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Determination of the defect depth by infrared thermography using finite element method

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Abstract. This paper focuses on determining of the defect depth in materials. The method is to solve the heat equation by finite element method for a chosen titanium plate in which a defect is inserted. Simulations have been carried out to determine the viability of using infrared thermography to detect internal defects and their depths. The plate was inspected by adding help plates with a perfect thermal contact and analyzing the surface temperature. The analysis of the temperature evolution curves of the conjugate surfaces of the studied system (the three plates fastened together) helps us to determine the defect depth with a very acceptable accuracy.

Keywords: defect depth, infrared thermography, heat equation, finite element; surface temperature

1 Introduction

The reliability of non-destructive evaluation techniques depends on many factors. These range from physical aspects of the used nondestructive technology and human factors. Various nondestructive evaluation methods are available and new ones are constantly developed [1].

In this article we are interested to study the infrared thermography by finite element method. The infrared thermography is one of the most promising nondestructive testing methods used in industry, it is an optical and non-contact technique, with fast diagnostic and good estimation of defect dimensions, based on quantitative and qualitative analysis through temperature evolution such as the measure is influenced by thermal properties of materials [2,3]. In general, the energy is taken to create a temperature difference between the specimen and the surrounding environment, and the heat flux is monitored as the sample returns to thermal equilibrium. The energy emitted by the sample depends on its temperature and on photon's wavelength [4].

The efficiency of infrared thermography to detect internal defects depends on the material to be inspected, the dimensions, the defect inclination and the defect depth. The infrared thermography can characterize the quality of the welding filler metal by analyzing the temperature distribution of the structure after welding [5,6].

The aim of our work is to show the capacity of infrared thermography as a non-destructive method for detecting internal defects in structures and to determine their depths.

2. Methods

2.1 Heat treatment

The heat equation (1) is given without voluminal heat source, for a homogeneous and isotropic material, in the orthonormal reference frame (x, y, z):

$$\rho C_p \frac{\partial T}{\partial t} = \lambda \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) \quad (1)$$

With:

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ρ: the material density [Kg/m^3]
C_p: the heat capacity at constant pressure [J/Kg.K]
λ: the material thermal conductivity [W/m.K]
T : the temperature to be calculated [°K]
With the boundary conditions (2):

$$\begin{cases} T=T_P \text{ on } S_T \\ \lambda(\vec{n}.\overrightarrow{gradT})=\varphi_S \text{ on } S_\varphi \\ S=S_T \cup S_\varphi \;, \quad S_T \cap S_\varphi = \varnothing \end{cases} \quad (2)$$

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 $t=t_0$ (3):

$$T(x,yz;t_0)=T_0(x,y,z) \quad (3)$$

2.2 Description of the study

In this paper we considered a titanium plate P of dimensions $L_x \times L_y \times L_z = 80\times60\times10mm^3$ in which a defect of dimensions $W\times L\times h=2\times20\times2mm^3$ is inserted.

To determine the defect depth in the titanium plate P by infrared thermography without destructing the integrity of the structure, help plates P1 and P2 are fastened together with the main plate P with a perfect thermal contact as presented in Figure. 1.

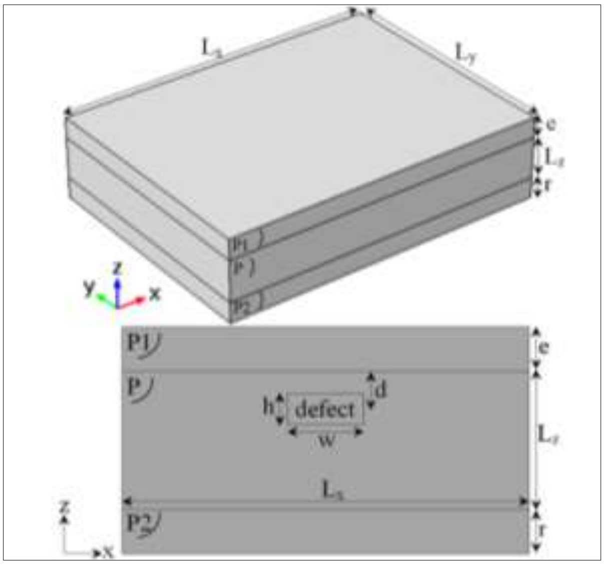

Figure. 1. studied specimen

The Figure. 1 illustrates in details the specimen, such as “e” and “r” are respectively the thicknesses of the added help plates P1 and P2. Such as $r=L_z$-e and “d” is the defect depth.

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2.3 Heat equation solving

In this work the heat equation is solved using the commercial software "COMSOL Multiphysics" based on the finite element method which allowed us to analyze and draw results.

The heat equation numerical solving of our specimen needs boundary conditions, initial conditions and thermophysical characteristics.

- The boundary conditions used in this study are presented below:
  - A heat pulse is applied on the upper surface of the specimen in case 1 then on the underside in case 2, with a heat flux density Q=15kW/m^2 (Figure. 2).
  - The other faces are assumed thermally insulated.
- The initial temperature of the subdomains is T_0=293.15°K.
- The thermophysical characteristics are presented in Table 1.

Table 1. Thermophysical characteristics

	λ[W/m.K]	ρ[Kg/m^3]	C_p[J/Kg.K]
titanium	7.5	4940	710
defect	0.0272	1.1845	1005

Such as λ is the thermal conductivity, ρ is the density of the material and C_p is the heat capacity at constant pressure

3. Results and discussions

The maximum of temperature T1 and T2, due to the existence of a defect, is evaluated. The Figure. 2 shows us the followed process to find the maximum of temperature T1 and T2.

The Figure. 3 shows the maximum of temperature T1 and T2 depending on the "e" parameter. At the intersection of the curves T1 and T2 (T1=T2) we can determine the calculated defect depth d_c as presented in (4) and (5) equations.

$$d_c = \frac{1}{2}(L_z + e_i + r_i) - e_i \quad (4)$$

$$d_c = L_z - e_i \quad (5)$$

With
e_i the help plate P1 thickness at T1=T2
r_i the help plate P2 thickness at T1=T2

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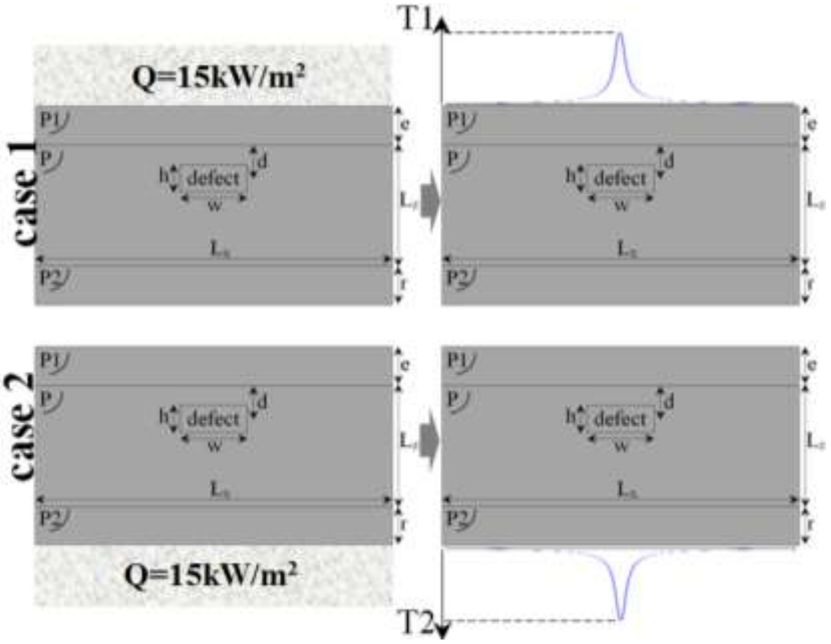

Figure. 2. The process of determining of the maximum of temperature T1 and T2.

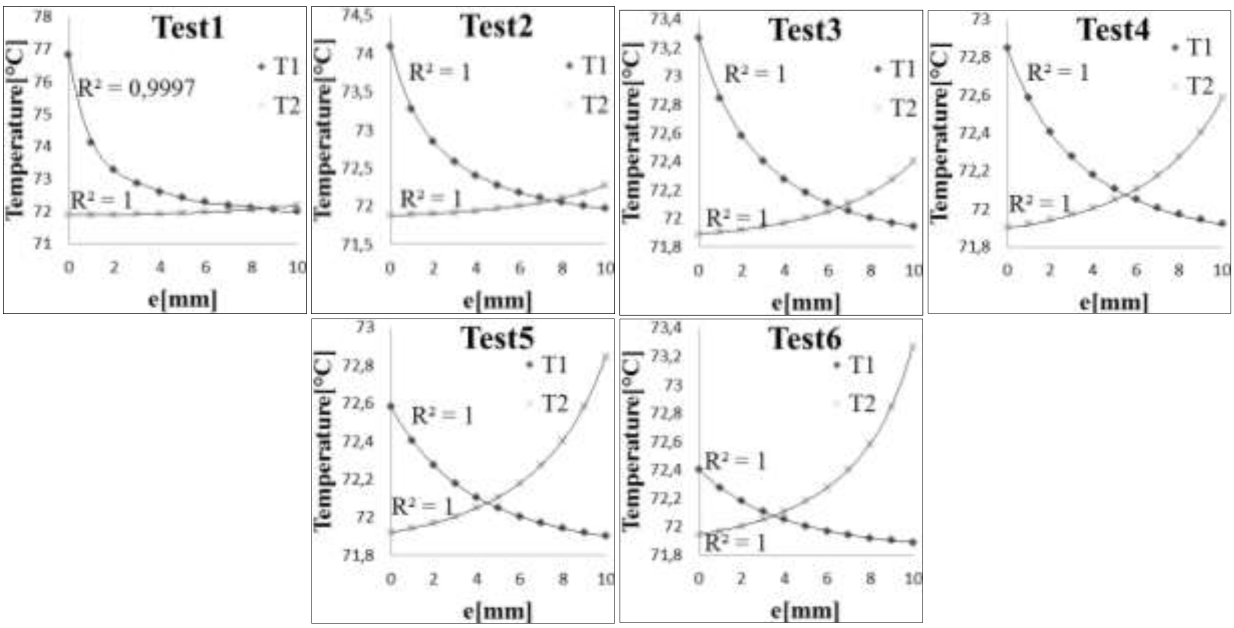

Figure. 3. Maximum of temperature T1 and T2.

From the Figure. 3 the defect depth is determined as shown in Table 2.

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Table 2. Defect depth determining

Test	d[mm]	e_i[mm]	d_c[mm]	a_d[%]
Test1	1.5	8.559	1.441	96.067
Test2	2.5	7.513	2.487	99.48
Test3	3.5	6.5	3.5	100
Test4	4.5	5.507	4.493	99.844
Test5	5.5	4.493	5.507	99.873
Test6	6.5	3.502	6.498	99.969

$a_d=d/(|d-d_c|+d)$ is the accuracy of the defect depth calculation.

It is deduced that infrared thermography with the technique described in this article allows us to reveal the existence of defects in structures, as well as to determine the depth of these defects with a good accuracy.

4. Conclusion

This article has described the infrared thermography as a nondestructive evaluation method for defect depth determination. Its utility is evaluated using simulated data generated by heat equation numerical solving. These simulations show that there are some interesting results when investigating the defect depth in a titanium plate. Therefore, there is an interest in extending the present diagnostic to other defect types in different structures.

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