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Merging Two Façade Types into a New Product: Glass Sandwich Panel

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Developed by seele for industrial and commercial buildings, iconic skin glass sandwich panel (GSP) is a novel glass panel façade that meets high-level design and economic demands. The idea is to merge two established façade products into a new one: The glass sandwich panel consists of an outer printed glass sheet bonded to a standard sandwich panel. This creates a glass exterior in the form of panels up to a height of 15 m. These huge formats allow architects to employ glass sandwich panels to create homogeneous and flush façade surfaces in glass. This paper discusses the structural testing and numerical verification of the glass sandwich panel with a main focus on the silicone bonding between glass and sandwich. Furthermore, an outlook is given how to integrate window and door elements flush with the façade surface.

Keywords: Sandwich, Façade, iconic skin, glass, silicone

1. Introduction

Seele has developed a new façade system combining two well established building products: sandwich panels and glass plies with a length of up to 15 m. The width depends on the sandwich panel and is typically 1 m. The sandwich provides the structural performance and provides excellent insulation values for the whole system. The glass plies are printed in any way imaginable (roller coating or digital printing). The result is an elegant glass surface at the exterior (figure 1) offering new design possibilities for building owners and architects. While the idea of bonding glass to the exterior face of a sandwich panel sounds easy at first, the challenges lie in the details and have been tackled with extensive testing, research and development. This paper presents key features of the product and provides additional information on the development of the glass sandwich panel.

Fig. 1 15 m long iconic skin glass sandwich panels presented at the international building fair BAU 2015 in Munich, Germany (photo © Olaf Becker/iconic skin).

2. Sandwich panels

Sandwich elements are well established and standardized through the European standard EN 14509. They consist of two metal skins at the external and internal side and an insulating core which is bonded to the metal skins. The core generally consists of non-flammable mineral wool or polyurethane (PUR/PIR). The former is slightly stiffer and offers excellent fire protection while the latter has its advantages in thermal insulation. The metal sheets, mostly galvanized steel with polyester or special coating, are either smooth, lined or profiled to provide a greater stiffness. The panel thickness varies typically from 60 mm to 220 mm. Figure 2 shows the general build-up.

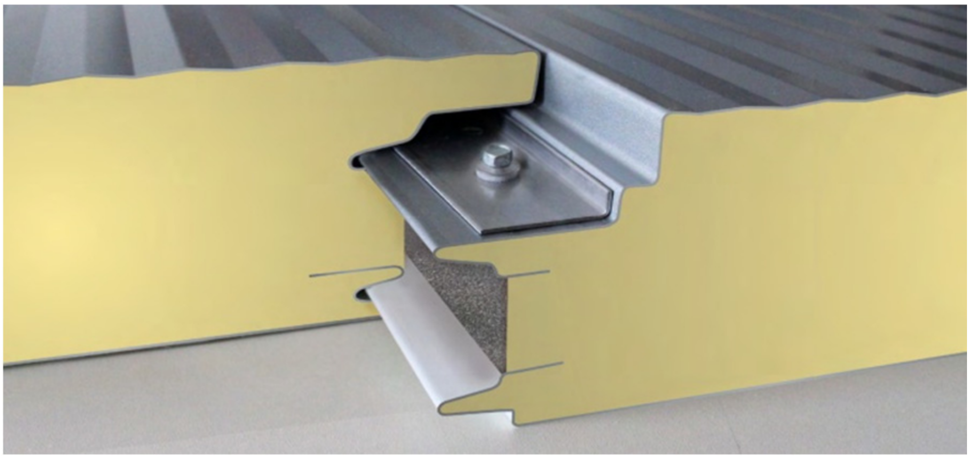

Fig. 2 Elevation through Brucha FP-P sandwich panel with PUR core, steel sheets and invisible fixation (special groove and tongue milling, and fixation clip for invisible fixing, © Brucha).

Sandwich panels are a durable and multi-functional building material, which offer excellent sound and thermal insulation, and fire protection with a mineral wool core. They are light in weight and easy to install. The construction type guarantees a rapid wall completion saving time and costs. Typical U-values are in the range of 0.15 and 0.35 W/(m^2K) depending on core material and thickness. The weight ranges between 10 and 40 kg/m^2 and depends on core material, core thickness and metal sheet thickness (typically 0.5 to 0.7 mm). Table 1 summarizes the main properties and shows the effect of a 6 mm thick glass sheet bonded to the sandwich panel.

Table 1: Properties of sandwich panels and influence of 6 mm thick glass panel

Physical property	Typical values for sandwich-panels with a core of		Approximate influence of bonded glass panel
	polyurethane	mineral wool	
U-value	0.1 – 0.35 W/(m^2K)	0.2 – 0.35 W/(m^2K)	almost no influence
Weight	10 – 20 kg/m^2	30 – 40 kg/m^2	+ 15 kg/m^2
Sound insulation	~ 25 db	~ 31 db	+ 5 db
Fire resistance	Euro class B-s2	Euro class A2-s1	almost no influence

Sandwich panels are used for many different wall and roof systems. They are loaded by static short-term loads (wind and temperature) or long-term loads (dead load and snow on roof panels). The temperature difference between the internal and external metal sheets result in out-of-plane deflections (curvature) and internal moments for statically undetermined continuous systems. The design and limit state verification is defined in the European standard EN 14509 which also describes the specifications for the factory made sandwich panels in detail. The technical approvals of sandwich panels in Europe (e.g. DIBt (2012), DIBt (2014)) are generally based on this standard. Further information regarding structural design of sandwich panels is also summarized in IFBS (2006).

3. Glass sandwich panel

The iconic skin glass sandwich panel combines a mineral wool or polyurethane sandwich panel with a heat strengthened glass sheet at the outer surface as illustrated in figure 3. The printed glass ply is structurally bonded to the external metal sheet with several linear joints of structural silicone over the whole length of the panel.

It is also possible to include openings and windows in the panel without a hidden, secondary structure in the opening area where the sandwich and windows are connected to (which is the typical solution for openings in normal sandwich panels). The current solution for openings in glass sandwich panels is based on work by Berner (2004), and the testing is currently in progress to validate the design. All window and door openings are fully integrated in the glass sandwich panel and feature a flush outer glass surface.

The glass sandwich panel needs less interfaces with other trades and appeals with a high degree of planning and budgeting reliability, especially considering the installation schedule. The prefabrication of the whole façade system minimizes erection time. The installation is shown in figure 4.

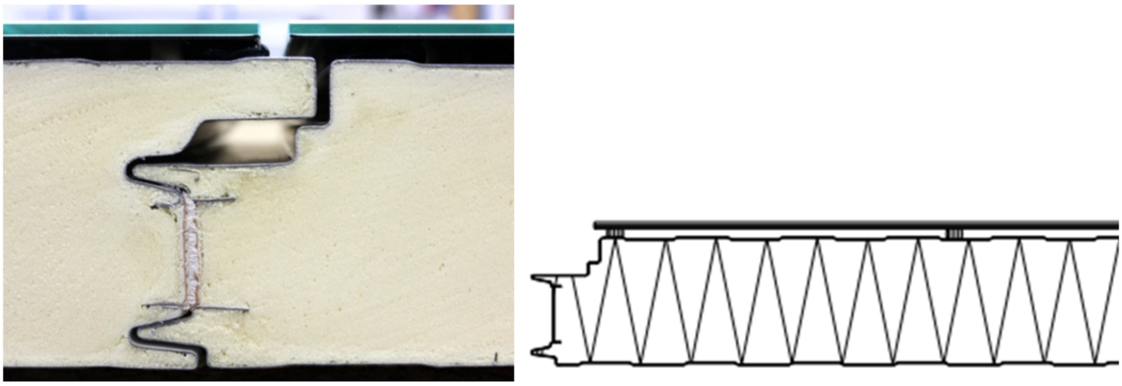

Fig. 3 Typical section through glass sandwich panel with polyurethane core (Brucha FP-P sandwich panel).

Fig. 4 Erection of glass sandwich panels at Munich BAU fair 2015.

4. Performance and Testing

4.1. Silicone

The silicone joint transfers the dead load of the external glass ply to the exterior metal sheet. Considering four 10 mm wide silicone joints per meter length, the permanent shear stress in the silicone is rather small:

- Self-weight of 6 mm thick glass ply: $G = 0.15\ kN/m^2$
- Bonding area of silicone: $A_s = 40{,}000\ mm^2/m^2$
- Shear stress in silicone: $\tau_{perm} = G/A_s = 0.00375\ N/mm^2 < 0.011\ N/mm^2$

Furthermore, the silicone joints are loaded in short-term shear due to temperature loading (τ_{Temp}). The thickness of the joint is chosen to be 8 mm so that the joint can be compensate the different thermal elongation of the exterior metal sheet and the glass ply. Wind loading mainly leads to compressive stresses σ_{Wind} in the joint, since “wind suction” is due to a air pressure difference between internal and external space ($p_i > p_e$). The air pressure in the 8 mm gap between sandwich and glass is close to the exterior pressure p_e due to the open joint at top and bottom of the glass sandwich panel.

Structural silicone with a European Technical Approval (ETA) according to ETAG 002 is the basis of the GSP product. In a first step, the adhesion of the silicone to the adherents is tested including accelerated artificial ageing, temperature, humidity, and UV exposure. Next, the load transfer of the shear and (if any) tensile stresses through the silicone joint and the external metal into the PUR core is tested. Figure 5 shows the principal test setup for the tension tests at different temperature level (hence the climate chamber). All joints loaded in shear and 90% of the joints loaded in tension show a cohesive failure mode (figure 6 left). 10% of the specimens failed in tension in the PUR core (figure 6 right). The achieved load level were in all cases beyond the required design values as shown for some selected tensile test in figure 7.

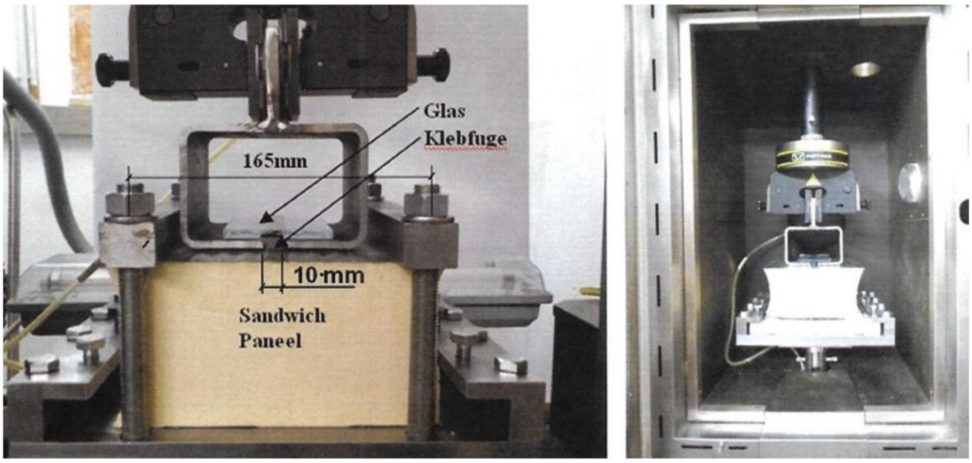

Fig. 5 Test setup for the transfer of tensile forces through the silicone joint into the PUR core for normal (left photo) and reduced/elevated temperature conditions (right photo).

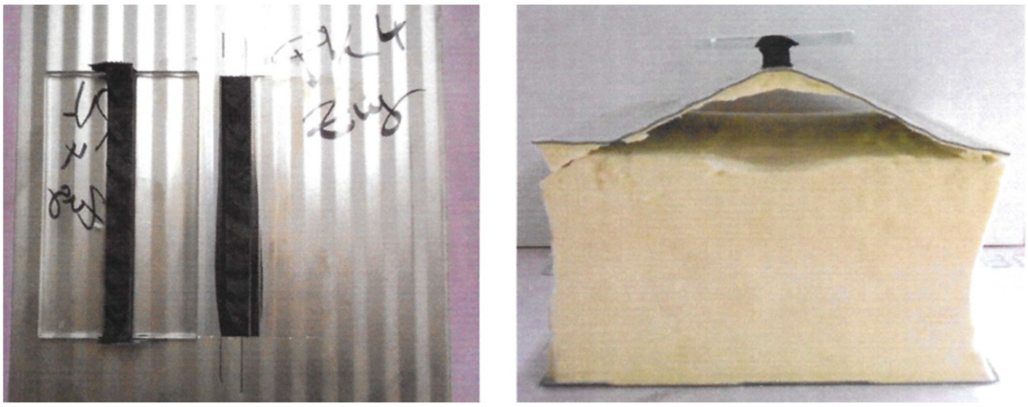

Fig. 6 Cohesive failure of silicone joint (right) and tensile failure of PUR core (left).

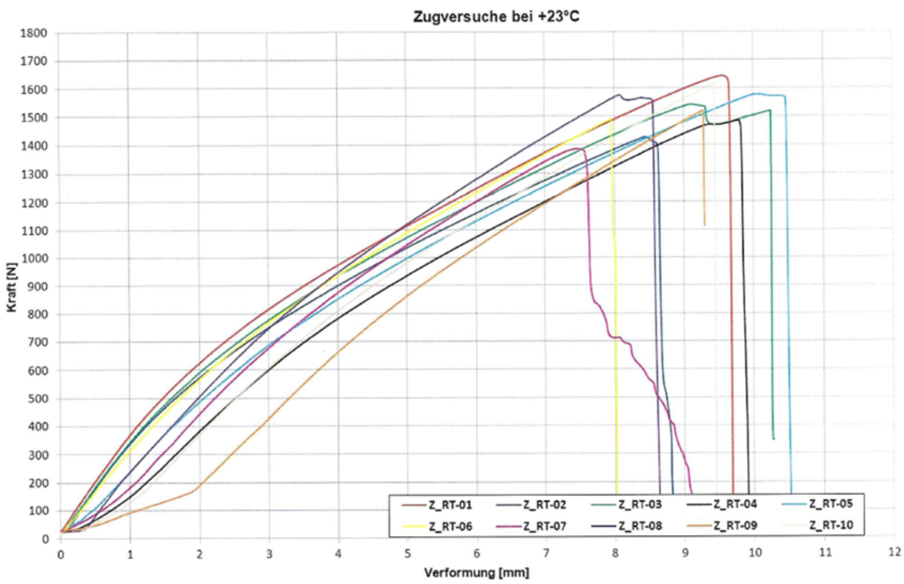

Fig. 7 Force-displacement curves for a 120 mm x 10 mm silicone joint with a height of 8 mm loaded in tension at 23°C.

4.2. Structural performance

seele conducted different of structural tests in order to evaluate the load distribution between sandwich panel and glass ply. The glass ply also affects the compressive failure stress (crippling) of the metal sheets. Other failure modes are delamination of core to face sheet, core crushing, failure of fixing details, failure of bonding, or glass breakage. The structural performance has been studied with bending tests in accordance with EN 14509 as shown in figures 8 and 9. Both, sagging and hogging moment are tested with the glass ply being at both top and bottom location (i.e., in total 4 test setups). The maximum sagging moment occurs in the center of continuous systems, while the hogging moment is maximum at intermediate supports. Strain gauges have been applied to all glass and metal surfaces for the structural tests as illustrated in figure 10.

Fig. 8 Bending test of glass sandwich panel in accordance with EN 14509 with bonded transparent glass ply at top (left) and bottom (right) of sandwich panel.

Fig. 9 Compressive failure of face sheet (crumpling); glass ply is bonded to bottom face sheet.

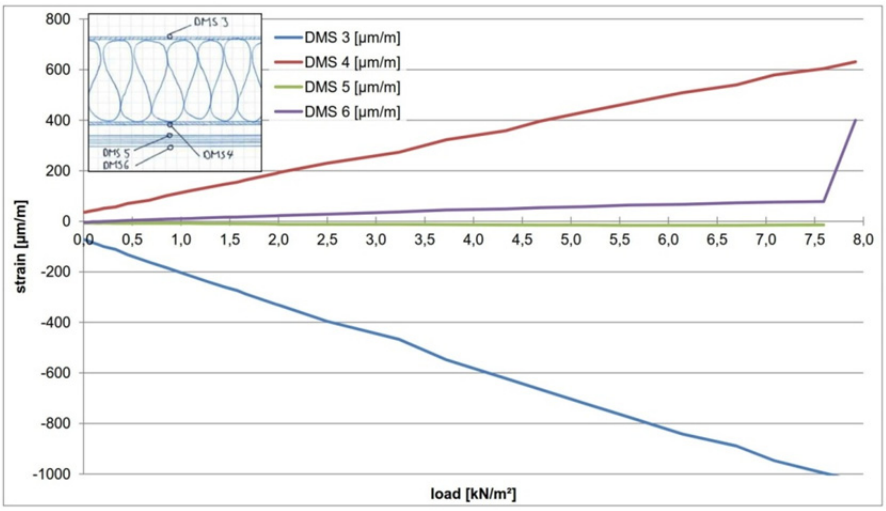

Fig. 10 Position of strain gauges (“DMS #3 to #6”) at metal sheets and glass and exemplary strain distribution in glass sandwich panel.

The ultimate load of 7.6 kN/m^2 which can be seen in figure 10 corresponds to a field moment of 6.2 kNm which results in very high strains and stresses in the metal sheets. This load results in a failure of the metal sheet in the compression zone (strain gauge DMS #3). It is of special interest to note the small strains in the glass ply. This underlines the argumentation that external loads are mainly taken by the stiff sandwich panel since the bonding is rather flexible and transfers only small shear forces, and the glass ply is very flexible compared with the stiff sandwich panel. This becomes clearer when looking at the moments of inertia: a 100 mm thick sandwich panel with 0.6 mm metal sheets has a moment of inertia of ~270 cm^4 while a 6 mm thick glass has a moment of inertia of only 1.8 cm^4 (stiffness ratio glass : sandwich ≈ 1:150).

The same tests were also conducted with standard sandwich panels (i.e., with no glass bonded to the surface sheet). The ultimate loads were found to be in a similar range. The influence of the glass bonded to the sandwich panel is thus negligible or likely to have a small positive effect on the ultimate load capacity. The positive effect can be observed when the bonded glass ply is in the compression zone: in this case, the glass stabilizes the metal sheet against compressive failure, and the ultimate loads are slightly higher for the glass sandwich panel than those for the pure sandwich panel without glass.

4.3. Glass breakage

Additionally, glass breakage and post breakage performance tests were performed in order to show that no glass fragments can fall down which could hurt people standing in front of the glass sandwich panel. Since the outer glass ply is heat strengthened glass, the glass fragments are so big that each fragment is still bonded to sandwich panel (figure 11). Furthermore, any structurally positive effect of the glass ply (e.g. stabilization of outer ply against compressive failure) should not be considered in the design process so that the structural performance is not reduced in case of broken glass.

Fig. 11 Breakage pattern of heat-strengthened glass ply bonded to a sandwich panel.

4.4. Other tests

Other tests include fire resistance with single burning item (SBI) tests according to EN 13823, sound insulation, thermal insulation, and the evaluation of the temperature distribution in glass sandwich panels. The temperature tests include natural exposure in Germany and Saudi-Arabia and artificial exposure with true-light lamps. Surface temperatures in the external glass and metal sheets up to 80°C were observed.

5. Structural verification

The structural tests are the basis for the development of a design and verification concept for the glass sandwich panel. The tests have shown that the main load is carried by the sandwich panel due to its much higher stiffness in comparison to the relatively flexible glass ply. The sandwich panel is verified according to the established European standard EN 14509. The stress in the thermally toughened glass is relatively small.

Special care is taken to study the stresses in the silicone. The dead load of the glass sheet is transferred through the silicone in the sandwich panel. The other silicone stresses are mainly shear and tension due to temperature and wind loading. The outer metal sheet and the outer glass generally experience a different temperature than the internal metal sheet. Due to the insulation core, the temperature difference between internal and external faces leads to out-of-plane deflection and, for continuous system, higher stresses in the metal face sheets and additional support forces. The structural bonding is tested (see section 4.1) but also modeled numerically with a set of springs having the axial and shear stiffness of the joint (derived from testing). The discussion of the FE model is beyond the scope of this paper and will be addressed in a subsequent publication.

6. Openings in the glass sandwich panel

Figure 12 illustrates the concept of integrating opening area in the GSP. The key is to connect the window frame rather rigid with the sandwich metal skins and to safety transfer the forces from the metal skins into the window frame mullions. Figure 12 illustrates the basic concept. Currently, tests are ongoing to validate the design and to develop a verification procedure.

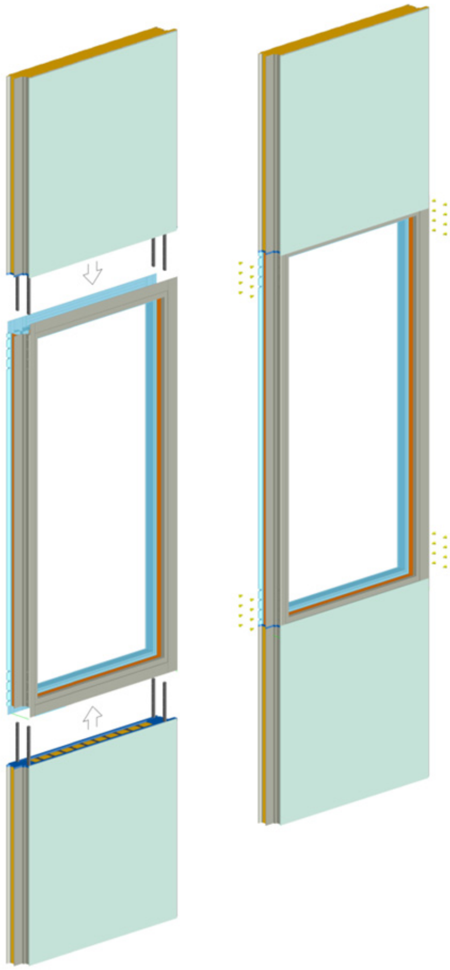

Fig. 12 Assembly of glass sandwich panel with integrated opening and window area (© iconic skin).

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