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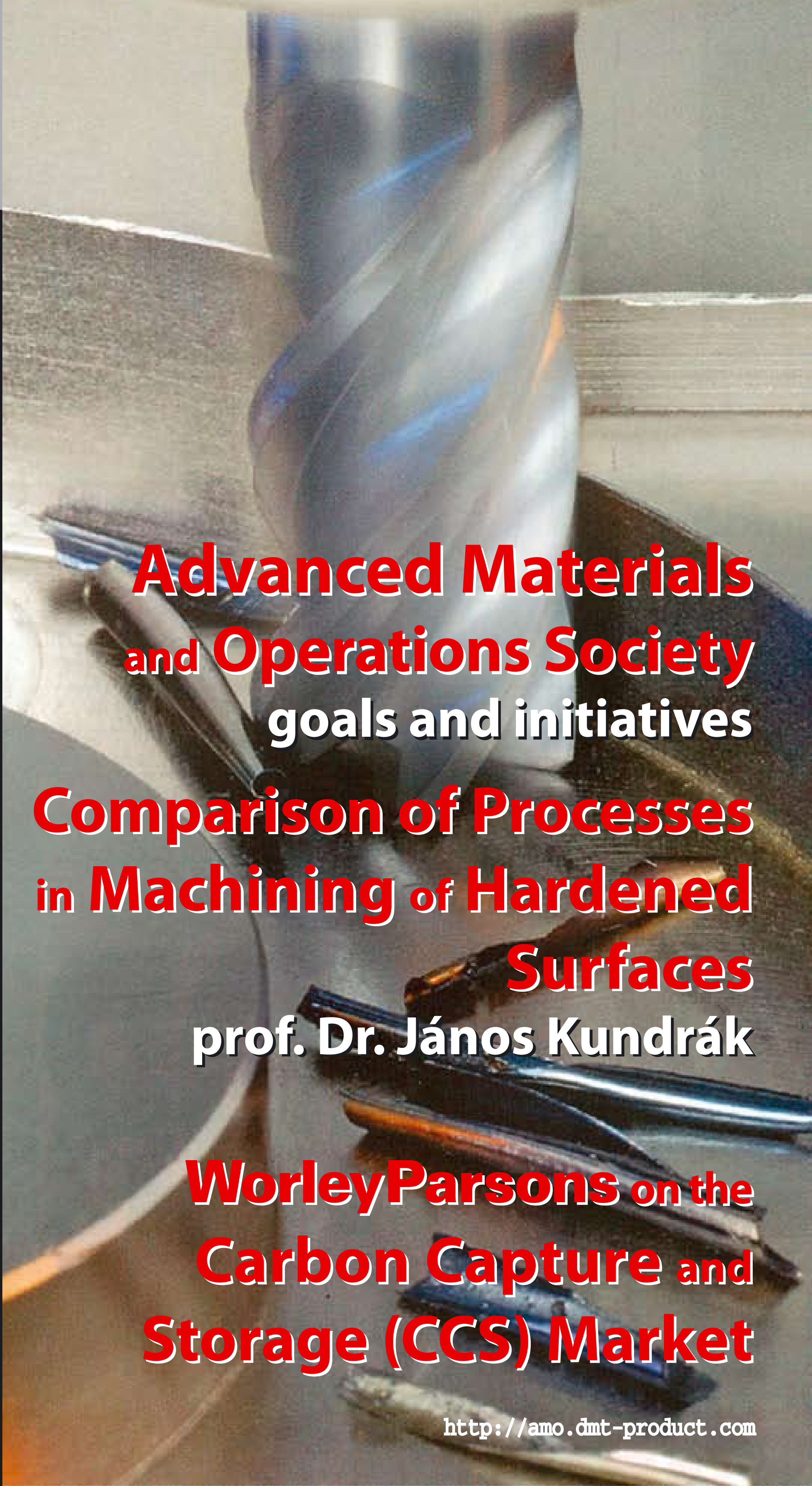

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Identification of Damage in Materials using Infrared Thermography

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Resume: The article will present an industrial application of infrared thermography (IRT) based on measurement of a very small change of temperature. which consist in a pulse uniform illumination of the surface of the studied specimen, followed y the analysis of its InfraRed (IR) emission as a function of time. This paper is devoted to the improvements brought to this analysis and which allows to strongly decreasing the effects of the lateral heat diffusion (3-D effects). As a consequence, the method leads to a high accuracy as regards the identified in-depth position of the defects, and to a better identified defect shape. The advantages of this new inversion will be assessed, by performing it on artificial and natural impact defects present in composite materials. A new inversion technique, using an early detection of the contrast, is presented to demonstrate how it recovers the depth of the defects with accuracy and partially removes the effects produced by the lateral heat diffusion.

Key words: thermography, infrarednondestructive testing, materials identifications

1. Introduction

Infrared thermography (IRT) is a non-destructive evaluation (NDE) technique that characterizes the properties of a material by monitoring its response to thermal loading. For IRT images to contain the desired temperature data, it is important to distinguish between the radiation emitted from an object (which is related to its temperature) and radiation that is reflected off of the object from other sources [1].

The problem of guaranteeing reliable and effcient safety checks has received great attention in recent years in many industrial contexts: quality controls and maintenance operations have to be reliable but also have to be performed at low cost in order to meet frequent schedules.

Among the recently emerging NDE methods, it is probably the less intrusive one since it really needs no contact at all with the tested structure providing a full field image of temperature.

The fundamental concept behind using IR thermography as a non-destructive evaluation technique is that sound and unsound materials have different thermal conductivity properties. If a constant heat flux is applied to the surface of a uniform homogeneous material, the increase in temperature on the surface of the object should be uniform. If, however, the material is non-homogeneous, the temperature along the surface will vary.

Transient thermography uses the thermal gradient variation to inspect the internal properties of the investigated area. The materials are heated by an external source (lamps) and the resulting thermal transient is recorded using an infrared camera.

The passive approach to IR thermography is simple and involves collecting temperature data from a scene without applying an external heat source. This method provides qualitative information about a situation and can be used to quickly determine if a problem exists.

Since IR thermography is only capable of monitoring the surface temperature of an object, the technique is usually limited to situations where defects are located near the surface. As defect depth increases and defect size decreases, assessment becomes more difficult. Active IR involves more elaborate test setups than are encountered in passive thermography. The required minimum resolvable temperature difference of IR camera equipment is smaller and heating of the specimen surface must be carefully controlled. As a result, most applications of active IR thermography are performed in a laboratory or well controlled manufacturing environment.

Infrared thermography is based on the principle that subsurface anomalies in a material result in localized differences in surface temperature caused by different rates of heat transfer at the detect zones [2]. Thermography senses the emission of thermal radiation from the material surface, and produces a visual image from this thermal signal which can be related to the size of an internal defect.

A new inversion technique, using an early detection of the contrast, is presented to demonstrate how it recovers the depth of the defects with accuracy and partially removes the effects produced by the lateral heat diffusion.

2. Experimental set-up

The set-up used in the experiments described in this paper, corresponds to the front surface configuration, i.e. illumination and detection on the same surface. The pulsed sources available in our investigation can be either pulse or continuous heater, the pulse being achieved, in that case, by the opening/closing of mechanical shutters. An infrared camera FLIR P640 in sequence regime allows to obtain a spatial resolution of 50μm with the close-up micro-objective used for these experiments.

Fig. 1 shows a schematic illustration of the experimental apparatus for the temperature variation detection using active IRT.

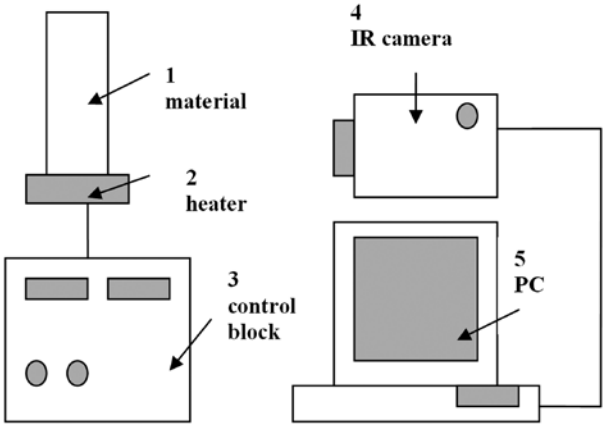

Figure 1: D schematic illustration of the experimental apparatus for the temperature variation detection

The detection and the characterization of the resistive subsurface defects is achieved by seeking local emergence of thermal contrast after the pulse illumination, i.e. an increase of the local temperature above the defect with respect to the temperature in a sound region, (figure 2a).

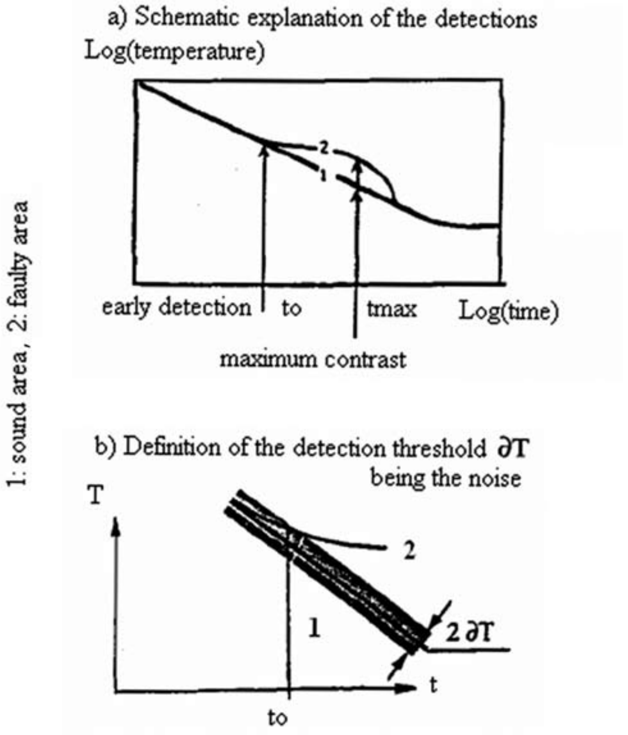

Figure 2: Thermograms of sound and faulty areas

Generally, the depth and the resistance of the defect are deduced from the value and the time of the maximum contrast [3]. This search is made pixel by pixel and finally leads to two synthetic images, respectively for the local depths and resistances of the subsurface defects. An alternative consists in the detection of the time corresponding to half the development of the contrast. The deeper the defects are, the longer these characteristic times are, with an important lateral heat diffusion as a consequence. Under these conditions, the inversion provides an underestimation of both the depths and the thermal resistances of the detected defects.

In order to reduce the importance of the lateral diffusion effects, it is obvious that the detection of the thermal contrast should be achieved as early as possible. The threshold of detection is depending upon the noise level of the experiment, $\partial T(t)$. Let us express this threshold, *DT*, as a percentage of the temperature above a sound region $T_{ref}(t)$ (more precisely the increase of temperature with respect to the temperature before the illumination):

$$DT = K \frac{\partial T(t)}{T_{ref}(t)} \quad \textbf{(1)}$$

This threshold is chosen very low, just a bit larger than noise, for instance 1, 3, or 5%, by adjusting the factor *K* (*K*>l). For a given threshold, the time variation of the temperature of each pixel, *T(t)*, is then analysed and compared with the time variation of the temperature of an area known to be sound, $T_{ref}(t)$. If *T(t)* exceeds $T_{ref}(t)$ by more than $(DT_{*}Tref(t))$, the pixel is recognized to be above a faulty area (figure 2b).

This early detection is insensitive to the thermal resistance, since it has been demonstrated [3] that, for a given depth, the relative thermal contrasts related to different resistances are merged at short times (see figure 2). Thus a very simple relation was found, between the depth z of the defect, the threshold *DT*, the time to at which the threshold is reached and the thermal diffusivity *k* of the material:

$$z = \sqrt{t_0 k Ln\left(\frac{z}{DT}\right)} \qquad \textbf{(2)}$$

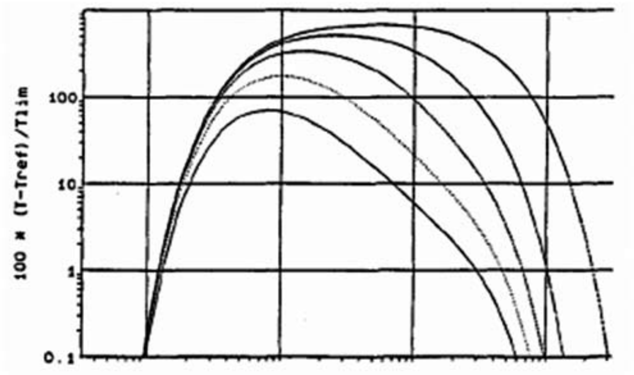

Figure 3: Relative thermal constrast vs time (thermal resistances: 0.32 to 32 times the resistance of the first layer)

After this depth identification based on the early detection, the resistance is deduced from the maximum or half-maximum contrast.

3. Results

In order to demonstrate the good in-depth localisation of deep defects using the early detection, two artificial samples (called respectively 1 and 2) were prepared (figure 4):

- the sample 1 is a 5.25 mm thick plate of carbon epoxy containing small implants of teflon (thickness 80 µm) at depths varying from 0.4 mm to 4 mm.
- the sample 2 is a disc of black plexiglas in the center of which concentric cavities of different depths were machined.

Figure 5 shows the in-depth thermography image deduced from the early detection inversion and a comparison between the results of the half-maximum contrast and early detection methods of inversion in which the depths, identified in the centers of the defects, are plotted as functions of the true depths.

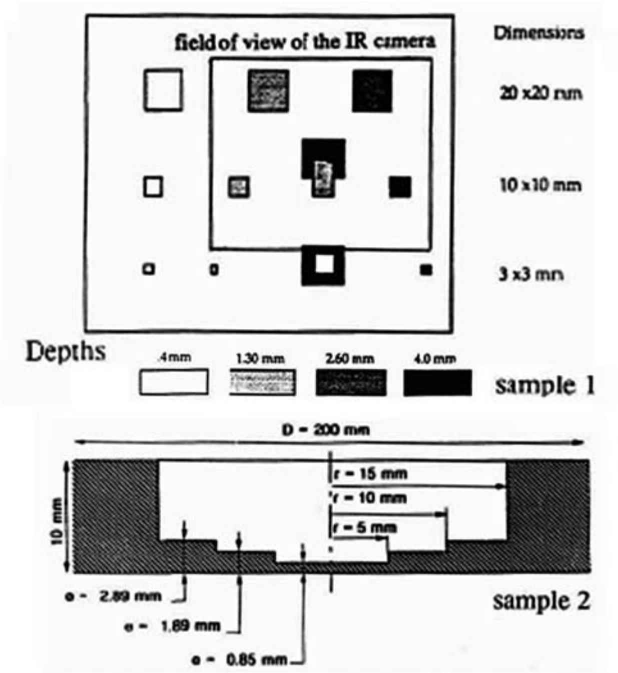

Figure.4: Artificial samples

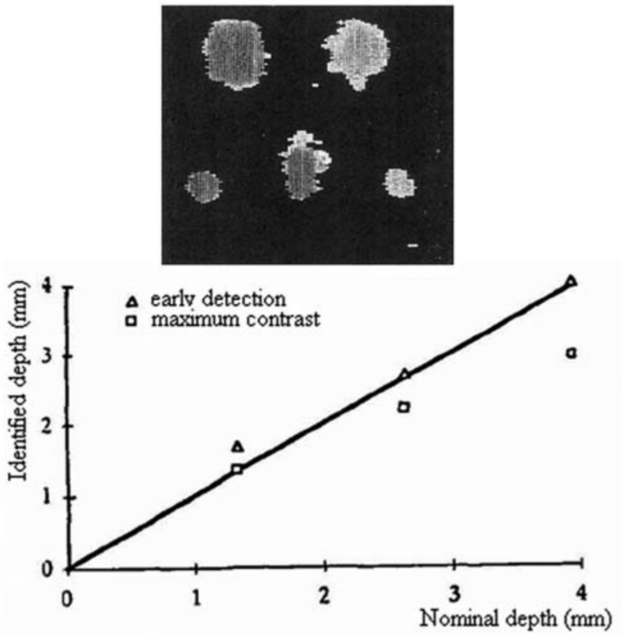

Figure 5: IRT in-depth inversion for sample 1

The improvements brought by the early detection are even more obvious in figure 6 obtained with the sample 2:

- the profiles of the concentric cavities are much more precise in the case of the early detection provided that the threshold is kept above the noise level (a deterioration of the results is observed when the threshold is taken smaller than 3%
- the location depth of the first interface is very precisely determined.

The last example is a piece of a composite airfoil impacted in several points with known impulses. In carbon epoxy composites, the defects produced by impacts are quite dangerous because, generally, they do not let any visible traces at the surface, even when large multidelaminations are present in the thickness of the material [3]. The quantitative NDT problem to be solved here, is more the evaluation as accurately as possible of the global extension of the internal damages than the exact reconstruction of the shape of each delamination.

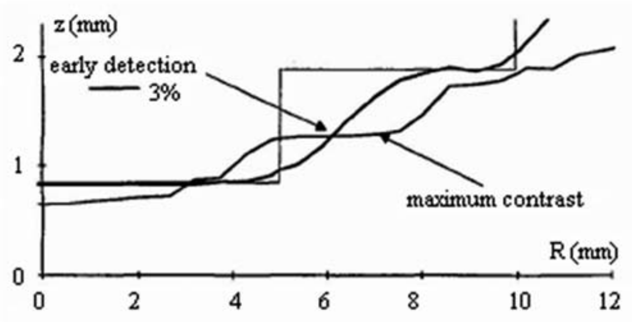

Figure 6: In-depth inversions by early detection and maximum contarst with sample 2.

The comparison between the thermography and ultrasonics in-depth images showed that the thermography early detection method was able to restore quantitatively the extension of this damaged area within an incertainty (by default) of 5%. This very good result proves that the lateral heat diffusion effect is well reduced by the inversion procedure. Figure 7 presents the projections of the delaminated volume determined from two thermography experiments, one on the impacted face, one on the opposite face.

4. Conclusion

The IRT method can be used to retrieve rapidly and accurately depths and thermal resistances of defects provided that a good inversion procedure is chosen. The early contrast method for depth combined with the half-maximum contrast method for resistance, presents the advantage to strongly decreasing the lateral diffusion effects. In the special case of the quantitative characterization of impact damages in composites, the IRT method appears very competitive with ultrasonics since it provides, in a much shorter time, realistic values for the damage extension .

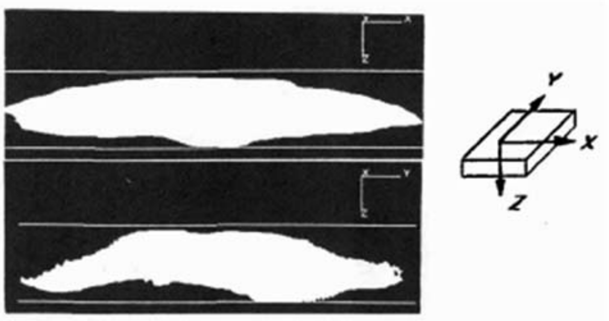

Figure 7:. Projections of an early detection IRT reconstruction of an impact defect in a composite

Acknowledgment

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