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Detection of hidden defects of small extension by infrared IR thermography: application to cracks detection

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1. Introduction

The objective of this study is to evaluate active infrared thermography as a potential tool for non-emergent cracks detection in building materials. The methodology used was to simulate the presence of cracks hidden behind a layer of plaster by using mosaics with joints of variable thicknesses. The feasibility of the method was presented in a preceding conference [1]. Infrared thermography measurements were performed in square pulse heating mode. Numerical simulations were performed using FLUENT™ to favour the study of a large number of configurations. However, numerical simulation results are compared with experimental results for some configurations: four joints thicknesses and two different materials configurations. This second step was used to study the influence of parameters that may affect detection efficiency of cracks such as materials thermophysical properties, crack size and depth… Another objective of the study was to analyse thermographic sequences using different methods, such as for instance contrast method [2] or singular-value decomposition [3] and to compare performances of these methods in some particular experimental test cases.

2. Experiments

During experiments, the sample under study was heated with halogen lamps during a given duration t_H. The evolution of the temperature field in the front face of the sample was measured using a long wave infrared camera. Different heating durations were tested. A value of 90s is suitable for joint located at a depth of 1cm. Infrared images are recorded at a frame rate of 1 Hz during 600s for each experiment. Temperature measurements, using thermocouples, were also performed in order to obtain additional data on the heat transfer inside samples. Thermocouples were fixed on both front and rear faces of the samples and some thermocouples were placed inside the sample during its building. The whole experimental set-up presented in figure 1 is controlled by a LabView application™.

A schematic view of one sample considered is presented in figure 2. Each sample is composed of nine parallelepipeds of 20mm × 20mm × 10mm dimensions. They are spaced from neighbours by joints of thicknesses varying between 1mm and 4mm. All joints in a sample have the same thickness. Parallelepipeds are fixed onto a mortar plate of 10mm thickness. They are then covered with a plaster layer of 10 mm thickness. In a first samples series parallelepipeds are made of extruded polystyrene and joints are made of plaster. In a second sample series parallelepipeds are made of plaster surrounded by joints of extruded polystyrene. In this second case joints are more thermally resistive than parallelepipeds. Thus, this simulates a case close to the presence of non-emergent air cracks inside a material. The choice of polystyrene is based on thermophysical properties which are close to air ones.

3. Numerical Modeling

A 3D mesh of the sample was performed using Gambit software. Structured mesh was used (figure 3). Numerical simulations were carried out using Fluent. A constant heat flux density is applied to the front face for a given duration and the temperature field is calculated on the plaster front face during the heating pulse (figure 4) and the subsequent cooling. Different configurations were considered in order to study the effect of power density and heating duration. In all cases, the temperature field on the sample front face is calculated with a step time of 1s. Thermophysical properties of materials used are listed in table 1. Boundary conditions were chosen as follows. First, we assumed that the sample is insulated on all its lateral faces. On the rear face of the sample, a constant global heat exchange coefficient of 10 $W.m^{-2}.K^{-1}$ was used. A variable heat exchange coefficient h was used to model heat exchanges on the sample front face, in order to take into account the front side temperature changes. This coefficient is defined as follows:

$$h = h_c + h_r = 1.2\left(T_W - T_{env}\right)^{1/4} + 4\sigma\left(\left(T_W + T_{env}\right)/2\right)^3 \tag{1}$$

where T_w is the front face temperature, σ is the Boltzmann constant and T_{env} is the environment temperature, kept constant and equal to 293K. The initial temperature of the whole sample is 293K. Some results are presented in figures 5 and 6. Temperatures at the center of the mosaic and seals are compared during the heating cycle and cooling. In a first case, we consider that the mosaics are composed of polystyrene and the joints are made of plaster. In a second case we consider that the mosaics are composed of plaster and the joints are made of polystyrene. In both cases we present the temperature variations for two joints thicknesses: 1mm (figure 5) and 4mm (figure 6). The study of the effect of defects depth is in progress and will be presented in the full paper.

Table 1. *Values of thermophysical properties of materials used*

Material	*Density ρ (kg.m^{-3})*	*Specific heat Cp* (J.kg^{-1}.K^{-1})	*Thermal Conductivity k* (W.m^{-1}.K^{-1})
Polystyrene	33	1450	0.05
Plaster	1150	1000	0.57
Mortar	2200	1000	1.4

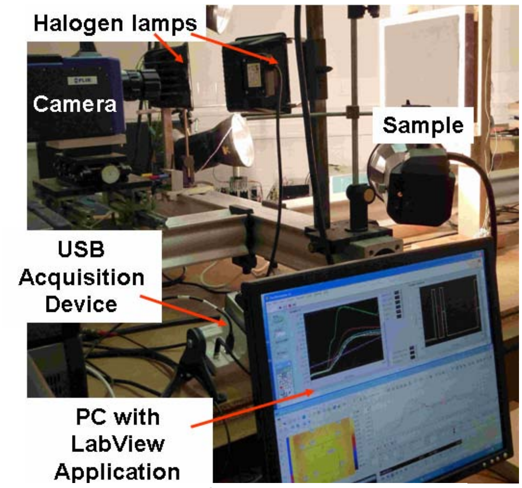

Fig. 1. *View of the experimental set-up*

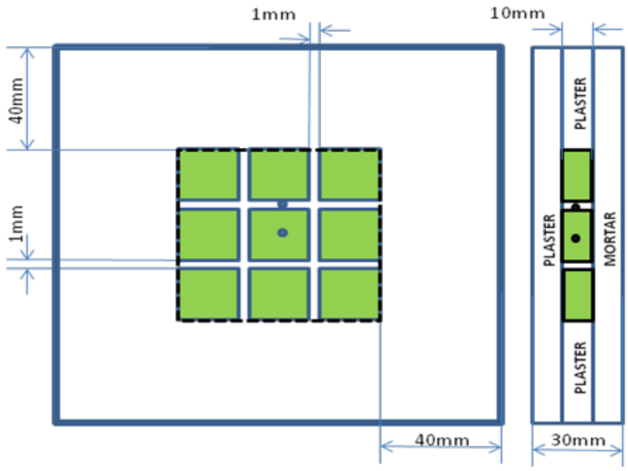

Fig. 2. *Sample with 1 mm thick joints*

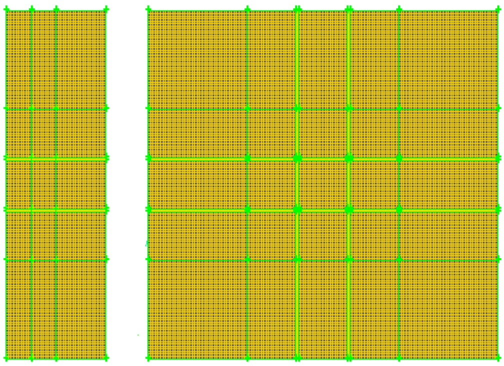

Fig. 3. *Example of some sections of the mesh (left: side view; right: front view)*

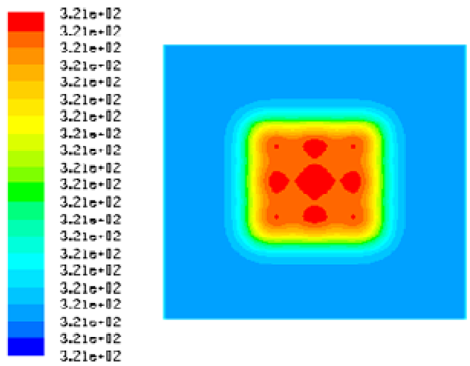

Fig. 4. *Front face temperature after 90s of heating for 1mm plaster joints*

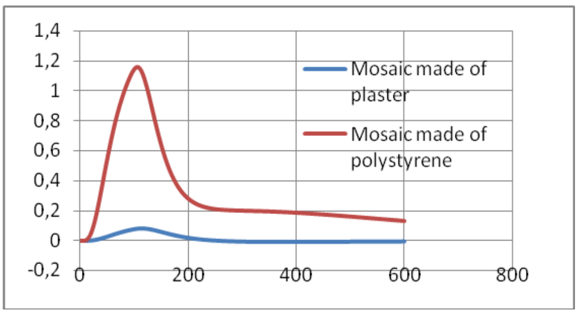

Fig. 5. *Temperatures differences for 1mm of joint*

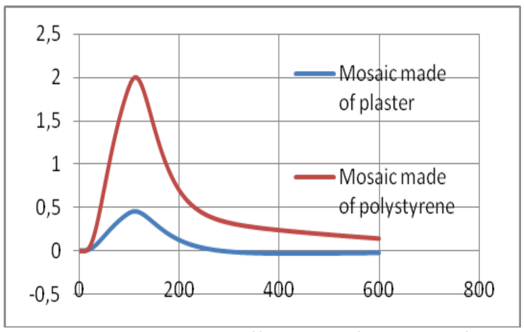

Fig. 6. *Temperature differences for 4mm of joint*

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