Evaluating Thermal Stresses from Measured In-plane Displacements Based on the Principle of Superposition

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Abstract. In this study, a hybrid experimental-numerical method that combines finite element analysis and digital image correlation is proposed to evaluate thermal stresses. This method allows the thermal strain and stress of a specimen made of different materials to be obtained. In addition, the proposed method utilizes measured displacement data of the entire analysis object, so reliable results can be obtained. In this method, the distribution of thermal loads is identified inversely from the measured displacement data based on the principle of superposition. At the same time, the thermal strains and thermal stresses can be obtained. As a result, the thermal stresses that appear due to the difference in thermal expansion coefficients can be obtained.

Introduction

Electronic packages have been miniaturized and highly integrated for weight saving and the performance improvement. Damages such as wire and solder debonding occur by thermal strains caused by the difference of the thermal expansions between materials in a package. Therefore, in order to ensure the structural reliability electronic packages, the development of a quantitative evaluation technique of thermal stresses is required. Thermal stresses are usually evaluated through a simulation using finite element analysis. However, with the miniaturization and the complication of structures, it is difficult to obtain reliable results by finite element analysis. Because of the heterogeneity and the complication of electronic packages, full-field optical methods such as moiré interferometry have long been used for measuring thermal strains [1].

Generally, the optical methods provide only the information of surface displacements. In other words, stresses and strains cannot be obtained directly by these methods. Therefore, it is required to differentiate displacement distributions to obtain strains. However, the numerical differentiation of measured data has the disadvantage that the errors in the measured values cause the greater errors in their derivatives. Furthermore, the temperature distribution needs to be measured to obtain the stresses from the strains. In order to obtain the accurate and reliable strains, one author [2] has developed an experimental-numerical hybrid method for evaluating strains from measured displacement fields. In this method, nodal forces along boundaries of a finite element model are inversely determined from displacement distributions obtained using digital image correlation. Then, smooth and reliable strain distributions are obtained. This method has been expanded to thermal strain analysis [3]. Nodal forces not only at boundaries but also inside a model are needed to be determined for thermal strain analysis. However, the stresses cannot be obtained because the temperature distributions cannot be identified.

In the present study, an inverse method for thermal stress evaluation is proposed. The displacement fields subjected to thermal load are measured using digital image correlation. The thermal loads at nodes of a finite element model are inversely identified from the measured in-plane displacements based on the principle of superposition using the method of least-squares with regularization. The effectiveness of the proposed method is demonstrated by applying it to the displacement fields of a dissimilar materials specimen. Results show that the proposed method allows the determination of stress distribution due to temperature change from the measured displacements.

Stress Analysis of Dissimilar Materials Specimen

A bimaterial plate made of an oxygen-free copper and a structural rolled steel, 20mm in width, 16mm in height, 2.9mm in thickness is used as a specimen. A finite element model is used for the proposed inverse analysis. In this model, 8-noded isoparametric elements are used. The numbers of the element and the node are 320 and 1033, respectively. The specimen is subjected to the uniform thermal load of 108 K in the heating chamber. Figure 1 shows the surface image of the specimen, and the displacements obtained using digital image correlation, which are used as the data input into the algorithm by the proposed method. Figure 2 shows temperature distribution inversely determined from measured displacements without and with the regularization. As shown in Fig. 2(a), the uniqueness of the solution is not guaranteed in this inverse problem. Furthermore, the measurement error affects the results. With the proposed regularization, the temperature distribution is obtained as shown in Fig. 2(b).

Figure 3(a) shows the distribution of the normal stress in the *y* direction obtained by the proposed method from the displacements in Fig. 1(b). The stress distribution is compared with that obtained using a finite element method shown in Fig. 3(b). As shown in these figures, the stress distribution obtained using the proposed method agree well with that obtained using the finite element method.

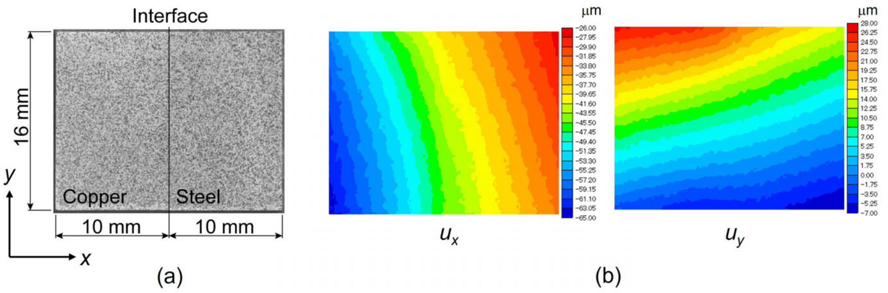

Fig. 1 (a) Image of dissimilar materials specimen and (b) in-plane displacements under thermal load (ΔT = 108 K)

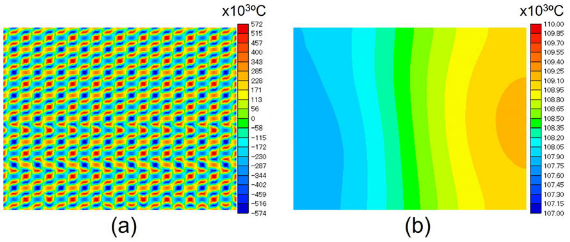

Fig. 2 Temperature distribution obtained (a) without regularization and (b) with regularization

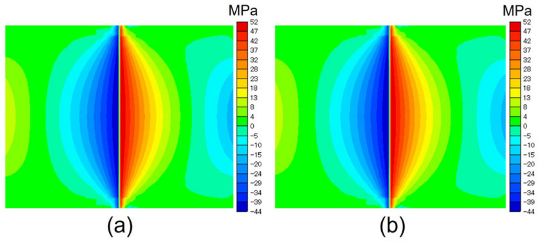

Fig. 3 Normal stress in the y direction obtained using (a) the proposed method and (b) FEM

Stress Analysis of Electronic Device Imitation Specimen

Figure 4 illustrates a specimen simulating an electronic device. A thermal load is applied to the specimen and the in-plane displacements are measured using digital image correlation. Then, the thermal stresses are evaluated using the proposed method. Figure 5 shows the strain and stress distributions obtained using the proposed method under the temperature change of 100 K. It is observed that the normal strain in the x direction concentrates in the aluminum wire part due to its high thermal expansion coefficient. Meanwhile, the negative normal stress in the x direction is observed at the aluminum wire part in Fig. 5(b). Since the aluminum wire is constrained by its surroundings so as not to expand, the compressive stress is generated in this part.

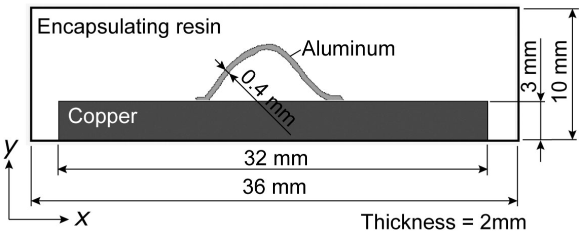

Fig. 4 Specimen imitating electronic device

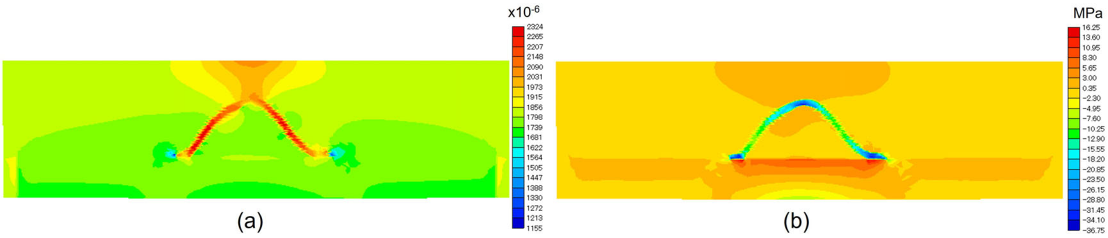

Fig. 5 Distribution of (a) normal strain and (b) normal stress in the x direction (ΔT = 100 K)

Conclusions

In this study, an inverse analysis method for determining stresses under thermal load is proposed. Nodal thermal loads of a finite element model induced by temperature change are inversely determined from measured displacements inside the analysis region. Then, the strain and stress distributions are obtained. Effectiveness of the proposed method is demonstrated by analyzing the strains of a bimaterial specimen and a specimen simulating an electronic device.

References

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