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Communication

# Mechanical and fracture mechanical characterization of building materials used for external thermal insulation composite systems

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**Abstract**

Fracture mechanical investigations of building materials applied for external insulation composite systems have been performed in order to provide material data for the numerical simulation of mechanical failure. For this purpose a wedge splitting procedure according to Tschegg has been employed and modified for the investigation of material layers with a thickness of approx. 5 mm. The testing method proved to be suitable for investigation of both the materials themselves and the compound of two layers. Results of commercially available building materials for external insulation composite systems are shown. From their dependence on different preparation procedures, it may be concluded how temperature and humidity may affect material properties under conditions of actual service.


*Keywords:* Characterization; Bond strength; Physical properties; Composite

## 1. Introduction

In spite of the fact that external thermal insulation composite systems (ETICS) are well known and applied since decades, there is still a lack of understanding the reasons and mechanisms of different failure cases. One promising possibility to broaden this knowledge is the application of numerical simulation, especially by the Finite Element Method. But this is presently restricted by the availability of the necessary material properties, and especially of fracture mechanical properties. The aim of the investigations presented here is on the one hand to try out the suitability of a test method for this purpose, and on the other hand to provide data of some commercially

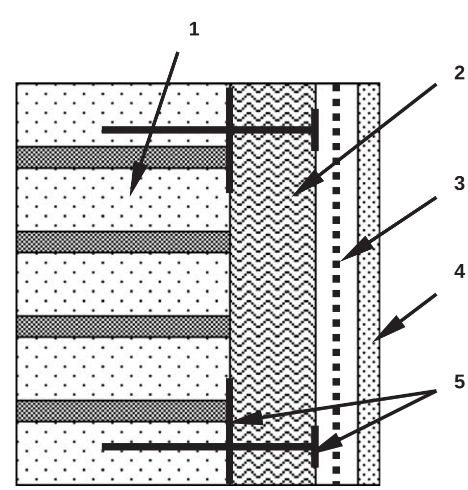


Fig. 1. Schematic representation of an external insulation composite system; wall construction (1), insulation material (2), cement bound mortar with reinforcement (3), rendering (4), fixation by dowels and mortar (5).

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available building materials. This paper will concentrate on a wedge splitting procedure which is modified to enable the testing of thin material layers.

The principal design of an ETICS is schematically shown in Fig. 1. An insulating board manufactured, e.g. from expanded polystyrene or mineral fibres is rawlplugged and/or glued to the wall. It is followed by a layer of a cement bound mortar with a thickness of approx. 3–5 mm. It is reinforced by a textile glass fabric placed in the middle of the layer. The rendering is attached to this mortar with a thickness of approx. 1.5–4 mm. In most cases a material with inorganic aggregate and a polymer bond is used. More details can be found in [1].

The appearance of failure may be very different [2]. From case to case cracks in the surface of the rendering can be observed. A detachment of the cement bound mortar from the insulating board and from the rendering may occur. Crack formation within the plane of the reinforcement is also observed occasionally. An understanding of these failure cases necessitates the determination of fracture mechanical properties of the materials themselves as well as those of the interfaces between two materials. Moreover it can be expected that the properties will be sensitive to the conditions of the pretreatment.

## 2. Testing methods and material preparation

A wedge splitting test for the fracture mechanical characterization of building materials was already described

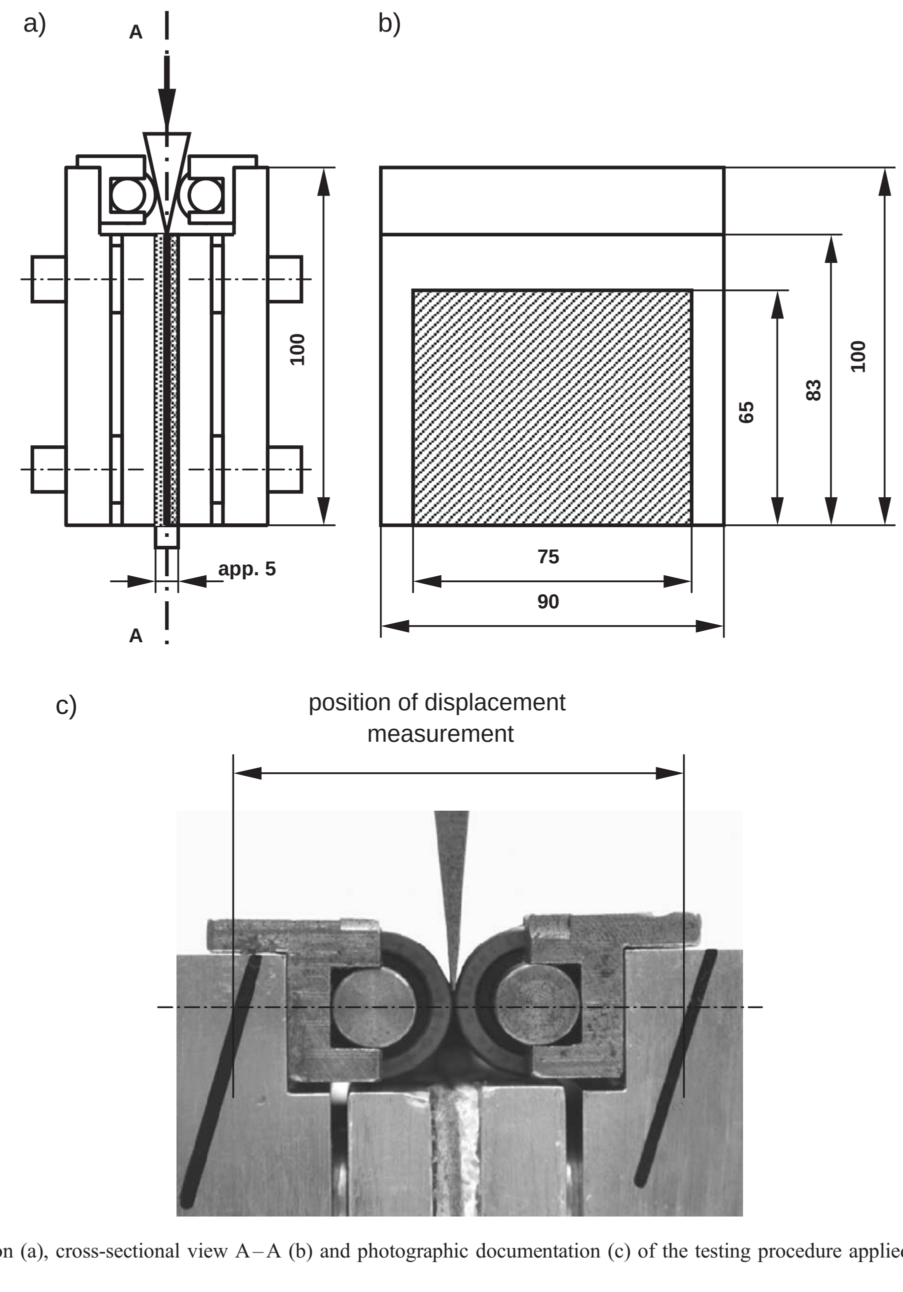


Fig. 2. Front elevation (a), cross-sectional view A–A (b) and photographic documentation (c) of the testing procedure applied; all measures in mm.

by Tschegg [3]. It was also applied for the investigation of the adherence of two building materials [4]. Due to the large drying shrinkage of rendering mortars, only thin layers can be tested. Therefore for the investigations described here the testing method was modified. A schematic representation of the testing equipment can be seen from Fig. 2. The specimen has a thickness of approx. 5 mm, in the case of a compound specimen each material layer is approx. 2.5 mm thick. In the middle of this layer (in the interface plane of a compound), a starter notch and two side notches for guiding the crack path are situated. These notches are not prepared mechanically but moulded with the help of a U-shaped cardboard inlay of the size of the notches. The cardboard was impregnated with vaseline to avoid adherence to the material. After the desired storage, both specimen surfaces are glued to aluminium plates which themselves are mounted to two load transmission plates. As can be seen from Fig 2 two load transmission pieces have the task to convert the vertical load of the wedge into a horizontal force splitting the specimen. During the testing procedure a constant displacement in vertical direction of 0.5 mm/min was applied. The testing method was chosen because it enables a stable crack propagation necessary for determination of the specific fracture energy [5]. The stable crack propagation results in a continuous load/displacement diagram. This is evaluated in the following way. The specific fracture energy $G_F$ was determined from the load/displacement diagram according to Eq. (1):

$$G_F = \frac{1}{A} \cdot \int_0^{\delta_u} F_H(\delta)\mathrm{d}\delta \tag{1}$$

Here $A$ denotes the nominal fracture surface, $\delta_u$ the ultimate displacement and $F_H$ the horizontal load determined from the measured vertical load $F_V$ by Eq. (2):

$$F_H = \frac{F_V}{2 \cdot \tan(\alpha/2)} \tag{2}$$

In Eq. (2) $\alpha$ is the wedge angle which was 10° for the investigations reported here.

Table 1
Composition and description of the investigated materials

| Material | Composition and description |
|---|---|
| Cement bound mortar | calcite gravel 0–0.5 mm<br>cement bond<br>polymer modified material with approx. 5% polymer dispersion<br>dry material, batch water has to be added |
| Polymer bound rendering | marble gravel 0–2 mm<br>polymer bound material with addition of modified cellulose fibre<br>white pasty material ready to use |
| Primer | polymer dispersion<br>oily liquid ready to use |
| Textile glass fabric | grid with mesh opening of 3.5×4.2 mm<br>tensile strength 2100 N/50 mm |

Table 2
Young's modulus, flexural strength and compressive strength of the investigated cement mortar

| Age of sample (days) | Dynamic young's modulus (GPa) | Flexural strength (N/mm$^2$) | Compressive strength (N/mm$^2$) |
|---|---|---|---|
| 1 | 0.48 | 0.21 | 0.85 |
| 3 | 3.60 | 1.26 | 3.32 |
| 7 | 5.10 | 2.29 | 7.13 |
| 28 | 6.91 | 4.92 | 13.00 |

From the maximum load, $F_{H,max}$ a nominal notch tensile strength $\sigma_{NT}$ was determined:

$$\sigma_{NT} = \frac{F_{H,max}}{B \cdot W} \cdot \left(1 + \frac{6y}{W}\right) \tag{3}$$

Here $B$ is the horizontal and $W$ the vertical dimension of the fracture surface and $y$ the distance of its center of gravity from the line of the horizontal force $F_H$. Eq. (3) adds the tensile and the flexural stress. The displacement was measured with a video extensometer by the help of the marks shown in Fig 2(c) and the vertical load by a load cell.

All investigated materials are commercially available and destined for ETICS. Table 1 gives an overview of these materials. In Table 2 dynamic Young's modulus and data characterizing strength of the cement mortar can be seen. It was investigated according to [6]. Compressive strength and flexural strenght were determined as described in [7].

To produce specimens of the necessary dimensions, all materials have been cast with a U-shaped cardboard inlay to mould the starter notch and the side grooves. The cement bound mortar was moulded with and without reinforcement and stored for 3 days at 95±5% relative humidity and 20 °C. Then the specimens were demoulded and further stored under the same conditions. The specimens of the polymer bound rendering material were manufactured similarly, but stored at 65±5% relative humidity. For the compound specimens first a layer of the cement mortar was cast and stored for 7 days at 95±5% relative humidity and 20 °C. In the next step the surface was treated with the primer which was allowed to dry for 24 h at 65±5% relative humidity and

Table 3
Specific fracture energy $G_F$ and nominal notch tensile strength $\sigma_{NT}$ of the investigated materials and their composites

| Material | $G_F$ (N/m) | $\sigma_{NT}$ (N/mm$^2$) |
|---|---|---|
| Cement bound mortar | 70.70 | 1.84 |
| Cement bound mortar reinforced with textile glass fabric | 79.14 | 1.68 |
| Polymer bound rendering | 182.40 | 0.60 |
| Composite of cement bound mortar and rendering | 27.85 | 0.56 |

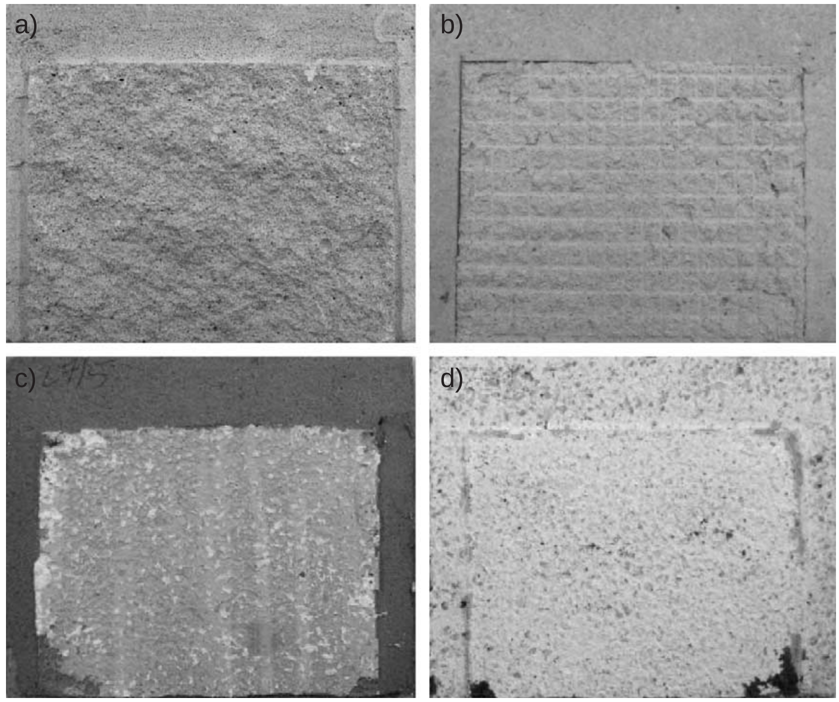


Fig. 3. Photographs of fractured surfaces (65·75 $mm^2$): pure cement mortar (a), fracture along the interface of cement mortar and textile glass fabric (b), fracture along the interface of cement mortar, primer and polymer bound rendering with U-shaped cardboard inlay (dark grey) (c), and counterpart of (c) showing polymer bonded rendering (d).

20 °C. These conditions maintained when afterwards the polymer bound rendering was applied with the U-shaped cardboard at the interface plane and stored for 3 more days. Afterwards the composites were demoulded.

## 3. Investigated materials and results

The specific fracture energy and the nominal notch tensile strength of the investigated materials and their composites can be seen from Table 3. Crack propagation along the reinforcement causes only a slight decrease of the nominal notch tensile strength and even an increase of the specific fracture energy. The relatively large specific fracture energy of the polymer bound rendering may be attributed to the polymer dispersion and the fibre addition. The compound shows a considerable decrease of the specific fracture energy relative to both materials, whereas the nominal notch tensile strength is similar to that of the rendering. In Fig. 3 some typical fracture surfaces are shown. Table 4 shows the dependence of the investigated properties of the compound on the storage conditions. A heat treatment at 50 °C for 7 days increases both the specific fracture energy and the nominal notch tensile strength. Increasing humidity after demoulding has the contrary effect.

Table 4
Dependence of the specific fracture energy $G_F$ and the nominal notch tensile strength $\sigma_{NT}$ of the compound specimens on the storage conditions

| | $G_F$ (N/m) | $\sigma_{NT}$ ($N/mm^2$) |
|---|---|---|
| 25 days at 65±5% r. h. and 20 °C, 7 days at 50 °C | 52.98 | 0.97 |
| 25 days at 65±5% r. h. and 20 °C | 27.85 | 0.56 |
| 25 days at 95±5% r. h. and 20 °C | 22.98 | 0.34 |
| 25 days under water at 20 °C | 9.66 | 0.17 |

## 4. Discussion and conclusions

The procedure described above was successfully employed to investigate thin layers of building materials. It enables testing of the materials using the same thickness as applied for ETICS. Therefore material properties determined are expected to be more realistic. The results documented here will be used for numerical simulations in order to investigate possible mechanical failure of ETICS. Properties of the compound show a considerable impact of the storage conditions. Therefore it may be expected that conditions during and after application of ETICS (temperature, humidity, weathering) are of influence for integrity and lifetime of the system.

## Acknowledgement

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