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Structural Adhesive Joints for Civil Engineering Use

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Abstract:

The paper reports on an experimental analysis focused on determining the mechanical characteristics of two types of acrylate adhesives applied in a double lap connection loaded by shear. The study comprises two basic substrate materials often used in façades both for cladding and for substructure – aluminium and galvanised steel. Both materials are applied with a smooth and mechanically roughened surface to compare adhesion in relation to the laboriousness of surface preparation. Except for blank aluminium, anodised aluminium was also used. Material and surface treatment has a great influence not only on adhesion and hence strength of the joint but also on failure mode, behaviour and safety of a particular joint. Moreover, every necessary surface treatment creates higher labour intensity, higher time consumption and thus increased costs. Our results showed different behaviour of both chosen acrylate adhesives in spite of their similar chemical bases. The first acrylate, two-part structural methacrylate, showed shear strength from 12 to 17 MPa in dependence on substrate material with shear strain between 0.6 and 1.2. The best adhesion was observed at roughened galvanised steel substrates. The second acrylate adhesive, two-part structural adhesive based on acrylic double performance polymer technology (ADP), proved shear strength from 8 to 9 MPa for aluminium substrates and less than 6 MPa for galvanised steel substrates. ADP adhesive also showed higher shear strain values (approx. 2.8). The experimental study proved that a choice of the adhesive has a great influence on the mechanical properties of adhesively bonded joint as well as on adhesion to a particular substrate even in the case of a similar chemical base of adhesives.

Keywords: Acrylate; Adhesive Joint; Mechanical Properties; Metal Substrate; Adhesion.

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1. INTRODUCTION

Thanks to improved characteristics of structural adhesives, there are new possibilities of using adhesive connections in civil engineering, e.g. in façade applications. [1-3] Façades have to fulfil not only architectural requirements but there are also construction and material technology requirements, as well as functionality. Connections between substructure and façade cladding can be advantageously designed as an adhesive joint [4, 5]. In dependence on the particular application, adhesive bonding provides higher efficiency of workmanship in comparison with bolted connection and esthetical qualities, e.g. the smooth, flat surface of façade cladding without visual interruption of bolts. An important benefit of adhesive joints in façades is elimination of local thermal bridge in comparison with bolted connections and the possibility of stress peak reduction in dependence on adhesive and substrates stiffnesses and geometrical arrangement of the joint. Despite wide usage of relatively low strength and elastic silicone sealants for a long period of time in façades, there is a lack of information about semi-flexible and semi-rigid adhesives with beneficial higher strength and reasonable elongation at break that is important for stress accommodation in case of joining two materials with different thermal expansion coefficients. There is a lack of standards and guidelines focused on adhesive connection in civil engineering applications,

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especially in building façade connections. The façade is a very specific type of usage for adhesive connections due to the requirements on durability, strict geometrical imperfections and also joining of unconventional materials often used in the façade design. For that reason, our research is aimed at the adhesives with higher strength than silicones and metal substrates which could be used in façade connections. The article is a part of extensive research focused on adhesive joints in the façades which are exposed to outdoor environmental conditions which may have a significant influence on mechanical properties of adhesive joint [6].

2. EXPERIMENTAL PROCEDURE

2.1 Adhesives and Substrates Chosen for The Research

Silicone sealants have been used for bonding in the façade industry for 40 years due to their great resistance to environmental aging factors [7]. Adhesive connections are required in modern architecture due to visually smooth surface of façade without interruption of bolts, high efficiency and accuracy of manufacturing. Nowadays, contemporary architecture requires slender metal framework and larger façade panels which create requirement on higher strength of adhesive than traditional silicone sealants have [8]. In addition to elastic and relatively low strength silicone adhesives applied in linear joints, there is increased interest in adhesives providing higher strength, such as polyurethanes, acrylates or the transparent structural silicone adhesive (TSSA) developed for point fixing of glazing [9]. It enables increased transparency and/or the use of lightweight cross-sections for the sub-frame as it was examined by Pasternak and Ciupack [10].

The adhesives for the research were selected on the basis of their applications in planar connections in the façade. The adhesive in the connection provides sufficient strength and stiffness to ensure the transmission of load from façade panels to supporting structure but the adhesive layer should also be flexible enough to accommodate the stresses originating from the different thermal expansions of the joining materials. In order to meet these requirements, two different acrylate adhesives were chosen for the study.

Two-part structural methacrylate (SMA) is a primer-less acrylic adhesive designed for bonding composites, thermoplastics and metals. SMA adhesive has a high toughness with gap-filling capacity up to 5 mm and it has excellent environmental resistance [11]. Lap shear strength is 13-18 MPa for galvanised steel and 17-22 MPa for aluminium substrates according to technical data sheet [11].

The second acrylate adhesive is a two-part flexibilized structural adhesive based on Sika´s Acrylic Double Performance (ADP) technology. This adhesive was designed to replace mechanical fixings. It has shear strength 10 MPa (to galvanised steel and aluminium) and elongation at break approximately 200% according to manufacturer data sheet [12].

Various substrates and their preliminary surface treatment have a great influence not only on adhesion and thus strength of the joint, but also on failure mode behaviour and safety of particular joint. For this reason, two basic substrate materials, which are often used in façade industry, blank and anodised aluminium and zinc-electroplated steel, were chosen for the study. Preliminary surface treatment of SMA adhesive comprised cleaning and degreasing by acetone. Surface of the specimens bonded by ADP adhesive was cleaned and activated by Sika® ADPrep according to manufacturer´s instructions in data sheet. Blank aluminium and zinc-electroplated steel substrates were used in joints with smooth or roughened surface to analyse the influence of roughening to mechanical properties of joint and its failure mode in relation to laboriousness.

2.2. Test Methods and Specimens

Specimens were prepared in accordance with ETAG 002 “Guideline for European technical approval for Structural sealant glazing kits” [13], but they were produced as double-lap shear joints. A shear double-lap joint is very suitable type of geometrical set-up for adhesive connections. It provides good feasibility and sufficiently large bonded surfaces [14]. Symmetrical arrangement minimizes the peel stress, which is induced in single-lap joints together with shear stress. Shear stress distribution depends considerably on the geometry of the joint (the overlap length and the bond line thickness), the mechanical characteristics of the adhesive and the elastic modulus of substrate materials and their thickness [15].

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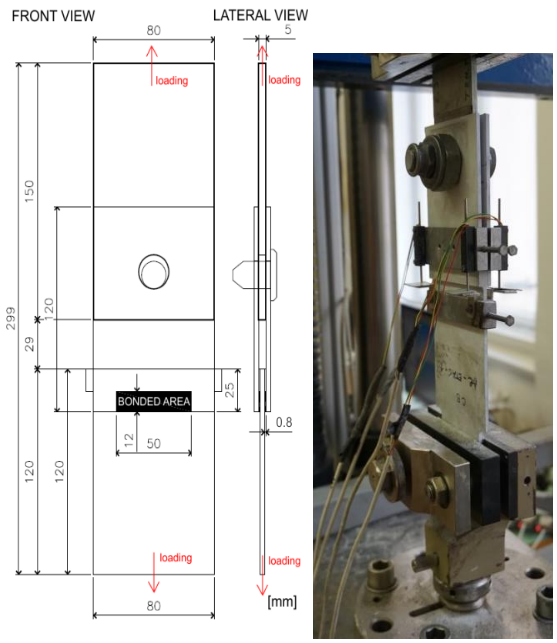

Figure 1. Specimen – a) Scheme of specimen, b) photo of specimen under loading.

Adhesive was applied in bonded area 2 times 12 x 50 mm, see Figure 1a, and 0.8 mm (average value) in thickness for both acrylate adhesives. The thickness of joint was designed in accordance with optimal thickness for the particular adhesive system given by the manufacturer. Shear loading of the bonded area arose from the tensile loading of the whole specimen. For tensile loading of specimens, TIRA testing system was used. Specimens were loaded at crosshead speed 1 mm/min until the total destruction of the joint. Deformation was measured by two linear potentiometric transducers at both ends of one overlap joint, therefore four transducers per one specimen were used, see Figure 1b. The average value of deformation was calculated for the evaluation of results.

3. RESULTS and DISCUSSION

The measured load-displacement curves were converted into engineering stress - engineering strain relationships, in order to compare the behaviour of different joints. Summarized results of shear tests were presented in Figure 2, where representative curves of the shear stress-strain diagrams of the joints were drawn for each of the adhesives and their tested substrate material and surface treatment.

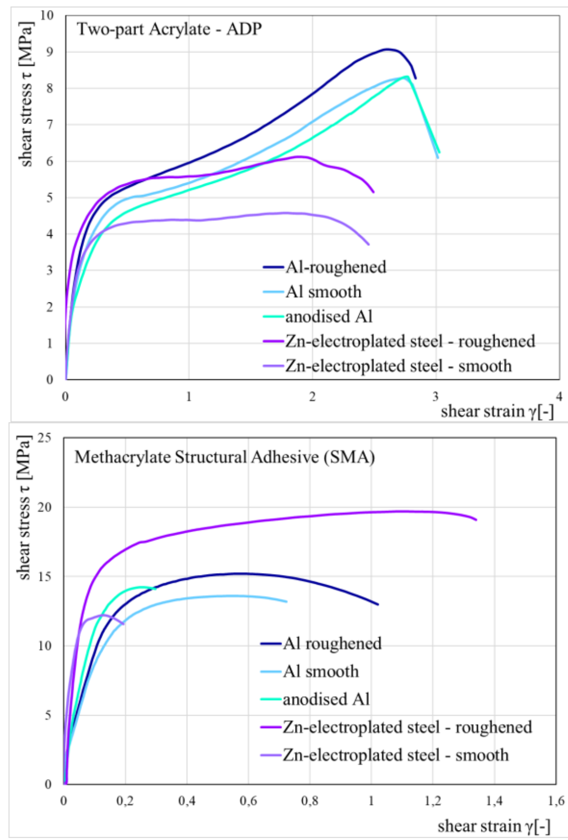

Figure 2. Shear stress-strain relationship a) ADP adhesive; b) SMA adhesive

3.1 Two-part Acrylate Adhesive (ADP)

Specimens bonded by ADP adhesive reached average shear strength 9.3 MPa for aluminium substrate with roughed surface and they showed lowering of strength for other substrates, see Figure 2a and Table 3. All specimens reached shear strain at break approximately 2.5 – 3.0. Experimental results showed significant influence of substrate material and roughening. Experimentally obtained values of shear strength are lower than it is stated in the technical data sheet, especially for zinc-electroplated steel substrates. Experimental results also showed positive effect of roughening on shear strength both for aluminium and zinc-electroplated steel. Aluminium specimens were mostly broken by cohesive failure, especially for specimens with roughened surface. Lower strength values of zinc-electroplated steel specimens were observed together with the adhesive or combined adhesive-cohesive mode of failure with

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prevailing adhesive mode. Typical failure modes of ADP adhesive were depicted in Figure 3.

Table 3. Average shear strength with standard deviation and prevailing mode of failure of two-part acrylate adhesive (ADP); A means adhesive mode of failure, C cohesive mode of failure.

Type of specimen (substrate/treatment)	**Average shear strength [MPa]**	**Prevailing mode of failure**
Aluminium / roughened surface	9.3 ± 0.7	C
Aluminium / smooth surface	8.4 ± 0.9	A/**C**
Anodised aluminium	8.5 ± 0.6	C
Zn-electroplated steel / roughened surface	6.2 ± 1.2	**A**/C
Zn-electroplated steel / smooth surface	4.7 ± 0.8	**A**/C

a)

b)

c)

d)

Figure 3. Mode of failure of ADP adhesive **a)** smooth aluminium substrate; **b)** smooth galvanised steel substrate **c)** anodised aluminium substrate **d)** roughened galvanised steel substrate.

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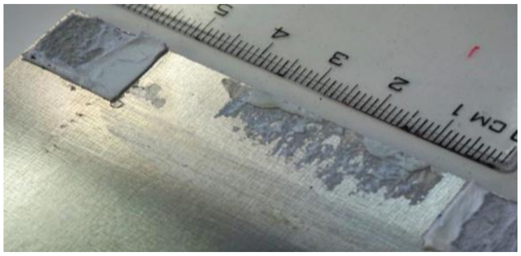
3.2 Structural Methacrylate (SMA) Adhesive

Specimens bonded by SMA adhesive showed the best performance with roughened zinc-electroplated steel substrate, where the average shear strength was observed 18.7 MPa, see Figure 2b and Table 4. Experimentally obtained values of shear strength are lower than it is stated in technical data sheet, especially for aluminium. According to the data in technical data sheet, we expected shear strength values for aluminium higher than 20 MPa and for zinc-electroplated steel about 15 MPa.

Table 4. Average shear strength with standard deviation and prevailing failure modes of SMA adhesive; A means adhesive mode of failure, C cohesive mode of failure, SCF cohesive failure close to substrate.

Type of specimen (substrate/treatment)	**Average shear strength [MPa]**	**Prevailing mode of failure**
Aluminium / roughened surface	14.6 ± 1.3	**A**/C + whitening
Aluminium / smooth surface	13.8 ± 0.5	**A**/C + whitening
Anodised aluminium	14.2 ± 3.2	**A**/SCF + whitening
Zn-electroplated steel / roughened surface	18.7 ± 1.4	SCF + whitening
Zn-electroplated steel / smooth surface	12.2 ± 1.2	**A**/SCF + whitening

a)



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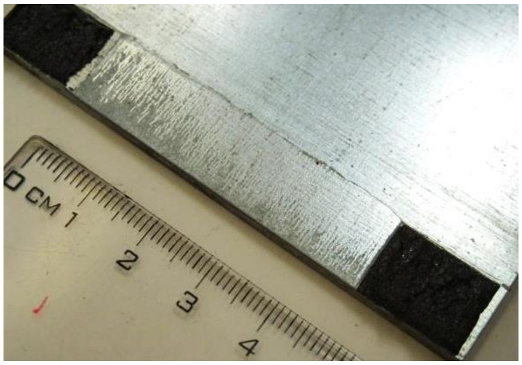

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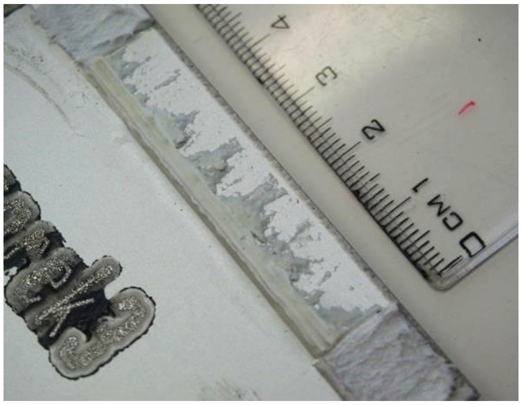

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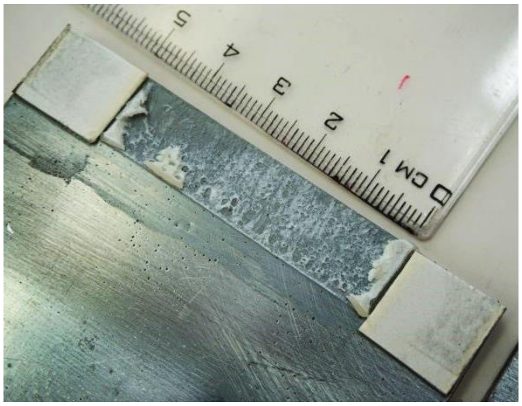

Figure 4. Mode of failure for SMA adhesive **a)** smooth aluminium substrate; **b)** smooth galvanised steel substrate **c)** anodised aluminium substrate **d)** roughened galvanised steel substrate.

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All specimens except zinc-electroplated steel were broken by combined adhesive-cohesive mode of failure with prevailing adhesive mode of failure (more than 60% of the bonded area). Roughened zinc-electroplated steel specimens were also broken by combined adhesive-cohesive mode of failure, but close-to-substrate cohesive failure mode was predominant (more than 90% of the bonded area). All specimens showed whitening of adhesive layer after loading which indicates polymer damage through force transmission [16]. It also indicates stress peaks in interfacial zone, where adhesive bond is finally broken by adhesive or cohesive mode of failure. Prevailing mode of failure depends on location where the weaker bonds exist. If the weaker bond is between adhesive and substrate, the adhesive failure mode was observed. If the weaker bond is in adhesive layer close to substrate, the cohesive failure mode happens. Typical failure modes of SMA adhesive were depicted in Figure 4.

4. CONCLUSION

A main objective of this investigation was to evaluate the effect of substrate materials and surface roughening on the mechanical properties of the selected adhesives. The following conclusions have been drawn from the findings of the tests:

- ADP adhesive specimens proved significant lowering of shear strength values for galvanised steel by 30% with roughened surface and 45% with smooth surface in comparison to the roughened aluminium substrate;
- ADP adhesive showed cohesive mode of failure for roughened aluminium and anodised aluminium;
- SMA adhesive proved significantly lower shear strength values for smooth aluminium substrates (by 25%) than for roughened zinc-electroplated steel;
- SMA adhesive showed whitening of polymer by excessive loading at all specimens., however only roughened zinc-electroplated steel specimens were broken by cohesive mode of failure close to the substrate;
- Roughening of surface had influence on reached shear strength values and failure mode for both acrylate adhesives;
- Technical data sheets provide only tentative information about strength of adhesive in joint; mechanical characteristics of adhesive in particular connection were influenced by substrate material as well as surface treatment and therefore strength of particular connection can vary significantly;
- Choice of the adhesive had a great influence on mechanical properties of adhesively bonded joint as well as on adhesion to a particular substrate even in the case of the similar chemical base of adhesives.

5. ACKNOWLEDGMENT

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6. REFERENCES

[1] A. Kwakernaak, J. Hofstede, J. Poulis, R. Benedictus, Improvements in bonding metals (steel, aluminium), in: D.A. Dillard (Eds.), Advances in Structural Adhesive Bonding, Woodhead Publishing, 2010, pp. 185-236. **DOI:** http://dx.doi.org/10.1533/9781845698058.2.185.

[2] M. Heshmati, R. Haghani, M. Al-Emrani, Environmental durability of adhesively bonded FRP/steel joints in civil engineering applications: State of the art, Composites Part B: Engineering. 81 (2015) 259-275. **DOI:** dx.doi.org/10.1016/j.compositesb.2015.07.014.

[3] F. Oikonomopoulou, F. Veer, R. Nijsse, K. Baardolf, A completely transparent, adhesively bonded soda-lime glass block masonry system. J. Facade Des. Eng. 2 (2015) 201–221.
DOI: http://dx.doi.org/ 10.3233/FDE-150021.

[4] M. Haldimann, A. Luible, M. Overend, Structural Use of Glass. IABSE-AIPC-IVBH, Zurich, 2008.

[5] I. Hartung, S. Boehm, Civil construction, in: L.F.M. da Silva, A. Ochsner, R.D. Adams (Eds.), Handbook of Adhesion Technology, Springer, Heidelberg, 2011, pp. 1263–1288.

[6] K.V. Machalická, M. Vokáč, P. Pokorný, M. Pavlíková, Effect of various artificial ageing procedures on adhesive joints for civil engineering applications, International Journal of Adhesion and Adhesives. 97 (2020).
DOI: http://dx.doi.org/10.1016/j.ijadhadh.2019.102476.

[7] C. Schittich, Glass Construction Manual, Birkhauser, Basel, 2007.

[8] S. Nhamoinesu, M. Overend, The mechanical performance of adhesives for a steel-glass composite

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facade systém, in: F. Bos, C. Louter, R. Nijsse, F. Veer (Eds.), Challenging Glass 3 - Conference on Architectural and Structural Applications of Glass, IOS Press BV, Amsterdam, 2012, pp. 293–306.

[9] S. Sitte, M.J. Brasseur, L.D Carbary, A.T. Wolf, Preliminary Evaluation of the Mechanical Properties and Durability of Transparent Structural Silicone Adhesive (TSSA) for Point Fixing in Glazing, Journal of ASTM International. 8 (2011) 1-27.
DOI: http://dx.doi.org/10.1520/jai104084.

[10] H. Pasternak, Y. Ciupack, Development of Eurocode-based design rules for adhesive bonded joints, International Journal of Adhesion and Adhesives. 53 (2014) 97-106.
DOI: http://dx.doi.org/10.1016/j.ijadhadh.2014.01.011.

[11] Scott Bader Company Ltd., Crestabond M7-05 Technical Data Sheet, Scott Bader data sheets. https://www.scottbader.com/wp-content/uploads/Crestabond-M7-05_ENG_TDS_Aug18.pdf

[12] SIKA Canada, SikaFast 5215 NT Product data sheet, Products and solutions: Commercial Vehicles, Products, Rails.
https://can.sika.com/dms/getdocument.get/67e576ce-e242-384e-89f3-bd717daa95cb/ind-pds-sikafast-5215.pdf

[13] European Organisation for Technical Approvals, Guideline for European Technical Approval for Structural Sealant Glazing Kit, ETAG 002, Brussels, 2012.

[14] E. Petrie, Handbook of Adhesives and Sealants, McGraw-Hill, New York, 2009.

[15] J. Vervloed, A. Kwakernaak, H. Poulis, The influence of overlap length, bond line thickness and pretreatment on the mechanical properties of adhesives: focusing on bonding glass, in: F. Bos, C. Louter, F. Veer (Eds.), Challenging Glass - Conference on Architectural and Structural Applications of Glass, IOS Press, Amsterdam, 2008, pp. 285–294.

[16] E. Sancaktar, Constitutive Adhesive and Sealant Models, in: L.F.M. da Silva, A. Ochsner, R.D. Adams (Eds.), Handbook of Adhesion Technology, Springer, Heidelberg, 2011, pp. 551-595.
DOI: http://dx.doi.org/10.1007/978-3-642-01169-6_23.

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