Tensile Loading of Silicone Point Supports - Revisited

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Contents

- Introduction - Transparent Structural Silicone Adhesive (TSSA)
- Point Support Results: Conventional SSA
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- Shear Tests TSSA Point Supports
- Eccentric Shear Tests TSSA Point Supports
- Comparison and Conclusions
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 *

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

Stress-Whitening Phenomenon

- TSSA shows the special property of losing 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

Region 1
- fully operational bonding

Region 2
- micro damages in the bulk of adhesive by increasing load

Region 3
- macro cracks occur and lead to total failure

Stiffness degradation at approx. 1700 N

Deflection [mm]

Load [N]

Ø = 50 mm, dA = 5 mm
Failure Hypothesis of Conventional Silicone Adhesive

**Phase 1**
Beginning of macro cracks at an inner circle

**Phase 2**
Crack-progress runs to inside and outside

**Phase 3**
Finally the core fails.

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.
Experimental results

- Three phases of behavior are visible, as known from conventional SSA.
- Similar global behavior is identified for geometry ratios $\Omega/t$ 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 coincidence 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

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.
Nummerical 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.

Note: Local stress peaks at edges
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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
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.
Tensile Stress Distribution Ø 50 mm: Eccentric Shear

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.

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

www.test-ing-material.de
www.a-hagl-ingenieure.de
www.dowcorning.com
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