Inspecting localized moisture in building materials by applying surface and microwave heating

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Abstract

While the safety issue is not involved into consideration, microwave stimulation is being often regarded as the most appropriate means of thermal stimulation in the inspection of moisture in porous materials. It is believed that a signal-to-noise ratio may be higher in this case to compare with surface heating due to the fact that microwaves warm up only moistened areas and leave "cold" dry sound areas.

In order to analyze possible advantages of using microwave heating in thermal nondestructive testing (NDT) of building materials, in this study, both surface and microwave types of stimulation have been modeled and experimentally compared by using the criterion of a signal-to-noise ratio. Potentials of some computer processing techniques, in particular, pulse phase thermography (PPT) and principal component analysis (PCA) have been also studied by analyzing experimental image sequences.

A reference sample (figure 1) was made of 2-cm thick gypsum pasteboard which is widely used in indoors construction. On front surface, gypsum was covered with 1 cm-thick decorative ceramics. Within gypsum, two 40x40x10 mm voids were filled with foamed polyurethane and then moistened with fixed amounts of water (from 1 to 8 g). Surface heating was accomplished with a quartz halogen lamp which ensured 8.5 kW/m^2 of absorbed surface power. Microwave heating was done by placing a sample into a commercial 1 kW oven of which delivered power was estimated to reach 1.5 W/cm^3 in the centre of the oven. Surface temperature was monitored with a Thermovision-570 IR imager during 300-500 s on both ceramics and gypsum surface following 10 s heating.

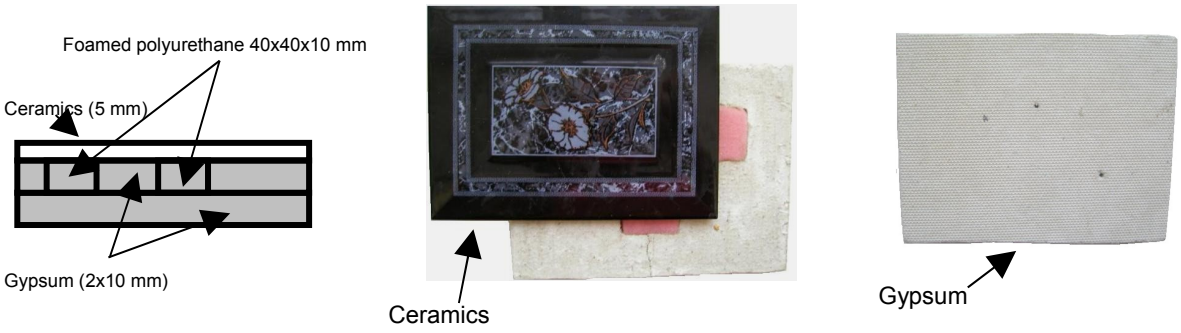

Fig. 1. *Three-layer ceramics-gypsum reference sample*

Thermal properties of moist polyurethane were determined by using the following formulas:

$$\lambda(w) = \frac{\lambda\lambda_w}{(1-w)\lambda_w + w\lambda};$$
$$\alpha(w) = \frac{\lambda\lambda_w[(1-w)C_w + wC][(1-w)\rho_w + w\rho]}{CC_w\rho\rho_w[(1-w)\lambda_w + w\lambda]}, \quad (1)$$

where $w = m_w/(m_w + m)$, m, m_w are the masses of dry material and water respectively, λ, C, ρ and α are the thermal conductivity, heat capacity, density and thermal diffusivity respectively, the subscript "w" is related to water. For example, if 4 g of water are uniformly distributed in 4x4x1 cm^3 of foamed polyurethane, the resulting thermal properties will be: $\lambda(w)$ =0.127 W/(m·K) and $\alpha(w)$ =0.107·10^{-6} m^2/s, while the thermal properties of dry polyurethane are: λ =0.04 W/(m·K) and α =0.31·10^{-6} m^2/s, and the thermal properties of water are: λ_w =0.59 W/(m·K) and α_w =0.14·10^{-6} m^2/s.

Surprisingly, our experimental results (see figure 2) have shown that advantages of microwave heating are not indisputable. For example, in ceramics, probably due to surface decorative paint and/or metallic inclusions, some spurious signals have appeared to fully destroy a phasegram (figure 2c) which is often considered as one of the most informative images of subsurface defects. It turned out that moistened areas have been better seen after applying the PCA algorithm (figure 2d).

On the other hand, performing one-sided thermal NDT on the gypsum surface has revealed no visible pattern of moistened areas in case of surface heating but was fairly successful in case of microwave heating with the following data processing by applying the PCA algorithm.

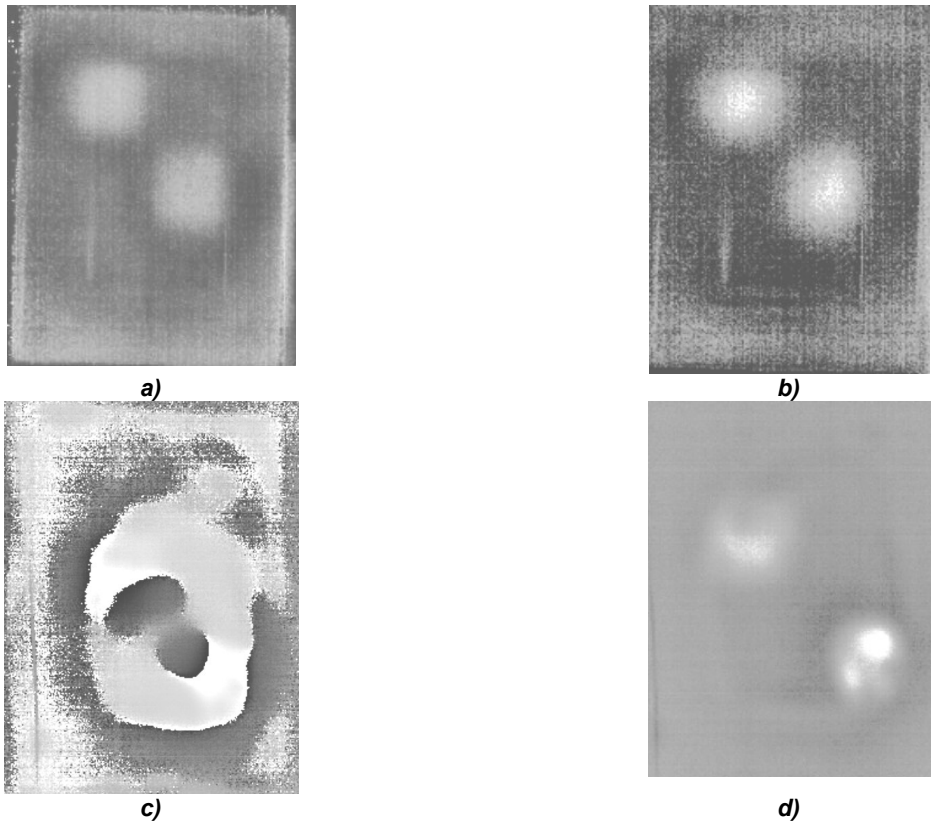

Fig. 2. *Comparing surface and microwave heating by monitoring ceramics (1 and 2 g of water):*

a – surface heating (phasegram),
b - surface heating (PCA image),
c - microwave heating (phasegram),
d - microwave heating (PCA image)

Numerical three-dimensional (3D) modeling of both surface and internal heating has been done by using ThermoCalc-6L and ThermoSource computer programs in order to compare theoretical and experimental results and understand better peculiarities of microwave thermal NDT.