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Quantitative Analysis of Subsurface Defects of STS Materials by Finite Element Modelling in Infrared Thermographic Testing

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Abstract

The suitability of infrared thermography is assessed through the estimation of the temperature variation or thermal contrast induced by a defect. In this study, finite difference numerical analysis is applied on the three dimensional solid body with artificially created subsurface defects at some depth to simulate the heat flow in the infrared thermography inspection process. The result shows that the numerical simulation is helpful to optimize the experimental conditions and explain the experimental data for infrared thermographic testing.

1. Introduction

Numerous experiments have demonstrated that infrared thermographic methods are effective for detection of subsurface defects in the materials. Infrared Thermography is an emerging approach for non-contact, non-intrusive, and non-destructive inspection of various solid materials such as metals, composites and semiconductors for industrial and research interests. Infrared thermography is a non-contact, non-intrusive and non-destructive inspection technique that can be used for the quantitative determination of the sizes and locations of subsurface defects.

It utilizes an infrared camera to monitor and record the temperature variation over the viewed surface. The presence of a defect at a certain depth interferes with the heat flow causing local surface temperature variations or any other changes in the thermal properties of the materials. It provides local colourful images of concerning area where local changes of surface temperature indicate surface defects [1-4]. Modelling of infrared thermography testing can help to obtain the physical insight of the thermal phenomena occurring during and after thermal excitation of specimen and fully understand all the aspects of their thermal behaviour. In this research, a finite element method based model has been applied to simulate the thermal phenomena for infrared thermography testing.

2. Numerical Approach

2.1 Theory and Procedure:

To simulate the thermographic inspection, 3D heat flow simulation model has been developed by using a commercial finite element modelling computer package 'ANSYS Version 14.0.[5] The influence of heat conduction, convection and radiation on the lateral heat flow through the defect, have been simulated and analyzed. The physical nature of the heat transfer is governed by the differential equations such as the one of the heat transfer by conduction, convection and radiation with temperature dependent thermal properties of materials involved. The differential equation, governing pure conductive heat transfer, to be solved on the model domain is [4-6],

$$\rho . C_p . \frac{\partial T}{\partial t} - \nabla . (k \nabla T) = 0 \qquad (1)$$

where ρ is the density (kg/m^3), C_p is the material heat capacity at constant pressure (J/kg·K), T is absolute temperature (K) and k is the material thermal conductivity (W/m·K) and t is time.

The ambient temperature T_{amb} measured in the room was used both as boundary condition and initial condition since it was assumed that the specimen was in equilibrium with the environment at room temperature before the experiment started.

Temperature is interpreted from the radiation emitted from the surface under investigation. If the emissivity of the surface is very low, then the radiation emitted from this surface is very weak. Low emissivity surfaces also suffer from the problem of secondary reflection, due to the presence of surrounding bodies. So for the detection sensitivity, it is assumed the emissivity of 0.95 for the surface of the specimen facing the camera in order to satisfy the conditions similar to the black body. It was supposed that the images were acquired from the same surface that was heated periodically in the experiment. So assumption of reflection method was adopted.

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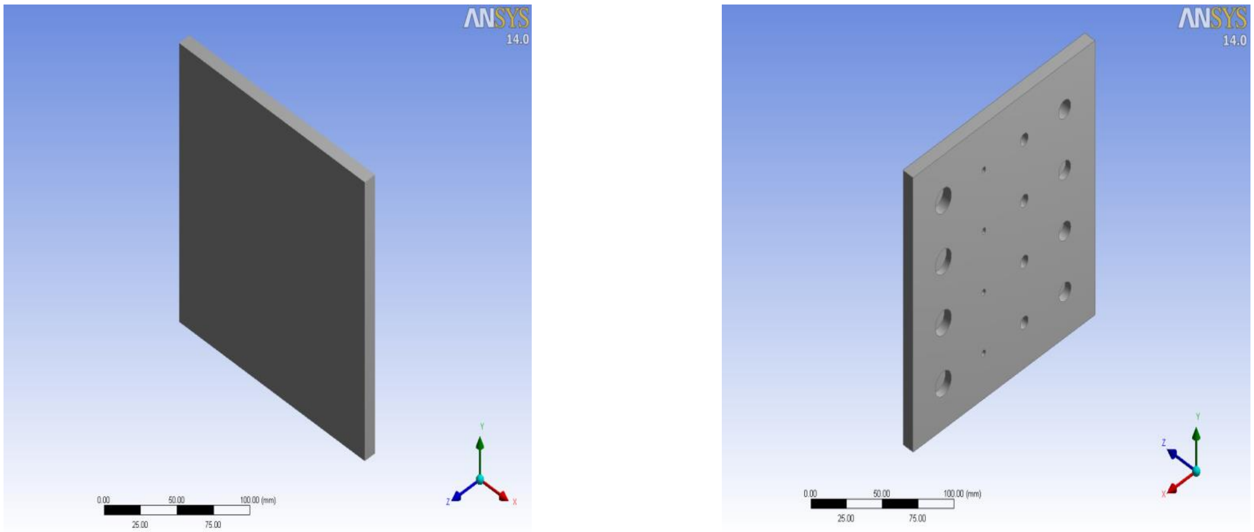
2.2 Model Setup

A square shaped (180 mm*180mm) specimen of the stainless materials (STS 304) with artificial defects (flat bottom holes) of different depths and diameters at the back side was modeled and transferred to a finite element package in ‘ANSYS Version 14.0.[7]. During meshing, physical preference was taken as mechanical, relative center was kept in fine mode and curvature was on in advanced size function. The resultant mesh had 54,700 elements and 86,366 nodes. The finite element model of the specimen with meshing is shown in Fig. 3. The thermal properties and geometrical parameters are defined for the FE-model. The general parameters & thermo- physical properties of the specimen are provided in Table 2.



(a) Front surface of the model

(b) Back surface of the model

Fig. 1 *Modeling of the specimen in ANSYS*

The initial condition used in the model was taken to the room temperature as measured prior to the experiment. The boundary condition included heat transfer by convection and radiation from the object surfaces and the heat source q_0 applied on the front surface for finding the surface temperature distribution on the specimen. The model simulates the transient temperature field for 80 sec.. The assumption of lock in thermography was adopted during heating and cooling of the specimen. Thus, the calculated heat flux was applied in the manner that it was on for the first 20 sec. and off for another 20 sec. for two cycles.

3. Results and Discussions

A finite element modeling scheme using ANSYS is proposed to completely simulate the active infrared thermography applied to STS plate. With the assumption of transient thermal condition, boundary conditions included the heat transfer by convection and radiation on all samples boundaries. The initial condition used in the model was taken at room temperature and was measured prior to the experiment.

In Fig. 2, finite element simulation results are shown at different time interval. The temperature scale varying from 20 °C to 25 °C has been adjusted in order to match to that of experimental data so that the images can be directly compared. .From the Fig. 6, it is observed that high heat flow value gives a greater temperature difference in the defect’s surface and is favorable for the defect detection. The thermal contrast depends on the variation of the defect depth. It increases with the increase in defect depth and decreases with decrease in defect depth.

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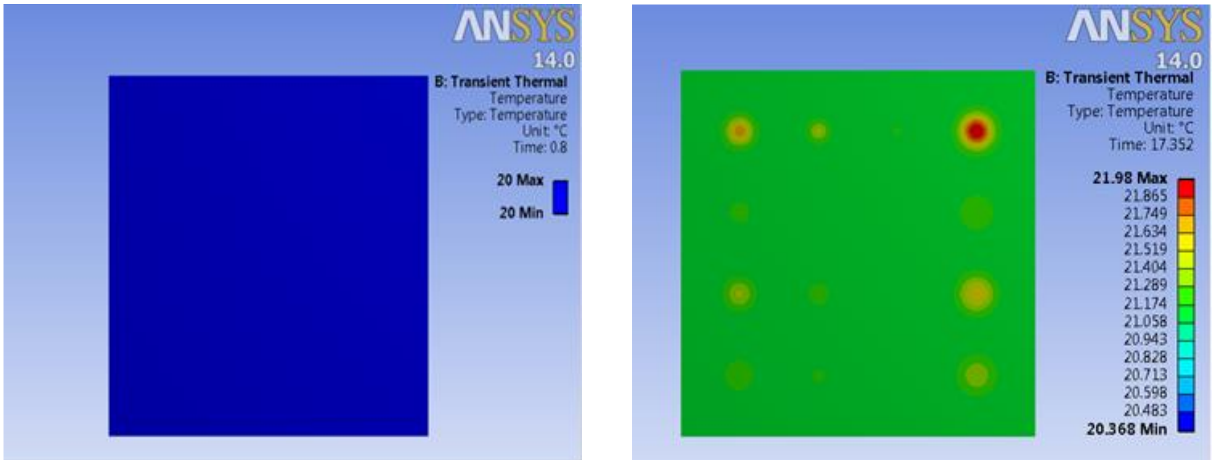
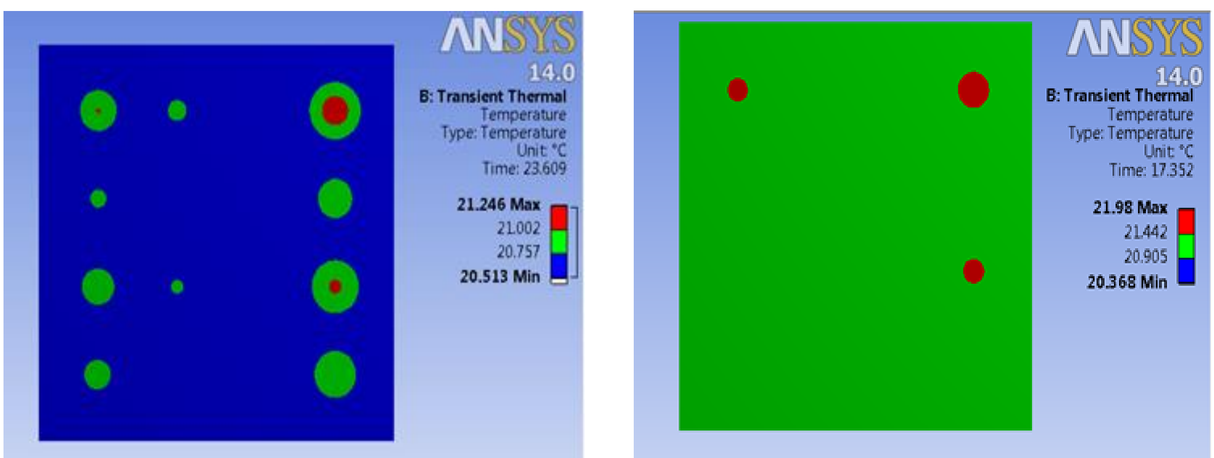


(a) Time at 0.8 sec *(b) Time at 17.35 sec*

Fig. 2 *Finite element simulation results at different time interval.*

Image processing algorithm for the image at the cooling time and heating time was used for image segmentation, which separates the light and dark regions in the image. These images provide better insights in to the defect locations and the relative contrast corresponding to different defects. From Fig.3 (a), it is observed that the apparent thermal image of the defective area seems much larger than the actual size of the defects during cooling time whereas it seems more realistic during the heating time. From Fig. 3, it was observed that defects A1, A4, and C1 have each peak contrast as they were visible in even after the threshold level is set at maximum during the heating time. Such images may help in the development of automatic defect recognition algorithms for thermal images.



(a) Cooling time *(b) Heating Time*

Fig. 3 *Image segmentations according to cooling and heating times*

4. Conclusion

A finite element modeling scheme using 'ANSYS Version 14' is proposed to completely simulate the active infrared thermography applied to STS plate. As per the simulation result, high heat flow value gives a greater temperature difference in the defect's surface and is favorable for the defect detection. The thermal contrast depends on the variation of the defect depth. It increases with the increase in defect depth.

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