DETECTION OF CRACKS BY INFRARED NONDESTRUCTIVE TESTING METHODS

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Abstract

Infrared nondestructive testing (IRNDT) is an active thermography method for inspection of material-surface inhomogeneities or discontinuities. It is based on an excitation of an inspected sample and a detection of its thermal response by thermographic methods. The IRNDT is commonly used for an inspection of delaminations. However, it is also applicable for surface and subsurface cracks detection, which is the focus of this contribution. Principles of IRNDT methods are introduced in this contribution. Flash-illumination, ultrasonic-loading, laser-heating and mechanical-loading excitation methods, which are mostly used for cracks detection, are described. Examples of results of an IRNDT inspection of cracks by different approaches are presented.

Keywords: Infrared nondestructive testing, active thermography, IRNDT, cracks

1. INTRODUCTION

Active thermography [1] is a method of infrared non-destructive testing (IRNDT). IRNDT is used for inspection of discontinuities (defects, inhomogeneities), which is based on an external excitation of an inspected sample and a measurement of its thermal response. The excitation induces thermal processes, which are influenced by discontinuities or inhomogeneities in the sample (possible defects). The thermal response can reflect an influence of the discontinuities, which can thus be identified by a thermographic measurement of the thermal response. The response is recorded by a thermographic camera and results of the inspection are contrast areas, which represent indications of the discontinuities. The indications are in most cases not visible or not contrasting enough by a pure thermographic measurement, thus, special methods are used to accentuate the inspection results. The very commonly used methods are, for example, lock-in or pulse-phase thermography, which comparison was published in [2].

Infrared non-destructive testing is a novel method in comparison with traditional NDT methods such as penetration, ultrasound or radiographic methods. However, it is the very flexible method, which allows modification of an experimental configuration to fulfil requirements of many applications. A number of measurement configurations has been developed, which used different excitation sources (flash lamps, halogen lamps, ultrasound etc.), excitation methods (pulse, periodical, step etc.) or evaluation procedures (pulse-phase, lock-in etc.). A methods overview of thermographic temperature measurements and IRNDT can be found, e.g., in [1] and [3].

IRNDT has some advantages - it is a non-destructive method, a response measurement is non-contact, there are in many cases short inspection times and no harmful radiation or chemical substances are used. It is traditionally well suited for an inspection of composites delaminations, voids, bubbles [4] or impact damages [5]. These methods have found a use for example in an inspection of aircraft components or wind turbine blades. However, a lot of IRNDT approaches were developed for testing of other materials in a wide range of thermal and optical properties, including for example an inspection of transparent materials, metal sheets spot welded joints, coatings, solar cells, inspection in food industry and many others.

Cracks are one of the very important material defects, which can play a crucial role in a usability, lifetime or usage safety for many components. Some advantages of IRNDT could also be used in cracks inspection. Recent research showed that it is possible to detect surface or subsurface cracks by thermographic methods at mechanical loading [6] or, for example, by using of high intensity light [7], laser [8] or ultrasound [9] excitation source. The goal of this contribution is to make an overview of methods and approaches of IRNDT for cracks detection. The methods are introduced including inspection examples in the section 2. IRNDT INSPECTION OF CRACKS. A summary, conclusions and discussion about advantages and disadvantages of IRNDT methods for cracks inspection is in the section 3. CONCLUSIONS.

2. IRNDT INSPECTION OF CRACKS

IRNDT methods can be sorted into two main groups based on excitation method principles: external excitation and internal excitation. External excitation is probably more traditional in IRNDT methods. It is based on a tested sample external heating, which is made by an external heat source. The most common heat excitation sources are based on radiation heating (sometimes called illumination methods, e.g. flash or halogen lamps), however, contact or convection sources can also be used. These methods are mostly developed for a detection of discontinuities (defects), which are parallel to an inspected surface, for example delaminations or voids.

However, the illumination methods can be also used for an inspection of discontinuities, which are mostly perpendicular to the inspected surface, such as, for example, cracks. To make such an inspection possible, a heat flux in the tested material should be directed perpendicularly to a crack. This can be done in two ways: (A) using a suitable geometrical configuration of a measurement set-up or (B) using a spatially defined heat source. A standard excitation source can be used in the case (A). However, a geometry of a tested sample has to allow a directionally defined excitation in such a way that an induced heat flux in the sample is not parallel with the crack. It is possible, for example, at an inspection of cracks in welds, as it is described in [7]. In this case, the weld protrudes above a basic material surface and a weld crack is excited by a flash lamp at a large angle perpendicular to the surface. A similar effect can be achieved in the case of a tube-shape sample, where there are cracks perpendicular to a tube surface in its longitudinal direction and a flash lamp excitation is applied from the direction perpendicular to the tube at a large angle perpendicular to the surface at a position of the crack (tangential direction). An example of a result of a flash-pulse inspection of a tube with a crack in longitudinal direction is shown in **Figure 1c**) (the crack is marked by an arrow). The measurement is made by a standard flash-pulse procedure and the results are evaluated by a pulse-phase method. A photo of the sample surface (the crack is not evident) and a standard magnetic-fluorescence inspection result are shown in **Figures 1a**) and **b**), respectively, for a comparison.

A configuration (B) of illumination IRNDT methods for cracks detection is based on spatially defined heating source. It is typically, for example, a laser source, which makes a laser spot of a defined shape (point, line, pattern, etc.) on an inspected surface. Such an excitation leads to a heat transfer perpendicularly to the surface under the spot area, but also on the surface - in the direction out of the laser spot. The crack then acts as a thermal barrier causing a disturbance of a temperature field, which can be detected by an analysis of a thermographic camera record. Such a measurement configuration is shown for example in [8].

The presented examples showed that the illumination IRNDT methods are applicable for cracks inspection if a heat transfer in a tested material caused by an excitation is (at least partly) directed perpendicularly to the crack. The second necessary condition is that the crack has to make a thermal barrier. This means in most cases that the crack should be opened - some gap should be between the walls of the crack. This state brings another option how to use a laser beam excitation source for the crack detection, as it is described in [7]. The opened cracks are places with an increased absorptivity during a high-energy IR irradiation. It is manifested as an indication (a hot-spot) at a thermographic camera record or its processing results.

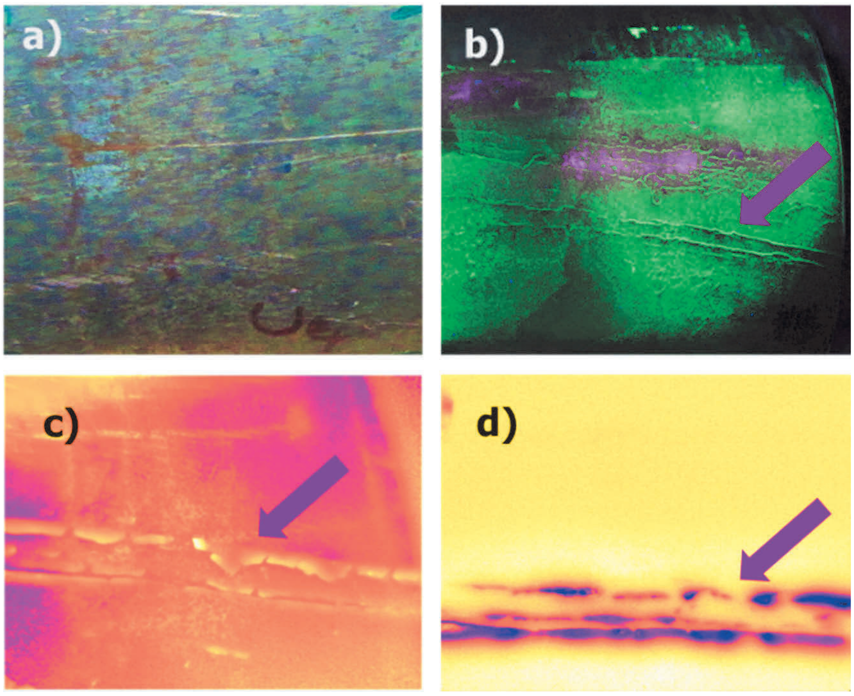

Figure 1 Example of a crack thermographic inspection results by different approaches (the crack is marked by an arrow): a) photo of an original surface (the crack is not evident), b) a standard magnetic-fluorescence test, c) flash-pulse thermography, d) vibrothermography (ultrasound excitation IRNDT). Results obtained by inspections made in laboratories of University of West Bohemia, New Technologies - Research Centre.

Internal excitation is the second possibility how to detect cracks by thermographic methods. Internal excitation is based on introducing into a tested sample energy, which is transformed into heat on discontinuities. Traditionally used excitation sources for cracks inspection in specific application are ultrasonic (vibrothermography), mechanical and electrical excitation.

The vibrothermography [9][10] is a method, which was developed mostly for cracks inspection. It is mostly based on an excitation of a tested sample by a contact-type ultrasonic converter. The vibrations (mechanical waves) in the sample are transformed to heat at closed cracks due to a friction forces. An example of a result of an ultrasonic thermography inspection of the tube with the crack is shown in **Figure 1d)**. The measurement was performed and evaluated in terms of lock-in method. The crack is marked by an arrow, the inspection results of the same piece made by the standard magnetic fluorescence test and the above presented flash-pulse thermography inspection are in the **Figures 1b)** and **c)**, respectively. The vibrothermography is a defect selective “dark-field” method [11]. Defects indications could therefore be very expressive, as it is shown in **Figure 1d)**. The other advantage of this method is that it is insensitive to crack direction, in contrast to the illumination methods. The main disadvantages of this method is a contact based excitation and a complicated inspection parameters set-up.

Mechanical loading and electrical excitation belong also to internal excitation methods. These method are however usable only in some special cases. Strain induced in the material by the mechanical loading is in connection with tested sample temperature changes due to thermo-elastic and thermo-plastic effects. The method is based on enhanced heat generation at locations under a plastic deformation, which can occur, for example, at crack tips. It is not a typical non-destructive testing method. However, this approach can be used for thermographic inspection of cracks at laboratory and technological testing or in terms of a diagnostic of cyclically loaded technological parts. The electrical testing is mostly used in special applications as for example solar cells testing [11]. The method is based on electrical excitation of a cell. The excitation causes a temperature rise, which is higher at defects positions (shunts, cracks) and can be detected by a thermographic analysis [12]. Both mechanical and electrical excitation methods use mostly a cyclic excitation procedure and, as well as the vibrothermography, belong to dark-field methods (in solar cells applications often referred as DLIT - dark lock-in thermography). Even if a usability of the methods is limited to the specific applications, the methods can be very effective in these applications.

3. CONCLUSIONS

Five approaches of thermographic inspection of cracks were introduced in this contribution. It was shown, that flash-pulse, laser, ultrasonic, mechanical and electrical excitation methods are usable for cracks detection. Flash-pulse or similar illumination-based excitation methods are fast and non-contact. However, an orientation of cracks has a strong influence on their detectability. These methods can thus be used for an inspection of opened cracks, if a suitable geometrical configuration of the experiment is possible. Laser excitation belongs to the illumination-based group methods. It allows a selective (position-defined) excitation of an inspected part. The main disadvantages of these methods are higher costs of measurement equipment, lower flexibility and more complicated measurement set-up connected with laser operation safety (eye protection etc.) issues. Ultrasonic excitation is suitable for closed cracks inspection. Advantages are that an orientation of a crack does not influence its detectability and it is also usable for geometrically complicated samples. Main disadvantages are that the ultrasound transducer should be in a contact with the measured and complicated set-up of excitation parameters. Mechanical excitation principally does not belong to non-destructive testing. However, the thermographic methods can be used for cracks detection and inspection of their evaluation at laboratory tests of components, technological testing or within an on-process inspection of cyclically loaded components. Electrical excitation is, in connection with cracks inspection, a specific method, which is typically used for solar cells testing.

As it was shown in this contribution, the IRNDT can be used for cracks detection. IRNDT brings some benefits compared to classic NDT methods, for example, a short measurement time or non-contact detection. However, there are also some limitations of these methods, which were summarized in this contribution.

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