Novel Laminated Connections

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Summary

As an alternative to standard adhesive connections, the PhD research project 'Novel Laminated Connections for Structural Glass Applications', which recently started at the ICOM-EPFL, focuses on the use of polymer foil/interlayer materials to laminate (metal) connections to glass. Two interlayer materials, namely the ionomer SentryGlas (SG) and the structural transparent addition-cured silicon (TSSA) seem good candidates for this lamination connection technique, and are investigated in this research. The research includes experimental and numerical studies, and aims at developing a model for predicting the deformation and failure behaviour of laminated connections.

Keywords: structural glass; laminated connection; SentryGlas; ionomer; TSSA; silicon.

Introduction

In contemporary architecture the structural use of glass is strongly increasing, following the exponential evolution of modern construction towards transparent appearance.

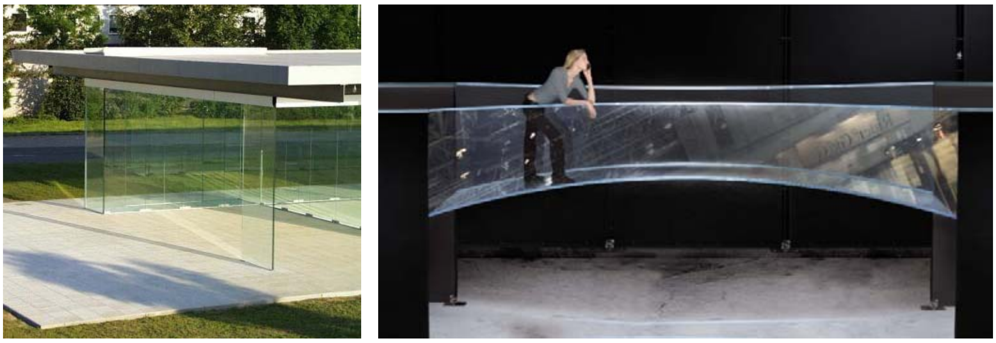

Figure 1. Structural use of glass material in load-carrying elements [1][2]

One of the main challenges in structural glass engineering is realizing the connection between the (glass) members. These can be either glass to glass connections or glass to metal connections for both beam-columns and beam-beam joints. The main characteristics of common glass joints are briefly explained in the following paragraph. Subsequently, a novel laminated joining technique is shortly described and finally the research plan of this PhD will be explained, which will be focused on the study of the aforementioned laminated glass connections.

Bolted and Adhesive connections

A common connection technique in glass engineering is the use of bolts, which has been already adopted for metal and wood construction. However, bolted connection in glass applications have some disadvantage, which are listed below:

- The drilling process introduces flaws at the perimeter/edge of the drill hole, which is the area where the highest stresses will occur, thereby locally reducing the strength of the glass panel [3];
- Strong stress field's intensification occurs and cannot be plastically redistributed by the glass. This phenomenon leads either to reducing the load carry capacity of the element or to a thicker element, comparing to another similar specimen without holes;
- The presence of holes in the glass locally affects the residual stress field in tempered glass, [4][5], causing uncertainties in the failure prediction of the glass panel;
- The drilling should be performed before the tempering process, and cannot be done afterwards;
- The bolted connections are highly visible and may affect the visual quality and smoothness's continuity of the glass structure/facade.

A promising alternative for bolted joints are adhesive connections which, avoiding bolts and holes' drilling, are characterised by the following enhanced features:

- The load is distributed over the whole adhesive connection surface resulting in a higher spreading of stresses compared to the hole's one;
- Additional flaws population are not induced onto the glass surface;
- The adhesives application can be performed also after the tempering process;
- The residual stress field is not altered near the connections;
- Adhesive joints are limited only to one side. The other side of the connections, which are generally the external ones, are totally free from continuity interruptions.

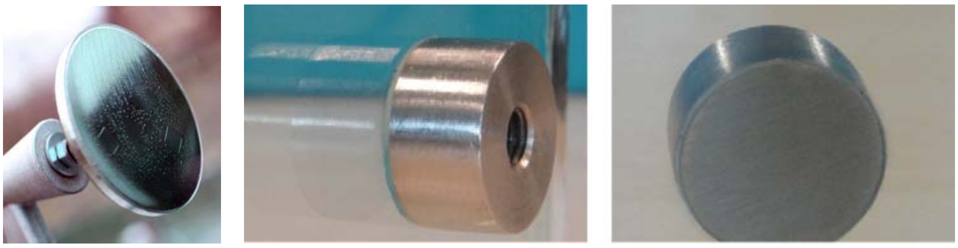

Figure 2. Adhesive glass-to-steel connections. [6][7]

However, adhesive connections may also imply some disadvantages such as:

- Necessity of high experience and great technical knowledge on glued connection in order to obtain satisfactory performance of the connection (especially for contact adhesion, i.e. adhesive thickness less than 1 mm).
- Strong dependence of both stiffness and strength on temperature variations;
- Strong dependence of both stiffness and strength on long term loads (time dependence). Under this topic (visco-elasticity) can be included the dependence on stress-strain rate [6];
- Durability: difficulties on quantifying aging effect and on defining a proper test procedure [8] which can simulate the real condition. Under this topic can be included the effect of humidity presence, both in the material (during the bonding process) and in the environment (during the life-time in service condition);
- Dependence of the viscous deformation behaviour on the stress level, i.e. ratio between stress and ultimate stress [6];
- Damage accumulation, also called Mullin's effect, i.e. different stiffness exhibiting during reloading for stress values under the maximum stress ever tested (virgin curve and re-loading curve) [9].

Additionally to the "traditional" types of adhesive connections, an innovative and emerging lamination connection technique has been recently developed, which makes use of polymer sheet materials to realize the elements' joining, as described in the following section.

Novel Laminated Connections

The main topic of this PhD research regards the study if this novel joining technique which consists in laminating a polymer layer between steel and glass element. It is inspired by the laminated "safety" glass panels, making use of the standard procedures of autoclave-heating curing. Examples of polymeric materials recently used for the aforementioned layer are SentryGlas (SG) from DuPont (transparent stiff ionomer [10]) and Transparent Structural Silicon Adhesive (TSSA) from DowCorning (addition cured one-component silicon [11]). Preliminary results on these material, collected in [12][13] [14] for SG and in [7] [11][13] [16] [17] for TSSA, seem to show some interesting characteristics, listed below, which lead to consider laminated adhesive joining as a promising type of connection for glass applications. Indeed:

- The ionomer molecular structure provides to SentryGlas enhanced values of stiffness and ultimate strength, which are comparable to the one of strong common adhesives, like the acrylate ones for instance. Therefore it seems to be acceptable for structural load-carry applications. This enhancing is more remarkable (as stated in [18]) if compared for instance to the standard laminating polymer layer, called PVB, usually used for realising laminated glass units;
- Compared to the standard sealant silicon, the TSSA silicon exhibits higher strength values [7] which seem to be acceptable for structural load-carry applications, even if quite lower than the above mentioned stronger adhesive. However, enhanced durability against water submersion and aging exposure for the TSSA material seems to be proved in [11] especially if compared with the acrylate and epoxy type tested in [19]. In the latter indeed, was stated that those type of acrylate and epoxy adhesive heavily worsen their performances or easily fail in case of water submerging or aging exposing. The TSSA's improving seems to be related to the siloxane groups which generally characterise silicon polymer [20]. In addition, TSSA material has showed a great stability of stiffness behaviour against temperature's variation conversely to the other common adhesive materials;
- Laminated connections should be less suffering from problems of tolerance and "out-of-plane" defects. Indeed they are characterised by higher adhesive's thickness (layers' thickness are usually between 1 and 2 mm) rather than the one of the more delicate U.V. cured acrylate connections, which is usually quite below 1mm.
- Technical machine and related equipment for laminating process are widely owned by glass manufactures which, therefore, do not need additional tools. Thus, they should be able to realise these novel steel-to-glass connection just using their own machines like ovens and autoclaves [11] [21].

Figure 3. Real scale application of laminated connection in structural elements.(Seele staircase) [22]

However, all the other aforementioned peculiarities that generally affects adhesive behaviour still play an important role also in the laminated connections behaviour, as stress-strain rate, long term load, temperature and aging effect, which therefore will be experimentally and numerically analysed in detail in the context of this PhD research.

Research plan

The aim of the PhD research 'Novel Laminated Connections for Structural Glass Applications', which recently started at the ICOM-EPFL, is therefore to experimentally and numerically investigate these two novel adhesive joints in order to define an engineering model able to predict the laminated connections behaviour in terms of deformation and failure criteria.

In the preliminary stage of the research several tests on dumbbell specimens will be performed with the main scope of characterising the deformation behaviour of the polymers. Then, an experimental campaign will be started on metal-glass connections (starting with point connections and then extending to linear connections), focusing at the beginning on both pure shear and pure tensile forces. However, connections in service condition are going to be subjected by a combination of the two. Thus, it will then be investigated the connections' failure behaviour applying different load combination, i.e. vary the shear-normal force ratio (α). In the second stage of the research campaign durability aspects will be investigated, in terms of performance reducing due to humidity presence, U.V exposure and thermal cycling application.

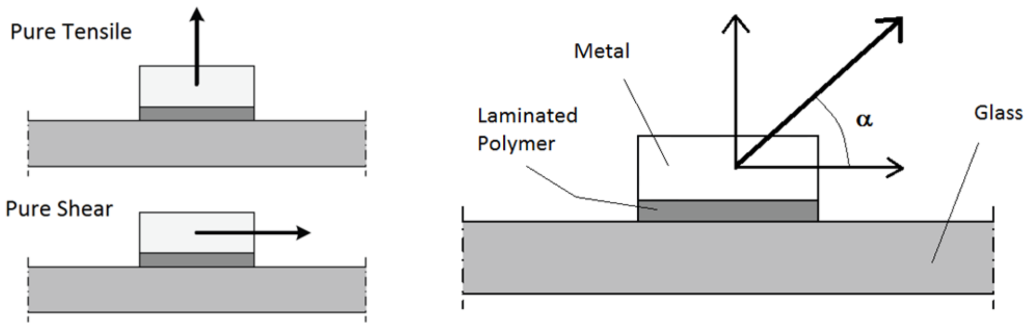

Figure 4. Pure Tensile and Shear tests (left); Combine Tensile-Shear tests (right).

All these tests will be followed by the conclusive experiences on some real-scale structures which should be previously analytically and numerically tested by a prediction model already defined at an earlier phase of this research. Indeed, numerical models will be defined according to the laboratory's results. On the one hand this model should be able to correctly simulate the deformation and failure behaviour of the laminated connections but on the other hand should be characterised by an acceptable complexity in order to be used by structural engineers without excessive difficulties, during their own design and safety assessing.

All the aforementioned tests will be performed firstly in standard condition (which has to be carefully defined) and then repeated parametrically, i.e. varying at least the main influencing parameters as temperature, stress rate, damage accumulation, aging and long term duration. Many other parameters influence the adhesive response like chemical composition of polymers, type of primer, connection's geometry, surface treatment and surface's extension. They will be also investigated in the present research in the case of economic and time possibilities.

Conclusion and prospects:

Two novel adhesive techniques, namely laminating process of stiff ionomer and structural addition-cured silicon, seem to be good candidate for glass-to-steel and glass-to-glass connections. An experimental research campaign is about to start. Together to these tests, numerical analysis will be developed to define a predicting model about failure and deformation behaviour of the connections.

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