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Characterization of delamination by a thermal method of non destructive testing

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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 modeling using the method of the finite elements by help of commercial software. The simulations realized take into account the position and the thickness of the delamination and its thermophysical characteristics.

Keywords: Finite elements, delamination, heat transfer, thermal NDT (TNDT).

1. Introduction

The processes of heat transfer seem to pervade all aspects of our life. These processes that occur, for example, in engineering equipment, in the heating and air conditioning of building, play a vital role that can be observed in a great variety of practical situations. Composite materials [1,2] are of increasing interest to the industry and their performance characteristics are desirable. Often, an internal anomaly within these structures modifies strongly their physical properties. Thermal non-destructive testing is able to reveal the presence of a defect without damaging the specimen [1]. It employs heated surface temperature variations caused by delamination [1-5], cracks, voids, corroded regions…etc. In all these cases, predictions offer economic benefits because no experimental study can be expected to measure the distributions of all variables over the entire domain. For this reason, even when an experiment is performed, there is great value in obtaining a companion computer solution to supplement the experimental information. Among the different methods of predictions [6,7], the numerical solution based on finite element method [8] seems quite promising. Numerical analysis is useful to consider different defect geometry and determine their detectability without the expense of making and testing the corresponding specimens. Will to improve quality and safety of materials, many techniques of non destructive testing (NDT), adapted to these new materials and the specific defects that they can present were born. Among them, the methods known as thermal [1-8], have the advantage of allowing a fast inspection and with or without contact. In this great family, the thermal control method is characterized by its simplicity of implementation and its relative insensitivity to the surrounding noises. It thus is particularly adapted to an industrial use.

2. Position of problem

The goal of this part is to calculate the thermal response of a delaminated wall [1-5] subjected to a uniform continuous and extended step function of flow Q on the input surface. The back face being maintained at a constant temperature Ta = 25°C, the others faces are insulated. It is supposed that the excitation is applied in a uniform way to considered surface. In order to simplify calculations, we limit ourselves to the case of a circular delamination in an isotropic material. The problem then has rotation symmetry around axis z (FIG. 1); it is thus possible to limit the study to 2D in which only a half-section

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of the object is represented (FIG. 2). Delamination is located at the depth l_1 and has a diameter d and a thickness e. The thickness of the back face of the sample is noted l2 and the simulated length is equal to 50 times l_1 in order to minimize the edge effects. The method of characterization use commercial software, based on the finite element method [9]. It permits, at any moment, to calculate the evolution of temperature and in any point of material supposed isotropic.

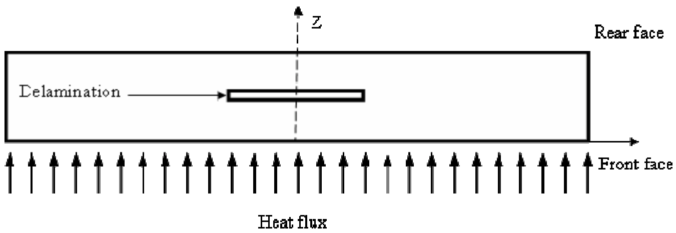

Figure 1: Geometry representation: complete wall

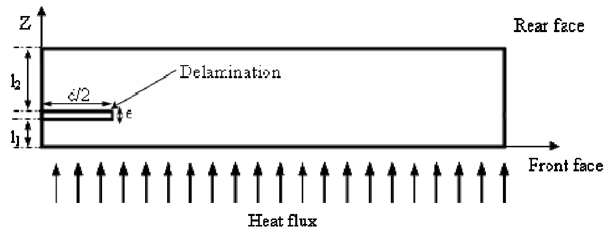

Figure 2: Geometry representation: half-section

3. Theoretical study

The equation of diffusion of heat is written, in cylindrical coordinates and supposing that thermal conductivity is constant, one obtains:

$$\frac{\rho C}{k}\frac{\partial T}{\partial t} = \frac{1}{r}\left[\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right)\right] + \frac{\partial^2 T}{\partial z^2} \quad (1)$$

Where: ρ represents the density of material, C its massive heat capacity, and K its conductivity thermal. We consider the depth l_1 of the defect as the characteristic length. The dimensionless variables marked of asterisk are:

$$r^* = \frac{r}{l_1},\ z^* = \frac{z}{l_1},\ e^* = \frac{e}{l_1},\ d^* = \frac{d}{l_1},\ l^* = \frac{l_2}{l_1},\ t^* = \frac{at}{l_1^2},\ \text{and}\ T^* = \frac{T}{T_a} \quad (2)$$

Where: t* is the Fourier number attached to l_1, *a=k/(ρ.c)* is the diffusivity of material, and Ta ambient temperature. In the space of the dimensionless magnitudes. The relation (1) becomes:

$$\frac{\rho^* C^*}{k^*}\frac{\partial T^*}{\partial t^*} = \frac{1}{r^*}\left[\frac{\partial}{\partial r^*}\left(r^*\frac{\partial T^*}{\partial r^*}\right)\right] + \frac{\partial^2 T^*}{\partial z^{*2}} \quad (3)$$

With the proviso of posing: $\rho^* = 1,\quad C^* = 1,\quad et \quad k^* = 1$ (4)

4. Resolution of the equations

The mesh description

In a cylindrical reference mark, only a "half-section" of the sample requires a mesh. In order to emphasize the mesh density around the defect the whole wall presented (FIG. 3). The defect is simply simulated by an absence of matter. Its thickness is constant and equal to $l_1/100$. Taking into account the symmetry of the problem, study is limited to two

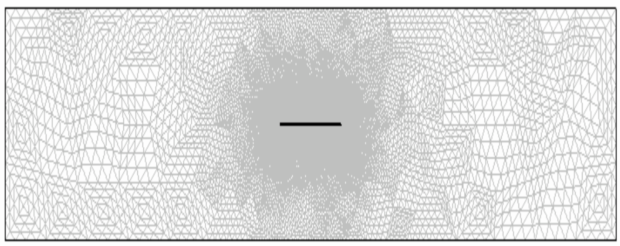

Figure 3: mesh representation of the complete wall with defect

dimensions one in a cylindrical.

5. Results of simulations

To illustrate the previous theoretical considerations, we present the computation results of the thermal response in the case of an isotropic material, the considered concrete is characterized by K = 1,7W/m.k (thermal conductivity) ρ = 2250 kg/m3 (density) and C = 827J/kg.k (specific heat). The delamination is characterized by K = 0,0272 w/m.k (thermal conductivity) ρ = 1,057 kg/m3 (density) and C = 717,8 J/kg.k (specific heat), d* = 1, and l* = 1. After resolution of the posed problem, it is possible to plot the distribution in temperature on the totality 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 avoiding the defect as shown it figure 5. This phenomenon conducts to the rise in the temperature at the location of defect, represented by a thermal patches figure 5. The maximum of this temperature gives an estimate on the required resolution of the equipment of non destructive testing. At the exit of the defect the lines of flow tend to be standardized. This could be information in the form and the position of the defect in material. Figure 6 shows the variation in the temperature along the entry surface (front face). In general a temperature higher than the average at the entry reveals the presence of a resistive defect in the structure. The agreement between these results and those already obtained by using a code of finished volumes [6,7], make it possible to validate this thermal calculation.

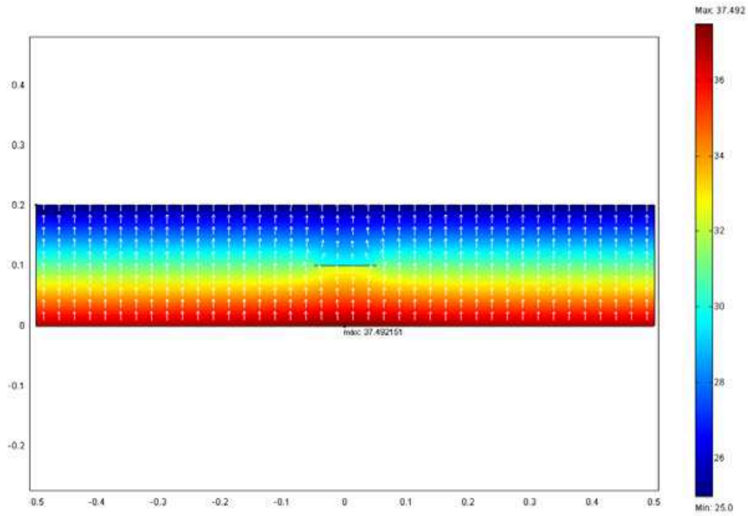

Figure 5: Temperature distribution of the complete wall (Arrow: Heat flux, Surface: Temperature)(d=1 - l*=1 - e*=0,01 - Q=100w)*

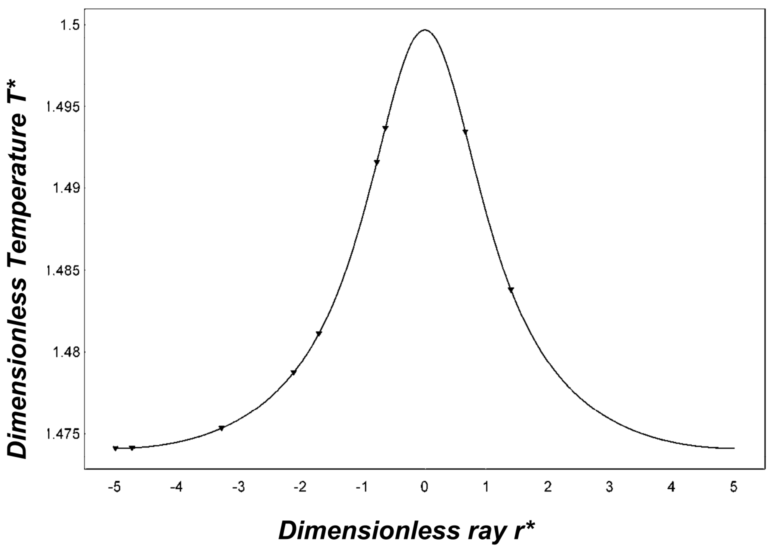

Figure 6: temperature profile on the entry surface (d=1 - l*=1 - e*=0,01 - Q=100w)*

5.1. Study of the influence of the defect parameters

The paramount parameters studied in this work are: defect diameter, defect position, defect thickness, and material, containing defect, nature.

5.1.1. Influence of defect dimensionless diameter

The curves of FIG. 7 represent the surface temperature for four values, of diameter d*, varying from 0.5 to 0,8 with the following progression: 0,5 - 0,6 - 0,7 and 0,8. At the location of defect deformation increases with the value of the dimensionless diameter.

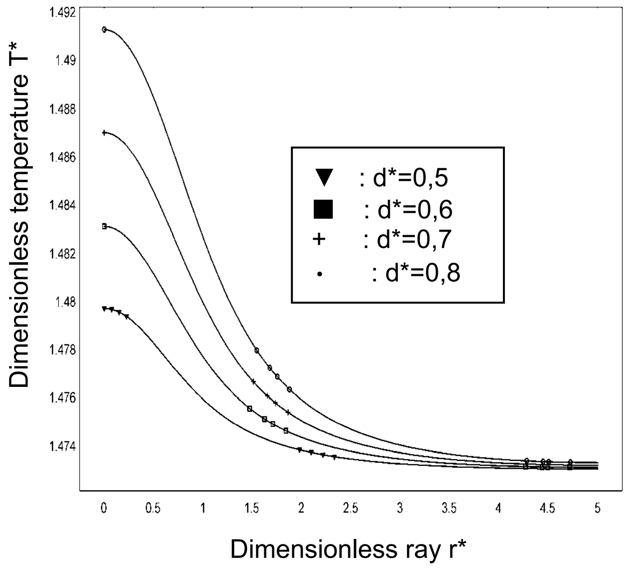

Figure 7: Influence of defect dimensionless diameter on the entry surface temperature profile (l=1 - e*=0,01 - Q=100w)*

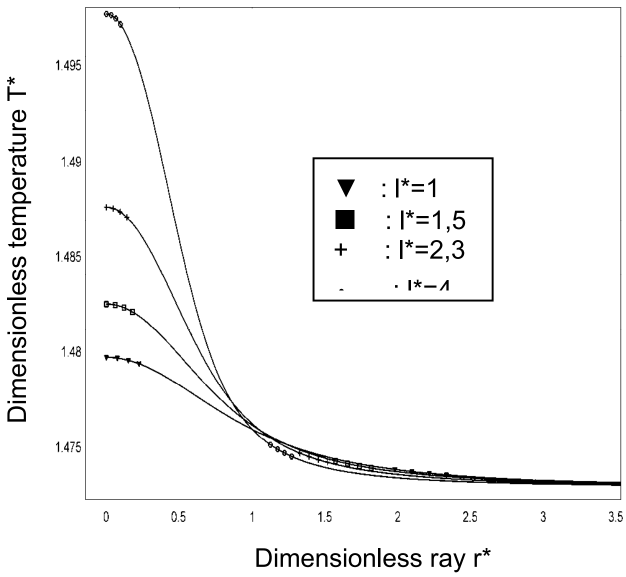

Figure 8: Influence of defect dimensionless position on the entry surface temperature profile (d=1 – Q=100w)*

5.1.2. Influence of the defect dimensionless position

To study the influence of the defect position, the response of the sample containing a defect (delamination) whose diameter dimensionless is d* = 1, is calculated. The defect position l* varying from 1 (defect with mid thickness) to 4 (defect close to the surface of entry). From the curves evolution according to r* (FIG. 8), one realizes that curves tend towards a limit as one approaches the case of a surface defect (l* = 4). This case, of course unfavorable for the NDT, constitutes the lower limit of detectability of the defects. The deformation at location of defect increases with the value of the dimensionless position. On the other hand, one can notice that the evolution form of these profiles is different from that obtained previously (FIG. 7).

5.1.3. Influence of defect dimensionless thickness

The curve, figure 9, represents the evolution of the surface temperature according to the dimensionless ray r*, for four different thicknesses of defect in the structure. The thickness e* takes the following values (0,01; 0,03; 0,06; and 0,09), and for each thickness the defect was placed at the position l*=1. The temperature profiles, show that the dimensionless temperature T* passes by a maximum, in the case of the resistive defect (figure 9). This maximum represents the point on the entry surface on the center 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 (figure 9). The curves figure 9 show that the profile of temperature T* is strongly related to the thickness of the defect. A great value of T* would result from a great thickness of defect (figure 9). In this case, the defect presence detection would be simple, with the help of adapted equipment, and in the contrary case, it is necessary to have very sensitive equipment.

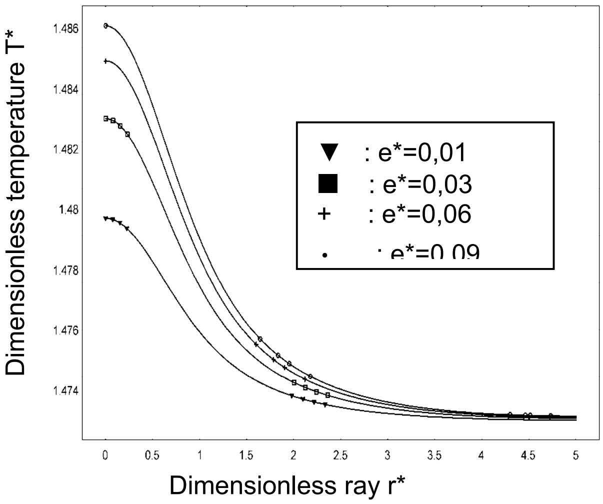

Figure 9: Influence of defect dimensionless thickness on the entry surface temperature profile (d=1 – Q=100w)*

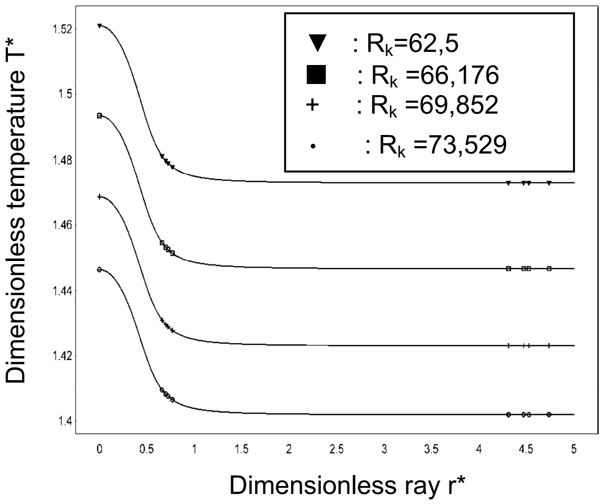

Figure 10: Influence of the material, containing the defect, nature on the surface temperature profile (l=0,11 - e*=0,05 - d*=5 – Q=100w)*

5.2. Influence of the material, containing defect, nature

The physical nature of material containing defect influences enormously on the difference in temperature T* as figure 10 shows it. It is a configuration where the wall takes four values of conductivities report/ratio $Rk=K_{material}/k_{Delamination}$ (Rk =62,5 (Concrete), 66,176 (Grinding door), 69,852 (other) and 73,852 (Marble) w/m.k). The defect is characterized by: l*=0,11, d*=5 and e*=0,05. The results represented by figure 10 shows that a strong conductivity of the defect compared to that of the structure which contains it, brings a deficit of temperature of surface to the structure entry, and a low value of conductivity will involve an excess of temperature. For our model a zero value of (T* material – T* delamination) is representative of the thermal homogeneity of material.

5.3. Influence of the excitation intensity

Whatever the thermal NDT method active or passive used and the type of equipment (thermocouple, radiometer, scanner, infra-red camera) the goal is to facilitate the location and to allow a control of the thermal anomalies. It is necessary to correctly choose the source of energy in the case of the active method and the time of measure in the case of the passive one. The curves, figure 11, represent the evolution of the surface temperature T* according to the dimensionless ray r*, for defect thickness e*=0,01 and four values of the heat flow (Q=100, 100,5, 101 and 101,5w). The defect position l* is taken equal to 1 in a wall of 500mm of thickness. A great value of T* would result from a great value of the flow of excitation as shows it the results represented by figure 11. In this case, the defect presence detection would be simple, with the help

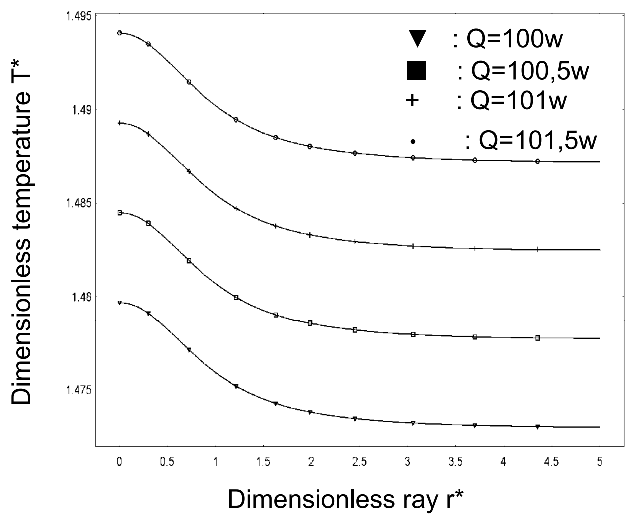

Figure 11: Influence intensity of the excitation on the profile of surface of entry (l=1 - e*=0,01 - d*=1)*

of adapted equipment, and in the contrary case, it is necessary to have very sensitive equipment.

6. Conclusion

In this work, we studied the case of a material containing a circular delamination subjected to a thermal excitation. We set out to analyse 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 and to have an important contrast in conductivities material defect, it is different in practice. Indeed, this model relates to a resistive defect in a rigorously plane plate. However, if one introduces a light initial curve (what is practically the case in reality), one realizes that the thermal gradient exiting 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 the defect. This phenomenon, which is very often observed at the time of measurements, makes that it very difficult to detect the defects whose dimensionless 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 which allows it.

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