Wooden Facade and Determination of Strength of Bonded Timber Joints

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Abstract— **A research case focused on vented wooden façade system with bonded joints is presented in this paper. The potential of bonded joints is studied and described in more detail and verified through experimental measurements. For the purpose of tests spruce timber profiles were chosen for the load bearing substructure and Wooden plastic composite façade sheeting for the cladding. Three types of industrial adhesives intended for structural bonding were selected. The article is focused on the preparation as well as on the subsequent experimental verification of substructure bonding retention to the cladding. The adhesive bonds were tested both in tension as well as shear at a temperature of (293.15 ± 3) K and a relative humidity of (55 ± 10) %. The test results proved the fact that bonded joints are more than suitable alternative to the mechanical joints. During the tests appeared some differences in stability and failure behaviour between the adhesive systems as well as within the sheeting material. Additionally, the suitability of selected group of adhesives in combination with wooden plastic composite cladding material as well as with the timber substructure was confirmed.**

Keywords-lightweight façades, adhesion system, wooden composite façade cladding, adhesion, cohesion.

I. 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. Thus, civil engineers are currently very often meeting with obstacles as revitalization or redemption of wooden facades. The most popular design of nowadays wooden facades is usually with vented layer where all elements are connected by mechanical joints. 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.

The term ‘adhesive’ is a very wide one and therefore a great number of standards exist which concern adhesives in general. However, they mainly deal with the classification of adhesives as such. The purpose of the research described here was not to create a new adhesive but rather to investigate existing, industrially-manufactured adhesive products available on the market which are potentially suitable for a given application, and to test their properties in conjunction with the intended specific application experimentally. For this purpose, testing procedures which are easy to carry out, versatile, provide the needed information and are related to the final finish of facades were selected.

Besides these facts also the trend of sustainability is currently more intense and the importance of usage of renewable sources is starting to be obligatory. Taking into consideration these details the authors of this research decided to design a possible solution of vented façades supposed mainly for timber and wooden houses which are considered as environmental friendly.

II. State of the Art

Design of vented façades with wooden cladding is not a new technology. Nevertheless, there are quite a few examples where the entire façade system was designed from bonded wooden elements. In 1998 Straalen [1] introduced methods to draw up design rules to calculate the resistance of adhesive bonded joints for structural applications. The results obtained from series of tests revealed that in case of adhesive bonded joints also the durability effects have to be considered and because the experience in 1998 with design rules for structural adhesive bonded joints was limited, the use of probabilistic techniques occurred to be a promising opportunity. However, 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 [2].

According to [3], adhesive bonding is a very demanding technique which requires procedures to be followed precisely and accurately, considering that even a small failure to comply with these requirements might result in the error of an entire system. 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.

The presented tests are following requirements given by Czech standards.

III. Methodology

A. Selection of adhesives and cladding material

The selection of the cladding material is usually given by the contractor, developer etc. and it should be the first step when considering bonded façade systems. Furthermore the material properties as are mechanical, physical or chemical performance have to be known even before the selection of adhesives.

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 of the 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 the wooden plastic composite façade cladding was selected. The wooden plastic composite (hereinafter WPC) 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 and wood based fibres. The material is lignin free and contains no harmful chemicals. Moreover, this material is suitable for vented facades without any other surface finish.

Standard spruce joists were selected as a material for substructure, since it is the most used material for timber façade substructure. The only demand on this material, is the strength class S10 and all used profiles have to be dressed.

Three high-strength adhesives, see Table I., were selected for experimental testing. Out of these three adhesives, two are designed specifically for bonded façade. The remaining adhesive is for general structural bonding and sealing. The selection of adhesives was made on the basis of suitability for use, i.e. the recommendation of the manufacturer, technical parameters and the total price of the entire bonding system. Furthermore, all manufacturers indicate that their material can be used in combination with timber substructure as well as with steel or aluminium structure [3].

TABLE I. ADHESIVES SELECTED FOR TESTS

Manufacturer	Adhesive system
Sika CZ, s.r.o.	SikaTack – Panel*
Dinol GmbH	Dinitrol F500 LP*
Bostik BV	Simson 007 SMP (Silyl Modified Polymer)

*Adhesive system intended for bonded façades.

B. *Test of the adhesion of the surface finish to the substructure*

The series of tests were designed according to the requirements of [4]. The aim is to observe and record the maximal force that would be able to tear off a given surface finish area from the substrate while applying the perpendicular tension.

1) *Production of test samples*

The components which represents the cladding material, WPC, are square in shape, with 100 mm long sides and a thickness of 9 mm. Likewise, the components which represents substructure, spruce joists, are square in shape, with 50 mm long sides, a thickness of 19 mm and total area of 2 500 mm^2.

The Czech standard [4] requires circular profiles of the substructure component in cross section, however, it would be very problematical to produce such a profile from timber as well as the fact that the square shape represents the real situation more suitably.

The production itself involved several steps. Each adhesive required a different modification to be made to the bonded surfaces depending on the requirements of individual manufacturer. All the dust and other dirt have to be mechanically removed and the surfaces have to be roughened. The spot of the adhesive bonding of the cladding material was raised by sandpaper P80, as well as the substructure material. Only test specimens meant for usage in combination with Simson 007 did not require any abrasion of the test sample surface.

Subsequently, the surfaces were chemically treated by cleaning liquid with the aim to achieve the maximal adhesion. That means that grease - free surfaces are created. After approximately 10 minutes the surfaces were treated by liquid primer with an application brush. The treatment is specified in detail and serves for a good adhesion of the adhesive to the support frame and the back - side of the facade plate. The prepared samples were left to dry for a period of 0.5 to 1 hour, depending on the bonding system.

After this period an unexpected phenomenon appeared.

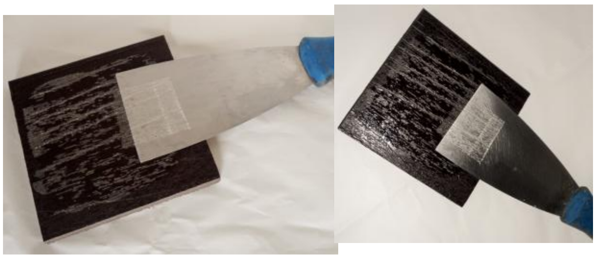

Figure 1. An easily-separable layer on the surface of the cladding

Although the WPC cladding should be porous material, since it is composed from timber flour by 60%. The appropriate Simson primer liquid for porous material have peeled off, see Figure 1.

Then 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 substructure element. After pushing the smaller element (substructure) 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 standard [4].

Subsequently, the square shaped element (substructure) 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 standard [3, 4].

2) *Curing of test samples*

The test samples were left to cure in a dry and clean environment as requires the relevant standard [4]. All test samples were stored in a room with an average air temperature of 294.15 K and a relative humidity of 52 %. The samples have to be cured at least for one week as to obtain a sufficient desiccation of the bonded joint.

3) General steps of the test method

Test samples were placed in a special mould which allowed attachment to a tearing device, as can be seen in Figure 2. The process of tests was monitored and recorded. All test samples were strained until they reached the limit state.

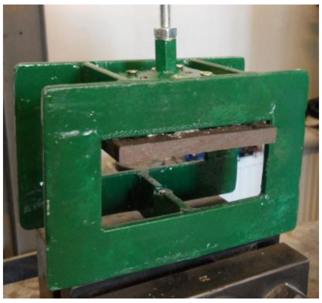

Figure 2. Testing of specimens in testing equipment - Test of adhesion of the surface (WPC) the the substrucutre – here with SikaTack - Panel

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

The series of tests were designed according to the requirements of [5]. The aim is to determine the strength during the exertion of shear stress on a single - lap joint under tensile loading.

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 substructure, 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 lapped, were treated, as it is mentioned in the previous test. 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 glue was ensured with the aid of “skewers”, used as spacers. A minimum of 5 samples had to be made for each glue, as demanded by the relevant standard [5].

2) Curing of test samples

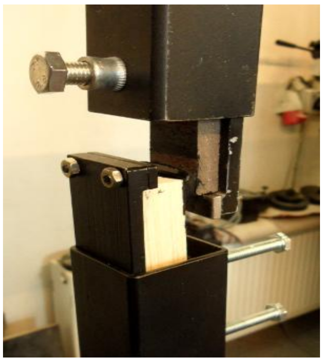

Figure 3. Testing of specimens in testing equipment – Determination of the tensile lap – shear of bonded assemblies – here with Dinitrol

The test samples were cured under the same conditions as in the previous test. All test samples were stored in a room with an average air temperature of 294.15 K and a relative humidity of 52 %. The samples have to be cured at least for one week as to obtain a sufficient desiccation of the bonded joint.

3) General steps of the test method

Before testing, the samples were placed in sheaths which prevented the damage of the ends of the plates in the clamping pincers of the tearing device, as can be seen in Figure 3.

IV. RESULTS

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 standard [4, 5]. The values, which are presented in Table 2. and Table 3., were calculated from the limit force required for debonding of the test sample in N. Also, the bonded area have to be taken into account. The calculated values are presented as an arithmetic average of all test samples.

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

The bonding of the surface finish to the substrate is calculated according to (1).

$$\sigma_{adh} = \frac{F}{A}, \qquad (1)$$

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

TABLE II. TEST RESULTS OF BONDING

Adhesive system	*Bonding σ_{adh} [MPa]*	*Standard deviation [MPa]*	*Variation coefficient [%]*	*Allowance*
SikaTack - Panel	1.07	0.13	11.7	0.016
Dinitrol F500 LP	0.82	0.13	15.8	0.017
Simson 007	0.44	0.16	35.3	0.024

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

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

$$\tau = \frac{F}{A}, \qquad (2)$$

where F is the force required for debonding, in N,
A is the area of over lapping in mm^2.

TABLE III. TEST RESULTS OF SHEAR STRENGTH

Adhesive system	*Shear strength τ_V [MPa]*	*Standard deviation [MPa]*	*Variation coefficient [%]*	*Allowance*
SikaTack - Panel	1.66	0.30	18.04	0.09
Dinitrol F500 LP	2.17	0.59	27.33	0.35
Simson 007	0.76	0.21	27.57	0.04

V. ANALYSIS

The results of the executed experiments are very varied and should be subjected to thorough analysis. The common feature of the resulting damage done to all test samples 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 more than sufficient. Furthermore, the measured values for the SikaTack and Dinitrol systems fulfil the strength limit requirements set by the related legislation.

It can be seen from the results listed in Table II. that the highest strength determined on the basis of the adhesion test was achieved in the case of the SikaTack – Panel adhesive system, where the average adhesion measured is 1.07 $N{\cdot}mm^{-2}$. In contrast, in the case of the tests for the determination of shear strength, test samples with the Dinitrol system showed the highest strength, the average shear strength of samples is 2.17 $N{\cdot}mm^{-2}$, see Table III.

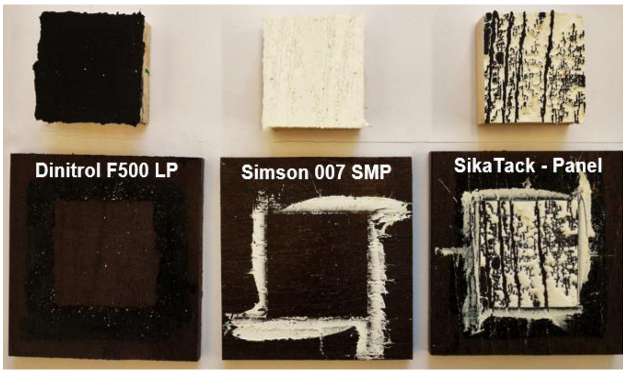

Figure 4. Adhesion failure of the bonding system with Dinitrol and Simson; cohesion failure with SikaTack - Panel

The technical procedure for the execution of bonding is very similar for each of the above-mentioned systems and involves the same components. In both cases, the surface of both the substructure and the facade cladding had to be roughened, which, in the opinion of the researchers, improved absorption capability. Subsequently, the penetrative agent was applied to the surface of the sample. As has already been mentioned, a penetrative coating was used in both cases: this proved to be a very important element of the whole glued system in this series of tests, see Figure 5. Despite this, the surfaces detached right where the adhesive and the penetrative layer connected in the case of both Sika and Dinitrol. Moreover, as can be seen in Figure 4., samples with SikaTack bonding system showed a failure of cohesion.

In the case of the Simson glued system, however, no roughening of the surface of the materials used is necessary according to the recommendations of the manufacturer. Therefore, no alterations were made (except for cleaning using a cleaning agent); a test then demonstrated that the test samples debonded very easily at the location where the adhesive and the cladding material connected, see Figure 1. For this reason, the resulting measured values are very low for both tests and they do not reach the requirements set by the standard. The average measured value of material adhesion is 0.44 $N{\cdot}mm^{-2}$ when the coefficient of variation is higher than 35% (the standard allows 30% maximum), and the average shear strength of the test samples is 0.76 $N{\cdot}mm^{-2}$ when the value of the coefficient of variation is 27.6% (the standard allows 20% maximum). It was also discovered that the use of a penetrative coating is not suitable for porous elements as it will form an easily-separable layer on the surface of the cladding (see the text above).

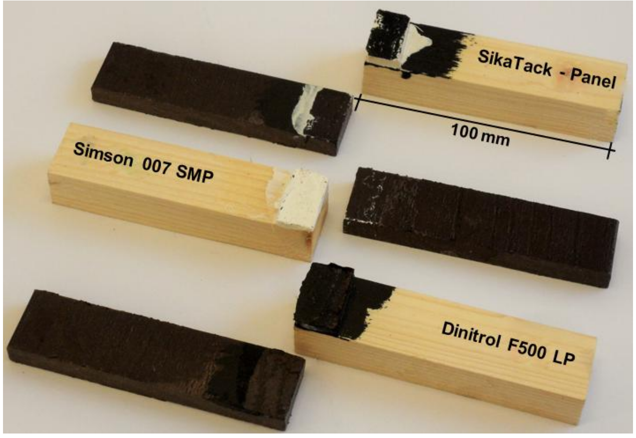

Figure 5. Adhesion failure of the bonding system

VI. DISCUSSION

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.

It was also demonstrated that the tested cladding material is suitable for use in combination with bonded joints but that certain technical principles must be adhered to. It is mainly necessary to obtain information from the manufacturer of the given bonding system as to whether the system is suitable for use in combination with wood plastic. A series of tests showed that even though wood plastic composite is a composite material with wood flour as the prevailing component, and therefore should be a porous material, its material properties are similar to those of non-porous materials. As has already been mentioned earlier in the article, wood plastic behaved completely unpredictably in combination with the Simson adhesive system and therefore, for example, the use of this combination needs to be evaluated with a further series of tests. Based on the presented test results, it can be assumed that the SikaTack and Dinitrol systems are both suitable bonding systems.

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.

VII. CONCLUSION

The performed tests showed the equivalence of the bonded joint system for ventilated facades in comparison with mechanical joints. Moreover, for certain types of cladding material, joint bonding may appear to be a more suitable attachment method as it does not disrupt the structure of the cladding, thus preventing the degradation of the material e.g. via penetration of moisture into the cladding. However, the installation procedure needs to be followed very strictly as the above-mentioned series of tests showed that the adhesion of wood plastic is very unstable. 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 aluminium substructure.

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