GLASS-PLASTIC HYBRID CONSTRUCTION

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Abstract

Transparent glass constructions are being used more and more often in the construction industry using up-to-date carrying systems. The progress in this field is determined by the methods to couple glass systems and transparent substructures in a durable manner while keeping the dimensions of the substructures as small as possible.
Experimental investigations have shown that carrying glass-hybrid beams are possible and that there are appropriate adhesive and surface pre-treatment substances available on the market to connect glass and plastic in an orderly manner.

1 Introduction

Maximum transparency as wished by architects is presently spoiled by necessary carrying elements made of steel, wood or concrete as well as by joint formation. A special problem which is to be solved here, is the connection of glass elements with each other as well as connecting them with the carrying substructure. (see Fig. 1 to 3).

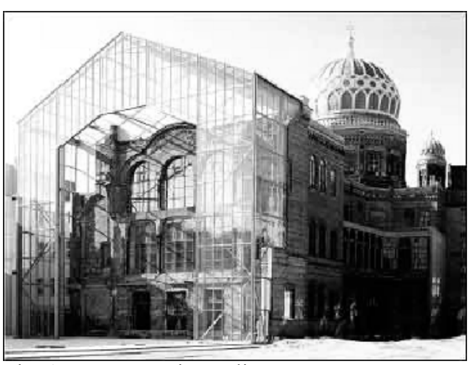
Fig. 1: synagogue in Berlin


Fig. 2: substructure


Fig. 3: monastery Volkenroda

Two reasons cause these problems:

- There are no industrial methods available for the production of transparent cross-sections which have sufficient bending and longitudinal force carrying capabilities, e.g. double-T cross-sections.
- The connection of glass elements with each other and the connection with the substructure are at present strongly limited by the lack of approved and durability-tested transparent adhesive substances and scientifically tested dimensioning guidelines.

There exists a great number of partly new construction forms which try to realise efficient substructures that do not spoil transparency more than necessary while taking into account durability, heat protection, etc. (Dodd,2004). All of those have in common that generally the carrying parts are non-transparent. The safety and reliability of the constructions are realised by safety and laminated glasses and by local connection elements, mostly made of stainless steel. The deployed techniques do not

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permit the production of cross-sections which are effective with regard to bending and longitudinal force stresses and the subsequent tension and stability problems.
Simply agglutinating individual glass sheets to get rectangular cross-sections as carrying bar cross-sections does not lead to optimal cross-section forms. Furthermore, connecting bars with each other is problematic, so that a great number of discrete connection elements - mostly made of metal – has been used so far along with agglutinating. These discrete couplings, i.e. the stress transmissions mean a high safety risk especially when one takes into account long-term impacts. This is a result of the carrying properties of the material glass which is very sensitive with regard to local tensile stress, and through external influences, e.g. heat, stress concentrations can occur.
The deployment of highly ductile synthetic construction elements as coupling element between glass sheets and as connection element of cross-section parts of profiles or construction parts, respectively, opens completely new possibilities in the design of transparent construction parts (Bemm, 2003). In this investigated field there are no other findings known to the author as to the carrying behaviour, the possibility of producing adhesive connections, on the durability and robustness as well as on the dimensioning (Freytag, 2004; Hess, 2000).

2 State of Research

In recent years more and more investigations on the carrying capacity and on the stability of glass profiles with rectangular cross-section have been carried out since these were mostly used so far. These investigations concentrated on the problems of local stresses as well as on global influences (Hess, 2002). All of this leads to a significantly increasing deployment of glass constructions – this applies for carrying elements, too. This development is not giving impetus, though, with regard to qualitatively new forms of construction or structure.

The recent research on the field of constructive glass building can be divided into three main areas:

- Carrying behaviour of construction elements (Hess, 2000; Hess, 2002),
- Problems of the local carrying behaviour especially with regard to bearing and connection (Schuler et al, 2004; Bernard et al, 2004),
- Adhesive techniques (Wiesner, 2004; Müller, 2004).

Recent investigations try to further develop the given technical possibilities of glass as well as those of connection elements. This applies basically for (Weller et al, 2004):

- Laminated glass (Schober and Schneider, 2004),
- a variety of local mechanic holders (Veer et al, 2001),
- the attempt to replace silicate adhesives by new acrylic adhesives or similar things (Dilger et al, 2003).

These developments have their significance as to an increased safety, easier execution and an enlargement of the glass sheets in relation to the necessary supportive constructions. All of these investigations have in common that they basically try to improve efficiency and reliability using known paths (Bornemann et al., 2003; Welters and Dilger, 2003).

3 Idea

Even glass-plastic hybrid connections have been used very successfully for quite a while in the field of laminated glass technology. Connecting glass sheets with relatively thick interlayers of special synthetics result in sheets which have a high breaking resistance. This construction form is limited to elements such as shop windows, security walls in buildings, doors, etc. (Business, 2003). Substantial investigations showed that there is no approach to deploy these hybrid connections - in a new quality - to create carrying elements.
When designed correctly the plastic sheets are capable of transmitting normal as well as shearing stresses, even though the e-modulus of the plastic is significantly lower than the one of glass. The

glass sheets within the hybrid elements can be coupled shear proof over the plastic sheets when appropriate adhesive techniques are deployed. In doing so, one achieves cross-sections with a favourable longitudinal force and bending carrying capacity while the coupling element is not in danger of a brittle fracture like glass since it is made of ductile plastic. The transmission of shearing forces between bridge and flange occurs through the ductile plastic. (See Fig. 4)

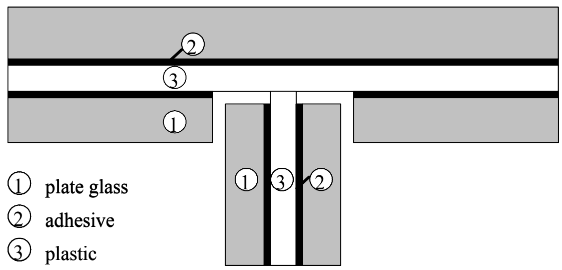


Fig. 4: principle of glass-plastic hybrid element

4 Investigation on the Adhesive

A problematic part in the production of glass-plastic hybrid connection is the large-area adhesion of glass sheets with plastic sheets. The goal is to produce connections which are durable, stress-relieved and optically clear. Especially the latter point poses a considerable technological challenge.
For the first experiments polycarbonates from the company Bayer (Makrolon GP 099) and from the company GE Plastics (Lexan PC) were chosen from the wide range of plastics (P). The used float glass belongs to the group of lime-natronsilicate glasses. The specimens consisted of a compound (3 mm glass – 3 mm plastic – 3 mm glass) with the dimensions 300 mm length and 80 mm width. With regard to the adhesives (A) and the surface pre-treatments (SPT) different combinations were investigated.
The aging cycle D3 „Heat, Coldness and Humidity“ taken from the standard DIN EN ISO 9142 (Standard, 2004) represents the climate conditions occurring in the case of glass constructions best. A determined humidity was not set in the experiments, they were limited to temperature cycles in the following steps:

- Exposure (15 ± 1) h at a temperature (+40 ± 2) °C
- Change within (60 ± 20) min to a temperature (-20 ± 3) °C; exposure (2 ± 1) h
- Change within (80 ± 20) min to a temperature (+70 ± 2) °C; exposure (4 ± 1) h
- Change within (60 ± 20) min to a temperature (+40 ± 2) °C

The pictures in Table 1 show selected specimens after 25 cycles given above. All specimens showed large-area debondings; partly microcracks occurred in the Lexan PC which were availed by the surface pre-treatment. The wished compound effect could not be achieved. The experimental program was changed with regard to plastic, surface pre-treatment and adhesive.
In Table 2 shows specimens of another series of experiments with changed adhesives and surface pre-treatment methods. Using the Pyrosil method had a very positive influence on the compound effect between glass and plastic. In this process a pre-treatment of the glass surface as well as of the plastic surface was carried out. The Pyrosil method produces an increased surface energy and thus improves the bonding.
After 25 cycles no microcracks or debondings occurred in polycarbonate Makrolon GP 099 (see Table 2, specimen 3-3). In the case of polycarbonate Lexan PC (see Table 2, specimen 4-3) microcracks occurred and - at the edge – debondings.
In addition to an acrylic adhesive two other adhesives were deployed (Epoxy and PUR). Both specimens showed large-area debondings leading to the destruction of the glass in the case of specimen 6-3. Both adhesives are probably not adequate to produce a durable compound between glass and Lexan. The Pyrosil method had no influence on the compound effect.

Table 1: pictures of selected specimens glass-plastic-glass after 25 cycles

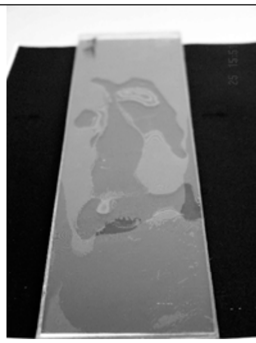
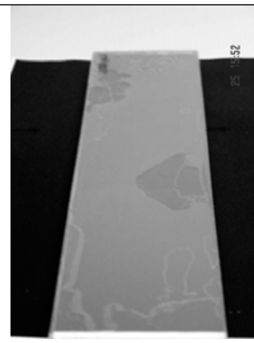
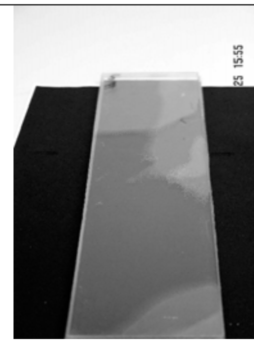
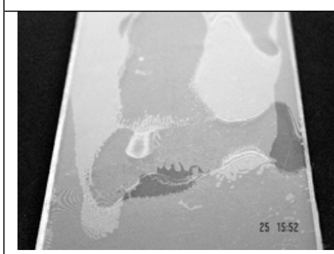
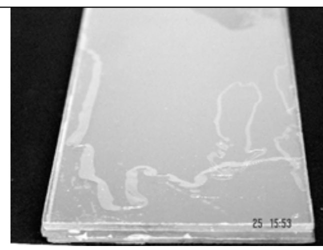
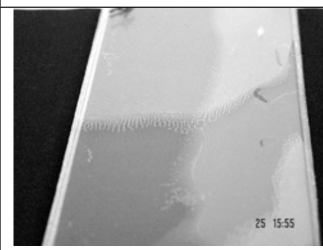
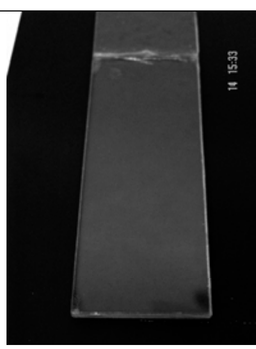
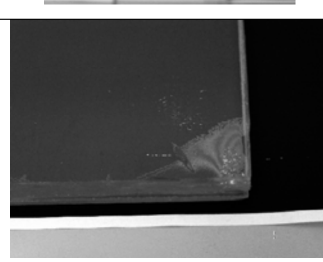
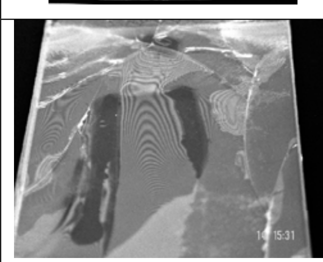
specimen 1-1 A	specimen 2-1 B	specimen 5-1 A
		
		
P: Lexan PC A: acrylic, uv-hardening SPT: alcohol	P: Lexan PC A: acrylic, uv-hardening SPT: plastic cleaner	P: Lexan PC A: silicone, uv-hardening SPT: alcohol

Table 2: pictures of selected specimens glass-plastic-glass after 25 cycles

specimen 3-3	specimen 4-3	specimen 6-3
		
		
P: Makrolon GP 099 A: acrylic, uv-hardening SPT: Pyrosil	P: Lexan PC A: acrylic, uv-hardening SPT: Pyrosil	P: Lexan PC A: PUR SPT: Pyrosil

For the production of a bending element the following materials and methods were used:

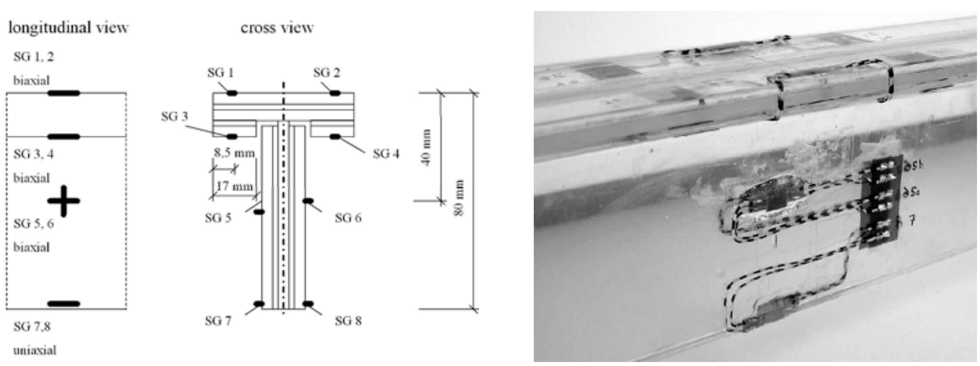
- Makrolon GP 099 as plastic,
- Acryl 1K, uv-hardening as adhesive,
- Pyrosil method as surface pre-treatment.

5 Static Carrying Behaviour of a T-Beam

For a first investigation on the carrying behaviour of a glass-plastic hybrid element a T-beam of 1 m length was produced. The Figs. 5a and 5b show the position of the strain gauges (SG) on the beam which consisted of a 50 mm wide flange and a 71 mm high bridge. The glass and plastic sheets had a thickness of 3 mm.

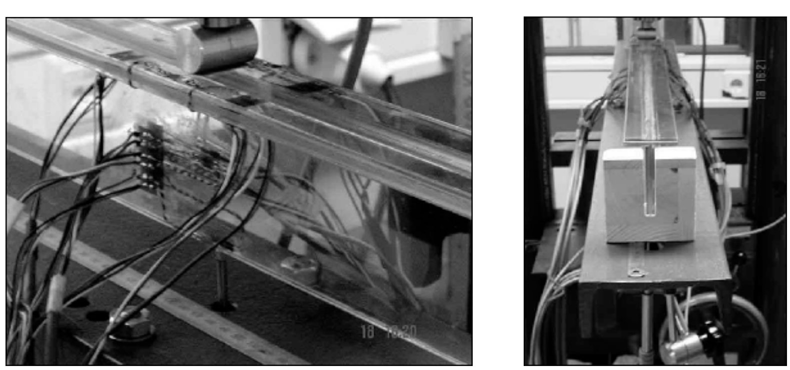
In a 3-point bending test the stress change at the flange and at the bridge was investigated for a quasi-static stress. The load was increased in the interval 250 N, 500 N up to 1000 N and held 2 mins. A complete relief was carried out after each load. The concentrated load was brought to the centre of the beam by means of the construction shown in Fig. 6.

The load was brought in over a period of 50 sec. at 500 N and for 120 sec. at 1000 N to avoid effects of to fast stresses. The stress-time development is exemplarily shown for two steps. (see Figs. 7a and 7b). The load of 500 N produced a stress of 20 N/mm² (tensile) in the glass at the underside of the web. The minimal difference between both graphs can be explained by the different positions of the strain gauges. During the time period 50 sec. - 170 sec. a slight increase of the stress occurred in the glass at 500 N. This seems to indicate a force rearrangement from the plastic to the glass. After the relief there was no residual stress in the glass to be found. The maximal deflection in this test was at 0.75 mm.



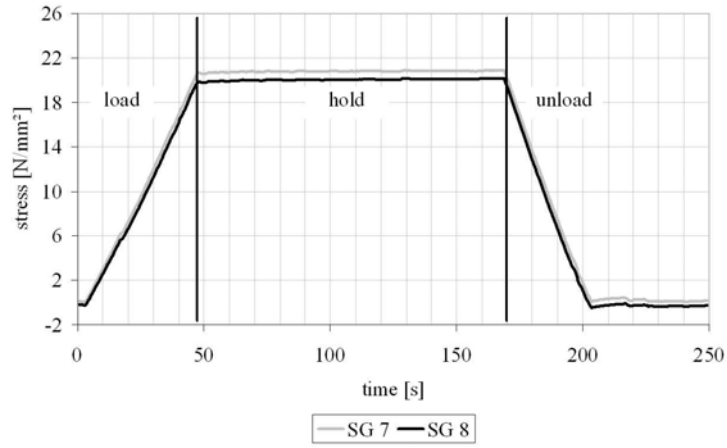
a) drawing b) web

Fig. 5: arrangement of the strain gauges (SG)

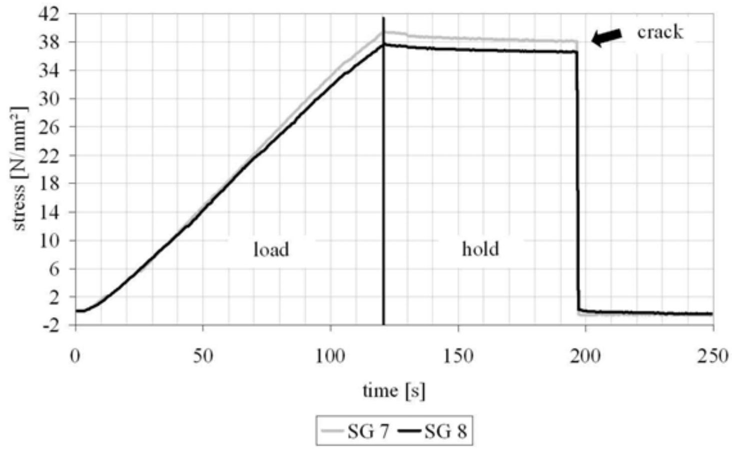


a) b)

Fig. 6: glass-plastic hybrid beam during the test



a) max. load: 500 N



b) max. load: 1000 N

Fig. 7: stress-time development at the underside of the web

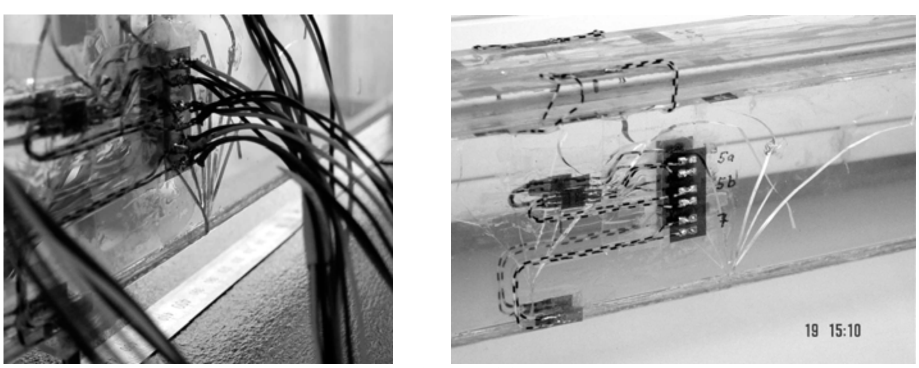
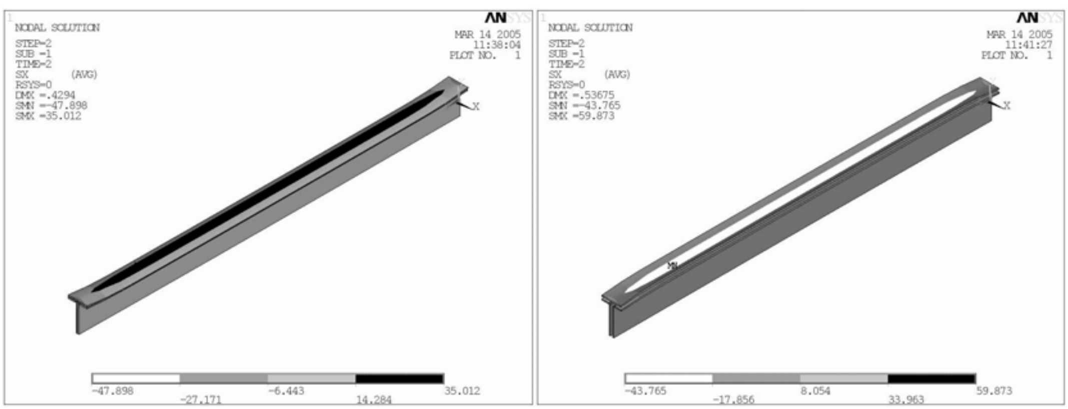


Fig. 8: picture of fracture

In Fig. 7b the max. carrying load of the T-beam is reached. At a stress of 38 N/mm² (tensile) a breaking of both glass sheets in the web occurred after 75 sec. A typical picture of fracture for float glass in the web was the result. (see Fig. 8) A maximum deflection of 2.0 mm could be measured. The residual carrying capacity of the plastic was sufficient to avoid the complete destruction of the beam.

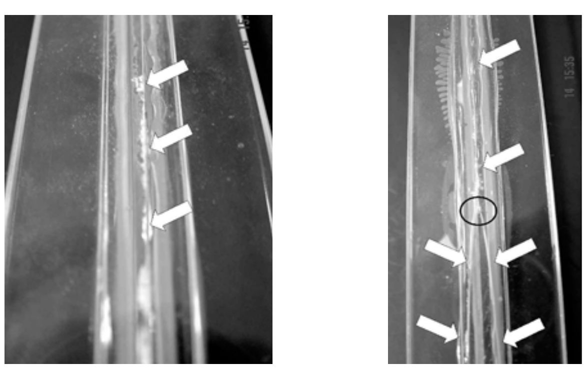
6 Behaviour of the T-Beam at Temperature Changes

Apart from the resistance capacity against loads the temperature behaviour plays an essential role. A second T-beam was exposed to 25 temperature cycles according to standard DIN EN ISO 9142 – Aging Cycle D3. This resulted in a longitudinal in the centre of the 50 mm wide glass sheet of the flange. This crack ran 150 mm before the end of both beam sides. At the marked point in Fig. 10b the crack divides and cuts out a wedge-shaped piece of glass at the ends of the upper flange. The detailed image in Fig. 10a shows spots where very fine glass pieces can be seen which are the result of the steady opening and closing of the crack (probably formed in the first temperature cycles) because of the temperature change. This process could be confirmed by a FEM-analysis of both temperature conditions (20°C and +70°C). At a temperature of -20°C tensile stresses of such a magnitude occur at the upper side of the flange which let the glass break in the static experiment. When the T-beam is exposed to a temperature of +70°C a high tensile stress occurs at the underside of the upper glass sheet of the flange. This high tensile strength leads to a crack which opens and closes in the following cycles.
The deformation in the opposite direction as a consequence of both temperature conditions is shown in Fig. 9. The movement of the upper flange was a result of its unsymmetrical design, (upper glass sheet continuous, lower glass sheet interrupted), it was worsened by the different heat expansion coefficients of glass and plastic. When further developing glass-plastic hybrid elements one has to find constructive solutions that neutralise effects of such deformations in the opposite direction.



a) beam at temperature -20°C b) beam at temperature +70°C

Fig. 9: stress in cross direction of a hybrid beam at different temperatures



a) crack in the center of the beam b) crack at the end of the beam

Fig. 10: path of crack in the upper glass sheet of the flange

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