

Delamination in a chimney, modelling and analysis

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Abstract

Non-destructive testing plays an important role in areas where security requirements are important, such as nuclear, automotive, aviation, rail and particularly in civil engineering structures. The used techniques are various: ultrasound, X-ray, infrared and the choice of a particular method depends on the structure geometry, the material nature and the required accuracy. In this range of methods, thermal non-destructive control based on infrared thermography has the advantage to be well suited to auscultation of large structures without any contact with them and the results can be exploited immediately without any prior treatment.

In this work, we present the results of simulations on non-destructive thermal characterization of a wall chimney having internal defects in form of cracks. In this application, the model is based on the finite element method. The influence of the size, position and nature of defects in the wall chimney are studied.

Key words: Thermal non destructive testing, defects, delamination, finite elements, chimney.

1. Introduction

The thermal non-destructive testing by infrared thermography became a powerful technique that allows the study of the surface temperature variation of structures, when this latter is submitted to a given heat flux excitation. The obtained external surface temperature can show the homogeneity or the non-homogeneity of the considered structure by analysis of the existence of a surface temperature contrast [1,2,3,4]. The presence of an eventual internal defect will be translated at this surface by a task on the thermographical image; however a healthy material will present a uniform surface temperature. This technique is often used in several areas of the industry and particularly in civil engineering domain for the search of a possible defect in these structures. The detection of anomalies in the object under examination is conditioned by a sufficient variation of thermal properties of defect compared to the healthy material to generate a significant contrast. In this work we are interested in the study of fireplace in the housing structures that can contain defects which need a regular control and preventive action must be developed. These methods depend on nature of the chimney and the objective on the diagnosis. Indeed, to control the concrete constituting such a work, one has recourse to the methods of non destructive testing, like the coring, the ultrasounds or infra-red thermography. The latter consists in exciting a surface by a heat flow and to take down the thermographical image on this surface using an infra-red camera. This image presents thermal tasks when the concrete contains inclusions. Such tasks are more or less hot according to the nature of these inclusions (conductor or heat insulators) [5]. In this work, The results of the surface temperature simulations of a chimney wall, containing a defects delamination type are presented. The influence of the thickness and the position of the defect by report to the surface and the edge of the chimney in order to highlight the impact of the geometrical parameters of the defects on the simulated thermographical image at surface is studied. The resolution of this problem is carried out using numerical computation software based on the finite element method.

2. Mathematical modeling

The heat equation is given, for a homogeneous and isotropic material, in the orthonormal reference frame (x, y, z) [6]:

$$\rho C_p \frac{\partial T}{\partial t} = k \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) + Q$$

With:

ρ : is the material density [Kg/m³]

C_p : is the heat capacity at constant pressure [J/Kg.K]

k : is the material thermal conductivity [W/m.K]

T : is the temperature to be calculated [°K]

Q : is the voluminal heat source [W/m³].

With the boundary conditions:

$$\begin{cases} T = T_p \text{ on } S_T \\ k(\vec{n} \cdot \vec{\text{grad}}T) = \varphi_s \text{ on } S_\varphi \\ S = S_T \cup S_\varphi, S_T \cap S_\varphi = \emptyset \end{cases}$$

T_p : is the imposed temperature on a surface S_T

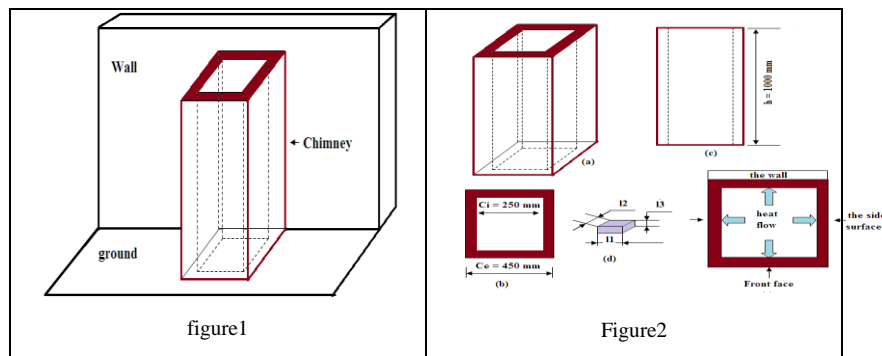
φ_s : is the imposed flux on a surface S_φ
 S : is the solid surface
 \vec{n} : is the unit normal to S directed outwardly
 The initial condition at the instant $t = t_0$:

$$T(x, y, z; t_0) = T_0(x, y, z)$$

The model is based on the resolution of the heat equation using the numerical finite elements method, as the analytical solutions generally inaccessible. For this implementation, we have used a commercial software which undertakes the study of the temperature evolution in any point of the considered problems.

3. Description of the problem:

the overall scheme of the device is represented by figure 1. A portion of chimney (fig. 2.a.) of a square base having as external sides $C_e=450\text{mm}$ and internal sides $C_i=250\text{mm}$ (fig.2.b.), and a height $H = 1\text{m}$ (fig. 2.c.). In one face of the chimney, we inserted defects of parallelepipedal form of different dimensions and positions, (fig. 2.d.). The study is relating to the thermal response of this structure with a thermal excitation spreading from the interior of the chimney. This excitation is due, naturally, to the heat transfer by convection between the internal medium presumably maintained a temperature of to 60°C [7] and the internal surfaces of the chimney. External surfaces of the structure, themselves, exchange heat by convection with the ambient conditions supposed at 25°C . The top and bottom faces are thermally insulated to simulate an infinite surface. To characterize the transfer through the wall of the chimney, we used numerical computation software, based on the finite element method combined to infrared thermography analysis. It will enable us to calculate and represent the temperature distribution on the chimney surfaces and to study thereafter the influence of the geometrical parameters of the defect on these distributions.



4. Results of simulations

In order to illustrate the considerations previously mentioned, we present the computation result of the thermal response in the case of a portion of a refractory concrete chimney characterized by the thermal conductivity $\lambda = 0.18 \text{ W/mK}$, the density $\rho = 1550 \text{ Kg/m}^3$ and the specific heat $C = 950 \text{ J/Kg.K}$ [2]. Thanks to the equation of heat and knowing the thermal characteristics of the chimney, it is possible to determine the temperature distribution in any point of the considered structure. The calculation hypotheses are:

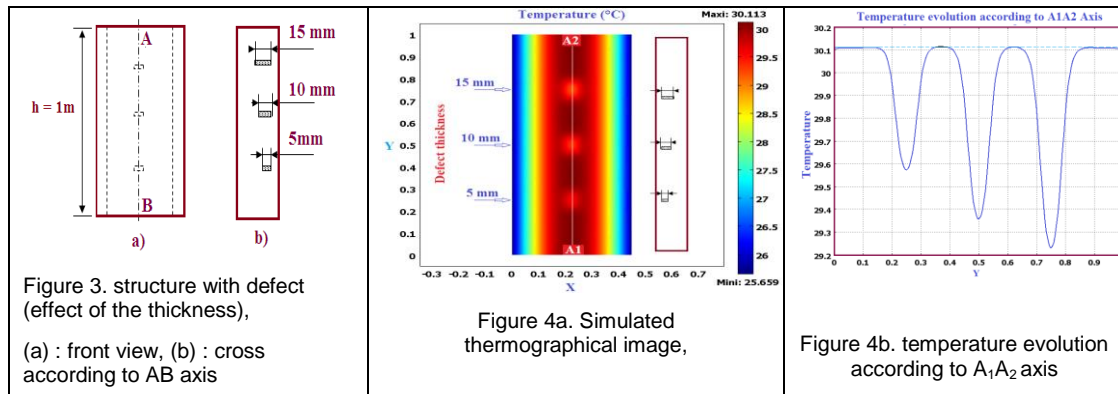
- The exchange of heat between the internal faces of the structure and the surrounding medium is done by convection, thus, we retained like intern exchange coefficient $h_i = 17$ and like external exchange coefficient, between external surfaces of the structure and the ambient medium $h_e = 9,09$.
- The defects of the type delamination (a blade of air) are characterized by: $\lambda = 0.0272 \text{ W/mK}$ (thermal conductivity), $\rho = 1.057 \text{ Kg/m}^3$ (density) and $C = 1000 \text{ J/Kg.K}$ (specific heat).

The results of simulations are given in the form of thermographical images representing the distribution of the apparent temperature, in degree Celsius on the surface. The chosen scale of temperature to describe the surface temperature variation is a color scale which associates to the highest temperatures of surface the red color and to the lowest temperatures the blue one.

4.1 Influence of the defect thickness

In this part, we inserted three defects, of a parallelepipedal form (fig. 2), having respectively like thicknesses $l_2 = 5\text{mm}$, 10mm and 15mm . The defect has a rectangle surface of width $l_3 = 50 \text{ mm}$ and length $l_1 = 80 \text{ mm}$. The three defects are located at 50 mm from the front face.

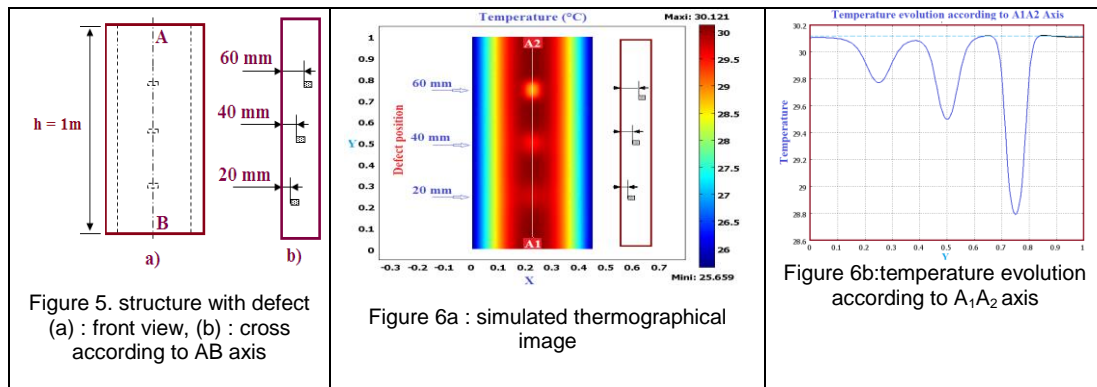
Figure 4.a. represents the thermographical image of the external surface of chimney. This image shows colder thermal tasks of different sizes corresponding to zones with problem. Indeed, the heat flow spreads from the chimney inside to the outside and the presence of a resistive defect (considered delaminating) is opposed to the heat flow diffusion which has as a consequence the appearance of cold tasks on the external surface. The figure 4.b shows the temperature evolution according to the A_1A_2 axis. It highlights the influence of the thickness defect on the surface temperature distribution. The thickness bigger is, the more the corresponding peak magnitude of temperature is weak and vice versa. The intensity of such tasks (temperature contrast) gives us an idea on the required resolution of the equipment of non destructive testing to use.



4.2 Influence of the position defect by report to the surface

In this part, we inserted defects of same dimensions 5cm X 8cm X 1,5cm, respectively located at 20 mm, 40mm and to 60 mm of the front face of the chimney (fig. 5).

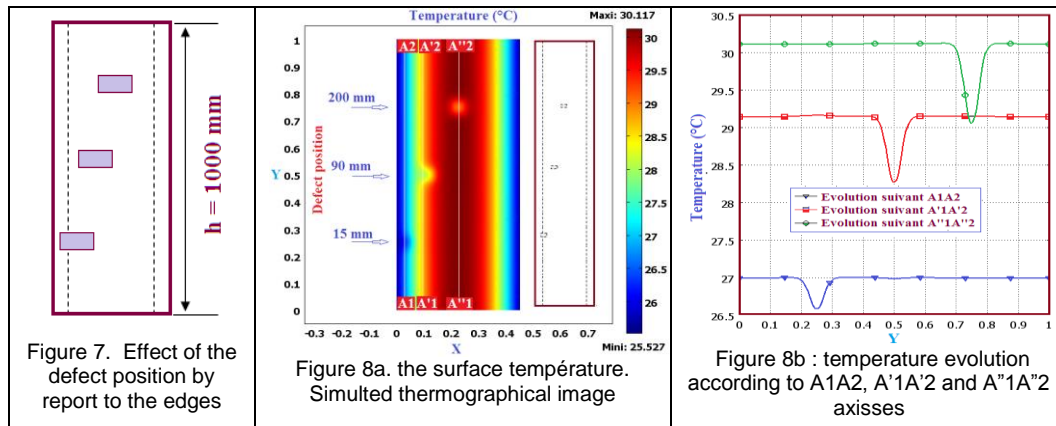
The figure 6.a. represents the simulated thermographical image of the chimney surface. According to the figure 6.b, which represents the temperature evolution according to A_1A_2 axis, for defects of the same dimensions, more one moves into the wall away from surface, more the amplitude of the temperature peak associated to the defect becomes low and the limit of detectability of such defects will depend on the resolution of the equipment used in control.



4.3 Influence of the defect position by report to the edges

To study the influence of the defects position by report to the edges, we placed three defects, of the same dimensions: 5cm X 5cm X 1,5cm, located at 2cm from the front surface into the wall. These defects are located at 1,5 cm, 9 cm and 20 cm by report to the left edge (fig. 7).

The figure 8.a represents the simulated thermographical image at the front face of chimney, one notices that more the defect is far from the edge more the intensity of the spot representing it is clear. In the same way, according to the figure 8.b, which represents the change of the temperature according to lines A_1A_2 , A_3A_4 and A_5A_6 , we notice that the magnitude of the peak reflecting the defect presence is larger for an intrusion being further from the edge.



5. Conclusion

In this work, the influence of the geometrical parameters of a delamination type defect on the thermographical image of surface is studied and analysed. One can conclude that theoretically, as in the case of other types of defects which were studied in other structures (cracks, moisture...) [4, 5], such defects can be detectable, but practically, it is necessary that the temperature difference between the healthy zones and that of the problematic ones is sufficient to be detectable by the non destructive testing equipment. One can conclude that, according this study and the others which were carried out previously, the thermal non destructive testing is of great importance, especially that the thermographical image is remotely taken and can be immediately exploited without any preliminary treatment, and the source of heat allowing to heat the structure is generally natural (solar ray for example or the convection heat in our case).

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