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An innovative Insulating Glass Unit

Albert Vidal
Strain Engineering (Bellapart Group),

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Abstract

The new Silken Hotel in London business and financial centre introduces a new challenge in architectural glass applications. The production of a 2.5 m high, 2 m width corner shaped Insulating Glass Unit (IGU) consisting of two leaves joined at 90º using an absolutely transparent mitred joint.

This paper describes the design and engineering of this innovative product emphasizing on stages which have been decisive to obtain a reliable product.

Long term integrity against moisture penetration, a key factor due to the lack of spacer inside its vertical joint, is solved trough an intense and creative conceptual design.

Manufacturing and installation steps trivial for conventional IGUs have been proved to be critical for this application. The solutions adopted are illustrated.

Introduction

Having a transparent corner using monolithic or laminated glass panes is not a big issue. Having an insulated corner using two conventional IGUs at 90º is neither one. Having both things, insulation and transparency, is possible since time ago through glass curving technology. The difficulties arise when insulation and transparency have to be combined with a sharp edge on the corner.

This is the starting point of a long design and engineering process which combined this unusual specification with the following ones:

- IGU general dimensions: 2525 mm high, 950 mm width (each leave), corner of 90º.
- Wind loads according to BS 6399-2:1997 [1]. Obtaining a maximum wind suction of -1566 N/m^2 and maximum wind pressure of 1347 N/m^2 (SLS loads).
- Internal loads (climatic loads and altitude loads) according to prEN 13474-1:1999 [2]. Considering the installation site was far from production facilities located in Logroño (Spain), transport had to be carefully checked to ensure that during the whole itinerary the altitude load would be smaller than the one after installation.
- IGU thermal transmittance equal or smaller than 1.9 W/m^{2}K
- Dark fritting along it's whole perimeter to hide window framework
- Two vertical strips of fritting simulating acid etched to hide the 2400 mm high cold cathode lights located close to the glass next to window lateral vertical edges.

This paper describes the development of this bespoke product which ends with a corner shaped IGU without spacer on its mitred joint which as built composition and properties are as follows:

6 mm Low Iron Heat Strengthened + 1.5 mm PU AG8451 + 6 mm Heat Strengthened
Variable width RAL 9005 fritting strip hiding IGU framework on face #2. Sunergy Clear on face #4. Acid etched fritting vertical strip on face #4.
16 mm thick air layer
6 mm Low Iron Heat Strengthened + 1.5 mm PU AG8451 + 6 mm Low Iron Heat Strengthened
Thermal transmittance: 1.9 W/m^{2}K (BS EN 673:1998 [3])
Light transmittance: 62% (BS EN 410:1998 [4])
Energy transmittance: 43% (BS EN 410:1998 [4])
Solar Factor: 48% (BS EN 410:1998 [4])

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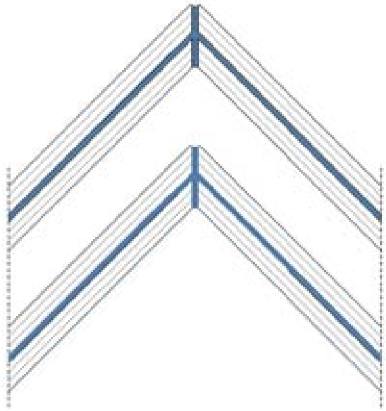

Figure 1 IGU mitred joint as built section

Figure 2 IGU corner internal view

Conceptual design

Omitting the spacer on the corner gave a chance for transparency but at same time threatened IGU's integrity against moisture penetration. The main goal of this stage was to ensure integrity against moisture penetration even for unpredictable scenarios. Many designs were studied and rejected before getting it.

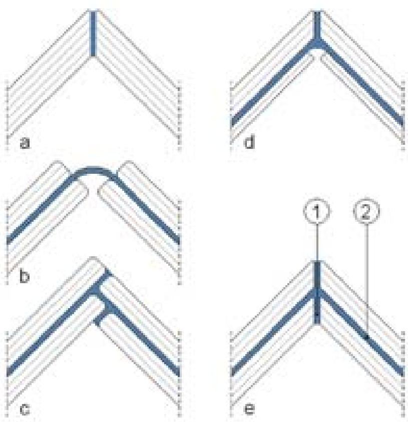

Figure 3 Several mitred joint concepts including solution finally adopted.

Alternative shown on figure 3a was rejected due to it's poor reliability. Although choosing the adequate material (UV resistance, rigidity, admissible stress and strain, peeling resistance, etc) it gave a weak protection against moisture penetration and any small flaw on the material generated before or after IGU installation would have ended on condensation into the air chamber.

Alternatives shown on figures 3b, 3c and 3d had a safer moisture barrier but they were rejected due to lack of transparency.

On the final design (shown on figure 3e) a double moisture defence line was provided. In case in any unpredicted scenario loads on mitred joint interlayer vertical strip (N1 on figure 3e) were higher than admissible and this strip was peeled off, the continuous interlayer (N2 on figure 3e) would have remained on its position preserving air chamber tightness.

Material selection

After an exhaustive search inside glass interlayer and acrylic foam tape fields, five products were selected for further analysis: 3M VHB, PVB, EVA, SGP, PU AG8451 (Polyether Aliphatic Polyurethane).

From these options SGP and PU AG8451 were selected for testing due to it's mechanical properties, good resistance to UV radiation and low permeability to water vapour.

Although general properties were given by suppliers, resistance to centred and eccentric tensions had to be calculated through experimental testing (see figure 4). Results obtained showed that primers application did not significantly increased resistance but significantly reduced the dispersion of results.

As an example, values obtained for SGP under eccentric tension were in the range from 19.1 MPa to 20.5 MPa when primer was applied and from 14.9 MPa to 21.7 MPa when primer was not used. (Load increasing at 5 mm/min until the end of the test).

Both, SGP and PU AG8451 were accepted for mock-ups production.

Figure 4 Material resistance testing

Numerical verifications

While glass panes dimensioning had no special difficulties, an intense work was necessary on mitred joint numerical verification. For this purpose both bi-dimensional and three-dimensional finite element models were used obtaining, as it was expected, big differences on joint stresses depending on interlayer's rigidity. For high rigidities (SGP, 1 minute, 20ºC, E=280 MPa) the maximum principal stress generated on the interlayer was of 30 MPa. For medium rigidities (SGP, 1 minute, 50ºC, E=12 MPa) this stress decreased to 22 MPa. Best results were obtained for low rigidities (Around 0.5 MPa. PU AG8451 datasheets give a Young Modulus of 0.06 MPa for strains smaller than 10%) which reduced the maximum principal stress to 4 MPa.

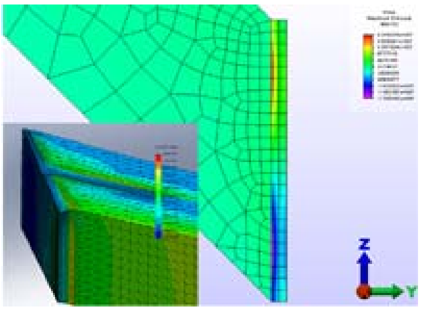

Figure 5 2D and 3D mitred joint FEM

Bespoke production process

This singular IGU required the design of a bespoke production process which most remarkable characteristic was the need for two autoclave cycles.

During first autoclave cycle left hand and right hand leaves were separately laminated taking care interlayer exceeded the mitred edge. Figure 6a shows cleaning and inspection of pre-processed (edge chamfered, coated, fritted and heat strengthened) monolithic glass panes before lamination. Figure 6b shows interlayer cutting. Interlayer excess was cut at all edges as usual except on mitred edge where exceeding interlayer was folded facing outwards onto glass edge surface. Best results were obtained for 8.5 mm excess (8.5=6/sine 45º. Edge of 6 mm glass pane cut at 45º).

During second autoclave cycle left and right hand leaves were laminated together forming a single unit (see figure 6c). Using a 90º mould where mitred joint thickness was controlled, 8.5 mm interlayer excess which on both leaves was folded on glass edge surface facing outside, was uniformly distributed over the whole 19 mm width surface of laminated pane edge (19=6+1.5+6/sine 45º). Non-stick materials were used on mould to avoid corner damage.

Following these steps twice, inner and outer laminate panes were ready and insulating glass unit was able to be formed.

Due to it's corner shape cleaning automatic lines couldn't be used after second autoclave cycle and consequently manual cleaning procedures using artificial back light had to be designed (see figure 6d). Once first units were produced this step was identified as one of the most critical ones.

As for cleaning lines, after second autoclave cycle conventional handling devices were no longer working and customized tooling was developed (see figures 6e to 6h).

Once outer and inner panes were produced double glazing phase started. Figures 6e and 6f show this stage where handling devices had the main role.

Finally, figure 6g shows some units waiting for perimetral seal curing before being turned into their vertical position for packaging and transport (see figure 6h). Horizontal transport was rejected to avoid the induction of stresses on the mitred joint from IGU self weight combined with vertical or horizontal vibrations.

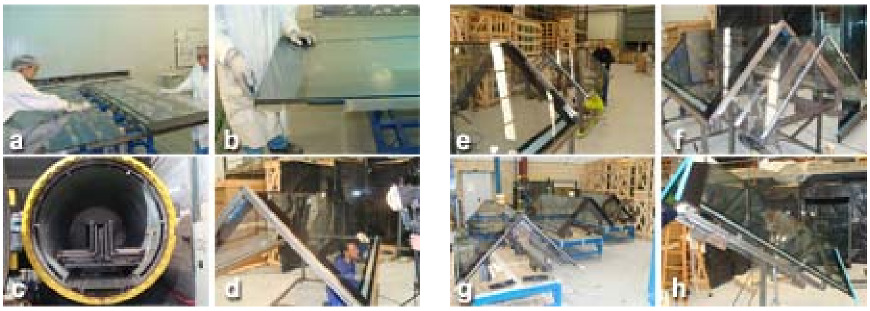

Figure 6 IGU bespoke production process steps.

Preliminary tests

Once production process was designed and all necessary customized facilities were ready, real size mock-ups using SGP and PU were produced obtaining high quality joints for both.

Using bespoke manipulation devices and controlling every single step to avoid any damage on the joint, IGU mock-ups were bonded on it's aluminium frame which at it's time was bolted to an steel framework. This gave an stiff unit which was erected on an outdoor testing facility reproducing onsite conditions.

A close visual inspection revealed some small delaminations on SGP mock-up mitred edge which did not exist when IGU was frameless stored (see figure 7). On the other side PU mock-up did not showed any change or damage.

Figure 7 Delaminations on SGP mock-up's mitred joint.

This gave rise to an investigation which conclusion was:
- Even using the most advanced production technologies, the IGU steel framework had a certain dimensional error due to manufacturing tolerances. Measurements showed that deviations of corner's angle were in the range of ±0.3º.
- Similar tolerances were reached for the IGU itself. Measurements showed that deviations of corner's angle remained in the range of ±0.2º.
- The combination of both manufacturing tolerances gave a maximum difference in angle of 0.5º.

- Although small, this difference combined with the high stiffness of SGP generated high stresses on the mitred joint. While the continuous interlayer remained on it's position without any damage (N2 figure 3e), the transversal interlayer (N1 Figure 3e) could not resist the stress.
- Nevertheless, thanks to the chosen conceptual design, the IGU was safe despite these delaminations.
- On the other side, the mitred joint done in polyurethane, with it's lower elastic modulus, acted as a hinge able to allocate the small manufacturing tolerances.

Conclusions obtained from these preliminary tests were in agreement with calculation results that showed tensions up to 7.5 times higher for SGP. As a consequence polyurethane AG 8451 was the interlayer chosen for production.

Tests

During conceptual design a short cycle moisture penetration test with an accelerated ageing cycle of 3 weeks [5] was done to anticipate if SGP and polyurethane were suitable for the application. Results were positive for both and consequently first real size mock-ups were produced in both materials.

Once after preliminary tests polyurethane had been chosen, long term moisture penetration test was performed on samples laminated with PU AG8451 according to EN 1279-2:2003 [6]. After 4 weeks inside the climatic ageing chamber suffering 56 temperature cycles of 12 h passing from -18±2 ºC to +53±1 ºC and other 7 weeks inside the same chamber at +58±0.5 ºC and a relative humidity higher than 95%, results showed that the average humidity infiltration index for all test samples was inside the allowable range. Figure 8 shows a sample inside the ageing chamber.

Something which has to be highlighted from moisture penetration tests results is the considerably high initial humidity content detected on the silica gel desiccant. Analyzing the production process for this bespoke product and comparing it with the one for conventional insulating glass units, it can be stated that this high content on humidity is due to the long time which air chamber assembly requires. In the light of this finding special attention was taken on this production stage to reduce as much as possible the desiccant saturation ratio and allow for a reasonably high humidity absorption capacity.

Simultaneously to these tests the mitred joint was mechanically verified against impacts according to EN 12600:2003 [7]

Figure 8 Sample inside ageing chamber. Courtesy of APPLUS.

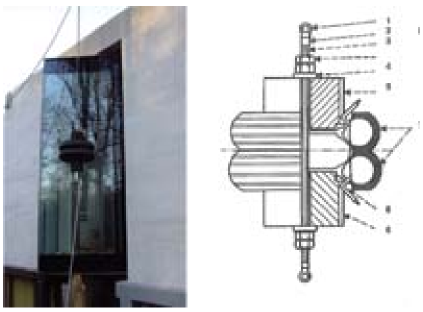

Figure 9 Impact test

Summary and conclusions

The paper has described the key development stages of an innovative bespoke corner shaped insulating glass unit consisting of two leaves joined at 90º using an absolutely transparent mitred joint.

This project corroborates that to success on the development of a new product all stages with no exclusion have to be carefully analysed. Operations such handling or cleaning, trivial for conventional and well known products, can become critical if not properly studied.

Figure 10 IGU onsite during façade erection.

Table 1 Project participants

Owner	Urvasco Ltd.	Pablo Couto
Architect	Foster & Partners	Giles Robinson, Nick Ling, Petra Hartmann
Façade engineering consultant	Arup Façade Eng.	Steve Bossi, Darren Anderson,
Project manager	IDOM	José Angel Fernández, Giuseppe Campaniello, Sergio Llamosas
Design and construction	Bellapart	Francesc Arbós, Albert Vidal, David Linares
IGU manufacturer	Rioglass	Félix Ainz

Acknowledgements

To all project participants detailed in table 1.

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