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Influence of Adhesive Layer Thickness and Temperature on Mechanical Properties of Two-part Acrylate Adhesive

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In recent years, architects, as well as customers, have been increasingly interested in glass structures. Glass is used except facades also for canopies above building entrances, bannisters, staircases or load-bearing structural elements such as beams or columns. Glass is a brittle material with elastic behaviour until brittle failure so particular attention should be paid to details and connections of glass with glass or glass with other material. This article is focused on double-lap shear glass-metal joint using a two-component acrylic adhesive. In addition to glass, two different materials were included in the experimental programme, Zn-electroplated steel and aluminium. Totally four sets of specimens were tested. Three sets of specimens are differing in adhesive thickness layer. The last set of specimens was tested at elevated temperature.

Keywords: Adhesives, Glass-metal connections, Elevated temperature, Effect of layer thickness

1. Introduction

Nowadays, glass structures are mostly bonded by mechanical fixings such as local edge supports or local point supports using bolts. Mechanical connections have several disadvantages as high-stress concentrations around bolt holes, weakening of cross-section and aesthetic reasons such as disrupting smooth surface of glass pane and transparency of glass. Adhesive connections eliminate these disadvantages because along the connection is more uniform stress distribution and bonded material is not weakened. Another advantage of adhesive joints is the possibility to combine various materials with different thermal expansion, reduce thermal bridges, soften vibrations and can also be used as a sealant. For these reasons, there is interest in adhesive bonding, especially in façade constructions. Research focused on the use of adhesive bonding in façade constructions has dealt with e.g. Bues et al. 2019, Ciupack et al. 2017, Liška et al. 2014, Nicklisch et al. 2016.

Silicones for various glazing or gaskets have been used for decades in civil engineering, but mechanical properties of current prevailing silicones do not meet today's requirements. In particular, these requirements are the strength and stiffness required for structural joints. Epoxy and acrylate are adhesives with high strength and stiffness. However, there is insufficient background to design bonded joints using higher strength adhesives, their durability (Sousa et al. 2018) and effect of temperature on mechanical properties.

2. Experimental program

The research was focused on experiments of glass-metal adhesive connections under shear loading for selected two-component acrylate Crestabond M7-05 that belongs to stiff, high-strength and fast curing adhesives. The study contained four series of specimens, see Fig. 1. Three sets of specimens were tested at room temperature which differed in the thickness of the adhesive layer (1 mm, 3 mm and 5 mm). The fourth set of specimen was tested at elevated temperature with the thickness of adhesive layer 3 mm. Each set contained ten specimens. Totally forty specimens were tested.

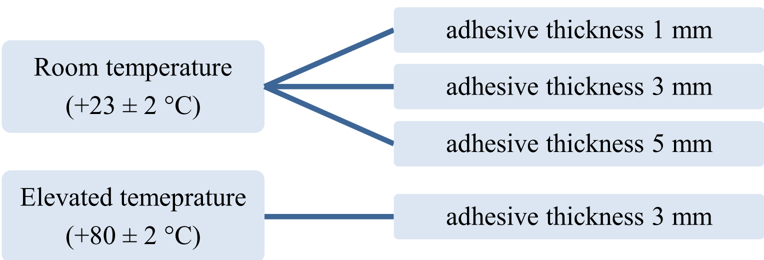
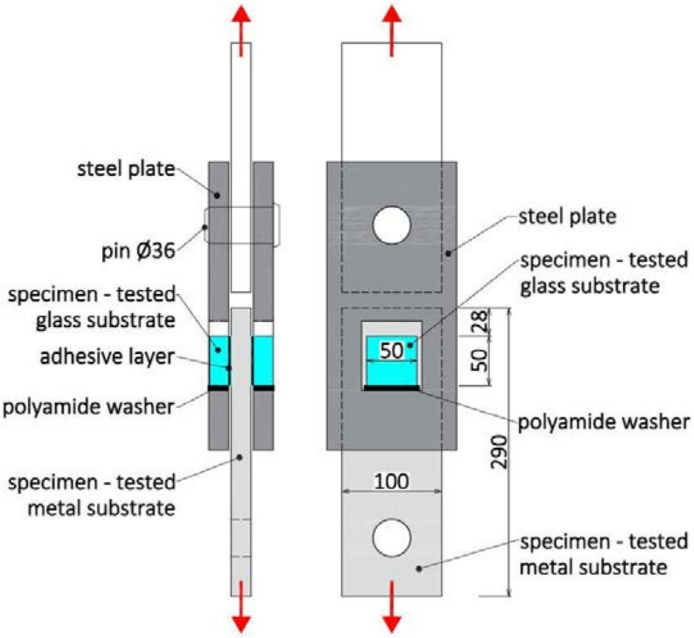


Fig. 1 Sets of specimens.

2.1. Specimen geometry

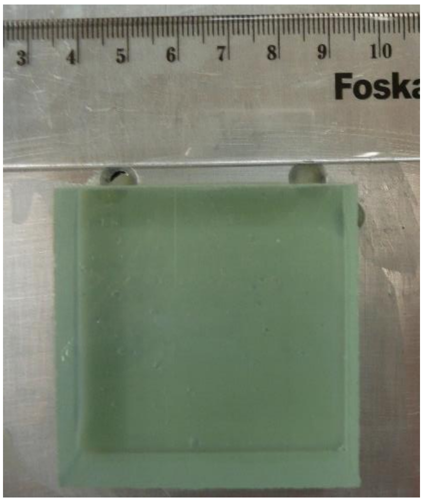
The test specimens were prepared as double lap shear joint, see Fig. 2. The specimen consisted of middle metal sheet and two glass plates which were adhesively connected to the metal sheet. Geometrical dimension of glass plates was 50 x 50 mm with the thickness 19 mm.

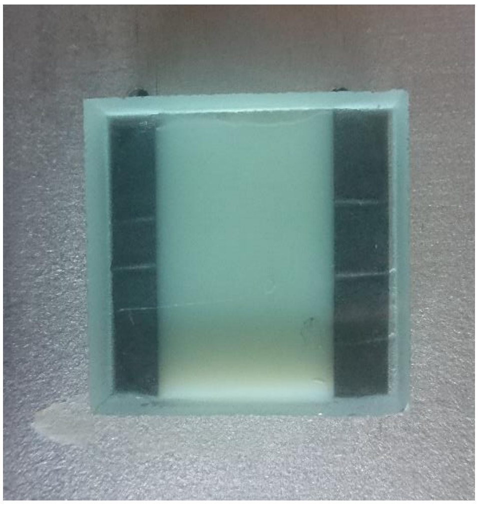


a) b)

Fig. 2a) Schema of double lap shear joint, b) Specimen in machine.

Specimens with 1 mm of adhesive layer thickness had size of bonded area 2500 mm^2 on each side, total 5000 mm^2 (whole surface of glass plates). Thickness of adhesive layer was provided by glass balls, which were sprinkled on the adhesive during bonding. The adhesive layer thickness for other specimens was provided by foam tape which was used on two sides of the glass, see Fig. 3b). The size of bonded area for adhesive layer thickness 3 mm and 5 mm was that why 1600 mm^2 on each side of metal sheet, total 3200 mm^2.





a) b)

Fig. 3a) Specimen with glass balls, b) Specimen with foam tape.

Two different metal substrates were used for the specimens: Zn-electroplated steel and aluminium. Glass plates were made from the float glass. The surface of metal sheets was mechanically roughened on the bonded area and subsequently both surfaces, metal sheet and glass, was cleaned and degreased before bonding.

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. The adhesive layer was loaded symmetrically by normal force which induced shear stress. The crosshead speed was different for each thickness of adhesive layer to ensure similar strain rate for every specimen. Specimens with 1 mm adhesive layer thickness were loaded by 1 mm/min crosshead speed, specimens with 3 mm adhesive layer thickness were loaded by 3 mm/min crosshead speed and specimens with 5 mm adhesive layer thickness were loaded by 5 mm/min crosshead speed. Loading was introduced continuously until the total failure of the joint. Displacement was measured by two linear potentiometer transducer (one transducer for each side of specimen).

The temperature chamber was installed to the machine for specimens exposed to elevated temperature. Specimens were heated up in this temperature chamber, see Fig. 4, and after approximately one hour were tested. Reaching a temperature of the specimens was measured with a thermocouple.

a) b)

Fig. 4a) Specimen in the temperature chamber b) Temperature chamber.

3. Results

3.1. Reference set

Average shear strength of specimens tested at room temperature is shown in Table 1 and Table 2. There is also shown average shear modulus and mode of failure. Shear modulus $G_{0.01\text{-}0.05}$ was determined from relative shear deformation between values 0.01 and 0.05. Mode of failure indicates how was the specimen broken. Adhesive failure is marked with the letter A, cohesive failure with the C, adhesively cohesive failure with the A-C. If one of the two failures is dominant, the corresponding letter of that failure is written in bold. If the substrate is damaged or destroyed (here it is glass substrate), it is marked with the letter S. The combination of all failures is called A-C-S.

There are contained specimens with aluminium substrates with different adhesive thickness layer in Table 1. Table 2 summarized results of specimens with Zn-electroplated steel substrates.

Table 1: Reference set of specimens with aluminium.

Type of specimen	Average Shear Strength [MPa]	Average Shear Modulus [MPa]	Failure
Aluminium 1 mm	11.267	110	S
Aluminium 3 mm	17.280	200	S
Aluminium 5 mm	15.221	189	S

Table 2: Reference set of specimens with Zn-electroplated steel.

Type of specimen	Average Shear Strength [MPa]	Average Shear Modulus [MPa]	Failure
Zn-electroplated steel 1 mm	12.356	141	A-C-**S**
Zn-electroplated steel 3 mm	15.550	195	**A**-S
Zn-electroplated steel 5 mm	14.105	198	**A**-S

Specimens with adhesive thickness layer 1 mm were damaged in all cases by breakage of glass. The glass on the specimens with aluminium substrate was completely destroyed and the glass shard remained on the adhesive. Glass on the specimens with Zn-electroplated steel was not destroyed so much (glass held together only with cracks), some part of adhesive connection had cohesive failure and some part failed adhesively. Specimens with adhesive thickness layer 3 mm and 5 mm with aluminium mostly had substrate failure. Glass was absolutely destroyed. Two specimens had adhesive-cohesive failure (adhesive failure from aluminium). Specimens with adhesive thickness layer 3 mm and 5 mm with Zn-electroplated steel had prevailing adhesive failure from steel together with substrate failure, glass held together but had cracks.

Specimens with a higher thickness of the adhesive layer do not have such large destruction of the glass and the shear stress was higher, see Fig. 5.

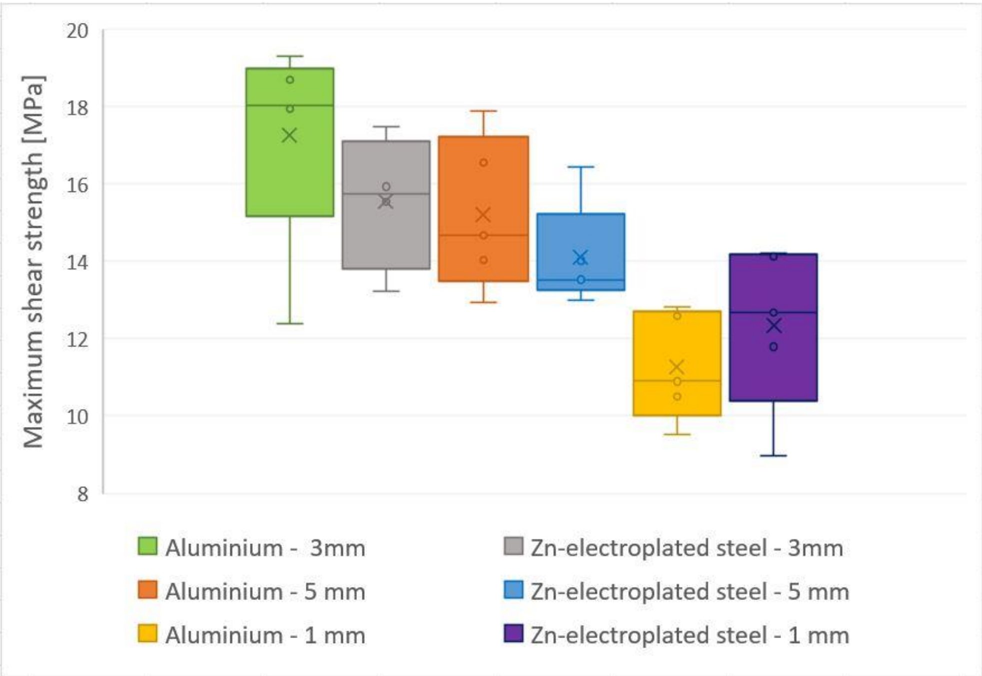


Fig. 5 Maximum shear strength for reference set of specimens.

The shear modulus was similar for all specimens, only specimens with 1 mm adhesive layer thickness had slightly lower shear modulus. The stress-strain relationship for one specimen from each reference set is shown in Fig. 6. The graph also shows brittle fracture especially in case of specimens with aluminium substrate and 1 mm adhesive layer thickness.

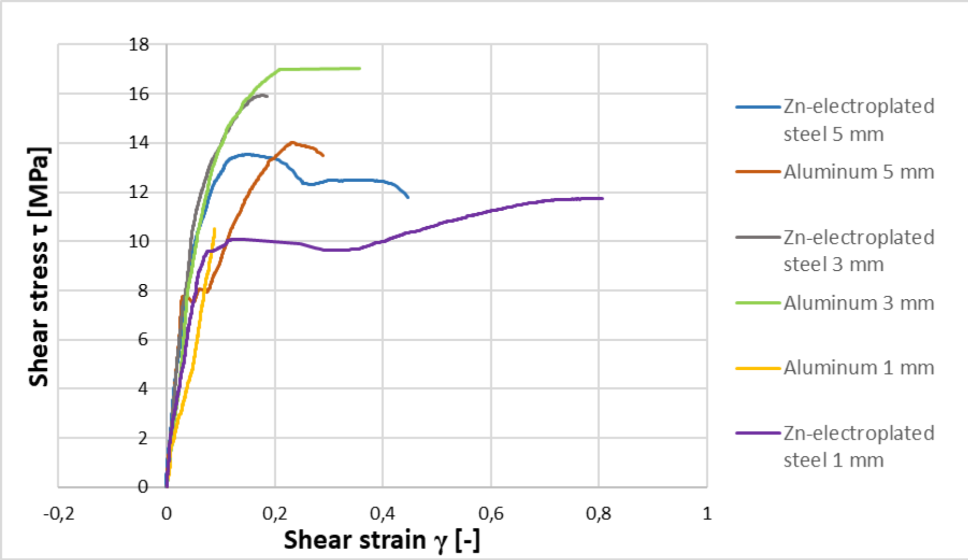


Fig. 6 Stress-strain relationship for reference set of specimens.

3.2. Set of specimens at elevated temperature

The experimental results of the specimens tested at elevated temperature are shown in Table 3, in which they are compared with the results of identical test specimens tested at room temperature. The shear strength of the specimens at elevated temperature is much lower than the specimens at room temperature (only 32% of the shear strength of specimens at room temperature). The shear modulus is also lower (only 13% for aluminium and 17% for Zn-electroplated steel). The typical failure mode for all specimens at elevated temperature was the loss of adhesion to the glass. In contrast, at room temperature, adhesion to steel was lost in case of specimens with Zn-electroplated steel. All specimens at elevated temperature also had higher shear strain than specimens at room temperature, see Fig. 7. In addition, the results of the test specimens at room temperature showed greater variation compared to specimens tested at elevated temperature, see Fig. 8.

Table 3: Specimens with 3 mm adhesive layer thickness.

Type of specimen	Room temperature + 23 °C ± 2 °C			Elevated temperature + 80 °C ± 2 °C			Strength ratio
	Shear Strength [MPa]	Shear Modulus [MPa]	Failure	Shear Strength [MPa]	Shear Modulus [MPa]	Failure	
Aluminium	17.280	200	S	5.072	31	A	31.94%
Zn-electroplated steel	15.550	195	**A**-S	5.032	26	A	32.36%

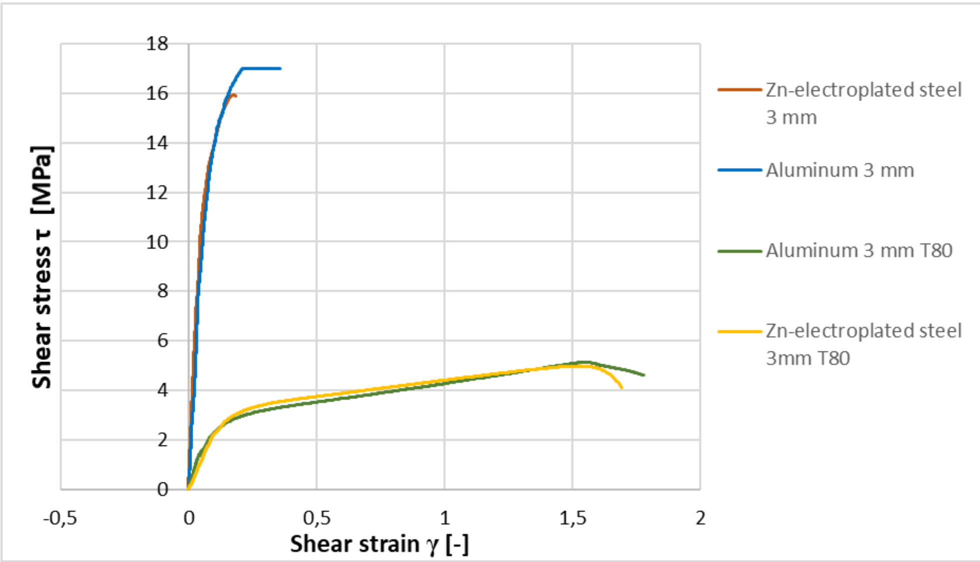


Fig. 7 Stress-strain relationship for specimens at room and elevated temperature.

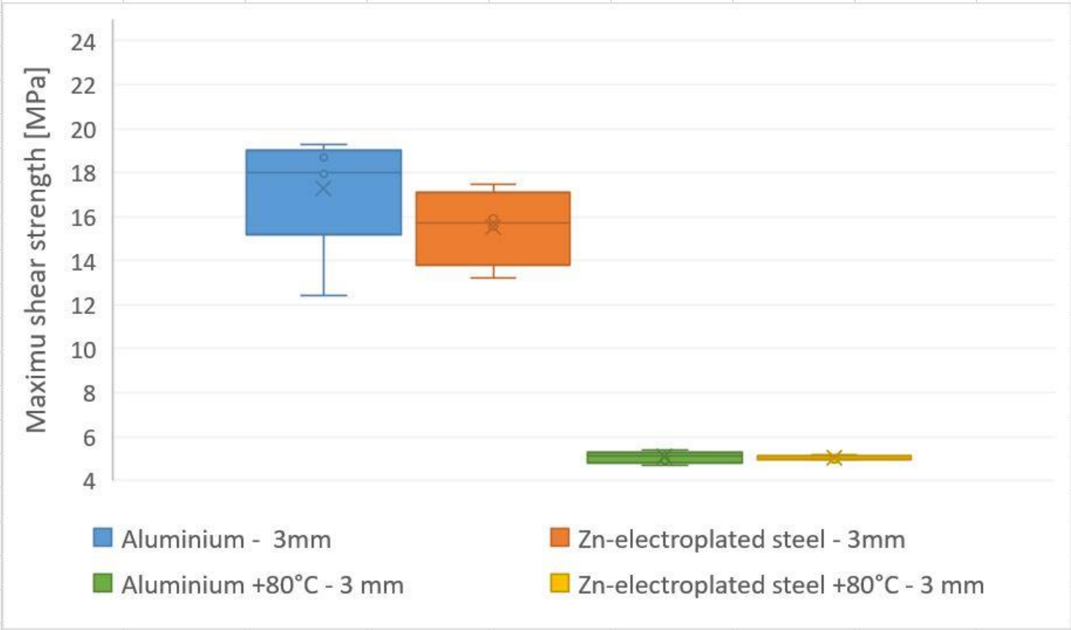


Fig. 8 Maximum shear strength for specimen at room and elevated temperature.

4. Conclusion

Acrylate adhesive showed high shear modulus and high shear strength. During the tests at room temperature, there was low deformation of the adhesive layer and an increase of local stress peaks, resulting in glass failure. By comparing the results of the test specimens with different thicknesses of the adhesive layer, it can be stated that the joint with the thickness of 1 mm has the least deformation, which leads to the greatest destruction of the bonded glass plate. Specimens with 3 mm and 5 mm adhesive layer thickness could deform more so that the local stress peaks in the glass are not so great. The acrylate adhesive shows good adhesion to glass at room temperature, but at elevated temperature adhesion is lost. In addition, at elevated temperatures, the shear strength decreases to 30% and the shear modulus to 17%.

5. Acknowledgement

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6. References

Bues, M., Schuler, C., Albiez, M., Ummenhofer, T., Fricke, H., Vallée, T.: Load bearing and failure behavior of adhesively bonded glass-metal joints in façade structures. J. Adhesion. (2019). Doi: 10.1080/00218464.2019.1570158

Ciupack, Y., Pasternak, H., Mette, Ch., Stammen, E., Dilger, K.: Adhesive bonding in steel construction – Challenge and innovation. Procedia Eng. 172, 186-193 (2017). Doi: 10.1016/j.proeng.2017.02.048

Liška, P., Šlanhof, J., Nečasová, B.: Revitalization of Façade Cladding with Use of Bonded Joints. Adv. Mater. Res. 1041, 191-194 (2014). Doi: 10.4028/www.scientific.net/AMR.1041.191

Nicklisch, F., Weller, B.: Adhesive Bonding of Timber and Glass in Load-bearing Facades – Evaluation of the Ageing Behaviour. World Conference on Timber Engineering. (2016).

Sousa, J. M., Correia, J. R., Cabral-Fonseca, S.: Durability of an epoxy adhesive used in civil structural applications. Constr. Build. Mater. 161, 618-633 (2018). Doi: 10.1016/j.conbuildmat.2017.11.168

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