STUDY OF DEFECT DETERMINATION USING ACTIVE MODE THERMOGRAPHY

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Abstract

Passive mode of Infrared Thermography (IRT) has proven to be an effective and reliable technique for condition monitoring and preventive maintenance purposes. However, active mode of IRT is considerably new for industry in term of measuring defect in Non-Destructive Testing (NDT) activities. For the project discussed herein, active mode of IRT, specifically Pulsed Thermal (PT) method was used to detect several simulated sub-surface defects in eight pieces of bakelite- a non-metal and low conductive material. The results demonstrate that the method has capability to detect all simulated defects where the sensitivity of the approached method is proportionately related to the size of defect diameter if the defects are at the same depth and at the same time it is inverserly related with the depth of defect if the defects have similar diameter size. As a conclusion the study has confirmed the ability and potential of active thermpgraphy as a technique for defect determination in material.

Keywords: infrared thermography, active mode thermography, pulsed thermal, sub-surface defects

INTRODUCTION

Infrared thermography (IRT) can be classified into two modes, "passive and "active" [1, 2, 4]. The passive mode which is commonly used in the investigation of materials or structures that are at the different temperature (normally higher than ambient) has been approved as a reliable technique for condition monitoring and preventive maintenance purposes [2]. While in the case of the active mode of IRT, an external stimulus is necessary to induce relevant thermal contrast. Depending on external stimulus, different approaches of this mode has been introduced, such as Lock-in, Step Heating, Vibrothermography, and the most common used, Pulsed Thermal method [1]. In this study, we only present the basic principles and methodology of Pulsed Thermal (PT) method as active mode of IRT to detect several artificial sub-surface defects in low-thermal conductive material namely bakelite. Basically, PT method consists of briefly heating the specimen and then recording its temperature decay curve. Time for heating may vary depends on type of the tested object or inspected materials. It could be just a few milliseconds for high conductivity material, such as metal or to a few seconds for low conductivity material such as composite, plastic etc [1]. Qualitatively, the phenomenon is as follows. The temperature of the materials first rises during the pulse. After the pulse, it then decays because the energy (on the thermal front) propagates by diffusion under the surface. Later, the presence of a subsurface defect for instance void, delamination, disbonding etc will reduce the diffusion rate so that when observing the surface temperature, such sub-surface defects appear as an area of higher temperature with respect to the surrounding sound area. In fact in such a case the reduced diffusion rate caused by the sub-surface defect presence translate into 'heat accumulation' and hence higher surface temperature just over the defect.

THEORETICAL ASPECT

There is a few theoretical approaches, which can be used as guidelines to execute the study. Nevertheless, among the famous is Vavilov and Taylor's explanation. In the 1980s, they discussed the principles of Thermal NDT (TNDT) and expressing the ability of TNDT to provide quantitative information about hidden defects in a material [7]. However, there are several important properties about the materials need to be considered and such properties are thermal properties, spectral properties etc. [8].

For instance, when a solid material presents any defect (void or pores) in its structure, then its thermal conductivity and density may decrease. At the same time its thermal diffusivity is being altered; therefore the conduction of heat transfer within the material is affected. This can be clarified by

$$\alpha = k/\rho C_\rho \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where;

α is the thermal diffusivity (m^2s^{-1}), k is the thermal conductivity ($Wm^{-1}K^{-1}$), ρ is the density (kgm^{-3}) and C_ρ is the specific heat capacity ($Jkg^{-1}K^{-1}$).

Another parameter, which can be considered, is thermal effusivity. Since;

$$\Delta T = Q/(e\pi t)^{1/2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where, ΔT is temperature increase of the surface, Q is the input energy (Joules), t is the time (s) and e is the thermal effusivity ($Ws^{1/2}m^{-2}K^{-1}$), therefore materials with low effusivity value will present higher temperatures as compared to material with high effusivity value.

Thermal effusivity (e) is calculated by;

$$e = (k\rho C_\rho)^{1/2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where, k is the thermal conductivity ($Wm^{-1}K^{-1}$), ρ is the density (kgm^{-3}) and C_ρ is the specific heat capacity ($Jkg^{-1}K^{-1}$).

Normally, defects will look warmer as compared to the surrounding since they unable to transfer the heat readily or in other words, they will restrict the cooling rate due to diffusion process. Therefore, these defects will appear as 'hot spot' surrounded by a cooler material normally depicted as dark background. The exact temperature rise of the heated surface is governed by the amount energy deposited and the speed of application, combined with thermal properties of the surface materials [1].

MATERIAL AND METHOD

In this study, eight samples, each containing drilling-induced defect of different size and depth were examined. These simulated defects were made by drilling circular flat bottomed holes in sheet of 6 mm-thick bakelite. These samples were thermally stimulated using 30kwatt tubular lamps. The technique used was PT one-sided test where both heating device and IR camera are located on the same side of the workpiece. The experimental work scheme is shown in Fig.1.

Four experiments had been carried out to collect four sequences of IR images (thermogram). The 1st experiment had been done by heating the samples in 5 s with 6393Wm^{-2} input energy. The step was repeated by heating the samples in 5 s with 12787 Wm^{-2} input energy. Next, the samples were heated in 10 s with 6393 Wm^{-2} input energy and lastly the samples were heated in 10 s with 12787 Wm^{-2} input energy.

The thermograms (see Fig.2) were recorded using THV 550 IR camera and were then analysed and processed using image processing called ThermoFitPro. The amplitude, shape and temporal evolution of temperature signals serve as the informative parameters, which allow us to detect subsurface defects and characterize their properties.

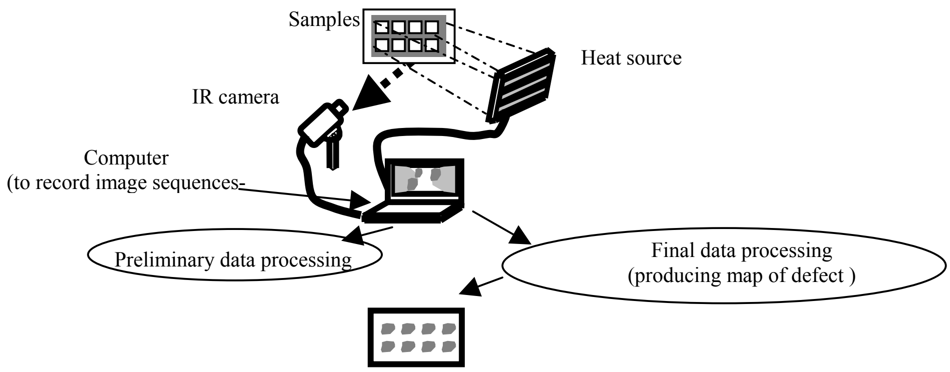

Fig.1 The experimental work scheme

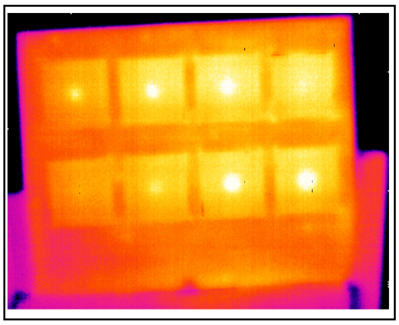

Fig.2. An example of recorded thermogram

RESULTS AND DISCUSSION

The potential of pulsed thermal method to detect the artificial defects in tested bakelite is determined by two pairs of informative parameters. The first pair is Maximum Absolute Differential Temperature Signal (ΔT_{max}) = (T_d – T_{nd}) and the time of its appearance τ_{max} (ΔT), while the second parameter is the Maximum Running Contrast (C_{max}) = (ΔT_{max} / T_{nd}) and its corresponding time, τ_{max} (C). T_d and T_{nd} are referred to *temperature on defect area* and *temperature on non-defect area.* However in this study we produced the first pair of informative parameters only. The values of ΔT_{max} and τ_{max} (ΔT which appeared in our experiment have been found by considering two points for each defect: a central (defect) point and a point placed close to a defect but still regarded as non-defect. These two points are subjective since they depend on how the operator defined them (see an example of point chosen in Fig.3).

Illustration on Fig.4 shows the value of the Maximum Absolute Differential Temperature Signal (ΔT_{max}) versus defect depth while illustration on Fig.5 shows the value of the Maximum Absolute Differential Temperature Signal (ΔT_{max}) versus defect diameter which referred as defect length. Based on both illustrations, we found that all defects were able to be detected, even for the smallest and deepest defect (sample no.4 and sample no.5). This result have a good agreement with Vavilov's observation, which, the range of specimen thicknesses that can be examined is roughly from 0.1 to 10 mm for solid materials, if defect are likely to occur anywhere within the material. In this case, minimum sizes should be as a rule is two to three times greater than the layer of material above them [5]. By looking at the trend of the chart, it shows that the combination of heating duration of 10 seconds with input energy of 12787 Wm^{-2} during 4^{th} experiment produced the highest ΔT_{max} value while the combination of heating duration of 5 seconds with input energy of 6393 Wm^{-2} in the first experiment produced the lowest ΔT_{max} value.

Moreover, according to the plotted exponential graph ΔT_{max} versus defect diameter and exponential graph ΔT_{max} versus defect depth, it can be concluded that the sensitivity of the PT technique to detect sub-surface defects of bakelite material is proportionately related with the size of defect diameter if the defects are at the same depth. On the contrary, the sensitivity of the technique is inverserly related with the depth of defect if the defects have similar diameter size.

In this study, heating energy is a primary condition. It must be enough to create a signal of $\Delta T_{max,}$ which will be sensed by IR camera. If all other parameters are optimal but the energy is not good enough, the defect will be invisible. The shorter is heat pulse (heating duration) the better is signal-to-noise ratio since energy is production of heat power by heating duration. This is mean for shorter heat pulse, input energy should be high. However if a pulse is short and too powerful, at the end of the pulse, tested samples can be overheated and even evaporate. In short, a good compromise between the requirements above will provide optimal testing conditions.

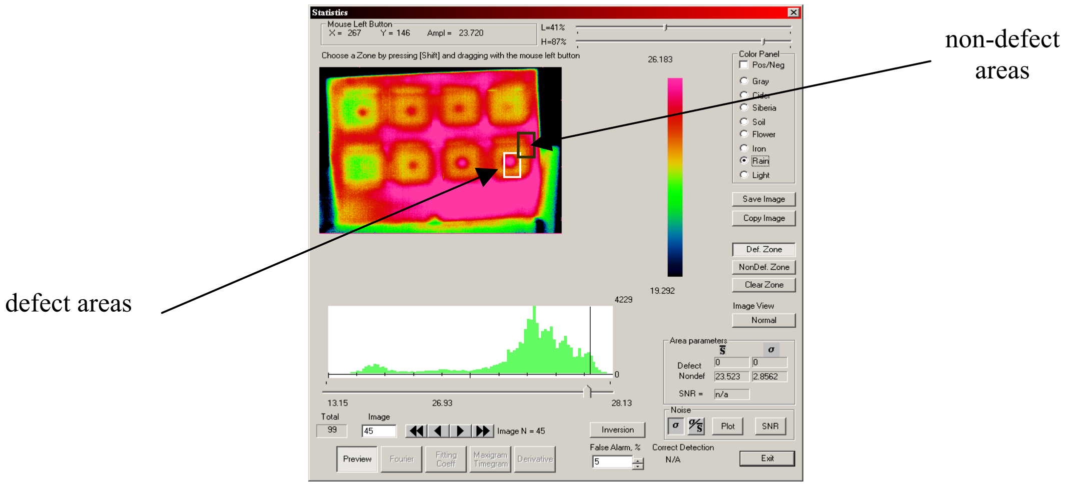

Fig.3 Identifying defect and non-defect areas in the samples

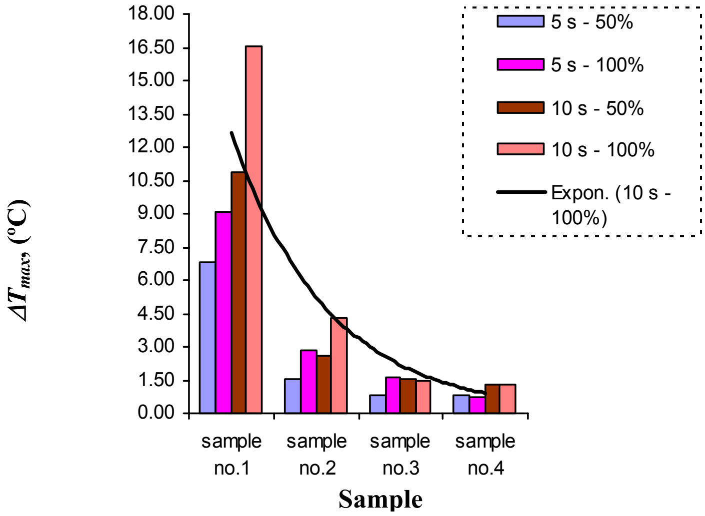

Fig.4. Illustration of Maximum Absolute Differential Temperature Signal (ΔT_{max}) versus defect depth

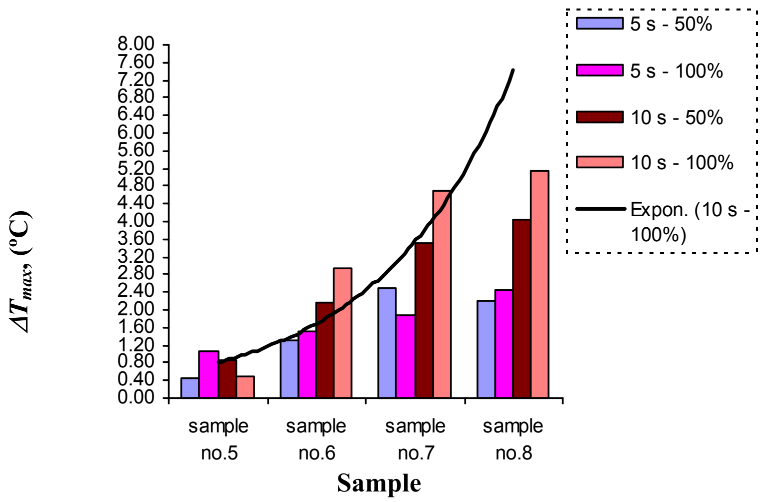

Fig.5. Illustration of Maximum Absolute Differential Temperature Signal (ΔT_{max}) versus defect diameter (length)

CONCLUSION

This study has confirmed the ability and potential of active mode of IRT, specifically PT technique for sub-surface defects detection. From the results, we may conclude that the sensitivity of the active mode of IRT to detect sub-surface defects of bakelite material is proportional to the size of defect diameter if the defects are at the same depth. On the contrary, the sensitivity of the approached technique is inverse to the depth of defect if the defects have similar diameter size.

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