ACTIVE THERMOGRAPHY FOR MATERIALS NON-DESTRUCTIVE TESTING

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Abstract

Active thermography is an advanced experimental procedure, which uses a thermography measurement of a tested material thermal response after its external excitation. This principle can be used also for non-contact infra-red non-destructive testing (IRNDT) of materials. The IRNDT method is based on an excitation of a tested material by an external source, which bring some energy to the material. Halogen lamps, flash-lamps, ultrasound generator or other source can be used as the excitation source for IR-NDT. The excitation causes a tested material thermal response, which is measured by an infra-red camera. It is possible to obtain information about the tested material surface and sub-surface defects or material inhomogeneities by using a suitable combination of excitation source, excitation procedure, infra-red camera and evaluation method. Active thermography and IR-NDT methods are introduced in this contribution. Different IRNDT configurations and their possibilities and limitations are described. The usage of the IRNDT for specific applications is shown in the contribution.

Keywords: Active thermography, material defects, non-destructive testing, flash

1. INTRODUCTION

Infrared thermography is an analytical technique, which is based on detection of objects radiation in the infra-red range [1]. This radiation is, according to the black body radiation law, emitted by all objects, which temperature is above the absolute zero. A device, which detects the infra-red radiation and forms an image using that radiation, is generally called an infra-red camera (IR camera) or thermographic camera. Images produced by the infra-red camera correspond to thermal radiation intensity field impacting the detector and they are generally called thermograms. The amount of the radiation emitted by objects is related to their temperature. Thus, the thermograms are images of the objects surface temperature fields and the infra-red thermography [2] is mostly used for the non-contact measurement of spatial and time distribution of the surface temperature field.

The infra-red thermography has a lot of advantages: it does not influence a measured object (non-contact method); it records a temperature field; moving or rotating objects can be measured, very high temperatures can be measured etc. However, the radiation detected by the IR camera contains not only information about a measured object temperature. It is influenced by the heat transfer inside the object, its surface thermo-optical properties [3] (emissivity, transmissivity and reflectivity), ambient temperature or atmosphere properties (temperature, transmissivity). These relationships should be taken into account by IR camera measurement and, in fact, it can make an accurate thermographic temperature measurement very complicated [4]. It is the main disadvantage of the IR thermography.

The thermography can be classified as *qualitative* or *quantitative* and *passive* or *active*. The *qualitative thermography* evaluates the temperature differences or IR radiation contrasts between the individual components, between different positions on a component or against a background. This contrast can be caused by temperature differences, local heat concentrators but also by thermo-optical properties differences. Although it is maybe the simplest thermography application, it has many very important applications [4] - for example heat leaks diagnostics, electrical components inspections, surveillance of people or medical applications. The goal of quantitative thermography is to evaluate the accurate numerical value of an object temperature. The measured object optical properties should be known in this case or a special high-emissivity painting can be applied on measured surface. The quantitative thermography takes place if the knowledge of a temperature, exact temperature difference or temperature progress is required. It is useful in many technological applications [5], for example heat treatment control and identification of thermal-boundary conditions for numerical simulations.

Both the qualitative or quantitative approaches can be based on the passive or active thermography. The temperature contrast or the temperature changes are of natural origin in the case of *passive thermography*. By contrast, the external source and an excitation of analyzed objects are used in cases of *active thermography*. The excitation causes a temperature contrast connected with thermal properties differences or local heat sources concentration for example. These temperature or signal differences can be quantified also and used for some advanced evaluation. The active thermography is important technique in defects detection - material non-destructive testing.

2. ACTIVE THERMOGRAPHY AND NON-DESTRUCTIVE TESTING

Active thermography uses an external source for the analyzed object excitation. There are a lot of sources based on different principles: laser heating, flash lamps heating, halogen lamps heating, electric heating, ultrasound excitation, eddy current excitation, microwaves, hot air etc. These sources can heat up the object directly (halogen lamps for example) or can cause an object heating by internal thermo-physical processes (ultrasound for example). The excitation source can act continuously, by one pulse or by harmonic loading.

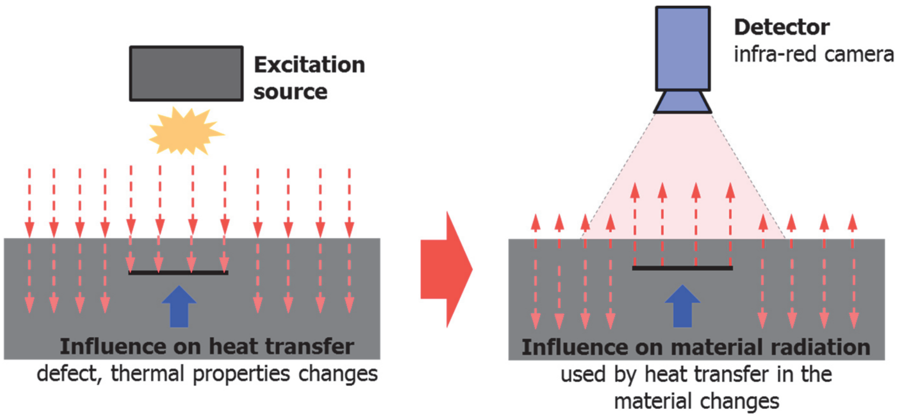

Fig. 1 Active thermography infra-red non-destructive testing (IRNDT) principle

The principle of the infra-red non-destructive testing and detection of materials defects IRNDT is based on changes of heat transfer conditions in the material due to defects or material inhomogeneities. The material surface can be exposed directly to a thermal excitation (hot air, flash lamps, halogen lamps etc.). The heat flux in the material is then affected by a presence of defects inside the material or on the exposed surface. This principle is illustrated in **Fig.1** in a reflective setup and it can be also used in a transmissive setup. The other approaches use excitation of the sample by ultrasound, mechanical, electrical or similar sources. The vibration, mechanical loading or electrical loading cause a local heat source in the material at positions of cracks or material inhomogeneities. The described thermal processes in the material result in both the cases in the surface radiation changes, which are detected by an IR camera.

The IR camera record can be evaluated by several methods based on used excitation technique, analyzed material properties, response intensity or evaluation requirements. In the simplest case the response is visible on the raw thermogram.

However, in the most cases the advanced evaluation methods should be used:

- **Pulse thermography**. The excitation on the measured object is applied for a very short time - heat pulse length about 1 ms and the object cooling progress is analyzed. Flash lamp or pulsed laser can be used as the excitation source for this method. The method is very fast and a great advantage is that it is possible to estimate depth of the defects. Disadvantage is detectability dependent on defects geometrical orientation and limited inspection area due to the energy of the excitation source, e.g. flash lamps. It is very good suited for thin layers and near surface defects.
- **Lock-In thermography**. Modulated-periodical excitation of the analyzed object is used. Amplitude and phase of the response signal is analyzed by different technics. The affordable sources like halogen lamps, electric excitation can be used for this method. It is applicable for large areas and the thermal load of the inspected sample is low. Disadvantages are longer measurement times and detectability dependent on defects geometrical orientation. The method is more suited for low-diffusivity parts. This method has a lot of modifications (Lock-In Ref, Lock-In Online) and it is probably one of the most important technics.
- **Transient Thermography**. The excitation is in principle similar to the pulse thermography, however, the excitation time is longer. The object is stimulated by a heat pulse and its time-thermal response is analyzed. It can be applicable for large areas and the measuring times are shorter than for the Lock-In thermography. An affordable heat source can be used (halogen lamps for example) and the defects depth can also be estimated. Disadvantage is detectability dependent on defects geometrical orientation. The method is more suited for low-diffusivity parts.
- **Vibro-thermography**. This method is based on stimulation of the measured object by modulated high-power ultrasound signal. The ultrasound object loading cause a local heat source occurrence at positions of defects that is detectable by the object thermal response time progress measurement. It is a dark-field method - only the defects are displayed. Advantages are high-depth range and defects geometrical orientation independent detectability. Disadvantage is high load the object at the position, where the ultrasound energy is applied. It is good suited for crack detection. The Lock-In evaluation can be used if the ultrasound signal is periodically modulated or the transient/pulse evaluation can be used if the pulsed high power ultrasound energy is applied.
- **Thermal stress analysis**. It is a special case of component indirect-thermal excitation. The inspected object is periodically stimulated by mechanical energy and thus internally heated due to the thermo-elastic or thermo-plastic effects. The stress concentrators occur at the defects positions and cause a local heating at these positions. The defects are determined by the measurement of the component thermal response measured by the IR camera. This method is good suited for cracks and other stress concentrators detection or fatigue properties diagnostics.

Different excitation sources can be used and combined with different evaluation methods for specific applications based on inspected material properties, requirements on measuring time, size of inspected area etc. Based on requirement both high-sensitivity and high-speed cooled cameras or un-cooled bolometric cameras are applicable. As the IRNDT systems are modular in most cases, a customized configuration for a universal high-flexibility scientific measurement system, for a single purpose production integrated systems or for a mobile inspection systems can be designed. The IRNDT is used in many scientific or industrial applications, for example for solar cells inspection, aircraft components inspection, wind turbine blades inspection etc. More about the usage of infra-red analysis for non-destructive testing can be found for example in [5], [6] or [7].

3. PULSE THERMOGRAPHY APPLICATION EXAMPLES

IRNDT Pulse thermography is the non-destructive testing method based on pulse excitation of the inspected object. Some applications and result examples of IRNDT Pulse analyses are shown in this section. The high-energy flash lamp is used as the excitation source. The maximum pulse energy is 6 kJ and the minimum flash time is 3 ms. The Pulse-phase, e-model or Root model offered by the AT software are used for the evaluation.

3.1 Laser treated stainless steel surface inspection

Laser marking of stainless steel surface can influence its corrosion properties. If the laser processing parameters are improper the corrosion resistance of the laser marked area can be significantly reduced. It is supposed that the surface local heating during the laser process has a crucial impact on its corrosion properties deterioration. The local heating also influences possible surface layer phase changes or an oxidic layer growth on the surface. A thickness of such oxidic layer is an indicator of possible thermal affection of the material and thus also an indicator of possible corrosion properties degradation.

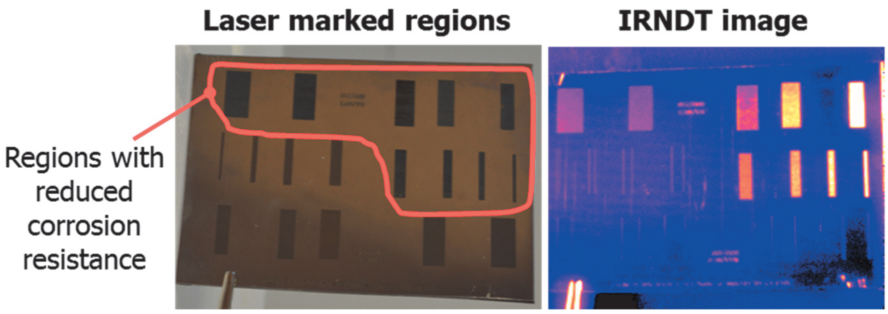

Fig. 2 Stainless steel samples with laser marked areas and IRNDT image with the evident areas, which corrosion resistance was reduced

The experiments showed that the phase changes and oxidization intensity can be detected by XRD diffraction analysis. However, the IRNDT Flash-Pulse analysis is capable to detect a very thin oxide layer. Laser marked areas using different processing parameters were made on a stainless steel sample. The IRNDT inspection showed in fig.2 indicated clear differences between the laser marked areas with good and reduced corrosion resistance. The reduced corrosion resistance areas are detected by the IRNDT, thanks layer of oxides, which occur during the laser marking process if the processing parameters are not suitable. The results were verified by corrosion tests.

3.2 Laser welded plastic part inspection

Laser welding of plastics is the very progressive joining technology, which is fast, efficient and reliable. It is based on joining of two plastics materials with different transmissive properties in the used laser wavelength. Similarly as in the case of other joining technologies, the welding process parameters and quality of the welds should be analyzed during the welding parameters initiation setup and continuously during a production process. Metallographic analysis of the welds cross-section or technological tests can be performed. However, these tests are slow and time consuming and therefore not suitable for a routine control.

Example of IRNDT Flash-Pulse analysis results are shown in **Fig. 3**. The plastic component consists of two parts joined by a laser welding technology. The weld-line is clearly visible on the IRNDT evaluation in the figure. Examples of evaluation results of a component with interrupted weld (A, B) and with properly done continuous weld are presented in the **Fig. 3**.

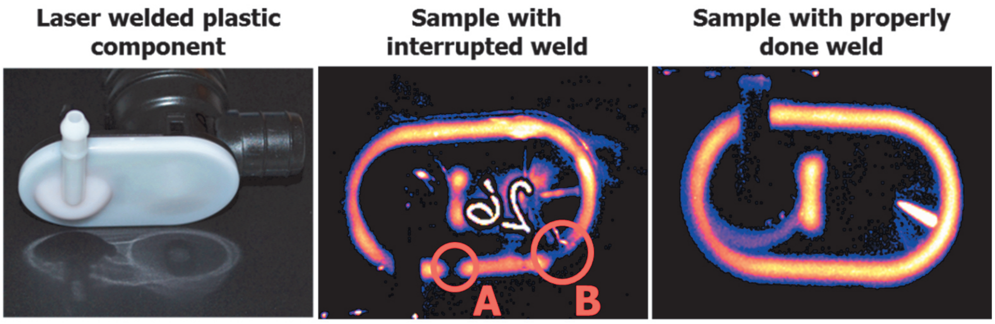

Fig. 3 IRNDT inspection of welded plastic component

3.3 Carbon-epoxy demonstration sample inspection

The carbide/epoxy test sample was prepared for IRNDT Flash-Pulse method depth resolution capabilities. The sample is a 150x120 mm and 5 mm thick plate with a 6 holes of different depth from one side that simulate defects in the material. The remaining material between the hole bottom and the opposite sample surface is from 1.3 to 3.8 mm (defects depth). The IRNDT inspection was performed at the holes-free surface

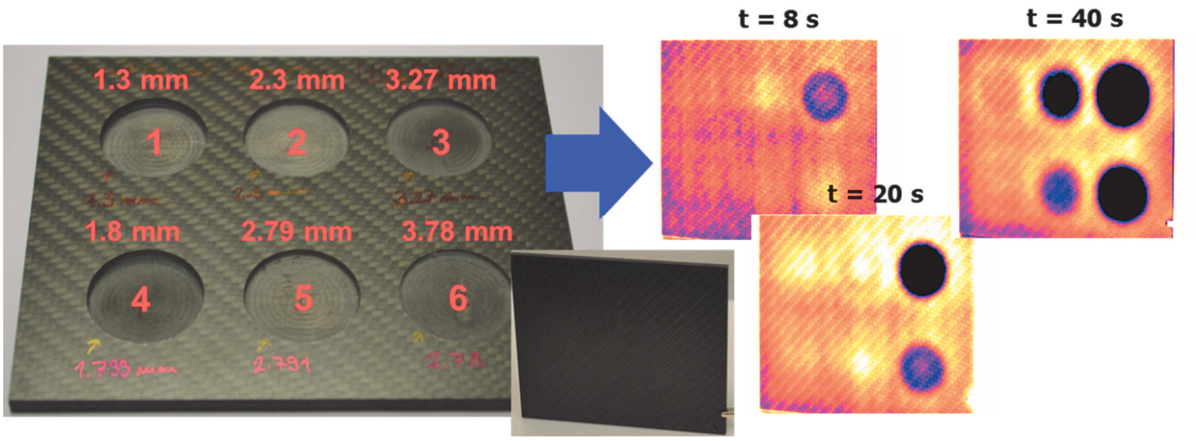

Fig. 4 IRNDT inspection of carbon-epoxy demonstration sample

The Flash-Pulse analysis results are presented in **Fig. 4**. The analysis show that "defects" up to depth 2.3 mm under the surface are very clear and "defects" up to depth about 3 mm under the surface can be detected in the carbon-epoxy material with the thermal diffusivity about 0.2 mm^2/s. As the defects are detectable at different evaluation times, the defects depths can be also estimated.

CONCLUSIONS

The IRNDT technique is the advanced method for material defects determination. It is a non-contact, non-destructive and very fast inspection method, which allows also analysis of new materials and usage in novel fabrication and processing technologies. The application examples showed some capabilities of the Flash-Pulse IRNDT. The usage possibilities for thin surface layers analysis, plastics welds quality analysis or the possibilities of defects depth estimation were presented. However, efficiency of this method can be different for different materials and experimental conditions.

The IRNDT systems are often modular that allows the choice of a suitable measurement configuration for individual applications. It is possible to design a wide range of configurations from single-purpose processingline integrated systems to high-end scientific systems using high-speed infra-red cameras. The disadvantage of this method is a necessity of a homogeneous excitation of an analyzed region, possible occurrence of parasitic signals due to the surface optical properties inhomogeneities or limited inspection depth, which is dependent on material type. However, the method features together with falling prices of both high-end and industrial IR cameras make this analysis technique very flexible and very useful in many particular cases.

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