Proven Performance that lasts

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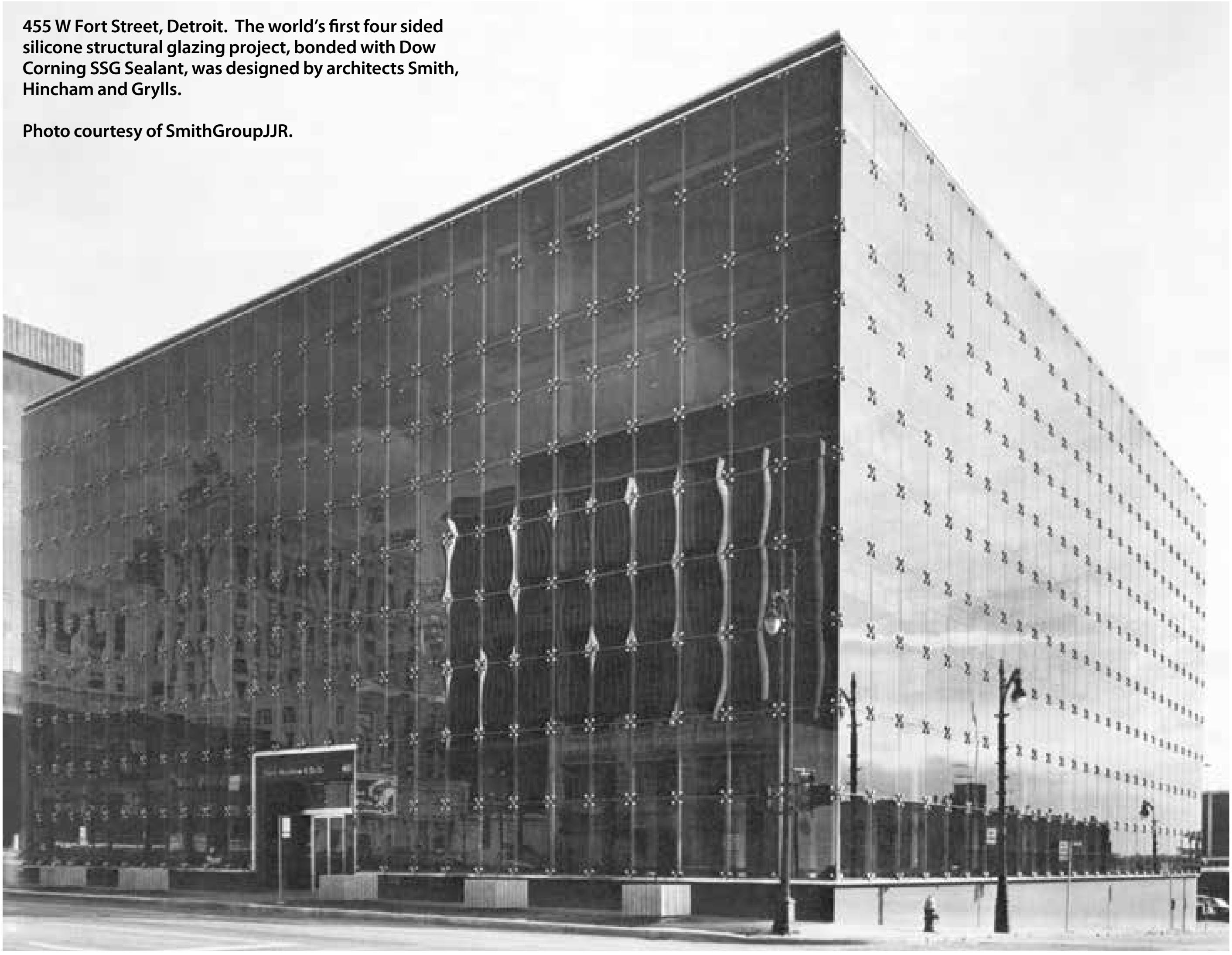
Structural Silicone Glazing (SSG) is a curtain walling method that utilizes a structural silicone sealant to adhere glass, ceramic, metal or composite panels to supporting framing members by means of a peripheral adhesive joint. In SSG curtain walls, silicone sealants serve not only as a weather seal, but also act as a structural bonding element, eliminating the need for exterior retainers and covers (1).

In the 1960's, the Dow Corning Corporation was a pioneer of this revolutionary technology that opened the eyes of architects to a new way of designing and realizing pure glass aesthetics: Dow Corning's first silicone structural glazing project in 1964 involved structurally bonding glass mullions to external glass in order to rigidify the facade structure, increase daylight opening and transparency. With growing interest in this technique, the 1980s saw the SSG curtain walling concept spread rapidly around the world as this glazing method allowed architects new levels of design freedom and offered a unique aesthetic appearance. SSG has become an outstanding success with literally tens of thousands of projects which showcase its aesthetic and performance benefits.



455 W Fort Street, Detroit. The world's first four sided silicone structural glazing project, bonded with Dow Corning SSG Sealant, was designed by architects Smith, Hincham and Grylls.

Photo courtesy of SmithGroupJJR.

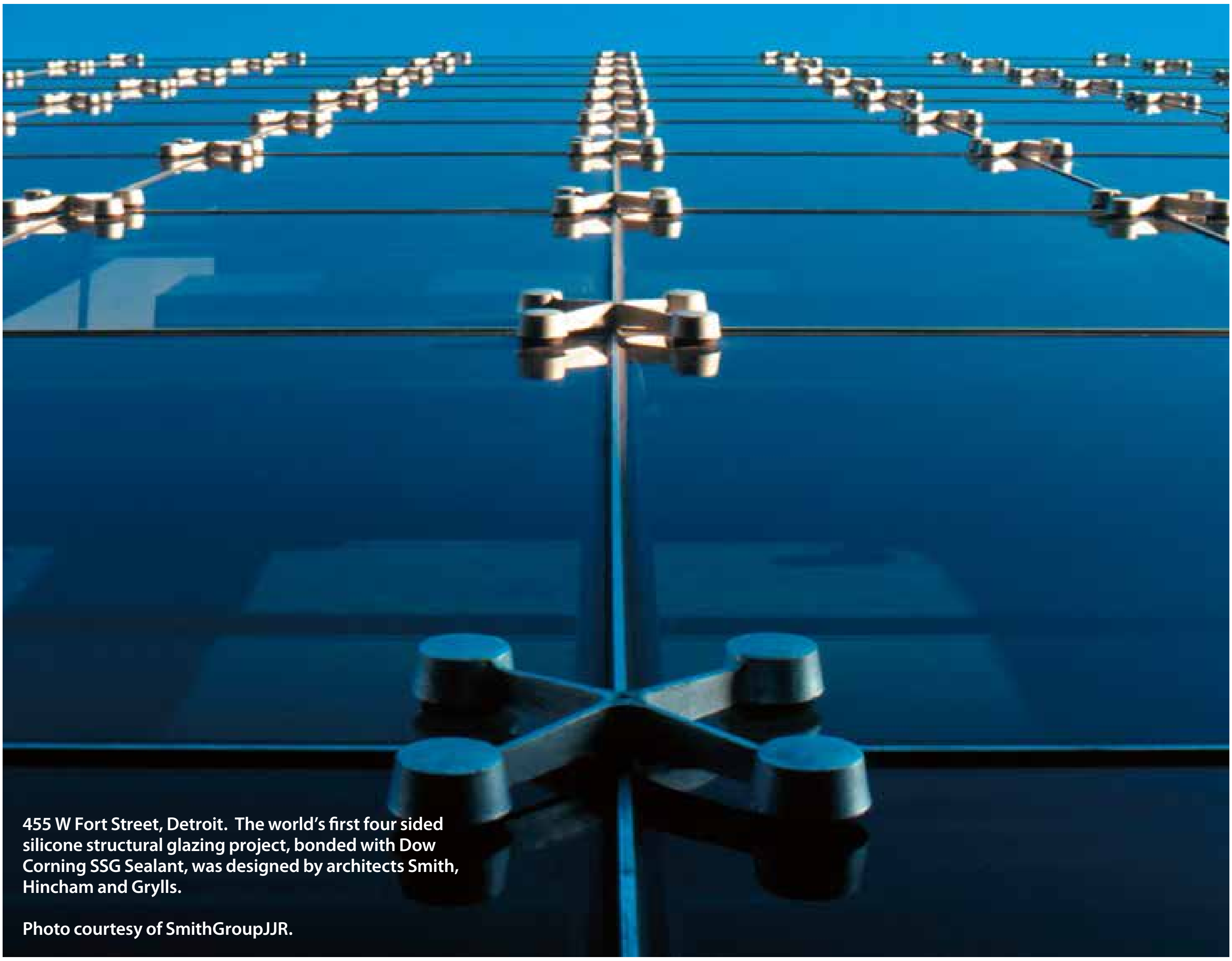
The Challenge: Estimating the Technical Useable Life of SSG Curtain Walls

One major concern with adhesively assembled structures in general is the long-term integrity of the structural bond. Therefore, with the aim of ensuring public health and safety, building code authorities in countries like Germany or Austria still require additional mechanical fasteners for four-sided SSG curtain walls to provide safe retention of the infill panel in case of structural sealant failure – unless the technical useable life can be predicted with the help of more suitable test methods.

Furthermore, despite their practically proven performance and stellar track record, uncertainty still exists regarding the ultimate (technical) scientific based service-life prediction of SSG curtain walls. Many SSG curtain walls are disassembled and replaced because of aesthetic and commercial considerations long before they have reached the end of their usable life. Still, there is a significant number of SSG curtain walls globally that have now reached 30+ years of service and building owners and code authorities are faced with the task of estimating the residual service life of these structures.

Ultimately, the underlying questions are, what is the 'theoretical' life of a SSG curtain wall – is it 50, 75 or even 100 years – and how exactly will a structural silicone sealant degrade and ultimately fail? Will it be possible to explore time-dependent performance and fatigue as well as failure mechanism - e.g. with the aim to detect fatigue and failure indicators? Can a scientific-based comparable investigation method over a simulated life time period under use conditions come close to reality? And which technical indicators describe normal operation and can be indicators for beginning degradation? In some countries, this uncertainty is responsible for inhibiting the wider use of the four-sided structural bonding technology.

Therefore, important issues that remain to be addressed are the prediction of the degradation behavior and the resulting long-term durability of adhesive-bonded structures. The basis to overcome these open questions, however, is firstly a performance-related understanding of the (mechanical) operating principle of each specific SSG solution under super-imposed loading. To describe the operational principle e.g. in mechanical terms, opens up the possibility to detect degradation and



455 W Fort Street, Detroit. The world's first four sided silicone structural glazing project, bonded with Dow Corning SSG Sealant, was designed by architects Smith, Hincham and Grylls.

Photo courtesy of SmithGroupJJR.

failure with the help of relative changes. The essential challenge that researchers face today is threefold:

a. How to develop a test method that allows study of the mechanical operating principle of an SSG solution, independent of the sealant's material or SSG construction, under superimposed (realistic) loading conditions?
b. How to develop durability test methods that provide a better representation of the actual service environment in the laboratory?
c. And, how to calibrate laboratory durability test results against actual in-service performance of SSG adhesive joints?

Besides the possibilities for a performance-related design of sealant materials as well as whole SSG constructions, another ultimate objective then, is a more realistic prediction of the technical usable life of SSG curtain walls. Two recent studies constitute major steps forward in this direction and, for the first time ever, provide compelling scientific support for service life estimates of SSG structures significantly in excess of 25 years. The findings validate anecdotal evidence gathered from successful field-performance of SSG buildings that have now been in operation for more than 30 years (2).

A Unique Opportunity: Calibrating ETAG 002 Test Requirements Against Actual In-Service Performance

In 1985, the southwest facing bow front façade section of a building at ift Rosenheim, an internationally renowned authority in the testing of windows and façades, was installed using the then-novel 'hybrid' four-sided SSG system. In this SSG design, special toggles engage in U-shaped glass edge spacers located at the periphery of insulating glass units.

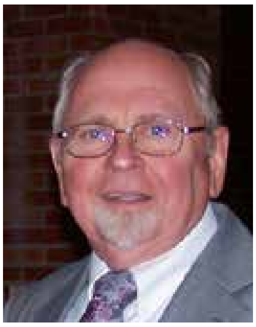
Regardless of their mechanical fixation to the substructure, toggle-glazed hybrid SSG designs still expose the insulating glass edge seal to structural loads; therefore, an approved structural silicone sealant must be used to adhesively bond the U-shaped retention channel to the adjacent glass panes.

The three-story high toggle-glazed hybrid SSG system broke new ground, as it was installed (in regards to the outboard glass panes) without additional safety retainers and without dead load support.

Such a hybrid SSG design corresponds to Type IV Glazing listed in ETAG 002, as the structural bond transfers not just dynamic external loads, such

Originally constructed in 1985, the façade of the ift Rosenheim was structurally bonded with Dow Corning SSG Sealant

Photo: ®ift Rosenheim



Jerry Klosowski, Klosowski Scientific Inc., about the pioneering spirit:

> It was an exciting time. There was a spirit of camaraderie in the industry. All of us working together in a community of trust to develop a new architectural concept and prove to the world that it would work.

as wind load, but also the self-weight of the infill panel. However, different from the situation in a regular SSG design, the structural bond in a hybrid SSG system is also subjected to climatic loads, as changes in temperature, atmospheric pressure, and altitude influence the sealed gas volume trapped within the insulating glass unit.

In their approval of the structure, the building code authority placed a high value on the documentation of the manufacturing, quality assurance, and installation of the SSG modules as well as on the structural health monitoring of the SSG bond during service. These concomitant studies, conducted by ift Rosenheim, created a wealth of reference data. When the façade was refurbished for improved energy efficiency after 23 years of service, the dissembled SSG structure offered the opportunity of 'calibrating' the requirements stated in the European approval guideline for SSG sealants and systems, ETAG 002-1.

ETAG 002 was developed by the European Organization for Technical Approvals (EOTA) in 1991 [3-5]. Its comprehensive range of tests and stringent assessment criteria makes ETAG 002-1 a very demanding standard for SSG sealants. The standard defines key provisions for bonding strength and durability of bonding strength of the SSG sealant and, notably, mentions that the provisions made in the ETAG 002-1 are based on an assumed service life of the SSG structure of 25 years.

In 2012, after the dismantled façade had been stored in an unheated warehouse for 2 years, Nikolaus Graf, an undergraduate researcher at the University of Regensburg, conducted an experimental and statistical evaluation of the natural aging behavior of the structural silicone sealant installed at the ift Rosenheim façade in light of the ETAG 002-1 requirements (6). Fortunately, the B.Sc. study was supported by the ift Rosenheim, a fact that allowed Graf to compare his data with the previously collected reference data.

A key consideration for determining safety in use and, thus, the suitability of a SSG sealant according to ETAG 002, is the stability of cohesive and adhesive properties when exposed to different environmental and aging conditions. Therefore, an important question to ask is whether or not the structural sealant that had undergone 25 years of environmental exposure would still pass the requirements of 'Initial Mechanical Strength' and 'Residual Strength' (now applied to natural aging) as laid out in ETAG 002-1 sections 6.1.4.1. and 6.1.4.2.

The aim of the Initial Mechanical Strength tests is to evaluate the bonding strength of the structural sealant when subjected to tensile or shear forces acting on the joint at different temperatures. Temperature-induced variations in the sealant's properties may lead to a drop in mechanical and bonding strengths. Therefore, ETAG 002-1 stipulates that the mean tensile and shear strength values measured at -20 °C and +80 °C must not drop below a minimum of 75% of the corresponding values observed at +23 °C and that rupture must occur at an average cohesive failure mode of 90% or greater.

In the B.Sc. study, test specimens were subjected to destructive tensile and shear tests at -20 °C, +23 °C, +60 °C, and +80 °C. Across the board, the sealant passes both the above mentioned ETAG 002-1 Initial Mechanical Strength requirements with flying colors.

The Residual Strength test is meant to determine the durability of the bonding strength. ETAG 002-1 stipulates that the residual tensile strength after all types of accelerated aging tests must still equal or exceed 75% of the sealant's initial strength measured at 23 °C and that the failure mode after aging must be ≥90% cohesive in nature. Despite 23+2 years of natural aging, the sealant successfully passes the ETAG 002-1 criteria.

Such strong performance against key performance indicators at the end of the 25-year service life assumed by ETAG 002 is quite reassuring. It may give conservative building code authorities the added confidence they need to consider future four-sided SSG structures without supplementary safety retainers. The findings of this study are especially remarkable as the silicone sealant used in the ift Rosenheim SSG application, *Dow Corning* ID200 (a two-part sealant similar to *Dow Corning*® 983 SSG Sealant), was commercialized long before the ETAG 002-1 guideline was developed and failed to meet its stringent requirements, once this standard went into effect. The inability of *Dow Corning* 983 Sealant to meet the ETAG specification then triggered the development of *Dow Corning®* 993 SSG Sealant, the next-generation, higher performance successor product, which is capable of passing all SSG standards globally.

Back to Basics: Developing a Performance-Based Durability Assessment for SSG Sealants

Inspired by the results of the case study mentioned above there is still an open question for further acceptance: How can we explore the functional principle and its possible changes in use with the help of an repeatable test standard as a basis for durability estimation accepted by the authorities?

In 2012, the German Federal Institute for Materials Research and Testing (BAM), a leading research institute for science and technology, picked up the challenge of developing a performance-based durability test method for SSG sealants that better reflects the actual service environment. The project was executed between 2012 and 2015 and accomplished the following major deliverables [7]:

a) Derivation of a realistic environmental and mechanical loading function suitable for accelerated durability testing under the most important SSG-loadings;
b) Development of a system test specimen that provides a better representation of the real SSG joint design;
c) Design and construction of a test facility capable of simultaneously imposing weathering and complex, multi-axial mechanical loadings on the test specimen independent of sealants nature or constructional design of the SSG-solution;
d) Evaluation of the durability of different 'benchmark' SSG sealants.

The test was designed to reproduce typical environmental exposure and service conditions. Consideration was given for the following loads [8,9]:

- Mechanical loads resulting from self-weight, temperature, wind and extraordinary theoretical loadings like human impact loads;
- Climatic loads taking into account typical average and extreme temperatures, humidity, the number of rainy days and the average amount of precipitation and solar radiation per year;
- Chemical loads resulting from water (rain) and cleaning agents (aqueous surfactant solution).

The deformation/stress loading was derived from parametric finite-element analyses (FEA) of a large-sized SSG glazing unit installed at a height of 50 meters on a building located in wind load zone II considering terrain categories II and III according to DIN 1055-4 [10]. The following assumptions were made in the parametric analyses [XX]:

- The SSG glazing module (2.5 m wide and 3.2 m high) is oriented vertically; the unit is structurally bonded on all four sides; the dimensions of the structural bond (sealant's cross section) are 12 mm x 6 mm;
- The SSG system is glazed with either single pane, insulating glass, or stepped insulating glass (3 options) and installed either with or without support of its own self-weight (types II and type IV according to ETAG 002);
- The design stress (σdes) of the structural sealant is 0.21 MPa. (So a 50% higher design strength compared to the typically used σdes =0,14MPa to calculate an SSG façade.)

Cameron Centre, Tsimashatui. The first four-sided structurally glazed building in Hong Kong, bonded with Dow Corning SSG Sealant

Furthermore, in order to simulate a human impact on the SSG module, a separate FEA study was conducted to investigate the effect a pendulum impact test according to DIN 18008-4. The multitude of FEA studies allowed the BAM researchers to derive the maximum tensile and shear deformations occurring in the SSG sealant for each loading event. In general, they assumed the worst-case combination of loads (and resulting movements). However, in order to derive deformation parameters for regular loads, they used the load distribution spectrum, as laid out in ETAG 002-1 section 5.1.4.6.5 Mechanical Fatigue.

50 test cycles successfully passed – equal to 50 years actual service exposure

Utilizing the knowledge of the life-cycle load profile that was established during the previous research, the BAM researchers subjected the test specimens to repetitive durability cycles. Each durability cycle, which exposed test specimens for 24 hours to simultaneous climatic and multi-axial mechanical loads, was designed to represent one year of actual service exposure. After the completion of 50 durability cycles, the test specimens were subjected to a rapid, complex deformation in order to evaluate the aged sealant's ability to sustain an accidental human

**Larry Carbary,
Dow Corning
Industry Scientist:**

"Structural glazing today provides a powerful tool for architects to achieve the most incredible building designs. Not only is it a proven method of curtain wall construction, this technique works as part of a complete system to facilitate state-of-the-art performance with regards to air infiltration, water infiltration, thermal performance, seismic performance, impact resistance, longevity and design freedom. This high performance technique is a benchmark for current and future materials regarding sustainability and green construction."

impact on glass. The impact simulation was then followed by another two durability cycles. Multi-axial mechanical loading was super-imposed taking into account worst loading scenarios.

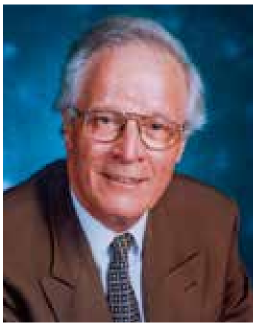
Simultaneously to the complex, two-dimensional shear and tensile deformations, test specimens undergoing durability cycles were exposed to surrounding temperatures of -10 °C to +60 °C, relative humidity ranging from 20% to 98%, rain events (distilled water) corresponding to a middle yearly rain fall of 620 l/m^2, and maximized energy input of UV light (290 to 410 nm). In order to investigate the effect of mechanical fatigue, additional test specimens were kept in the BAM weathering chamber that were subjected only to weathering without movement.

Dow Corning® 993 Sealant was chosen by the BAM researchers as one of the benchmark sealants. After completion of the durability test, the system test specimens were cut by water-jetting into standard-sized ETAG 002-1 samples, which were then tested for their residual strength. Table 5 displays the results observed initially (prior to testing) and after completion of the durability test from comparable test sections under comparable test conditions. Tensile and shear strength values along with the corresponding residual strength ratios (after aging) are shown. The data gathered at the completion of the durability test differentiate between test specimens that had undergone simultaneous weathering and enforced movement and those that were subjected only to weathering. This underlines the most important influence of mechanical loading on the durability behaviour and confirms the new approach and testing methodology introduced.

Table 5. Tensile and Shear Strength Values and Residual Strength Ratios for Dow Corning 993 Sealant, observed in the BAM Durability Testing

Specimen	DC 993 Sealant			
	Tensile Strength (MPa)	Residual Strength Ratio (%)	Shear Strength (MPa)	Residual Strength Ratio (%)
Initial	1.59	-	1.18	-
Weathering	1.52	0.95	1.18	1.00
Weathering + Movement	1.23	0.78	0.98	0.83

As can be seen, *Dow Corning* 993 Sealant successfully passed the ETAG 002-1 criterion for residual tensile strength The substrate adhesion was good and in accordance with the ETAG 002 requirements. Resulting from additional visual bond control only a marginal loss of adhesion was observed primarily at the corners of the specimen. After more than 50 cycles of super-imposed mechanical as well as climatic loading, extraordinary mechanical loads and chemical loading both the sealant and the specific SSG construction still shows performance behaviour according to the requirements.



Karl-Heinz Rückeshäuser, KHR Consulting:

"Beside the challenges and hurdles we had to take to establish structural glazing in Europe, it was an exciting time and a pleasure to work with the "Innovators" on implementing this concept in a quite conservative market environment. I am pleased to see how popular this design concept is now after more than 25 years in Europe."

Summary and Conclusions

Recently, two research studies focusing on the investigation of the durability and service life of SSG structures were completed. Both studies provide compelling scientific support for service life estimates significantly in excess of 25 years. A test method was introduced able to explore the functional principle and with it a test tool for performance-related further advancement of sealant materials as well as SSG construction is given. The findings validate anecdotal evidence gathered from successful field-performance of SSG buildings that have now been in operation for more than 30 years.

Such strong performance against key ETAG 002-1 performance indicators after natural and accelerated exposure is quite reassuring. It may give conservative building code authorities the added confidence they need to consider future four-sided SSG structures without supplementary safety retainers. SSG has proven its reliability now for many years, which is a testament to the performance of the structural silicone sealants involved and the implementation of effective quality assurance procedures.

The long track record confirmed by the ETAG002 test carried out after 25 years and the developed proposal for a performance based durability assessment re-enforce confidence and trust in this structural bonding technique. Equally important to ensure longevity and long-term durability is the quality of workmanship, the structural joint dimensioning, the design requirements itself and the assessment of adhesion and compatibility. Dow Corning provides the well-established *Quality Bond*™ programme to ensure high quality during application based on regular audits, quality controls and testing during project execution, documentation, adhesion and compatibility testing.

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