THE INFLUENCE OF GROUT THICKNESS ON THE ADHERENCE OF CERAMIC TILING SYSTEMS

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ABSTRACT

This work describes the investigation carried out in order to establish the influence of grout thickness on the stresses of ceramic tiling systems. Both an experimental program and a theoretical 2-D finite element model were performed. The work describes the main results obtained with the theoretical model. Joint thickness ranged from 4 mm to 10 mm. It could be seen that both normal and shear stresses are influenced by changing the joint.

1. INTRODUCTION

Wall tiling has been used through the ages for aesthetic and durability purposes. However, problems related to ceramic tile detachment on buildings are very common at earlier ages or after long period of adequate performance.

Detachments are often related to differential movements that can be caused by building settlements or temperature changes. Heat-cold cycles produce movements of expansion or shrinkage in the tiling system. The magnitude of the movements depends on the thermal and mechanical properties of materials in each layer (substrate, mortar rendering, adhesive mortar and ceramic tile), and on the level of the thermal changes. As the thermal coefficient expansion is not the same throughout the system, differential movements will be developed in each layer. According to Billi et al. (1995), the coefficient of thermal expansion (CTE) of ceramic tiles ranges from 6 to 7 x 10^{-6} $^{o}C^{-1}$. This value is two times lower than cement based materials (CTE around 15 x 10^{-6} $^{o}C^{-1}$ according to Illston, 1994) such as rendering, adhesive and grout mortars. Since free deformation of each layer is limited by the bond between them, tensile and shear stresses will appear. These stresses may produce loss of adherence, and detachment of tile can occur by reaching the bond strength or by fatigue of the material. The thermal gradient developed by non-uniform heating is also responsible for setting up stresses.

Grout plays a very important role in the system, since it is responsible for absorbing tile deformations. The sensitivity of the tiling coating system to the variation of the thickness of the grout was investigated by analyzing shear and normal (in the direction of the detachment) thermal stresses on the system rendering/adhesive and adhesive/tile interfaces. It is possible to estimate the stresses on the various layers of a ceramic tile coating systems subjected to temperature changes by numerical modeling (Bowman and Banks, 1995, Silva et al., 1999). In this paper, a 2-D finite element linear elastic analysis was developed to estimate such stresses. Experimental tests were carried out to obtain data to calibrate the model. The input used was the temperature evolution through system layers and physical and mechanical properties of the materials. Values obtained by other researchers were used when there was no possibility to perform tests.

2. CERAMIC TILING SYSTEM

The ceramic tiling system considered was a composite, consisting of four layers, as can be seen in Figure 1. Each layer performed a different function and is generally made from different materials. The system can be either of an external wall, where the outermost layer is formed by the ceramic tiles with grouted joints that protect the wall from the environment and provide a decorative finish to the building, or of an internal wall. In both cases the movements due to wall heating or settlement may induce the appearance of stresses. The tiles are laid on the adhesive layer, which is responsible for the adhesion of the tiles to the wall. Both polymer modified and unmodified mortars have been used in the construction industry as adhesive mortars. The rendering corrects the deviations from flatness and reduces the surface defects and irregularities of the substrate. This layer is generally formed by cementitious binders. The substrate is the base structure to be covered, and may be constructed of brick, concrete blocks, etc.

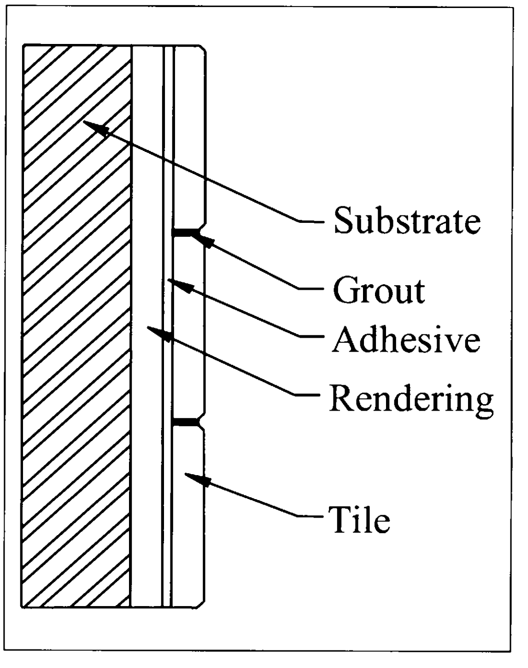

Figure 1. Ceramic tiling system

3. EXPERIMENTAL PROCEDURE

3.1.- MATERIALS CHARACTERIZATION

Ceramic tile, adhesive mortar, rendering mortar and grout were tested in order to obtain values for model input. The ceramic tile used is called gres, obtained from powder pressing and twice firing, resulting in a high performance material. The adhesive used was an organic mortar made with cement, sand, filler and polymer methyl-hydroxyethyl-cellulose (MHEC). Table 1 shows the proportion mix of this mortar.

Cement	Sand	Filler	MHEC	Water/dry materials relation **
1	2.8	0.2	0.020	0.18

** the weight of MHEC was not considered

Table 1: Proportion of materials in adhesive mortars (weight)

Material	CTE ($^{o}C^{-1}$)	Young modulus (MPa)	Poisson coefficient
Ceramic tile	4.6×10^{-6}	38779	0,10*
Grout mortar	10.0×10^{-6}	12265	0.18
Adhesive mortar	10.0×10^{-6}	10745	0.18
Rendering mortar	9.6×10^{-6}	5918**	0.17**
Substrate	6.5×10^{-6}	20000	0.07
Mortar	9.6×10^{-6}	8000	0.17

* estimated

** by Mohamad, 1998

Table 2: Average coefficient of thermal expansion, Young's modulus and Poisson coefficient for mortars and ceramic tile

The characteristic values considered for the rendering mortar were those of a mix of Portland cement, medium sand and hydrated lime, in proportions of 1:1:6 by volume (cement:lime:sand) and water/cement relation of 1.76 (Mohamad, 1998). The grout mortar, used to fill the joints between each ceramic tile, contained Portland cement, fine sand, and MHEC polymer. The proportions used were 1:3:0.002 (by weight).

The coefficients of thermal expansion (CTE) of the materials described above were determined, using a Netzsch Model 202 and a Shimadzu Model 50H Thermomechanical Analyser (TMA). The Young modulus and Poisson coefficient of the materials were also determined. The mortars were tested in compression according to the Brazilian Standard NBR 8522 (1984). The specimens of ceramic tile were cut in dimensions of 35 x 35 x 8 mm, and were also tested in compression. Table 2 shows the CTE values, the Young modulus and the Poisson obtained for each material.

4. TEMPERATURE PROFILE

In order to perform the experimental program a laboratory test was performed. A 91 x 91 cm brickwork wall was built and covered with ceramic tiles of 45 x 45 cm, see Figure 2. The brickwork was covered with 2 cm of 1:2:6 (cement:lime:sand) mortar rendering. The wall tiles were glued over the rendering with adhesive type AC-II (according to NBR 14081:1998). The tiles were placed with 6 mm joints which were later grouted with industrial flexible grout.

The wall was placed in the door of the climatic chamber with the ceramic tile and grout joints face placed in the internal side of the door. Thermocouples and strain gauges were installed at the middle of the layers and layers interface to get the temperature gradient and the deformations through the system. The internal face of the wall with ceramic tile and grout joints, was heated from 26°C (room temperature) to 62°C. Figure 2 shows the obtained graphic of temperature distribution in the system, at the time the tile surface reach the highest desired temperature (62°C). These values were also used as the numerical model input.

5. FINITE ELEMENT MODEL

5.1.- DESCRIPTION OF THE MODEL

The thermal stresses on the adhesive mortar/ceramic tile interfaces were obtained by a numerical model, using 2-D finite element analysis. The model consists of a two-dimensional cross-section of the brickwork wall finished with two square tiles of 45 x 45 cm, placed side by side. The grout joint thicknesses analyzed were 4, 6, 8 and 10 mm. The tiling system was defined as a four-layer composite (tile / adhesive /rendering / substrate) deforming linearly under a thermal loading. A full adhesive coverage was assumed.

The COSMOS-M program was used to model the system behavior under positive thermal loading. The materials were assumed to be isotropic and linearly elastic with perfect bond at the interfaces. The material properties adopted to run the model are those from Table 2. A fine coarse mesh was defined by using four-node plane strain elements.

The system was assumed to be unrestrained at the tile and adhesive mortar run and laterally simple supported at the rendering and substrate. The geometry used is shown in Figure 3.

The tile surface was considered to be heated from 26 °C to 62 °C, as occurred with the tested panel. The temperature through the system ranged from 62 °C, in the tile surface, to 26 °C, at the outer face of the brickwork. The values were also taken from the experiment, as shown in Figure 2. The temperature was applied to the nodes. A linear interpolation between the two nearest nodes was assumed for nodes where temperature was unknown.

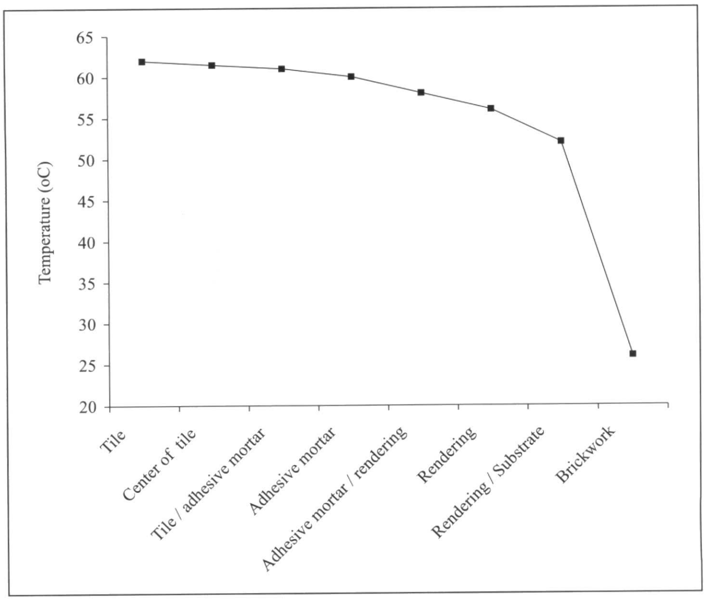

Figure 2. *Temperature evolution diagram.*

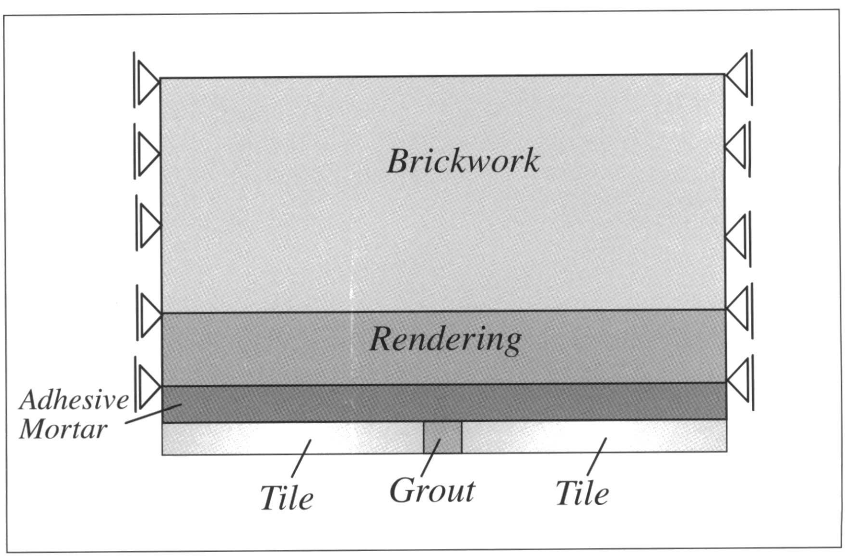

Figure 3. *Geometry of the model.*

5.2 STRESSES DUE TO THERMAL VARIATION AND SENSITIVITY ANALYSIS

The main results for normal and shear stresses can be seen in Figures 4 to 7. Taking advantage of the symmetry of the model, only half of the system was plotted. For normal stresses the positive sign means compression whilst negative is tensile stress. Figure 4 shows that, for all simulations, the normal stress in the interface ceramic/adhesive is very close to zero. There is increase in the normal stress near the interface ceramic/joint. The stress in the free boundary is the same regardless of the joint thickness. The normal stress found in the joint was tensile for 4 mm thick grout changing to compression with increasing grout thickness. It can also be seen that the compressive stress increases with increasing grout thickness, as can be seen in the Figure 5. On the other hand, the stresses in the middle of the grout are tension in all cases, decreasing with increasing joint thickness.

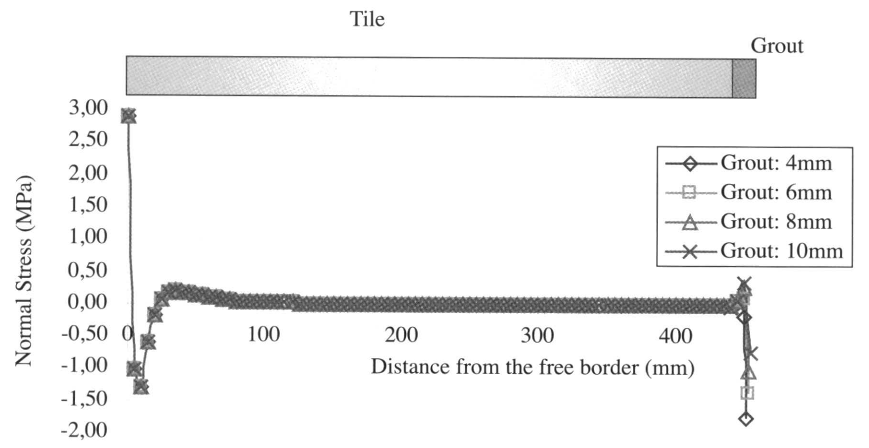

Figure 4. Normal stress distribution at the tile / adhesive mortar / grout interface..

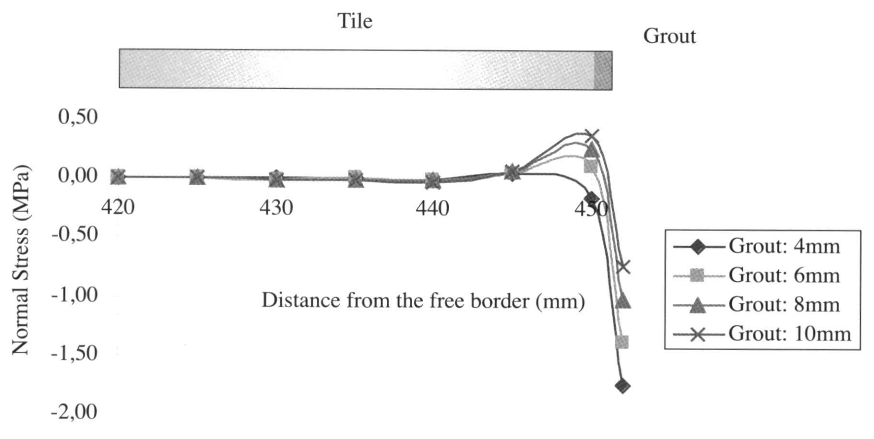

Figure 5. Normal stress distribution near the boundary ceramic/joint.

Figures 6 and 7 show the shear stress in the tile/adhesive mortar interface along the half model and near the boundary ceramic tile/grout respectively. It is shown that the higher values of shear stress appear close to the free border, with comparatively smaller results near the tile/grout interface. It is also shown that the shear is virtually zero along the tile length. Figure 7 shows that increasing grout thickness leads to increasing shear stress in the tile/adhesive mortar interface. On the other hand, in the tile/grout/adhesive mortar interface the behavior is the opposite, i.e., the higher grout thickness the lower shear stress. Moreover, shear stress decreases to zero at the center of the grout in all cases. Figure 6 shows that the highest value of shear is near the free boundary, regardless of the grout thickness.

6. CONCLUSIONS

The results analysis allows concluding that the normal stresses due to the thermal loading might be significant, depending on the type of adhesive mortar used, since the stresses range from approximately –0.5 MPa to + 0.2 MPa in tile/adhesive mortar/grout interface.

The shear stresses have shown different behaviour. The values range from zero in the middle of the grout joint, to maximum values in the interface tile/adhesive

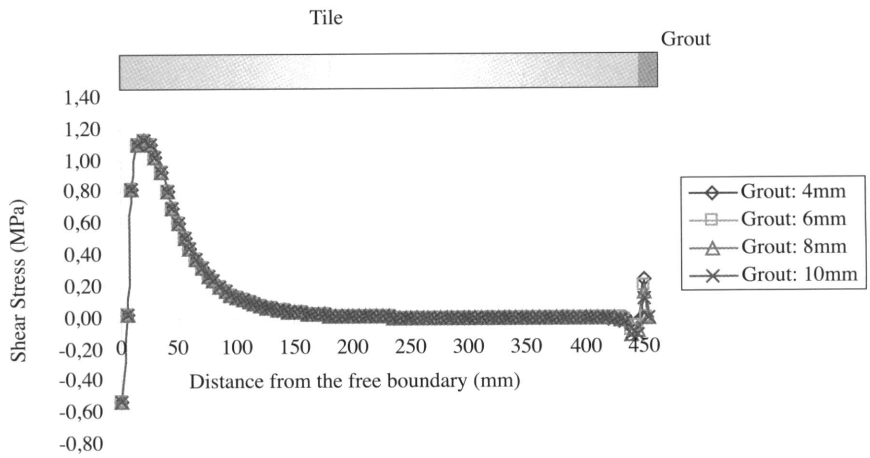

Figure 6. *Shear stress distribution at the tile / adhesive mortar / grout interface.*

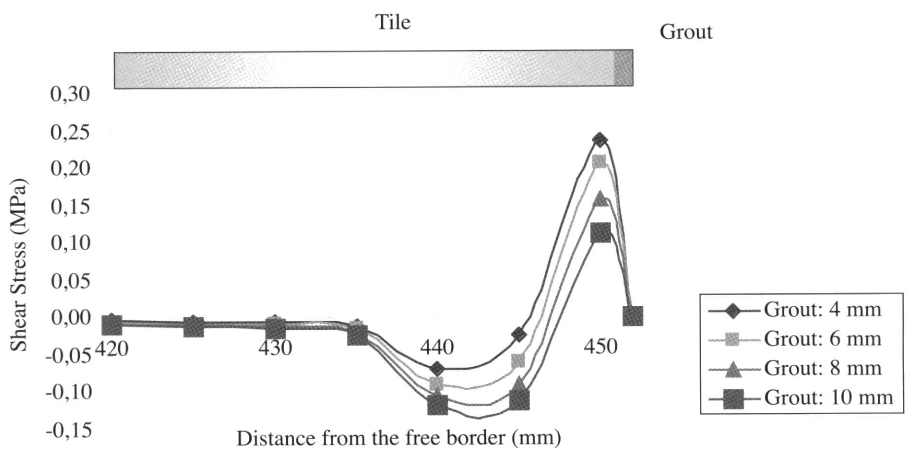

Figure 7. *Shear stress distribution near the boundary ceramic/joint.*

mortar/grout. In all cases the shear stresses were not very high, ranging from 0.11 MPa to 0.24 MPa. However, it is important to note the very high stress which appears near the free boundary, independently of the grout thickness.

The results, both for normal and shear stresses, seem to indicate that the grout thickness is not a major problem for defining the level of stresses in the ceramic tile system tested.

7. REFERENCES

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