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Determination of adhesion of silyl modified polymer adhesives to wooden façade cladding – case study

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Abstract

Adhesives are currently very often designed specifically for bonded façade systems. The potential of bonded joints should be studied and described in more detail and verified through experimental measurements. Presented results are therefore focused test methods intended for vented wooden façade systems with bonded joints. For the purpose of tests two types of silyl modified polymer adhesives intended for structural bonding were selected, however, only one of them is recommended for façade systems. The spruce profiles and three types of façade cladding (i.e. Cement-bonded particleboard - Cetris, Siberian larch and Wooden Plastic Composite - WPC) represent the structure of vented façade. The focus was on experimental verification thus all test procedures are following relevant European technical standards. The adhesive bonds were tested in adhesion of the surface finish to the substructure as well as in tensile lap - shear at a temperature of (20.0 ± 3) °C and a relative humidity of (55.0 ± 10) %. The performed tests showed the equivalence of the bonded joint system for ventilated facades in comparison with mechanical joints. During the tests appeared differences in stability and failure behaviour between the adhesive systems as well as within the sheeting material. Another conclusion arising from the series of tests is the fact that the use of a wooden substructure for ventilated facades is not a limiting element for the whole system and is a more financially viable option in comparison with an aluminum or steel substructure.

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Keywords: Adhesive system; Adhesion; Adhesive failure; Cetris; Cohesion; Cohesive failure; Modified Polymer;Siberian larch; WPC

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1. Introduction

Wooden structures and wood elements used in exterior can experience a series of chemical and physical changes that spoil its aesthetic appeal, durability and service life. Therefore, civil engineers are currently very often meeting with obstacles as revitalization or redemption of wooden facades. One of the most popular design is with mechanical anchor elements. However, the durability of these joints is limited. Moreover, mechanical joints can cause premature degradation of façade cladding. Hence, the potential of bonded joints should be studied in more detail. Design of vented façades with wooden cladding is not a new technology. As early as 1998 Straalen et al. [1] introduced methods to draw up design rules to calculate the resistance of bonded joints for structural applications. The results obtained from series of tests revealed that in case of bonded joints also the durability effects have to be considered. Later, Krüger and Schneider [2] tested the behavior of bonded joint on existing construction in Stuttgart. They verified that the elastic adhesive technique allows an invisible back-panel fixing without any weakening of the cross-section of the plate. Due to an extensive bonding area along the edges of the panels, the loads resulting from wind, temperature and the self-weight of the plate are carried out uniformly. A stress concentration as produced i.e. by anchors is avoided. In the case of failure of a facade plate the adhesive joint is able to hold large fragments in place. One of very important parameters that can influence incoming behavior of bonded joint's performance was described by Banea et al. [3]. It is the adhesive layer thickness. Most of the results from literature are for typical structural epoxy adhesives which are generally formulated to perform in thin sections. However, polyurethane adhesives as well as modified polymers are designed to perform in thicker sections and might have a different behavior as a function of adhesive thickness. In this research case was used a thickness of 3 mm which is usually stipulated for this type of adhesive by all manufacturers Davies [4]. Even though, this technique is not a new technology, there are no examples where the entire façade system was designed from bonded wooden elements. Furthermore, till now, the adhesive bonding technology has not been able to properly establish in construction and design rules anchored in Eurocode standards were not developed yet Pasternak [5]. According to Krüger and Schneider [2] and Liška et al. [6], preliminary to the introduction of a complete bonded facade system to the market, the new design of the structure have to endure series of load tests.

2. Materials

The selection of appropriate facade cladding components is a significant phase in the design of ventilated facade. Wrong combination of selected materials can cause a substantial reduction in durability of the entire façade system and in particular can lead to a remarkable increase of requirements concerning the maintenance. Therefore, it is important to pay close attention to the selection not only of the cladding material however, of all materials used in the construction of the façade system.

2.1. Load – bearing substructure

Common spruce joists were selected as a material for the load bearing substructure, since it is the most used material for timber façade substructure and also the most available timber profile on the market. The only demand on this material is at least the strength class C22, general material properties can be seen in Table 1. Also, all used profiles have to be dried to a max. 15 % humidity. Sometimes the profiles have to be dressed (on the bonded side), however, the manufacturer of selected group of adhesives does not demand such a process.

Table 1. Material properties of Spruce – strength class C22.

Material properties	Mean values
Density	410 $kg{\cdot}m^{-3}$
Shear strength	3.8 $N{\cdot}mm^{-2}$
Tensile strength perpendicular to grain	5.0 $N{\cdot}mm^{-2}$

2.2. Cladding material

When selecting the cladding material for the preparation of test samples, the emphasis was mainly on the possibility of usage of the material in an outdoor environment. It was also important to test only wooden or wood-based materials. On the basis of these criteria a cement-bonded particleboard (hereinafter Cetris) with a smooth surface, Siberian larch exterior planks and Wooden Plastic Composite (hereinafterWPC) were selected. Cetris is, according to the data given by manufacturer CIDEM Hranice, a.s. [7], produced by pressing a mixture of wood chips (63%), Portland cement (25%), water (10%) and hydration additives (2%). Benefits of this material are its low maintenance and resistance to decay. Siberian larch façade cladding was selected due to its benefits as are dimensional stability, low maintenance and natural resistance to decay. The wooden plastic composite is unique timber alternative which combines the traditional appearance of timber with the durability and resilience of an engineered composite that is capable to withstand the harsh weather changes. The principal ingredients are specially selected clean plastic polymers, thermoplastic resin (40%), and wood based fibres (50%) with additives (10%), as are pigments, lubricants, UV inhibitors or coupling agents. The material is lignin free and contains no harmful chemicals DG Tip, spol. s r.o.[8]. Moreover, all selected materials are suitable for usage as a cladding of vented facades without any other surface finish, comparison of material properties can be found in Table 2.

Table 2. Material properties of cladding material.

Material	Cetris	Siberian larch	WPC
Material Properties		Mean Values	
Density	1350 kg·m^{-3}	660 kg·m^{-3}	890 kg·m^{-3}
Shear strength	1.8 N·mm^{-2}	10.0 – 12.0 N·mm^{-2}	8.0 N·mm^{-2}
Tensile strength perpendicular to grain (or board plane)	0.63 N·mm^{-2}	1.5 N·mm^{-2}	5.0 N·mm^{-2}

2.3. Adhesives

In this paper two different adhesives manufactured by Bostik BV [9-10] were examined, all of which belong to the group of silyl modified polymer adhesives. Both of them are commercially used for structural bonding, however, only one was designed especially for a structural bonding of wood and wooden materials, Simson PanelTack HM. The second selected adhesive, Simson 007 SMP, is according to the information given by the manufacturer suitable for seam sealing, sealing of connection- and expansion joints. The possible behaviour of Simson 007, when used in vented façade system, was already verified by Liška et al. [6], thus the comparison of recorded results could be more than interesting. Specifications of selected adhesives can be seen in Table 3.

Table 3. Specifications of adhesives.

Material	Simson 007 SMP	Simson PanelTack HM (High Modulus)
Material Specification	Mean Values	
Ultimate tensile strength	2.3 N·mm^{-2}	1.8 N·mm^{-2}
Ultimate shear strength	2.0 N·mm^{-2}	2.25 N·mm^{-2}
Temperature resistance	-40 °C till 100 °C	
Application temperature	-5 °C till 30 °C	
Skinforming	approx. 15 min	
Curing speed	3 mm/ 24 hrs at 20 °C/ RH 50%	

According to Adhesives and glues [11], modified silanes are one component adhesives which react and cure under the action of moisture, during its curing process by polycondensation this type of adhesives emit methanol and once cured acquire elastic properties and typical strength of an elastomeric material. One limitation of the silane modified, as do all the moisture cure adhesive, is the maximum thickness of application due to their curing process goes outside inside, if applied too thick the adhesive require a long time to cure inside, it may not even reach completely cure.

3. Methods

The presented series of tests are following requirements given by Czech technical standards as well as European standards. In the following text the details of used test methods are described in detail.

3.1. Test of the adhesion of the surface finish to the substructure

The series of tests were designed according to the requirements of ČSN 73 2577 [12]. The aim was to observe and record the maximal force that would be able to tear off a given surface finish area from the selected substrate (cladding material) while applying the perpendicular tension.

3.1.1. Production of test samples

The components which represents the cladding material were square in shape, with 100 mm long sides and a thickness of 20 mm or 9 mm in the case of WPC. Likewise, the components which represent load-bearing structure, were square in shape, however with 50 mm long sides, a thickness of 19 mm and a total area of 2 500 mm^2. The production itself involved several steps depending on the requirements of individual manufacturer. All the dust and other dirt have to be removed, the surfaces were chemically treated by cleaning liquid with the aim to achieve the maximal adhesion. When using Simson products it is necessary to apply separately cleaner for porous and non-porous materials. The cleaner for non-porous materials is more aggressive than the one designed for porous materials. After approximately 10 minutes the surfaces were treated by liquid primer with an application brush. Again, it is very important to use primer designed for the particular type of material, thus it is necessary to know the material properties closely.

According to Adhesives and glues [11], the advantages of modified polymers are that they do not require use of primers or adhesion promoters prior to adhesive application, in many cases cleaning of the surface is enough to ensure adhesion between the substrates, thereby reducing both cost of materials and cost of application, also avoid errors during the treatment surface before apply the adhesive. However, during the production of test samples it was verified that the use of proper elements of the adhesive system is more than important, because after the above mentioned period an unexpected phenomenon appeared. As described in Nečasová et al. [13], the Simson primer liquid for porous material have peeled off, therefore an improving liquid primer intended for non-porous materials have to be used.

Afterwards, a sufficient quantity of adhesive was applied, to form a conical shape in the centre of the cladding element. This allowed the distribution of the adhesive all over the surface under the square shaped load-bearing structure element. After pushing the smaller element (load-bearing structure) onto the adhesive, four spacer elements (“beads”) with a diameter of 3 mm were inserted into the adhesive. Distance of exactly 3 mm is demanded by the relevant standard. The importance of the adhesive layer thickness was discussed in the introduction by Banea et al. [3]. Subsequently, the square shaped element (load-bearing structure) was pushed down to the correct distance. The excessive adhesive was removed. A minimum of 6 samples had to be created for each adhesive system, as stipulated in the relevant technical standard.

3.2. Test of the tensile lap - shear of bonded assemblies

The aim of this method was to determine the strength during the exertion of shear stress on a single - lap joint under tensile loading. Likewise the previous test method also this one was designed according to the requirements of ČSN EN 1465 [14].

3.2.1. Production of test samples

The test samples were composed of two identical plates, the area of such a plate is 25 by 100 mm. One of the plates represented the load-bearing structure of the façade system, while the second plate represented façade cladding. Initially the distance of lapping, 12.5 mm (± 0.25 mm), was marked on one of the plates. Afterwards, the ends of the plates where both surfaces should over-lapped, were treated, as it is mentioned in the previous test method. An accurate amount of adhesive was applied to the one plate. The second plate was placed and pressed until the required thickness of approximately 3 mm was obtained. The thickness of the adhesive was ensured with the aid of “skewers”, used as spacers. A minimum of 5 samples had to be made for each adhesive, as demanded by the relevant standard.

3.3. Curing of test samples

All test samples were left to cure in a dry and clean environment as require the relevant technical standards. All test samples were stored in a room with an average air temperature of (20.0 ± 3) °C and a relative humidity of (55.0 ± 10) %.

3.4. General steps of test methods

All test samples were placed into a specially designed testing mould which allowed attachment to a tearing device. The process of tests was monitored and recorded. All test samples were strained until they reached their maximal break point. Testing was carried out in an FP 10/1 tearing device with a maximum strength of 10 kN which enabled the monitoring and recording of the course of deformation with dependence on load. The speed of loading was 8.00 mm·min^{-1}.

4. Results and discussion

The bonding of the surface finish to the substrate and the determination of shear strength during stress was calculated according to the equation given by relevant technical standard. The values, which are presented in Table 4 and Table 5, were calculated from the maximal force that is required for debonding of the test sample in N. The calculated values are presented as an arithmetic average of all test samples from one tested group, see Fig. 2 and Fig.3.

4.1. Test of the adhesion of the surface finish to the substructure

The bonding of the surface finish to the substrate was calculated according to ČSN 73 2577 (1981), see (1).

$$\sigma_{adh} = \frac{F}{A}, \tag{1}$$

Where: F is the force required for debonding, in N, A is the area of bonding in mm^2.

Table 4. Test results of the adhesion of the surface finish to the substructure.

	Adhesive system							
Material	Simson 007 SMP				Simson PanelTack HM			
	Bonding σ_{adh}	Standard deviation	Variation coefficient	Variance	Bonding σ_{adh}	Standard deviation	Variation coefficient	Variance
	[N·mm^{-2}]	[N·mm^{-2}]	[%]	[-]	[N·mm^{-2}]	[N·mm^{-2}]	[%]	[-]
Cetris	0.730	0.058	7.98	0.003	0.989	0.205	20.76	0.042
Siberian Larch	1.484	0.154	10.37	0.024	0.948	0.222	23.45	0.049
WPC	0.440	0.155	35.27	0.024	0.239	0.056	23.47	0.003

4.2. Determination of the tensile lap-shear of bonded assemblies

The determination of the tensile lap-shear of bonded assemblies was calculated according to (2).

$$\sigma_{adh} = \frac{F}{A} = \frac{F}{l * b}, \tag{2}$$

Where: F is the force required for debonding, in N,
A is the area of bonding in mm^2,
l is the length of bonded joint in mm,
b is the breadth of bonded joint in mm.

Table 5. Test results of the tensile lap-shear of bonded assemblies.

	Adhesive system							
Material	Simson 007 SMP				Simson PanelTack HM			
	Shear strength τ [$N \cdot mm^{-2}$]	Standard deviation [$N \cdot mm^{-2}$]	Variation coefficient [%]	Variance [-]	Shear strength τ [$N \cdot mm^{-2}$]	Standard deviation [$N \cdot mm^{-2}$]	Variation coefficient [%]	Variance [-]
Cetris	1.40	0.254	18.19	0.065	1.57	0.174	11.06	0.069
Siberian Larch	1.06	0.190	17.60	0.040	1.80	0.440	24.53	0.200
WPC	0.76	0.209	27.57	0.044	0.00	0.000	0.00	0.000

The results of the executed experiments are very varied and should be subjected to thorough analysis. The common feature of the resulting damage was the failure of the adhesive bond between the adhesive and the facade cladding, especially when used in combination with WPC cladding.

Fig. 1. Examples of observed failures (a) Cetris; (b) Siberian Larch; (c) WPC.

The obtained results when the adhesive system was tested in combination with Cetris are very satisfying and the resulting strength measured is more than sufficient. Furthermore, in all cases was observed cohesive failure because the cladding material was always damaged. In contrast, in the case of the tests for the determination of shear strength, test samples with Simson 007 reached almost the same strength as with Simson PanelTack. As was already mentioned, within all test samples the bond was torn off in the mass of the cladding material, see Fig. 1. This proved the high quality of applied adhesives and low resistance of the cladding.

When the adhesive systems were tested in combination with cladding material from Siberian Larch, according to the data presented in the Table 4 and Table 5, both selected adhesives exhibit similar strength properties. Moreover the Simson 007 reached better results when tested to adhesion. The average strength of the timber substructure perpendicular to the grain is approximately 1.5 $N \cdot mm^{-2}$ and the calculated average strength of the bonded joint in combination with Simson 007 is 1.484 $N \cdot mm^{-2}$ thus these results are very promising. However, the tests took place only in standard indoor conditions thus it is desirable to put the test samples through further testing, e. g. testing for resistance to frost and to sudden temperature changes. These tests should confirm or disprove the results obtained so far.

The common feature of the resulting damage done to all test samples, where the combination with WPC cladding was tested, was the failure of the adhesive bond between the adhesive and the facade cladding. Even though the facade element detached from the substructure in the case of almost all the samples, the resulting strength measured is sufficient in the test series with Simson 007. However, the combination of WPC and Simson PanelTack HM is unsatisfactory, as can be seen in Table 5, when all test sample prepared for a test of shear strength had fallen apart. Thus, this combination should not be used without other precautions, see Nečasová et. al. [13].

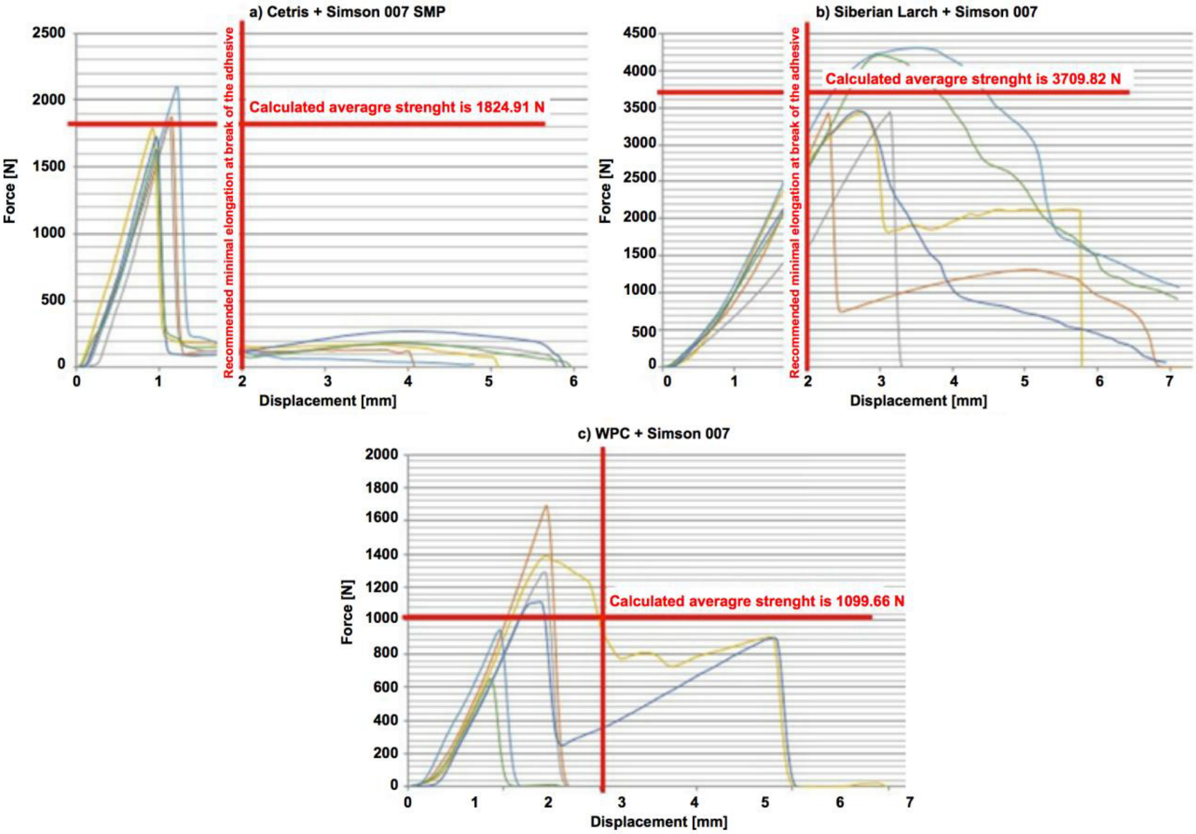

Fig. 2. Comparison of stress strain curves recorded during the test of adhesion of the cladding to the substructure (a) Cetris; (b) Siberian Larch; (c) WPC here with Simson 007.

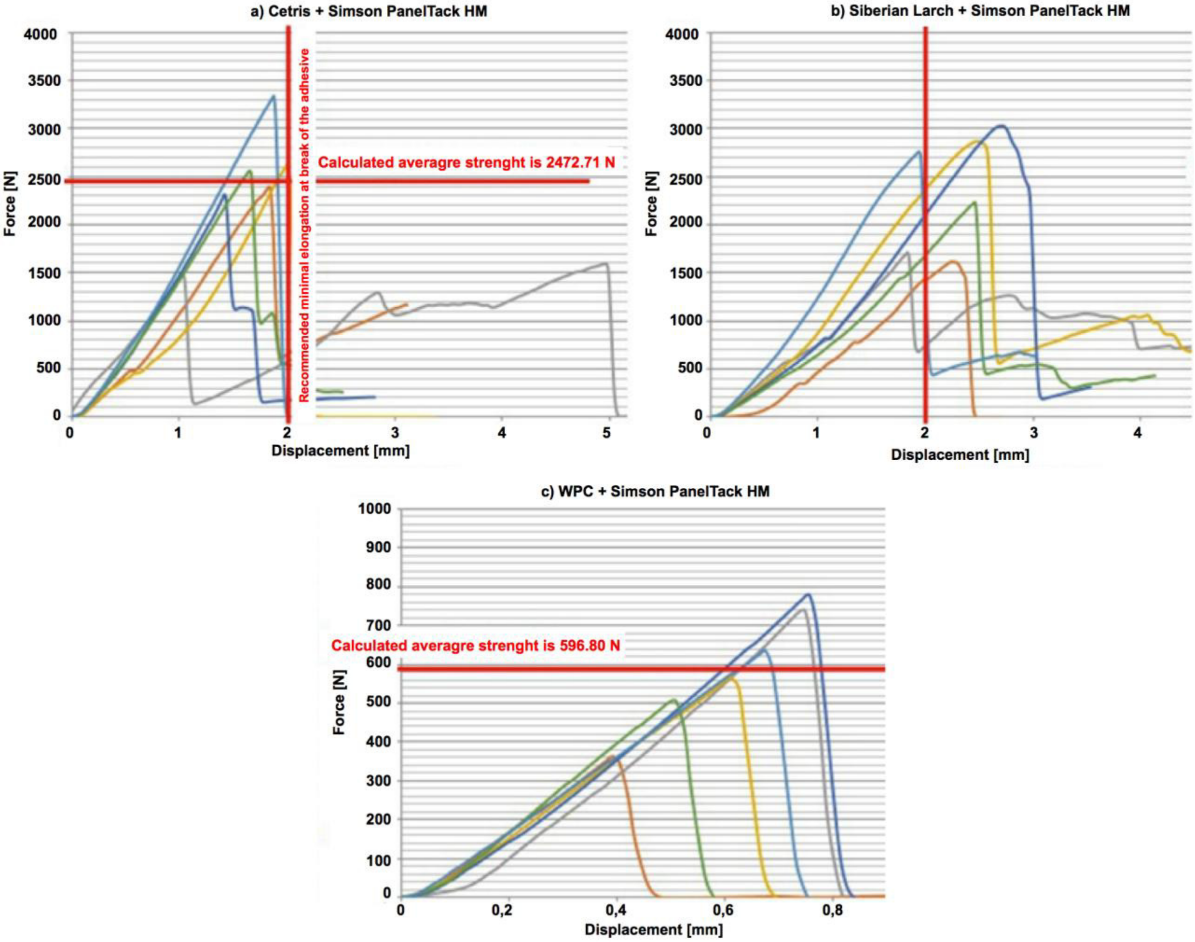

Fig. 3. Comparison of stress strain curves recorded during the test of adhesion of the cladding to the substructure (a) Cetris; (b) Siberian Larch; (c) WPC here with Simson PanelTack HM.

However, from the presented stress curves in Fig. 2 and Fig. 3, it is obvious that Simson PanelTack HM behaved very uniformly in combination with Cetris and Siberian larch cladding.

5. Conclusions

Based on the measurements carried out and described above it was discovered that a wooden substructure is a suitable alternative in the construction of ventilated facades. Moreover, an immense advantage of wood is its sustainability and environmentally-friendly properties. A series of tests showed that in some cases the adhesion of the selected cladding material, i.e. exactly what was tested here, will be one area of weakness for bonded joints.

However, testing also needs to be conducted in an environment which is not completely ideal. This would involve a series of tests which simulate the real outdoor environment, or the climate: the values subsequently determined would be a more authoritative indicator of the suitability of a selected combination of cladding and wooden substructure. The authors of this article are continuously working on the presented research case to release more relevant data, i.e. determination of resistance to freezing or to variable temperature changes.

Another conclusion arising from the series of tests is the fact that the use of a wooden substructure for ventilated facades is not a limiting element for the whole system and is a more financially and ecologically viable option in comparison with an aluminium substructure.

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