High Performance, Material Efficient Glass Inserts

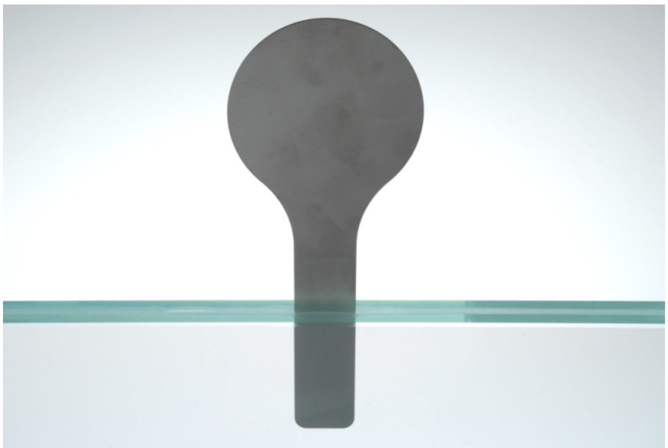
Dipl.-Ing. Kerstin Puller, M.Sc.

M.Eng. Jürgen Denonville

Dr.-Ing. Walter Haase

Prof. Dr.-Ing. Dr.-Ing. E.h. Werner Sobek

June 2012



University of Stuttgart
Institute for Lightweight Structures and Conceptual Design
Prof. Dr.-Ing. Dr.-Ing. E.h. Werner Sobek
Prof. Dr.-Ing. Balthasar Novák

Research project:	High performance, material efficient glass inserts
Funding agency:	Research Initiative "ZukunftBau" Federal Institute for Research on Building, Urban Affairs And Spatial Development Deichmanns Aue 31-37 53179 Bonn (Germany)
Project number:	Z 6 - 10.08.18.7-08.24 / II2-F20-08-21
Project duration:	01. 01. 2009 bis 30.06.2010 Extended until 30.06.2012
In collaboration with:	Dipl.-Ing. Kerstin Puller, M.Sc. M.Eng. Jürgen Denonville Dipl.-Ing. Christian Bergmann Dr.-Ing. Walter Haase
Start:	Januar 2009
Location:	**Institute for Lightweight Structures and Conceptual Design** Director: Prof. Dr.-Ing. Dr.-Ing. E. h. Werner Sobek Pfaffenwaldring 7 + 14 70569 Stuttgart Telephone 0711 / 685 63599 Telefax 0711 / 685 66968

Acknowledgements

The project was funded by the Federal Institute for Research on Building, Urban Affairs and Spatial Development.
(No: Z6-10.08.18.7- 08.24/ II2-F20-08-21)

Special thanks go to the members of the working group:

Dipl.-Ing. Architekt Guido Hagel
Prof. Dr.-Ing. habil. Manfred Bischoff
Prof. Dr.-Ing. Christian Bonten
Dipl.-Ing. Fabian Beilharz
Dr. sc. techn. Rudolf Hess

Special thanks also go to the participating industrial partners

Seele Sedak GmbH & Co. KG
Du Pont de Nemours (Deutschland) GmbH
Hottinger Baldwin Messtechnik GmbH

1 Objective of the research project

The technology for joining glass elements is by far less advanced than the material itself. Further developing a joining technique suited for the material glass which produced promising results in previous tests should close this existing gap. This innovative joining technique intended to lead to a more economic design of glass elements, ensure the residual strength of the structure after failure, increase the structure’s transparency and improve its behavior during assembly as well as during disassembly.

This project examines multi-layer-systems connected by a polymer interlayer with embedded inserts as load-carrying device. Tests and numerical analyses are to be used to obtain the basic parameters of the high performance load-carrying devices. The loadbearing behavior of the connection under different types of stress was analysed followed by the structural optimization of the connecting element.

First the material characteristics of the polymer interlayer (SentryGlas®Plus) were determined supplementing the existing information provided by the manufacturer and publications. The material parameters were examined with respect to temperature changes, stress rate and stress duration. The specimens were designed to allow to directly compare the material parameters with those of PVB (Polyvinylbutyral- mainly used in interlayer material of laminated glass). This was tested extensively at the Institute for Lightweight Structures and Conceptual Design (Institut für Leichtbau Entwerfen und Konstruieren (ILEK)) in the course of a previous research project funded by the trade association for structural glass (Fachverband für Konstruktiven Glasbau (FKG)) [1].

The next step involved experiments to study the loadbearing behavior of this innovative connecting technique using pull-out tests of inserts in the interlayer under short- and longterm stress, followed by the description of the pull-out tests using numerical analysis.

After the analysis of the stress distribution within the components the insert geometry was modified aiming at reducing the peak stresses and to obtain a homogenous stress distribution.

2 Research Work Plan

This work plan gives a summarized description of the tasks carried out in the course of this research project:

Work package 1: Analyses of the material behavior of the interlayer (SentryGlas®)

- i. Identification the material parameters of the polymer interlayer
- ii. Development of a material model for the numerical simulation of the material behavior

Work package 2: Load application element for tensile stresses – Variation of the boundary conditions (short-term loading)

- i. Development of a test apparatus for load tests
- ii. Sedak (partner in the project) produces test specimens (standard geometry)
- iii. Pull-out tests under specific conditions (temperature, load rate)
- iv. Development of a numerical model to simulate the structural behavior
- v. Comparison of the results derived from the tests and the numerical analyses

Work package 3: Load application element for tensile stresses – Long-term loading

- i. Design of a test apparatus for long-term loading tests
- ii. Preparation of a testing program
- iii. Production of test specimens (standard geometry)
- iv. Construction of the test apparatus
- v. Configuration and calibration of the measuring technology and establishment of a test-related data-recording system
- vi. Test setup (placing the specimens in the testing frame, adding the measuring technology)
- vii. Conducting the tests according to the testing program
- viii. Evaluation of the tests

Work package 4: Load application element for tensile stresses – Variation of the geometry (short-term loading)

- i. Deriving different geometries based on previous knowledge
- ii. Sedak, a partner in the project produces test specimens with different insert geometries
- iii. Pull-out tests under constant boundary conditions
- iv. Comparison of the test results from the tests of the insert geometries in WP4 with the standard insert from WP2

Work package 5: Tests of the loadbearing behavior of an optimized insert geometry under tensile stress (short-term loading)

- i. An optimized geometry of a load application elements is derived based on the results from WP1, WP2 and WP3
- ii. Numerical simulation of the loadbearing behavior of the optimized geometry
- iii. Summary of results

Summary of Results

The introduction of a new interlayer material (SentryGlas®, SG) has enabled the development of an innovative glass connection technique which involves a metal element partially embedded in the interlayer (insert) acting as load-carrying device.

In order to analyse the loadbearing behavior of this type of connection, the mechanical behavior of SG under tensile stress at different temperatures and loading rates was examined. An increase in temperature and a decrease in the loading rate resulted in softer mechanical behavior.

Then tests were conducted to examine the loadbearing behavior of the connection under short-term and long-term loading. The specimens and the test apparatus were designed to obtain measurable deformations in the SG and to avoid premature glass failure and metal yielding. The recorded force-displacement relationship was found initially to be linear. The initial stiffness decreased accompanied by a loss of adhesion (23 °C, 40 °C) and the formation of bubbles (75 °C). At peak load a gap between the end of the insert and the SentryGlas® occurred, clearly visible at 40 °C and 75 °C.

The basic loadbearing behavior of the connection could be examined using long-term testing at constant boundary conditions. Now it is possible to compare the long-term behavior for three different states of stress and at three different ambient temperatures for a duration of 400h. It became obvious that at 75 °C the initial deformations and the deformations occurring after 400h were greater by far than the deformations at 40 °C or at room temperature. This behavior was expected because a temperature of 75 °C significantly exceeds the glass transition temperature. Therefore, deformations at room temperature are negligible in the design of these façade inserts. The same applies for deformations occurring below 40 °C if the facade is designed to allow temperatures above the glass transition temperature. Here the temperatures above the glass transition temperature are relevant

Another significant aspect of this research project was to describe the loadbearing behavior of SG and the insert using numerical simulation. Multi-linear material models were derived on the basis of the data obtained from the tensile tests of the SG-specimens for discrete temperatures and test speed followed by a numerical simulation of the tensile tests. A comparison of the test results and the numerical results showed good agreement.

After analyzing the strain rate the insert geometry was structurally optimized to minimize stress peaks. To ensure comparability the interface area between the insert and SG, the applied load and the material models used remained unchanged. With this type of connection great variations in stiffness should be avoided, especially at 75 °C, since these will cause stress peaks. Instead of ending at the embedment depth, the optimized insert ends gradually. To utilize a larger SG-area for the load transfer the insert is divided into several fingers pointing in the direction of the load. At 23 °C most of the load is transferred at the upper edge of the glass which is, however, of lower strength. Therefore the insert is prevented from coming in contact with the SG at the edge of the glass resulting in the load transfer to set in at a distance to the edge and in avoiding stress peaks at the edge of the glass. Compared to rectangular inserts this structurally modified geometry resulted in a reduction of stress peaks in the glass of about 20 % at 23 °C and 53 % at 75 °C.

References

[1] W. Sobek und W. Haase, „Temperaturversuche an Verbundsicherheitsglasscheiben unter Sonneneinstrahlung“, Versuchsbericht, 2001.