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TENSILE STRENGTH OF ADHESIVELY BONDED FAÇADE JOINTS

Summary

In this paper, the influence of the temperature and the surface preparation prior to bonding on the tensile strength of adhesively bonded facade joint was investigated. Two types of the surface preparations prior to bonding were considered: only degreasing with the solvent and cut wire blasting followed by degreasing of the surface. The tests were conducted on the samples tested at room temperature or preconditioned at 80°C for one day and then tested at the room temperature. Results have showed that both surface preparation and temperature have a strong influence on the tensile strength of the investigated joints.

Keywords

Adhesive joints, tensile strength, temperature, surface preparation

ZATEZNA ČVRSTOĆA ADHEZIONIH FASADNIH SPOJEVA

Rezime

U ovom radu je prikazan uticaj temperature i pripreme površine pre spajanja na zateznu čvrstoću adhezionih fasadnih spojeva. Ispitivana su dva tipa priprema površine: samo odmašćivanje površina rastvaračem i sačmarenje površina praćeno odmašćivanjem. Uzorci su podeljeni u dve grupe. Jedna je čuvana na sobnoj temperaturi, a druga je bila postavljena u u klima komoru i izložena temperaturi od 80°C u trajanju 24h neposredno pre ispitivanja. Rezultati su pokazali da i priprema površina i izlaganje visokoj temperaturi znatno utiču na zateznu čvrstoću ispitanih spojeva.

Ključne riječi

Adhezioni spojevi, zatezna čvrstoća, temperature, priprema površina

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1. INTRODUCTION

Adhesives have been used in structural applications for more than 60 years. They have pushed their way in many industries, especially in automotive and aerospace industry. Moreover, successful application in civil engineering structures in past few decades has showed that they represent a promising alternative to the traditional joining methods in this field. Although it has been estimated in [1] that in the past they have been used mainly for repairs (more than 75%), there is a variety of examples of the use of adhesives for structural joints. The bridge over the Lippe channel in Marl was built in 1955 and used until present without any major intervention, using the adhesive to join components and supporting them with bolts for the case of the bond failure [2]. Another example is the Pontresina pedestrian GFRP bridge, built in 1997 with primary adhesive joints [3]. When compared to the other joining methods, there are many advantages of using adhesive bonding, which are extensively summarized in [1, 4].

There is a big potential of using adhesives lightweight steel structures due to their ability to join dissimilar materials (including metals like aluminium and zinc-coated steels) as well as the ability to join thin-sheet materials [5]. However, the limiting factor for their wider use is the lack of standards for design and application of such joints and the fact that their behavior varies with the joint configuration. The potential of adhesively bonded steel connections has already been investigated at BTU in the scope of research projects [6,7] and in the Ph.D. dissertation [8]. The ongoing research project [9] continues the research on bonding technology in steel construction, investigating the behavior of the adhesively bonded façade joint under the influence of the temperature and cyclic loading. In order to investigate the effect of temperature on the tensile strength of the façade connection, component like joints were tested at room temperature and at 80ºC. In later case the samples were tested at room temperature but preconditioned at 80ºC for 24 hours in the climate chamber. Since the joint strength is highly dependent on the level of adhesion between the adhesive and the substrate, samples were prepared by two different surface preparation procedures: only degreasing with the solvent and cut wire blasting followed by degreasing of the surface. These two surface preparations were chosen since the more efficient surface preparations are usually much more expensive which is usually not justified for the civil engineering applications.

2. STUDDIED FACADE SYSTEM

In this research so called mullion and transom façade system was studied. Its geometry is shown in Figure 1. The façade system consists of the mullion and transom profile, which are supporting trapezoidal façade sheet. In order to reduce shear creep in adhesive layer, a separate connection was designed for carrying the dead load. The closed transom profile is located at the top of the façade which carries the weight of the trapezoidal sheet. They are connected with the bolts. All other connections are realized using the T-profiles, adhesively bonded to the trapezoidal sheet, and bolted to the supporting structure. The bolts are transferring the load only in the direction normal to the façade. In vertical direction displacements are not prevented. In this way, eventual additional stresses due to the thermal deformation can be avoided. Additionally, this type of connection is relatively easy to be made in workshop, minimizing the manufacturing errors.

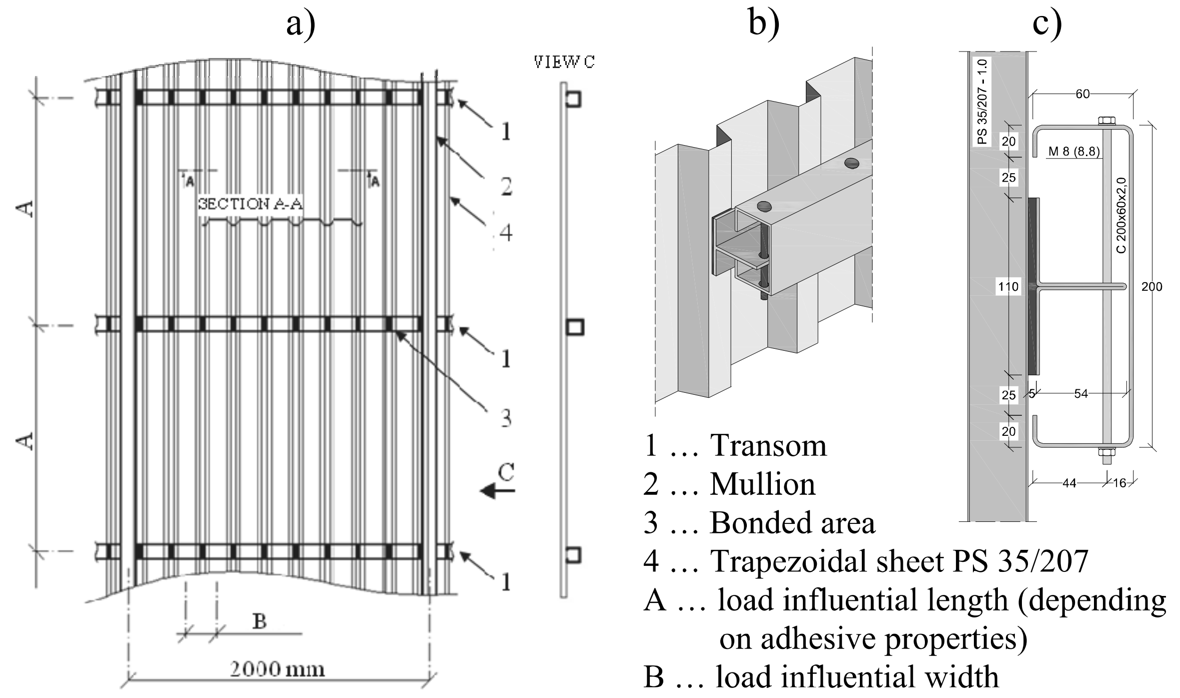

Figure 1. Façade with adhesively bonded connections: a) technical view; b) schematic figure; c) cross section normal to the longitudinal axis

3. EXPERIMENTAL INVESTIGATION

3.1. MANUFACTURING OF THE JOINT

The geometry of the joint was optimized in order to reduce the stress concentration. This was of great importance due to the fact that stress concentrations can significantly for influence the load capacity of the studied joints. The optimization was performed in the scope of project [8]. It was deduced that the best result would be obtained using the T-profile for the realization of the connection between trapezoidal sheet supporting structure.

3.1.1. Materials

Adherends

For the manufacturing of the façade joints thin sheets of galvanized steel were used. The sheets are first deformed to the desired trapezoidal shape and then cut into joint elements. The length of the joint element is chosen to be 500mm, which is the distance between zero moments in a continual beam with the span A (see Figure 1a). The quality of the steel is S355.

Adhesives

Selection of adhesives is essential for the proper design of adhesively bonded joints. Several criteria should be considered in the process of adhesive selection. Since it is recommended for the joints to have the same or greater strength than the base material, the strength of the used adhesive system is very important for the proper design. Additionally, the ability of its applications for the specific substrate material, influence of the environment conditions such as humidity and temperature, and the need of specific surface preparation should be considered. One more parameter that is of great importance and for the successful application of the adhesive bonding is the glass transition temperature. The glass transition temperature is defined as the temperature below which the mechanical properties have higher values, and after exceeding it they decrease considerably [10]. For the proposed façade systems, glass transition temperature should be as high as possible since the temperatures at the façade surface should exceed 80°C in summer period. The most widely used groups of adhesives for structural applications are epoxies, polyurethanes and acrylics. For each mentioned type one adhesive was selected and tested:

- SikaPower-477, a two component epoxy based structural adhesive suitable for bonding aluminium and steel.
- Körapur 842/20, a two component polyurethane based adhesive.
- Lord 410 acrylic adhesive with accelerator 19GB, suitable for replacing welding, brazing, riveting and other mechanical fastening methods especially subject to high impact or high peel loads.

3.1.2. Surface preparation

The selection of the proper surface preparation is directly related to the used adherends and the selected adhesive. In order to manufacture an efficient connection, it is of great importance that the surfaces of the elements are adequately prepared so that the highest possible initial adhesion, as well as long-term joint durability, is achieved. This implies removal of contaminants, rust, paint, grease, oils or any weak or loosely bonded layers that will reduce the adhesion to the adherend and, where necessary, priming the surface ready for the application of the adhesive.

Two different surface preparations were chosen for investigation of the quasi-static strength of the presented joints. Step by step surface preparation procedures are given in table 1:

Table 1. Surface preparation procedures

SP1	- 2 times degreasing with acetone - air blasting to remove any dust
SP2	- degreasing with acetone - cut wire blasting for 1 min. (grit type - StD-Z 0,4 mm/HV 600) - air blasting to remove particles from the cut wire blasting process - 2 times degreasing with acetone - air blasting

3.1.3. Application of the adhesive and curing

For the application of adhesive different schemes pouring of adhesives were examined and the best one is chosen according to the criterion of lowering the possibility of the occurrence of air voids in the adhesive layer. In order to assure the dimensions of the adhesive layer, 1mm thick adhesive tape was used for the transverse sides of the bonding area. On the two other sides very thin transparent adhesive tape was applied (see Figure 2), in order to prevent the bonding between the adherend and the excessive adhesive squeezed out during the assembling process. Additionally, to assure the thickness of the adhesive layer, small pieces of cut wire with the diameter of 1mm were used.

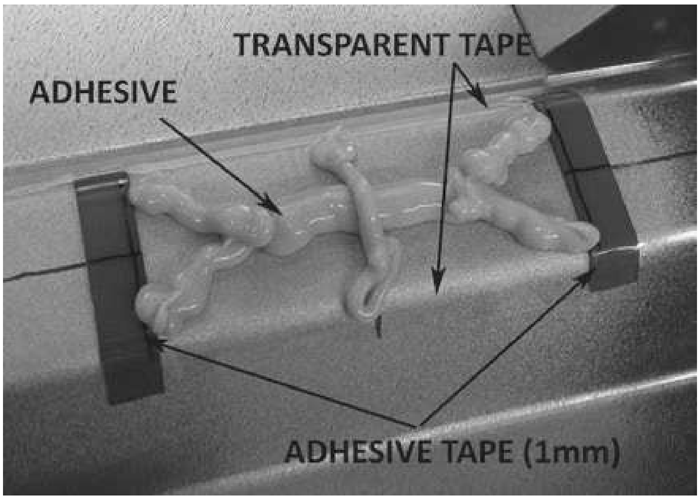

Figure 2. Applied adhesive on prepared bonding area of the trapezoidal sheet

Curing of the adhesives was performed according to the manufacturer's recommendations given in the product datasheet. All bonded joints were cured at room temperature with the curing time of 7 days, 48 hours and 24 hours for Sikapower-477 R, Körapur 842/20 and Lord 410/19GB respectively.

3.2. TEST CONDITIONS

In order to investigate the influence of the surface preparation and the temperature of the façade on the joint strength, joints prepared by the two described surface preparation procedures were tested at room temperature or preconditioned at 80°C for one day and then tested at the room temperature of 22°C. The later temperature was chosen after determination of the extreme temperatures of the façade for a period of 50 years (for the weather conditions in Germany). The calculation procedure and the results were published in [11]. This temperature is also in agreement with the German codes [12] and the Eurocode 1[13].

Prepared specimens were tested with the servo hydraulic tensile testing machine. First, the trapezoidal sheet was fixed on the bottom of the machine, and the connector ("T") profile was installed in the clamp using a rig, specially designed for this purpose. The test setup is shown in Figure 3. The tests were conducted in a displacement controlled regime, with the constant crosshead speed of 10mm/m. The crosshead displacement and applied force were measured.

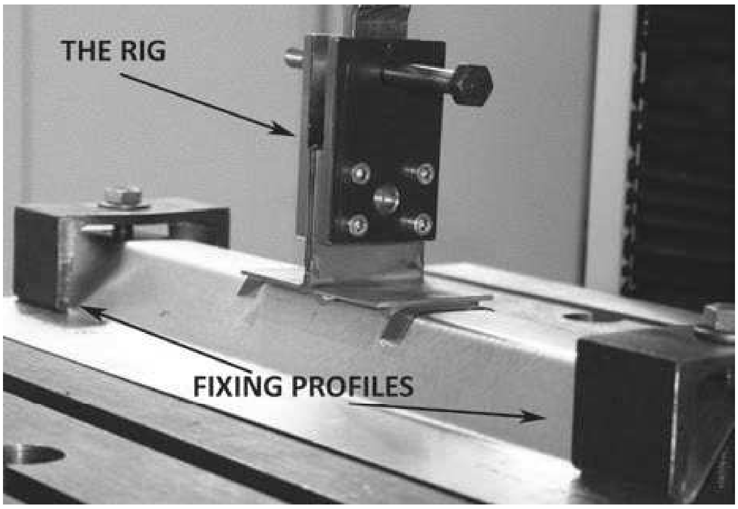

Figure 3. Test setup

4. RESULTS AND DISCUSSION

The results of the tests are shown in table 1. The labels beside the tensile strength of the tested samples designate the failure pattern. The designation of the failure pattern is done according to [14]. The failure patterns for grit blasted samples are shown in Figure 4.

Table 2. Quasi-static strength of the tested specimens (mean value)

Tensile strength [kN]	SP1		SP2	
	RT	80°C	RT	80°C
SikaPower-477R	0.97 A	0.64 A	6.31 SC	5.35 SC
Körapur 842/20	-	-	4.84 C	2.52 A
Lord 410	1.92 A	1.62 A	5.66 SC+S	6.68 C

A – adhesive failure C – cohesive failure
SC – special cohesive failure S – substrat failure

When discussing obtained results, two aspects should be considered. The first one is the change of the failure pattern and the second one is the change of the tensile strength with the change of the surface preparation and the temperature.

It was noticed that all the specimens prepared by SP1 procedure failed adhesively. It should be noted that the Körapur adhesive was not tested for this type of the surface preparation. It is obvious that only degreased galvanized steel shed could not provide good adhesion with the adhesive. This problem is exhibited mainly when samples are loaded in tension. In the case of grit blasted samples (SP2 procedure), with rougher surfaces, mainly cohesive and special cohesive failure patterns were evidenced. However, in the cases of Körapur and Lord adhesive, this was changed when the samples were treated at the temperature of 80°C. The failure pattern of Körapur has changed from cohesive to the adhesive, and in the case of Lord adhesive, it has changed from special cohesive to cohesive.

The results of the tests showed that the tensile strength of the joint changes due to the influence of the high temperature. It has been noticed that SP1 procedure of surface preparation provides significantly lower tensile strength of the joints due to the adhesive type of failure. The full potential of the adhesive could not have been exploited because of the weak bond between the adhesive and the substrate. The tensile strength of the joints prepared by SP1 procedure was only 15% and 34% of the tensile strength of the joints prepared by SP2 for SikaPower-477R and Lord 410/19GB respectively. Körapur 842/20 was not tested for the SP1.

The tensile strengths of the joints were higher at the room temperature than at the 80°C, for all cases except Lord 410(SP2). The decrease of the tensile strength of the samples bonded with SikaPower and Körapur adhesive was 15% and 48% respectively. The bigger decrease for the second adhesive could be contributed to the change of the failure pattern. In the case of Lord adhesive, the increase of the tensile strength for 18% was noticed. It is not clear whether this can be contributed to the change of the failure pattern or maybe to additional curing of the adhesive treated at 80°C. However, it is clear that for all the samples it is more preferable that the failure happens within the adhesive layer than at the interface between the adhesive and the substrate.

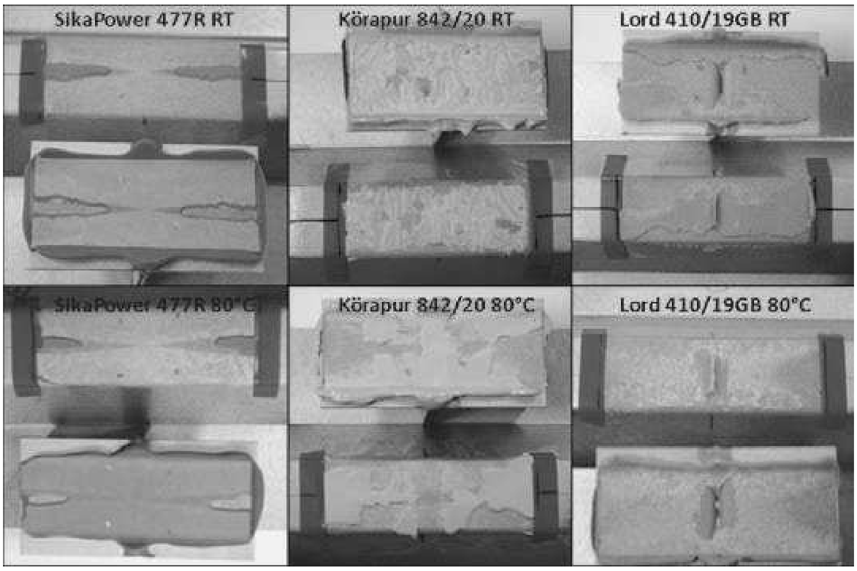

Figure 4. Failure patterns of grit blasted samples

5. CONCLUSIONS

From the obtained results of the experimental investigation of the adhesively bonded façade connection, the following conclusions could be derived:

- Galvanized steel with the surface prepared only by degreasing provides very low adhesion with the structural adhesives used in this research.
- The surface preparation by cut wire blasting provides much better adhesion between the adhesive and galvanized steel.
- The exposure of the samples to a high temperature influences on both the failure pattern and the tensile strength, mainly detrimentally.
- The tensile strength is dependent on the failure pattern.
- Higher tensile strength is obtained when failure pattern is cohesive than when it is adhesive.

From above mentioned it is clear that many factors influence the strength of the adhesively bonded façade connections. In order to enhance their use in civil engineering, it is essential to carry out the standardization process and provide clear instructions for calculation and application of the adhesively bonded joints.

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