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Analysis of the effect of surface pre-treatment on selected properties of the glass-metal bonded joint

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Abstract: Due to its properties, glass is a material that is increasingly used in technical practices including construction and architecture. Products that combine both glass and metal are often used in the construction industry. Nowadays, modern methods of joining these materials are being sought, which include gluing. Bonding is a multi-step process that is affected by both internal and external factors. The resulting quality of the joint, which can be evaluated by destructive and non-destructive tests, is important for the application of a glued joint that is exposed to external stress. The presented article deals with the analysis of the effect of pre-treatment on selected properties of the bonded glass-metal pair using selected methods of destructive testing.

Keywords: glass-metal, pre-treatment, joint, testing

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Introduction

Glass is a material that has accompanied mankind for several centuries. In technical practice, it is used for its good insulating properties, resistance to noise, UV radiation, impacts, and many more. These are just some of the reasons why it finds its application in construction; see today's modern buildings in the Persian Gulf.

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Glass in architecture and construction is often combined with various metals, and possibilities are currently being sought for joining them together by gluing.

Bonding is an important technology used in the field of construction, engineering, transport, etc., where a close connection of two materials is required. Bonding is based on technologies that are based on the laws of chemistry, physics and material science (Katsivalis et al., 2020; Machalicka & Eliasova, 2017; Malecki & Della Corte, 2005; Robert et al., 2021; Ruixiang et al., 2020). In order for glued joints to serve us well, it is important to know not only the properties of adhesives and glued materials, but also the way in which the glued materials will be stressed. Choosing an appropriate bonding process can result in better end-use performance, higher efficiency, and more flexibility in the final design of the bonded joint (Gil et al., 2022; Machalicka & Eliasova, 2017; Ruixiang et al., 2020). Industrial bonding is a progressive technology that is most prevalent in the automotive, aerospace and the construction industries. Greater and greater demands are placed on the design of glued joints, not only with regard to the mechanical properties of the resulting glued joint, but also to the aesthetic design of this joint. Glued metal-glass joints belong to the most widespread solutions in the field of bonding, where they are applied in the construction industry (Tatic Lucic et al., 1997). Most of the joints glued in this way are directly visible to the end user of the product, whether it is safety glass on a post office counter, a facade glass element on a high-rise building, or the driver's windshield on a high-speed train (Hamada et al., 2022). Technical bonding technology generally consists of surface preparation of the bonded materials, preparation of the adhesive, application of the adhesive, assembly of the bonded parts and formation of a solid joint due to the curing of the adhesive. The quality of the glued joint is influenced by factors of bonding technology, such as the method of applying the glue, the thickness of the applied layer of glue, the conditions during the curing of the glue (time, pressure, temperature), the preparation of the glue for its use and the preparation of the surface of the material and the substrate before the actual gluing (Petrie, 1999; Machalicka & Eliasova, 2017). Pre-treatment of the surface of the bonded materials can be carried out either mechanically, chemically, thermally or by plasma. After the desired connection is created, the quality of the created connection is evaluated (Machalicka & Eliasova, 2017; Malecki & Della Corte, 2005; Ruixiang et al., 2020). Since glass bonding is a multi-stage technological process that is influenced by a number of internal and external factors (Kuśmierczak & Majzner, 2017), rigorous testing of the created connections is needed (Lifang et al., 2017; Ligaj et al., 2018; Santos et al., 2021; Trinh et al., 2021). Bonded joint tests can be classically divided into destructive and non-destructive. Frequently used tests of metal-glass bonded joints include surface tension measurement of bonded substrates according to ISO 8296, tensile testing of glued samples according to ČSN EN ISO 8339, and visual assessment of fracture of the glued joint according to ČSN ISO 10365. The aim of the article is to analyze the influence of surface pre-treatment on selected properties of the glued glass-metal joint.

1. Experimental material

Four series of test samples of 3 pieces each were made. The test samples were made of two substrates, which are 6 mm clear float glass according to ČSN EN 572-2 and aluminium profile EN AW 6060/T6 (AlMgSi0.5 F22) according to ČSN EN 573-3. The substrates were bonded using two-component silicone materials: a structural adhesive and a secondary sealant for structural insulating glazing. The shape and dimensions of the samples correspond to the requirements of ETAG 002 SSGK (Fig. 1).

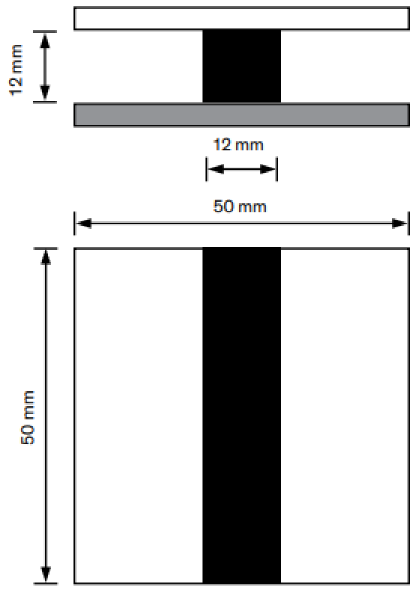

Fig. 1. Detail of sample for H-test (*own research*)

The samples were cleaned of surface dirt and grease using isopropyl alcohol, which is commonly used as a cleaning agent and degreaser. For each series, a surface pre-treatment procedure was established, where, in view of easy availability, a chemical surface pre-treatment in the form of an activator and primer was applied to most samples, while the aluminium profiles were anodized. Manual roughening of the surface using 3M Scotch Brite abrasive cloth was chosen for these profiles. For the S4 series of samples, a mechanical surface pre-treatment was chosen, the purpose of which was to roughen the contact surfaces on both substrates. The aim of the roughening of these surfaces was to increase the contact bonded surfaces and thus ensure an increase in adhesion. To roughen the surface of 6 mm glass, mechanical surface pre-treatment was used in the form of blasting (sandblasting) of mineral, sharp-edged, demagnetized abrasive in the grain size of F-240 Al_2O_3 artificial white corundum. Overview of experiment samples presented in Table 1.

Table 1. Overview of experiment samples (*own research*)

Substrate	Pre-treatment of the surface	Substrate	Pre-treatment of the surface	Gluing system	Sample identification	Number of pieces
Al profile EN AW 6060	without	Glass 6 mm	without	2K SIL DC 993	S1.1 – S1.3	3
	Activator (R40)		Activator (R40)		S2.4 – S2.6	3
	Activator (R40) + Primer		Activator (R40) + Primer		S3.7 – S3.9	3
	Sanding ScotchBrite + Activator (R40) + Primer		Blasting (F240) + Activator (R40) + Primer		S4.10 – S4.12	3

2. Testing methods

The resulting effect of chemical surface pre-treatment of the surface was tested using surface tension measurement according to the ISO 8296 standard, tensile testing of glued samples according to ČSN EN ISO 8339 and visual evaluation of the fracture of the glued joint according to ČSN ISO 10365.

2.1. Surface tension measurement according to ISO 8296

Surface tension is one of the decisive criteria for successful adhesion on any surface. In general, it can be stated that the higher the surface tension of the material, the better the adhesion will be when fixing to the surface of the given material. The general limit for this characteristic is the stated value of 38 mN/m, and in the case when the surface tension is below this value, the adhesion will be poor, on the contrary, above this value, the adhesion should be good. For the purposes of the test, the test inks fy. Plasmatreat with values of 32, 42, 52 and 62 mN/m were used. The performance of the test is governed by the ISO 8296 standard. The values measured during the surface tension test always represent the entire series (i.e. three samples) and are listed in Table 2.

Table 2. Measured values of surface tension (*own research*)

Series	Substrate	Pre-treatment of the surface	Surface energy [mN/m]	Substrate	Pre-treatment of the surface	Surface stress [mN/m]
S1	EN AW 6060	N/A	< 32	Glass 6 mm	N/A	< 32
S2		Activator	< 32		Activator	< 32
S3		Activator + Primer	32-42		Activator + Primer	32-42
S4		Activator + Primer + Grinding	32-42		Activator + Primer + Blasting	32-42

2.2. Tensile test according to ČSN EN ISO 8339

The test was carried out according to the ČSN EN ISO 8339 standards and the European regulation for structural glazing ETAG002. The prepared samples were conditioned for three days at (23 ± 2)°C and (50 ± 5)% relative humidity. The minimum force for sufficient adhesion was determined by the adhesive manufacturer and was at least 420 N, where a properly cured sealant should have a minimum strength of 0.7 MPa with > 95% cohesive failure. The load time was at least 10 seconds. In the case of this tensile test, the glued joint must be stressed with a force of at least 425 N at an air pressure of 4 bar for a minimum of 10 seconds. If the test specimen withstands the specified tension for the specified time, the tensile force will increase until the specimen breaks. For a satisfactory test, there must be > 95% cohesive failure of the adhesive itself, the adhesive must not separate from the profile or from the glass. The values achieved during the tensile test are shown in Table 3.

Table 3. Values achieved during the tensile test, EN AW 6060, substrate glass 6 mm (*own research*)

Sample number	Pre-treatment of the surface	Gluing system	Air pressure [bar]	Force [N]
S1.1 – 3	N/A	993	3	339
S2.4 – 6	Activator		4	452
S3.7	Activator		5	565
S3.8 S3.9	Primer		6	679
S4.10	Grinding Activator Primer		7	792
S4.11			6	679
S4.12			7	792

2.3. Visual evaluation of the fracture of the glued joint according to ČSN ISO 10365

After breaking all the samples in the tensile test, the fracture of the glued joint was evaluated on each individual sample. For the test to be successful, it is necessary that, in addition to the specified strength, the fracture should be > 95% of a cohesive nature, i.e. that the fracture should occur in the mass of the adhesive and not to detach the adhesive from the substrate. Visual evaluation is carried out according to the ČSN EN ISO 10365 standard, which lists the parameters for visual evaluation (Table 4). The values found during the visual evaluation of broken samples are shown in Table 5.

Table 4. Criteria for evaluating the fracture of the glued joint according to ČSN EN ISO 10365 (*own research*)

Fracture	Evaluation	Adhesion
1	Satisfying	> 95% cohesive failure
2	Basically satisfying	> 75% cohesive failure
3	Unsatisfying	< 50% cohesive failure
4	Unsatisfying	< 25% cohesive failure

Table 5. Resulting visual evaluation of broken samples, EN AW 6060, substrate glass 6 mm (*own research*)

Sample	Force [N]	Fracture
S1.1	339	3
S1.2		2
S1.3		3
S2.4	452	2
S2.5		2
S2.6		2
S3.7	565	1
S3.8	679	2
S3.9	679	1
S4.10	792	1
S4.11	679	1
S4.12	792	1

Conclusion

The aim of the presented article was to analyze the effect of surface pre-treatment of materials before gluing on selected mechanical properties of the bonded metal--glass joint. Surface pre-treatments have been chosen so that they can be carried out and applied without special processes.

If we compare the series that were bonded with the same material – high-strength two-component silicone adhesive DC993, which is specially designed for structural bonding of glass, metal and other building components, i.e. series 1-4, we find that the achieved strength value for series 4 is approx. 2.5 times higher (792 N) than for Series 1 (339 N) and also very different is the cohesive fracture failure occurred when the specimen ruptures during the tensile test, where for Series 4 the value is 1, which corresponds to > 95% cohesive failure (desirable) and for Series 1 the value is 3, which corresponds to < 50% cohesive failure (undesirable). The influence of the applied surface pre-treatments is clearly observable in these four series and the trend of the strength achieved during the tensile test is completely upward, copying the care and sophistication of the applied surface pre-treatments, where for the 1st series the samples were only degreased, for the 2nd series a single-stage chemical surface pre-treatment in the form of an activator, for the 3rd series a two-stage chemical surface pre-treatment of activator + primer was used, and for the 4th series, a mechanical surface pre-treatment in the form of glass blasting and fine manual grinding of the Al profile was additionally performed before the two-stage chemical pre-treatment. The results of the destructive testing in the form of a tensile test confirmed the theory that it makes sense to spend time and be consistent in preparing the surface of the materials before gluing, because the effect of the applied surface pre-treatments on the resulting mechanical properties of the examined glued joint is clear from the results of the experimental part.

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