EQUIVALENCE OF THERMAL AND MECHANICAL LOADS IN BIMATERIAL STRIPS WITH INTERFACE CRACKS

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Introduction

Electronic packages usually consist of bonded materials with different thermal and mechanical properties and bimaterial strips are the simplified models used to analyse these. Significant thermal stresses are induced in these due to large mismatch in coefficients of thermal expansion, even for small changes in the ambient temperature [1]. The interfaces are prone to crack initiations near the free edges due to the high stress gradients present [2]. A bimaterial strip subjected to whole field cooling by convection undergoes bending because of thermal expansion coefficient mismatch [3]. It is of interest to determine the equivalent mechanical bending load for a given thermal load on the bimaterial strip. To that end, in this paper, photoelasticity, an optical experimental technique used for stress analysis, is used to compare the whole field stress distribution in an Aluminium–Polycarbonate (PSM-1) bimaterial specimen with interface cracks subjected to pure bending and whole-field cooling by convection. Quantitative photoelastic data is evaluated for the whole-field using refined three fringe photoelasticity (RTFP) combined with colour adaptation [4,5]. In order to make a quantitative comparison, the stress intensity factors (SIFs) for the interface cracks are evaluated using the method of least squares [6].

Experimental analysis

Preparation of bimaterial specimens

Rectangular pieces of PSM-1 and aluminium of the same thickness (5.5 mm) are machined to the required dimensions. PSM-1 is selected because among the available photoelastic materials, its material properties [7] remain invariant in the range -10°C to 55°C and its thermal expansion coefficient is about six times higher than that of aluminium. Bonding is done using a suitable polyester adhesive. Teflon tapes with silicon grease applied on them are used to form the interface cracks at desired locations. After curing, these are easily removed forming the interface cracks. One specimen (Fig. 1a) is bonded at room temperature (28°C) and has a provision to apply 4-point bending load, while the other (Fig. 1b) is bonded slightly higher than room temperature (34°C).

Fig. 1 Bimaterial specimens with interface edge cracks shown for (a) bending (b) convection-cooling.

Experimental procedure

Photoelasticity is a whole-field optical experimental technique used for stress analysis. Using the dark-field circular polariscope arrangement, fringe contours of constant principal stress difference (isochromatics) are seen. For the thermal load, the specimen is allowed to reach steady state at room temperature, 6°C lower than the bonding temperature, while for the mechanical load, a bending moment (10 Nm) is applied to the aluminium portion. The specimens are placed in a circular polariscope and the dark-field isochromatics with a white light source are recorded using a 3CCD camera (Fig. 2a,b). It can be seen that the fringe patterns compare reasonably well qualitatively. Zoomed dark-field isochromatics for the region surrounding the crack tip are also recorded (Fig. 2c,d).

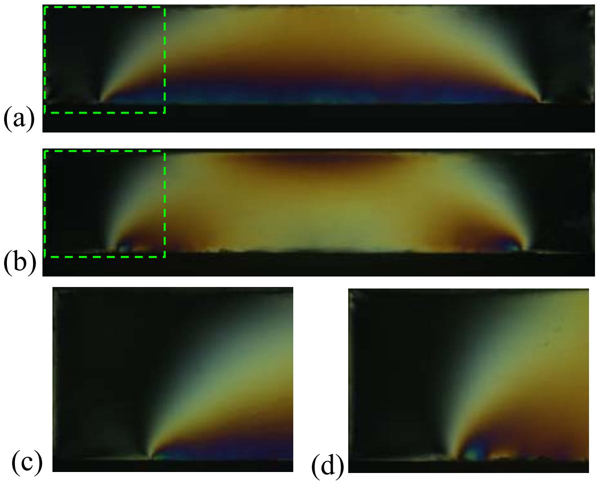

Fig. 2 Dark field isochromatics recorded in colour for bimaterial specimen under (a) thermal load (b) bending load (c,d) Zoomed isochromatics for the tiles shown in (a,b) respectively.

Isochromatic parameter estimation using RTFP

Quantitative evaluation of whole field isochromatic parameter, related to the principal stress difference, over the domain is made possible using a single tricolor image by RTFP [4] by suitably comparing the colour with a calibration specimen; fringe order continuity is ensured by using an additional term. Figures 3a and 3c show the image representations of the total fringe order obtained using RTFP. A *composite-field* image consisting of bright, dark and *mixed-field* fringes (fringes in steps of 0.25) is generated from the whole field fringe order data for ease of data extraction for SIF studies (Figs. 3b,d).

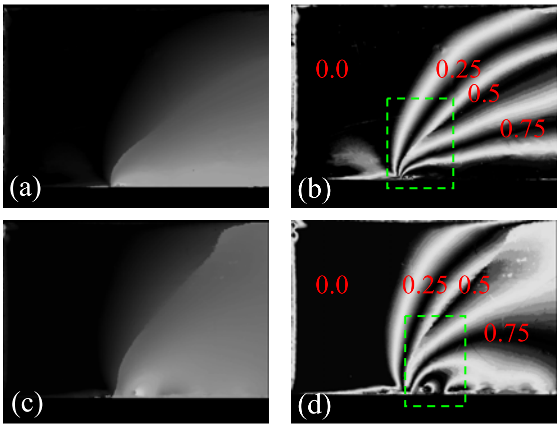

Fig. 3 Image representation of total fringe order for (a) thermal load (b) bending load. Generated composite field image for (c) thermal load (d) bending load.

SIF evaluation

The method of least squares described in Ref. [6] is used to evaluate the multi-parameters governing the stress field, iteratively. The fringe order and the corresponding positional coordinates at fringe locations are collected from the composite field fringe order data. Since the number of parameters involved in characterizing the stress field are not known *a priori*, the iteration is started with two parameters each of K_I and K_{II} series and stopped using the fringe order error minimization criteria. Using the solution of the parameters thus obtained as starting values, the number of parameters in each series is increased until the convergence error is less than 0.05, and the fringe field reconstructed from the evaluated stress field parameters closely matches the collected data points. It can be seen from Figs. 4a and 4b that the reconstructed fringe field closely matches the collected data points. The evaluated SIFs are tabulated in Table 1.

Table 1. SIFs of the bimaterial interface cracks

Load	**No. of terms**	$\mathbf{K_I}$ $\mathrm{MPa}\sqrt{m}$	$\mathbf{K_{II}}$ $\mathrm{MPa}\sqrt{m}$	$\mathbf{\lvert K \rvert}$ $\mathrm{MPa}\sqrt{m}$
Thermal	6	0.025	0.048	0.054
Bending	5	0.034	0.035	0.049

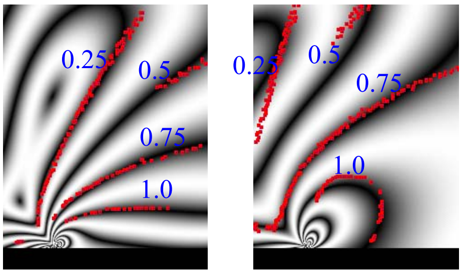

Fig. 4 Composite field image reconstructed from evaluated stress field parameters with data points echoed for (a) thermal load (b) bending load for tiles shown in 3(b,d) respectively.

Closure

A study of bimaterial strips with interface cracks subjected to thermal and mechanical loading conditions has been carried out using recent advances in digital photoelasticity. The SIFs which characterize the crack tip stress fields have been evaluated using the method of least squares. For the thermal load, the shear mode is found to be dominant, while for the mechanical load, both modes are equally present (Table 1). A small variation in ambient temperature of 6^{o}C, produces stress levels at the interface which are reasonably close to the stress levels produced on application of a bending moment of 10 Nm. Thus in design, when materials of different thermal and mechanical properties are bonded together, it is of utmost importance to study the temperature fluctuations that it might be subjected to.

References

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