,000 |
| load ratio: | R = 0.1 |

# Tests to be performed, types of specimens

**Tests with small scaled pipe specimens:**

§ joint filling

§ mechanical properties of small scaled adhesively bonded pipes (tensile and torsion loads, also combined tension and torsion)

§ aging tests with small scaled pipes specimens (water filled, heated pipes aged in climate chamber)

§ results shall be assigned on full scaled pipes specimens and verified in full scale tests

**Impact tests:**

§ impact tests are proposed in the general agreement

§ Do we need to perform impact tests and how should they be performed?

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# Administration of the project

**Reporting:**

§ project is structured in periods of six month (reporting periods)

§ for every reporting period a six-monthly report has to be delivered to the European Commission (except for the reporting periods preceding the mid-term report and the final-report)

§ mid-term reporting containing all relevant technical achievements and financial information concerning the project

§ final-report: containing all information and achievements reached during the project including all administrative information

# Administration of the project

**Six-monthly reports:**

§ Description of the scientific and technical achievements and/or progress for the relevant period, along with any possible corrective actions required

§ A simple compilation of individual reports produced by the project partners will not be accepted by the European Commission

§ First six-monthly report has to be delivered to the Commission until **31st March 2008**

→ **Tasks for the Coordinator:**

§ Collecting all relevant information

§ Preparing the report

→ **Tasks for project partners:**

§ Providing all results and data to the coordinator

§ Information shall include a short description and explanation of the results (testing facilities, standards etc.)

§ Information shall be delivered until

**Friday 8th February**

# Administration of the project

## Time Sheets

§ preparation of time sheets containing information of how many man hours were worked on the project by each project partner

§ information needed:

- § who was working
- § how many man hours were spend
- § which working points were treated with (only work package title necessary)
- § time sheets have to be consistent and have to pass auditings

## Consortium agreement

§ setup of a consortium agreement :

- § specifying the commercial exploitation of new Foreground created in this project
- § model contract DESCA to cover the topics (e.g. Intellectual Property Rights) in detail which were described in the general agreement

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