Bond properties between concrete and ceramic tiles

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Bond Properties between Concrete and Ceramic Tiles

Propriétés d'adhérence entre le béton et les carreaux de céramique

Haftfähigkeit zwischen Beton und Klinkerplatten

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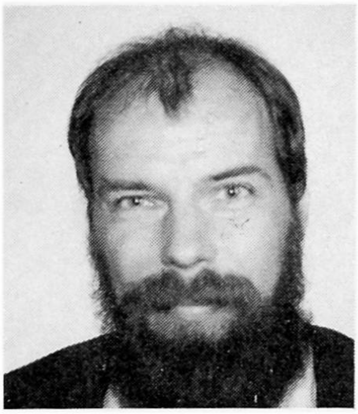

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SUMMARY

This article deals with the factors affecting the bond between ceramic tiles and concrete in sandwich facade panels. The temperature distribution in a wall has been calculated, and based on this the shear stresses between tiles and concrete. The bond properties of ceramic tiles designed with different texture have been tested in the laboratory by different test methods.

RÉSUMÉ

Cet article présente les facteurs influençant l'adhérence entre des carreaux de céramique et le béton dans des éléments de façade sandwich. La distribution de température dans une paroi est calculée, et s'appuyant sur ces résultats la résistance au cisaillement entre les carreaux et le béton est calculée. Des essais des propriétés d'adhérence des carreaux de céramique avec diverses structures des sont effectuées en labratoire à l'aide de plusieurs méthodes.

ZUSAMMENFASSUNG

Dieser Artikel behandelt die Faktoren, die die Haftung zwischen Klinkerplatten und Beton in Fassadenelementen von Sandwich-Konstruktion beeinflussen. Die Temperaturverteilung in einer Wand ist berechnet worden, und daraus die Schubspannung zwischen Platten und Beton. Die Haftfähigkeitseigenschaften der Klinkerplatten mit verschiedener Oberflächenstruktur sind im Labor mit Hilfe verschiedener Prüfverfahren geprüft worden.

1. INTRODUCTION

The use of concrete sandwich panels, on which ceramic tiles are applied to form the front face, has greatly increased in Finland during the last few years, and the trend is expected to continue in the future, too.

As the panel consists of two materials with different properties, the bond and the interaction between the materials must fulfil certain requirements due to great stresses in the boundary layer.

2. FACTORS INFLUENCING THE BOND STRESSES BETWEEN CONCRETE AND TILES

2.1 Stresses during production

In Finland these elements are generally manufactured by placing the ceramic tiles on the bottom of the mould and concrete is cast directly on the tiles. The concrete is then thermally treated up to a temperature of 50°C to allow the mould to be removed at an age of one day.

In the layer between tiles and concrete stresses will now occur as a result of the following factors:

- the shrinkage of concrete,
- different heat contraction in the materials when the panels are cooling,
- stresses caused by the panels' dead weight during storage and transportation.

Simultaneously with these time-dependent stresses in the boundary layer, the bond capacity between tiles and concrete and the shear strength capacity of the concrete continue to increase during the curing process. It is to be assumed that the time-dependent stress development will in principle follow the curves in Figure 1. In the long run concrete creep is expected to reduce these stresses [1].

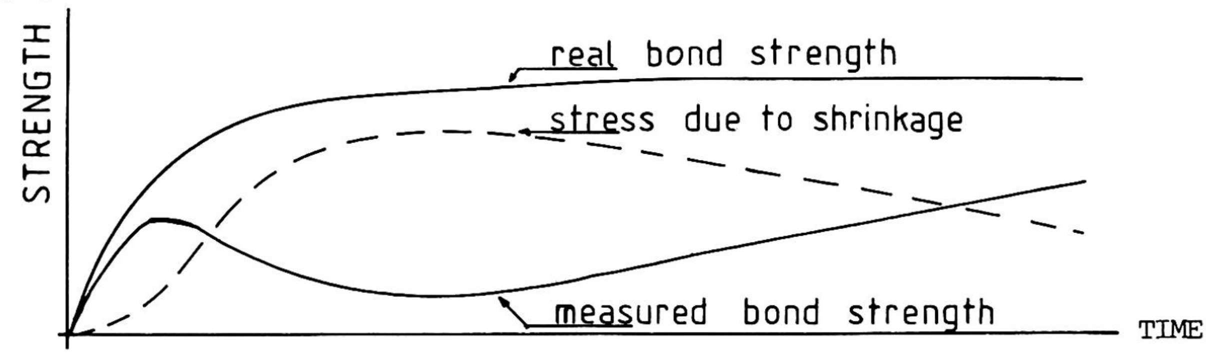

Fig. 1 The development of stresses and strength in the boundary layer between tiles and concrete.

2.2 Stresses caused by climatic actions

These stresses are caused by [2]

- seasonal differences in temperature,
- temperature differences related to day and night,
- variations in humidity,
- frost-thaw cycles,
- wind and other mechanical forces.

In this case we can also assume that those stresses related to seasonal differences in temperature will at least partly be reduced by the creep of concrete. In the present situation the influence of frost-thaw cycles would be very slight, because frost-resistant concrete is generally used.

The crucial and decisive factor is probably the temperature difference between day and night. It is important to remember that this relates to the microclimate, and the surface temperature may show great variations due to solar radiation in daytime and counter radiation at night.

2.3 Factors influencing the bond capacity between concrete and tiles

To improve the interaction between the tiles and the concrete attempts could be made to reduce the stresses by changing the material properties or to strengthen the bond between the tiles and concrete.

Stresses caused by temperature variations can be reduced by modifying the concrete composition in order to reduce the coefficient of thermal expansion and get it close to that of the tiles. The aggregate is of crucial importance in this respect [3].

Stresses related to the shrinkage of concrete can also be reduced by a modification of the concrete composition and by suitable after-curing [4].

In this study emphasis is laid on the role of the surface structure of the tiles. The results of the study are presented below.

2.4 Analytical solution of the temperature distribution [5]

The temperature distribution in the construction shown i Fig. 2 has been calculated according to Fourier's differential equation by the aid of a two-dimensional program using the finite element method.

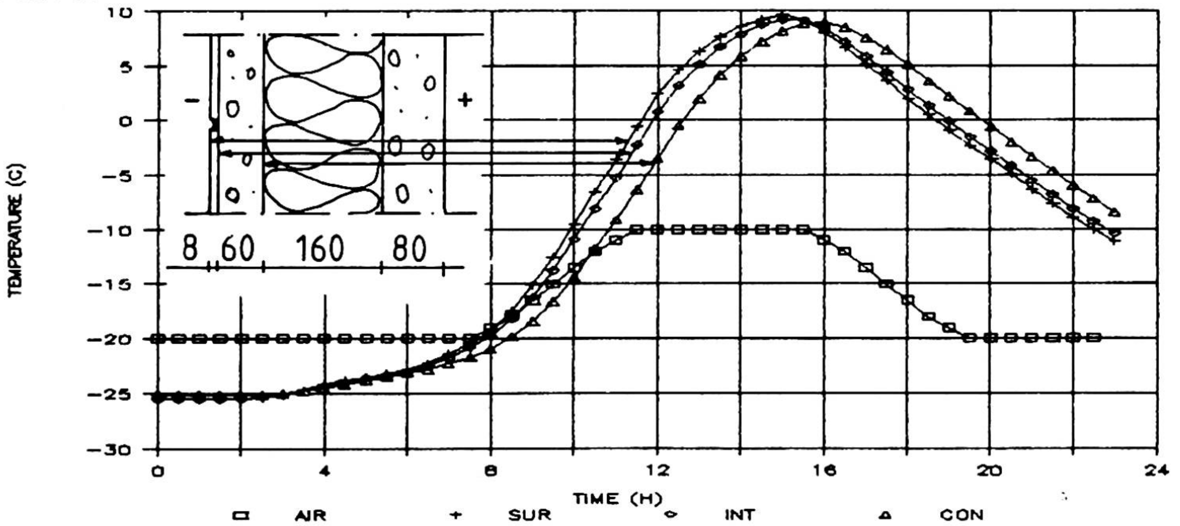

Fig. 2 Example of the temperature distribution in the outer layer of a sandwich element clad with clinker finish; in mid March in Helsinki.

The figure shows that temperature variations up to 35-40°C during a day are possible. Field measurements verify these calculations.

3. ANALYTICAL SOLUTION OF SHEAR STRESSES [3]

The tensions between the tiles and the concrete, caused by temperature variations and the different coefficients of thermal expansion, can be calculated according to the equations:

$$\sigma_t = \varepsilon \cdot E_c \cdot A_c \cdot \left(\frac{1}{A_e} - \frac{y_c}{I_e} \cdot y_t \right) \quad ; \quad \tau = \frac{\sigma_t \cdot A_t}{l}$$

where
σ_t = compressive stress in tiles (MPa)
ε = deformation of concrete related to tiles
E_c = the coefficient of elasticity of concrete (MPa)
A_c = cross section of the concrete (m^2/m)
y_c = distance of the centre-of-gravity axis of the concrete to that of the whole cross section (m)
y_t = distance of the centre-of-gravity axis of the tiles to that of the whole cross section (m)
τ = shear stresses between tile and concrete (MPa)
l = bond length (m)
A_t = cross section of ceramic tiles (m^2/m)

A_e and I_e are calculated according to the following equations:

$$A_e = A_t + A_c \cdot \frac{E_c}{E_t} \quad ; \quad I_e = I_t + y_t^2 \cdot A_t + (I_c + y_c^2 \cdot A_c) \cdot \frac{E_c}{E_t}$$

where
E_t = the coefficient of elasticity of tiles (MPa)
I_t = the moment of inertia of tiles (m^4/m)
I_c = the moment of inertia of concrete (m^4/m)

With the material properties (E_t = 50,000 MPa, E_c = 25,000 MPa, $\alpha_t = 6 \times 10^{-6}\ {}^\circ C^{-1}$, $\alpha_c = 10 \times 10^{-6}\ {}^\circ C^{-1}$ $T > 0^\circ C$, $\alpha_c = 13 \times 10^{-6}\ {}^\circ C^{-1}$ $T < 0^\circ C$) we can calculate the stresses in the element in Fig. 2 and the following results are obtained:

ε = 0.23 o/oo, σ_t = - 5.0 MPa, τ = 0.8 MPa

The shear stress between ceramic tiles and concrete is calculated for an edge tile assuming that the bond length is 50 mm.

4. INVESTIGATION OF THE BOND PROPERTIES OF DIFFERENT TILES

Small concrete elements of 65 x 600 x 1200 mm in size were made to test the influence of the tile bottom structure on the bond. The concrete used was a normal facade concrete with a 28-day compressive strength of K_{28} = 30 MPa. The elements were normally cast with the ceramic tiles on the bottom of the mould and without a jointing compound. They were then stored in conditions where T = 20°C and RH = 95%. The tiles used are specified in Table 1.

Type	Bottom structure	Size [mm]
1	Smooth	8 x 100 x 200
2	Honeycomb, deep profile	8 x 100 x 200
3	Honeycomb, mean profile	8 x 150 x 150
4	Honeycomb, low profile	8 x 150 x 150

Table 1 The ceramic tiles used.

The bond strength of the tiles was determined by drilling a cylinder (ø 78 mm) through the tile about 10 mm into the concrete. An anchor tie beam was fixed to the tile and the tensile strength was determined by a pull-out-method.

The bond was determined at an age of 28 days after the elements had been stored in conditions mentioned above. The bond was also determined according to a Finnish standard, i.e. the frost-thaw test [6], where the element are exposed to 100 frost-thaw cycles between -20 and +20°C. The thawing takes place in water and one cycle lasts 8 hours. Elements only stored in water during the test period are used as reference test specimens.

Moreover, a thermal shock test was used where the elements were placed in a freezer at a temperature of -25°C and the surface temperature of the tiles was raised by IR radiation according to Fig. 3. In this test the length of a cycle was also 8 hours and the number of cycles 100. Then the bond strength was determined. The obtained test results are summarized in Table 2.

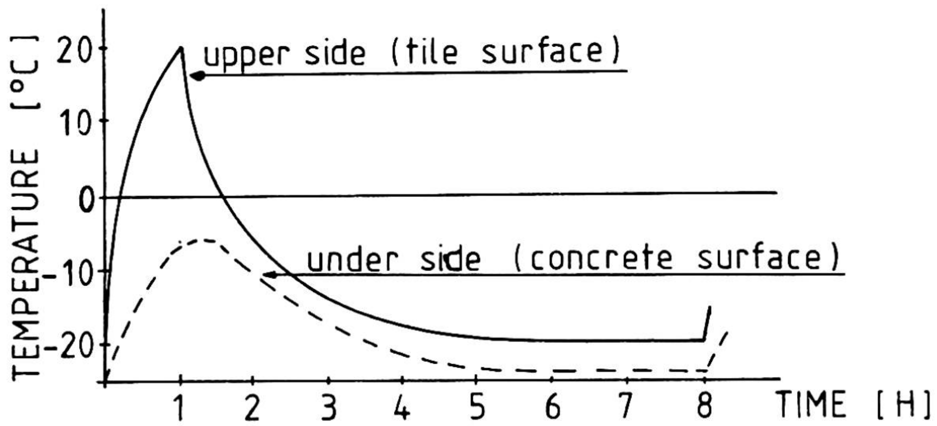

Fig. 3 The rise of temperature in the thermal shock test.

Bond strength (MPa)	Ceramic tiles			
	1	2	3	4
28-day	1.30	1.22	0.84	0.96
Frost-thaw test	0.86	1.12	1.01	0.96
Reference	1.57	1.57	1.53	1.16
Thermal shock test	0 (1)	1.13		
Type of rupture	A	C	B	A

(1) got loose during drilling.
A = bond rupture, no concrete on the tile
B = partial bond rupture, concrete on the tile < 40%
C = rupture in the concrete surface layer, the tile is covered by a thin concrete layer.

Table 2 Summary of the test results

5. CONCLUSIONS

If attention is only paid to the bond strengths no great differences are observed between the ceramic tiles. The reasons for this are as follows:

- great deviation,
- the bond strength is approaching the tensile strength of concrete,
- the stresses initiated by concrete shrinkage need not to be as great in the different tiles (see chapter 2, Fig. 1),
- the test method is unreliable and not suitable for this test in all respects.

A better conception of the bond is obtained if one looks at the fracture pattern. In this respect tile No.2 and 3 differ clearly from the others.

In my opinion the test method should be changed in order to determine the shear strength in the boundary layer between tiles and concrete instead of the tensile strength.

The thermal shock test also seems to correlate better with the real situation than the frost-thaw test.

The difficulty encountered during all these tests is that the stresses initiated by concrete shrinkage during storage and testing are not known.

Element factories are in a great need for a simple test method for determining the bond capacity. Efforts are made by the Technical Research Centre to develop the desired method.

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