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Glued Wood-Glass Constructions of Windows
Aspects and details for evidence of suitability

Structural sealant glazing systems are one of the technologies of the future for the window industry. For the wood industry, this is a completely new technology, and as such requires an extremely precise workmanship and stringent quality assurance when it comes to the intended use and the durability of the bond. The current report summarizes important aspects of the design, the sealant and the production based on the current state of research and experience.

Klaus Peter Schober

1 Design Variety

1.1 Window development and wood-glass sealants

Essentially, the process of sealant glazing is not a new technology and has been successfully used for decades by the automotive industry, for example. In building construction and particular in facade construction silicone based glass-metal seals have been tried and proven technologies for structural glazing facade systems.

Although the process of bonding wood with glass is a new technology in the field of wood window construction, it is nevertheless a technology that was used previously, e.g. in single and casement windows where the window system is reinforced by the panes being glazed into the very slim casement profiles by application of putty around the perimeter of the glazing. As regards the technological development of wood windows featuring IGUs, only setting blocks are used to fix the position of the glass pane within the casement and this also provides a slight amount of reinforcement to the casement frame The disadvantage of blocking is the occurrence of point loads with the associated risk of peak stress and the resulting glass breakage. By bonding the glass, the loads can be linearly transferred to the glass, peak stress avoided and significantly higher loads transferred (see Fig. 1).

The first wood-glass window constructions in the 1990's were jointed only by mechanical means. As a result the design details were very complicated. In order to use the bonding technology, glass was later bonded onto metal adapters and mechanically fixed in the wood casement. In recent years, research into directly bonding glass to wood has progressed so far that first concepts have developed into designs which are ready to be marketed.

1.2 Why sealant glazing systems?

The question of why we need sealant glazing and cannot simply stick with the proven blocking systems can be explained using three examples:

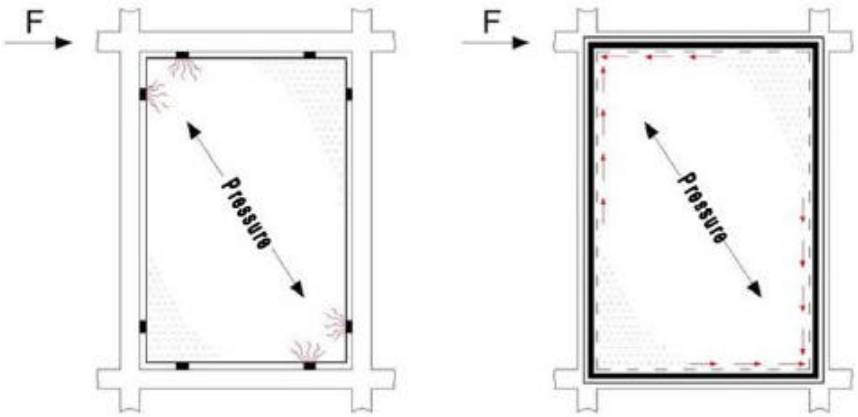


Figure 1
Load transfer to the glass

? Architecture:
A wood-glass window assembly offers the manufacturer the possibility of a completely new type of window design. The surfaces exposed to weathering are maintenance-free. This new design provides the window industry with the option of changing the way its customers perceive wood windows.

? Reinforcement:
The adhesive bond allows significantly higher loads to be transferred to the glass, and the glass pane itself to act as a form of reinforcement for the entire assembly. This, combined with the option of reducing the casement profile cross sections, is a decisive advantage given the trend toward increasingly large window units.

? Cost effectiveness
With the appropriate matching of materials and design and the use of advances in production technology the new generation of windows will be extremely cost effective.

For this forward-looking technology to gain market acceptance, however, it is crucial that the durability of the adhesive bond be assured. It is therefore vital that all aspects relating to the fitness for intended use and durability of both the adhesive bond and the entire window construction be given highest priority.

1.3 Glass positions

There are four main types of structural seal when glazing IGU into wood windows (see Fig. 2).

Furthermore, the sealant can be applied to the rebate platform. In this case, however, special care must be taken to ensure compatibility with the edge seal. Furthermore as a rule, only lower loads can be transferred due to the lower level of adhesive geometry.

1.4 Design variants

A wide variety of designs are feasible based on the possible positions of the glass bonds. Fig. 3 shows several examples.

Fig. 3a shows the bond of the IGU on the interior side of glass position 4, and the blocking of two glass panes. In this case the interior glass pane

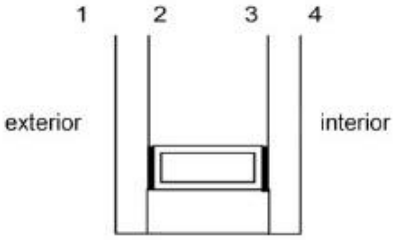


Figure 2
View of the glass positions

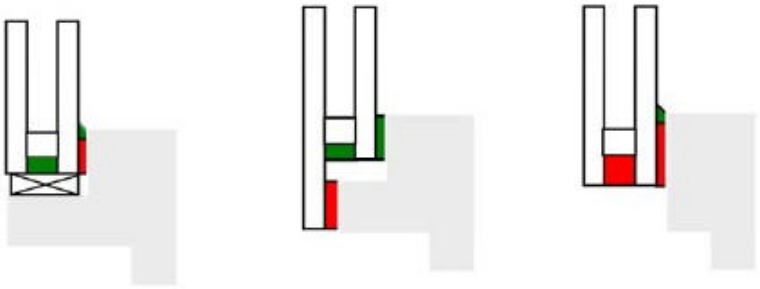


Figure 3
Design variants

reinforces the casement, while the existing blocks accommodate the load of the glass.

Fig. 3b shows a stepped insulating glass unit (IGU), which is bonded to the wood frame both at position 2 and at position 4. In this case the wood-glass bond has a double function: it reinforces the casement and transfers the load.

Fig. 3c shows an IGU, which is sealed to the wood frame on the room interior at position 4. In this case the wood-glass bond also has several functions: it reinforces the casement, transfers the load, and ensures the load transfer from the exterior pane to the interior glass pane through the structural edge seal (in acc. with EN 13022-1).

These three examples (to which numerous other variations could be added) show which structural aspects have to be taken into account when designing wood windows featuring sealant glazing systems. These structural aspects include in particular exposure of the window to negative and positive wind pressures, the reinforcement of the casement at the plane of the glass pane, and the load transfer of the dead weight of the glass panes. Most attention should be paid to the long-term behaviour of the adhesive bond (creep).

1.5 Type of opening and fall protection

The type of opening of the window and the position of the glass pane in the window frame may require additional measures to prevent the glazing from falling out. Inward opening windows whose glazing is secured by the overlap of the window frame (window profile) in the case of four-edge (or at least two-edge) linear support, do not require any additional fall protection. If the pane is not supported by the window frame (window profile), e.g., in the case of outward opening windows, the glazing system definitely requires fall protection.

There is an extremely wide variety of designs of sealant glazing systems in the field of wood window construction. This makes it exceedingly difficult to draw up generally valid design rules for every possible type of design. At present due performance of the existing designs can best be ensured by testing to the relevant criteria to ensure sufficiently long service life and fitness for the intended use of the adhesive bond and the entire window system.

Urs Uehlinger

2 The new way of bonding

Since the early 1990s research has been conducted in the field of bonding glass to wood. The primary idea underlying this research was to use the glass in structural wood construction as an additional loadbearing, reinforcing element. In these research projects it was mainly existing adhesive systems from other, related fields that were used. The main problems in evaluating the suitability of adhesives for glass-wood bonding

related to the lack of knowledge about the requirements for such sealants/adhesives. Various research projects and practical applications have since shed light on these requirements. Based on these findings, adhesives have been modified or new sealants have been developed for use in window construction in recent years.

The wide variety of possible window designs described in part 1 is reflected in the requirements for the adhesives used. Various properties are required depending on the task of the adhesive joint. To be able to judge which adhesive is best suited, there must be at least some knowledge of the window design. In evaluating the adhesive the window manufacturer must also know what he wants to achieve with the adhesive bond. It is not always the structural improvements that are the first consideration. The reinforcing effect of the adhesive bond in the pane level or the improvement of the flexural strength of the double casement centre section is frequently only a positive spin-off. The main focus may be on modifying the appearance and aesthetics of the window or the bond is useful for optimizing the production process and thus saves costs. A further aspect is that of possible material savings.

The result of these observations is a sophisticated profile of requirements for the bond. Due to the different performance characteristics, the various commercially available adhesives

Table 1 Parameters for evaluating a bond

Durability parameters	– temperature resistance – moisture resistance – water resistance – UV resistance – resistance against cleaning agents – elasticity – creep – adhesion on various materials – compatibility with surrounding materials (direct or indirect contact) – interaction of various parameters
Design parameters	– structural strength values – structural design values – elasticity (elastic, semi-elastic, rigid) – creep – etc.
Production parameters	– pot time, reaction time – time until further processing – ambient climate – application and mixing plants – quality of glue lines (quality of workmanship, coating, cleaning etc.) – jointing method (pressing, one-time pressing etc.) – etc.

meet these requirements to a varying degree. The properties of the adhesive and the bond can be broken down approximately as follows:

- properties relating to the durability of the bond,
- structural properties of the bond,
- properties relating to the processing of the adhesive in the production process.

The adhesives must be optimally adapted to the desired production process. It is generally not possible to process various adhesive systems without additional investment in the application systems. In some cases various adhesives may require that the substrates be pre-treated, which can lead to expensive adaptations to automated plants.

Various objectives can be pursued with regard to the structural properties (structural engineering). The pane plane may also be reinforced by using a relatively elastic adhesive (e.g. when bonding the rebate platform). However, the improved rigidity of a double casement centre section (deflection vertical to the pane plane) resulting from the adhesive bond, may also be positively influenced by a rigid adhesive. A rigid adhesive bond may therefore be required in a particular window system and be unnecessary or even undesired in a different window system.

Numerous parameters have to be taken into account in terms of durability. One major aspect is the position of the adhesive joint within the window construction. If, for example, the adhesive bond is at glass position 4, as a rule, there will be no likelihood of water accumulation. Furthermore any temperature peaks that might occur are substantially lower than they would be with bonds at positions 1 or 2. The picture is similar with UV-resistance. The adhesive applied to the rebate platform does not have to be fully UV-resistant.

Table 2 shows the groups of sealant/adhesive that are used in current window construction. The performance characteristics of these adhesives differ greatly in some cases. The same applies to those within one single group. Accordingly, it is not possible to select an adhesive without having at least some basic information on the window construction.

Conclusion: In window construction, no two adhesives are quite identical. They must be carefully selected in terms of performance requirements and integrated into the development of new window systems.

Table 2 Sealant/adhesive systems

Silicone	1-component and 2-component systems, liquid
Polyurethane	1-component and 2-component systems, liquid
Silane	1-component and 2-component systems, liquid
Acrylate	1-component and 2-component systems, liquid
PSA (Pressure Sensitive Adhesives)	1-component systems, adhesive tapes

Karin Lieb

3 The new window

3.1 What is particular about the production process of sealant window systems?

3.1.1 Fully automated production

The glazing process of sealant systems can be integrated into fully automated production systems. Mechanical engineering offers perfect solutions for all production phases: from length optimization when using laminated blanks, to profiling work, frame manufacture, surface treatment, equipping with hardware, and glazing based on the bonding process. The production line must be coordinated to the design and the

respective bonding system to be used. In wood window production a capacity of up to 400 windows per day is considered standard, for example, provided the process is running smoothly.

3.1.2 Automation of the glazing process

In addition to the extreme solution of fully automated production, partial solutions are also possible. Extending a conventional production process, casement frames and IGU are provided by the system and only the bonding process and the positioning of the glass are mechanically handled. Here too – as with the overall solution described above – the environment must be as dust-free as possible. A separate room for the storage of the IGU, the casement frames to be bonded and the bonding station, without any interfering influences, is a precondition here as well. Interfering influences include for example gas emissions from other chemicals, excessively high or low temperatures and humidity.

3.1.3 Methods of application used by the trade

The typical method of application using a cartridge or the process of gunning have proven unsuitable when tested. The outcome in terms of processing quality, consistency and completeness of adhesive spread and the way of application do not meet the visual and technical requirements for the bond. A manually operated guide of an automatic dosing device is conceivable, but requires very well trained personnel.

All described methods have one thing in common: they all require a quality assurance system. Factory production control (FPC) should, e.g. include the following regular checks: the bonding areas, the thoroughness of mixing of the adhesive and the adhesive tensile properties after curing. In the case of sensitive adhesive systems, an automated application system must provide for adjustment of the reaction times to ambient temperatures and humidity.

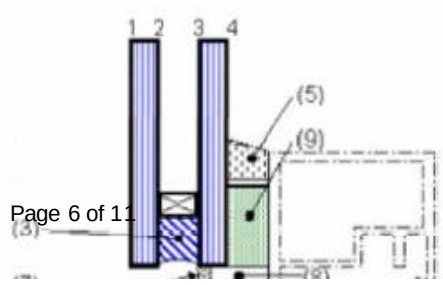
3.2 What considerations have to be taken in account with supplied products?

3.2.1 Insulating glass units

Depending on the constructional design of the window casement, the edge seal of the IGU performs either structural or weatherproofing tasks. The various types are shown in part 1 (Fig. 3) of this report. If the edge seal is designed to fulfil structural functions, the adhesives and the dimensions of the height of the edge seal are subject to the requirements of EN 3022-1. When the order is placed the IGU supplier must be informed on the further processing of their products.

What does this mean for the respective system?

As illustrated by the example shown in Fig. 4 the edge seal must durably accommodate the dead weight of the exterior glass pane. The function of the IGU (impermeability to gas loss and water penetration) must not be affected by permanent exposure to load. This means that the IGU sealant exposed to the exterior must be able to withstand increased temperature loads and, depending on exposure, UV radiation and environmental effects without incurring any damage. The creep behaviour of the sealant at increased temperatures must have been verified. Due to the effects of the loads on the bond the upstand or height h of the exterior adhesive joint must be calculated.



(3) structural seal in IGU – edge seal
(9) structural seal in glazing system (joint glass – frame)
(5) interior weatherstripping against water accumulation on the structural seal
h height/upstand of seal

Figure 4
Typical example of a glazing system with structural seals at position 4 and in the IGU – edge seal (positions 2 and 3)

3.2.2 Other products

Examples of other products are the adjoining sealing materials such as the sealing material on the interior room side shown in Fig. 4, as well as cover profiles, glass supports, weatherstripping, cleaning agents and similar. The products must be compatible with the structural sealants. A frequent change of supplier and/or materials always involves additional costs.

3.3 What are the implications for quality assurance?

Window casements with sealant glazing are part of windows which must be CE marked according to the European product standard. Since windows are subject to conformity level 3, factory production control (FPC) must be conducted. In this case, glazing technology deviates from the applicable technical guidelines. The production process considers bonding as a separate production stage. Assistance in introducing FPC

Table 3 Comparison of national building codes: Germany – Austria – Switzerland

Product/Characteristics	Germany	Austria	Switzerland
Conventional structural glazing system (facades, seal not retained in closed state)	Construction Products List B Part 1, no. 3.1, Provisions ETAG 002, Systems I and II	Construction Materials List OE, no. 3.1, Provisions ETAG 002, Systems I und III	Product liability of companies, Provisions ETAG 002
Glazing of windows	DIN 18545, Technical rules for glazing systems with linear support. TRLV and/or for safety barrier glazing TRAV	Federal and state law must be observed	SIGaB glass standards, SIA 331
National marking	Ü mark according to none Construction Products List A, Part 1, Line 8.5		none
Windows with deviating characteristics	Construction Products List A, Part 1, Line 8.5, National technical approval (ABP)	Evidence of suitability	none
CE marking	Product standard DIN EN 14351-1, 2-year transition period from harmonization up to CE mark	Product standard ÖNORM EN 14351-1, 2-year transition period from harmonization up to CE mark	is not mandatory for products placed on the market within a single country
Purpose of the ift guideline:			
Windows with sealant glazing	For scope and evidence according to ift guideline: CE marking possible (so far)	For scope and evidence according to ift guideline: CE marking possible	Evidence acc. to ift guideline recommended marking and/or Ü

for the bonding procedure is provided by various sources:

? Specifications regarding adhesives and processing is supplied by the adhesive manufacturer.

? EN 13022-2, glazing rules for structural sealant glazing, provides help in the form of check lists, divided into material control, assembly and finished product.

? The planned extension of the present draft guideline also contains recommendations regarding quality assurance, product certification of structural sealant glazing, and a quality management system integrated into the production.

3.4 The national building codes

The national building codes differ from country to country. Table 3 shows a comparison of the provisions for Germany, Austria and Switzerland.

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4 Creation of a basis for the assessment of sealant glazing systems

Building on previous research results and experience, ift Rosenheim, in partnership with Holzforschung Austria and SH Biel, has attempted to create a basis for assessing sealant glazing systems. This breaks down into two parts: first, evidence of bonding quality; second, evidence for the entire window system. The participating institutes want to make this first draft available to the industry in order to stimulate discussion. After completion of the discussion process this guideline should be published to represent a first means to provide evidence of suitability for sealant glazing systems in window construction.

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1980	Obtained university entrance qualification at the Leibniz-Gymnasium in Altdorf
1980 – 1981	First year of vocational training as joiner at Nuremberg Vocational School
1981 – 1982	Vocational training as joiner, obtaining qualification from the Central Franconia Chamber of Handicraft
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1983 – 1989	Studied for diploma in Wood Technology at Rosenheim Polytechnic University with work placements in metalwork and in interior conversion and mortarless construction
1989	Diploma in Wood Technology
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since 1998	Assistant lecturer at the Vienna University of Technology, Department of Structural Design and Timber Engineering
10/2000 – 03/2001	Interim Director of 'Holzforschung Austria'
1999	Laureate of the International Josef Umdasch Research Prize by the University of Natural Resources and Applied Life Sciences for excellence in the field of forestry and timber science
2003	ÖGUT-environmental award, category ‚sustainable, innovative corporate strategy in the IT-business' for the project www.dataholz.com

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– Timber Construction prize Vienna, Tyrol, Salzburg, Upper Austria
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1993 – 1997	Production Manager and Member of the Management in a Swiss medium-sized window manufacturing company
1998	Consultant of a window manufacturing company in Romania and of a Swiss Manufacturer of window scantlings
since 1999	Berne University of Applied Sciences, Architecture, Wood and Civil Engineering in Biel, Switzerland: Head of the Research Group Product Engineering Key activities and main focus of research: – windows, doors, building components, furniture – Head of testing laboratory for windows, doors and furniture – Collaboration with developing and emerging countries