Tensile Loading of Silicone Point Supports – Revisited

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Next Generation Silicone Adhesive - TSSA

- **A new advanced high performance silicone adhesive is available with special characteristics:**
  - **Excellent transparency and superior mechanical properties**
  - **Heat-curing one-component material produced in thin sheets with a nominal layer thickness 1 mm**
    - **Curing process 120°C – 130°C for period of 20 min – 30 min**
    - **Applied pressure 0.15 MPa – 1.3 MPa e.g. in autoclave**
- **Representative properties ***

Property	Test Method	Typical Value	Unit
Indentation Hardness	JIS K 6253 Durometer	70	JIS A
100% Modulus	JIS K 6251 (dumbbell #3)	4.0	MPa
Young's Modulus	ISO 527 Parts 1 and 2	9.3	MPa
Max. Tensile Strength	JIS K 6251 (dumbbell #3)	9.0	MPa
Elongation at break	JIS K 6251 (dumbbell #3)	250	%
Tear Strength	JIS K 6252 (crescent specimen)	35	N/mm

* Sitte, S., Brasseur, M.J., Carbary, L.D., and Wolf, A.T., Preliminary Evaluation of the Mechanical Properties and Durability of Transparent Structural Silicone Adhesive (TSSA) for Point Fixing in Glazing, Journal of ASTM International, Vol. 8, No. 10, 2011, Paper ID JAI104084

Stress-Whitening Phenomenon

- **TSSA shows the special property of loosing transparency in highly strained regions.**
- **The phenomenon of changing transparency is nearly reversible after unloading.**
- **The phenomenon occurs for load-levels significantly below ultimate failure.**

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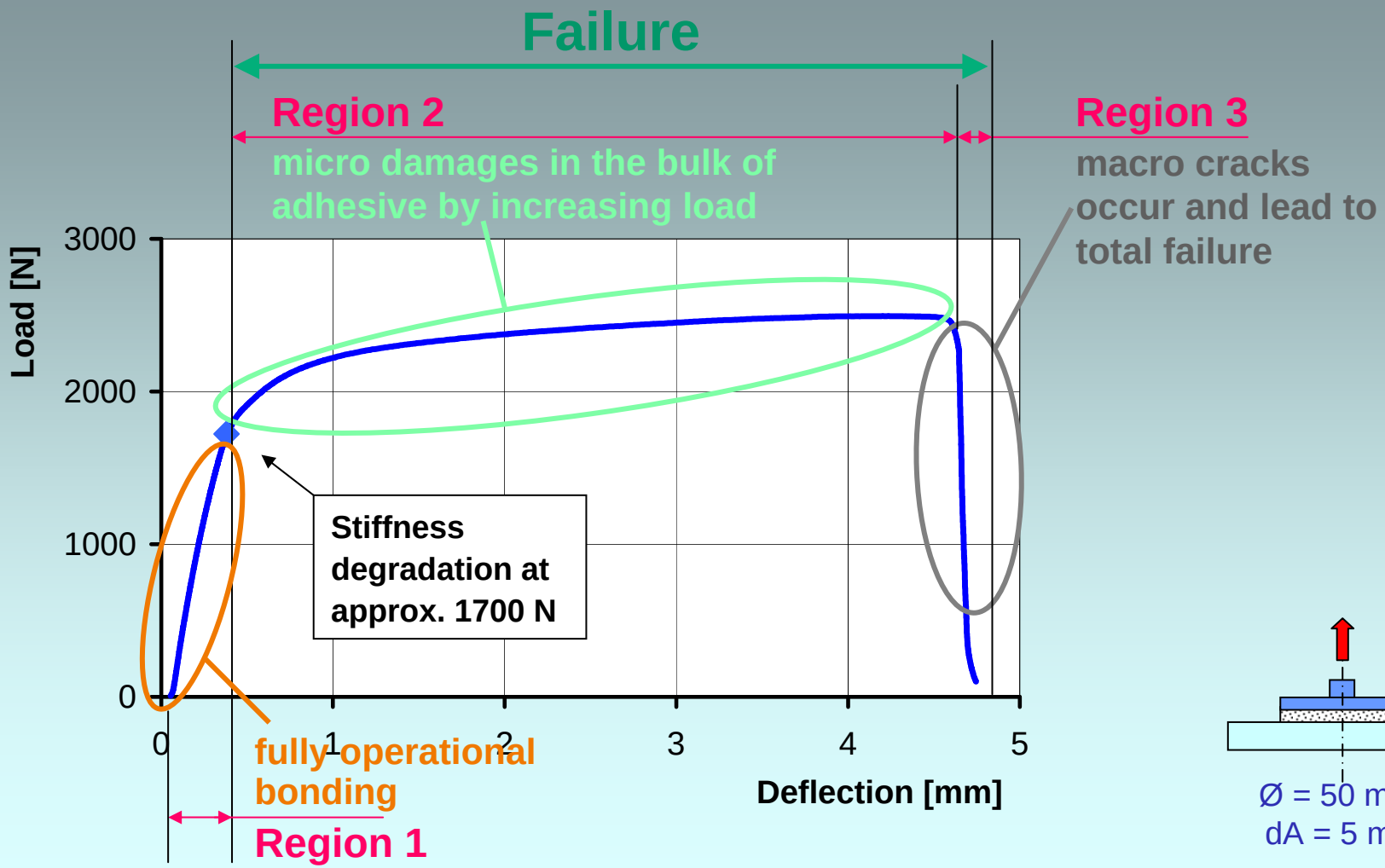
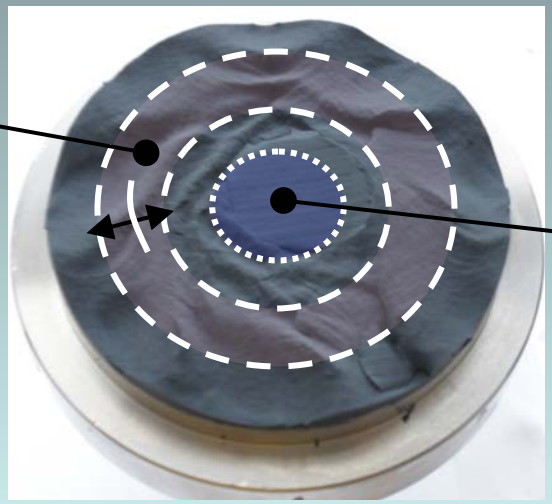
Tensile Test Characteristics – Conventional SSA



Failure Hypothesis of Conventional Silicone Adhesive

Phase 1

Beginning of macro cracks at an inner circle



Phase 3

Finally the core fails.

Phase 2

Crack-progress runs to inside and outside

The specimen was cut open before final failure.

The failure mechanism was determined by comparing the measurements synchronized with the video of the test run.

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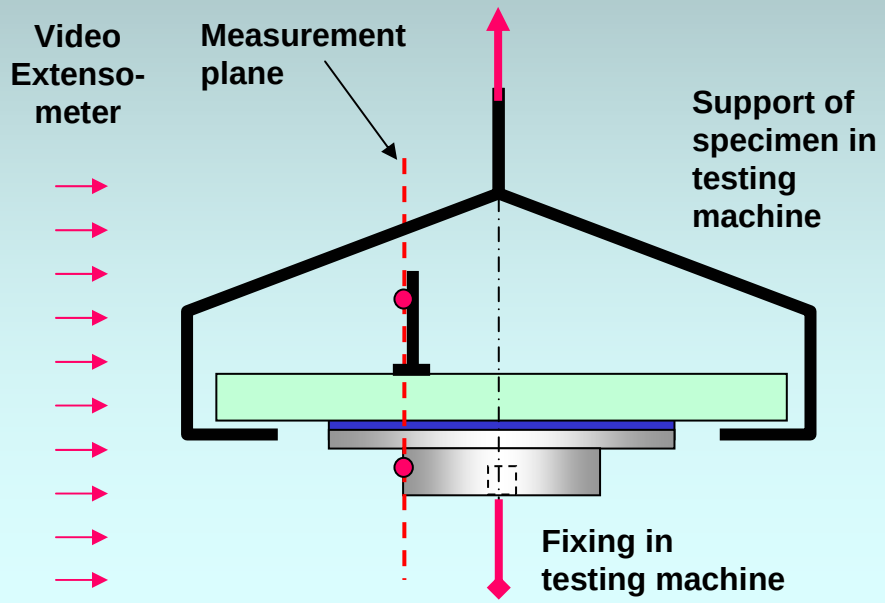
Test Set-up for Tensile Loading

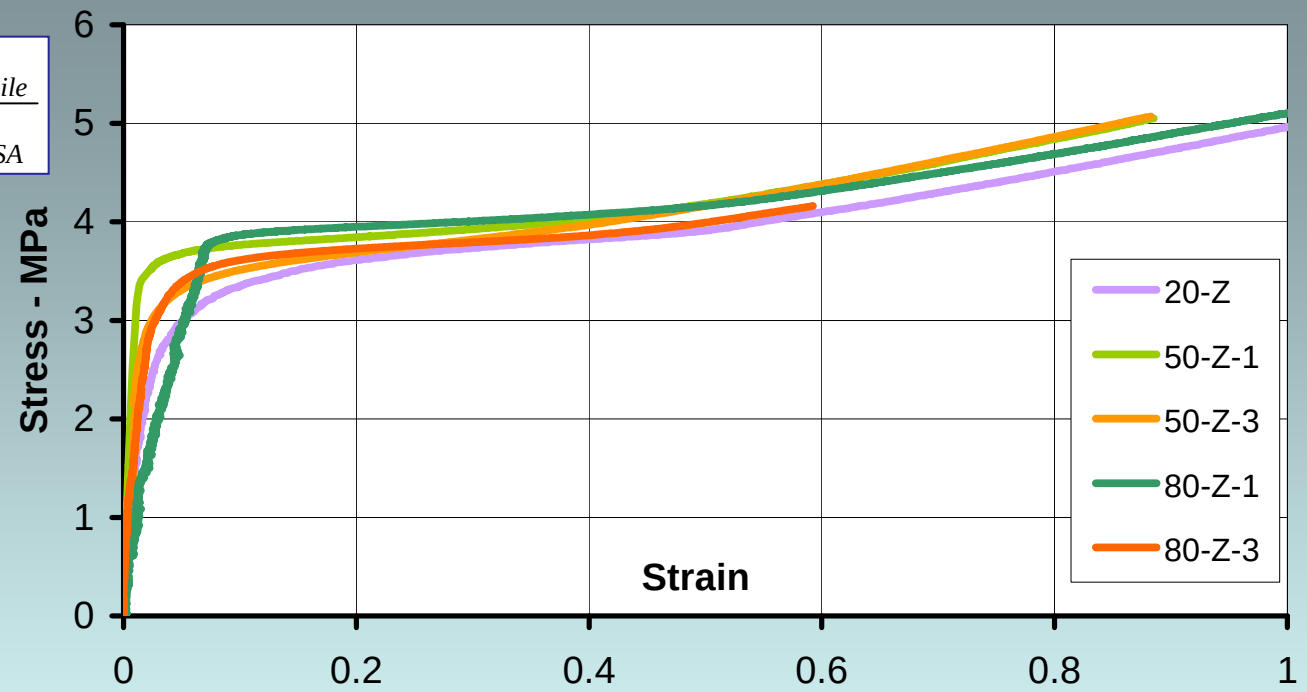
Special requirements for testing are:

- **The set-up has to be suitable for Ø 20 mm to Ø 80 mm specimens.**
- **The monitoring of whitening needs optical access.**
- **Dedicated markers for video-extensometer have to be applied.**
- **An additional challenge is the high bonding stiffness due to stiffer material and smaller thickness.**



Tensile Tests of Round Point Supports – TSSA

$$\sigma = \frac{F_{tensile}}{A_{TSSA}}$$

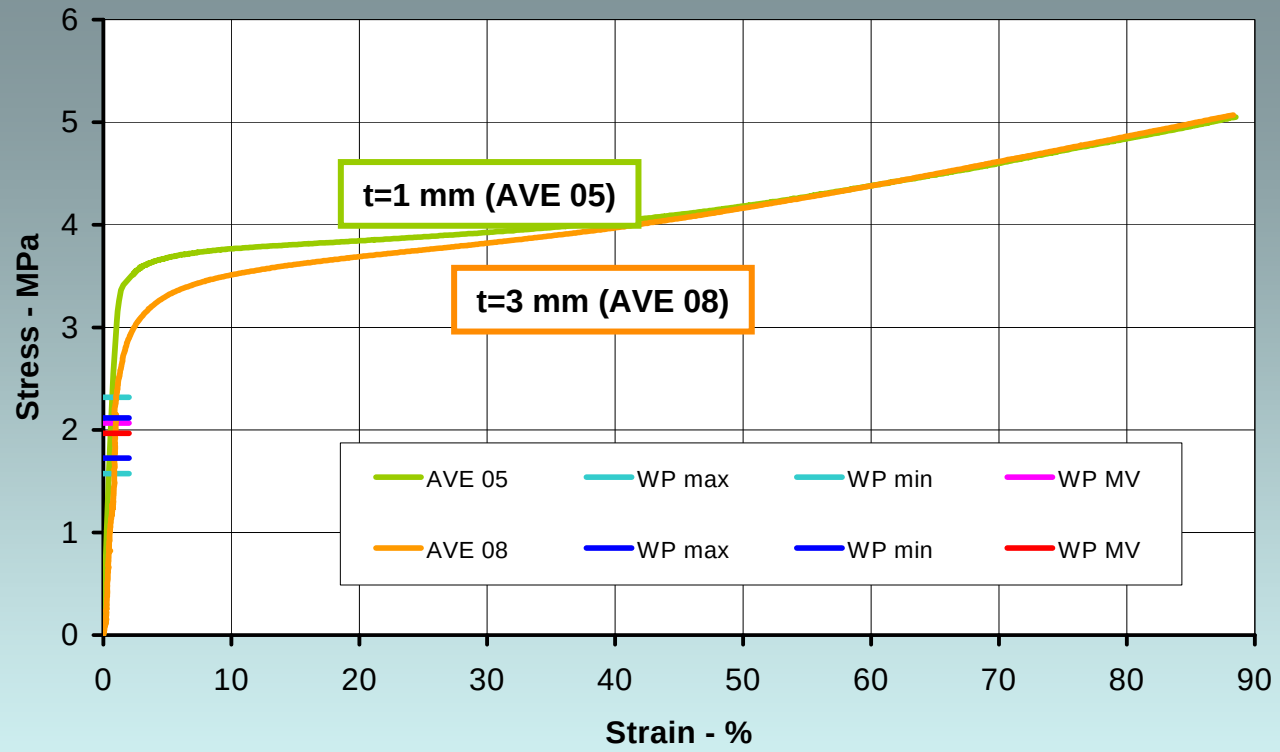


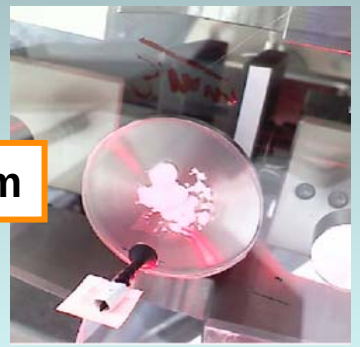
$$\varepsilon = \frac{\Delta_{tensile}}{t_{TSSA}}$$

Experimental results

- **Three phases of behavior are visible, as known from conventional SSA.**
- **Similar global behavior is identified for geometry ratios Ø/t from 20 to 80**
- **According to the results there is a minor impact of the free surface along the circumference allowing lateral contraction.**

Whitening Points in Stress-Strain Curves Ø50, t = 1/3 mm

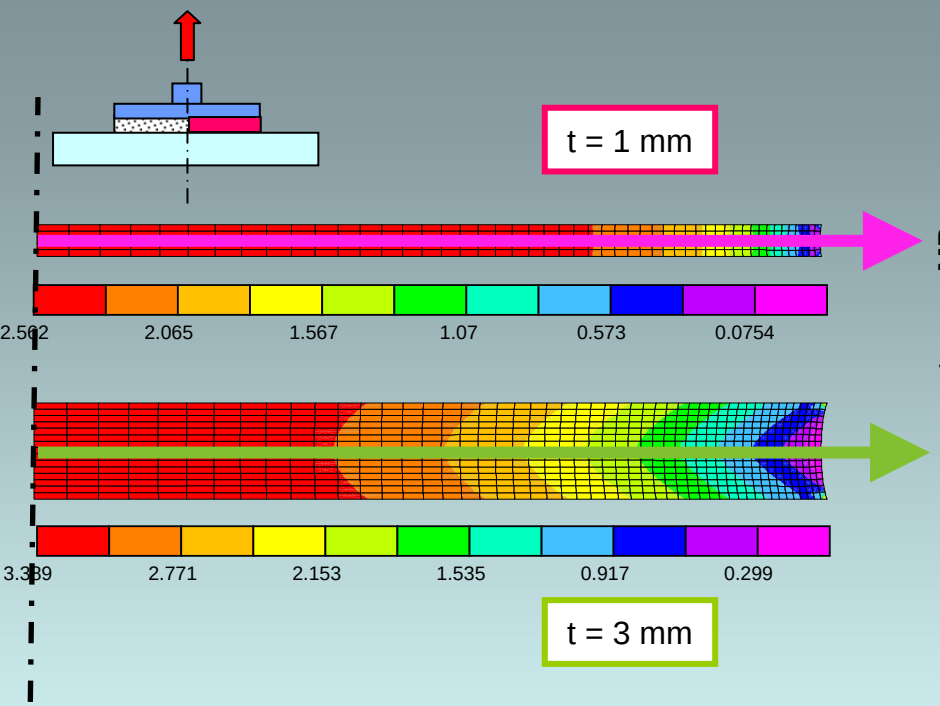


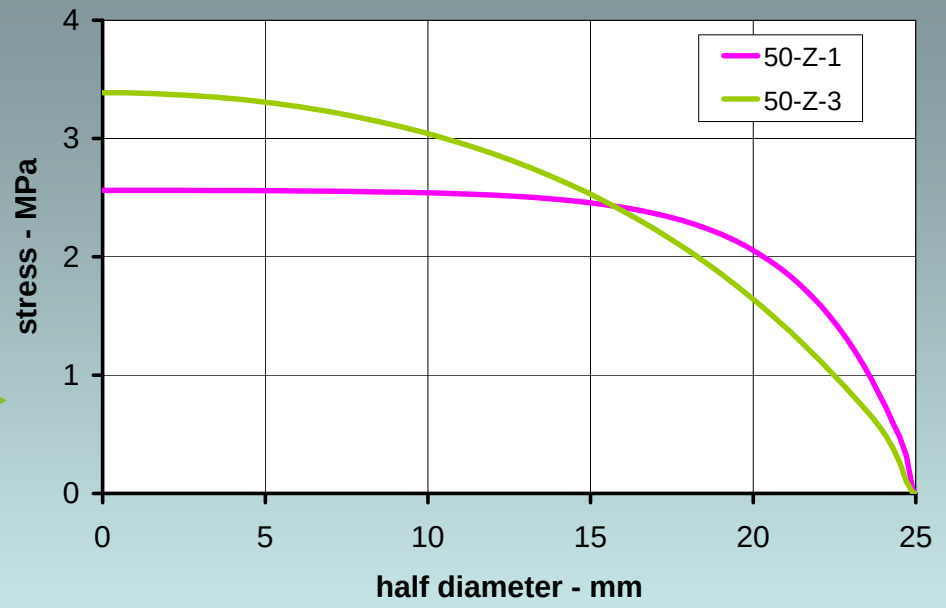


Experimental results

- The whitening appears at similar load levels.
- The impact of free surface due to thickness variation is obviously small.
- The begin of softening between 2.5% - 40% strain shows different characteristics.
- Different whitening patterns and stress distributions obtained by FEA might explain this behavior.

Planar Point Supports Ø50 mm under Tensile Loading





Numerical results

- Normal stress distribution is more uniform for smaller thickness which is expected due to less impact of free surface.
- Larger stresses for small radial locations are visible for t = 3mm which is in co-incidence to whitening starting in the middle of the specimen.
- But there is no indication of extreme loading at 30% - 60% radial position for t = 1 mm.

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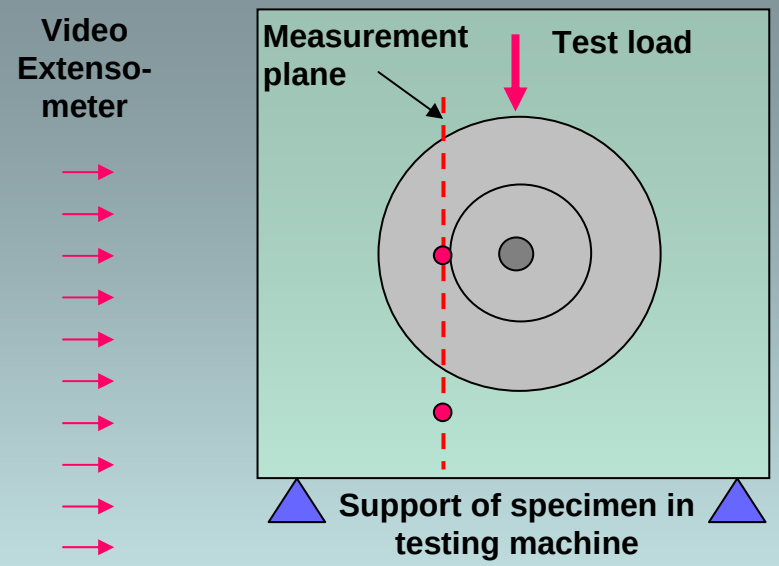
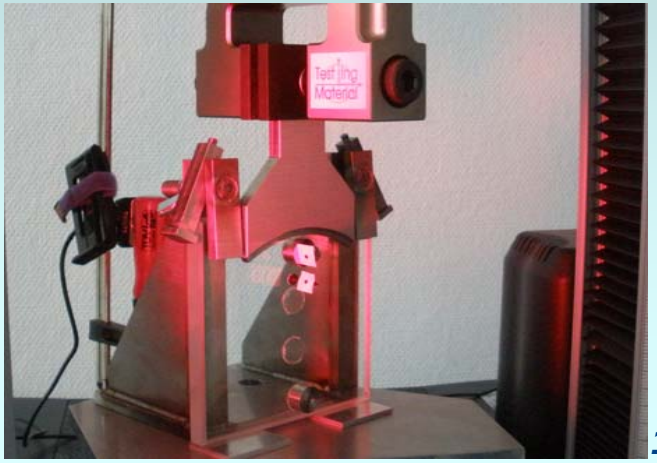
Test Set-up for Shear Tests



Special requirements for testing are:

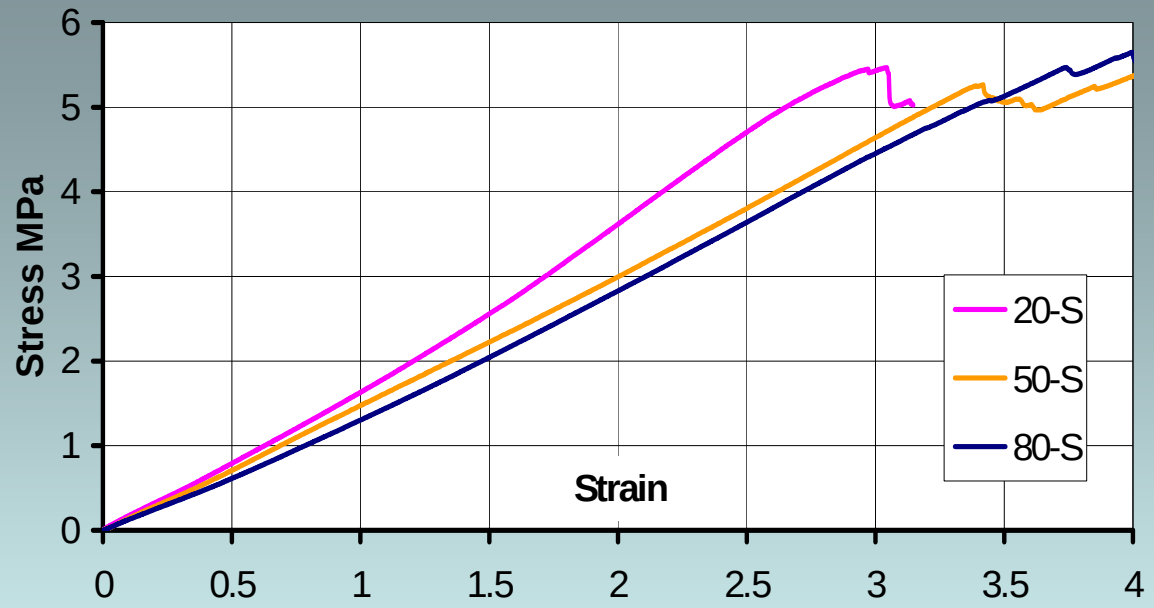
- The set-up has to be suitable for Ø 20 mm to Ø 80 mm specimens.
- The monitoring of whitening needs optical access.
- Dedicated markers for video-extensometer have to be applied.
- The pushing device contacts only the point support, not the adhesive.

  → The load introduction offset from the glass surface is slightly larger than the bonding thickness



Shear Test of Point Supports – TSSA

$$\tau = \frac{F_{shear}}{A_{TSSA}}$$



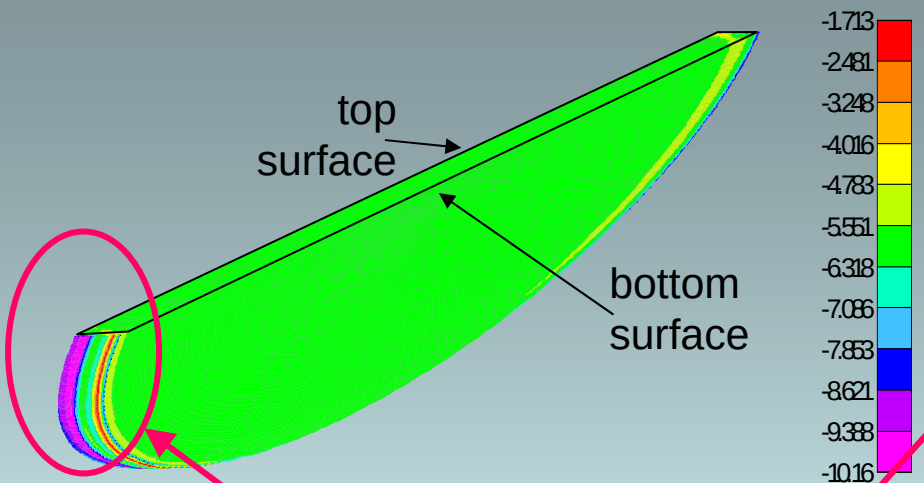
Ø 20, t = 1mm

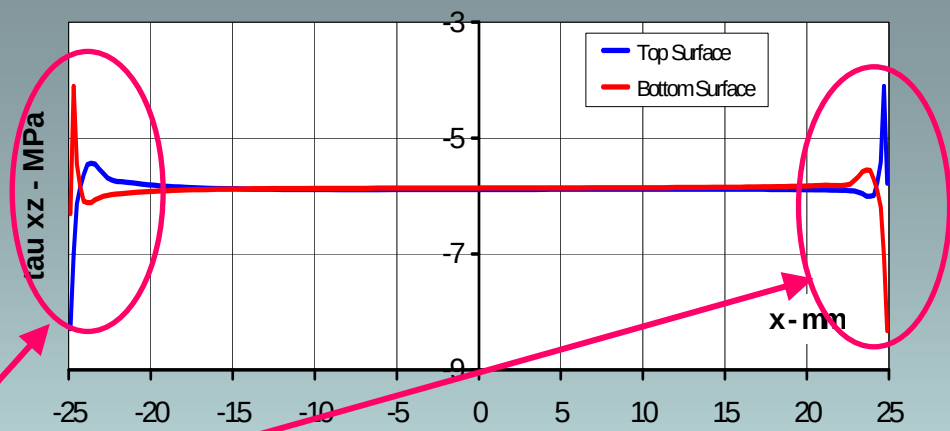
$$\gamma = \frac{\Delta_{shear}}{t_{TSSA}}$$

Experimental results

- Generally, the typical behaviour of silicone shear specimens (as also known from ETAG H-type) is visible – it is more or less linear up to failure.
- Ø 50 mm and Ø 80 mm point supports show a high level of similarity.
- The Ø 20 mm configuration differs probably due to the load introduction offset leading to a larger bending impact for small specimens.
- Please note: The whitening is only observed for Ø 20 mm.

Shear Stress Analysis Ø 50 mm: Ultimate Shear Load





Note: Local stress peaks at edges

Numerical results

- **Stress peaks in small regions near the edges are expected to initiate failure.**
- **The missing whitening is probably due to high stress levels in these small regions**

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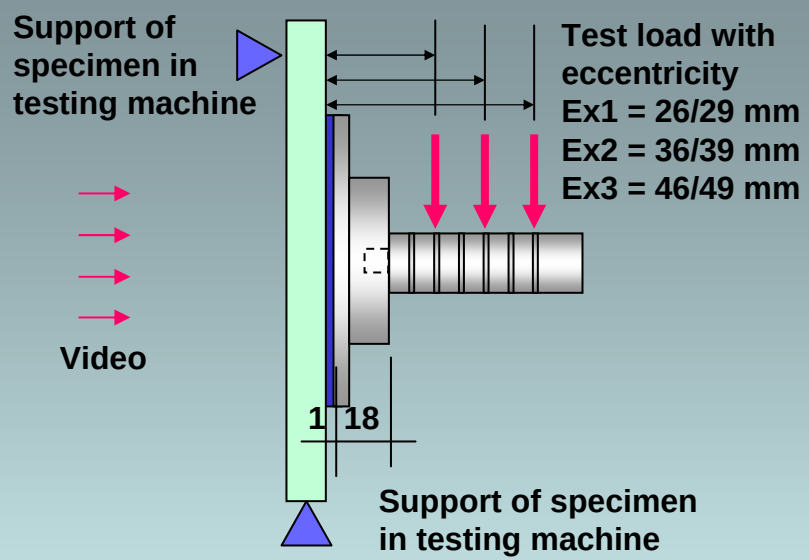
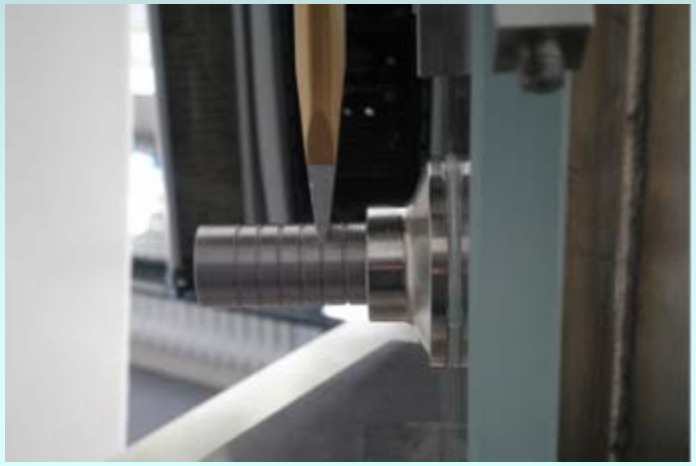
Test Set-up for Eccentric Shear Tests

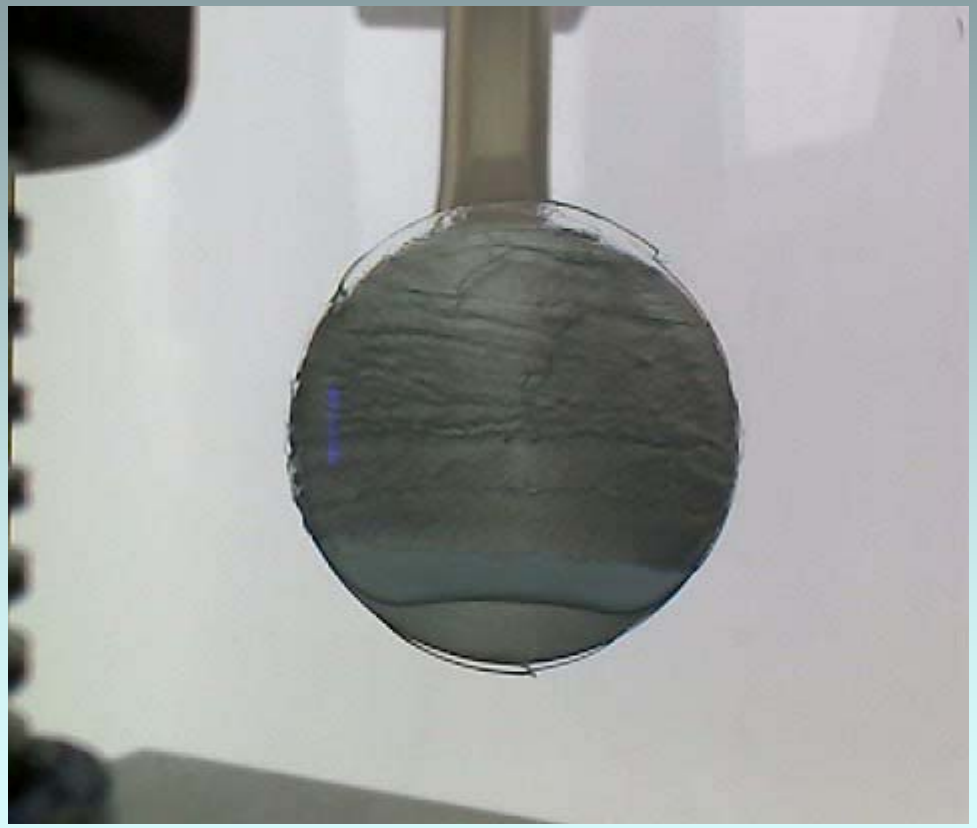
Special requirements for testing are:

- **The set-up has to be suitable for Ø 20 mm to Ø 50 mm specimens.**
- **The monitoring of whitening needs optical access.**
- **Eccentricity for 20 mm diameter**
  - **26 mm**
  - **36 mm**
  - **46 mm**
- **Eccentricity for 50 mm diameter**
  - **29 mm**
  - **39 mm**
  - **49 mm**



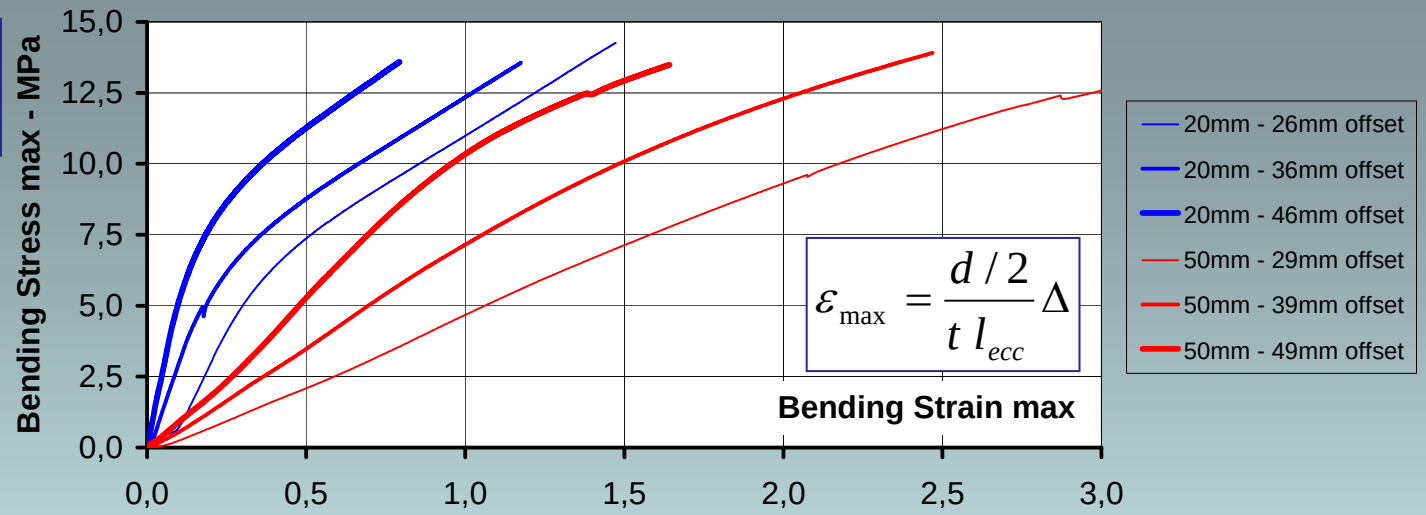


Eccentric Shear Test (49 mm) Ø 50 mm - Whitening



Eccentric Shear Tests: Ultimate Load – TSSA

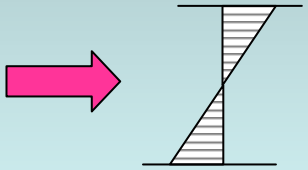
$$\sigma_{max} = \frac{M_{ecc}}{W_{TSSA}}$$



$$\varepsilon_{max} = \frac{d/2}{t\, l_{ecc}} \Delta$$

Assumptions for post-processing of experiments are:

- Classical beam bending theory which leads to a linear strain distribution where strain and max. stress are at outboard locations.
- Bonding material is approximated by linear stress-strain relationship.

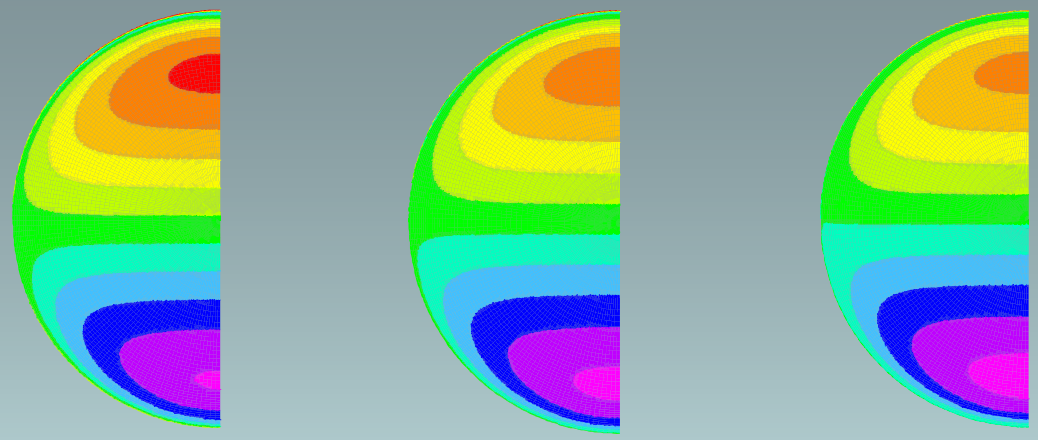


Experimental results for bending due to eccentric shear

- Failure occurs at approximately the same stress levels.
- The whitening is visible for all eccentric shear tests.
- The larger the diameter is, the softer is the behaviour.
- The larger the eccentricity is, the stiffer is the behaviour.

Ø 50, t = 1mm, eccentric loading

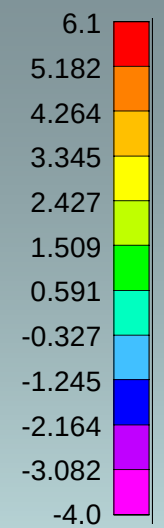
Tensile Stress Distribution Ø 50 mm: Eccentric Shear

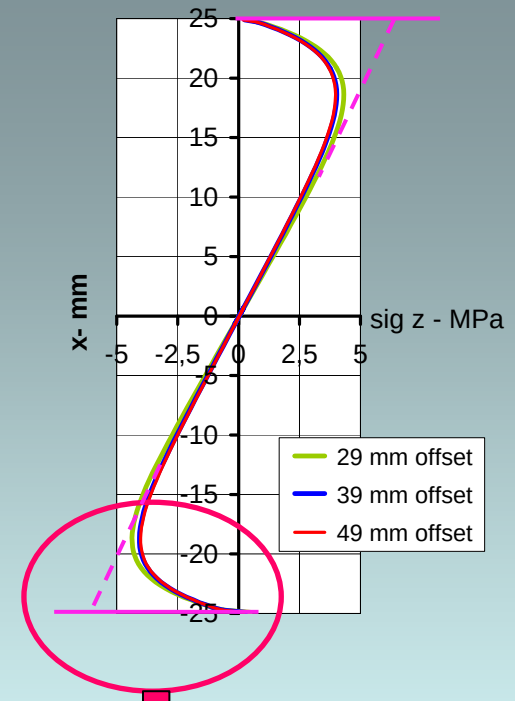


Shear, Eccentricity 1
29 mm

Shear, Eccentricity 2
39 mm

Shear, Eccentricity 3
49 mm





Deviation from linear beam bending theory due to reduced effective stiffness of outboard free surface allowing free lateral contraction

Model Set-up

- **Load levels are adjusted to the begin of whitening.**

Numerical results

- **Similar stress distributions are obtained for all eccentricities according to**
  - **contour plots**
  - **stress distribution-plot along symmetry plane**
- **Similarities demonstrate dominance of bending.**

Contents

Comparison of Conventional and Next Generation Silicone Adhesives for Ø 50 mm

- **Significant difference in bonding thickness between conventional SSA and TSSA**
  - **For conventional SSA typically a bonding thickness of 5 mm is recommended.**
  - **TSSA is available in sheets with a nominal thickness of 1 mm.**
- **Similarities exist in complex behavior under tensile loading**
  - **Three phases in the stress-strain relationships are observed**
    - **Fully functional adhesive featuring high stiffness**
    - **Significant degradation of stiffness - but no visible macro-cracks**
    - **Global failure due to rupture**
  - **Cohesive failure is obviously initiated at approximately 60% radius of round point supports for bonding thicknesses mentioned above.**

Conclusions

- A new transparent structural silicone adhesive was experimentally and numerically analyzed for tensile, shear and eccentric shear for point supports with different diameters.
- Focus was given to whitening phenomenon which indicates obviously highly strained regions of adhesive material. This property allows the monitoring of local strains.
- There are significant similarities detected between one-component heat-cured adhesive and conventional two-component adhesive for point supports.
- Bending moments are identified as critical load parameters for mixed loading as introduced by shear with an offsets.
- To be investigated next:
  - Correlation of whitening begin with point support stiffness degradation
  - Dependency of diameter / thickness relation concerning whitening

End

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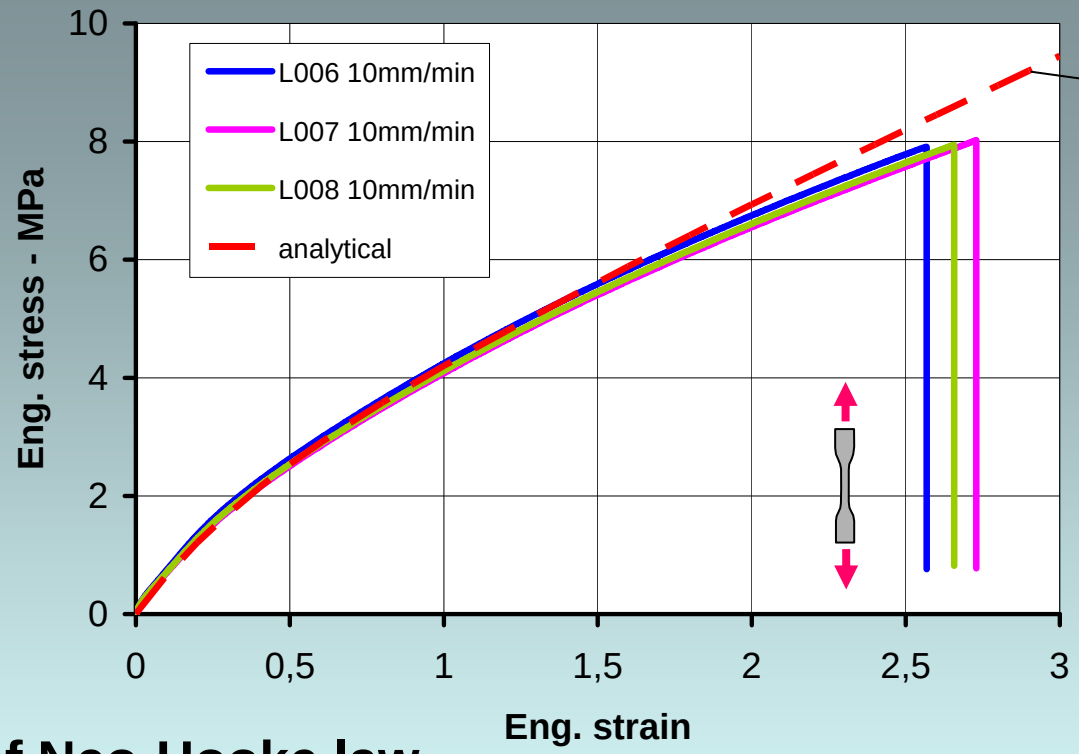
Dumbel Test for Derivation of Material Law



$$W = \frac{G}{2}\left(\lambda_1^2 + \lambda_2^2 + \lambda_3^2 - 3\right)$$

Selection of Neo-Hooke law

- Hyperelastic material law is based on strain energy density.
- One parameter material model shows high modelling robustness.

Experimental and numerical results

- High level of coincidence of test curves is obtained.
- Excellent agreement up to 150% strain