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INFLUENCE OF AIR GAPS ON THE THERMAL BEHAVIOR OF PLASTER-CONCRETE-BONDS

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Abstract

The delamination of a plaster layer, which covers a concrete structure, can be detected by active thermography. In this paper, a systematic series of measurements is described, where the gap between plaster and concrete was varied. These investigations were compared to FEM-simulations. The experimental and simulated data were in good agreement. It was found that the used experimental setup yields only marginal differences between fixed and lose plaster in the thermal behavior. However, significant characteristics within the temperature decays could be resolved, which are clearly related to the air gap.

1. Problem

Thermography is widely used for the investigation of buildings, especially if some quality and safety problems are appearing. One kind of a problem is an inadequate bonding between a concrete structure and the plaster layer which covers the concrete. In such cases, the thermal behavior of the complete structure is influenced by the air layer between plaster and concrete. Air has much lower thermal conductivity than plaster or concrete, therefore an air layer acts as an additional heat resistance. After heating the plaster surface the unsteady heat conduction from the surface into the concrete volume is reduced on areas with delaminations. This reduced heat conduction is followed by a spatially and temporally limited temperature rise at the surface, which can be observed by suited instruments like thermography cameras. Techniques for thermal excitation and evaluation are described in [1, 2, 3, 4].

In order to detect such bonding failures as early as possible the following questions have to be discussed: Which thickness of the air layer is required for thermal defect detection? Is even a loss of the bonding strength between plaster and concrete detectable?

A rough a priori approximation leads to the following result: Assuming the additional thermal resistance due to the air gap should be at least 10% of the value of the plaster layer caused by the difference in thermal conductivities, the air layer has to have a minimum thickness of 50 µm. This value is on the order of magnitude where the mechanical bonding is probably lost.

In this paper, investigations at test specimens with different air gaps between plaster and concrete are presented.

2. Simulation

The influence of air gaps on the temperature distribution at the plaster surface was simulated using a commercial finite element (FEM) analysis and solver software package [5]. The 3D transient heat transfer equation can be written in the following form:

$$\frac{\partial T}{\partial t} = \alpha \, \nabla^2 T \quad . \tag{1}$$

Here, T is the absolute temperature, t is time, and α is the thermal diffusivity:

$$\alpha = \frac{k}{\rho c_p}, \tag{2}$$

where k is thermal conductivity, ρ is the mass density, c_p is the specific heat capacity.

In order to study the influence of an air gap between plaster and concrete on the temperature distribution at the plaster surface, simulations have been performed with different boundary conditions. The focus of these simulations was on the influence of the gap. Further parameters like thermal diffusivity of plaster and the power of the heat source were varied, additionally. In accordance to the experimental setup, an isolated piece of plaster disposed on a much bigger concrete plate was considered. Starting from thermal equilibrium of all components the simulations included a heating period of 10 min,

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followed by a cooling-down phase of same duration. The FEM-tool calculated the time dependent temperature distribution inside the entire plaster piece. The assembly used for the simulation is shown in figure 1. All corresponding numerical values are summarized in table 1.

Table 1: Simulation parameters

Thermal parameters of plaster	k in **W m^{-1}K^{-1}**	c_p in **J kg^{-1}K^{-1}**	ρ in **kg m^{-3}**	
	0.6	800	1600	
	1	1000	1800	
Geometrical sizes of the plaster layer in **mm**	width = 80, length = 100, height = 16			
Thermal parameters of concrete	k in **W m^{-1}K^{-1}**	c_p in **J kg^{-1}K^{-1}**	ρ in **kg m^{-3}**	
	1.4	840	2000	
Geometrical sizes of the concrete specimen in **mm**	width = 300, length = 300, height = 50			
Thermal parameters of air	k in **W m^{-1}K^{-1}**	c_p in **J kg^{-1}K^{-1}**	ρ in **kg m^{-3}**	
	0.024	700	1.2	
Geometrical sizes of the air defect in **mm**	width = 80, length = 100		height =	0.0
				0.2
				0.6
				1.0
				6.0
Power input in **W/m^{-2}**	350		240	
Duration of energy input in **s**	600			

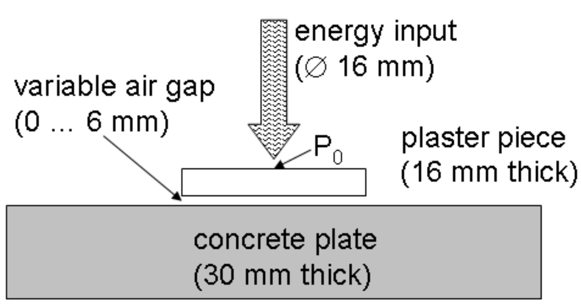

Fig. 1: Drawing of the assembly, which was the basis for all simulations (side view)

Fig. 2: photo of the test specimen consisting of a single plaster piece applied to a concrete plate (top view)

Due to the complexity of the spatial distribution of cooling kinetics, only the thermal behavior at $P_{0,}$ i.e., in the centre of the heated area, was regarded in detail. Figure 3 demonstrates the calculated temperature in P_0 during the complete time period of heating and cooling down. The results indicate clearly, that the temperature on the surface should be influenced by the airgap itself and its thickness, too. The following features can be identified:

(i) After 200 s of heat input small temperature differences of 0.1 K occur.
(ii) Temperature differences keep small in relation the temperature increase on the surface.
(iii) After heating the temperature differences near to remain.

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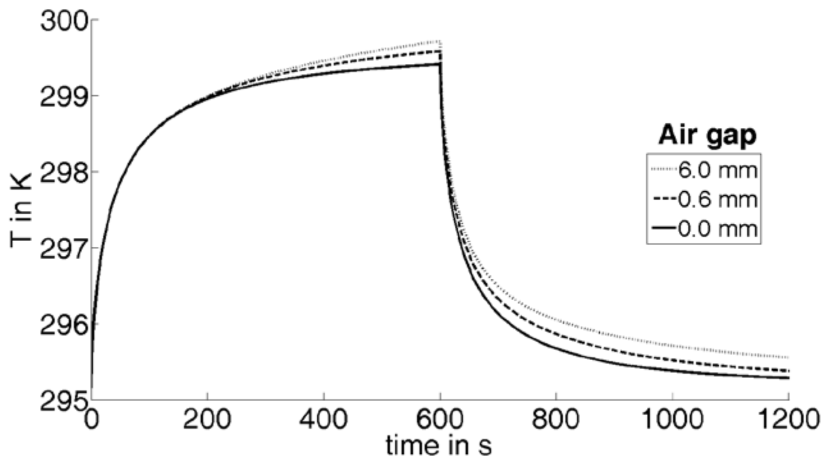

Fig. 3: Simulated temperature as a function of time at P_0 (plaster thickness 16 mm, thermal diffusivity of plaster $4.7*10^{-3}$ cm²/s, thermal input 350 W/m² for 600 s)

From the experimental point of view the observation of the plaster surface during the heating process is really complicated, because the heating source is located close to the surface. Both, the thermal radiation of the source and the reflected radiation are detected by thermography cameras and disturb a determination of the intrinsic plaster surface temperature. Therefore, we focused on the cooling down period. The next two figures illustrate the influence of the power density during the heating period (figure 4) and of the thermal diffusivity of plaster (figure 5) on the simulated temperature decays at P_0.

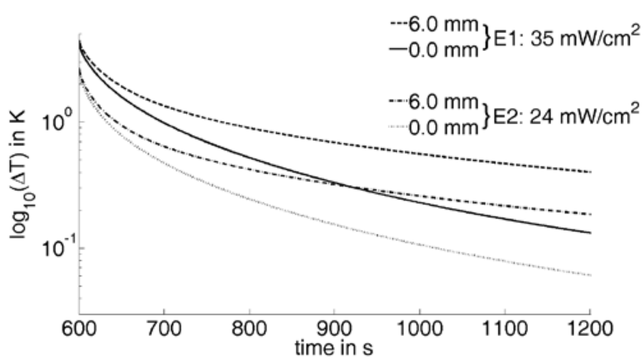

Fig. 4: Comparison of the simulated temperature decays at P_0 for bonded plaster and delaminated plaster (distance between plaster and concrete 6 mm), after different thermal energy inputs E1 and E2 where $\alpha = 4.7*10^{-3}$ cm²/s

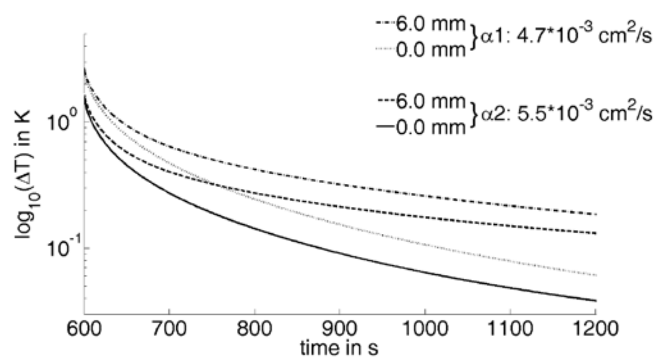

Fig. 5: Comparison of the simulated temperature decays at P_0 for bonded plaster and delaminated plaster (distance between plaster and concrete 6 mm), calculated with different values of thermal diffusivity of plaster $\alpha 1$ and $\alpha 2$ where E = 240 W/m²

These simulations show that a variation of the energy input or of the thermal diffusivity of plaster affects the thermal behavior of the considered structure, but typical differences between bonded and unbonded plaster areas on concrete remain. As a result, it could be possible to distinguish whether or not a plaster layer is bonded to the background, even if the current measurement conditions are varying.

3. Experimental

The plaster pieces, used during the whole set of measurements, were taken directly from a construction site. For the first test specimen, a piece with dimensions of about 10 cm x 7 cm and a thickness of 1.6 cm, corresponding to the values of the simulation, was used (see figure 2). The surface is completely covered with white wall paint. The implementation of different air gaps was performed in such a way that the piece of plaster was mounted on a concrete plate. The variation of the distance between both was realized with different spacers located at the four corners of the plaster piece. It should be remarked that the plaster "in contact" had not a real bond to the concrete but was disposed without any spacer, i. e., in direct contact. However, the real distance is below 0.1 mm.

Furthermore, a second test specimen was assembled, which consists of another original plaster piece embedded and fixed with mortar on a concrete plate. This specimen is called "fixed" and acts as a reference to the measurement set of not fixed plaster.

An area of 1.8 cm x 1.4 cm was illuminated for 10 minutes with a halogen lamp with an optical input of 320 mW. Regarding the reflectivity (85%) of the white painted surface, the real input power density amounts 240 W/m², leading to a temperature rise between 2.5 K and 3.0 K in the centre of the heated area. Thus, the geometric relations and the exciting conditions were in accordance with the simulations.

The temperatures were measured with a microbolometer IR-camera (Variocam hr from Infratec) with a maximum frame rate of 50 Hz and an array size of 640 x 480 pixels. Figure 6 presents the temperature decay after the heating step, measured on the lose plaster piece with different air gaps and on the fixed sample. Obviously, the distance between plaster and concrete influences the cooling-down process. The observed behavior is very similar to the predictions obtained by simulation (note the logarithmic temperature scale).

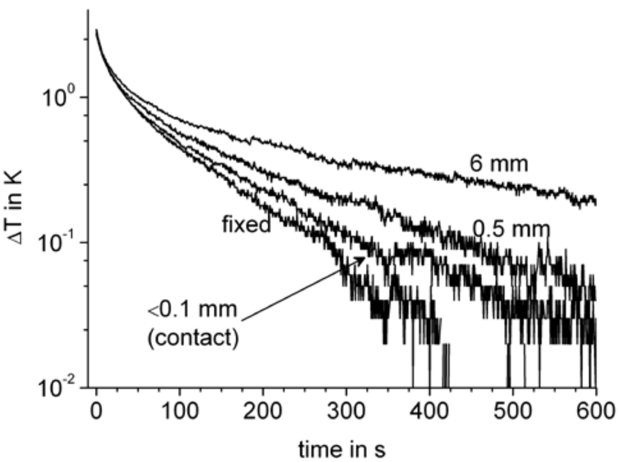

Fig. 6: Comparison of the measured temperature decays on plaster disposed on a concrete plate with different spaces and well bonded (after thermal energy input of 240 W/m² for 600 s)

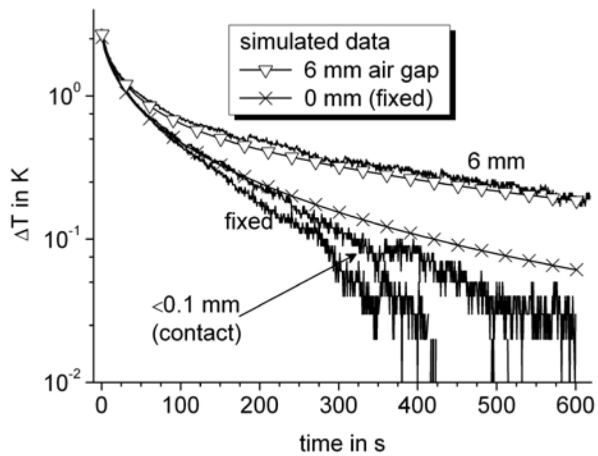

Fig. 7: Comparison of the measured and simulated temperature decays on plaster, disposed on a concrete plate with different spaces and well bonded

Direct comparison of experimental and simulated data is given in figure 7 and reveals only small differences. The accordance for the 6 mm distance is quite good, although the simulation predicts slightly smaller temperatures in the long term region. For the fixed plaster sample the simulated temperature data decrease a bit slower than the observed temperature decay.

4. Discussion

The simulations clearly predict the influence of a hidden air gap on the thermal behavior of the plaster surface, detected as a decreased cooling-down rate after optical excitation. However, the effect is quite small, depending on the given values for input energy, thermal diffusivity of the plaster and the thickness of the plaster itself. The surface temperature difference between a bonded and a detached area with 6 mm air gap varies only between 0.1 K and 0.3 K, immediately measured after thermal activation. This is due to the fact that altogether four parallel processes are responsible for the temperature decay after heating the surface:

i) lateral thermal conduction into the entire plaster volume
ii) heat transfer through the interface between plaster and concrete
iii) thermal radiation of the surface
iv) convection at the surface

Only the second process is influenced by the bonding conditions at the interface. Radiation and convection losses can be neglected because the temperature differences are small. Probably, the heat transfer through the interface is much smaller than the lateral heat transfer, leading to the predicted weak effect at the plaster surface.

Here, the predicted effect could be measured, but under laboratory conditions, using a microbolometer camera with a NETD of 0.08 K without averaging. The application of semilog-plotting enabled the visualization of the measurement data down to the 0.1 K region.

Small deviations between simulation and experiment for the case of fixed plaster could be due to the assumed thermal properties of the concrete plate. If the thermal diffusivity of concrete is higher, than process ii) is not constrained by an air gap and will be more important. Then, the temperature decrease should be faster, how it was observed during the measurement. On the other hand, an altered thermal diffusivity should not have significant impact on the curve progression of lose plaster pieces, because an air gap hinders an effective heat transfer into the concrete.

In order to reduce the influence of the lateral heat transfer (process i)), the geometrical relations between plaster piece and heated zone could be changed. If the heated area includes the complete plaster piece, the lateral heat transfer should be reduced, leading to an enhanced influence of process ii). However, the power density will be reduced followed by a smaller temperature difference. Those investigations require well prepared test specimen, because lateral energy input at the edges of the plaster piece and direct heating of the concrete basis have to be avoided.

Further on, simulations with different material parameters for the concrete plate are planned. Additionally, the thermal diffusivities of the plaster and the concrete will be determined experimentally.

5. Summary

The influence of an air gap between a plaster layer and a concrete structure in terms of cooling kinetics on the plaster surface was investigated systematically. It was found that this influence is only marginal if thermal excitation is inserted on a small and limited part of the surface. However, in the long term region after 100 s, typical temperature decays were resolved in relation to the air gap. Simulating the experimental setup resulted in time resolved temperature curves, which were in good agreement with the experimental data. The investigations will be continued with other geometries in order to improve the measurement method for on-site application in the building industry.

REFERENCES

[1] Maierhofer, Ch., Brink, A., Röllig, M., and Wiggenhauser, H., “Quantitative impulse-thermography as non-destructive testing method in civil engineering - Experimental results and numerical simulations,” *Construction and Building Materials*, 19, 2005, pp. 731-737

[2] Maierhofer, Ch., Arndt, R., Röllig, M., Rieck, C., Walther, A., Scheel, H., Hillemeier, B., “Application of impulse-thermography for non-destructive assessment of concrete structures”, *Cement & Concrete Composites*, 28(4), 2006, pp. 393-401

[3] Maldague, X.P., “Theory and Practice of Infrared Technology for Nondestructive Testing,” 1. edn, Wiley & S., 2001.

[4] Meola, C., Di Maio, R., Roberti, N., Carlomagno, G.M, “Application of infrared thermography and geophysical methods for defect detection in architectural structures”, *Engineering Failure Analysis*, 12, 2005, 875-892

[5] COMSOL Multiphysics, COMSOL Multiphysics Heat Transfer Module. COMSOL Multiphysics User's Guide. Version: COMSOL Multiphysics 3.5a.