Thermal Resistance of Bonded Facade Joints

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Abstract—**Mechanical joints are the most frequently used option in the construction of vented facades. However, bonded joints are becoming a viable and accessible alternative. This article deals with the issues connected with testing the most critical elements in the whole system – bonded joints – from the point of view of exposure to high temperatures. For these purposes, "Cetris" cement-bonded particleboard was selected for use as cladding material, and a substructure made from aluminium alloy was chosen. Five types of adhesive were selected in order to find the most suitable bonding material. During the testing procedures, the suitability of selected adhesives for the chosen combination of materials was tested, as was the assumption that the use of the most expensive sealant does not always provide the best results.**

Keywords - Bonded Joints; Cement Tiles; Aluminum Substructure

I. Introduction

Contemporary vented facade systems for buildings are typically based primarily on the mechanical connection of cladding materials to a substructure. Bonded joints are gradually becoming a viable alternative, with properties approximating those of mechanical joints. Bonded facade systems differ in that the mechanical attachment of cladding materials is replaced by bonding. Installation of such systems is a relatively demanding process in which it is necessary to adhere exactly to the required procedure, and which necessitates a disciplined approach. The authors focus on the testing of bonded joints, which are the most important components of the whole bonded system. The aim is to discover the influence of increasing environmental temperature on the properties of bonded joints. In the following text, the production of the samples themselves and their testing are both described. The materials used can be utilized in real-world facade applications, and it is therefore beneficial to check their suitability and usability with regards to the combination of adhesives and tile materials.

II. Methodology

A. *Selection of the Adhesive and Tile Material*

Five high-strength adhesives were selected for experimental testing. Three of them are designated by their manufacturers as being specifically for bonded facades. The remaining two adhesives are intended for general structural bonding and sealing tasks. "Cetris" cement-bonded particleboard was selected as the cladding material, while the substructure was fabricated from aluminium alloy.

B. *Selection of the heating temperature*

The temperatures to be used in the testing of adhesion and shear strength in a tearing device were chosen on the basis of preliminary tests. The samples were heated from 373.15 to 453.15 (K). A temperature of 433.15 (K) was used in the adhesion testing, and 393.15 (K) was employed for the testing of shear strength. The stated temperatures were chosen in order that any weakening of joints that may occur might be ascertained, while allowing the values for the force acting during the tearing tests to remain measurable.

C. *Test for Surface Finish Adhesion of Building Structures to the Base*

The essence of the test was to measure the force that would be able to tear off a surface finish with a given surface area from a base using vertical traction [1].

1) *Production of Samples*

The test samples consisted of two elements. They were manufactured from cement-bonded particleboards, square in shape, with 100 mm long sides and a thickness of 18 mm, which represented the cladding material, and from aluminium alloy discs, which represented the substructure. The discs were circular in cross section, with a total surface area of 2 500 mm^2 and a thickness of 19.5 mm. Four threaded holes were drilled into the discs for attaching the test specimen to a tear test device.

It was necessary to modify both surfaces in order to improve the adhesion of the glue to the cladding material as well as the substructure. Each kind of adhesive required a different modification to be made to the glued surfaces, according to the requirements of the individual producers. As a rule, coarse dirt had to be mechanically removed and the surfaces roughened. The cladding material was roughened using P40 sandpaper and the aluminium discs were roughened using abrasive cloth with a roughness of P320. Subsequently, the surfaces were chemically degreased and ventilated for approximately 10 minutes. A substrate enhancement coating was added with an applicator brush and left to dry for a period of 0.5 to 2 hours, depending on the gluing system used. Then, a sufficient quantity of adhesive was applied to form a conical shape in the centre of the plate and the disc was pushed into the adhesive. Spacer elements with a diameter of 3 mm ensured the thickness of the adhesive was as required [4].

2) *Curing*

The test samples were left to cure in a dry and clean environment, i.e. in an average air temperature of 294.5 (K), with a relative humidity of 36.41 %. As the cladding material was porous and its diffusion resistance was low, the samples cured within about 48 hours. In the case of the SIKA gluing system it took about 10 days [2].

3) Conditioning

Conditioning essentially involved the warming of the samples to a temperature of 433.15 (K) directly within the test device using a hot-air pistol. The temperature was checked with a contact thermometer. After the correct temperature was reached, tests were carried out, as can be seen in Fig. 1 (right).

4) Testing of Samples

The testing took place using a FP 10/1 tearing device with a maximum force of 10 kN, which enabled the monitoring and recording of the course of deformation with dependence on the load. The testing itself took place in such a way that the samples were inserted into a specially manufactured mould which enabled the tearing device to grasp it, as can be seen in Fig. 2 (right). The speed of loading was 8.00 mm·min^{-1}. The samples were loaded until they were destroyed.

D. Determination of the Tensile Lap-Shear of Bonded Assemblies

The test involved the determination of strength during the exertion of shear stress on a single-bonded joint between rigid adherents under tensile loading [3].

1) Production of Samples

The test specimens were composed of two plates 25 x 100 mm in size. One of the plates represented the substructure, while the second plate represented the cement-bonded particleboard cladding. First, the lapping distance, which was (12.5 ± 0.25 mm), was marked on the aluminium plate. Then, the ends of the plates where both surfaces lapped were treated, as in the previous test. A cone-shaped quantity of adhesive was applied to the aluminium plate. The second plate was placed and pressed until the required thickness of approximately 3 mm was obtained, which was ensured by spacers [4].

2) Curing

The samples were cured in a dry and clean environment. This was at an average air temperature of 294.5 (K) and a relative humidity of 36.41 % for a period of 48 hours [2].

3) Conditioning

Conditioning involved warming the specimen to a temperature of 393.15 (K) directly within the testing device using a hot-air pistol, as can be seen in Fig. 1 (left). The temperature was checked with a contact thermometer. After the correct temperature was reached, tests were carried out.

Figure 1. Warming of the specimens to the required temperature (shear – left, bonding – right)

4) Testing of Samples

Before testing, the samples were placed in a mould which prevented the ends of the cement-bonded particleboards from being crushed in the clamping pincers of the tearing device and ensured they were loaded along their axes, as can be seen in Fig. 2 (left). Testing was carried out in the FP 10/1 tearing device with a maximum force of 10 kN, which enabled the monitoring and recording of the course of deformation with dependence on the load. The speed of loading was 8.00 mm·min^{-1}. The samples were loaded until they were destroyed.

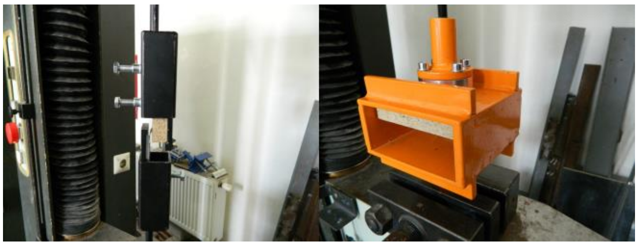

Figure 2. Testing of specimens in testing equipment (shear – left, bonding – right)

E. Testing of adhesion during high temperatures

1) Production of Samples

For the purposes of these tests, specimens from previous tests were used to determine the adhesion without conditioning.

2) Curing

Test samples were cured under the same conditions as in the previous tests.

3) Testing of Samples

The samples were tested on a hot plate, as can be seen in Fig. 3. Before putting the samples on the plate, it was heated to a temperature of 643.15 (K). Subsequently, the samples were warmed up to the critical temperature when the adhesion of the glue to the substructure or cladding material was lost. The temperature was measured across the glued top surface of the aluminium disc. However, in the case of HQ Bond adhesive the temperature was measured on the surface of the adhesive. The test gave rise to excessive stench and smoke.

Figure 3. Heating of a specimen on a hot plate

III. Results

A. Test for Surface Finish Adhesion of Building Structures to the Base

The bonding of the surface finish to the substrate is calculated according to Eq. 1:

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

where F is the force required for debonding, in N,

A flat disc – bonding, in mm^2.

In Table I the calculated values are presented as an arithmetic average of three samples, including standard deviations.

TABLE I. Values for bonding, including standard deviations

Adhesive	*Bonding σ_{adh} [MPa]*	*Standard deviation [MPa]*
SikaTack – Panel*	0.480	0.010
Dinitrol F500 Polyflex (FP)*	0.438	0.045
HQ Bond UNI*	0.063	0.037
Simson 007 SMP	0.491	0.027
Technobond	0.445	0.026

*comprehensive system intended for bonded facades

B. Determination of the Tensile Lap-Shear of Bonded Assemblies

The determination of shear strength is calculated according to Eq. 2:

$$\tau = \frac{F}{A} \tag{2}$$

where F is the force required for debonding, in N,

A surface lapping – shear, in mm^2.

In Table II the calculated values are presented as an arithmetic average of three samples, including standard deviations.

TABLE II. Values for shear strength, including standard deviations

Adhesive	*Shear strength τ [MPa]*	*Standard deviation [MPa]*
SikaTack – Panel*	0.288	0.078
Dinitrol F500 Polyflex (FP)*	1.154	0.073
HQ Bond UNI*	0.190	0.112
Simson 007 SMP	0.830	0.025
Technobond	0.737	0.175

*comprehensive system intended for bonded facades

C. Testing of adhesion at high temperatures

Table III presents results which were measured during testing on a hot plate. These are temperatures at which the bond between adhesive and cladding material or substructure failed, and the table includes the time when this was achieved.

TABLE III. Values for temperatures and the times at which adhesive bonds failed

Adhesive	*Temperature [K] at failure*	*Time [s] of failure*
SikaTack – Panel*	493.15	195
Dinitrol F500 Polyflex (FP)*	478.15	180
HQ Bond UNI*	458.15	360
Simson 007 SMP	518.15	510
Technobond	Not achieved	Not achieved

*comprehensive system intended for bonded facades

IV. Analysis

From Fig. 4 it is clear that the bond was torn off from the surface of cement-bonded particleboard when the HQ Bond gluing system was used. In the case of the other samples, tearing off occurred either partially or completely within the material of the cladding itself, but with significantly lowered strength at normal temperatures. This shows that adhesives are sensitive to high temperatures.

Figure 4. Test Test specimen after testing (shear – left, bonding – right) – HQ Bond

When testing adhesion on a hot plate, the glue only separated from the cladding material in the case of HQ Bond adhesive, as in the previous test. In the case of Technobond adhesive, the adhesive did not separate from the cladding material or the substructure at all. Instead, the adhesive turned brown and started to crumble. The three remaining adhesives separated from the aluminium disc at the level of the bonding primer, which proved to be a separator, as can be seen in Fig. 5.

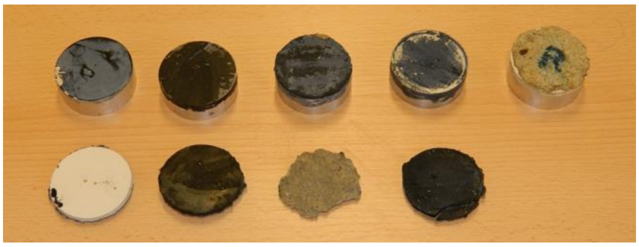

Figure 5. Specimen after testing – hight temperatures

V. Conclusion

The tests showed that the HQ Bond system produced by HQ Bonding B.V. is completely unsatisfactory for use with the given cladding material from the aspect of exposure to higher temperatures, and it is the least suitable of all the tested adhesives.

In contrast, the Technobond gluing system from RETECH, s.r.o. proved to be the best choice in the case of exposure to higher temperatures, when cladding wasn’t torn off from the substructure even at a temperature of 543.15 (K). However, this adhesive was not successful when resistance against sudden temperature changes [5] and frost resistance were tested [6], as it had the worst adhesion and shear strength results of all the selected adhesives.

In the case of other gluing systems, the joint was weakened.

In conclusion, it can be stated that gluing is a functional alternative to mechanical anchoring for the attachment of cladding materials to the outer shells of structures. With regards to the results of all tests [4], [5], [6] carried out so far it must be emphasized that both the design and the implementation itself of bonded systems must be carried out exclusively by suppliers with relevant qualifications who are highly familiar with such systems and who also have the needed experience. Then, with suitable structural design and the correct choice of application, the long-term reliability of the system can be guaranteed. Rising temperatures can influence the properties of bonded joints significantly, and therefore it is always necessary to implement the design proposal hand in hand with the fire safety measures developed for the structure.

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