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A simple method based on Thermal response analysis for determining defects depth

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Abstract: Infrared thermography is one of non-destructive testing techniques; it consists of exciting the surface of the controlled sample by a heat pulse to create a temperature difference between healthy areas and defective areas. The defect depth determining by thermography technique is a topical subject that has been the subject of several studies. Most of these works require prior knowledge of the thermal properties of the controlled material. In this work, we propose a new method based on graphical analysis of the infrared radiation emitted from the surface of the inspected specimen to determine the depth of inside defect. This method helps avoid errors related to thermal properties of the inspected specimen and estimates the defect depth value with a good accuracy. The experimental results confirmed the virtue of the proposed method in determining the defects depth.

Keywords: Infrared radiation, finite elements, defect depth, pulsed thermography.

1. Introduction

Pulsed thermography is a nondestructive testing technique, based on stimulating the auscultated material surface by a heat source and using an infrared camera to measure its surface temperature. The analysis of obtained thermograms permits the characterization of defects located in the interior of the inspected structure [1-5].

Most of the recently used methods in the thermal control by pulsed thermography are based on a parameter 'characteristic time' which is specific to the method for obtaining the depth of the defect; in addition, these methods require prior knowledge of the thermal properties of the auscultated material, particularly the thermal diffusivity [6-10].

In this work, we propose a method based on graphical analysis of the temperature variation in the surface above the defect as a function of time to determine the defect depth without considering the thermal properties of the material. This allows to avoid errors related to the accuracy of the used thermal properties and gives more precision to the determined value of the depth.

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2 Principle of the method

The principle of pulsed thermography consists in applying a heat flux of a short duration and to record the temperature variation as a function of time (Fig.1).

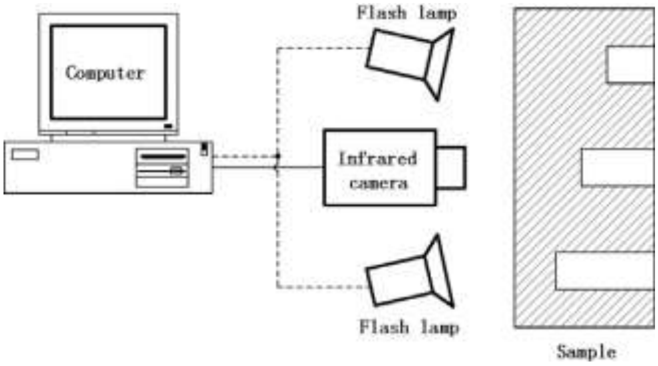

Figure. 1. The pulsed thermography Principle.

We consider aluminum samples with dimensions 235 mm x 150 mm x 20 mm, each sample contains a cylindrical defect of 25 mm in diameter and located at different depths from the heated surface (Fig. 2-a and Fig. 2-b).

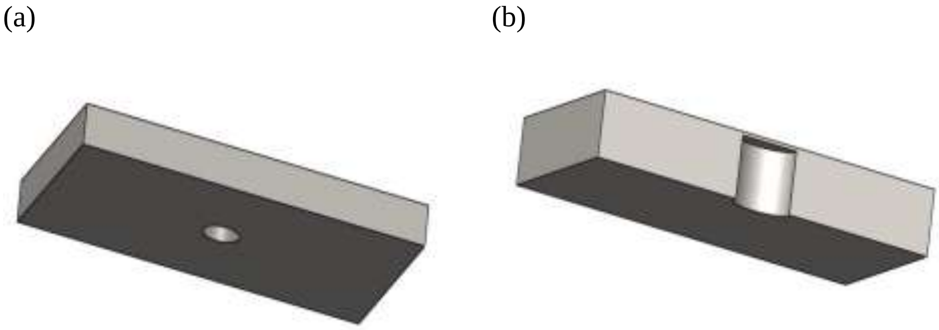

Figure. 2. (a) 3D aluminum sample with an inside defect, (b) Cutaway view of the aluminum sample with an inside defect.

We applied a heat flux of a short duration on the surface and we calculated, by the finite element method, the temperature on the heated surface. In Figure 3, we have represented the evolution of the temperature difference (calculated temperature minus the initial temperature) as a function of time for different defect depth.

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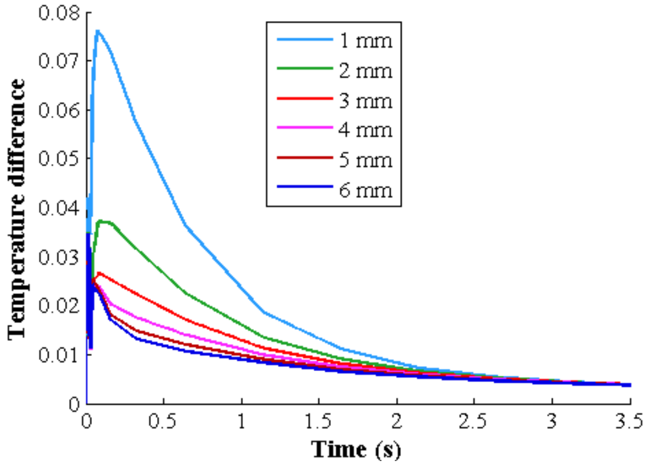

Figure. 3. Temperature evolution vs. time **-** the defect depth varies from 1mm to 6mm.

In the area where the thermal response of the sample to be controlled are different for different depths of the defects. We considered straights with director coefficient a passing through the origin and cut the thermal responses curves of Fig. 3 at various points (Fig. 4).

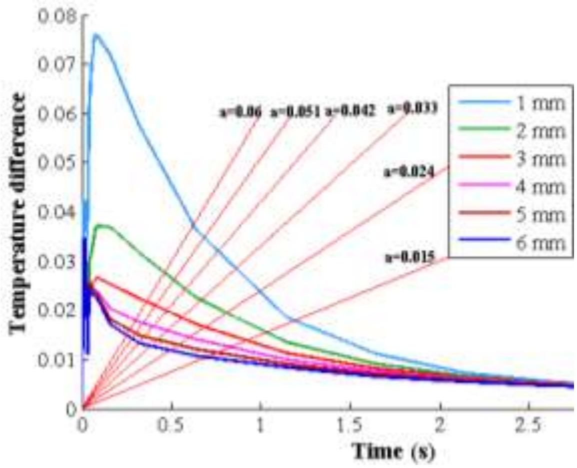

Figure. 4. Intersection points of a straight of the slope with the temperature curves.

To avoid the errors relative to the graphical determining of intersection points in Fig. 4, we developed a Matlab program to determine automatically these points. For each specific point, we calculated the distance between this point and the origin of the axes.

In the case of a straight with a director coefficient a=0.033, we have represented the variation of the distance as a function of the defect depth(Fig.5).

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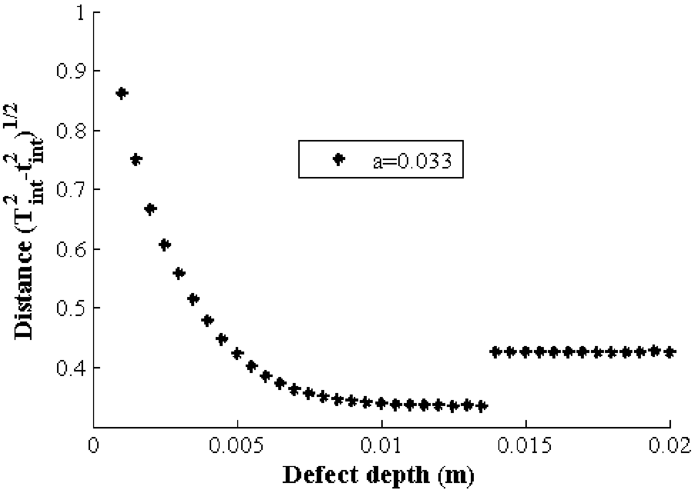

Figure. 5. Variation of the distance as a function of the defect depth director coefficient a=0.033.

We note that the distance varies exponentially as a function of the defect depth. From a given value of the depth, distance becomes insensitive to variation of the depth which explains the limits of pulsed thermography method to detect deep defects.

We limit ourselves to the area where the variation of the distance is proportional to the variation of the defect depth. In Fig. 6, we represent the variation of the distance as a function of the defect depth for different values of the director coefficient a.

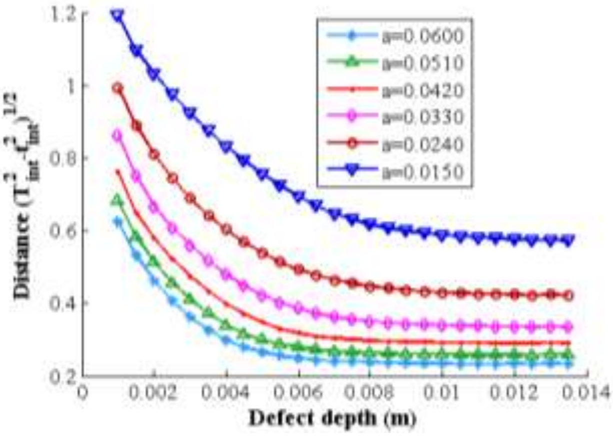

Figure. 6. Variation of the distance as a function of the defect depth for different director coefficient values a.

We note that for a given value of the director coefficient a, the distance variation as a function of the depth is a bijection and the inverse may be represented as shown in Fig. 7.

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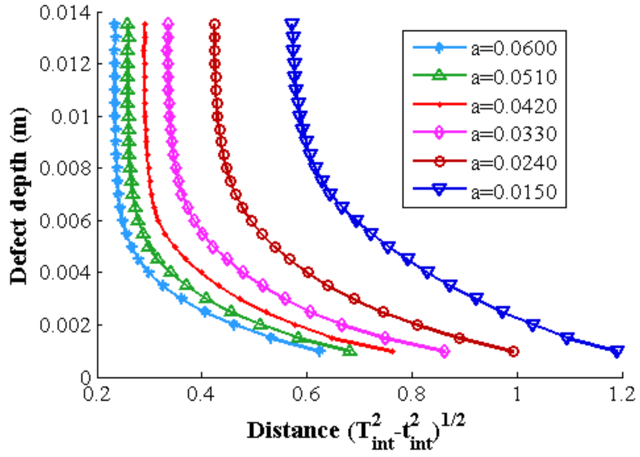

Figure. 7. Variation of the distance as a function of the defect depth for different director coefficient values a.

We can then determine the defect depth p from the distance d and the director coefficient according to the following empirical formula:

$$p = Ad^B \quad (1)$$

The constants A and B are dependent on the selected value of a. They are determined from two reference curves for which the depth p is known and the distance d is determined graphically by the intersection of the curves with the straight of slope a.

3 Experimental validation

To validate the effectiveness of the proposed method, we applied it at the experimental data shown in the Fig. 8 as following [11].

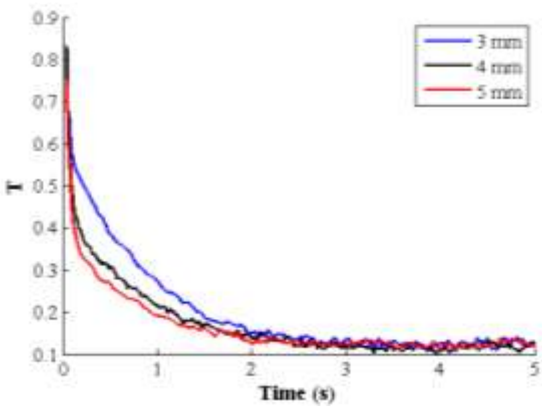

Figure. 8. Experimental temperature curves for an aluminum sample.

Firstly, we applied linear regression to reduce the effect of thermal noise on the measured values of temperature and we chose a value of the director coefficient (Fig. 9).

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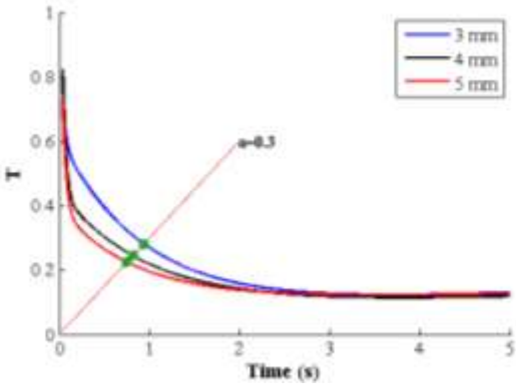

Figure. 9. Graphical determination of the intersection points between temperature curves and the straight of director coefficient a = 0.3.

The coordinates of the intersection points of Fig. 9 are as follows (Table1):

Table 1. Coordinates of the intersection points of the experimental curves and the straight defined by a=0.3

	Time t	Temperature T
Curve for p=3 mm	0.9352	0.2806
Curve for p=4 mm	0.8138	0.2442
Curve for p=5 mm	0.7471	0.2241

As a reference curves, we consider the experimental curves of temperature in the case of a defect located at 3 mm and 5 mm. We replace in equation (1) and we get A =0.0028 and B =-2.2741.

We can deduce subsequently the depth corresponding to the remaining curve. Indeed, the deducted value for the 4mm curve is p = 4.1157 mm, with an error of 0.1157 mm.

For other values of director coefficient a, we determined the defect depth with the same approach, Table 2 shows the obtained values: Table 2 shows the effectiveness of the proposed method in the experimental measurement of the defect depth.

Table 2. Determination of the depth value corresponding to the 4mm experimental curve for different values of director coefficient

Director coefficient a	Constant A	Constant B	Defect depth p (mm)
0.15	0.0089	-3.1601	4.1050
0.2	0.0050	-2.7097	4.0982
0.25	0.0036	-2.4489	4.1053
0.3	0.0028	-2.2741	4.1157
0.35	0.0024	-2.1473	4.1268
0.4	0.0021	-2.0496	4.1374
0.45	0.0019	-1.9716	4.1470
0.5	0.0018	-1.9076	4.1560
0.55	0.0017	-1.8539	4.1642
0.6	0.0016	-1.8081	4.1718

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4. Conclusion

In this work, we proposed a new method based on the analysis of thermograms obtained by pulsed thermography. This method consists in determining the constants of an empirical formula from the intersection points of temperature curves with a straight passing through the origin of the axes. The application of the proposed method allowed the estimation of the defect depth without thermal properties knowledge of the auscultated material.

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