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Infrared radiation emitted due to scanning of a hot spot as a probe of hidden defects

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HIGHLIGHTS

- A scanning hot air nozzle is applied to introduce energy in a researched sample.
- The hidden defect has an increased temperature in comparison with the surround area.
- The scanning a controlled sample.

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ABSTRACT

Specially created subsurface defects in a sample are detected using a high resolution infrared camera FLIR SC7000. A scanning hot air (about 110 °C) nozzle is applied to introduce additional energy in a researched sample. The hidden defect has an increased temperature in comparison with the surrounding area that is a result of changed emissivity and thermal diffusivity. The suggested method is compared with pulse thermography which uses a xenon lamp for excitation.

1. Introduction

The non-contact method of temperature measurement by detecting radiation emitted from the surface in the entire spectral range is well-known as infrared (IR) thermal imaging or IR thermography (IRTG) [1]. Good progress in research on IR thermography to detect defects in the surface layer of materials has been observed in the last years. Thermography offers noncontact, wide area detection of material defects, and can be used as an alternative of or a complement to the conventional inspection technologies [2–9]. The essence of these researches is the thermal response analysis of a material stimulated by an external heat impulse.

The presence of areas containing defects with thermal properties different from those in defect-free areas changes the diffusion rate that enables to observe the location of defects by analyzing the temperature distribution on the researched sample surface [2,7]. On the other hand, the size of defects detected using the pulse thermography method should be not less than a few millimeters if a whole surface (usually the macroscopic one) of the researched sample is stimulated [8,9]. It seems that this paucity of method can be removed using a scanning laser source to deposit heat into a sample surface [3–5]. However, the IR thermography signal will be depended strongly from the optical characteristic of the surface in this case to a greater extent than on the subsurface defects.

Other methods of excitation can be used in thermography to detect defects, namely ultrasound [10,11]. The ultrasound thermography uses the interaction between mechanical and thermal waves to detect material defects. If a damage in a component absorbs excited high energy ultrasound waves then it will locally heat up. The resulting temperature gradient is captured by an infrared camera on the sample surface. This method is suitable for many applications such as the crack detection, the delamination and impact damage control or adhesion and welded joints testing. In another words, it is also possible to detect some macroscopic discontinuities in materials using the ultrasound method [10,11].

This paper describes a new probe of subsurface defects of submillimeter sizes. It provides scanning over the controlled sample

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surface with a specially designed hot air nozzle used as an excitation source, and then infrared radiation emitted from the sample is detected.

2. Theory

The radiation emission from a tested body is the basis of thermography. According to the Stefan–Boltzmann law and taking into account the reflected ambient radiation as background and the self-radiation of the infrared thermometer, the electric signal of an IR detector is to be considered as follows [12]:

$$U = C\left[\varepsilon T_{sam}^{n} + (\varepsilon - 1)T_{bgr}^{n} + T_{trm}^{n}\right] \qquad (1)$$

where U is a detector signal, T_{sam} is the temperature of a measured sample; T_{bgr} is the temperature of background radiation; T_{trm} is the temperature of an IR detector (IR camera); C is a constant specific for the IR detector; the exponent n depends on the wavelength λ because the infrared thermometers do not cover the entire wavelength range: at wavelengths ranging from 1 to 14 μm n is between 17 and 2 (at long wavelengths it is between 2 and 3, and at short wavelengths it is between 15 and 17) [10]; $r = 1 - \varepsilon$ is reflection of the object, $\varepsilon = E/E_s$ is emissivity of the sample surface material equal to the ratio of the emission intensity E of a real body to the emissivity E_s of the absolute black body at the same temperature.

Eq. (1) shows the basic correlation for non-contact temperature measurements. Furthermore, strong dependence of the detector signal U on the sample temperature T_{sam}^{n} ($n \geqslant 4$) allows registering a change of the temperature distribution caused by some inhomogeneity (discontinuity) of the material properties.

When the excitation energy is introduced the heat diffusion through measured material becomes important. Heat diffusion through a solid can be described by the Fourier's law of the heat equation [13]. If a Dirac heat pulse is this excitation energy, a 1D solution of the Fourier equation can be found as the propagation of an ideal waveform defined as an intense unit-area pulse in a semi-infinite isotropic solid. Such solution has the form [14,15]:

$$T(t) = T_0 + \frac{Q}{e\sqrt{\pi t}} \qquad (2)$$

where Q is the energy absorbed by the surface, and T_0 is the initial temperature, e is the effusivity:

$$e = \sqrt{k\rho c_p} \qquad (3)$$

which is a thermal property that determines the ability of a material to exchange heat with its surroundings and is an important parameter in this method. In Eq. (3) k is the thermal conductivity of the sample material, ρ is the material density, and c_p is the heat capacity at constant pressure.

The effusivity e is changed if the material properties (k, ρ, c_p) are changed due to inhomogeneity (discontinuities of the material properties: inclusions, voids, delaminations and so on) that causes the local change of temperature ΔT and consequently, leads to the change of the detector signal ΔU. The time of this change is associated with another parameter – the thermal diffusivity α. Any

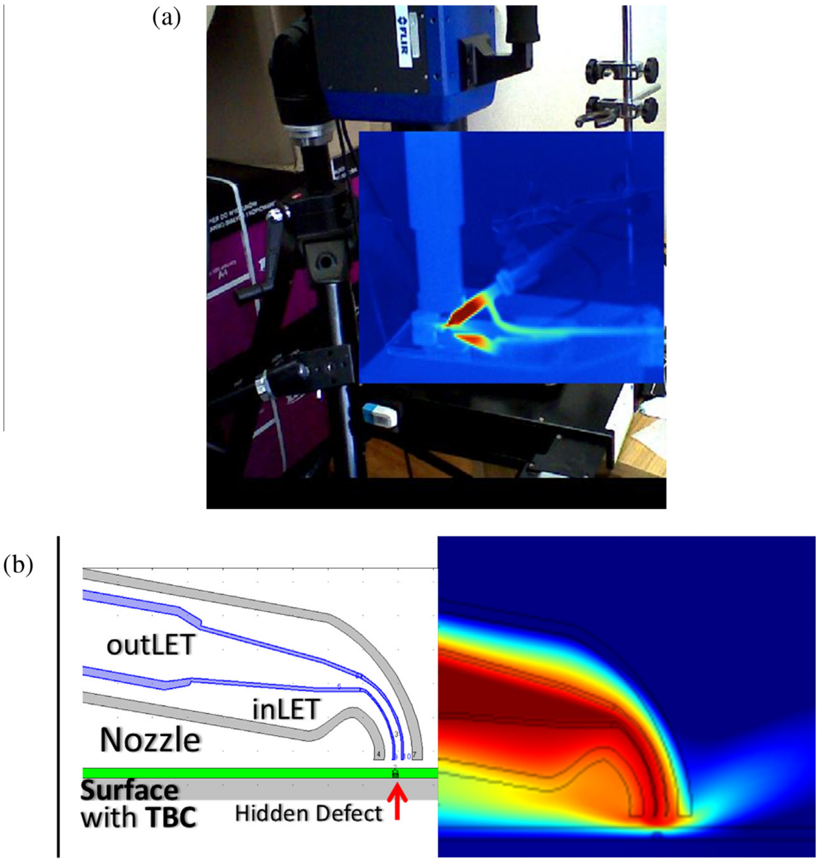

Fig. 1. (a) Scheme of the experiment; a hot air nozzle: hot air is getting out from the nozzle of 0.4 mm in diameter (blue color) and sucks up the air reflected from the investigated surface (white color); (b) Nozzle scheme.