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Defect detection of Al specimen of using Lock-in photo-infrared thermography technique.

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Abstract

Over the years, Infrared thermography (IRT) has been used as a non destructive testing methods of the various kinds of materials. This technique has many merits and applied to the industrial field but has limitation to the materials. Therefore, this method was combined with lock-in technique. So IRT detection resolution has been progressively improved using lock-in technique. In accordance with this paper describes location of subsurface defects and measurement resolution in the Al s and SUS plates by using Lock-in photo-infrared thermography technique. In lock-in thermography, a phase difference between the defect area and the healthy area indicates the quantitative location and size of the defects. The results obtained from two kinds of specimens Al6061-T6 and SUS304 are compared the thermal diffusivity differences. It measures the resolution of the defect detection of Al 6061-T6 specimen. This result may be used for life time estimation of the object and measurement of resolution of IRT of the defect material. Experimental results for SUS and Al plate with artificial subsurface defect show good agreement with actual values.

Keywords: Lock-in, IR camera, penetration depth, defect, resolution, thermal diffusion

Introduction

Infrared thermography (IRT) is a thermometric technique based on the IR radiation emitted from object surface. IRT generate real-time colorful images of specimen that local changes in surface temperature of each point on the surface indicate subsurface defects. It is a non-destructive, non contact, non-intrusive method to thermal contact which made by measurement of IR radiation [1]. Applications of this method have been expended into the stress analysis, thickness measurement, fatigue limit analysis, defect detection, electronic plant flame measurement and medical diagnosis. Since most IRT applications depend on a temperature difference between defect and health area. Also, IRT detection capacity was limited the sampling of detection element.

This problem can be solved that the combined lock-in method. The theory behind lock-in IRT is that temperature modulation induced at the surface of the inspected component from the outside propagates as a harmonic thermal wave [2-3]. The modified thermal waves are captured by the infrared camera, and thermal image result can be analyzed by image processing. Lock-in IRT is less sensitive to external environment condition and it is easy detectable as compared with IRT. Lock-in IRT can be sensing the thermal variation. In this paper, the Aluminum 6016-T6 specimens can be detected defect detection resolution because of thermal diffusivity difference compared the between Al 6061-T6 and SUS304. So the defect can be confirmed image by lock-in IRT. It may be used for life time estimation of the object and measured resolution of IRT in the defect material.

2. Theory

2.1 Lock-in thermography

The concept of lock-in IRT was presented by Carlomangno and Berardi and later developed by many researchers [4-5]. Basically, lock-in IRT is coherently combined with a thermal wave source which is operate in such a wave that a sinusoidal temperature modulation results. The modulation makes the non-linear electrical signal produced by the lock-in Module which has a waveform. The heat source induced from the outside has to be calibrated (for each frequency) to make the temperature waveform of the heat source truly sinusoidal. That method can acquire a phase and amplitude by using signal processing. This method is expressed in Fig. 1

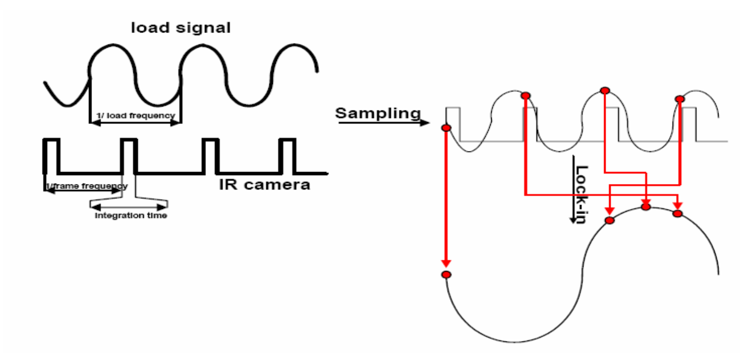


Fig.1 Signal processing of lock-in infrared thermography and system

2.2 The penetration depth of light source

The method of defect detection is very important to know the thermal diffusion coefficient about material property of specimens. Thermal diffusion coefficient was expressed the heat transform coefficient and specific function of heat at constant pressure and density. It is expected that the penetration depth of light source. Eqn. (1) was shown a main cause of the penetrating depth of light source.

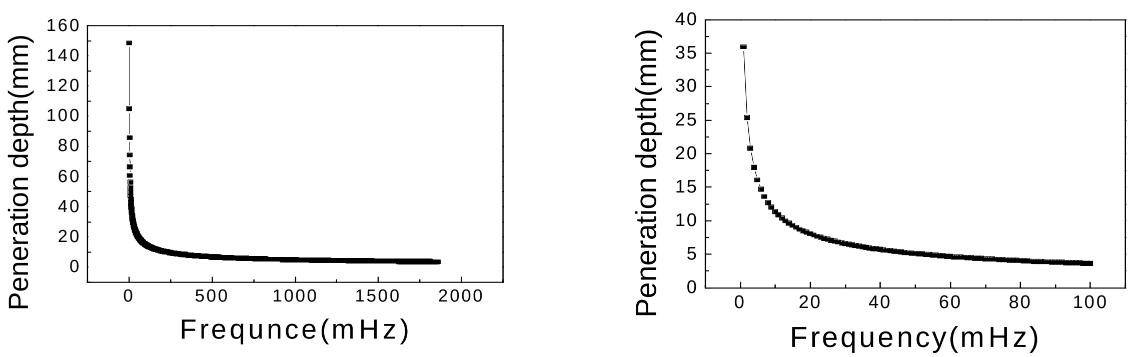
$$\mu = \sqrt{\frac{\alpha}{\pi f}} \qquad (1)$$

(μ = Penetration depth, α = thermal diffusion coefficient $\left(\frac{k}{\rho c_p}\right)$, f =wave frequency)

The penetration depth of light source is decided that variation of wave frequency because a thermal diffusion coefficient is property in the identity material [5]. Fig. 2 shows frequency of the penetration depth by using the Eqn. (1) and Table.1 presents the material property.

Table 1 Thermophysical property of specimens

Specimens	**Heat transfer coefficient(k)**	**Density (ρ)**	**Specific heat(c)**	**Thermal diffusion coefficient(α)**
Al	167w/m-k	2700 kg/m^3	896 J/kg-k	$6.9\times10^{-5} m^2/s$
STS	16.2w/m-k	8000 kg/m^3	500 J/kg-k	$4.5\times10^{-6} m^2/s$



(a) Aluminum 6061-T6 (b) STS 304

Fig. 2 Estimation of penetration depth to each frequency

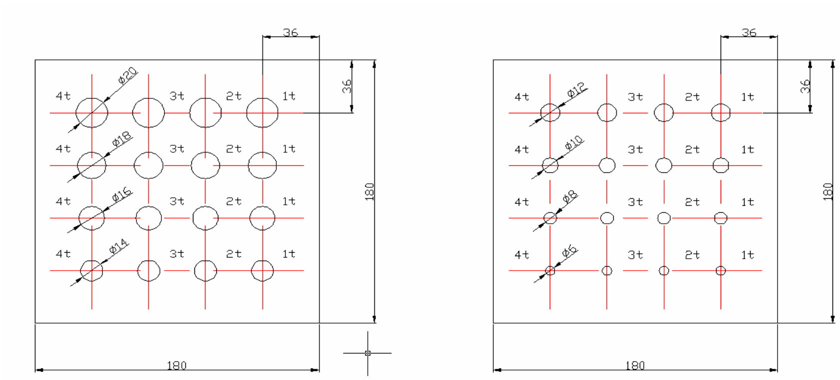
Theoretically, the specimen of Al6061-T6 is detected defect of 4mm in the frequency of below 137mHz. Other specimen is fined defect of 4mm in the frequency of below 80mHz.

2.3 Defect size

In the defect detection, the defect size is influenced size a material of metal quality. The heat transfer is appeared to the depth direction as well as 3 dimensional shape. Therefore, the metals differ from each thermal diffusion coefficient have considered the defect size. If the specimens were made non condition in depth and length about thermal diffusion coefficient, the defects can't be detected.

3. Specimens and experimental procedure

Four specimens with known defect of depth, shape, size have been prepared as shown in Fig. 3. Four specimens made the flat-bottom hole according to different depth and size. And each specimen material are the Al 6061T-6 and SUS304.



(a) Specimen I (b) Specimen II (Thickness: 10, unit: mm)

Fig. 3 Artificial specimens with back-drilled-bottom plate defects

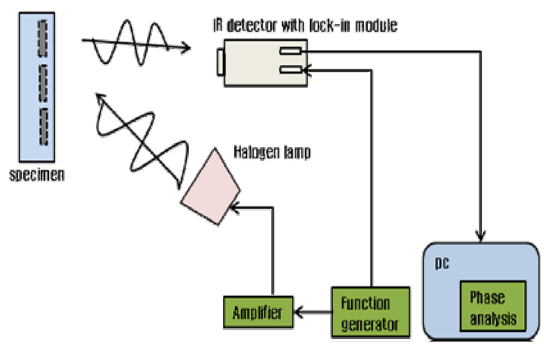


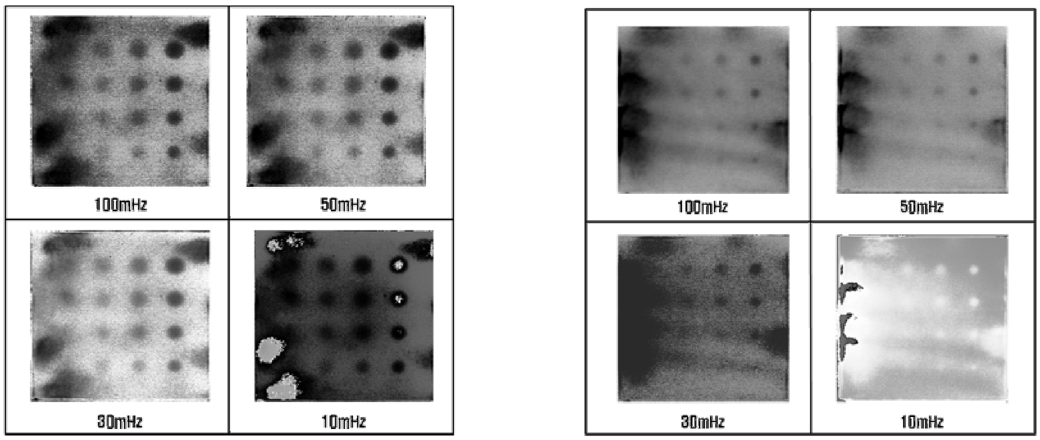
Fig. 4 Lock-in thermography system

Experiment system (Sliver480 [FLIR.co]) consists of the IR camera, function generator, heat source (l Kw halogen lamb), as shown in Fig. 4. The heat source is combined with function generator and also IR camera is connected. Each connection is synchronized with the sinusoidal signal of the function generator. The paints having 0.95 emissivity spread on the surface of specimens. Phase images are attained to each heat-generating frequency.

4. Results and discussion

The penetration depth μ is closely related with frequency of light source. That light source can be penetrated an inside of specimens. Also thermal diffusion with the property of specimens is correlated with the frequency of light source variation. Therefore, experiment result will be considered the above conditions.

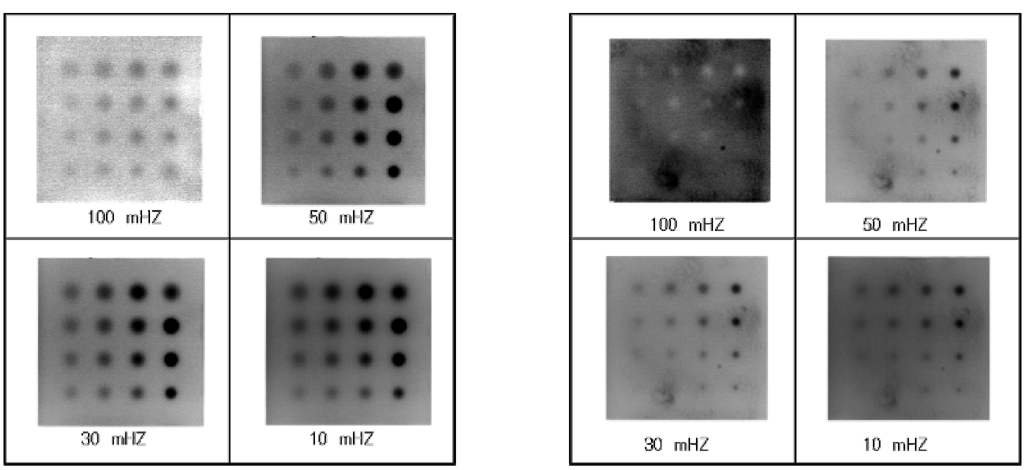
Fig. 5 is shown the defect of Al specimen detected using Lock-in IRT. The results in specimen I, II was show the detected defect. Until the defect of 4mm thickness of diameter 5 mm in specimen I is measurable according to the frequency variation. So other specimen is found defects which 3mm thickness defect of diameter 10mm. The detected resolution of Al6061-T6 specimen is measured the 3mm thickness of defect zone in diameter 10mm.



(a) Specimen I (b) Specimen II

Fig. 5 Defect detection of Al 6061-T6 to each frequency

Fig. 6 is shown the defect of SUS specimen detected using Lock-in IRT. From defect of all thickness is detected defect in specimen. Until the defect of 4mm thickness of defect zone in diameter 8 mm in specimen II is measurable according to the frequency variation. The detected resolution of SUS304 specimen is expressed above sentence. When trying to compare Al and SUS specimen, a defect of Steel is easy found compared the Aluminum because of the heat transfer coefficient is different.



(a) Specimen I (b) Specimen II

Fig. 6 Defect detection of SUS304 to each frequency

In the Aluminum experiment until 150mHz frequency enforces, the defect was detected only some hole and other specimen wasn’t detected above 200mHz frequency enforces

5. Conclusion

In this study, resolution of defect detection is estimated through comparison between Al 6061-T6 and SUS304 specimens by using Lock-in photo-infrared thermography. In case of Al 6061-T6, optimum frequency range is about a 100mHz. These results are acquired experimentally considering detectable depths and thermal conduction of 3-axis direction. Frequency bands less than optimum frequency increase not only in photo detectable depths but also inspection time increase. In other words, in case of frequency bands less than optimum frequency, inspection efficiency is deceased. Otherwise, defect of SUS-304 is easy detected. Also the two specimens differ from defect resolution. Like this fact is caused by the different of thermal diffusion coefficient and heat conduction of surface. Also the error of experiment may be appeared because the spry was spread irregular. In the future, if the detection of defect is used the specimen of multiplicity, each specimen can be quantitative analysis. So the detection resolution may be improved with a high resolution camera or by capturing a close up image inspection area. Therefore, his research will be studied in the non destructive measurement field.

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