Mechanical Properties of Laminated Glass: FEM Study
About Saflex

• Saflex, a unit of Solutia Inc., is the world’s largest manufacturer of polyvinyl butyral (PVB) interlayers for laminated glass.

• For more than 80 years, Saflex has been providing real-world solutions for every glazing challenge – collaborating with architects, engineers and fabricators to meet the most demanding glazing designs.
Markets - Automotive

- Saflex protective interlayers are the world’s leading brand of laminated glazing interlayers and can be found in nearly 50% of automobiles worldwide.
- Saflex protective interlayers are used commercially by vehicle manufacturers in windshields, side windows, rear windows and panoramic roof applications.
- Benefits from automotive laminated glass made with Saflex include: interior noise reduction, weight reduction, security, safety and enhanced color.
Markets - Architectural

• Recognized as the world’s leading brand of PVB interlayers, Saflex interlayers are used in commercial and residential applications.
• Saflex interlayers can resist hurricane-force winds and wind-borne debris, plus provide additional safety, solar, security and sound control advantages.
• The Vanceva® color system by Saflex provides limitless color possibilities for innovative glazing design.
Saflex’s speakers

Gérard Savineau
Architectural Application Manager for Saflex Europe/Africa

Associated with Saflex for more than 30 years, and guest speaker of GPD since 1995
Mr. Savineau will be presenting:

“Mechanical properties of laminated glass, FEM study”

During the Glass in Architecture – Use of Laminated Glass
(Monday June 18th)
Mechanical Properties of Laminated Glass: FEM Study

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Introduction

• Predict the deformation of laminated safety glass based on different PVB interlayers under different loads/boundary conditions and at different temperatures.
• Solutia FEM: ABAQUS Program
• Experimental data generated by TNO
• Comparison between the experiments (TNO) and the software simulations from Solutia & DuPont
Rheological Model

- Establish a mathematical description for the mechanical properties of the interlayer
- Dynamic rheological experiments from 0°C to 80°C
- Definition of a mastercurve by shifting the dynamic moduli at 20°C (time-temperature superposition principle)
Standard Saflex® PVB Master Curve

- **Storage modulus G'**
- **Loss modulus G''**

Reference temperature = 20°C
Rheological Model

- Transformation of the mastercurve into a relaxation curve (Ninomiya and Ferry)
- Comparison of the calculated relaxation curve with the visco-elastic model for PVB published by DuPont (S.J. Bennison’s model)
- Solutia’s model slightly different from Bennison’s model.
Relaxation Curve for Standard Saflex PVB Interlayer
Shift Factor

Meaningfulness

• Express the degree of shifting required to correlate the dynamic moduli at any temperature to the moduli at the reference temperature

• Used to calculate the mechanical properties of PVB at temperatures deviating from the reference temperature
Shift Factor of Standard PVB Interlayer as a Function of Temperature

![Graph showing the shift factor of a standard PVB interlayer as a function of temperature. The x-axis represents temperature in °C, ranging from 0 to 100. The y-axis represents the shift factor, ranging from $10^{-8}$ to $10^5$. The graph includes experimental data points.](graph.png)
Deformation Study

• Experimental set-up (TNO)

• Solutia Model:
  – Element type for the viscoelastic layer: C3D8IH element
  – Element type for the glass: C3D8I element or a continuous shell element
  – Amount of elements per layer ~900
  – Temperature range: 5° to 40°C
Experimental Set-up

Simple 4-side support

Pressure load representing the weight of laminate

Additional force (200 N) applied to the surface in middle of laminate

1.25 m × 1.25 m

44.2 Configuration

Simple 4-side support
Results

Central Laminate Deflection at 5\(^\circ\)C

[Graph showing deflection over time for different composites at 5\(^\circ\)C]

Construction: 3.9 mm glass/0.76 mm PVB/ 3.9 mm glass

Load: during 5 first seconds deformation is due to own weight

After 5 sec.: 200 N force is applied in middle of the laminate
Results

Central Laminate Deflection at 10°C
Results
Central Laminate Deflection at 20°C
Results

Central Laminate Deflection at 40°C
Tensile Stresses in the Central Cart of the Laminate as a Function of Temperature

(data after 1 hour under stress)
Results
Mid Plane Deflection for 2-sides Supported Laminate (temperature = 20°C)

- Middle point deformation
- Load: During the first 5 seconds, deformation is due to its own weight. After 5 sec., 200 N force is applied in the middle of the laminate.
- Laminate is supported only on two sides.

Construction: 3.9 mm glass/0.76 mm PVB/ 3.9 mm glass.
Results

Effect of windload duration on the panel deflection

- Wind velocity = 120 km/h - 3 sec
- 120 km/h - 10 sec
- 120 km/h - 60 sec

Deformation in case of 7.8 mm glass panel

Deformation in case of a 8.56 mm glass panel

Laminate = 3.9 mm glass/0.76 mm PVB/3.9 mm glass
Results

Recovery of the Laminate Deflection Over Time

Recovery
Results

Mid point deflection at 20°C

- Standard PVB-20°C
- RM-20°C
- DNG
- VSO-2-20°C
- 7.8 mm glass
- Twice 3.9 mm glass

Temperature = 20°C
Applied pressure = 1000 Pa
Size of laminate = 3 m x 2 m
Results

Mid point deflection at 30°C.

- Standard PVB 30°C
- RM-30°C
- VSO2-30°C
- 7.8 mm glass

Temperature = 30°C

Size of laminate = 3 m x 2 m
Results

Mid point deflection at 40°C

The graph shows the mid point deformation over time for different samples at 40°C. The size of the laminate is 3 m x 2 m. The graph includes data for standard, VSO2, and RM samples.
Results

*Mid point deflection at 50°C*

![Graph showing deflection over time for different materials and thicknesses.](image-url)
Results
Glass Strength factor

• Difficult to define a single value because it depends on
  – The temperature
  – The duration of the load (short term or long term)
  – The viscoelastic properties of the interlayer (Tg)
  – The relative thickness of the interlayer

• The center deformation of standard laminated glass is larger than the deformation of a monolithic glass of the same thickness but always smaller than the deformation of the decoupled glass.
Conclusions

• FEM (ABAQUS) was developed by Solutia to predict the deformation of laminated glass.
• Predicted values (FEM) fit with experimental data (TNO)
• Degree of correlation depends on the rheological model but in general a good match was observed
• Solutia’s FEM allows to calculate the Glass Strength Factor for laminated glass
• The bending stiffness of laminate remains higher than the fully decoupled glass panels
Thanks for your attention

Questions?