Comparison of Mechanical and Adhesive Joints for Structural Glass – A review

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Abstract. The presented paper compares types of connections mostly used for glass structures. Two groups are recognised and it is mechanical connections and adhesive joints. Bolted connections are mostly used as it is relatively simply to design and to provide, but to be able to create such a connections holes needs to be drilled in glass panes, which leads to discontinuities in geometry, weakening the glass panes and to creation of local stress peaks in the area where the bolt is inserted. On the other hand, adhesive joints don’t lead to peak stresses as the stress is redistributed along larger area. Huge variety of accessible adhesives enable the joints to be used in almost each conditions. Main disadvantage of adhesives the change in behaviour over time, mainly decrease in strength. Also, mechanical properties are influenced by UV radiation, humidity, temperature, etc. The most common adhesives used for structural glass and their performance is shown and discussed in the paper.

1. Introduction

As the dimensions of glass panes are considerably limited, it is necessary to combine the individual components to create large dimensional elements, often designed in modern architecture in order to achieve a safe transfer of loads to foundations and then to soil. Whether it is the attachment of glass facades to a supporting part, usually a steel structure, or the joining of individual segments of pillars or beams in large dimensional elements, it is necessary to carefully focus on detail design to avoid stress accumulation at these points leading to brittle fracture. For this reason, the requirements not only for the design but also for the construction of the joints are high. To prevent the creation of peak stresses plastic, resin, polyamide, and light metal materials [1] are placed in the contact area of glass and metals [5].

2. Mechanical connections

The most widespread types of glass joints are bolted joints. However, the architecture of nowadays is increasingly focusing on the minimal visual effect of connections, so research takes place in the development of glued joints that create a sense of uninterrupted construction. Thereby the attractiveness and impressiveness of such structures are increased. The most common joints of glass constructions are described in more detail in this chapter.

2.1. Supports of glass slabs

Linearly supported slab around its perimeter is one of the simplest supports for glass panes. In this type of support, glass is fitted into a frame made of aluminium, steel, plastics or timber. The disadvantage of this solution is the uneven distribution of stresses along with the support which must be taken into account in design [2]. Other types of panel support include local edge support, structural silicone seal and local point support [3].
2.2. Standard bolt connection – shear bolt
This is the simplest joint of the glass structures, where the bolt’s head protrudes from the glazing plane. The load is transmitted from the glass to the screw through the inner flexible material. The contact surface is very small, therefore the load capacity is smaller, compared to other types of joints. Because the glass element is firmly attached to the support structure, this makes it almost impossible to move. Therefore, local peak stresses occur around the bolts [5].

Figure 1. Types of supports of glass slabs [3].

Figure 2. Standard bolt connection – shear bolt [3].
2.3. Simple countersunk-head bolt
This type of joint is similar to the previous one. The main difference is that the bolt’s head is recessed in a plane with a glass plate. Also in this connection, local peak stresses are generated around the bolt. The described connection does not allow ratification between glass and steel.

![Image of Simple countersunk-head bolt]

**Figure 3.** Simple countersunk-head bolt [3].

2.4. Bolted connection with steel splices
In this type of joint, steel splices are added on both sides of the glass pane, which are firmly connected by the bolts, so there is no mutual displacement between the glass and the steel plates. The opening for bolt may be larger than the diameter of the screw, which makes it possible to align the glass sheet when assembled. In practice, the joint is made using pre-tensioned screws tightened to the prescribed stress by a torque wrench. Load transfer occurs through friction between the steel and the glass, therefore the contact surfaces must be suitably adjusted and flexible material (plastics, neoprene, etc.) must be inserted between the glass and steel.

The latest research, however, points to the negative impact of the friction joints used in the laminated glass, where the interlayer is squeezed out at the joint site and consequently the mechanical properties of the laminated glass are changed [5].

Bearing bolts with steel splices are suitable only for tempered or heat-strengthened glass. In this type of connection, the load is transferred directly from glass pane through interlayer to bolt. Load bearing capacity depends on a number of bolts and their diameter. The scheme and behaviour of such connection are illustrated in the figure below [3].
Figure 4. Bolted connection with steel splices [3].

Figure 5. Bearing bolt connection with steel splices [3], a) Scheme of the connection, b) Compressive stress in the glass pane, c) Tensile stress in the glass pane [4].
2.5. **Bolted connection with stud assembly**

The main advantage of this type of connection is the transfer of vertical load by a stud that is part of the connecting steel plate. This stud is larger in size than the bolt, which leads to the higher pressed area and to lower stresses in the glass. The horizontal load is transferred by countersunk-head bolts. The diameter of holes for bolts is larger than the bolt’s diameter to prevent the in-plane load from being transferred by them. The disadvantage of the joint is the need to drill more holes in close proximity [5].

![Bolted connection with stud assembly](image)

**Figure 6.** Bolted connection with stud assembly [3].

2.6. **Spider connection**

Spider joints are used for connecting the individual glass panes of facades to supporting structures. This joint may have one, two, three or four cantilevered arms that extend from the center. The steel part of the connection is attached to supporting structures. The advantage of this type of joint is the possibility of partial rotation of the glass pane using flexible profiles not only in the opening itself but also in brackets. This adjustment reduces the moment transmitted by the glass pane, resulting in a more economical design of the joint [5].

![Spider connection](image)

**Figure 7.** Spider connection [3].
3. Adhesive joints
The glued joints according to the type of adhesive used are divided into elastic (silicone) or hard (resin). The main advantage of glued connections is the distribution of stresses in the vicinity of the joint where, unlike the bolted connections, the local stress peaks do not occur [2]. Further advantages such as weight reduction, the ability to connect thinner materials, the possibility of bonding and, at the same time, sealing and aesthetic enhancement contribute to the development of these less researched areas of glass connections [3]. The design should take into account the minimum shear stiffness of the flexible adhesives, as well as the influence of the temperature and the length of the load to its strength. Also, the decrease in stiffness shall be noticed due to the aging of the adhesive.

It should be also said that the behaviour of the adhesive bond strongly depends on a type of adhesive and the thickness of the adhesive layer. The following are the most used adhesives [4]:

- Cyanoacrylates
- Modified epoxies
- Polyurethane resin
- Structural silicones

![Figure 8](image)

**Figure 8.** Stress distribution in the connection made with hard adhesive [3].

![Figure 9](image)

**Figure 9.** Stress distribution in the connection made with thick elastic adhesive [3].

The adhesive material has to be strong and stiff enough to transfer the design loads for long periods of time without degrading. However, it must also be flexible to redistribute stresses and to compensate dimensional tolerances and thermal expansions without breaking or causing the breakage of the glass elements. A progressive breakage is desirable; the failure of a connection must not result in a total and instantaneous collapse of the whole structure. There are some design considerations that may help in reaching a safe breakage. For example, designing structures with alternative load paths, in order to
redistribute loads in case of local breakage, and implementing secondary support structures with the sole purpose of preventing the collapse of the main glass structure [2].

In one-part component adhesives, the curing process is generally done by exposure to UV. In two-part component adhesives, the curing happens as a result of a chemical reaction when the two components are mixed. The curing process may be affected by the thickness of the material. Some materials are specially formulated to cure for thin or thick sections, depending on its intended application. The thickness of the adhesive also affects its mechanical behaviour: thicker adhesive layers have a better capacity to redistribute stresses and to absorb shear strain caused by differential thermal expansion. However, thicker adhesives tend to have lower strength, especially for more rigid adhesives [7].

Table 1. General comparison of different adhesive systems, + good, ++ better, +++ the best [6].

| Adhesive | Tension and shear strength | Stiffness | Ductility | Viscosity | Temperature resistance | Ageing behaviour | UV resistance | Transparency and colour |
|----------|---------------------------|-----------|-----------|-----------|------------------------|-----------------|---------------|-----------------------|
| Epoxy resin | +++ | +++ | + | +++ | +++ | ++ | ++ | + |
| Polyurethane | ++ | +++ | + | +++ | + | ++ | ++ | + |
| Acrylates | + | ++ | + | ++ | ++ | +++ | ++ | +++ |
| Silicones | + | + | +++ | + | +++ | ++ | +++ | + |

4. Conclusion

A very common form of joining glass components to one another or to various primary load-bearing structures made of materials such as steel, concrete or wood is a bolted connection in which holes need to be drilled into the glass panes. These openings negatively affect the load-bearing capacity of the glass components. At present, all-glass constructions are very popular in which the glazing (secondary load-bearing structure) is associated with a primary load-bearing structure which is also made of glass. Nowadays, the glued joint comes to the forefront, which, when used correctly, can be not only stronger, but also more durable than a conventional bolted joint.

5. References

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