# Thermal Non Destructive Characterization of a Wall in the Presence of Moisture

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**Abstract**. Thermal non destructive testing (TNDT) is a technique for obtaining surface temperature profiles on a structure, and subsequently relating this information to some imperfections within the structure. The tests of TNDT are generally based on the observation and the exploitation of a thermal phenomenon disrupted by the presence of an anomaly or heterogeneity. Indeed, an anomaly or a flaw inside the structure will generally alter the heat flow through the structure due to the difference in its heat transfer properties and those of the unflawed structure. If the heat flow pattern is sufficiently altered, a difference of temperature in the structure in the unflawed and the flawed regions is observed. The methods of analysis of these phenomena are based on the codes of numeric modelling using the method of the finite elements by help of commercial software. The simulations realized take into account different defect (moisture) parameters such as: the diameter, position and thickness.

## 1. Introduction

The appearance of moisture [1-3] in the envelope of buildings is generally allotted to the phenomena of diffusion and condensation of the interior humid air. There are other sources of moisture, like the beating rain, the moisture of construction which can also affect the whole of the built inheritance: historic buildings and recent constructions. Its is the same for other phenomena like the condensation in summer, the cycles humidification-drying, the freezing thaw, the transitory storage of moisture and the loss of heat by evaporation, which can either involve damage (delamination [4-8], mould, corrosion, freezing, or the damage caused by salt and moisture [1-3],…), or to increase the consumption of energy. To predict and follow the movements of moistures in the envelope of buildings, many tools for simulation were developed in the world and were validated during last years. To illustrate the possibilities offered by this software, we study in this article, the response of a material containing defects of the moisture type, when it subjected to the thermal excitation. The objective of this study is to analyze the behavior of a sample according to the geometrical and thermo physical characteristics of the defect. The method adopted for the resolution of the equations is that of finite elements [2-8]. This method is applied, through the use of commercial software of calculation. The results obtained for each studied case are presented in a detailed way. The influence of the various parameters of the problem (diameter, position, and thickness of the defect) on the temperature of surface material is studied.

## 2. Description of the Wall

In order to illustrate the application of the TNDT method, the results of the non destructive testing of a standard sample (mortar) (fig.1) of thickness e = 20 mm, length L = 156mm, and width l=146mm, containing 12 equidistant defects in honeycomb are presented. The defects have a cylindrical form of diameter d = 6; 12 and 18 mm, thikness h = 15mm, located at the position $l_1$ = 1; 2; 3 and at 4 mm from the entry face (fig.2). Lines $A_2A_1$, $A_4A_3$, $A_6A_5$, $A_8A_7$, $B_2B_1$, $B_4B_3$, $B_6B_5$, pass respectively by the points of co-ordinates {(29.4,0,0), (29.4,146,0)}, {(61.8,0,0), (61.8,146,0)}, {(94.2,0,0), (94.2,146,0)}, {(126.6,0,0), (126.6,146,0)}. {(156,30.5,0), (0,30.5,0)}, {(156,67,0), (0,67,0)}, {(156,109.5,0), (0,109.5,0)}.

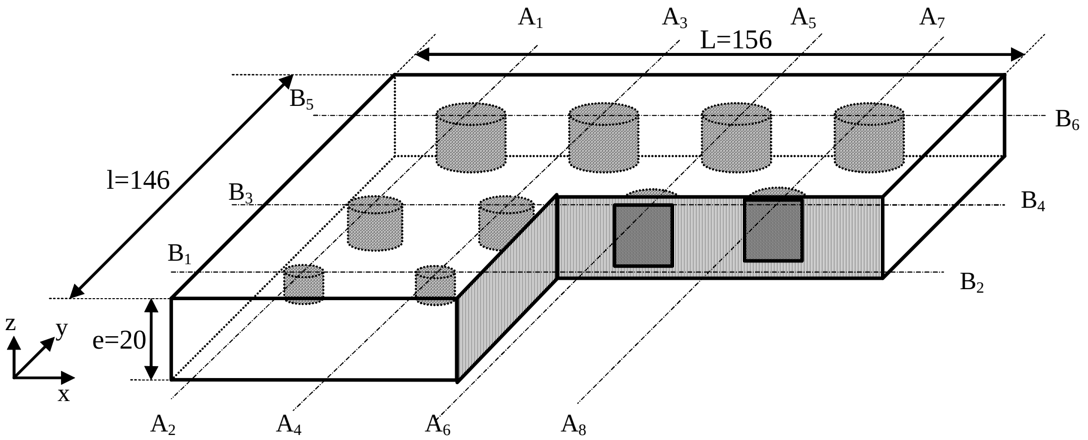


**Figure 1.** Geometry of the 3D problem

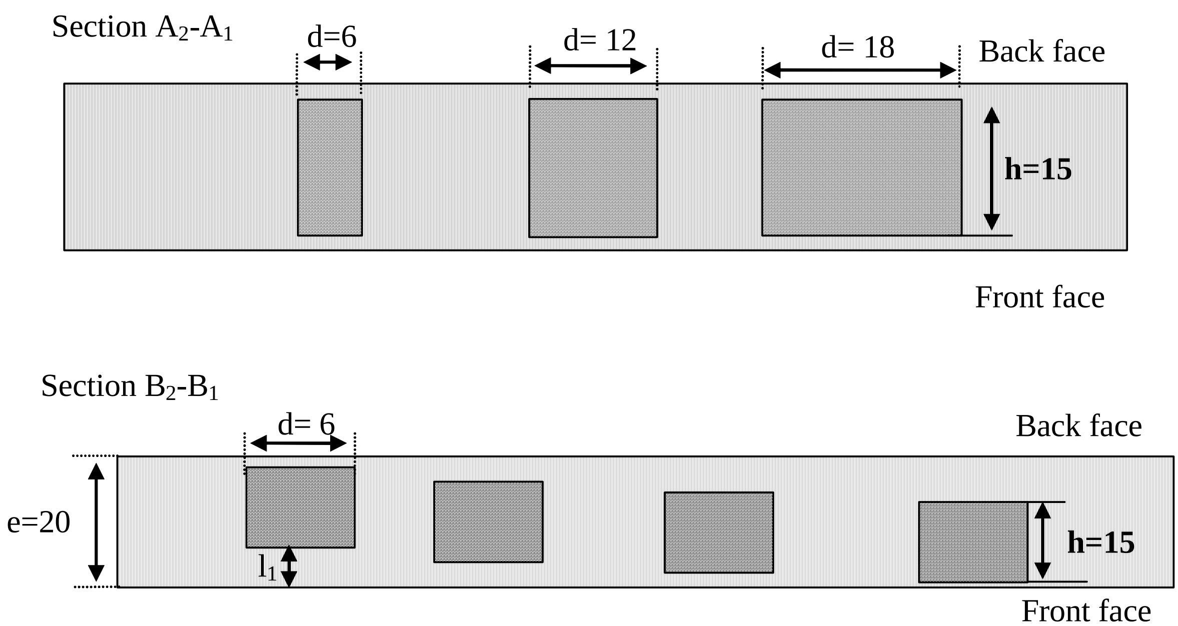


**Figure 2.** Cuts according to $A_2$-$A_1$ and $B_2$-$B_1$ sections

## 3. Mathematical description of the model, boundary and initial conditions

To solve the following thermal equation [3-8]:

$$a\nabla^2 T = \frac{dT}{dt} \tag{1}$$

The ratio a=λ/ρC is called thermal diffusivity. We call upon the numerical method of the finite elements [4-8]. The analytical resolution is indeed impossible being given the geometry of the problem. The method consists in using an approximation by finite elements of the unknown functions T to discretize the variational form of the equation (1) and to transform it into system of algebraic equations of the form:

$$[\mathrm{A}]T = F \tag{2}$$

With: [A] square matrix of dimension [N, N]
F a vector of N components
T the vector of the temperatures to be calculated

We start by building the variational form of the equation (1). We carry out a spatial discretization which consists in calculating the elementary integrals by using the finite elements and a temporal discretization. There are many specialized software which makes it possible to implement the resolution method of problems by finite elements in a more or less simple and convivial way. They take care in particular of the mesh of the studied object, of the automatic classification of the elements and the nodes, of the calculation of a solution then of the graphical representation of results. The use of commercial software, based on the finite element method [4-8], makes it possible at any moment to calculate the evolution of temperature and in any point of material. The material is considered isotropic. The calculation of the thermal response is made in the case of a moisture plate [4-8] subjected to uniform step function of flow on the surface on the front face, of intensity Q=1000 W/m$^2$. The back face being maintained at a constant temperature Ta= 25°C, the others faces are insulated (Q=0) (fig.3). The initial temperature is of $T_0$=25 °C, near to the ambient temperature.

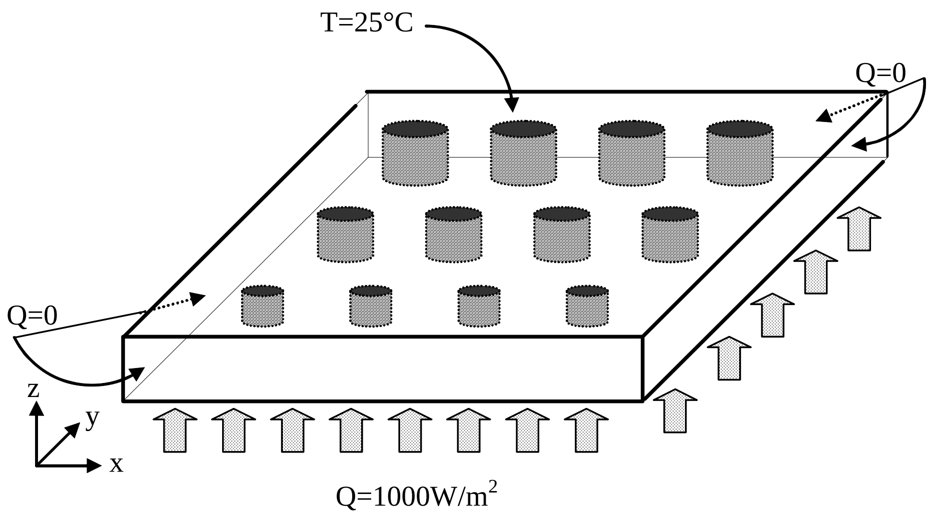


**Figure 3.** Boundary conditions

## 4. Resolution of the Equations

### *4.1 The mesh description*

We present the whole wall to emphasize the mesh density around the defect (fig. 4). We chose a mesh made up of triangular elements. Its density increases when one is around the defects (fig. 4). The latter is simply simulated by moisture.

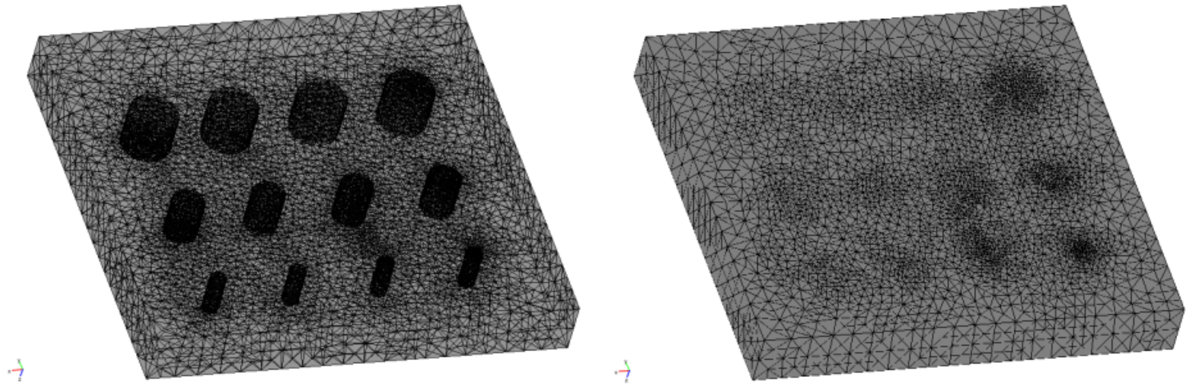

**Figure 4.** Mesh of the wall with 12 defects

## 5. Results of Simulations

In order to illustrate the previous theoretical considerations, the computation results of the thermal response in the case of an isotropic material, mortar composed of 20% of water with fine sand, whitewash and cement in the proportions of 8:2:1, in terms of mass, with a porosity of 31% are presented. In this case, dry mortar is characterized by K = 0,7W/m.k (thermal conductivity) ρ = 1710kg/m3 (density) and C = 921,1J/kg.k (specific heat) containing water saturated mortar characterized by K = 2,95 W/m.k (thermal conductivity) ρ = 1710kg/m3 (density) and C = 921,1J/kg.k (specific heat) [1].

The diameters d of the defects are taken equal to 6; 12 and 18mm and the positions of the front face $l_1$ are equal to 1; 2; 3 and 4mm. After resolution of the considered problem, it is possible to plot the temperature distribution on all or a part of the wall at a given moment, as well as the temporal evolution of the temperature in a given point (fig. 5). In the presence of the defect the heat flow has tendency to propagate by converging to the defect as showed in figures 5 and 6. This phenomenon explains the minimum of the temperature at the place of the defect, represented by a low thermal patch fig. 5 and 6. The minimum of this temperature can be taken an estimate on the required resolution of the non destructive testing equipment. At the exit of the defect the flow lines tend to be uniform. This could be information on the form and the position of the defect in material.

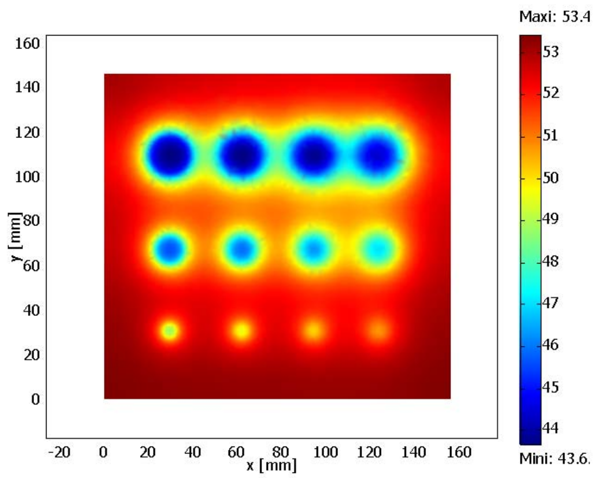


**Figure 5.** Temperature distribution on the front face of the wall with defect

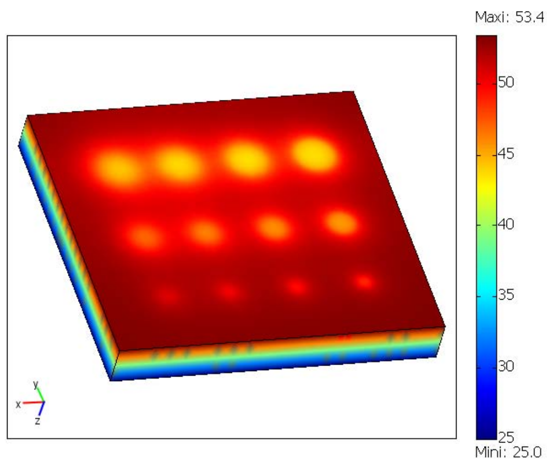


**Figure 6.** Temperature distribution in the wall with defect

*5.1 Influence of the defect parameters*

Let us interest in the influence of paramount parameters, namely the defect diameter d, defect position $l_1$, and thickness of the defect h. In this study, we consider the case of moisture with the following thermophysical characteristics: K = 2,95 W/m.k (thermal conductivity) ρ = 1710kg/m$^3$ (density) and C = 921,1J/kg.k (specific heat) [1], and located at depths $l_1$ of 1; 2; 3 and 4mm of the front face.

*5.1.1 Influence of defect diameter*

The curve of fig. 7 represents the evolution of the temperature profile of the entry surface (front face), according to y along lines $A_2A_1$, $A_4A_3$, $A_6A_5$, $A_8A_7$, for varying values of d from 6 mm to 18 mm with the following progressions: 6 mm, 12 mm, and 18 mm. The defects are placed at depths $l_1$ of 1; 2; 3 and 4mm of the front face. In general a temperature lower than the average, at the entry, reveals the presence of a capacitive defect in the structure. The agreement between these results and those already obtained, by using a code of finite volumes [9], permits to validate thermal calculation. The deformation at defect entry increases with the value of the diameter and decreases when the position increases. One can see that the temperature passes by a minimum in the case of capacitive defect (fig. 7). This minimum represents the point with the bottom of the center of defect where it is more effective or optimal to make control. It is the point to which the maximum of temperature difference T for the defect detection appears. While moving away from the defect the surface temperature tends towards a constant value (fig. 7). The curves, fig. 7, show that the temperature profile T is strongly related to the diameter of the defect. A small value of T would result from a large diameter of the defect (fig. 7). In this case, the detection of the defect presence would be simple. With the help of adapted equipment, and in the contrary case, it is necessary to have very sensitive equipment.

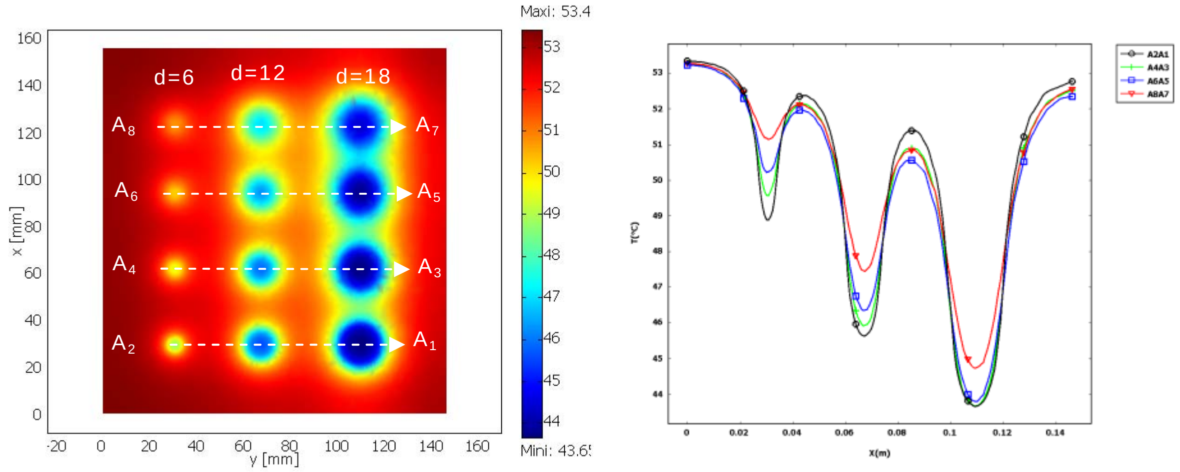


**Figure 7**. Influence of defect diameter on the entry surface temperature profile along the lines d=6, 12, et 18mm ;(O : $A_2A_1$, $l_1$=1mm); (+ : $A_4A_3$, $l_1$=2mm); (□ : $A_6A_5$, $l_1$=3mm); ( ∇: $A_8A_7$, $l_1$=4mm)

*5.1.2 Influence of defect position by report to the front face*

The curves, fig. 8, represent the entry surface temperature profile evolution (front face), according to x along lines $B_1B_2$, $B_3B_4$, $B_5B_6$, $B_7B_8$. To study the influence of the position, we calculated the response of the sample with defects whose thermophysical characteristics are: K = 2,95 W/m.k (thermal conductivity) ρ = 1710kg/m$^3$ (density) and C = 921,1J/kg.k (specific heat) and of diameter d varying from 6 to 18 with the following progressions: 6mm, 12mm and 18mm, for values of $l_1$ varying from 1 (defect close to the entry surface) to 4mm. On the curves of profile evolution according to x (fig. 8), we can note that more the defect moves away from the entry face more the difference in temperature becomes weak and thus the detection more difficult. This case, of course unfavorable for the NDT, constitutes a lower limit of defect detection. The deformation at the defect location increases when the position decreases. The results show that the form of these temperatures profiles is different from those obtained previously.

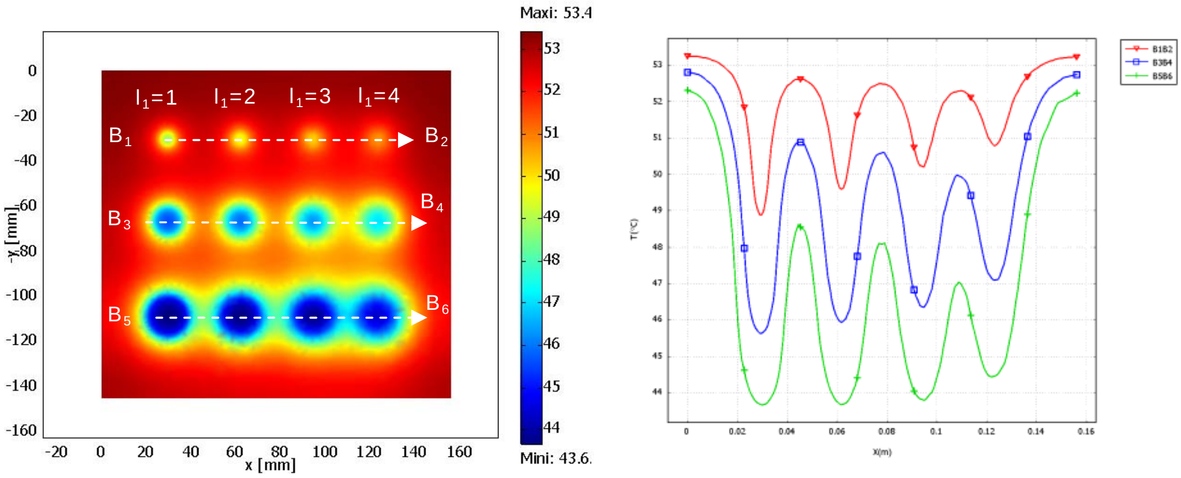


**Figure 8.** Influence of defect position on the entry surface temperature profile along the lines (∇ : $B_1B_2$, □ : $B_3B_4$, + :$B_5B_6$)

*5.1.3 Influence of defect thickness*

The considered defects have a cylindrical form of diameter d = 6 mm, height h = 3; 5; 10 and 15mm, located at the some position $l_1$ = 2 mm from the entry face (fig.9). The curve, figure 10, represents the evolution of the surface temperature according to the x along line $B_2B_1$, for four different thicknesses of defect in the structure. To study the influence of the thickness, we calculated the response of the sample with defects whose thermophysical characteristics are: K = 2,95 W/m.k (thermal conductivity) ρ = 1710kg/m$^3$ (density) and C = 921,1J/kg.k (specific heat) and of thickness h varying from 3 to 15 with the following for values of h varying from 3 to 15mm (3; 5;10 and 15)(fig. 9). The temperature profiles show that the temperature T passes by a minimum, in the case of this, capacitive, defect (figure 10). This minimum represents the point on the entry surface on the centres of defect where it is more effective or optimal to make control, because it is the point to which the maximum in temperature difference T for detection occurs. While moving away from the defect the surface profile tends towards a constant value. The curves, figure 10, show that the temperature profile T is strongly related to the thickness of the defect. A low temperature T would result from a great thickness of defect and the defect detection would be simple, with the help of adapted equipment, and in the contrary case, it is necessary to have very sensitive equipment.

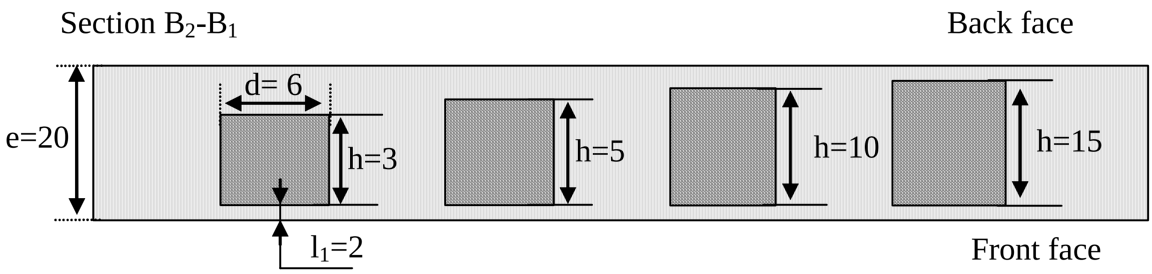


**Figure 9.** Cut according to $B_2$-$B_1$ section

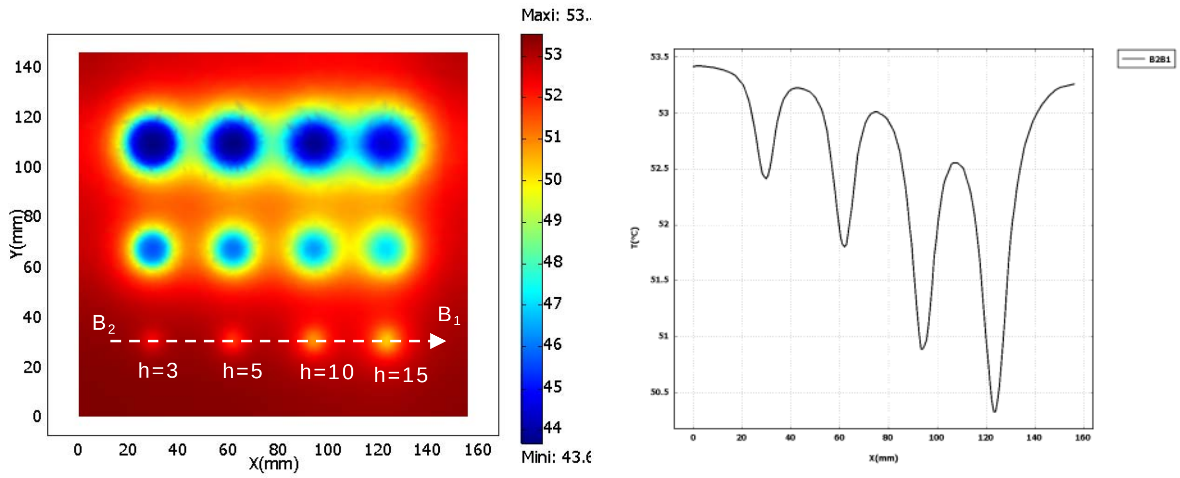


**Figure 10**. Influence of defect thickness on the entry surface temperature profile along the line ( $B_2B_1$, $l_1$=2mm, h=3, 5, 10, and 15mm)

## 6. Conclusion

In this work, we studied the case of a material containing cylindrical moisture subjected to a thermal stress. We carried out a systematic study of the temperature evolution according to the geometrical characteristics of the defect. This enabled us to conclude that, on the assumption of the less deep defects, diameter and position play a determining role in the thermal response of moistening material. By studying the influence of the defect parameters on the measurable magnitude, we showed that it is theoretically possible to detect any defect, with the proviso of applying a sufficient energy of excitation and to have an important difference between conductivity of material and that of the defect, which is different in practice. Indeed, this model relates to a capacitive defect in a rigorously plane plate. However, if one introduces a light initial curve (what is practically always the case in reality), one realizes that the heat gradient which exists between the heated face and the back face is at the origin of a total deformation of the plate which can completely occult the deformation at the location of defect. This phenomenon which is very often observed while a measurement makes that it very difficult to detect defects whose diameter is very low. All calculations were carried out in the case of an isotropic material, but the taking into account of the anisotropy would be possible with the proviso of using a computer code allowing it.

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