PULSED IR THERMOGRAPHY FOR DETECTION OF MATERIAL DEFECTS

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1. Introduction

The application of IR thermography to detect flaws in the subsurface layer of the tested material needs a thermal stimulation of its surface. One of the most common thermal stimulation method used in the nondestructive material testing is the pulsed IR thermography. It is based on monitoring of the temperature distribution on the material surface during its self-cooling after stimulation. The surface temperature distribution is disturbed by the flaws inside the tested material. This disturbance as an indicator of flaw presence can be used. Thus, it is necessary to know the time dependence distribution of the temperature on the surface of the sound material. This dependence is known when the surface of the tested material is uniformly heated by an impulse with infinitesimal duration [1, 2]. In this paper the layer of the examined material is approximated by a semi-infinite body and the self-cooling process of semi-infinite uniform body after stimulation by a rectangular impulse with a finite duration is considered. The criterion of long time regime approximation is formulated and verified experimentally.

2. Time dependence of temperature field on semi-infinite body surface heated uniformly by the heat impulse of constant strength with a finite duration

When the surface of a tested material is heated uniformly, we can limit the analysis to the one-dimensional differential heat conduction equation. Then we have:

(1) $$\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial z^2} + \frac{w}{c\rho}$$

where α is the thermal diffusivity of the material, c is the specific heat, ρ is the material density, w is the volume density of the heat impulse power absorbed, t and z are coordinates time and distance, respectively. Then the initial boundary conditions are as follows:

(2) $$T(0,z) = T_0, \frac{\partial T}{\partial z}(t,0) = 0 \text{ and } T(t,\infty) = T_0.$$

The solution of the differential equation of heat conduction for the initial boundary conditions as above is as follows:

(3) $$\Delta T(t) = \frac{2Q_s(\tau)}{c\rho\sqrt{\pi\tau\alpha}}\left(\sqrt{\frac{t}{\tau}} - \sqrt{\frac{t}{\tau} - 1}\right)$$

Thus, it has been shown that when the surface of the tested material was heated uniformly by the heat impulse with the finite duration time τ and the time of the surface self-cooling $t \gg \tau$, then:

(4) $$\Delta T(t) \sim \frac{1}{\sqrt{t}}$$

Deflection from the form of Eq. (4) indicates a presence of flaws in the tested material, because defects change thermal diffusion process. On logarithmic scales the graph of the function given by Eq. (4) is a straight line with slope $-\frac{1}{2}$.

3. Experiments, results and discussion

Experiment was performed on the specimen containing a simulated delamination. The specimen was made of two austenitic steel plates. In one of them (3.6 mm thick) the flat bottom hole has been drilled. The second plate was 2 mm thick and it has been stuck to the previous one. It allowed us to obtain the simulated delamination located at the depth of 1 mm. The surface of the specimen was heated uniformly by a conventional IR lamp of 500 W during 3 seconds. A temperature distribution on the surface during its self cooling process was measured by IR camera (ThermaCam 595) with a frame rate 50 Hz.

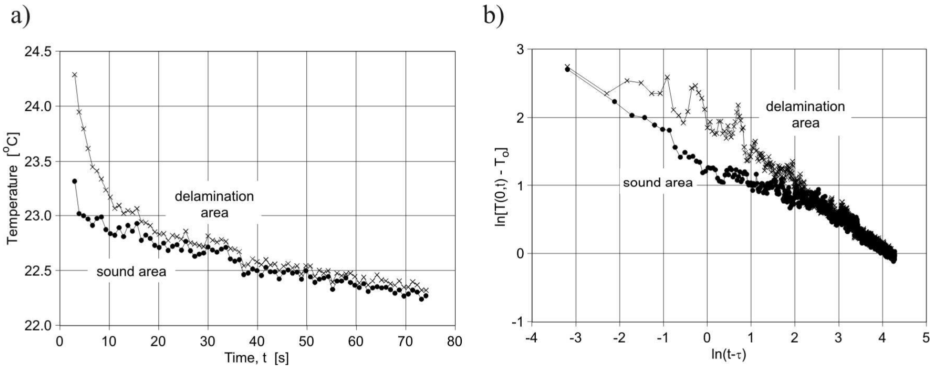

Fig. 1. a) The time evolution of the average temperature for the surface zones over defect and over sound material; b) Logarithmic time evolution of the surface temperature after the end of uniform heating for the surface zones.

In Fig. 1b the diagram $ln\left[T\left(0,t\right)-T_0\right]$ vs. $ln\left(t-\tau\right)$ for the sound and delamination zone is presented. The term $T\left(0,t\right)$ is average surface temperature of two investigated zones and T_0 = 21.7 °C is the temperature of the tested surface before heating. It is seen that the slope of the graph line corresponding to the sound zone is nearly $-\frac{1}{2}$. This confirms correctness of the derived formula (4) and of the taken assumption. A deflection from the $-\frac{1}{2}$ slope, as the indicator of a presence of flaws under a tested area of the material surface can be used.

It has been shown that monitoring of temperature field on the material surface after its uniform thermal stimulation by a heat impulse of a finite duration makes possible to detect flaws under tested surface.

4. References

[1] A. V. Luikov (1968). *Analytical Heat Diffusion Theory*, Academic Press, 377–398.

[2] H. S. Carslaw, J. C. Jaeger (1959). *Conduction of Heat in Solids*, 2nd ed., Clarendon Press, 50–92.