THERMAL DEFORMATION ANALYSIS OF ALUMINIUM HEAT SINK USING ELECTRONIC SPECKLE PATTERN INTERFEROMETRY

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ABSTRACT
When a solid material is subjected to severe temperature variations, the structure of the material changes and produces a volumetric enlargement which induces stresses in the material. Thermally induced deformation analysis has considerable importance in the mechanical and structural design application of numerous solid materials. The potentially excessive thermally induced distortions can be reduced if one can diagnose the current mechanical state of the material and update the diagnosis at every stage so that stress/strain variations and thereby the fracture may be predicted as an early state as possible. The present work reports a qualitative analysis which directly reflects the situation of thermal deformation of an aluminium heat sink material using out of plane Electronic Speckle Pattern Interferometry (ESPI) setup. The temperature contrast developed on the surface of the sample due to thermal transmittance provides a clear indication of thermal deformation of the specimen. The variation of fringe densities obtained from ESPI images has been taken as a qualitative tool to depict this deformation.

KEYWORDS: *Thermally induced deformations, Electronic Speckle Pattern Interferometry (ESPI)*

I. INTRODUCTION

Thermal deformations are usually introduced in electronic circuit boards, ceramic materials, metals etc when they are subjected to different temperature conditions. The deformation often results from localized strain which may be due to heating being localised (e.g. welding a plate), or due to two bonded materials having different expansion coefficients expanding together (e.g. heat sinks in electronics).Conventional methods of measuring thermal strain utilize strain gauges and other mechanical or electrical sensing devices [1]. The chief drawback of these methods is the requirement for connection with the surface under examination and the localized measurement region [2]. Full-field measurement techniques offer better solution for such measurement environments. Speckle interferometric techniques and their electronic and digital analogs, which are whole field techniques, are reported to be promising candidates for such kind of Non-destructive testing (NDT). Several optical interferometric techniques are used nowadays as a tool to characterize thermo mechanical behaviour of microelectronic devices [3].The whole field information with various sensitivities and resolutions provided by the ESPI technique make it ideally suited for the thermal deformation study of a broad range of problems in engineering applications. Simple and reliable procedure for measuring shape and deformation of electronic components based on conventional ESPI and phase shifting ESPI (PS-ESPI) was reported formerly to understand common failure mechanisms of electronic components [4]. Qualitative detection and differentiation of cracks and fractures on metallic surfaces under thermal load was also undergone using an out-of-plane ESPI setup [5]. In the recent past, the study of component damage initiated by differential thermal distortions due to the inherent complexity of electronic packaging (EP) in terms of geometry or construction using ESPI technique was reported [6]. Ching-Chung Yin et al most recently probed thermal deformation analysis on PV cells for rapidly testing the cracks building on it has established ESPI as a powerful experimental platform for the researches of automated full-field nondestructive measurement [7]. Wen, Tzu-Kuei, and Ching-Chung

Yin investigated thermally induced cell deformation of defect-free and defect-bearing PV cells which were formerly patterned with numerical simulations and then experimentally studied by optical configuration for ESPI out-of-plane deformation measurements [8].Most recently, Salah Darfi and Said Rachafi presented a technique for heated plate temperature measurement using electronic speckle pattern interferometry and Fourier Transform Method algorithm [9]. These results validate the use of ESPI setup to observe material defects/deformations. The present paper reports the capability of ESPI for assessing the response of surface deformation of aluminum heat sink material under constant thermal stressing.

This paper has been organized as follows. Section II deals with the theoretical background behind the ESPI Measurement method, while, the details and results of the experiments are described in Section III. The paper concludes with a brief note on the prospects of the current work in Sections IV and V respectively.

II. THEORETICAL BACKGROUND

2.1 ESPI experimental Setup and fringe generation

ESPI utilizes surface generated laser speckle effect to generate correlation fringes produced by electronically subtracting in real time the speckle patterns after and before a deformation on a test surface [10]. The measurement system comprises of a 10 mw He-Neon laser source, CCD camera, host computer having image processing software and a display monitor. The schematic of basic layout is shown in figure.1

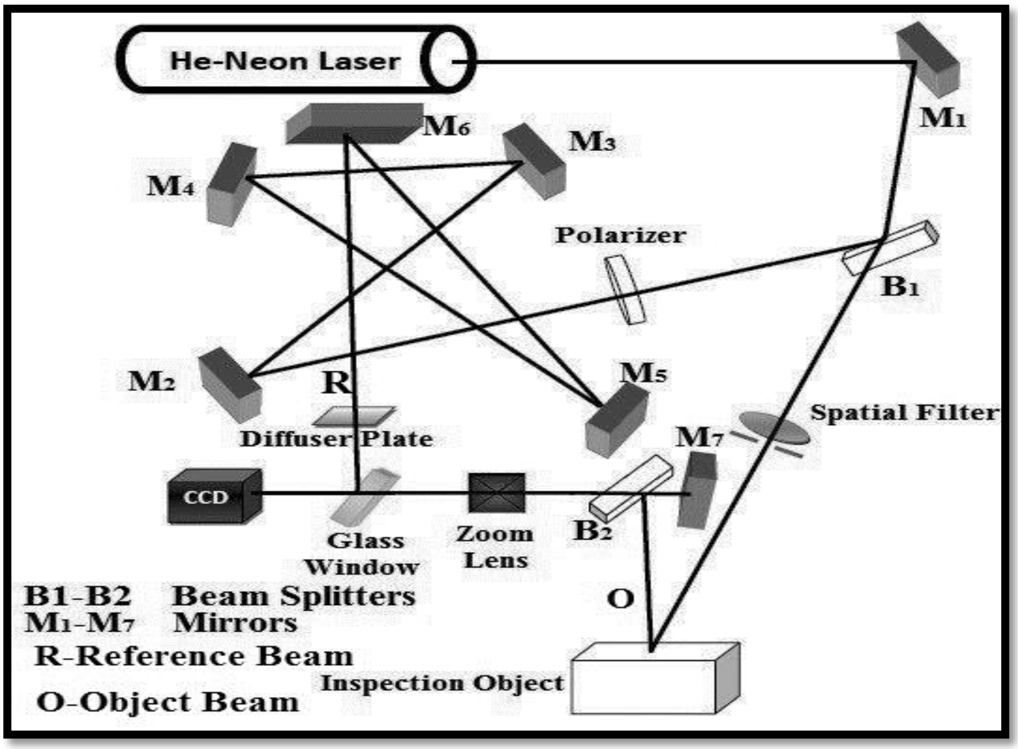

Figure 1.ESPI layout

An object illuminated with an expanded laser beam forms a speckle pattern. The scattered speckle pattern is projected onto a CCD sensor array. As the speckle size can be controlled by the lens aperture, it can be matched to the resolution of the electronic detector. The analogue video signal from the CCD array is sent to an analogue-to-digital converter (frame grabber), which samples the video signal at a given rate and records it as a digital frame in the memory of the computer for further processing. A reference wave is added at the observation plane to achieve interference between the object and reference waves. The resultant speckle pattern is stored in the processor and displayed on the monitor. The object deformation creates a path difference between the wavefronts scattered from its surface and the reference wave, and this modified speckle pattern is digitally subtracted from the previously stored pattern to get fringes in quasi real time. These bright and dark fringes displayed on the monitor are referred to as correlation fringes and represent contour lines of constant surface displacement [9]. The intensity $\mathbf{I_d}$ at a particular spot on the image plane can be interpreted as [12]

$$\mathbf{I_d = |I - I'|}$$
$$= (\mathbf{I_0 + I_r + 2(I_0 I_r)^{1/2}\cos\phi_m}) - (\mathbf{I_0 + I_r + 2(I_0 I_r)^{1/2}\cos(\phi_m + \delta)})$$
$$= \mathbf{4\sqrt{I_0 I_r}\sin\left(\phi_m + \frac{\delta}{2}\right)\sin\frac{\delta}{2}} \qquad -(\mathbf{1})$$

where **I** and **I'** represent intensities at a particular spot before after deformation. Here $\mathbf{I_0}$ and $\mathbf{I_r}$ are the average intensities of object beam and reference beam respectively while $\boldsymbol{\phi_m}$ denotes random phase difference between object and reference waves. As the object is deformed, the object wave undergoes additional phase change $\boldsymbol{\delta}$.The resulting signal thus produced has both positive and negative values .Since negative signals are displayed as black areas on the monitor, the difference signal is rectified before being displayed on a monitor . It is also high-pass filtered in order to diminish the effect of the varying intensity of the laser beam across the field of view [13]. The brightness **B** is given by eq. (**2**)

$$\mathbf{B = 4K\left[I_0 I_r \sin^2\left(\phi_m + \frac{\delta}{2}\right)\sin^2\left(\frac{\delta}{2}\right)\right]^{\frac{1}{2}}} \qquad -(\mathbf{2})$$

where **K** is a proportionality constant . If the brightness B is averaged along a line of constant $\boldsymbol{\delta}$, the maximum brightness values occur when

$$\mathbf{B_{max} = 4K\sqrt{I_0 I_r}} \qquad \boldsymbol{\delta = (2n+1)\pi}, \quad \mathbf{n = 0, 1, 2\ldots}$$

Minimum values occurs when

$$\mathbf{B_{min} = 0} \qquad \boldsymbol{\delta = 2\pi n}, \qquad \mathbf{n = 0, 1, 2\ldots}$$

Consequently the correlated areas, i.e where $\boldsymbol{\delta = 2\pi n}$, appear dark on the monitor in subtractive ESPI. As a result, bright and dark fringes occur in areas of minimum and maximum correlation respectively. Pixels having the same brightness tend to generate macroscopic lines (fringes) in the resulting image I_d .

2.2 Design of inspection specimen

The inspection specimen used for the present study is an aluminium heat sink material with 1.5 cm diameter and 3 mm thickness. The heat sink is affixed with an LED (XML-L model from CREE, Inc.) to absorb heat generated by LED. The LED is powered by a driver circuit made up of **LM3405** IC which is basically a current-mode control switching buck regulator and a PWM controller designed using IC **NE555**.Figure.2 illustrates a schematic block diagram of LED driver circuit implemented in the experiment.

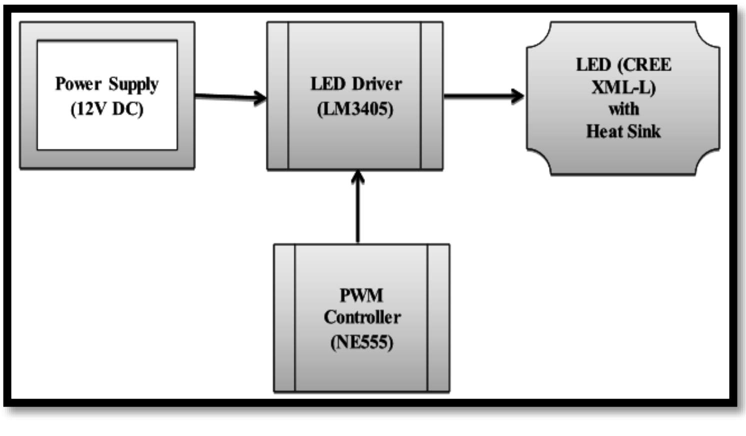

Figure 2.Schematic of LED driver circuit

The IC **LM3405** is a current-mode control switching buck regulator designed to provide a high efficiency solution for driving LEDs with a preset switching frequency of 1.6MHz. The current to LED can be controlled by PWM using IC **NE555**. The driver IC LM3405 is powered by a 12v dc supply. The actual snapshot of the inspection mechanism is shown in figure.3.

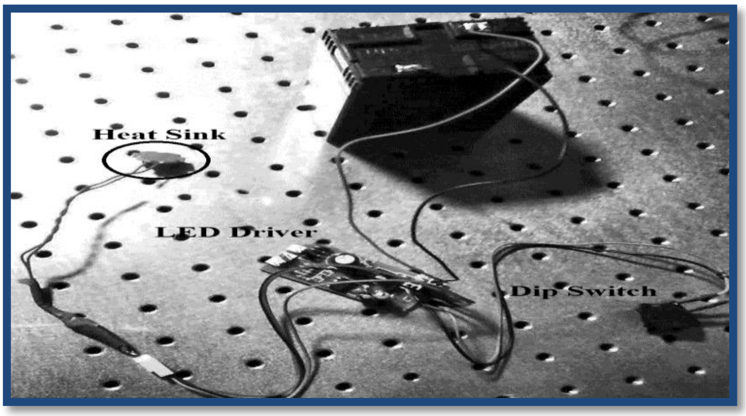

Figure 3.Snapshot of inspection system

III. EXPERIMENTAL DETAILS AND RESULTS

During the experiment, the LED is power-driven by means of a dip switch arrangement and the corresponding surface temperature variations of the heat sink are monitored by using a portable digital Infrared Thermometer (METRAVI MT-2). The surface temperature of the specimen is gradually varied from 20^0C to 90^0C and in the interim, the resultant speckle patterns are grabbed with the help of ESPI measurement facility. During this heating process, the temperature contrast developed on the surface of the specimen starts to generate thermal deformation phenomenon. During heating and cooling process, the interference fringes obtained from the subtracted speckle images before and after the deformation process are shown in figures 4 to 9.

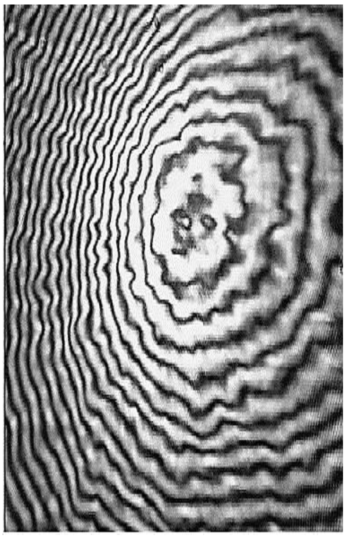

Figure 4.Interferogram at 20^oC

Figure 5. Interferogram at 50^oC

Figure 6.Interferogram at 80^oC

It can be observed that the heating up process (figures 4 to 6) produces higher fringe density since the expansion of the heated specimen has led to thermal deformation which initiates increase in optical path difference. Also the contraction of the specimen in natural cooling process (figures 6 to 9) has initiated the optical path difference to decrease thereby causing reduction in fringe density. Consequently, the quantities of interference fringes are decreased with the falling temperature.

Figure 7. Interferogram at 65ºC

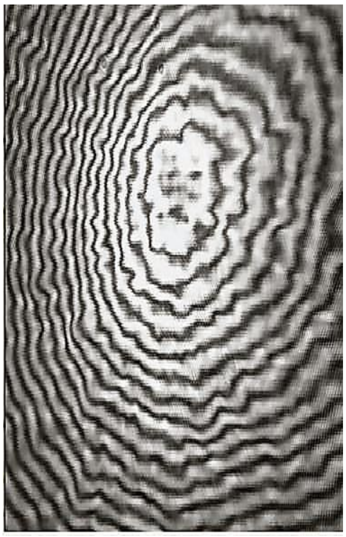

Figure 8.Interferogram at 45ºC

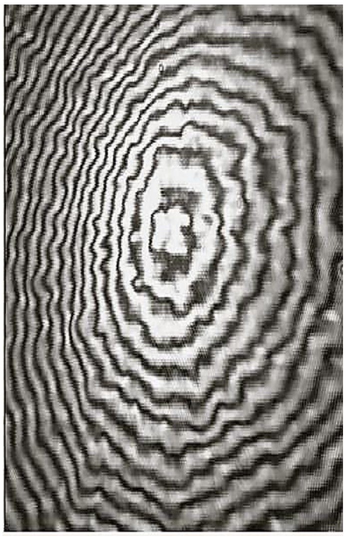

Figure 9.Interferogram at 25ºC

The experimental findings of those heating and cooling process are furnished in the following table 1and table 2 respectively.

Table 1.Heating up Process

Temperature (degree celsius)	Distance of fringes (millimetre)
20	2.46
30	1.68
35	1.54
40	1.18
45	.96
50	.83
55	.75
60	.64
70	.49
75	.45
80	.41

Table 2.Cooling off process

Temperature (degree celsius)	Distance of fringes (millimetre)
80	0.41
75	0.92
70	1.31
65	1.53
60	1.65
55	1.72
50	1.91
45	1.99
40	2.12
30	2.46
20	2.53

From the above experimental data, it can be understood that whether in heating or cooling process the metallic sample undergoes deformation with varying optical path difference. So it is evident that distance between the fringes is changed by the thermal deformation of aluminium heat sink material.
In response to those experimental data from table 1 and table 2, the following graphs (figure 10 & figure 11) show the descending and ascending temperature-fringe distance curves for both heating up and cooling off process respectively.

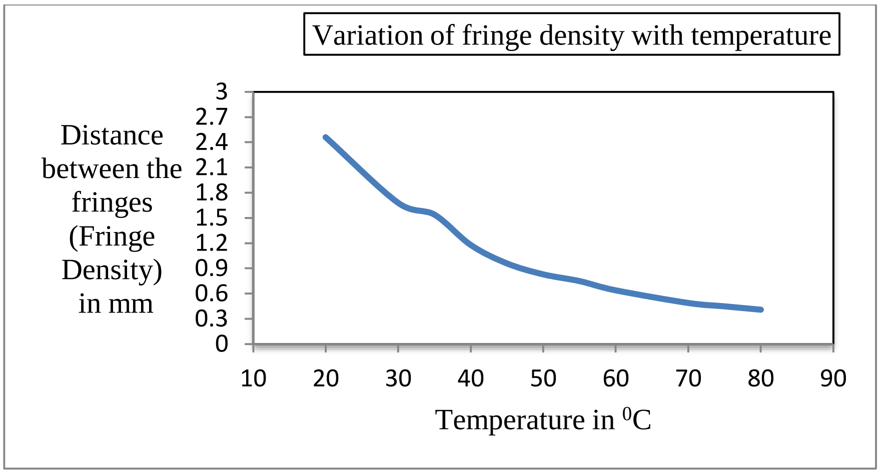

Figure 10.Heating process

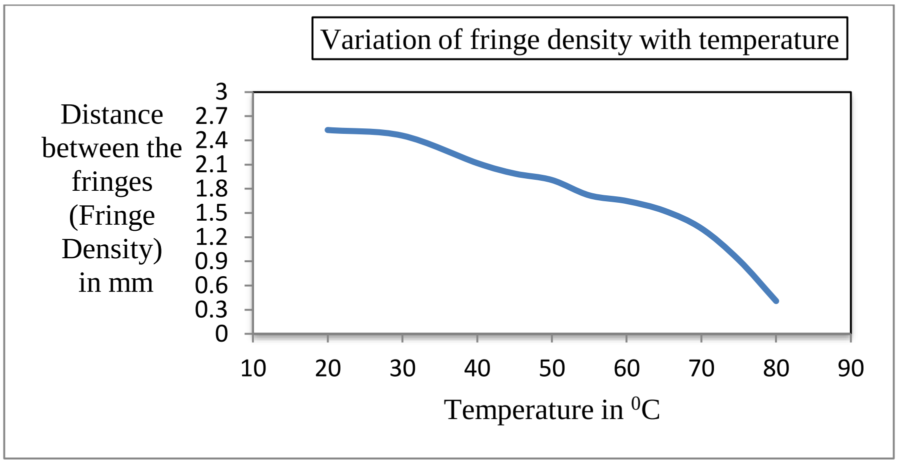

Figure 11.Cooling process

IV. CONCLUSIONS

The experiment thus interprets the fringe density as the physical quantity which clearly reveals the states of thermal deformations in the aluminium heat sink material. ESPI technique thus offers the possibility of monitoring deformation processes over a wide range of rates by stepwise change in loading parameters.

V. FUTURE PROSPECTS

ESPI method are lately being used as a tool for rapid quality assessment of Photovoltaic cells, evaluation of damage characterisation of glass/silica fibre, damage evaluation of polymer matrix composites, etc. Qualitative analysis of fringe patterns can easily reveal localized hotspots in micro-scale devices like electronic circuits, while the quantitative analyses can be used for predicting failure patterns in a nondestructive way.

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