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A New Reactive Thermoplastic Spacer with Excellent Durable Energy Efficiency for Structural Glazing Façades

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For the use in structural glazing (SSG) applications a new generation of warm edge system has been developed. This new technology is a spacer system based on polyisobutylene, especially designed for silicone sealed units, which replaces the conventional edge seal components: metal or plastic spacer, desiccant and primary sealant. In contrast to these components, this hot applied spacer system is an integrated polymer matrix incorporating the desiccant, which meets the high requirements regarding long term stability and in particular the demands for noble gas tightness of insulating glass units (IGUs) with silicone secondary sealant. In contrast to rigid spacer frames, this new spacer generation utilizes the whole inner gap size of the IGU to absorb movements caused by environmental stresses and allows full flexibility in shape of IGU. Excellent durability of the edge seal is insured by a chemical bond of the spacer matrix to glass and silicone secondary sealants. Due to the computer controlled application and the low permeability of the spacer the IGUs fulfil the requirements of the EN 1279-3 (gas tightness) even under standard mass production process conditions. This allows for an especially easy production even of triple IGUs, large formats and free shape designs with outstanding accuracy. The innovative reactive thermoplastic spacer is a new milestone in IGU technology with excellent durable energy efficiency for façades and contributes a significant step towards energy sustainability in building envelopes.

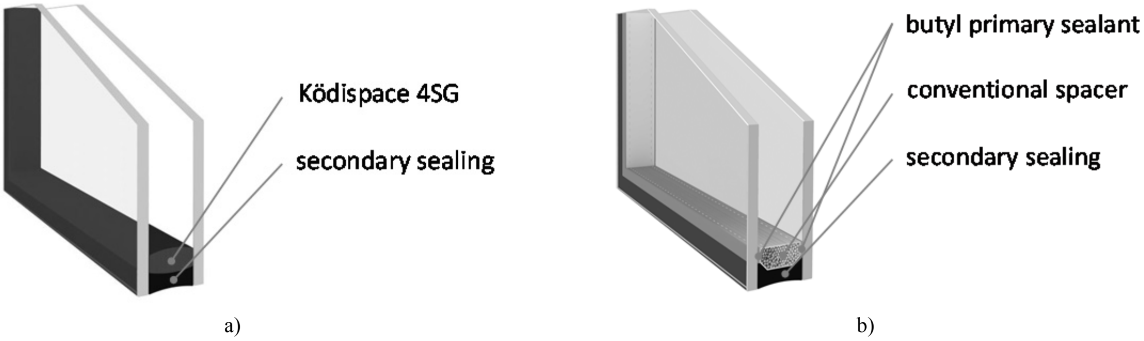
Keywords: Warm Edge, Spacer, Structural Silicone Glazing (SSG), Gas Tightness, Energy Efficiency, Flexible Shape

1. Introduction

Minimizing the energy consumption of buildings has become a global objective and an important goal in architecture in recent years and future will even see a continuous tightening of energy efficiency standards on an international level, and with them, also of the energy performance level of building envelopes. For new buildings, the 2010/31/EU (The European Parliament and The Council 2010) policy for example stipulates the demanding "almost zero-energy building" specifications for government buildings beginning in 2019 and in 2021 for all other buildings. To decrease the demand for primary energy sustainability, an optimized thermal insulation - especially in the façade and window surface of buildings - has to be ensured. As a result of highly effective glass coatings as well as energetically optimized façade/frame profiles, gas filled double and even more triple pane IGUs have developed to highly thermal insulating assembly parts. Therefore, one of the last options to optimize thermal insulation performance of IGUs, the edge seal, has become the focus of attention. The traditional aluminum spacer systems create a significant thermal bridge in the edge seal and are therefore affecting the thermal properties of IGUs and reducing the energy efficiency of the building envelope. On this background, a wide variety of spacer systems -so called warm edge solutions- have been developed to reduce this thermal loss. In common terms of fenestration and façades, “warm edge” originally states not more than that the respective spacer is less thermally conductive than the traditional aluminum spacer reference. As long as it improves thermal performance, even at a relatively small level, it was considered to be “warm edge” (Glassmagazine.com 2015). While stainless steel and other metal-based spacer systems can offer some improvement over traditional aluminum spacers in terms of condensation resistance and U-values, it's undeniable that they are still 80 times more conductive than state-of-the-art high-end warm edge spacer systems. Metal free thermoplastic spacers represent such high-end warm edge systems. They offer the lowest level ψ-values, which lead to improvements in the Uw values of the window and the Ucw values of structural glazing elements. Compared to the ψ-values of the edge seal, the contribution of gas filling plays an even more important role for superior thermal transmission coefficients of double or triple glazing. To maintain the low Ug-values for the whole life time of a façade IGU, only the lowest gas loss rates are acceptable. According to the European product standard for insulating glass EN 1279-3 (European Committee for Standardization 2010), the maximum limit for the gas loss rate is one per cent per year after a specified climatic load cycle. Some warm-edge systems may have proven gas tightness to this standard even with silicone sealant. But with many of those new warm edge spacer systems, large façade units are not easy to produce. Furthermore, there is a growing discussion about the durability of edge seals, especially in more challenging climates and edge loads. Modern structural glazing façades with gas filling and warm edge are highly demanding on the edge seal. Additionally a secondary sealing with silicone, which has inherently no gas retention capability, is often mandatory due to its UV stability. It is somewhat difficult to produce durable gas filled IGUs with silicone secondary sealing. However, there is a growing demand for such units for structural glazing façades. The gas will only stay inside the IGU with an absolutely tight primary butyl seal – for conventional edge bond with spacer profiles this is a nearly impossible demand. With focus on the use in structural glazing applications, Kömmerling has developed Ködispace 4SG, the new generation of thermoplastic warm edge system.

2. The Ködispace 4SG System

Ködispace 4SG is a warm edge spacer system based on polyisobutylene, especially designed for silicone sealed units, which replaces the conventional edge seal components: metal or plastic spacer, desiccant and primary sealant (see Fig. 1).



a) b)

Fig. 1 Comparison IGU with a) Ködispace 4SG and b) aluminum spacer

Ködispace 4SG is, in contrast to these components, an integrated polymer matrix incorporating the desiccant, which meets the high requirements regarding long term stability and in particular the demands for gas tightness of IGUs with silicone secondary sealant. Different to conventional TPS-types, this reactive spacer bonds chemically to both the glass surface and the silicone sealant (see Fig. 2). As a result the whole edge seal melts to one integrated system and any dislocation of the spacer is impossible.

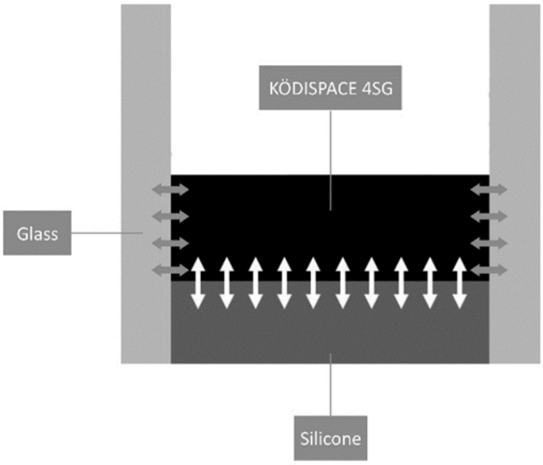


Fig. 2 Sketch of the chemical bonding of Ködispace 4SG to glass and silicone

In addition this material has an extended service temperature range up to +90 °C coming along with excellent UV and weathering resistance. Gas leakage and moisture penetration are critical factors, which have to be considered when working with silicone – which is almost exclusively used for structural glazing applications – as secondary sealing. Ködispace 4SG utilizes the well-known very low gas permeation and moisture vapor transmission rates of butyls. (see Fig. 3and Table 1).

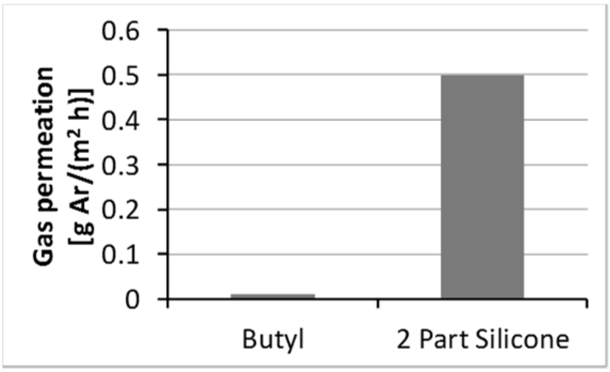


Fig. 3 Argon permeation of butyl vs. 2 part silicone

Table 1: Gas permeation and moisture vapor transmission of butyl vs. 2 part silicone

	Butyl	2 part silicone
Gas permeation (Argon) [g/(m2 h)]	< 0.001	< 0.5
Moisture vapor transmission rate [g/(m2 d)]	< 0.03	< 20

Therefore, even with silicone sealing, which has no gas retention capability, it is possible to produce absolutely tight IG units using Ködispace 4SG. Due to the chemical bond between Ködispace 4SG and the silicone additional stability is achieved, compared to a nonreactive TPS product which does not bond chemically to silicone. In addition automatic application options for this flexible, high-end warm-edge spacer system can dramatically improve efficiencies while offering the best available long-term sustainable performance.

3. Application

3.1. CNC Controlled Production

Ködispace 4SG is applied automatically by a CNC controlled robot directly onto the glass without any manual steps in between. For the application, Ködispace 4SG is pumped at a temperature of approx. 130 °C directly from drums to the robot head of the applicator, which is controlled by a computer with a precision of a tenth of a millimeter. The joint between start and stop is perfectly sealed by special patented closing technique. As the application robot is following the glass edge, the spacer material is always precisely positioned, even for large sized spacer frames. This is why a thermoplastic warm edge system is so convenient for large façade units.

Because of its special composition, Ködispace 4SG adheres immediately to the surface of the panes and can be applied on glass with an inner space of up to 20 mm. Due to the easy application, the thickness of the spacer is very flexible and can be varied from 3 mm to 20 mm in any combination and also for triple glazing from the same drum. The gas filling press is perfectly aligned to the applicator. Corner keys or linear connectors are not required and desiccant is already included in the material. Once installed inside a window frame, the frame color is reflected by the black spacer, so the spacer adapts its color to its background improving the aesthetics – an advantage for architects and building owners.

In addition a thermoplastic spacer like Ködispace 4SG allows the precise adjustment of glass package thicknesses as well as the production of irregular shapes and small radii down to 100 mm. Because of this precision, the thickness of the final IGU package fits perfectly to frames or design variations. The fully automated application leads to perfect alignment of the two spacers in triple pane units since the robot applies the bead perfectly to the glass unit for unit and therefore there is no misalignment of the two frames (see Fig. 4) – a fact that is often the cause of complaints with bent frames made of warm edge spacer profiles. Due to the CNC application various design possibilities referring to the shape of the units are feasible, which are very difficult or even impossible to achieve with standard spacers.

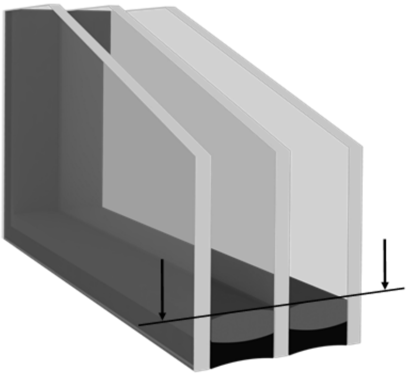


Fig. 4 Exact Alignment of the two frames with Ködispace 4SG

3.2. Shape Independent Production

The flexibility and the shape independent application of a thermoplastic spacer offer a wide range of opportunities regarding the shape of IGUs. For instance, it is possible to apply a thermoplastic spacer on various plane geometries such as triangle or diamond shaped panes (see Fig. 5).

a) b)

Fig. 5 Examples for shaped IG Units: a) Hessing car dealer (NL) (Photo: Flachglas Wernberg) b) Art museum (FI) (Photo: Pedro Pegenaute)

Furthermore a thermoplastic spacer provides the opportunity to either assemble IGUs out of warm bent glass or even cold bend the whole IGU on site. In case of a bent IGU the flexibility of a thermoplastic spacer provides a maximum of gas tightness unlike a metallic spacer, where the tightness is limited to the bendability of the spacer and the ability of the butyl layer to compensate the relative displacements between the spacer and the glass. Fig. 6 shows a variety of possible planar and Fig. 7 a variety of bent shapes.

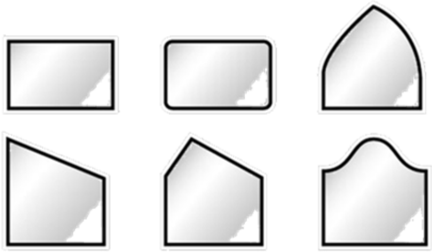


Fig. 6 Examples for realizable planar glass shapes

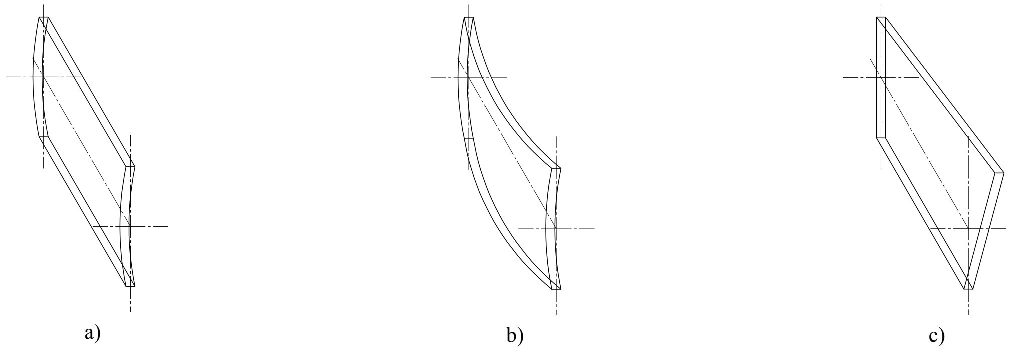


Fig. 7 Examples for possible bent glass shapes, a) 1-axial bending, b) 2-axial bending, c) Torsion

The possibility to use complex IGU shapes offers a maximum of design freedom and the option for new and innovative designs to the architect. Fig. 8 shows an example of a building contour where some of the IGUs had to be warped to fit the shape of the contour. In this case you need one of the edges of the IGUs to be bent out of plane resulting in a torsion like shown in Fig. 7 c).

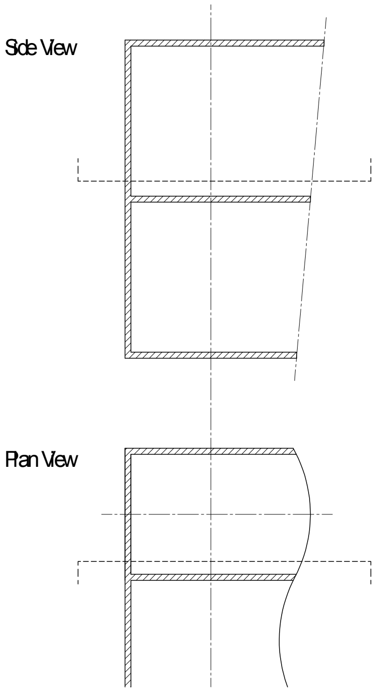


Fig. 8 Sketched contour for a façade with bent IGUs

Cold bending of the whole IGU leads to deformation of the edge compound. Because of the high difference in stiffness between a conventional spacer and the butyl gaskets, the butyl will see very high strains that might cause gas leakages. Ködispace 4SG is much more flexible and capable of assuring gas tightness even at high deformations. This makes a Ködispace 4SG a much better choice for these applications in comparison to conventional spacer systems.

4. Mechanical Performance

4.1. Glass Stress Reduction

Glass panes in IGUs of façades have to endure multiple impacts such as wind or thermal loads (due to expansion or contraction of the gas in the cavity) and pressure differences (e.g. between the production and installation site). A flexible edge seal can reduce the resulting stresses especially those resulting from relatively high or low pressure in the cavity. IGUs manufactured with a rigid spacer frame compensate pressure loads by deflection of the glass panes. An IGU with a flexible spacer frame can additionally compensate pressure difference by a widening or compression of the edge seal in order to reduce glass pane deflections and thus lower stresses in the glass. Fig. 9 depicts the ability of Ködispace 4SG to reduce the pressure difference between the cavity and the atmosphere through widening or compression of the edge compound.

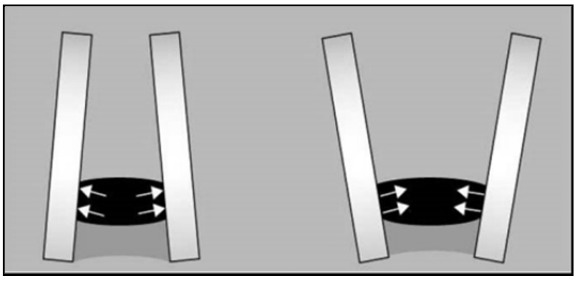
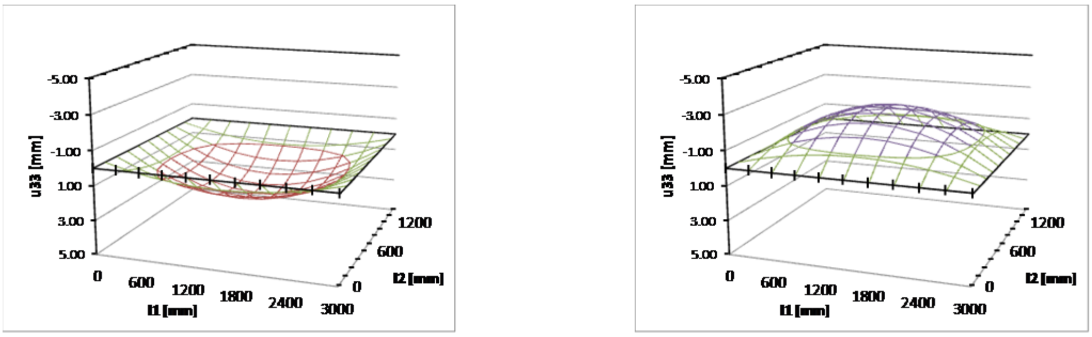


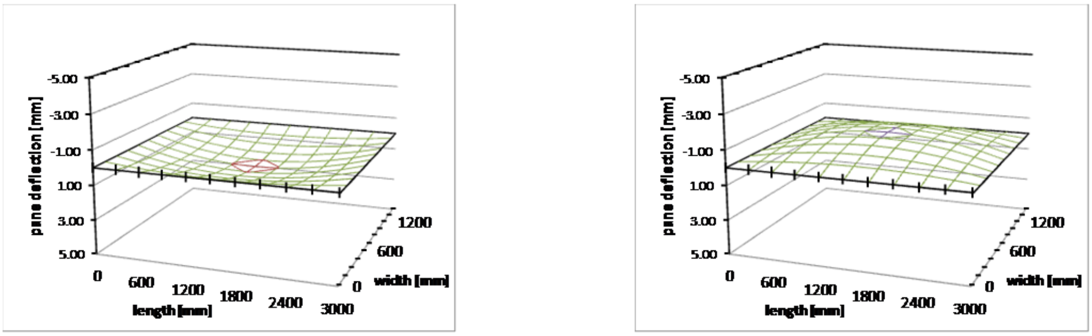
Fig. 9 Ködispace 4SG is capable to reduce the pressure difference

This effect is illustrated by the following example: Consider an IGU that is produced at room temperature and then exposed to -20 °C (-4 °F). The panes of this IGU will deflect due to the pressure difference. Fig. 11 shows the deformation of the glass panes (thickness 6 mm, 1500 x 3000 mm) of an IGU under the mentioned climatic loads with a thermoplastic spacer (Ködispace 4SG) and Fig. 10 shows the deformations for the same load case for an IGU with aluminum spacer (the inner space is in both cases 16 mm).



a) b)

Fig. 10 Deflection of IGU glass panes (1500 x 3000 mm) with aluminum spacer, a) ext. pane, b) int. pane

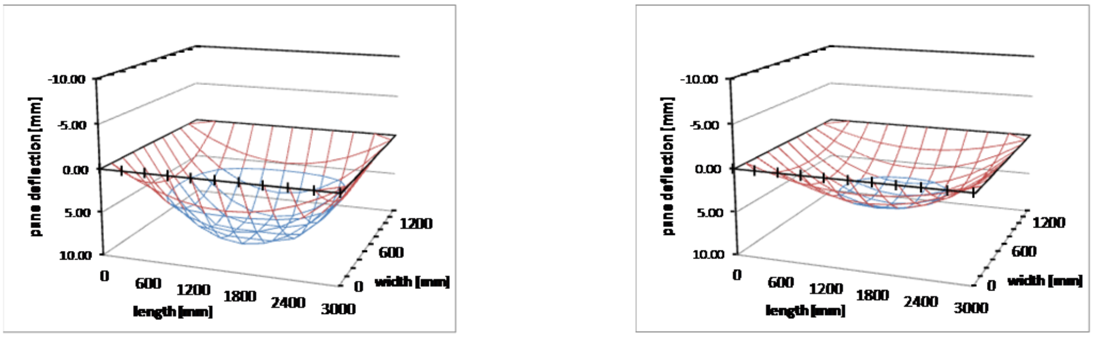


a) b)

Fig. 11 Deflection of IGU glass panes (1500 x 3000 mm) with Ködispace 4SG spacer, a) ext. pane, b) int. pane

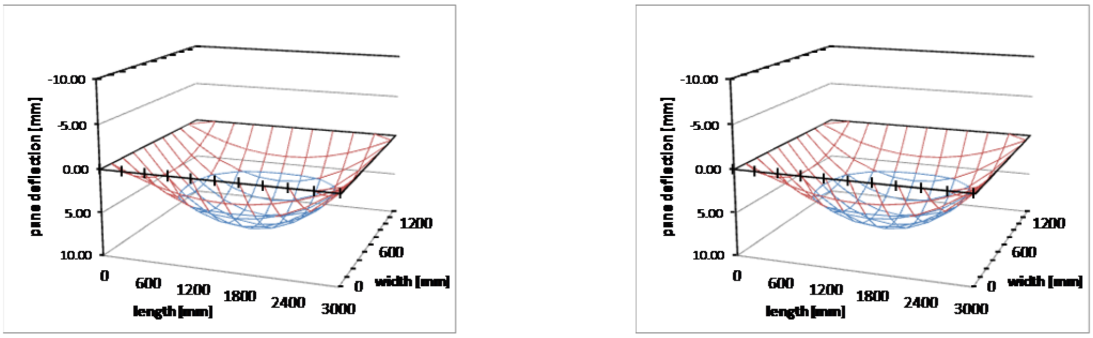
The glass deformation for this and all following examples is calculated based on the plate theory equations of Feldmeier (2003). The volume change due to elastic behavior of the edge compound is based on a linear elastic approach for the aluminum spacer (E = 73 000 MPa) and nonlinear elastic for the thermoplastic spacer (Ködispace 4SG). The results demonstrate, that the maximum deflection of the glass in the IGU with Ködispace 4SG is significantly (59 %) smaller than the deflection of the panes with aluminum spacer. Since the Kirchhoff-Love plate theory (Love 1888) is used to determine the deformation of the glass panes it is not possible to consider the deformation of the edges because they are assumed to be zero in this approach. Nevertheless a real IGU will show an edge deformation which will reduce the volume change caused by the deflection of the glass panes. A corresponding FEA analysis of the load case described above, that takes the edge deformation into account, gives 8 % smaller deflections and therefore lower glass stresses for both the thermoplastic and the conventional edge compound. This shows that the used analytical approach slightly overestimates the glass deflections. Since it overestimates the deformation of both IGU-edge-seals in the same way the comparison of the results is still valid.

Furthermore Ködispace 4SG also causes glass stress reduction in wind load cases. Consider a load case were the above mentioned IGU panes (1500 x 3000 mm, two 6 mm glass panes, width of cavity 16 mm) with a wind pressure at the outer pane of 0.47 kN/m². This wind-load corresponds to the pressure (or suction) caused by wind in zone 3 according to DIN 1055-4 (DIN Deutsches Institut für Normung e.V. 2005). Fig. 12 and Fig. 13 show the calculated glass deformation for an edge compound with conventional spacer and with Ködispace 4SG.



a) b)

Fig. 12 Deflection of IGU glass panes (1500 x 3000 mm) with aluminum spacer , a) ext. pane, b) int. pane



a) b)

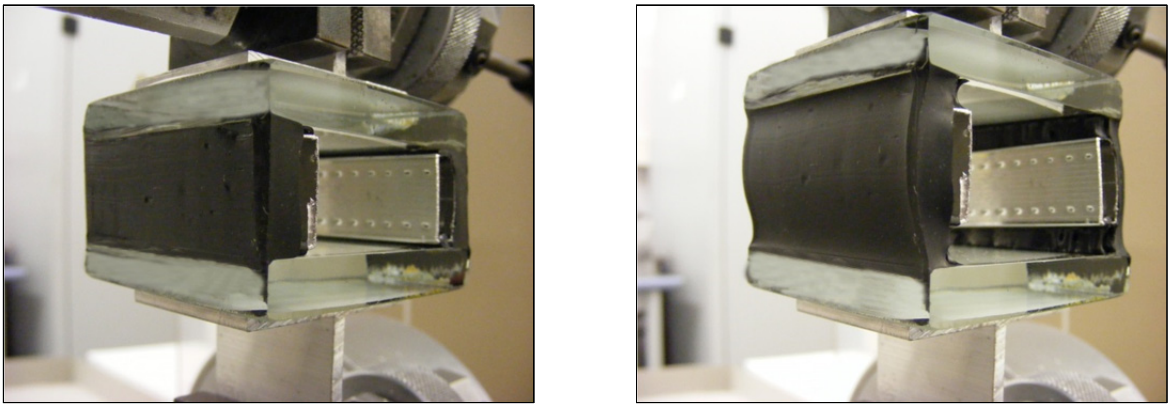
Fig. 13 Deflection of IGU glass panes (1500 x 3000 mm) with Ködispace 4SG spacer, a) ext. pane, b) int. pane

The calculation results show maximum deflections of 11.6 mm (external) and 6.5 mm (internal) for the conventional spacer vs. 9.0 mm (external) and 9.2 mm (internal) for the Ködispace 4SG spacer. The higher elasticity of the Ködispace 4SG edge compound leads to a higher pressure in the cavity which results in a distribution of the external wind pressure to both panes were else the external pane of the IGU with conventional spacer has to endure much higher loads than the internal.

The given examples show how Ködispace 4SG reduces the stresses both in pneumatic load cases and in load cases resulting from wind. It is obvious that this effect is even higher for a combination of these load cases. A reduced glass stress helps to achieve required design standards e.g. DIN 18008 (DIN Deutsches Institut für Normung e.V. 2010) or prEN 16612 (European Committee for Standardization 2013).

4.2. Durable Edge Compound

As mentioned before a Ködispace 4SG edge compound distributes stresses and strains where else a conventional edge compound shows local stress and strain maximums when deformed. Fig. 14 a) and b) show a conventional edge compound of an IGU model (width of cavity 12 mm) both before and after applying a load in normal direction to the glass panes.



a) b)

Fig. 14 a) Edge compound of an IGU model (undeformed), b) Edge compound of an IGU model after applying a load in normal direction to the glass panes

The applied load in Fig. 14 is much higher than the permissible load for this edge compound but it gives a good indication where the maximum strains are localized. The relatively high stiffness of the metallic spacer forces the butyl primary sealant to endure all the strains.

To quantify these strain maximums an optical 3D deformation analysis of the edge compound has been performed. Therefore a stochastic pattern is applied to the surface using a color spray which is then tracked with a stereo camera system to derive a 3D surface model and the major strains on the basis of digital image correlation (measurement System used: GOM ARMAIS (Gom.com 2015)). Fig. 15 shows the results of this measurement at a distance of 14 mm between the glass panes (Δl = 2 mm, l0 = 12 mm).

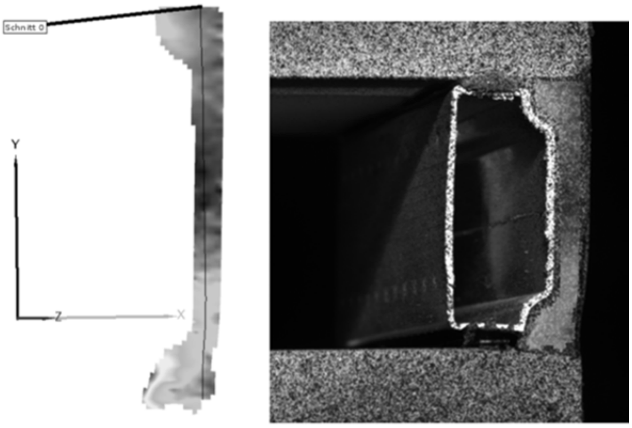
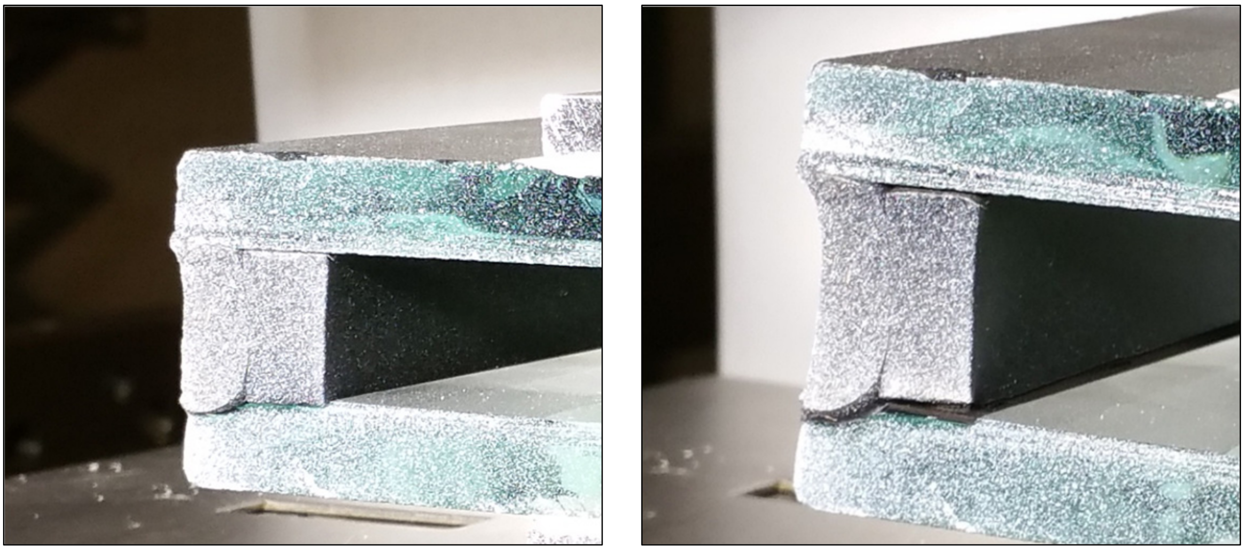


Fig. 15 Edge compound of an IGU model after applying a load in normal direction with stochastic pattern and derived major strains

The deformation state shown in Fig. 15 shows significant higher strains in the edges of the secondary sealing compared with the mid areas of the edge compound cross section. The primary sealing at this state is already damaged and therefore not trackable any more. To compare a Ködispace 4SG edge compound with the shown results for a conventional spacer, these measurements have been repeated with a Ködispace 4SG edge compound. Fig. 16 a) show the undeformed and Fig. 16 b) the deformed test specimen.



a) b)

Fig. 16 a) Ködispace 4SG edge compound of an IGU model (undeformed) with stochastic pattern,
b) Ködispace 4SG edge compound of an IGU model after applying a load in normal direction to the glass panes with stochastic pattern

It can be observed that the deformation of Ködispace 4SG and the whole edge compound in Fig. 16 b) is much smoother than the deformation of the conventional edge compound (with aluminum spacer) in Fig. 16 b). Furthermore one can see that the Ködispace 4SG has still adhesion to the galls surface even at the shown high strain level.

The Results from the 3D deformation analysis for the Ködispace 4SG edge compound are depicted in Fig. 17. It shows the IGU test specimen with Ködispace 4SG edge compound when the distance of the glass panes is 14 mm (Δl = 2 mm, l0 = 12 mm) which is the similar deformation state to the results shown in Fig. 15 for the IGU with aluminum spacer.

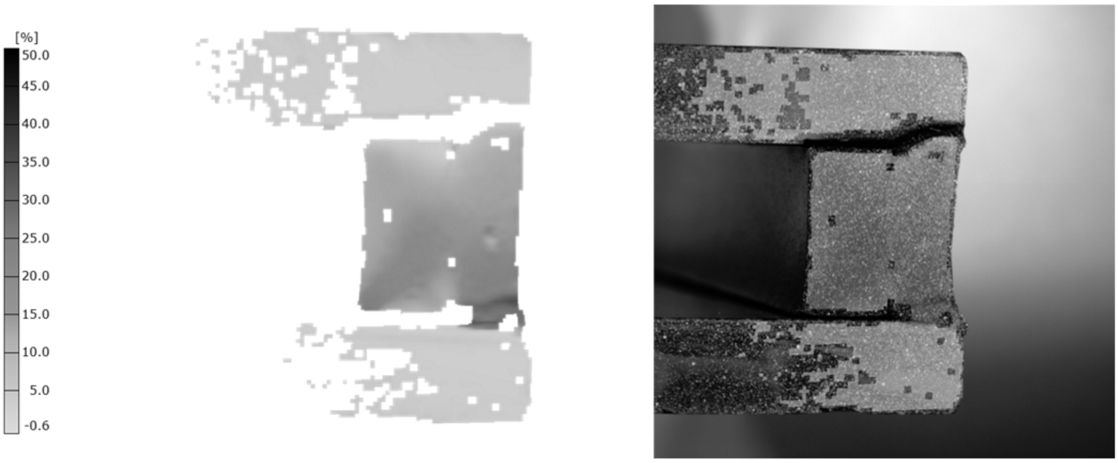


Fig. 17 Ködispace 4SG edge compound of an IGU model after applying a load in normal direction with stochastic pattern and derived major strain

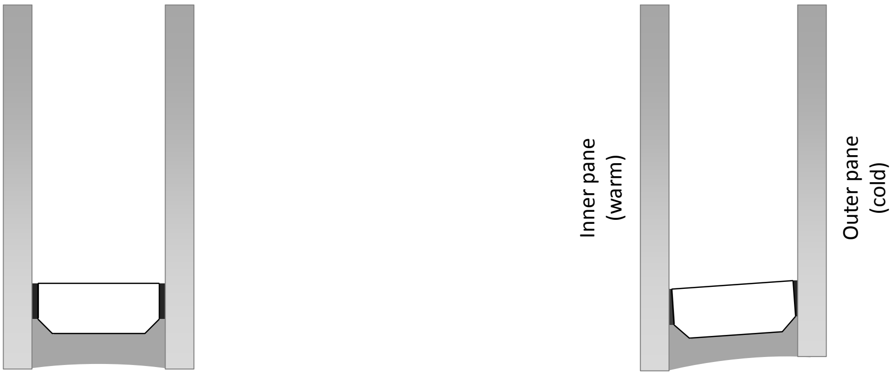
These measurements show the significantly different stress and strain distribution within the edge compound of a conventional spacer compared with a Ködispace 4SG edge compound. The stresses and strains in a Ködispace 4SG edge compound distribute over the whole material (both the primary and secondary sealing) and therefore ensure a maximum of gas tightness and mechanical strength. On the contrary a conventional spacer shows local stress and strain maximums which may cause damage especially of the primary sealing material.

4.3. Improved Δα-Tolerance

In all multi-material designs, differences in the thermal expansion of the components made from the respective materials result in stresses or deformations, when the system is exposed to temperature variations (often called Δα problem). Temperature gradients within the system can add up even higher load levels.

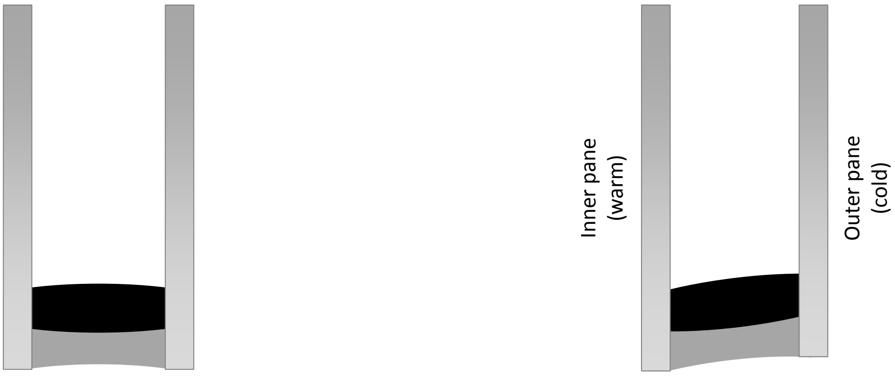
Within an IGU with rigid spacers usually the high-viscosity butyl primary sealant layers are the softest components, which compensate any movement of the much stiffer glass panes and spacer bars. This limits the feasible IGU geometry, as it often leads to leakages or bubbles in the butyl gaskets. In other cases, the butyl is even pressed out by the mechanical stress into the cavity of the IGU.

A flexible spacer has a much higher volume for compensation of movements as it acts as an integral connection between the glass panes. Displacements caused by different thermal expansions are well distributed over the whole inner space and therefore result in much lower stresses in all components and much lower strain within the gas barrier. Therefore, Ködispace 4SG is much more robust towards thermal expansions or contractions within the IGU system. Fig. 18 shows the deformation of a rigid spacer (e.g. with metallic spacer) caused by different thermal expansion of the inner and outer glass pane. The deformation causes high strains in the butyl primary sealant, which might cause cracks and leakages. Fig. 19 illustrates the deformation of an edge seal with Ködispace 4SG. The deformations are much more homogeneous which guarantees a maximum of gas tightness.



a) b)

Fig. 18 Deformation of an IGU with conventional spacer due to thermal expansion, a) undeformed, b) deformed



a) b)

Fig. 19 Deformation of an IGU with Ködispace 4SG spacer, a) undeformed, b) deformed

4.4. Investigation of the Behavior under Cold Bending and Torsion

To investigate the performance and time dependent response of a Ködispace 4SG based edge compound 1-axial-bending and torsion tests with two pane IGUs have been performed. Fig. 20 shows the test assembly for the torsion test of an IGU with two 4 mm glass panes and a width of the cavity of 16 mm and Table 2 shows the relevant technical data for the torqued IGUs.


a) b)

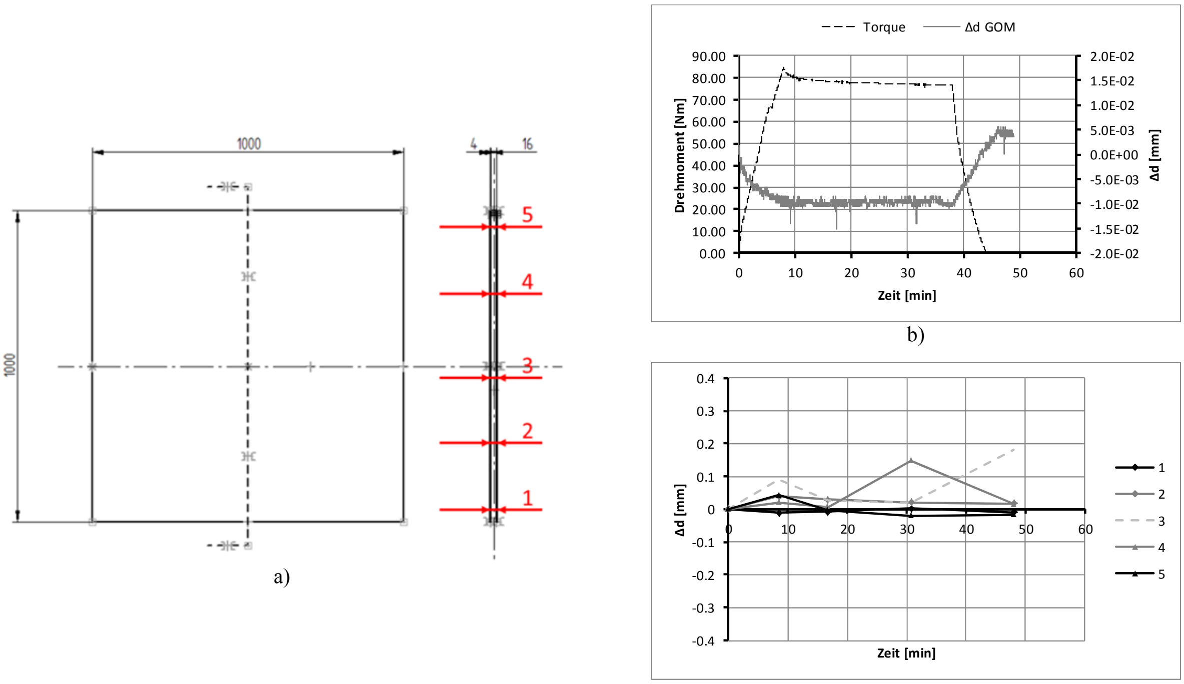
Fig. 20 Test assambly for the torsion tests with 1 000 mm x 1 000 mm IGUs;
a) no laod applied; b) M = 200 Nm

Table 2: IGU Data for the torqued IGUs

Constant	Value
width	1 000 mm
higth	1 000 mm
width of cavity	16 mm
gass filling of cavity	Argon
glas panes	both panes 4 mm toughened glass
secondary sealing	6 mm Kömmerling GD 920 D
primary sealing	7 mm Kömmerling 4SG

In these tests the 1 000 mm x 1 000 mm IGUs have been clamped on two opposing edges and then torqued in a tension torsion machine (Co. Zwick GmbH & Co. KG, Type Z010). In these tests the load has been held for 30 min at $\Delta l = 12$ mm (Δl being the normal distance of one corner to the plane defined by the three other corners of the glass pane) to investigate the behavior over time. During the test the torque and the thickness of the free edge has been measured. The thickness in the middle of the free edge has been determined using the 3D deformation analysis camera system (Co. GOM mbH, Type Aramis) described in chapter 4.2. Further on at four more positons distributed over the free edge (cf. Fig. 21 a)) using a micrometer.

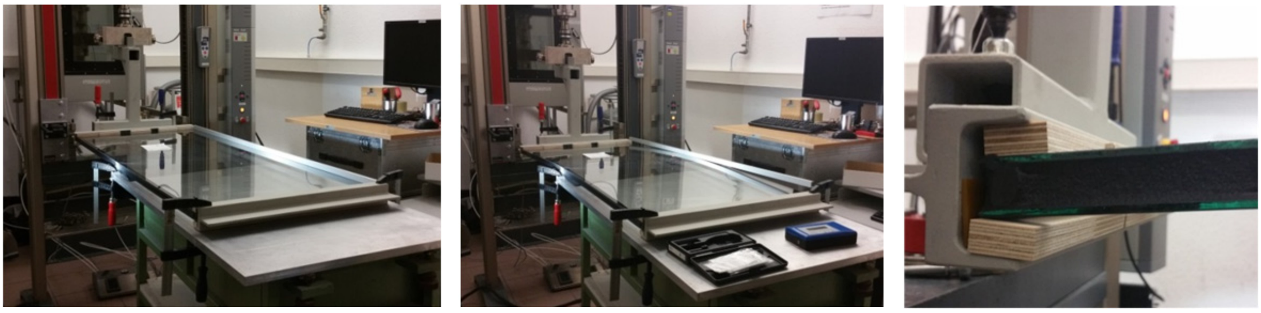
Fig. 21 b) shows the torque and the change in thickness in the middle of the free edge over time. During applying of the load it shows a decrease of just 0.01 mm (≈0.06 % of the undeformed width of the cavity) and stays constant over the holding time. The measuring with the micrometer shows just changes within the measuring tolerance (cf. Fig. 21 c)).



a) b) c)

Fig. 21 Test results of the torsion test with IGUs Δl = 12 mm
a) geometry and position of measuring point
b) Troque and change of thickness over time (GOM System)
c) Change in thickness over time measured with the micrometer

Analog tests have been performed for a 1-axial bending load case. The test assembly is shown in Fig. 22 and the technical data of the used IGUs are shown in Table 3. The 1 500 mm x 600 mm IGUs have been bended over the longer site. The short edges have been clamped in a u-profile. In the middle of the pane a round steal bearing (Ø = 20 mm) has been placed. One of the bended edges was pushed downwards using the same universal testing machine that was used for the torsion tests. This assembly results in a load situation that is analog to a three point bending test. Fig. 22 b) shows the bended IGU and Fig. 22 c) depicts the clamping of the free edge. The chosen load for this test is Δl = 25 mm (Δl being the normal length that one edge was pushed out of the surface defined by the opposing edge and the middle of the glass pane). This is equal to the maximum deformation that is allowable according to UK standards.



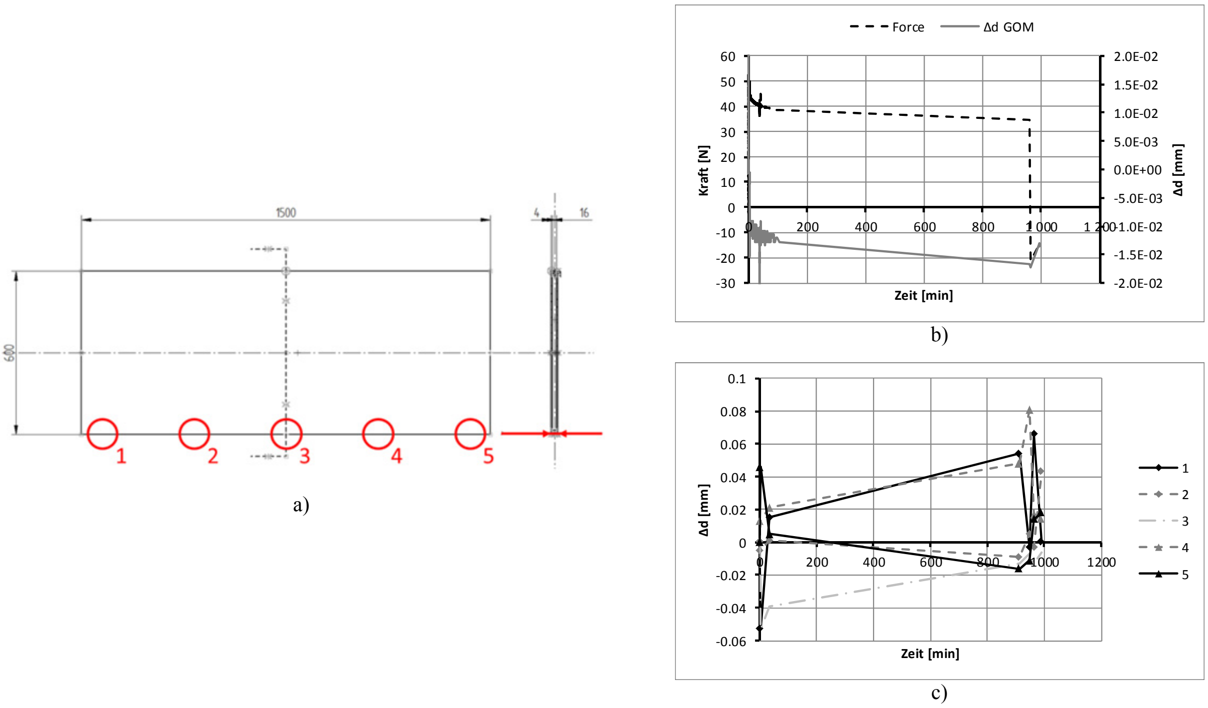
a) b) c)

Fig. 22 Test Assembly for the 1-axial bending tests with 1 500 mm x 600 mm IGUs;
a) no laod applied; b) Δl = 50 mm c) clamping of one edge @ Δl = 50 mm

Table 3: Technical data of the IGUs used for the 1-axial bending tests

Constant	Value
width	600 mm
higth	1 500 mm
with of cavity	16 mm
gass filling of cavity	Argon
Glas Panes	Both panes 4 mm toughened glass
Secondary Sealing	6 mm Kömmerling GD 920 D
Primary Sealing	7 mm Kömmerling 4SG

The results for this test (cf. Fig. 23) show similar deformations compared with the results of the torsion tests. Similar to the torsion tests the measurements with the micrometer show no quantifiable change in thickness (cf. Fig. 23 c)). Therefore only the 3D deformation analysis is capable to deliver a digestible result. The maximum deformation is lower than 0.01 mm which is less than 0.07 % of the undeformed thickness of the edge compound (cf. Fig. 23 b)). The trend of the deformation curve indicates that the relaxation of the edge compound has not ended after the measuring time. Since it grows quite slowly and the applied loads are much higher than allowable for the glass panes in a permanent load case it is not to be expected that this becomes critical.



a)

b)

c)

Fig. 23 Test results of the torsion test with IGUs Δl = 25 mm
a) geometry and position of measuring point
b) Troque and change of thickness over time (GOM System)
c) Change in thickness over time measured with the micrometer

Both, the 1-axial bending and the torsion test show nearly no change in thickness of the cavity. The change is much lower than 0.1 % while the applied load is at the maximum or even higher than the allowable deformation of the glass. For example the German technical standard TRLV (DiBT 2006) allows just a maximum of l/200 for the bending of a glass pane (l being the length of the bended edge). British standards (BSI 2011) allow l/60 the applied load in Fig. 23 is equal to that. The fact, that the change is not even measureable with a micrometer illustrates that the edge compound is capable to resist the loads from cold bending or torsion of an IGU.

5. U-Value Reduction

5.1. Warm Edge System

Warm edge has become synonymous for thermally improved edge sealing of IGUs. While conventional aluminum or steel spacers are forming a thermal transmission “short circuit” in the edge seal of the IGU, a state-of-the-art warm edge spacer reduces this thermal bridge by use of materials with a significant lower thermal conductivity (see Table 4). Therefore, the edge of the IGU remains warmer at the inner side in wintertime. As a result the inside condensation on the glass edge is greatly reduced and the comfort of the interior is improved. Furthermore the thermal transmission coefficients of windows and facades are reduced.

Table 4: Examples of the thermal conductivity of materials according to EN ISO 1007-2 Annex A

Material	Thermal conductivity λ [W/(m K)]
Aluminum	160
Steel	50
Stainless Steel	17
Glass	1
Polysulphide	0.4
Silicone	0.35
EPDM	0.3
Ködispace 4SG	0.3

Beside the (warm) edge, there are other properties of the IGU, which improve the thermal transmittance of the glazing in the façade. The low emissivity coatings have by far the highest effect followed by the Argon or Krypton gas filling. The effect of the warm edge has, compared to these, the lowest contribution to the U-value reduction of the IGU (see Fig. 24).

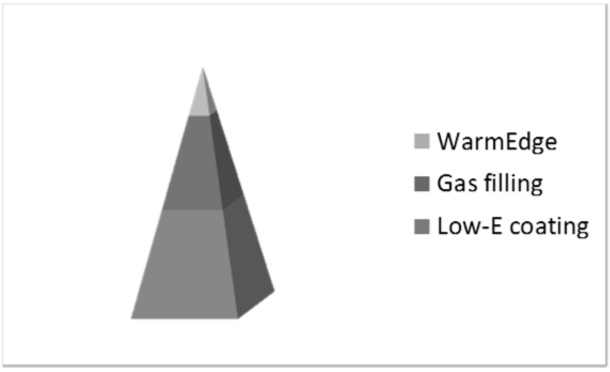


Fig. 24 Contribution to the U-value of double or triple glazing units

In the recent past, with a Ug value of 2.0 W/(m² K) or even without coating of 3.0 W/(m² K), the contribution made by warm-edge systems was minor. But in times, where the Uw values of windows are in a range of 1.1 W/m²K, or for triple glazing even of 0.8 W/(m² K), this contribution becomes significant. The improvement is between 0.1 and 0.2 W/m²K, depending on the glazing type, which is a roughly 10 % improvement for a whole window/façade. Regarding the Ψ-value, thermoplastic spacer systems like Ködispace 4SG are among the best warm edge systems on the market (see Table 5).

Table 5: Comparison of the PSI values of different spacer systems for a metal window with thermal break (Bundesverband Flachglas 2008)

Spacer Material	Representative PSI values [W/(m K)]	
	Double glazing	Triple glazing
Aluminum	0.111	0.111
Stainless Steel	0.061 - 0,068	0.057 - 0.066
Hybrid system stainless steel / plastic	0.037 - 0,050	0.033 - 0.045
Butyl based	0.045	0.040

Nevertheless, for a spacer system - especially with silicone as secondary sealant - beside the Ψ-value the gas tightness is mandatory to achieve certain energy ratings with reliable durability.

5.2. Durability

Initial type tests according to EN 1279 part 2 & 3 or the ASTM 2188 & 2190 standards are the minimum requirements for durability for IGUs in fenestration. In order to prove the long term durability of the Ködispace 4SG-system, especially for the usage of IGUs in the façade and at higher service temperatures, extended internal test programs have to be done. For example, the gas tightness of the flexible thermoplastic spacer system Ködispace 4SG in combination with structural glazing silicones has even been proven after running subsequently the EN 1279 climatic load cycle multiple times (see Fig. 25)

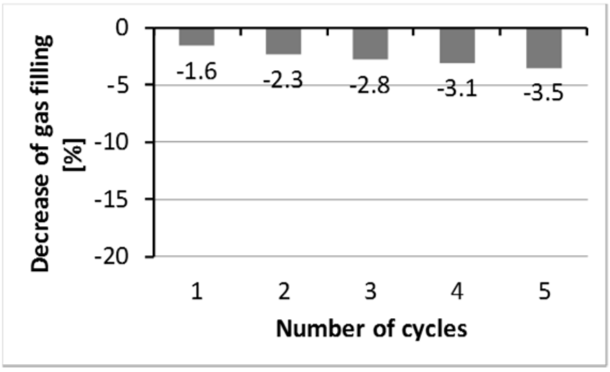


Fig. 25 Decrease of Ar-content after multiple EN1279p2 climate loads

In addition, these tests were repeated by an independent test laboratory with perfect results (National Glass Quality Supervision and Inspection Center). Even after the last of the five climate cycles, dew point is still below -40 °C, moisture penetration index below 13 % and the gas content is still above 89 % of Argon (see Table 6).

Table 6: Test Results after multiple cycling acc. EN1279 p2

	Dew Point [°C]	Moisture Penetration Index I [%]	Argon Concentration [%, V/V]
Initial	< -40	-	93.4
After 1. Run	< -40	2.86	92.5
After 2. Run	< -40	4.63	91.6
After 3. Run	< -40	5.30	90.8
After 4. Run	< -40	10.18	90.1
After 5. Run	< -40	12.12	89.3

For the higher service temperature range, a climate cycle from -20 °C up to +80 °C combined with high humidity of 95 % r.h. at the hot part of the cycle (see. Fig. 26, one cycle is 8 hours, 3 cycles per day), or from +23 °C up to +100 °C/dry has been chosen in other tests.

Even after a test duration of more than one year (actually, 64 weeks = 1344 cycles !) for the -20/+80°C-cycle, the test units are still moisture and gas tight and show no adhesion loss of the Ködispace 4SG.

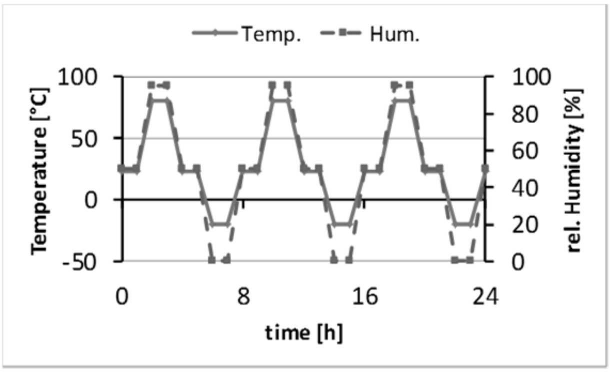
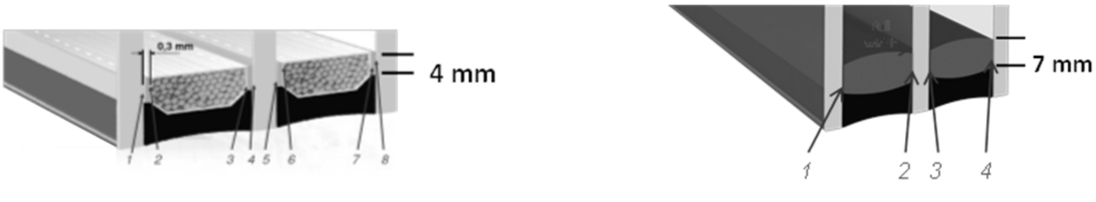


Fig. 26 Temperature cycling from -20 °C up to +80 °C at 95 % r. H.

Beside these many reasons, like the fully automated application of the spacer with the perfect tightness around the entire perimeter, the physical and chemical properties of the Ködispace 4SG, the outstanding durability is as well based on the unique design of the edge seal system. The key factor is the reduction of the number of boundary layers (compared to other conventional spacer systems) by half (see Fig. 27). These boundary layers contribute most to moisture vapor and Argon diffusion/permeation.



a)

b)

Fig. 27 Number of boundary layers and diffusion/permeation pathways a) conventional b) Ködispace 4SG

6. Conclusions

Ködispace 4SG allows the standard production of gas filled IGUs for façades with a silicone secondary sealant creating a new standard for durability in high-end thermal insulation. Structural glazing façades with best Ψ- and Ug-values are now available with reliable long-term performance. Furthermore a Ködispace 4SG edge compound guarantees a better mechanical performance as shown in the mentioned measurements and calculations. The high elasticity of Ködispace 4SG combined with a maximum of adhesion results in reduction of the glass stress and ensures gas tightness. All these advantages provide a greater design freedom and make more advanced constructions feasible. Those who want to be at the fore of these market developments should put the appropriate fenestration and façade products in place. This will enable you to match every increasing requirements and more stringent energy requirements of tomorrow.

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