




Proceeding Paper

# Use of Bonded Joints for Fastening Sheet-Metal Components to Contemporary Facades Fitted with an External Thermal Insulation Composite System with Thin-Layer Acrylic Plaster <sup>†</sup>

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**Abstract:** This paper deals with the issue of fastening sheet-metal components on the facades of contemporary buildings that are massively insulated with external thermal insulation composite systems. This research focused on facades with thin-layer acrylic plaster and sheet-metal components made of aluminium, copper and hot-dipped galvanized sheet metal. Two different test methods and test sample geometries were used to determine the most critical aspects for the studied application sectors. Surprisingly high tensile properties as well as shear stresses in the bonded joints were recorded for all the selected combinations. The presented results confirmed the assumed benefits for the construction industry and the future practical use of this technology in construction, although the durability of a bonded joint will always depend mainly on the quality of the bonded substrate.

**Keywords:** adhesion; adhesive; joint; sheet-metal construction; facade; sheet-metal components; thin-layer plaster



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## 1. Introduction

Saving energy has been a major issue in recent years as part of the efforts to maintain the sustainable development of society. In 2022, the situation in Europe changed dynamically due to the military conflict in Ukraine, which resulted in the virtual collapse of energy markets and an uncontrollable rise in gas and electricity prices. Countries were forced to search for solutions in an unprecedented situation and the pressure for energy saving was intensified. The greatest potential of the construction industry lies in savings in heating buildings [1]. In new buildings, the desire to reduce heat loss is reflected both in the design of the building structure [2] and in the thermal parameters of the structures. However, the greatest potential, regarding the number of buildings, lies in existing structures, where the most common way of improving the energy balance has been additional insulation [3]. This can be implemented in two ways. The first is the use of suspended facade systems, which consist of a load-bearing (usually aluminium) structure, mineral wool thermal insulation, a windproof diffusion-open membrane, a ventilated air gap and a facing cladding board [4,5]. The second option is external thermal insulation using a composite system that is in full contact with the original surface of the facade and consists of thermal insulation (most often expanded polystyrene or mineral wool, or other materials that are used less frequently) and reinforcing layers of cement screed with fibreglass mesh, coloured primer and coloured thin-layer plaster [6,7]. Both options include a thick layer of thermal insulation that can be sized as required to provide the desired energy savings. Each of the two options has both advantages and disadvantages. In general, however, contact insulation is significantly more widespread. This is primarily due to its lower cost, which represents approximately one-third of a suspended ventilated facade system. The authors of this paper focused on the issue of sheet-metal facade components in contact-insulated facade systems, where secure

fastening to the substrate becomes increasingly difficult due to the increasing thickness of the thermal insulation.

Currently, 200 mm thick layers of thermal insulation are common, and 300 mm thick insulation is not an exception. These surfaces are largely unsuitable for plumbing work, mainly due to the impossibility of firm fastening, as the outer plaster layer is too thin, and the insulation itself is not a load-bearing substrate. While there are system solutions for connecting sheet-metal components to multi-layer plaster, e.g., parapet connection profiles with integrated adhesive surfaces for bonding metal parapets or connection profiles for inserting vertical facade flashings, these are always components intended to be fitted during the installation of the insulation system. Using these solutions requires precise coordination during the construction process. Moreover, they are not always applicable as they do not allow the fitting of sheet-metal structures during additional work onto older, previously insulated facades. This article deals with the issue of fastening sheet-metal components by bonding them to the surface of thin-layer plaster. It presents an initial series of tests to verify the perspectives of this technology for further research. The technology of bonding sheet-metal components to thin-layer plaster, if properly validated, would be widely applicable, even outside the field of contact thermal insulation systems.

## 2. Materials and Methods

### 2.1. Materials

Materials commonly used for sheet-metal components such as aluminium alloy, copper alloy and hot-dipped galvanized steel were tested. These materials are used in the form of thin sheets on construction sites; however, this research required the production of solid circular plates (hereinafter referred to as targets) and strips to be bonded to the substrate. The metallic materials used were aluminium alloy EN AW-2011 according to the EN 573-3 standard [8] with a tensile strength of 295.0 MPa and a yield strength of 195.0 MPa, copper alloy CW004A-R250—SH (Cu-ETP) according to the EN 13,601 standard [9] with a tensile strength of 250.0 MPa and a yield strength of 200.0 MPa, and hot-dipped galvanized steel brand S235JR (1.0038) according to the EN 10025-2 standard [10] with a tensile strength of min. 360.0 MPa and a yield strength of 235.0 MPa. The thixotropic silane modified polymer adhesive ARDEX CA 20 P for external applications produced by Ardex Baustoff GmbH was chosen for bonding to the substrate. No mechanical properties were provided by the manufacturer. The following materials were used for the production of the solid plasterboard test specimens for bonding the metal tear-off elements:

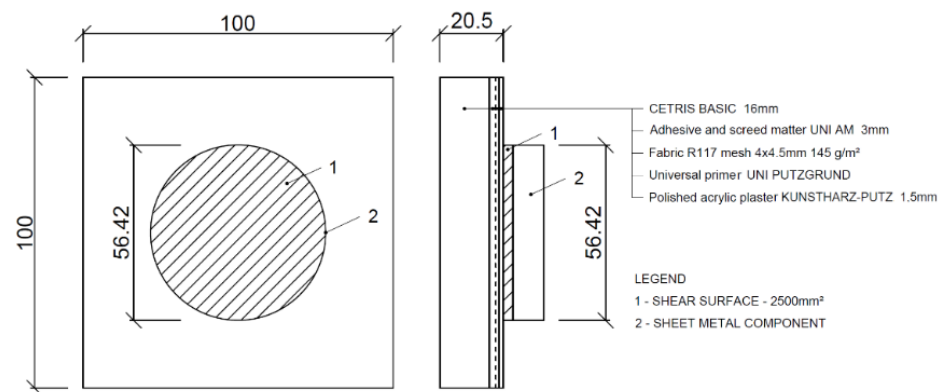
- White pasty structural acrylic dispersion plaster with the brand name PROFI AKRY-LATPUTZ produced by the manufacturer Profibaustoffe CZ, s.r.o., with a bond strength of min. 0.30 MPa;
- Universal primer coating used under the white pasty plaster with the brand name PROFI UNI Putzgrund produced by the manufacturer Profibaustoffe CZ, s.r.o., with a styrene–acrylate binder;
- An adhesive and screed compound for facade thermal insulation boards with the brand name PROFI UNI AM produced by the manufacturer Profibaustoffe CZ, s.r.o., with cement binder and a bonding strength to the solid substrate of min. 0.25 MPa;
- Fibreglass fabric for screed compound with the brand name R117 A101 produced by Saint-Gobain Vertex, s.r.o., with a tensile strength of 2100 N/50 mm;
- A smooth-surfaced cement-bonded particleboard with a thickness of 16 mm with the brand name CETRIS BASIC produced by the manufacturer CIDEM Hranice, a.s., with a transverse tensile strength of min. 0.63 MPa.

### 2.2. Methods

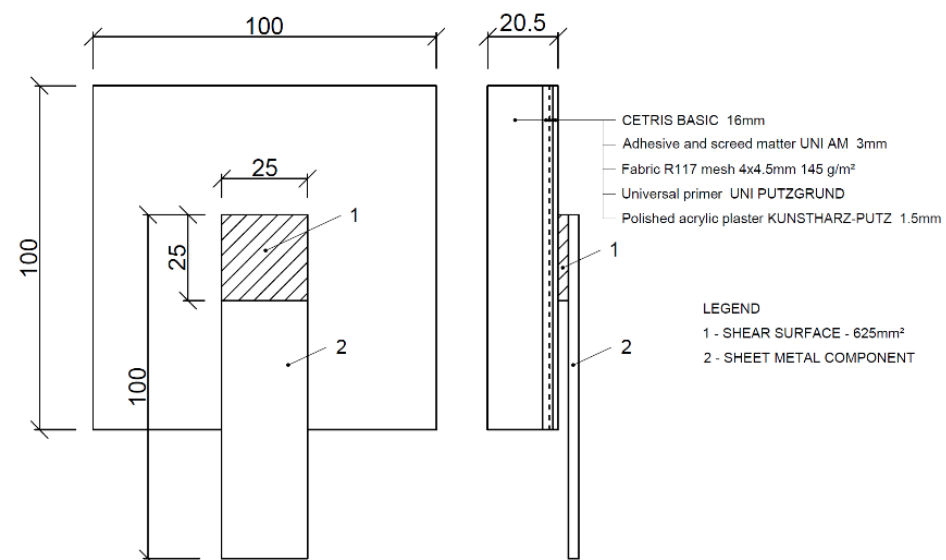
#### 2.2.1. Preparation of Test Specimens

The test specimens consisted of a base plate, adhesive and a metal target of a circular shape with a bonding area of 2500 mm<sup>2</sup> for the tensile tests and a metal strip of 100 × 25 mm with a bonding area of 625 mm<sup>2</sup> for the shear tests. The base plate consisted of a layer

that corresponded to the actual composition used in facades with contact insulation. The soft and easily deformable thermal insulator was replaced by a solid cement-bonded particleboard for laboratory purposes. The intention was to measure only the deformation of the tested adhesive without the undesired influence of any deformation of the thermal insulation. It was assumed that the adhesive would be torn off either in the plaster or in the screed. The cement-bonded particleboards were cut into  $100 \times 100$  mm squares from a production size of  $3350 \times 1250$  mm, and then cement screed with a thickness of 3 mm was applied to them in two layers. A fibreglass fabric was fitted between the first and second layers of the cement screed. After the screed had cured the surface was coated with a primer, and a final 1.5 mm thick layer of acrylic plaster, was applied. The composition of the test specimen for the tensile test is shown in Figure 1, and in Figure 2 the test specimen for the shear test can be seen. Close attention was paid to the production of the bonded joint, where a constant adhesive thickness of 3 mm had to be maintained. Inaccuracies of this basic parameter would adversely affect the measurement results [11].



**Figure 1.** Test specimen for tensile test.



**Figure 2.** Test specimen for shear test.

### 2.2.2. Adhesion Tests

The tests were carried out on a LaborTech E.2 measuring device fitted with L06 vice jaws under normal laboratory conditions. The adhesion tests included both tensile and shear stresses. The basis of both the chosen test methods was the recording of the force course required to tear the adhered metal component of the substrate as a function of the elongation of the adhesive under testing. The loading was carried out at a rate of 5 mm per

minute until failure, defined by a drop in force to 5% of the maximum achieved force for the tensile test and 30% for the shear test. The most important values for the evaluation were the maximum achieved force  $F$  (in N) and the corresponding elongation  $\Delta l$  (in mm). The tensile test was based on the procedure defined by the Czech technical standard ČSN 732,577 [12]. The principle of the test was to measure the force required to break away from the adhering body by tension applied perpendicular to the substrate. The tensile strength  $\sigma_{adh}$  (in MPa) was subsequently calculated according to the following relation:

$$\sigma_{adh} = \frac{F}{A} = \frac{F}{2500} \quad (1)$$

The shear test was based on the procedure defined by the European technical standard EN 1465 [13]. The principle of the test was to measure the tensile force acting parallel to the surface of the bonded joint. The shear adhesion (in MPa) was calculated according to the formula:

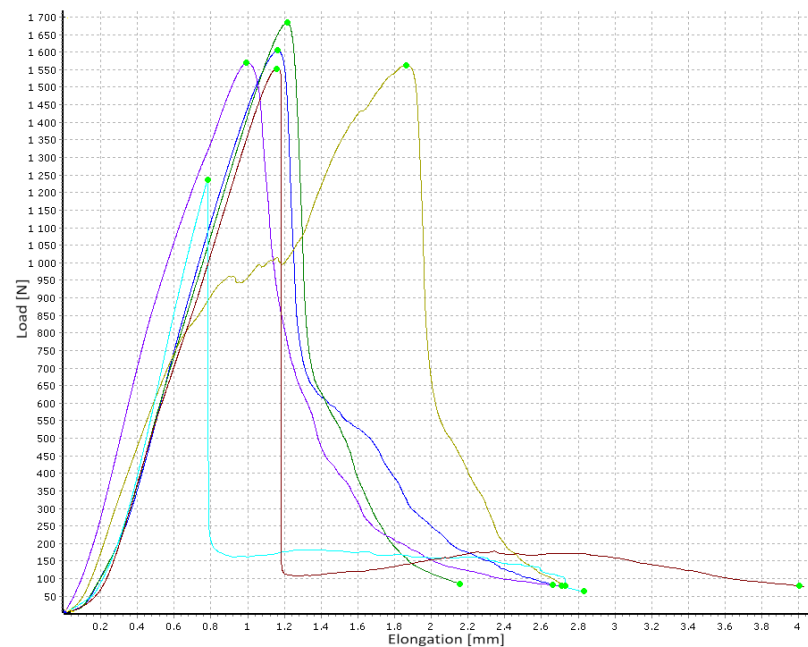
$$\tau = \frac{F}{A} = \frac{F}{625} \quad (2)$$

The elongation (in %) was subsequently calculated from the increment of the length  $\Delta l$  (in mm) to the original length  $l$  (in mm):

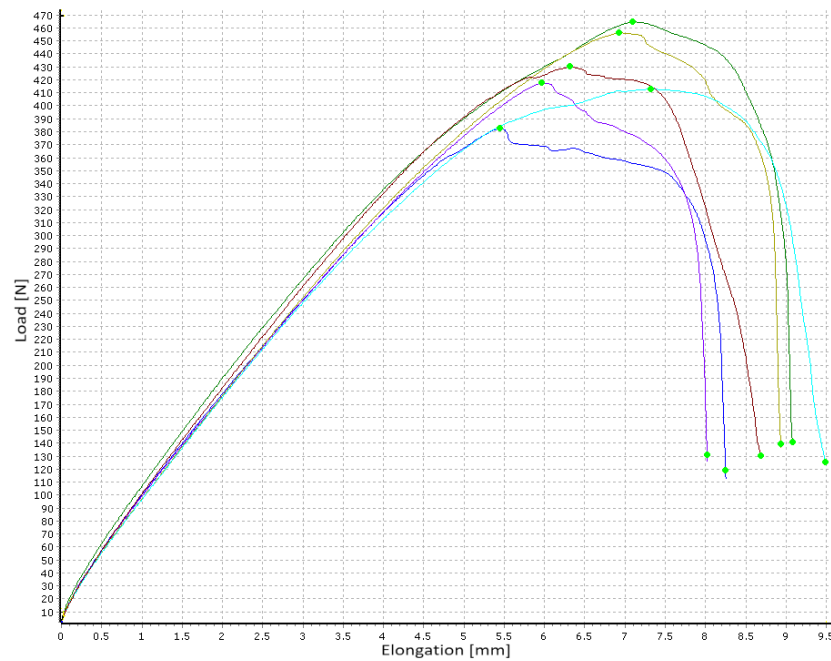
$$\varepsilon = \frac{\Delta l}{l} * 100 \quad (3)$$

### 3. Results

The results were used to generate a number of charts showing the dependence of the elongation  $\Delta l$  on the applied force  $F$ . An example of a chart for the tensile test is shown in Figure 3, and an example of a chart for the shear test is in Figure 4.



**Figure 3.** Example of tensile test results for measuring adhesive deformation on aluminium targets.



**Figure 4.** Example of shear test results for measuring adhesive deformation on galvanised strips.

The data from the deformation diagrams were tabulated in a clear way, with the decisive point for the evaluation being the maximum tensile or shear force and the corresponding elongation. Based on this data, the tensile adhesion  $\sigma_{adh}$  was calculated according to Formula (1), the shear adhesion  $\tau$  was calculated according to Formula (2) and the elongation  $\varepsilon$  for both tensile and shear adhesion was calculated according to Formula (3). Statistical evaluation was performed for all the calculated parameters in the form of calculating the standard deviation  $s_x$  and the coefficient of variation  $v_x$ . The tensile test results can be seen in Table 1, and the shear test results are presented in Table 2.

**Table 1.** Results of tensile adhesion  $\sigma_{adh}$  (in MPa) and elongation  $\varepsilon$  (in %), standard deviation  $s_x$  (in MPa for  $\sigma_{adh}$ , in % for  $\varepsilon$ ) and coefficient of variation  $v_x$  (in %) <sup>1</sup> for aluminium alloy (Al), galvanised steel (FeZn) and copper alloy (Cu) targets compared to results of adhesive alone (AD) on aluminium targets.

	Al	FeZn	Cu	AD
$\sigma_{adh}$	0.614	0.694	0.585	0.849
$s_x$	0.056	0.138	0.074	0.035
$v_x$	9.2	19.8	12.7	4.1
$\varepsilon$	39.8	35.5	33.3	90.1
$s_x$	11.1	8.3	10.4	10.2
$v_x$	27.8	23.4	31.3	11.3

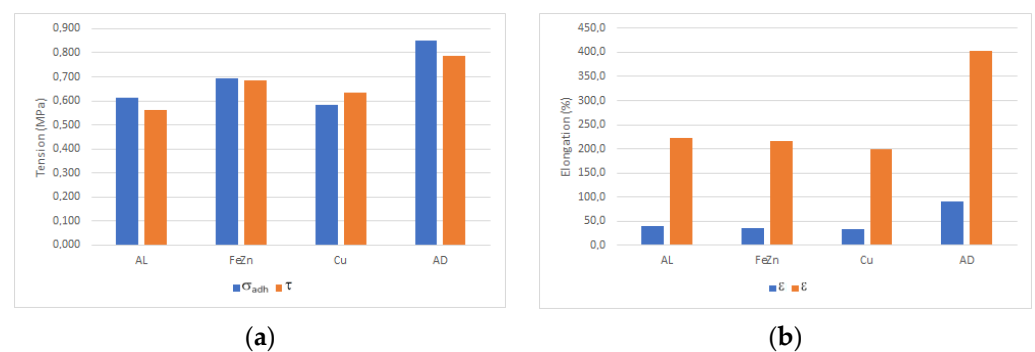
<sup>1</sup> The average values are a sum of six measurements conducted for each tested combination.

A comparison of the adhesion and elongation in both tests can be seen in Figure 5. Possible types of destruction are shown in Figure 6. The most common type of destruction in the adhesion tests was the tearing of the metal target or strip, including the adhesive from the plaster surface. The second most common type of destruction was the tearing of the plaster, including the covering layer of the screed to the layer of the reinforcing fibreglass fabric. The least common destruction type presented only in copper strips in the shear test was the peeling of the adhesive from the copper material.

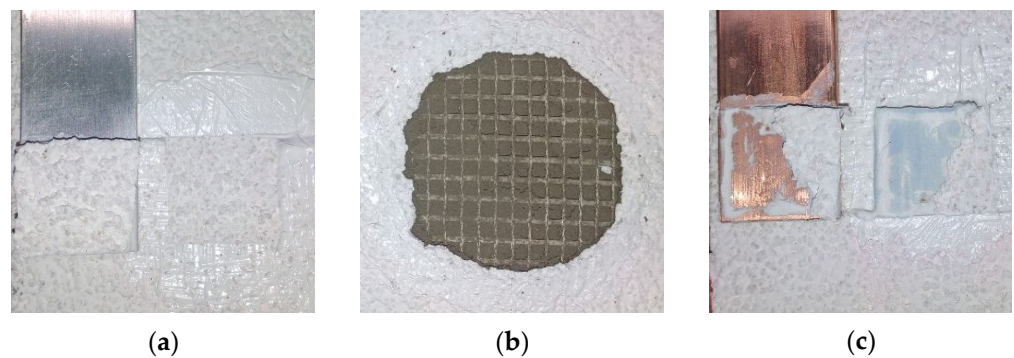
**Table 2.** Results of shear adhesion  $\tau$  (in MPa) and elongation  $\varepsilon$  (in %), standard deviation  $s_x$  (in MPa for  $\tau$ , in % for  $\varepsilon$ ) and coefficient of variation  $v_x$  (in %) <sup>1</sup> for aluminium alloy (Al), galvanised steel (FeZn) and copper alloy (Cu) targets compared with the results of adhesive alone (AD) on aluminium strips.

	Al	FeZn	Cu	AD
$\tau$	0.562	0.684	0.634	0.786
$s_x$	0.075	0.044	0.054	0.080
$v_x$	13.3	6.5	8.5	10.2
$\varepsilon$	223.3	217.0	200.0	403.3
$s_x$	18.6	22.1	24.2	69.2
$v_x$	8.3	10.2	12.1	17.2

<sup>1</sup> The average values are a sum of six measurements conducted for each tested combination.



**Figure 5.** Comparison of test results: (a)  $\sigma_{adh}$  (in MPa) for tensile test (blue) and  $\tau$  (in MPa) for shear test (orange); (b)  $\varepsilon$  (in %) for tensile test (blue) and shear test (orange).



**Figure 6.** Possible types of destruction: (a) tearing of the metal strip including the adhesive from the plaster surface; (b) tearing of the plaster including the covering layer of the screed from the layer of reinforcing fibreglass fabric; (c) peeling off the adhesive from the copper strip.

#### 4. Discussion

For the steel and aluminium components, no metal came off the adhesive in any of the measurements; the destruction always occurred in the underlying plaster. In the case of the copper alloy, a difference was determined between the tensile and shear tests. While in the tensile test the adhesive was torn off the plaster in all cases, in the shear test, on the other hand, all the measurements showed a complete peeling of the adhesive from the copper surface, and only in one case did a partial peeling of the adhesive from the copper surface combined with destruction in the plaster occur, as can be seen in Figure 5. The declared strength of the plaster by the manufacturer was 0.3 MPa. The real values of the observed tensile and shear adhesive strengths essentially exceed this value two-fold, which was clearly due to the higher strength of the plaster and its inherent adhesion to the underlying screed. In terms of the measured data, there was no significant difference in



whether the destruction occurred in the surface thin-layer plaster or the screed, and the values of the measured forces and the calculated stresses were similar. However, lower values were obtained in the case of copper in the shear test, where the destruction occurred almost exclusively by peeling off the copper strip.

In addition to the tests of the bonded joint between the metal element and the plaster substrate, the tensile and shear properties of the adhesive itself were measured. The measurements were carried out using a standard tensile and shear test, where the aluminium targets and strips were bonded together, and subsequent destruction in the adhesive itself occurred during the measurement. Copper and steel zinc-plated elements were not used to measure the adhesive parameters. As expected, the adhesive itself performed better in both tests in terms of both adhesion and elongation (see Figure 5). In terms of tensile adhesion, the adhesive performed better by 34% on average, and in terms of shear adhesion, it performed better by 25%. In the case of elongation, the adhesive parameters were on average 150% better in the tensile test and 89% better in the shear test. However, elongation is not as important as adhesion in the case of bonding sheet-metal components to a facade. In this respect, the results demonstrated the fundamental fact that, under standard laboratory conditions, the tensile- and shear-load capacities of the adhesive itself were not significantly better than those of the bonded joint, which involved a metal element bonded to the surface of the used multi-layer facade plaster. It should be noted that the research did not include other important factors such as the effect of freezing and thawing, the effect of moisture, sudden temperature changes as described by Franco and Royer-Carfagni [14], adhesive thickness or ageing of the multi-layer plaster [15–19]. In practice, it would be glued to facades already subjected to external environmental influences, as described by Bochen [20].

## 5. Conclusions

The aim of the research was to verify in laboratory conditions whether it is reasonable to consider the technology of bonding sheet-metal components to the thin-layer plaster of thermal insulation systems. The start of the research was accompanied by a preliminary concern that the load capacity of the spot-bonded components would be low, which was estimated to the units of kilograms. The measured forces required to tear off a 2500 mm<sup>2</sup> bonded target were surprisingly high, ranging across all the materials tested from 99.3 kg to 199.5 kg of static load. For the 625 mm<sup>2</sup> adhesive strips, the range of forces required to tear it off ranged from 25.4 kg to 46.5 kg. The following conclusions were drawn based on the results obtained:

- The research was carried out exclusively under laboratory conditions and it provided interesting results at this initial stage;
- Even small bonded areas could carry significant tensile and shear loads sufficient for the anticipated loads, and the required load capacity of the bonded joint could be determined depending on the bonded area;
- The load capacity of the bonded joint will always depend on the quality of the substrate. In the case of a new plaster implemented in accordance with technological procedures, the use of the technology of additional bonding of any components to the surface of the multi-layer facade may be considered. However, the technology used must be properly tested;
- The obtained results do not yet allow the combinations of the materials used in this research to be declared a proven technology. The validation will continue with the inclusion of other influences acting on facades in outdoor environments. The results will be published separately.

The bonding technology of the sheet metal components and the issue of bonding to the surface of insulated facades, in general, appears to be promising for the future; however, further research is needed.

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