ICMIEE18-330

Influence of Interlayer Thickness on the Singular Stress Field in 3D Three-Layered Bonded Joints Using FEM

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ABSTRACT
Bonded joint is widely used in different fields of science and technology, especially in making electronic chip. Every bonded joint may have vertex at the interface which is the region where joint may fail under mechanical or thermal loading due to propagation of stress singularity. The propagation of stress singularity is highly governed by interlayer thickness. It is necessary to investigate the influence of interlayer thickness on the propagation of stress singularity at the vertex to avoid stress singularity to prevent bonded joint from being deboned. In the present paper, a tri-material bonded joint composed of SiC, Resin (interlayer) and SiN is used to investigate the phenomenon. This model has better electro-mechanical property than a chip made by silicon only. The interlayer thickness is varied to analyze its influence on stress singularity through FEM using ABAQUS 6.14 software. It is found from the analysis that stress singularity increases with the increase in interlayer thickness and vice versa.

Keywords: Finite Element Method, Interlayer thickness, Interface, Stress singularity, External load.

1. Introduction

In this tri-material joint, SiC is used as upper material, Resin as middle material and SiN at the bottom. This model has high thermal conductivity, high die-electric breakdown and wide band gap than silicon.

As it consists of three different materials with an inter-layer, there is a probability of occurring stress singularity at the vertex of interfaces. So, it is necessary to investigate the variation of stress singularity with inter-layer thickness. Williams analyzed stress singularity for different boundary conditions in angular corner of extended plate [1]. Aksentian investigated stress-strain state of singularities of a plate near an edge [2]. Hartranft analyzed stress singularity resulting from crack having an arbitrary curved front [3]. Munz and Yang investigated stress singularity at the interface of dissimilar material bonded joint due to thermal and mechanical loading [4]. Munz, Matthias and Yang determined thermal stresses in ceramic-metal joint having an inter-layer [5]. Pengfei, Ishikawa and Kohno analyzed order of stress singularity at the corner of a diamond shaped rigid inclusion under bending [6]. Hideo Koguchi analyzed stress singularity at three dimensional bonded joints [7]. Barut, Guven and Madenci investigated singular stress field at multiple dissimilar material joints due to mechanical and thermal loading [8]. Ioka, Masuda and Kubo analyzed singular stress field at bonded dissimilar material joint's interface with an interlayer [9]. Hideo Koguchi and Masato Nakajima investigated how intensity of singular stress field varies with interlayer thickness in three-dimensional three-layered joint due to external load using boundary element method [10].

In this paper, the influence of interlayer thickness on singular stress field is analyzed in tri-material joint consisting SiC, Resin and SiN using Finite Element Method through ABAQUS 6.14 software.

2. Formula of analysis

The stress for three-dimensional isotropic material is determined from following relation [11]:

Consider a body subjected to normal stress σ_r, σ_θ and σ_ϕ independently.

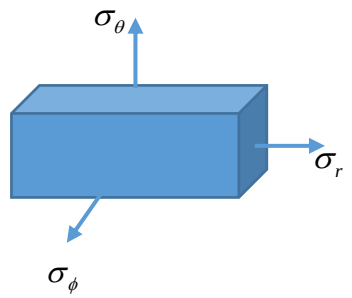

Fig.1 Body subjected to normal stress

The positive stress in the r direction produces positive strain in that direction

$$\varepsilon_r^{'} = \frac{\sigma_r}{E} \tag{1}$$

The positive stress in the θ direction produces negative strain in the r direction due to Poisson's effect

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$$\varepsilon_r'' = -\frac{\nu\sigma_\theta}{E} \tag{2}$$

The positive stress in the Φ direction produces negative strain in the r direction due to Poisson's effect

$$\varepsilon_r''' = -\frac{\nu\sigma_\phi}{E} \tag{3}$$

By superimpose,

$$\varepsilon_r = \frac{\sigma_r}{E} - \frac{\nu\sigma_\theta}{E} - \frac{\nu\sigma_\phi}{E} \tag{4}$$

Similarly,

$$\varepsilon_\theta = -\frac{\nu\sigma_r}{E} + \frac{\sigma_\theta}{E} - \frac{\nu\sigma_\phi}{E} \tag{5}$$

$$\varepsilon_\phi = -\frac{\nu\sigma_r}{E} - \frac{\nu\sigma_\theta}{E} + \frac{\sigma_\phi}{E} \tag{6}$$

Solving these equations, we obtain,

$$\sigma_r = \frac{E}{(1+\nu)(1-2\nu)}\left[\varepsilon_r(1-\nu) + \nu\varepsilon_\theta + \nu\varepsilon_\phi\right] \tag{7}$$

$$\sigma_\theta = \frac{E}{(1+\nu)(1-2\nu)}\left[\nu\varepsilon_r + (1-\nu)\varepsilon_\theta + \nu\varepsilon_\phi\right] \tag{8}$$

$$\sigma_\phi = \frac{E}{(1+\nu)(1-2\nu)}\left[\nu\varepsilon_r + \nu\varepsilon_\theta + (1-\nu)\varepsilon_\phi\right] \tag{9}$$

Again, for shear stress

$\tau_{r\theta} = G\gamma_{r\theta}, \tau_{\theta\phi} = G\gamma_{\theta\phi}, \ \tau_{\phi r} = G\gamma_{\phi r}$

In matrix form, stresses can be written as

$$\begin{Bmatrix} \sigma_r \\ \sigma_\theta \\ \sigma_\phi \\ \tau_{r\theta} \\ \tau_{\theta\phi} \\ \tau_{\phi r} \end{Bmatrix} = l \begin{bmatrix} 1-\nu & \nu & \nu & 0 & 0 & 0 \\ \nu & 1-\nu & \nu & 0 & 0 & 0 \\ \nu & \nu & 1-\nu & 0 & 0 & 0 \\ 0 & 0 & 0 & m & 0 & 0 \\ 0 & 0 & 0 & 0 & m & 0 \\ 0 & 0 & 0 & 0 & 0 & m \end{bmatrix} \begin{Bmatrix} \varepsilon_r \\ \varepsilon_\theta \\ \varepsilon_\phi \\ \gamma_{r\theta} \\ \gamma_{\theta\phi} \\ \gamma_{\phi r} \end{Bmatrix}$$

Where,

$$l = \frac{E}{(1+\nu)(1-2\nu)}, \ m = \frac{1-2\nu}{2}, \ G = \frac{E}{2(1+\nu)}$$

3. Model of analysis

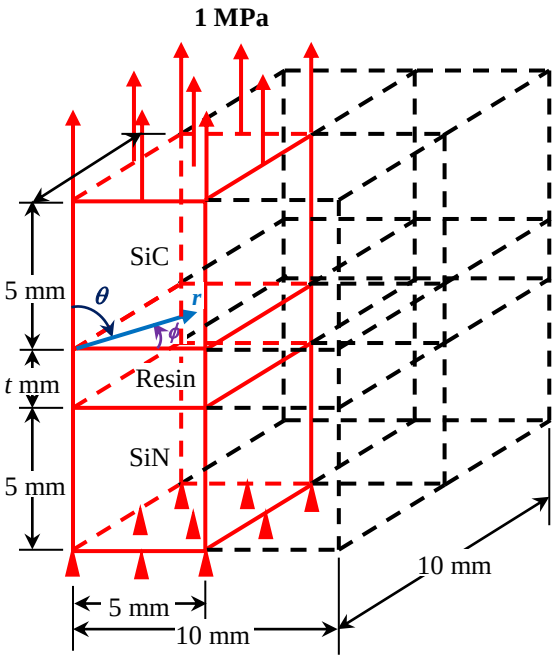

Fig.2 Model for Finite Element Method analysis

The lower surface is kept fixed. A 1MPa force is applied on the upper surface. The thickness of resin is varied to investigate its influence on singular stress field at the vertex using linear hexagonal element. Due to symmetry one-fourth of the model is analysed.

Table 1 Property of isotropic material.

	SiC	Resin	SiN
Young's modulus, E (GPa)	450	2	295
Poisson's ratio, υ	0.22	0.39	0.22

4. Accuracy verification

In this paper, Finite Element method result is compared with a journal paper [10] working on Boundary Element Method with maximum error of 0.88%. The minimum and maximum element size are 0.0001mm and 1mm respectively with 2326581 elements.

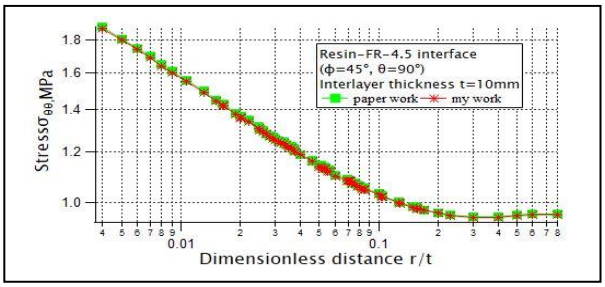

Fig.3 Accuracy verification of the present analysis

5. Checking mesh dependency

For interlayer thickness 5mm the number of element is varied from 48thousands to 6lac. But stress does not vary when the number of element is 5lac or above. Results are taken with approximately 5lac element.

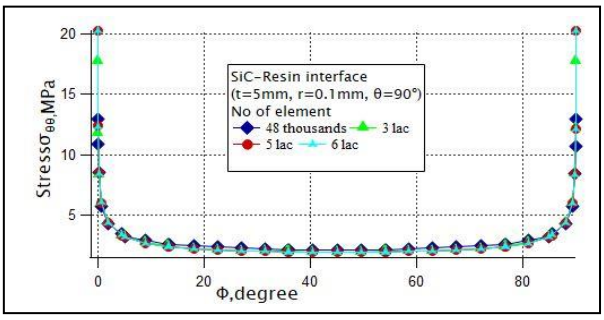

Fig.4 Mesh dependency check of the present model

6. Result and discussion

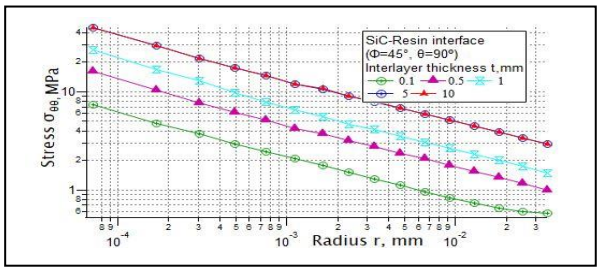

Fig.5 Distribution of stress $\sigma_{\theta\theta}$ against radius, r

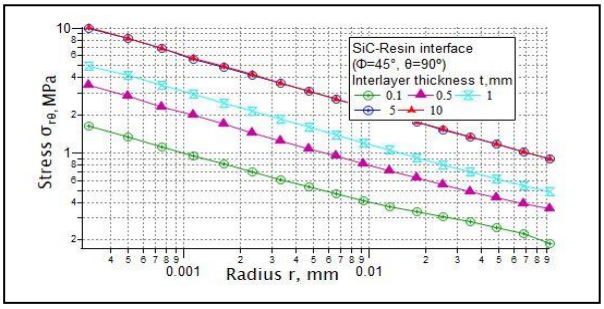

Fig.6 Distribution of stress $\sigma_{r\theta}$ against radius, r

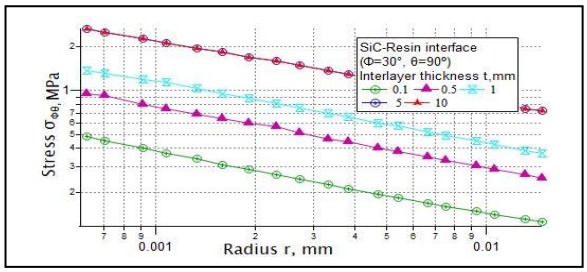

Fig.7 Distribution of stress $\sigma_{\phi\theta}$ against radius, r

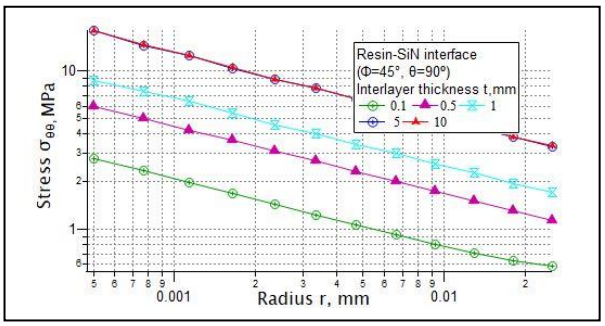

Fig.8 Distribution of stress $\sigma_{\theta\theta}$ against radius, r

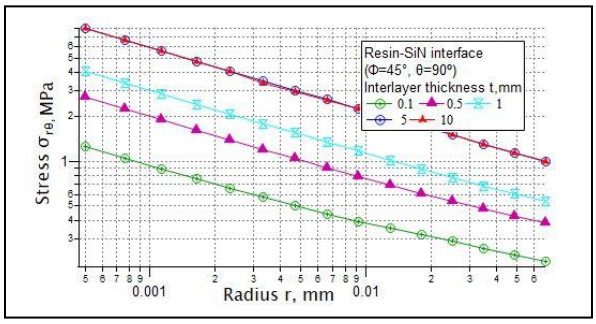

Fig.9 Distribution of stress $\sigma_{r\theta}$ against radius, r

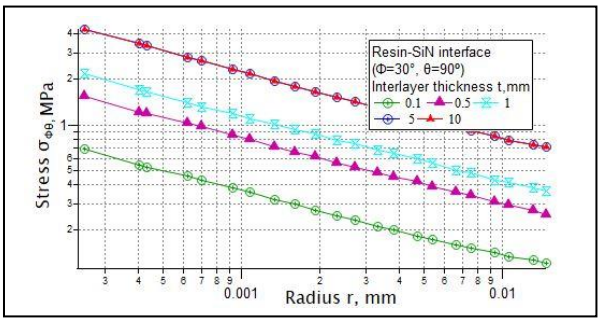

Fig.10 Distribution of stress $\sigma_{\phi\theta}$ against radius, r

Stress is plotted against radial distance, *r* from figs. 5 to 10 for various interlayer thickness. It is shown that stress increases with the increase in interlayer thickness. Also stress is maximum at the vertex and decreases with radial distance. So the bonded joint can be deboned at the vertex. There is more possibility of failure near the vertex or corner than inner portion of the joint.

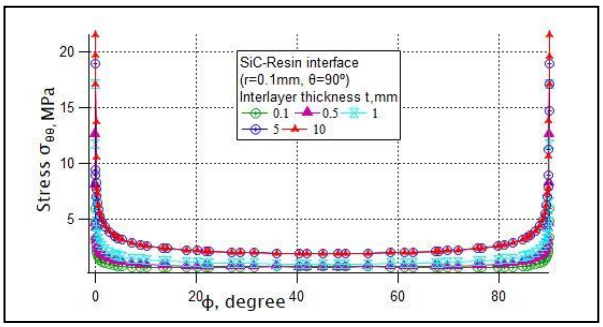

Fig.11 Distribution of stress $\sigma_{\theta\theta}$ against angle, ϕ

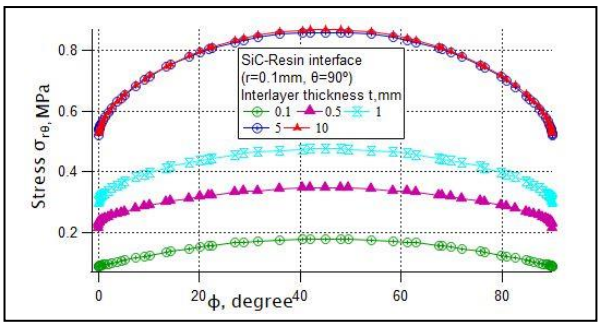

Fig.12 Distribution of stress $\sigma_{r\theta}$ against angle, ϕ

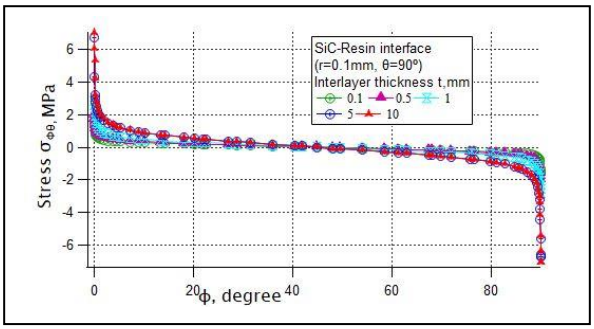

Fig.13 Distribution of stress $\sigma_{\phi\theta}$ against angle, ϕ

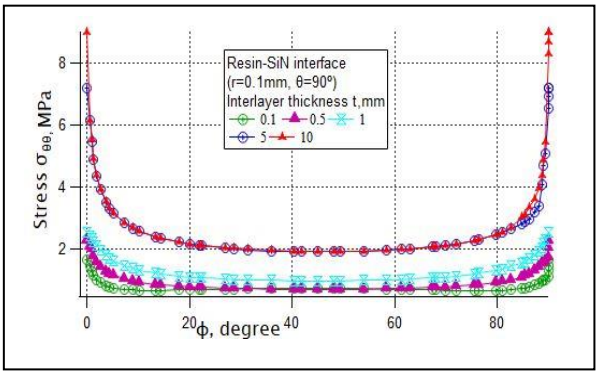

Fig.14 Distribution of stress $\sigma_{\theta\theta}$ against angle, ϕ

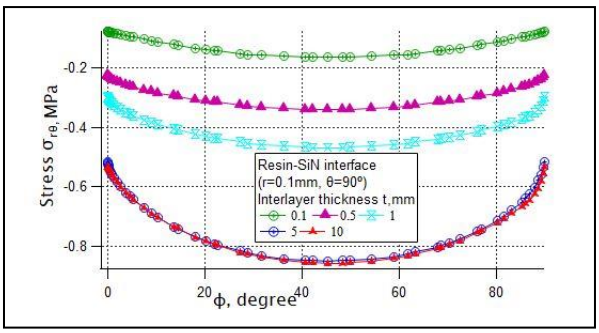

Fig.15 Distribution of stress $\sigma_{r\theta}$ against angle, ϕ

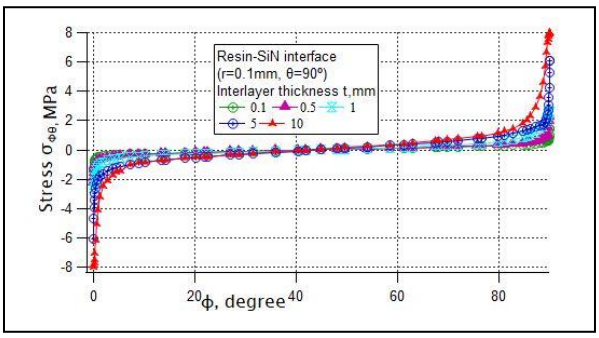

Fig.16 Distribution of stress $\sigma_{\phi\theta}$ against angle, ϕ

Figs. 11 to 16 show variation of stress against angle ϕ *at* θ=90° for various interlayer thickness. It is shown that stress increases with the increase in interlayer thickness similar to previous one. Also stress is maximum near interface edge and decreases along inner portion. So there is also the possibility of the joint to be deboned near interface edge.

7. Conclusion

In the present paper, the stress distribution of a tri-material joint was analyzed. Stress increases with the increase in interlayer thickness. Farther more, stress is maximum near the vertex and interface edge where the joint may be deboned.

NOMENCLATURE

σ : Stress, MPa
ε : Strain
E : Young modulus, MPa
ν : Poisson ratio
r : Distance from origin, mm
t : Interlayer thickness, mm
ϕ : Angle, degree
θ : Angle, degree

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