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Diagnostic methods of detecting defects within the material with the use of active infrared thermovision

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ABSTRACT

Article presents the methods of detecting defects within material with the use of active infrared thermovision. During the study ABS and PVC samples were used inside which internal structure defects and defects of glue conjunction between components were modeled. During combining composite materials with the use of glue joints, there is a problem with homogenous distribution of the glue layer on the surface of an element, which results in the creation of defects in joint structure and the decline of active surface of adhesion forces on the combined materials. It is then necessary to control the quality of the conjunction between the glued surfaces. The use of non-contact diagnostic methods allows to analyze a larger surface which conditions in more efficient quality control process.
In the study, external heat excitation was used – optical excitation with periodic variable signal (LockIn method) and unit step excitation (Pulse method). The methods of analysis of the obtained thermograms are presented.

1. INTRODUCTION

The increase of quality requirements of the finished products introduces the necessity of quality control of compositional elements conjunctions including glue joints, responsible parts, as well as internal material structure, cracks detection and layers delamination in compositional elements. The purpose of the control is to ensure the safety of use and failure-free of the product.

Classic control methods are based on ultrasonic diagnostics allowing spot checking of the material structure or glue joint and also requiring direct contact of a sample with the measured element. In case of sensitive surfaces it is undesirable. The introduction of optical diagnostic methods allows the quality control and defects detection in a non-contact way, faster and with a view of the entire measured surface [1, 2].

1.1. Research purpose

The purpose of the research was to compare the possibilities of non-contacting method of material defects detection, determine parameters excitation for a given group of materials influencing the quality of thermal imaging and mapping of geometric defects, diagnostic of glue joint between the combined materials and also presentation of possibilities of data analysis from the obtained thermal image.

The presented methods are based on active thermovision in infrared radiation, using optical excitation (periodically variable and impulsive). The study aimed to determine the area of the use of active thermal imaging in diagnostics and the possibilities of its application in the quality control process.

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2. THE METHODOLOGY OF RESEARCH

In the study the FLIR X6540sc thermal imaging camera and FLIR T620 were used with the FLIR ResearchIR MAX software and IrNdt compatible with the Automation Technology driver. Composite samples with the visible defects occurring in the glue joint of combined surfaces and in the internal structure of the material were examined (*Fig. 4, Fig. 8*). The methodology of research was based on the use of an active thermovision with the use of external heat excitation generated by FLASH lamp with the impulse to 6 kJ (Pulse method) (*Fig. 1*) and 2500W halogen lamp (LockIn method) with regulated amplitude and frequency signal (*Fig. 2*) [3, 4]. The test stand is shown in the figure (*Fig. 3*).

The Pulse method is one of the mostly used thermal stimulation method due to the ease of use and rapid control process (short time of the influence of heat wave). Short impulses with the low power are used with the materials of high heat conductance like metals. For the composite materials of low heat conductance the impulses of high power, longer duration or several following excitation impulses are used. The advantage of this method is the small influence of warming of examined material and elimination of the risk of damaging it. In the Pulse method the image is analyzed at the moment of cooling of examined element after the thermal excitation due to the saturation of the received thermal image at the moment of stimulation.

The LockIn method modulates the excitation signal in the periodically changed way (usually sinusoidal signal). The recorded sequence of images in the time of excitation allows to analyze the image using Fourier transforms (amplitude and phase) and the recorded images are characterized by a very good signal to noise ratio. This method is usually used to detect defects occurring in deeper parts of the material or for materials of lower heat conductivity (polymers).

The objects of the research were two polymers made of ABS and PVC materials. In the ABS plate (*Fig. 4*) defects in the shape of cracks and holes at three depths to the examined surface were modeled. The ABS plate was made by 3D printing. The sample shown in the figure (*Fig. 8*) consists of two 2 mm thick PVC plates glued together with a polyurethane glue. The adhesive bonding layer did not exceed 1 mm. In order to simulate defects of the glued conjunction, the geometric shapes were made (in order to diagnose the presence of binder-material contact) and the binder was unequally distributed on the surface of elements (Fig 8b).

To the samples made of different materials, optic thermal excitation with the same parameters was used in order to compare both diagnostic methods.

The LockIn method used halogen lamp of sinusoidal excitation characteristics, a signal frequency of 0,5 Hz, amplitude of 0 to 100% of the lamp power and the time of heat wave influence of 20s.

For Pulse method the time of influence of the 20ms impulse of 5kJ energy was applied.

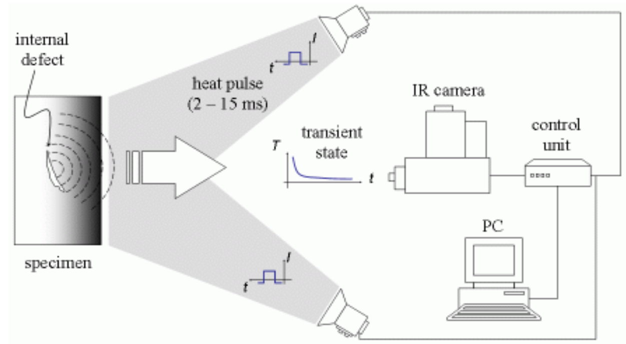

Fig. 1. Schematic view of thermal excitation – enforce Pulse[5]

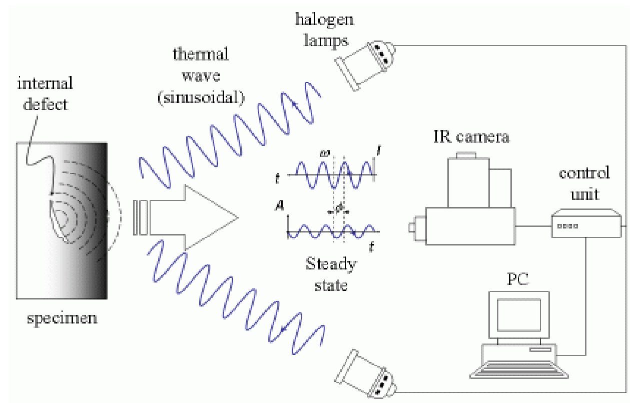

Fig. 2. Schematic view of thermal excitation – enforce LockIn[5]

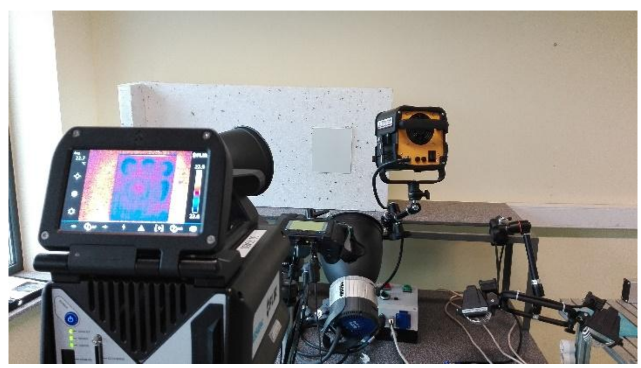

Fig. 3. The view of test stand – enforce optical

3. THE RESULTS ANALYSIS

The use of diagnostics method allowed the detection of defects within examined materials and defects of glue joints. The methods which use the active thermovision allow to diagnose large surfaces in a non-contact and fast way.

The quality of geometric mapping of the found defect decreases with the increase of the depth of its occurrence. The important aspect influencing the correctness of detection of material defects or glue joint is a proper choice of the right diagnostic method and excitation parameters for the type of material from which the examined model was made. The factor influencing the right choice of excitation is conductivity and heat capacity [6].

For the plate made of ABS material more proper type of stimulation was impulsive heat wave – Pulse method (*Fig. 5b*). The obtained thermal image was characterized with the lesser impact of the heat energy on the inside of the material, advantageous temperature distribution on the sample's surface which conditioned clearer thermal image. In case of using excitation of a periodic variable sinusoidal signal with a longer time of its impact on the examined surface, the obtained thermal image was characterized with less focus. The cause of this phenomenon was infiltration of the bigger amount of heat into the depth of material with less contrast between thermal areas visible on the surface (*Fig. 5a*).

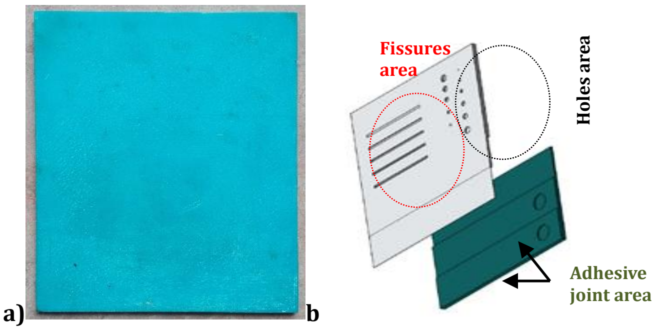

Fig. 4. The view of tested sample – defected area; material ABS: a) The real view of sample surface; b) area with defect (3D model)

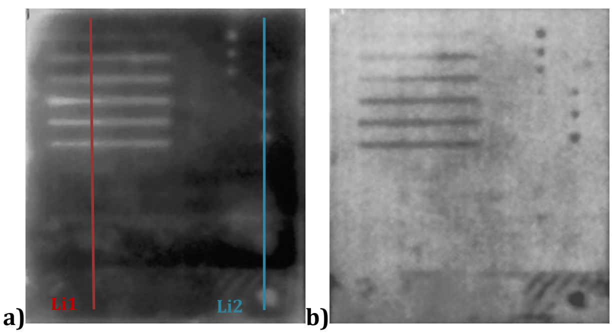

Fig. 5. The thermal image of measured sample: a) LockIn method ; b) Pulsemethod

Data from thermogram allowed to analyse the image in the form of temperature distribution profiles (*Fig. 6*).

By analysing the profile (temperature values in its length) the geometric measurements of defect can be determined, and knowing thermal properities of the object and the value of the stimulating signal, it can be determined at which depth the defect is. The graph shows two exemplary temperature distribution profiles placed on cracks and holes in the examined element. The increase of the temperature where the defects occur can be noticed, what should be interpreted as empty spaces in the structure of material (smaller material input condition shorter preheating time).

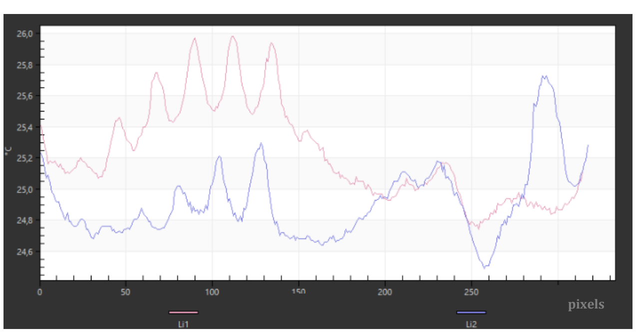

Fig. 6. Thermal profiles data of ABS sample

The thermal image gives also the possibility to 3D spatial imaging of temperature on the surface of the element (*Fig. 7*). This type of imaging allows for an overall analysis of the examined surface and the analysis of geometric features. Similarly as with the data obtained from the temperature distribution profiles in this case the local temperature increase in the area of empty spaces occurance can be noticed [7].

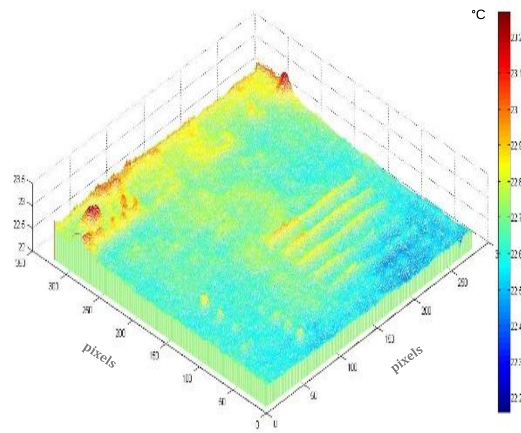

Fig. 7. Temperature distribution on the surface of the sample - defect depth detection - 3D view (ABS sample)

For a sample made of PVC material with the glue joint (materials with different thermal features) (*Fig. 8a, 8b*) more proper way of stimulation was LockIn method (*Fig. 9a*).The longer thermal stimulating wave impact and its periodic nature allowed the heat distribution to the inside of the sample, preheat its surface and glue joint which allowed to obtain better image contrast than for the Pulse method. The use of unit step stimulation (Pulse) in this case conditioned just the preheating of the surface of examined element on the minor depth (*Fig. 8b*) and thermal distribution did not sufficiently emblazon defects of the conjunction.

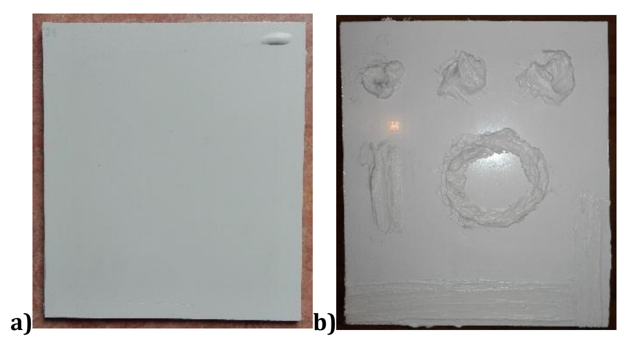

Fig. 8. The view of tested sample; PVCmaterial: a) The real view of the surface of the sample; b) the defect of glue joint

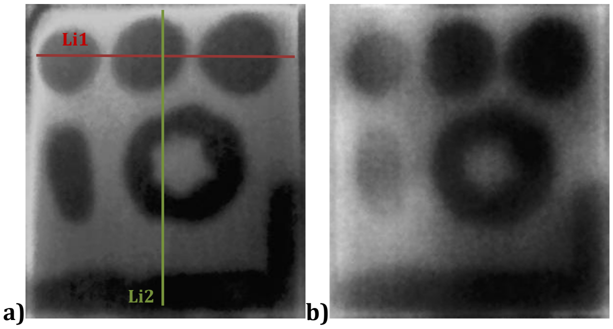

Fig. 9. The thermal image of measured sample:
a) LockIn method ; b) Pulse method

By analyzing the profile obtained from thermogram for the PVC plate the local occurrence of the area with lower temperature than the temperature of examined surface can be seen (*Fig. 10, 11*). These are the areas of glue joints occurrence. The local temperature drop determines the greater material share at the point of the occurrence of the joint (the longer time of prehearing of the area with the joint is needed than the time to preheat the homogenous flat plate).

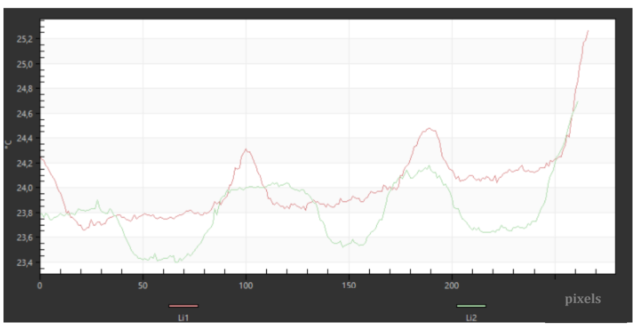

Fig. 10. The data obtained from thermal profiles (PVC sample)

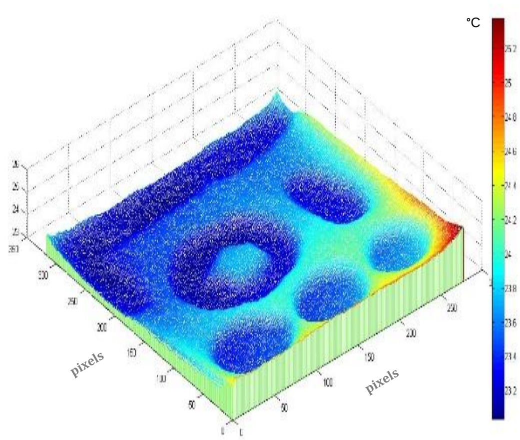

Fig. 11. Temperature distribution on the surface of the sample - defect depth detection - 3D view (PVC sample)

4. SUMMARY AND CONCLUSION

Based on the research it was found that the best of the proposed methods of thermal stimulation to detect and map defects located under the surface is obtained using the Pulse method. The defects of the glue joint (material other than the sample material) or defects located deeper in the material are detected more accurate with the use of the LockIn method with periodically changed signal and a long time of the impact of the heat wave on examined material. Knowing the energy of the generated signal, emission prosperities and thermal conductivity, it is possible to estimate the depth on which the defect is and the analysis of the geometric size. The disadvantages of the thermovision method in diagnostics include limitation concerning the depth of defect detection and the choice of the proper type of excitation to the given group of examined materials.

Data from the thermogram allows the analysis of the image in terms of the value of the emitted signal by the examined object, the temperature distribution on its surface, the interpretation of its results in the form of 2D profiles or 3D mapping.

Active thermovision method makes it possible to diagnose the larger area in a faster and non-contacting way.

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