

Simulation and Experimental Validation of Pulsed Thermography Technique for Damage Quantification

Aparna Gajendragadkar
CSIR-National Aerospace Laboratories, Bangalore
080-25086232, aparna@nal.res.in

Abstract

Infrared thermography is one of the advanced NDT techniques. This is a noninvasive method for damage detection. It covers a large area of inspection in a very short time. Literature in this area is confined to use of analytical models for surface temperature estimation or special purpose codes developed for thermography. The usage of commercially available software packages for simulation of thermographic experiments is scant in literature. The aim of this work is to develop modeling procedure for thermography experiments using commercial FE package that is extensively used in aerospace industry. This work uses Hypermesh and MSC-Nastran with inbuilt modules to simulate the pulsed thermography experiment. The simulation results help establish a relation between various damage parameters with experimental variables. The present work gives a procedure to model a pulsed thermography experiment. To validate the model an experiment was conducted to detect flat bottom hole defects in a stainless steel plate. Surface temperatures from theoretical model and experiment are compared. Peak time of contrast detection is used as a parameter for defect quantification. The depth quantification is attempted with simulation results.

1.0 Introduction:

Infrared thermography is gaining importance amongst non destructive evaluation methods. It is purely non contact method and inspects large areas in short time. It was used as condition monitoring tool in late 70s [1] particularly in steel and petrochemical industries. The process then evolved with active thermography methods like pulsed thermography (PT) and lock-in thermography (LT). In pulsed thermography a flash lamp is used which increases the specimen surface temperature instantly. Infrared camera captures the temperature response on the surface. Defects have different thermal properties resulting in hot or cold spot, depending on their nature, in the surface temperature plot suggesting the presence of an abnormality [2]. Pulsed thermography is widely used and documented for defect detection in composite materials. High reflectivity of metals is a major hurdle while inspecting metallic materials by IR thermography. Hence very few publications are available on defect characterization in metals [3]. Metals are widely used in various industrial applications like aerospace, nuclear and process industry. These industries require early defect detection methodologies with shorter detection time for large areas of inspection. Also major research makes use of specially developed in-house software codes for

modeling of PT experiment. This work models the same with commercial finite element software packages that are widely employed in aerospace industry. A previous work [4] published in this area has established the relation for defects with square geometry. In the current work the peak contrast time behavior is studied for circular shaped defects with the same diameter and differing depths.

2.0 Modelling:

Commercial grade stainless steel, selected as material of study, was carefully cut to a size of (150×120×3 mm) plate. Four holes of 10mm ϕ were drilled to different depths as 2, 1.5, 1 and 0.5 mm respectively starting from top left hole in clockwise sense resulting in defect depths of 1, 1.5, 2 and 2.5 mm. These holes were created with milling operation using end milling cutter.

Finite element analysis was performed using MSC-Nastran[®] software to carry out transient thermal analysis. Altair-Hypermesh was used for preprocessing. A specimen plate of dimensions (150×120×3) mm was modeled with 27780 hexagonal solid elements. The elements at defect location were removed according to the depths of the blind holes made in the specimen. Thickness of the plate was divided into 6 parts measuring depth of element to be 0.5 mm and typical element length taken as 2 mm. Conduction surface elements (QBDY[®]) were modeled on the plane face to conduct the heat from the heat source to the specimen. On the back surface heat loss was modeled through convective elements (CHBDYE[®]). The thermal conductivity and specific heat density values for stainless steel material are as in (Table 1) along with other parameters used for the model. Initial time step for transient analysis was given as 1 ms. Initial and boundary conditions were imposed on the temperature. All nodes were assigned initial temperature. The iterative Newton Raphson algorithm is used to calculate the approximate temperature at any given node in Nastran software [5]. Solution 159 was used to carry out transient thermal analysis. Finite element model is as shown in Fig. 1 below.

Table 1: Input values for simulation

<u>Parameter</u>	<u>Value</u>
K (W/mK)	16.2
C_p (J/kg K)	500
ρ (kg/m ³)	7990
h (W/m ² K)	10
Time step (s)	0.001
T , Ambient temperature (^o C)	30

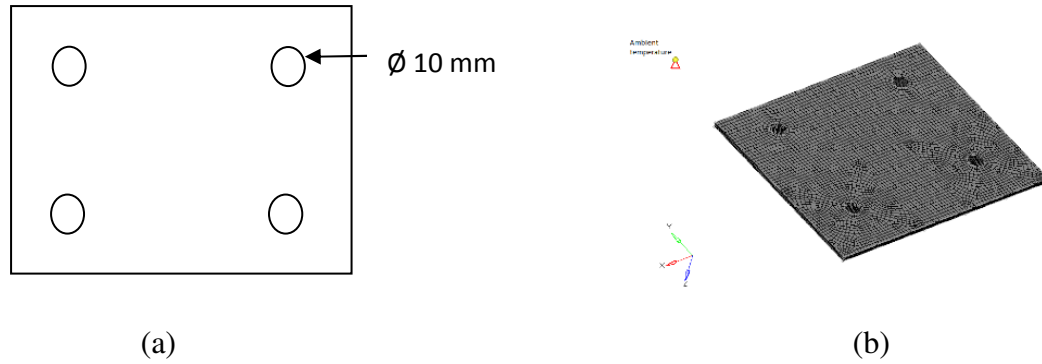


Figure 1: (a)Schematic of specimen, (b) Finite element model of specimen

4.0 Experimental details:

Various parameters set for the experiment are tabulated in table 2 below. IrNDT software was used to execute the pulsed thermography experiment. Image acquisition and analysis was performed using IrNDT and Altair software. As the experiments were done on metals having high thermal diffusivity, very high frame rate, 200-300 Hz, was selected for thermal image acquisition.

Table 2: Experimental parameters

<u>Parameter</u>	<u>Value</u>	<u>Parameter</u>	<u>Value</u>
Frame rate (Hz)	200	Acquisition period (seconds)	4
Excitation period (seconds)	0.005	Ambient temperature ($^{\circ}$ C)	30

5.0 Results and discussion:

The thermal images acquired through experiments were exported to Matlab in .mat format for further processing and analysis. The surface temperature gradient was analyzed for defect and non defect area. It is observed that at the defect area the temperature is higher than at non defect area. The heat waves impinging on defect area are obstructed at defect boundary and get reflected. Whereas, the heat waves striking a non-defect area pass through the whole thickness and get reflected only at the opposite surface. This increases the temperature over the defect area as compared to a normal surface. The temperature contrast variation was plotted against time for simulated results. The graph is shown in Fig. 2. It is seen from this plot that shallow defects show higher contrast than deeper defects. As thermal wave passes through the specimen, it diffuses and its amplitude reduces because of attenuation. The reflection of the attenuated wave reaching surface, from a deeper defect, is still less resulting in a lower contrast on the surface.

Peak contrast time was calculated from Fig.2 for all the defect depths. It can be observed from the figure that as defect depth increases, peak contrast time also tends to increase. The analogy is logical as reflected thermal wave from a shallower defect will take less time to reach the surface. Whereas thermal wave reflected from a deeper defect will need more time to reach the surface. Hence the peak contrast time can be treated as an important parameter in defect depth quantification.

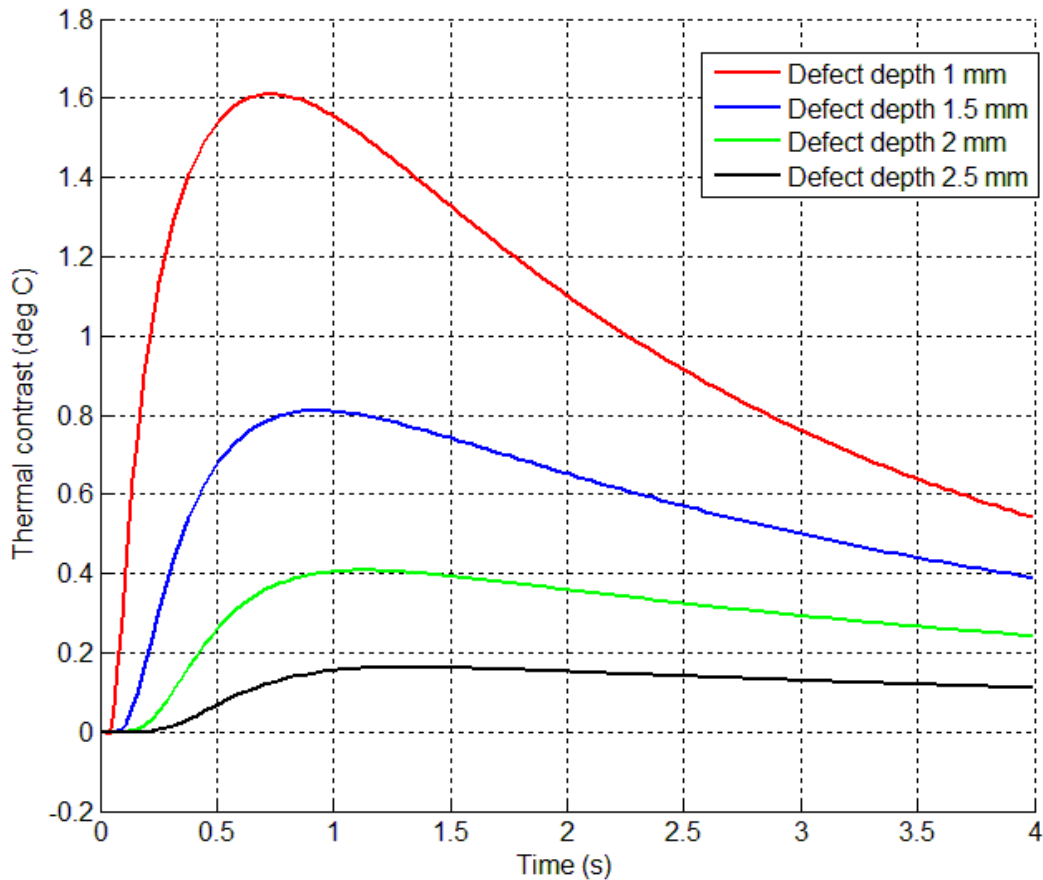


Figure 2: Simulated temperature contrast plot against time for various defect depths

The peak time when plotted against square of defect depth shows a linear relation as shown in Fig. 3, also reported in [4]. A least square line is fitted for the simulated data. Matlab basic fit tool is used to calculate the residuals at each data point. A good linear fit for simulation data may be observed from R^2 value (0.9914). The equation of line developed by this method can be used for defect depth prediction with known peak time values from experiments.

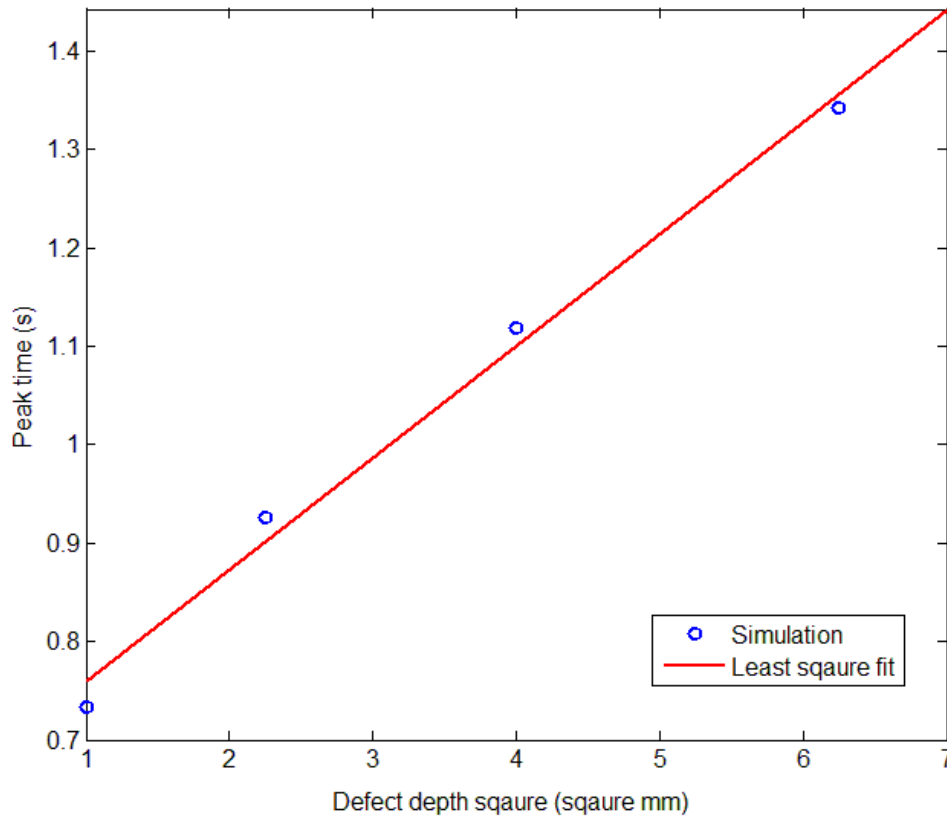


Figure 3: Relation between peak time and defect depth square

The simulation and experimental data were compared as shown in Fig.4. A good agreement between the temperature contrast values with time for 1mm deep hole defect may be observed from the plot. The initial difference seen in the experimental data might be because of direct reflection temperature recording from the flash lamp.

Non uniform heating of the specimen surface is observed with single flash lamp. Even though care was taken to position the flash lamp and the camera in such a way as to avoid the effect of non uniform heating, it could not be completely eliminated in the experimental image data.

6.0 Conclusion:

It is demonstrated that commercial software packages that are widely employed in aerospace industry can be used to simulate IR thermography experiments. A model was developed to quantify defect depths in a stainless steel plate. The experimental data and the data from simulated model compare quite well for a set of given conditions. It is observed that a linear relationship exists between peak contrast time and the square of the defect depth.

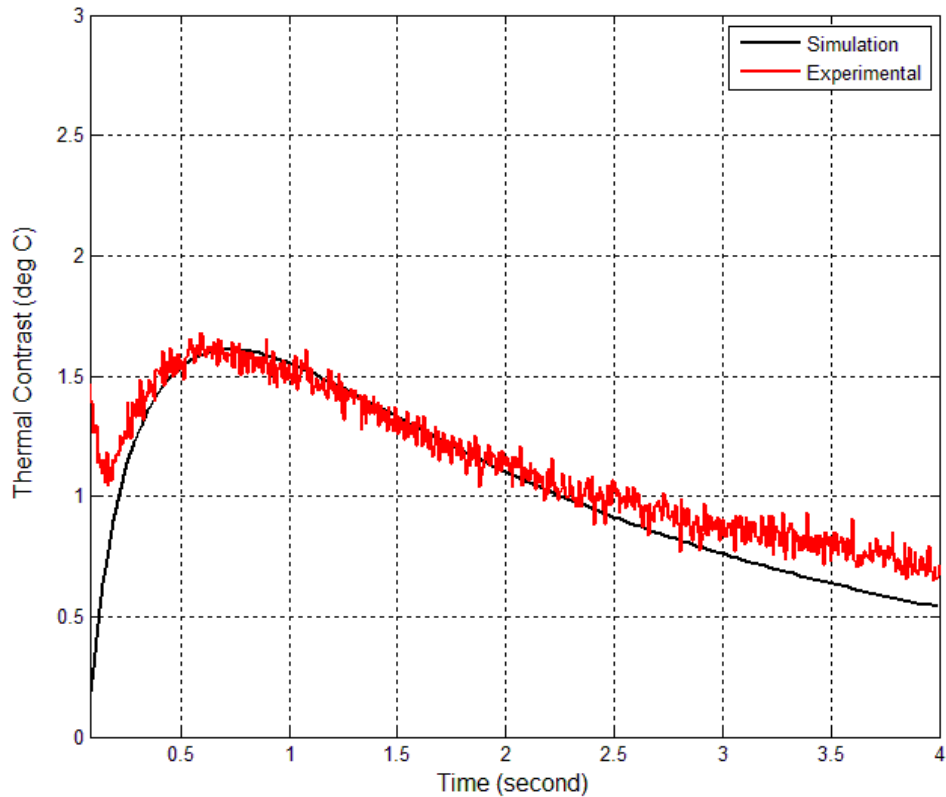


Figure 4: Comparison of simulation and experimental results

References:

- [1] Smith BMQ, *Condition Monitoring by thermography*, NDT International 0308-9126/78/1103-0121 (1978)
- [2] Maldague XPV, Marenetti S., *Pulsed phase thermography*, Journal of Applied Physics, Vol. 79, Issue 5, 2694 (1996)
- [3] Maldague XPV, *Theory and practice of infrared technology for non-destructive testing*, John Wiley and Sons (2001)
- [4] Sharath D. et al., *Defect Characterization using Pulsed Thermography*, Journal of Non Destructive Evaluation,32:134-141 (2012)
- [5] MSC Nastran Thermal Analysis User's Guide