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Thermo-Mechanical Stress Analysis in Electronic Packaging with Continuous and Partial Bond Layer

D. Sujan[1,a], T. K. Piaw[1b], Dereje E. Woldemichael[2c]

[1]Curtin University, Sarawak Malaysia, 250 CDT, 98009 Miri, Sarawak Malaysia

[2]Universiti Teknologi PETRONAS, Mechanical Engineering Department, Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia

[a]d.sujan@curtin.edu.my; [b]7D8A5887@student.curtin.edu.my,
[c]dereje.woldemichael@petronas.com.my

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Abstract. Interfacial stress due to thermal mismatch in layered structure has been considered as one of the major causes of mechanical failure in electronic packaging. The mismatch due to the differences in coefficient of thermal expansion (CTE) of the materials in multi-layered structure may induce severe stress concentration to the electronic composites namely interfacial delamination and die cracking. Therefore, the studies and evaluation of interfacial stress in electronic packaging become significantly important for optimum design and failure prediction of the electronic devices. The thermal mismatch shear stress for bi-layered assembly can be analyzed by using the mathematical models based on beam theory. In this study, Finite Element Method (FEM) simulation was performed to an electronic package by using ANSYS. The shear stress growth behavior at the interface of the bonded section was studied with the considerations of continuous and partial bond layers in the interfaces. Based on the analysis, it can be observed that the partial bond layer with small center distances can be simplified as a continuous bond layer for bi-layered shearing stress model analysis.

Introduction

In electronic packaging,namelymother board, power electronics devices, circuit boards and semiconductor devices, dissimilar materials are bonded together to form laminated structures. Therefore, interfacial stresses are induced between two dissimilar layers due to thermal mismatch. The interfacial stresses are mainly induced due to CTE mismatch occurred during manufacturing and operating stages which cause the overall bending of the assembly [1]. Interfacial stresses due to thermal mismatch usually contribute structural failure to the electronic package such as interfacial delamination and die cracking which cause the failure of transfer in electronic signals or malfunction of the entire system. Thus, thermo-mechanical reliability of microelectronics devices becomes one of the major concerns of the electronic industry [2].

Therefore, applying analytical solutions to predict the magnitude and the distribution of interfacial stresses in multilayer structures has been widely adopted by many electronic packaging and Micro-Electro-Mechanical System (MEMS) researchers [3]. In reality, the bi-layered electronic assemblies such as micro and Opto-electronics are adhesively bonded or soldered [4]. Moreover, the bi-layered electronic model can be a useful reference for similar scenarios such as wall painting or adhesive layers. Bi-layered analytical model was first developed by Suhir solving an intergra-differential equation for interfacial compatibilitybased on the popular beam theory proposed by Timoshenko [5]. In this research, interfacial stresses developed in continuously and partially bonded layers are analyzed using FEM simulation.

A. Bi-layered assembly with continuous bond under uniform temperature change

Fig 1 shows the full length of the model analyzed. The model length is taken as $2L$. In the 2-Dimentional model, it is considered to be of unit width in a direction perpendicular to the plane of the paper and the forces and moments are defined with respect to the unit width. Here, i = 1, 2, material /layer number, Fi = force, Mi = moment, and hi = layer thickness (mm). A temperature change, ΔT is assigned to the entire model.

Including the solder bond layer thickness, the strain compatibility condition at the interface can be expressed as

$$\in_{x(1)} - \in_{x(2)} = K_0 \frac{\partial \tau}{\partial x} \quad (1)$$

The axial strains at the interface take the form as [6, 7],

$$\left.\begin{aligned} \in_{x(1)} &= \alpha_1 \Delta T + \lambda_1 F_1 + \frac{h_1}{2R} - K_1 \frac{\partial \tau}{\partial x} \\ \in_{x(2)} &= \alpha_2 \Delta T - \lambda_2 F_2 - \frac{h_2}{2R} + K_2 \frac{\partial \tau}{\partial x} \end{aligned}\right\}, \quad (2)$$

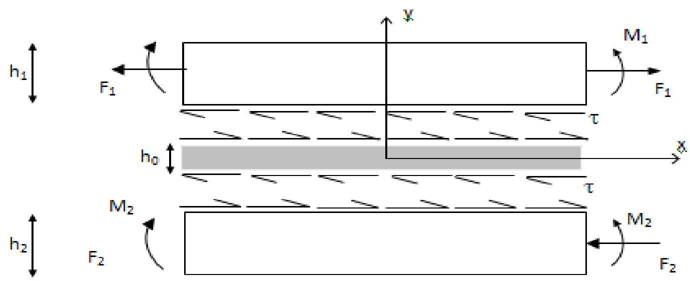


Fig. 1: Free body diagram of continuous bond layer [6-8]

where $K_0$is the interfacial compliance coefficient of the bond layer.

Applying the strain terms from eq. (2) in to eq. (1), the shear stress model with bond layer effect is expressed as

$$\tau(x) = \frac{(\alpha_1 - \alpha_2)\Delta T}{K\mu \cosh(\mu L)} \sinh(\mu x) \quad (3)$$

The above model is same as the shear stress expression for perfectly bonded assembly expressed by Suhir [5]. In eq. (3), the thickness parameters h, axial compliance parameter λ and the equivalent interfacial compliance parameter$K$are expressed as follows:

$$h = h_1 + h_2 + 2h_0; \quad \lambda = \lambda_1 + \lambda_2 + \frac{h(h_1 + h_2)}{4D}; \quad K = K_1 + K_2 + K_0$$

B. Bi-layered assembly with continuous bond: A case study

The properties of the material of the packaging assembly example are shown in Table 1.

Table 1: Bi-layered Assembly with continuous bond Material Properties

Properties	*Symbol*	*Layer*		
		1	2	0
Young Modulus (GPa)	E	188	49.7	70.5
Poisson's ratio	v	0.3	0.29	0.41
CTE (1/°C)	α	$3.0\text{x}10^{-6}$	$2.5\text{x}10^{-5}$	$1.68\text{x}10^{-5}$
Thickness (m)	h	3.5x10-4	1.5x10-4	1.0x10-5
Length (m)	L	0.0025		
Temperature	ΔT	60°C	60°C	60°C

For FEM analysis, 2*D* model is considered to verify the analytical results. Since the system is symmetric, for 2*D,* half of the model is analyzed. Results are presented from *x/L* = 0.7 to 1 only because the stresses values are considered insignificant beyond this point. It can be seen that the FEM shows very good agreement with the analytical results except beyond the region around the interfacial edges where *x/L*> 0.95. According to [8-9], those singularities are indicated as a boundary layer edge effect. According to [9],those singularitiesare merely because FEM models are based on elasticity clarification which predicts that stresses approach infinity at the free edge and cause FEM results inaccurate at the free edge.

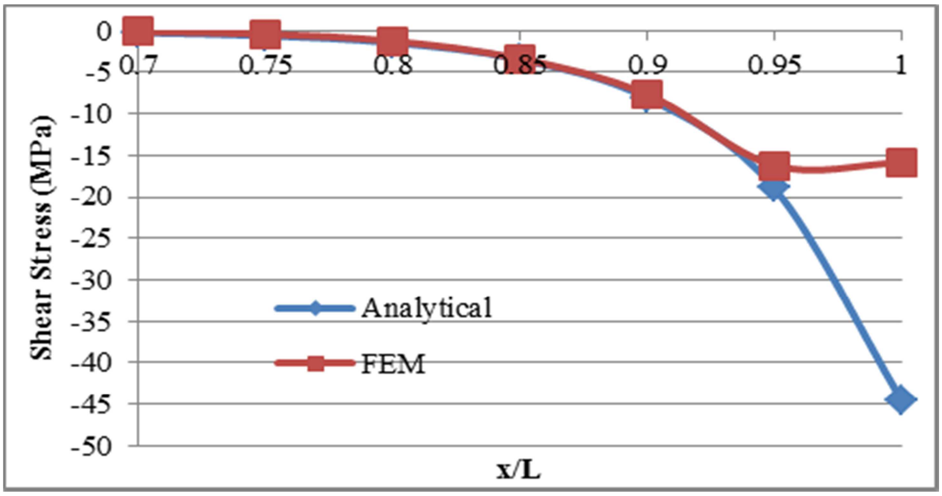
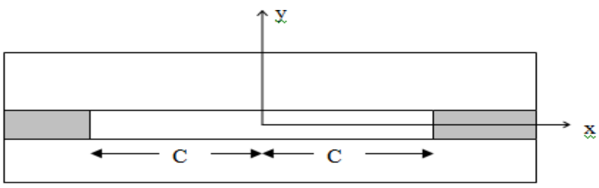


Fig. 2: Comparison of shear stress between analytical and FEM solution for bi-layered assembly with continuous bond

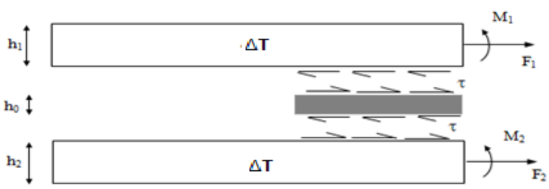
BI-LAYERED ASSEMBLY MODEL WITH PARTIAL BOND

A. Bi-layered assembly with partial bond under uniform temperature change

Fig. 3 (a) represents a model of a unit section of a partially bonded bi-layered assembly where *C* is the center distance between two solder balls. Fig. 3 (b) shows the free body diagram of half of the model of Fig. 1 with forces and moments notations



3(a)



3(b)

Fig. 3(a): The model of a unit section of a partially bonded bi-layered assembly;Fig. 3 (b) The free body diagram of half of the model [10]

In terms of compatibility condition, the displacement on the top and bottom surfaces of the bond section to the shear stress is same as eq. (1)

The equation for the shearing stress τ can be expressed as

$$\tau = C_1 \sinh \kappa(x - C) + C_2 \cosh \kappa(x - C) \quad (4)$$

Based on [9], manipulating eq. (2) and (4) and applying boundary conditions, can obtain,

$$C_2 = C_1 \kappa C \quad (5)$$

and

$$C_1 = \frac{(\alpha_1 \Delta T_1 - \alpha_2 \Delta T_2)}{K\mu\left[\mu\, C \sinh\mu(L - C) + \cosh\mu(L - C)\right]} \quad (6)$$

Replacing the expressions for C_1 and C_2 from eq. (5) and (6)into (4), the equation for shearing stress for partial bond can be expressed as:

$$\tau = \frac{\Delta T(\alpha_1 - \alpha_2)\left[\sinh \kappa(x - C) + \kappa C \cosh\kappa(x - C)\right]}{K\kappa\left[\kappa C \sinh \kappa(L - C) + \cosh \kappa(L - C)\right]} \quad (7)$$

B. Partial bond with different centre distances (*C*): A case study

A case study of the bi-layered assembly with partial bond was conducted. The properties of the material of the assembly are maintained same as in Table I. In this case study, the center distance, *C* = 0.0015m, 0.00175m and 0.0020m are considered in order to observe and compare the shear stress induced in different location of partial bond sections. The interfacial shear stresses are analyzed by using analytical and FEM approach and compared.

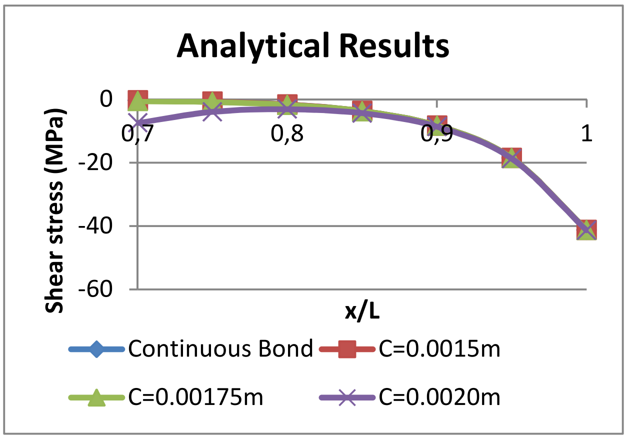


Fig. 4: Shear stress distribution of analytical results for bi-layered assembly with partials bond

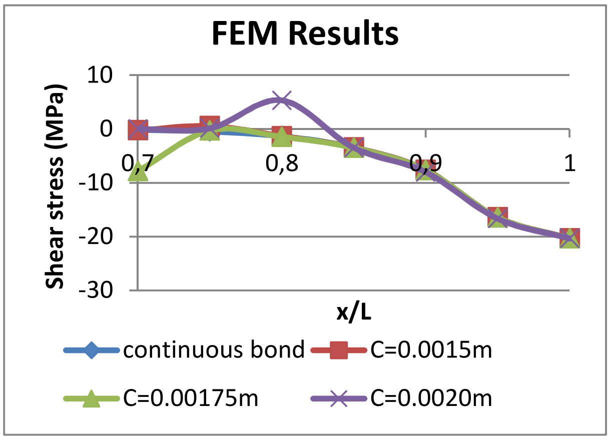


Fig. 5: Shear stress distribution of FEM results for bi-layered assembly with partial bond

Fig. 4 shows the analytical results for continuous and partial bond with different *C* values. The comparison is presented for only the region near the free end of the assembly since it is the area where the partial bond is located and therefore, shear stress generated most significantly. It is observed from Fig. 4 that the analytical results of partial bond for *C* = 0.0015m and 0.0175m are in good agreement with the analytical results of continuous bond along the length of the interface. However, the results for *C* = 0.0020m, itdisagrees with the continuous bond case at the region *x/L* =

0.7 to 0.8. This might have been resulted since the bond area for C = 0.0020 was located from x/L = 0.8 to 1 (practically there is no bonding at this location) which had resulted the inaccuracy in the solution. Moreover, the stress value at the location x/L = 0.7 to 0.8 are quite insignificant compared to the stress values at location at x/L = 1. Therefore, the above disagreement can be ignored. Fig. 5 shows the FEM results for continuous and partial bond with different C. From the plot, it can be observed that the FEM results are in good agreement at the free end where x/L is approximately from 0.85 to 1. However, the results for C = 0.00175m and 0.0020m at the region x/L = 0.7 to 0.85 are not in good agreement with the other two cases. As mentioned earlier this might be due to the location of partial bond as explained above. Thus it concludes that the bi-layered electronic packaging with partial bond can be simplified as a continuously bonded assembly for analysis.

CONCLUSION

The shearing stress thermal mismatch bi-layered model was analyzed with the consideration of continuous and partial thin bond layer sections. The analytical and FEM results for continuous and partial bond with small center distance were found in good agreement except the free endwhich isindicated as a boundary layer edge effect. Based on the analysis, it can be concluded that the partial bond layer with small center distances can be assumed as a continuous bond layer for bi-layered shearing stress model analysis. The research work presented in this paper is expected to be a useful reference to address thermo-mechanical stress in electronic packaging in order to minimize mechanical and functional failures.

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