Structural Silicone Glazing
Life Expectancy of more than 50 years?

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What is Structural Silicone Glazing (SSG)?

- Structural silicones are applied in facades, roofs, windows, doors, solar collectors, photovoltaic modules and internal partition walls to fix glass elements to metallic frames.
- Only certified silicones are proven to:
  - take over dynamic loads from wind and impact
  - take over permanent load components from glass weight
  - resist thermal cycles and sun radiation
  - stay durable over a long time
Brief History of Structural Silicone Glazing

1964  first projects in US using 1-part silicones for structural bonding
1968  first 2-sided SSG projects in US using 1-part silicones on site
1971  first 4-sided SSG project in Detroit/US using silicone on site and additional safety devices
1974  first 4-sided SSG project Chicago/US using silicones without safety devices
1984  first generation of 2-part silicone developed in US
1985  IFT facade as first SSG Project in Rosenheim/Germany, special approval by DIBT Berlin, toggle system with insulating glass, no safety devices, no dead load support for outer glass, monitored over full life time, deinstalled and retested 2012, test report available
1990  development of second generation of 2-part silicone meeting European EOTA requirements
1992  first SSG projects in Europe using new 2-part silicone generation by shop glazing
1993  first general SSG system approvals for Germany

So far: numerous SSG projects globally, most without additional safety devices, some unsupported
Historic SSG projects

1971 Detroit/US, 4-sided SSG with retainers

1987 Selb/Germany, 4-sided SSG with safety devices

1985 Rosenheim/Germany, 4-sided insulating glass toggle system, no safety devices
Benefit of Structural Silicone Glazing

- Allows to realise glass architecture with high transparency
- Shop glazing of complete elements allows quick installation
- Long life expectancy and low maintenance costs

Requirements for Structural Silicone Glazing

- Consistent quality controls during bonding process
- Silicones used for SSG must be tested and certified
- Proven durability:
  - testing according ETAG002 (European Guidelines for SSG) and ASTM C1184
  - SSG projects with first generation of 2-part silicones now have >30 years
  - SSG projects using 2nd generation 2-part silicones now have 25 years
  - question of building owners and authorities: Life expectancy of SSG? 25, 50 or 75 years?

Key question: What is the best test method?
Monitoring old SSG projects

- A full monitoring during the life time of 25 years was done on a SSG project in Rosenheim/Germany: facade of the IFT test institute (Institut für Fenstertechnik)
- Units produced 1985, installed 1986, using first generation of 2part Structural silicone
- Deinstalled in 2012, stored in a warehouse for 2 years before testing
- Samples cut by waterjet from glass units, then tested according ETAG002
- Results from testing in tension and shear until rupture show sufficient remaining strength

<table>
<thead>
<tr>
<th>Type of Test</th>
<th>Test Temperature (°C)</th>
<th>Average Breaking Stress $X_{\text{mean}}$ (MPa)</th>
<th>Residual Strength Ratio</th>
<th>ETAG002-1 Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ITT (New) Natural Aging (23+2 Years)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tensile</td>
<td>+23</td>
<td>0.95 0.75</td>
<td>0.79</td>
<td>≥ 0.75</td>
</tr>
<tr>
<td></td>
<td>-20</td>
<td>1.7 1.1</td>
<td>0.65</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>+60</td>
<td>0.81 0.73</td>
<td>0.90</td>
<td>-</td>
</tr>
<tr>
<td>Shear</td>
<td>+23</td>
<td>0.94 0.67</td>
<td>0.71</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>-20</td>
<td>1.54 0.97</td>
<td>0.83</td>
<td>-</td>
</tr>
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<td></td>
<td>+60</td>
<td>0.71 0.67</td>
<td>0.94</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 2: Tensile and Shear Strength Values in Initial Type Testing (1985) and after 23+2 Years of Natural Aging and Corresponding Residual Strength Ratios

1985 Rosenheim/Germany, 4-sided insulating glass system, no safety devices, outer glass unsupported

Samples cut out from the units
Summary

• Monitoring old SSG projects using 1st generation silicones, sufficient remaining silicone performance has been proven after 25 years of real service life, another 25 years anticipated.

• Several SSG projects using 2nd generation silicones now have also fulfilled 25 years of real service life, sufficient remaining performance of the structural silicone was observed during monitoring, another 25 years of service life is anticipated.
PRACTICAL APPROVED LIFE EXPECTANCY OF SSG –
PROGNOSIS OF LIFE EXPECTANCY BY A
PERFORMANCED-BASED TEST METHOD

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Dipl.-Ing. Ch. Recknagel; BAM

www.bam.de
Working life representing load function – General loading categories

Essential loading categories results in

- **Deformation** of the Sealant → Fatigue
- **Weathering** of the Sealant → Ageing

both categories must be **quantified**

must be **transferred**

in a generalised load function
Permanent Load: glass weight: 2500 kg/m³

Temperature:
- $T_{\text{glass Surface}}$: -40 to +80 °C
- $T_{\text{Frame}}$: -15 to +80 °C
- $T_{\text{Fabrication}}$: +19 to +27 °C

Wind loads: 2526 direction changes

Human Impact: acc. to DIN 18008-4

Working life representing load function – Quantification of Deformations

A: -2016 Pa (Suction)
B: -830 Pa (Suction)
C: -1304 Pa (Suction)
D: +1186 Pa (Pressure)
Working life representing load function – Representative SSG Model

... loads applied on **Representative Façade element** designed as SSG-System
(anodized aluminium frame – sealant - float glass panel)
Working life representing load function – Load induced sealant deformations

\[
\Delta x \Delta y = \pm \sqrt{\text{max} |\Delta x|^2 + \text{max} |\Delta y|^2} \quad \text{(Shear)}
\]

\[
\Delta z = \pm \text{max} |\Delta z| \quad \text{(Extension/Compression)}
\]
1 simulated annual cycle:

Mechanical loading \((f = 0.03 \text{ Hz})\)
- 2526 x Ext./Compr. cycles
- 2526 x Shear cycles
- 1 x most severe condition

Representative local Weathering
- Temperature range -10 to +60°C
- Rain (de-ionized water): \(~ 620 \text{ l/m}^2\)
- UV (290 to 410 nm) : \(~ 1.1 \text{ MJ/m}^2\)
- Cleaning by surfactants

Simulated working life by 50 cycle repetitions + impact
Development of complex test facility
which consists of ....

Environmental chamber

Specimen Fixture

Upper clamping

lower clamping

Bi-axial sensor
(with specimen)

climate control device

temperature control device

mechanical loading device
Potential of the new test method – Sealant sensitivity to weathering

- Differences between external and internal temp.-distribution
- Weathering induced temperature effects
Potential of the new test method – Bond loading of SSG system

Real Bond stresses:
- max. $\sigma_{\text{Ten.}}$: +0.33 N/mm² (exceed $\sigma_{\text{Design}}$: +0.20 N/mm²)
- max. $\sigma_{\text{Comp.}}$: -0.59 N/mm²
- max. $\tau$: 0.24 N/mm² (exceed $\tau_{\text{Design}}$: 0.14 N/mm²)

Mechanical Loading Extension/Compression
(Hysteresis loops over 1 simulated year)
Potential of the new test method – Mechanical SSG system performance

- System response (mechanical performance) (storage modulus, loss modulus, tan δ)
- System stiffness $E_{\text{dyn}}$
Potential of the new test method – Durability assessment model
System Stiffness under Compression $E_{\text{dyn;Compr.}}$:

- Indicator for changing sealant behaviour (ageing)

Potential of the new test method – Durability assessment (Ageing)
Potential of the new test method – Durability assessment (Fatigue)

System Stiffness under Extension $E_{\text{dyn};\text{Ext}}$:

- Indicator for changing bond behaviour (fatigue)

- Inflection point to Phase III (deterioration to malfunction)

- Abrupt stiffness decrease (bond cracking)
Potential of the new test method – Visualisation of Ageing/Fatigue

Silicone 1st Generation

Silicone 2nd Generation
Potential of the new test method – Traceability to technical rules

Table: Tensile and Shear Strength acc. to ETAG 002 after BAM-Durability Test

Comparison of Residual Strength Ratio

<table>
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<tr>
<th>Specimen</th>
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<tr>
<td></td>
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<td>Residual Strength Ratio ($\sigma_T$)</td>
<td>Shear Strength (MPa)</td>
<td>Residual Strength Ratio ($\tau$)</td>
</tr>
<tr>
<td>Initial</td>
<td>1.02</td>
<td>-</td>
<td>0.68</td>
<td>-</td>
</tr>
<tr>
<td>Weathering</td>
<td>1.05</td>
<td>1.03</td>
<td>0.84</td>
<td>1.24</td>
</tr>
<tr>
<td>Weathering + Movement</td>
<td>0.63</td>
<td>0.62</td>
<td>0.58</td>
<td>0.83</td>
</tr>
<tr>
<td></td>
<td>1.59</td>
<td>-</td>
<td>1.18</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1.52</td>
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- Tensile behaviour is a sensible indicator for durability assessment
- Significant decrease in tensile strength after superimposed loading
- Silicone 1st generation do not pass the conventional requirements
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- Tensile behaviour is a sensible indicator for durability assessment
- Significant decrease in tensile strength after superimposed loading
- Silicone 1st generation do not pass the conventional requirements
- Weathering-based durability assessment shows opposite/unvaried strength effects

Durability assessment true to reality requires superimposed loading
Summary

- A new **performance-based test methodology** (load function, test facility, system specimen) for SSG assessment was successfully proved and offers various potentials:
  - allows **exploration of mechanical** behaviour of sealants resp. complete SSG-systems under realistic loading
  - allows **differentiation of sealant's performance, ageing and fatigue** behaviour
  - allows proof of measured data by **visual observations**
  - allows **traceability to conventional/empirical assessment methods**

**Working Life ≥ 50 years** could be successfully simulated for 2nd Generation Silicone

**limited capability and durability of 1st Generation Sealants** could be identified
Thank you for your attention!

„Futurium“ Berlin; Source:https://www.bundesregierung.de.html