Mechanical Properties of Transparent Epoxy Adhesives for Glass Structures

Markéta Zikmundová, Martina Eliášová
Czech Technical University in Prague, Faculty of Civil Engineering, Thákurova 7, 166 29 Prague, Czech Republic
Marketa.zikmundova@fsv.cvut.cz

Abstract. Adhesive connections are commonly used in many industries as automotive, aerospace, electronics and also in civil engineering. Adhesives in civil engineering are used for non-load bearing structures but nowadays are requirements for using adhesive also for load-bearing structures especially for glass structures. Silicones are mostly used adhesives in civil engineering, they have good resistance to external environment but their lower strength and lower stiffness does not meet requirements for many applications. For this reason, are better semi-rigid or rigid adhesives but there is a lack of information about them. The paper is focused on experimental testing of transparent adhesive connection glass to glass. Four epoxy adhesives were chosen for double lap shear joint. Specimen were exposed to shear test until failure. Shear force and displacement were measured during test. Shear stress, elongation at break, shear modulus and failure mode were obtained from the tests. Only one epoxy adhesive had low adhesion to glass. Specimen with this adhesive had the lowest shear strength. Other three adhesives showed good adhesion to glass and had shear strength 6.5 times higher. Failure mode of specimen with these adhesives was always breaking of the glass.

1. Introduction
Glass belongs to the modern elements of architecture. Glass railings, glass canopies at the entrances to the buildings are very often designed, but there are designed also glass facades or glass stairs [1]. Is necessary to design not only glass, but also connections to the surrounding structure.

Mechanical joints such as clamps or screws are currently used first for the connections [2]. The disadvantages of mechanical joints are stress peaks at the materials, weakening of the cross-section (for screwed joints), the joints are visible and thus disrupt the aesthetic appearance.

In addition to mechanical joints, they are adhesive joints which do not have these disadvantages. Other advantages of adhesive joints include the possibility of joining different materials with different thermal expansion, bonding thin materials together, eliminating thermal bridges, damping vibrations. The disadvantages of adhesive joints are their mechanical properties at elevated temperatures, behavior under long-term load, resistance to the environment (humidity, UV radiation, temperature). Silicones are resistant to ageing and there are also silicones of higher strength and stiffness [3], but they are not suitable for all applications. There is still not enough information about high stiffness and strength adhesives such as epoxies for their use in civil engineering.
2. Experimental Programme
The paper is focused on experimental testing of adhesively connected glass to glass specimens. The material properties of the glass to glass adhesive bonding can be easily verified experimentally on small scale test specimens. The results of the performed experiments will be used to select the adhesive that will be usable for structural joints, e.g. the connection of a glass column with a beam. Based on the technical sheets, four adhesives were selected, suitable for structural glass connection. In addition to transparency, the basic requirements were UV stability, moisture resistance, sufficient strength open time and type of curing. Four transparent epoxy adhesives were chosen, 3M DP270, Araldite 2020, Polycol 117 + 593, Dawex Epox G300. Set for each adhesive contained five test specimens, totally 20 specimens.

2.1. Specimen geometry
The test specimens were prepared as double lap shear joints, see figure 1. Three glass panes with dimensions 50 x 50 x 19 mm were used for one specimen. The middle glass pane was connected 10 mm above the outer panes. Thickness of adhesive layer was 1 mm. The gap for adhesive layer was secured by inserting plastic sheets of thickness 1 mm. The actual bonded area was measured for each specimen separately. The bonded area was cleaned and degreased before bonding with acetone.

![Figure 1. Schema of double lap shear joint (left), example of specimen (right)](image)

2.2. Mechanical test of adhesive joint
Experiments were carried out in the laboratory of the Faculty of Civil Engineering, CTU in Prague. The specimens were subjected to displacement-controlled test in machine Shimadzu AGS-X 300 with continual loading until the collapse of the test specimen. The crosshead speed was 0,1 mm/min. The adhesive layer was loaded symmetrically by normal force which induced shear stress, see figure 2. To prevent a direct contact between the glass and the steel, washers were inserted between the cross head and the test specimen, as well as between the glass and the support plate, see figure 2.
Displacement was measured with four linear potentiometers. Two potentiometers measured displacement of the middle glass, another two potentiometers measured pushing of the specimen into the pad (one potentiometer on one side of the specimen). The difference between the two displacements (displacement of the middle glass and pushing into the pad) gives the resulting displacement of the middle glass.

3. Results and discussions
During the test, the force and displacement were measured, and after the collapse, the type of failure mode was recorded. Then the shear strength and elongation at break was calculated. Average shear strength, standard deviation and mode of failure are shown in table 1.

|            | Average shear strength τ [MPa] | Standard deviation [MPa] | Failure mode |
|------------|-------------------------------|--------------------------|--------------|
| 3M DP270   | 1.08                          | 0.53                     | A<sup>a</sup> |
| Araldite 2020 | 7.22                        | 1.64                     | S<sup>b</sup> |
| Polycol 117+593 | 6.61                       | 1.58                     | S<sup>b</sup> |
| Epox G300  | 7.20                          | 2.18                     | S<sup>b</sup> |

<sup>a</sup> Adhesive failure, <sup>b</sup> failure of the glass.

One adhesive, 3M DP270, showed low shear strength, only 1.08 MPa and was only of the four tested adhesives to show an adhesive failure mode, see figure 3. Shear strength of each specimen with adhesive from 3M was very different, some specimens had twice higher shear strength than others, see figure 4, figure 5.

Other three adhesives were break by rupture of glass (failure mode S – failure of substrate), see figure 3. Araldite and Epox had quit similar average shear strength 7.2 MPa, but Epox showed higher standard deviation. Polycol had little bit lower average shear strength than Araldite and Polycol, see figure 4.
Figure 3. 3M adhesive specimen with adhesive failure mode (left), Araldite adhesive specimen with glass failure (right)

Figure 4. Maximum shear strength for reference sets of specimens

Each specimen with Araldite adhesive behaved differently, although the resulting value of shear strength was with the smallest standard deviation. Specimens with Polycol and Epox adhesive showed relatively the same behavior, see figure 5. The behavior of specimens with Araldite can be caused by bubbles that were present in the adhesive joint (in various amounts). This could affect the stiffness and strength of the joint. Polycol and Epox managed to bond almost without bubbles.
3. Conclusions

Three of the tested adhesives, Araldite, Polycol and Epox, showed very similar behaviour. The average shear strength and standard deviations were very similar and the failure mode was the same. Only 3M adhesive showed adhesive failure mode and achieved the lowest shear strength.
It would be advisable to treat the glass surface before bonding for 3M adhesive to improve adhesion. Plasma treatment could be used for treatment of the surface, which shows good results in the treatment of plastic surfaces [4].

The adhesion to the glass was good for the other three adhesives, and the acetone surface treatment could be considered sufficient. The failure of the specimens was caused by glass rupture. It could be caused by stress peaks in the glass caused by inaccurate bonding of the glass panes or to the uneven surface of the glass edges. It would be appropriate to use machined glass edges and to use softer pads during testing which would be able to better compensate unevenness and the stresses would be applied more uniform which could eliminate glass rupture.

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