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Prodigious Application of Pulsed Flash Thermography for the Characterization and Fault Detection of Surface Material

[1]Ratnesh Pathak

[2]Dr. Shuchitangshu Chatterjee

1 Research Scholar, Department of Physics, RKDF University, Ranchi, Jharkhand, India

2 Vice Chancellor, RKDF University, Ranchi, Jharkhand, India

ABSTRACT

The aim of the present study is to demonstrate the assistance provided by infrared thermography (IRT) in the characterization of materials. Infrared thermography is a surface temperature mapping technique which is two-dimensional and contactless method which can be practically applied for quality assurance of manufacturing processes and for non-destructive testing (NDT) of end products. Infrared thermography based on NDT can be accomplished in two basic ways: pulse thermography (PT) [1], or modulated lock-in thermography (MT). Here we emphasis on pulse thermography and pulse flash thermography. Pulsed thermography is commonly used as non-destructive technique for evaluating defects within materials and components. However, raw thermal imaging data are usually not suitable for quantitative evaluation of defects.

The thermal examination using NDT [2] can find the presence of fault based on temperature distribution irregularities that are created on the surface as a result of a fault. There are many factors that affect the temperature distribution of the surface being tested by Infrared Thermography. We consider a simple structure of the surface with several defects, whose surface we heated with a uniform heat flux impulse. We conducted a theoretical analysis of the method for case of defects on the surface. First, we create intentionally the defects on the surface of material in order to find conditions and boundaries for application of the method. The pulsed flash thermography (PFT) [1] method was performed on simulated defects on surface with air and other compounds which has tendency of Phase Change. Study results indicate that it is possible, using the PFT method, to detect the type of material inside defect holes, whose presence disturbs the homogeneous structure material.

Key words: IRT, NDT, PFT, fault estimation, phase change material.

Introduction

Infrared Thermography (IRT) is one of more advanced methods of nondestructive testing (NDT). IRT applies to NDT measure and interprets the temperature field of the surface of the body being tested. NDT based on IRT can be applied using either a passive or an active approach. The objective is to create a thermal contrast on subsurface anomalies, i.e., the defects. Many different stimulation methods can be applied and most of them can be classified as optical, mechanical or inductive. The most common methods are based on optical stimulation, which uses light to deliver energy to the specimen. [3]

In pulsed thermography (PT) energy is applied to the specimen using a pulsed excitation by applying the energy sources like flash lamps whose flash duration varies from a few milliseconds for good thermal conductors to a few seconds for low-conductivity materials. The applied energy creates a thermal front that propagates from the specimen's surface throughout the specimen. During the cool down process the surface temperature decreases uniformly for a sample without internal defects. When the thermal front intersects an interface from a high to low conductivity layer, like in the case of permeability, the cooling rate is disturbed. This results in an increase of heat above the defect that is also revealed at the specimen's surface and can be detected by an IR camera. Thus, allowing defective areas to be distinguished from non-defective areas. Image processing is commonly used for two purposes. Its first use is to improve the visual appearance of images to a human viewer. Filtering and color map adjustments are commonly applied to make an image more pleasant to look at. Its second purpose is to prepare the images or data for the measurement of features present. This can include applying a threshold [12] to create a binary image, applying morphologic filters, etc. The processed image allows the operator to measure the size of the features of interest and could also be used for automated flaw detection and measurements.

Pulsed thermography (PT) is an NDT method, which involves briefly heating the specimen with a short pulse of thermal stimulation and then recording the temperature decay curve [4-6]. The temperature in the material varies rapidly after the initial thermal pulse, while the thermal front propagates by diffusion through the material. The presence of a discontinuity will change its local diffusion rate, so that, by observing the temperature of the surface, the discontinuities appear to be among the areas of different temperatures with respect to its surrounding areas.

Nowadays this method is usually called pulsed flash thermography (PFT). In this paper we described basic principles and gave some examples of PFT application on materials with wide spectra of thermal properties. The objective of the study is to find the influence of phase changed material on the surface temperature distribution and the value of the maximum temperature difference.

Material and Methods

The major property that distinguishes pulsed flash thermography from other methods is direct measurement. Shape of the time-dependent surface temperature curve depends on the extent of penetration of excitement radiation into the examined material, thermal diffusivity and transmission for emitted IR radiation of the material. Time-dependent surface temperature is a source of information about material defects.

According to Fourier's Law equation for heat conduction in solid bodies is [7,8]

$$\frac{\partial\theta}{\partial t} = \frac{k}{c.\rho}\nabla^2\theta \text{ ----------(1)}$$

Where θ = rise in temperature, k = heat conductivity, c = specific heat,

ρ = volumetric mass density and $c.\rho$ = volumetric temperature capacity.

If we assume that heat flow in *y* and *z* direction is negligible and that the contributions to the heat flow from thermal radiation and from contact at *x=0* with air or other materials are negligible we can use an equation for one dimensional heat conduction.

$$\theta(x) = \theta_0 e^{-ax} \text{ ----------(2)}$$

Where $\theta_0 = \frac{E_0 a}{c\rho}$ here

E_0 = input energy per unit area and a is thermal diffusivity and

a = thermal diffusivity

For testing of material with pulse flash thermography we use two parameters; one is amount of heat that need transfer to the unit of surface to get wanted level of contrast, and the other is the last time necessary to develop that contrast on the sample surface. [9]
Because impulse light sources transfer energy to heat in very short time intervals, to avoid too big increase in initial temperature having destructive effects on the materials, there should be pre
calculated maximum temperatures of the front side θ_f for impulses of different shape.
For examination of defect with PFT method we can use different materials with broad spectrum [10]. Especially important are materials which are being used for the purpose of thermoregulation because they require special thermos-physical properties. Phase change materials (PCM) possess the ability to change their state within a certain temperature range. These materials absorb energy during the heating process as phase change takes place, otherwise this energy can be transferred to the environment in the phase change range during a reverse cooling process. The large heat transfers during the melting process as well as the crystallization process without significant temperature changes makes phase changed material interesting as a source of heat storage material in practical applications.

Material	**Specific Heat (c) J/Kg^{0}C**	**Density (ρ) Kg/m^3**	**Volume Heat Capacity (c.ρ)**	**Thermal Conductivity (k) W/m^{0}C**	**Thermal Diffusivity (a) m^{2}s^{-1}**
Soft Iron	0.44×10^3	7.9×10^3	3.48×10^6	46	13×10^{-6}
Steel	0.5×10^3	7.9×10^3	3.9×10^6	16.2	4.06×10^{-6}
Aluminium	0.88×10^3	2.7×10^3	2.4×10^6	230	95×10^{-6}
Water	4.2×10^3	1×10^3	4.2×10^6	0.68	0.14×10^{-6}
Air	1×10^3	0.01×10^3	0.01×10^6	0.03	2.3×10^{-6}

Table 1. Thermo physical properties of materials that can be used with PFT

Here we consider that flash time is so short that only thin surface layer will be exposed to high temperature. Table 2 gives values for time *T* (time needed to raise temperature of opposite surface to half of the maximum value, for a plate of *Th* thickness) **[11]**

Material	**T (sec)**	**θ_f (K)**	**Th (mm)**
Soft Iron	1.10	9.6	0.3
Steel	2.00	13	0.2
Aluminium	0.15	5.2	0.8
Water	97.2	77.4	0.03
Air	6.20	26.5	0.5

Table 2. Thermal raise times and surface temperatures for PFT usable materials

Where T= Time taken for the temperature of the opposite surface to reach half of its maximum
θ_f = Maximum temperature of the front side with flash deposition
Th= Thickness of material heated to temperature. θ_f

Temperature difference is defined as the difference in temperature between the area on the surface over the defect and over the non-defect material. Analysis of the time dependence of the temperature difference change with time, gives us the possibility of determining the depth of the defect. The temperature difference is changing over time, reaching a maximum value. The maximum temperature difference is the specific parameter which depends on the defect depth and the type of materials by which defects holes are filled. The temperature difference is an important parameter for the defect quantitative analysis, whose extreme values (minimum or maximum) represent the time *t* at which the reflection of the defect on the material surface is most clearly seen.

Result and Conclusion

The testing plate is made out of any material (iron, steel, aluminum etc.) of size 180 mm*50 mm*8 mm Simulated defects are hollow cylindrical spaces (series of circular holes: A, B, C, D and E) with flat bottom.

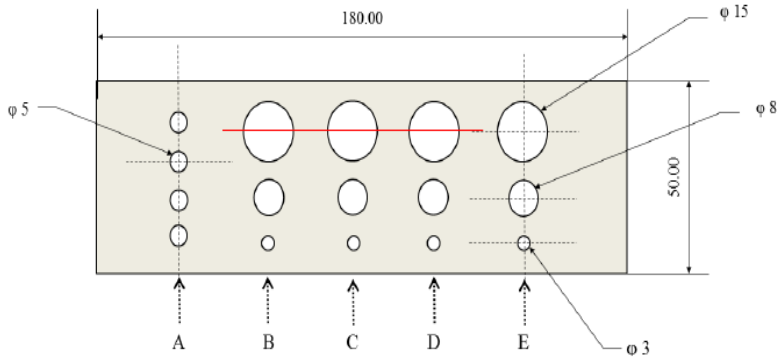
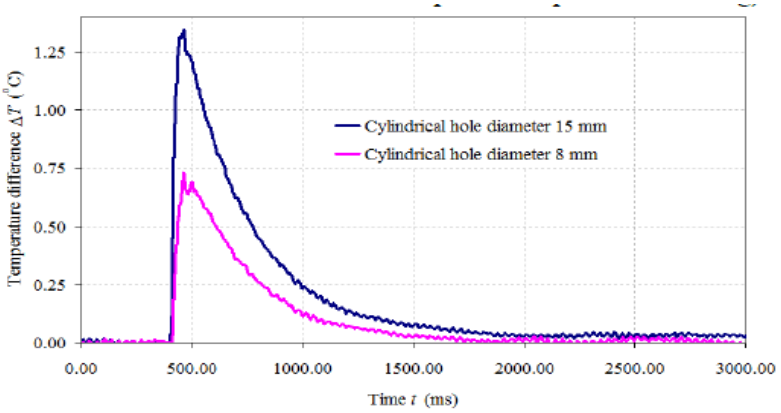


Figure1: Testing Plate (Aluminium)

Holes have different diameters, but holes of the same series have identical depths. Series A has four holes with identical diameter of 5 mm, while series B, C, D and E all have three holes with differing diameters of 15 mm, 8 mm and 3 mm. By method of impulse thermography using infrared camera we recorded temperature change on aluminum plate surface right above the defects, in areas with no defects and above defects filled with phase change material. We measured emissivity of the aluminum plate surface by using thermographic method with a tape over a surface of known emissivity. We performed selection and analysis of IR recordings by using software for analysis of recorded sequences. On the picture of the aluminum TS after the lighting of the surface with light impulse defect contours are easily spotted as places warmer than surfaces without defects.

The temperature difference as a function of time between a defected area and non-defected area for different size (15 mm and 8 mm taken) of defect holes on aluminium testing plate is calculated and represented by a graph as shown below



Temperature difference between area above defects and no-defect area is increasing until it reaches maximum value, after which it drops off. Slope of the curve depends on the type of defect in material. In our study we treated two types of defects in aluminum plate: air defect and defects with material from PCM group. Temperature contrast was computed by taking the temperature difference between defective and non-defective areas and plotted as a function of time.

Conclusion:

PFT method is very applicable because it does not require physical contact with the examined material except for the heat transfer, it can also be very quick and can be applied when only one side of the object is accessible. Because of these characteristics the method has become a subject of numerous scientific studies, especially in the area of nondestructive testing of multilayer materials. This study clearly tells the potential of pulsed flash thermography for defect estimation in a surface of material like aluminum. We used a simplified theoretical model for heat transfer in the examined sample which to determine time dependence of sample surface temperature in the presence of defects and with no defects.

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