Research on Defects Detection by Image Processing of Thermographic Images

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Abstract - This paper presents the results of experimental investigation of thermal phenomena in a square shape (180 mm *180 mm) STS 304 specimen with 10 mm thickness and artificial defects with circular cut-outs of varying depth and diameter at the back side. The material is aimed to be tested by means of thermal wave thermography. Lock-in thermography is employed for the detection of defects. The temperature field of the front surface of material tested is observed and analysed. The four point correlation algorithms are applied to extract phase angle of thermal wave's harmonic component. Phase image are analyzed to find the qualitative information about the defects. Phase contrast method was used for better identification and analysis of the existing defects of the specimen.

Keywords: Infrared Thermography, Lock-in Thermography, Image Processing, Phase Image, Phase Contrast

I. INTRODUCTION

Currently, the use of STS materials has been gradually extended to various application fields such as nuclear pipes, automobile, railroad and building structure. Increased usage of STS materials has led to an increased interest to the production processes [1,2]. High quality of materials and structures is an important factor in many areas of human activities [3]. A major effort to reach the high level of quality is to implement various inspection tasks. Non-destructive testing (NDT) is one of the most important means to detect and verify the quality of items [4]. In this context, Infrared thermographic (IRT) technologies are used nowadays as a very fast NDT tool for examination of a wide range of materials. NDT using active IRT provides information on material, structure, physical & mechanical properties and discontinuities & defects present on the analyzed specimen [5]. The inspection of a material or component by means of thermographic techniques consists of the measurement and interpretation of the temperature field over the component. The detecting device (Infrared Camera) receives different levels of infrared radiation from the surface of the sample generating a map of its distribution, thus creating an image called thermogram [6-8].

Defect detection principle in IRT is based on the fact that a difference in thermal properties exists between the sound and a defective area, which can be used for defect detection and quantification purposes [9-11]. Lock-in thermography (LIT) facilitates better subsurface defect detection than ordinary infrared thermography because the thermal wave is very sensitive to interfaces between materials and less sensitive to non-uniform emission and surrounding conditions [12].

There are a large number of image processing techniques in NDT using active infrared thermography; their application depends on the characteristics and objectives of the study. This paper is focused on study of phase contrast technique for processing of thermographic sequences obtained in LIT.

II. THEORY

The periodical transfer of heat at the surface of a homogeneous semi-infinite material results in a thermal wave, which in one dimension is given by [7, 13, 14],

$$T_{z,t} = T_0 \exp(-\frac{z}{\mu}) \exp i\left(\omega t - \frac{z}{\mu}\right) \tag{1}$$

where, T_0 [°C] is initial change in temperature produced by the heat source, ω [rad/s] is the modulation frequency, f [Hz] is the frequency, λ [m] is thermal wavelength, z [mm] is the defect depth, and μ [m] is thermal diffusion length which determines the rate of decay of thermal wave as it penetrates through a material and defined by [7,9,15],

$$\mu = \sqrt{\frac{2\alpha}{\omega}} = \sqrt{\frac{\alpha}{\pi f}} \tag{2}$$

From the Eq. (1), we can get the phase difference ($\emptyset$), which is related to the defect depth as [16],

$$\emptyset = \frac{z}{\mu} \tag{3}$$

In lock-in thermography, the system collects a series of images and compares their temperature computing amplitude and phase of the sinusoidal wave pattern at each point and the resultant image may be amplitude or a phase image. If S_1, S_2, S_3 and S_4 are four equidistant thermographic images as shown in Fig. 1 in a complete period then the phase ($\emptyset$) and amplitude (A) are given by [4, 9],

$$\emptyset = \tan^{-1}\left(\frac{S_1 - S_3}{S_2 - S_4}\right) \quad (4)$$

$$A = \sqrt{(S_1 - S_3)^2 + (S_2 - S_4)^2} \quad (5)$$

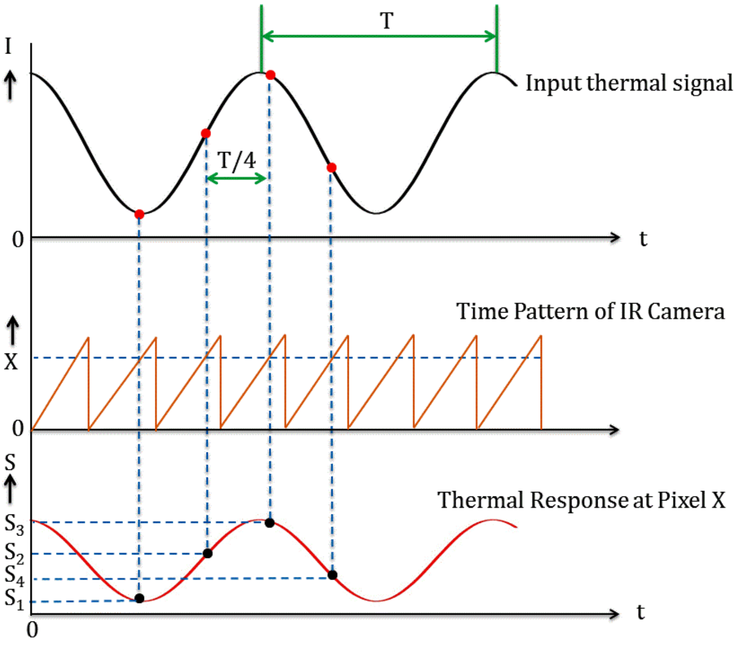


Fig.1. Principle of computation of thermal, amplitude and phase images in lock-in thermography

Phase contrast method enables to increase the level of contrast between a defective and a sound area which allows a better identification and analysis of the existing defects of the specimen. The phase difference between the defective area and non-defective area is defined as [12, 17],

$$\Delta\emptyset = \emptyset_d - \emptyset_s \quad (6)$$

where, $\emptyset_d$ is the phase of pixel on a defective area and $\emptyset_s$ is the phase of pixel on a sound area.

III. EXPERIMENTAL METHODOLOGY

Artificial defects (flat bottom holes) of different depths and diameters were created at the back side of the specimen. The schematic of the specimens with defect locations is shown in Fig. 2. For generation of sine waves of a single frequency, a programmable function generator, (Agilent 33210A, Malaysia) was used and for detection of thermal waves infrared camera (SC645, FLIR Systems, Sweden) was used that has a 640×480 pixel resolution and sensitivity of 7.5-13µm. The sample was heated with a sinusoidally modulated heat wave from two, 1 kW halogen lamps (connected to the output of function generator) kept at 100 cm away from the specimen. The camera was kept at a distance of 50 cm from the specimen in such a way that the axis of the camera coincides with the axis of the sample. Reflection method was adopted, i.e., images were acquired from the same surface that was heated periodically.

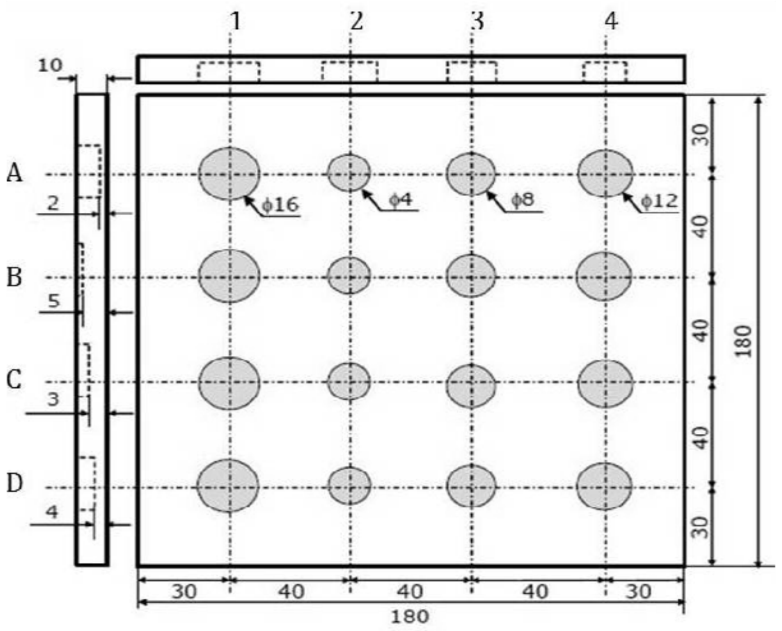


Fig.2. Inclusion defect specimen of STS 304

IV. RESULTS AND DISCUSSIONS

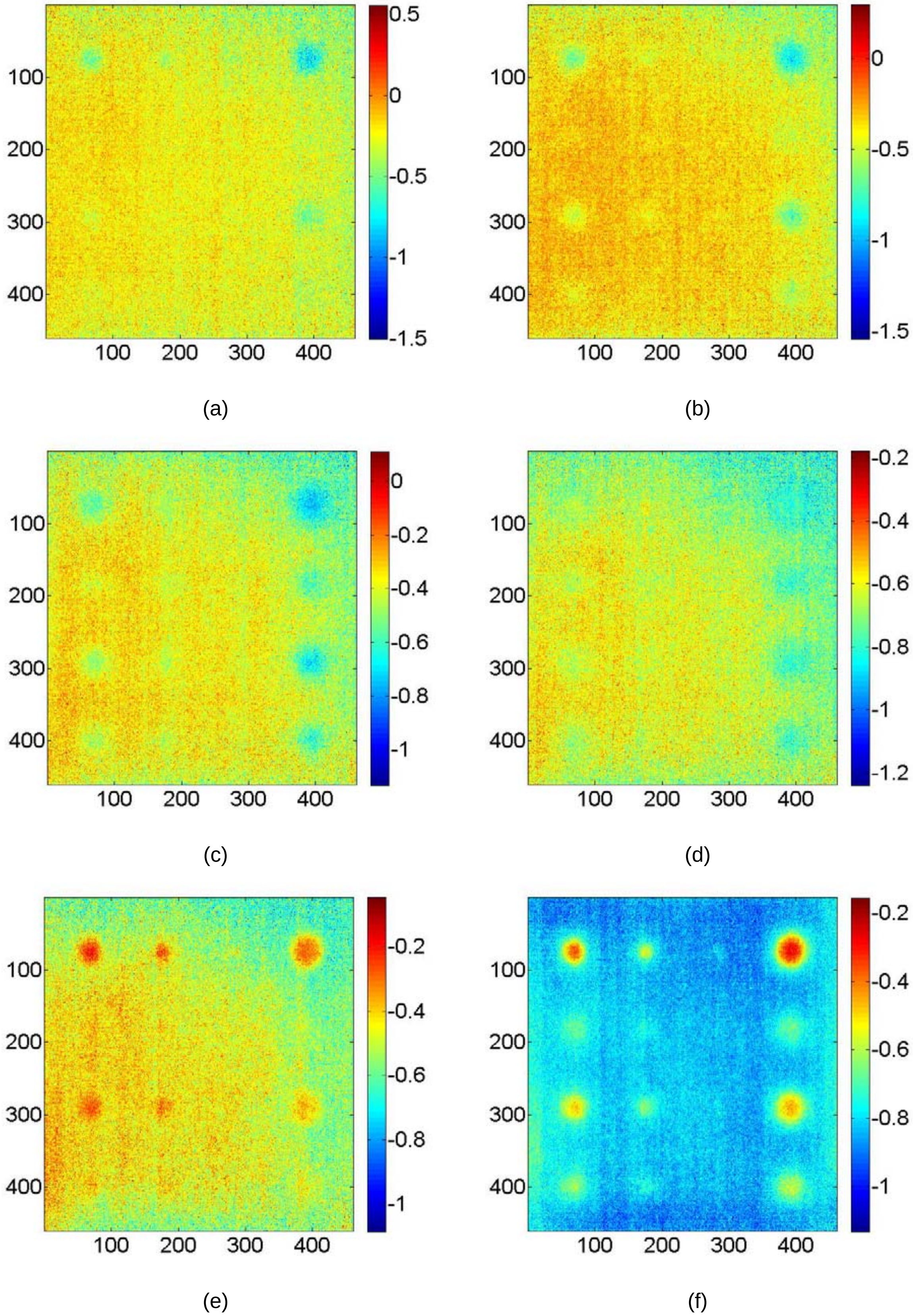
A range of modulation frequencies was used to interrogate the STS 304 specimen ranging from 0.182 down to 0.01 Hz. Longer acquisition time required for the low frequencies to obtain a number of periods. A higher degree of noise was observed at high frequencies. Increasing the number of periods aided in reducing the noise level and to improve image clarity. So the thermal images were selected from the 2nd cycle for each excitation frequencies and then post-processed to determine the phase data of the periodic temperature change at the sample surface.The Eq. (4) was used in post processing every pixel of thermographic images using the MATLAB programming language. The phase images obtained by LIT from experimental investigation at different frequencies ranging from 0.182 Hz down to 0.01 Hz is shown in Fig.3. As per the experimental results, it is observed that no clear defects were detected at the highest frequency 0.182 Hz. As the frequency decreased to 0.126 Hz, the contrast begins to improve and when it goes down to 0.01 Hz, the surface defects in phase image become more visible.

Phase difference was evaluated by subtracting the phase value located centrally over the defects from the phase value measured in the sound area near the defects. Analysis of phase image was performed in relation to excitation frequency and defect depth.

The Fig. 4 shows the plot of defect's phase as a function of excitation frequency. The defect A_1 with larger diameter 16 mm and deeper depth 8 mm is chosen for the analysis. It is observed that the phase contrast is negative at higher frequencies. That means the phase angle of defective region lags from that of sound area. As the frequency begins to decreased, the phase contrast becomes zero and starts increasing in positive scale. The frequency at which the phase angle of defective area becomes equal to the sound area leading to zero phase contrast is called blind frequency. At the blind frequency, the defect 'appears to disappear'. With further decrease in the frequency, the phase angle of defective area leads the phase angle of sound causing a positive phase contrast. The phase contrast which is initially negative at higher frequencies becomes positive for lower frequencies and this change in phase contrast is referred to as 'phase inversion'. Phase inversion is clearly seen in Fig.3 which is the phase images at frequencies 0.182 Hz and 0.01 Hz.

The Fig. 5 shows the plot of defect's phase as a function of defect's depth for the same diameter. The defects B_1, D_1, C_1 & D_1 with different depth 5, 6, 7 & 8 mm and same diameter 16 mm were chosen for the analysis. It is observed that the phase contrast increases with the defect's depth.

Similarly, the analysis was done for the defects A_3, A_4 and A_1 with different diameter 8, 12 and 16 mm and same depth 8 mm. The Fig. 6 shows the plot of defect's phase as a function of defect's diameters for the same depth. It is observed that the phase contrast increases with the defect's diameter. Finally, it is realized that measured phase is affected not only by its depth but also by its size.



(a) (b) (c) (d) (e) (f)

Fig.3. Phase Images (a) 0.182 Hz, (b) 0.093 Hz, (c) 0.055 Hz, (d) 0.038 Hz, (e) 0.02 Hz and (f) 0.01 Hz

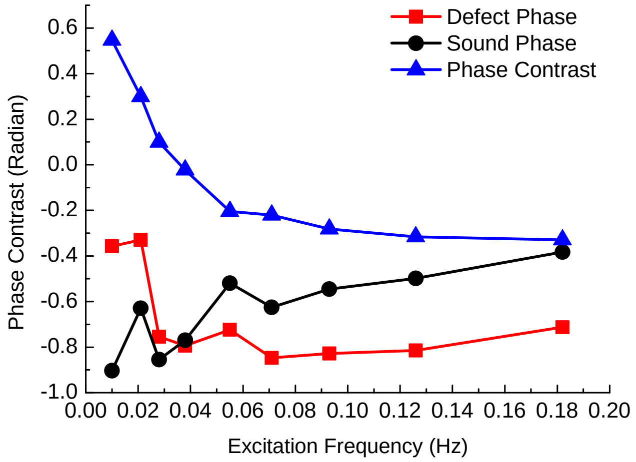


Fig.4. Phase Vs Excitation Frequency

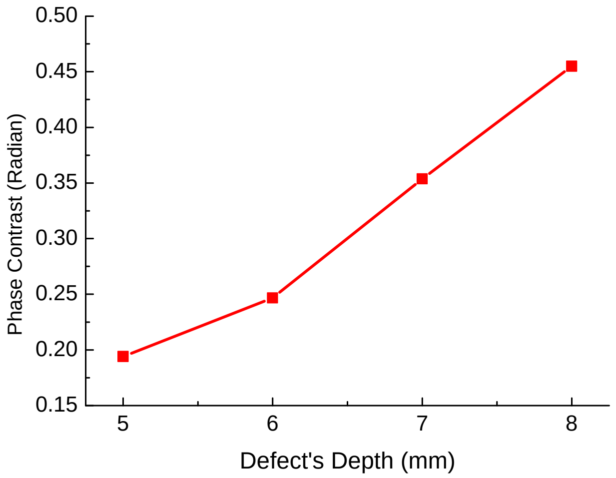


Fig.5. Phase Contrast Vs Defects Depth

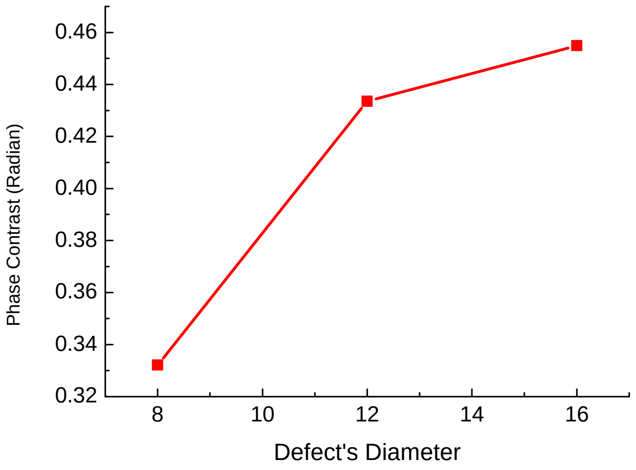


Fig.6. Phase Contrast Vs Defects Diameter

V. CONCLUSIONS

This study explored the use of LIT and image processing algorithms for quantitative assessment of sub-surface defects in STS 304 material. The results shows, infrared thermography is a reliable non-destructive method for detecting the defects and the detachability improves as the defect radius to defect depth ratio approximates unity. The detachability of subsurface defects by LIT depends on material properties, defect size and depth, geometry and surface finish of the component, IR Camera thermal sensitivity, excitation frequency, heating power etc.

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