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INFLUENCE OF BOND LAYER ON TRI-MATERIAL ASSEMBLY SUBJECTED TO TEMPERATURE CHANGE

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Abstract

When two layers are bonded together in electronic circuit board, an extremely a thin layer of third material exists in between two layers called bonding material. The thermo-mechanical stresses or interfacial stresses are induced in the tri-material assembly under different temperature conditions. This thermal mismatching stress is one of the reasons for the structural failure between two or more connected devices. Therefore, it is very essential for understanding and accurate estimation of induced stresses in the interfaces as they play an important role in the design and reliability in micro-electronic devices. In the present investigations, a model is proposed for the shearing and peeling stresses occurring at the interface of three bonded thin layer of dissimilar materials in between the tri-layer assembly to account for unknown different temperatures. It is found that the shearing stresses and peeling stresses decreased considerably at the interface with the increase of bond layer thickness up to optimum value.

Keywords— Tri-layer assembly, Bond layer, Shearing stress, peeling stress, Compliance, Uniform temperature.

1. Introduction

From last twenty years, it is known fact that the electronics industry is one of the fastest developing industries. Electronic circuit boards and its components are usually operating at higher temperature conditions. Thermal loading takes place during the normal operation of electronic circuit, structures, packages, equipment, and systems, as well as during their fabrication, testing, transportation, or storage [1]. Thermal stresses, strains and displacements are the major contributors to today's structural and environmental failures of the equipment. If the heat, produced by the chip, cannot readily escape, then the high thermal stress in the integrated circuit (IC) can result in the failure of the *p-n* junction [2].

In the literature, it is observed that, the thermal stress in layer assembly comprised of dissimilar materials was conducted by Timoshenko [3] based on the strength -of-material approach. Papkovich [4] and Aleck [5] have analyzed using theory-of-elasticity methods. The numerical techniques like FEA and other computer-aided techniques are developed in the late 1950s. Chang [6] used the strength-of-materials approach and in the later stage the author employed, Ribiere's theory-of-elasticity solution for a long and narrow strip to evaluate the interfacial compliances in a bi-material assembly. It is observed in many practical problems that, the theory of elasticity leads to complicated and cumbersome expressions, from which it might be quite difficult to understand the role of various factors affecting the characteristic of interest. The formulas obtained by using theory of elasticity cannot be easy-to-use. In additional that simplifying assumptions have to be made to obtain, in one way or another. A solution to a particular practical problem and strength -of-materials methods has to be used to come up with an acceptable engineering solution to a practical problem. However, these two analytical approaches in thermal stress modeling should complement each other in any thorough engineering analysis and physical design effort. Both approaches should be carried out when possible and appropriate in addition to the FEA simulations.

Since from past twenty years the application of computers and FEA computer programs has made analytical solutions less important this is because of when application of numerical methods encounters no significant difficulties . It is always advisable to investigate the problem analytically before carrying out computer-aided analyses. Such a preliminary investigation helps to reduce computer time and expense, develop the most feasible and effective pre-processing model, and, in many cases, avoid fundamental errors. Those that have a hands -on experience in using FEA know well that it is easy to obtain a solution based on the FEA software, but it might not be that easy to obtain the right solution. It is easy to generate thousands of data using FEA packages, but the results might be either erroneous or hard to interpret and explain.

The tri-layered assembly in its closed-form model subjected to uniform temperature change was proposed by Brown [7] and Suhir [8]. However, both the solutions had mathematical inconsistencies in consideration of the exponent parameter k in the shearing stress expression. Sujan et al. [9] addressed the inconsistencies both in Brown [7] and Suhir's [8] model and proposed an improved tri-material solution for interfacial shearing and peeling stress. The proposed solution considered both the roots for the exponential component κ in the governing equation which led to the correct solution. It is observed that the comparison between the corrected proposed model and the FEM analysis had good agreement compared to the earlier models. The most typical electronic, , and photonic structures are multi-material or composite structures comprised of a broad variety of dissimilar materials. The thermal loading in electronic and photonic equipment is due to the thermal expansion/contraction mismatch of the dissimilar materials in the system or to the non -uniform distribution of temperature. It is quite typical that electronic and photonic structures are being subjected to the combined and concurrent action of thermal, mechanical, and dynamic loads. Thermal loading takes place during the normal operation of electronic and photonic assemblies, structures, packages, equipment and systems, as well as during their fabrication, testing, transportation, or storage. The induced stresses, displacements, and strains can be linearly or nonlinearly elastic or elasto - plastic. In some other cases the bonding materials e.g., for epoxy adhesives or solders time-dependent effects might be important, and the effect of time-dependent phenomena on thermal stresses should be taken into consideration. As to the applied loads, it is the thermal loading that is of primary interest for, and is of major concern to, "physical" designers and reliability engineers in the field. But, it is obvious that when two materials are bonded together there must be an existence of an extremely thin bond layer of third material. This bond layer, in fact, acts as interfacial shear stress compliance between the two principal layers. Consequently, it will have some influence on the interfacial stresses in a Bi-material assembly. The value of interfacial shear stress compliance for the bond layer at the interface was proposed by Sujan [10] which is given as K_0 as h_o/G_o. A Gold-Tin solder bond is introduced as the bond layer between silicon and diamond layers and they show that the effect of bond layer on the interfacial shearing and peeling stress. Recently, Sujan et al. [11] studied the tri-layered interfacial stress model with the effect of different temperatures in the layers only. The effect of bond layer on interfacial shear and peeling stresses is not considered. It is observed that the effect of linear temperature gradient may influence interfacial stresses considerably.

It is observed from the literature that, several studies have been carried out in past two decades on the interfacial shearing and peeling stress in various fields and applications. Although, it is observed in the open literature that the effect of with and without bond on interfacial shearing and peeling stress in bi-material is studied. The study conducted interfacial shearing and peeling stress is limited to bi-material with bonding and tri-material without bonding only. Thus in the present study, computations have been performed to analyze the tri-material assembly with full length bonding. The need for study of interfacial shearing and peeling stress in the electronic package to reduce the damage on the most valuable and important printed circuit board due to rise in temperature in the electronic package. The objectives of the present research work are, to develop a model for the shearing and peeling stresses occurring at the interface of three bonded thin plates of dissimilar material for uniform temperature changes using the simple differential equation. To study the effect of bond material at the interface of the tri-material assembly for uniform temperature change. To compare the developed uniform temperature model with FEM simulation of a known tri-material package. To compare the shearing and peeling stresses for without bond and with bond at the interface of the tri-Material assembly.

2. Methodology

2.1 Analytical method

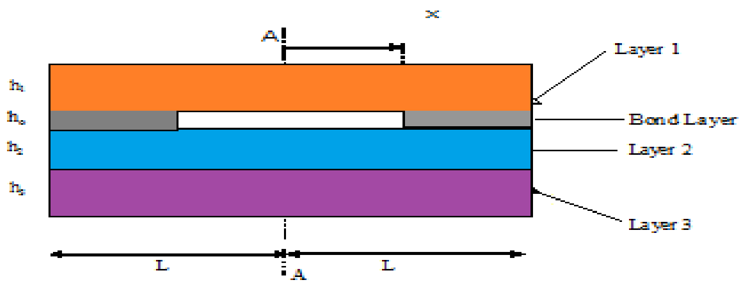

Fig 2.1. Tri-material assembly with partial bonding at 1-2 interface

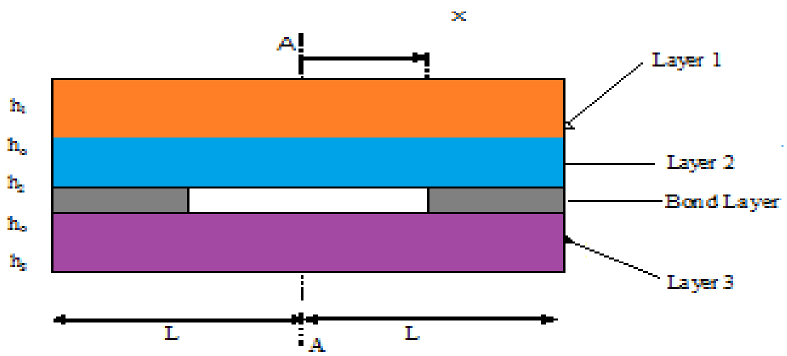

Fig 2.2: Tri-Material Assembly with Partial Bond Layer at 2-3 interfaces

Fig 2.1 shows the tri-material assembly with partial bonding at 1-2 interface and there is no bonding at 2-3 interface .The fig 2.2 shows the tri-material assembly with partial bonding at 1-2 interface and there is no bonding at 2-3 interfaces.

$$U_{x(1)} - U_{x(2)} = K_0 \tau \qquad (2.1)$$

The solution for shearing stress τ can be given as,

$$\tau = C_1 \sinh \mu(x - C) + C_2 \cosh \mu(x - C), \qquad (2.2)$$

Where $\mu = \sqrt{\frac{\lambda}{K}}$,

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

Differentiating equation (2.1) and the expressions of $\frac{\partial U_1}{\partial x}$ and $\frac{\partial U_2}{\partial x}$ from equation (2.1) into (2.2) and then multiplying both sides by C, equation (2.2) results in

$$CK\frac{\partial \tau}{\partial x} = (\alpha_1 \Delta T_1 - \alpha_2 \Delta T_2 + \lambda_1 F_1 + \lambda_2 F_2 + \frac{h_1}{2R} + \frac{h_2}{2R})C \tag{2.3}$$

Solving for τ from equation (2.3) gives

Equating for τ from equations (2.3) and (2.2), gives

$$C_2 = C_1 \mu C \tag{2.4}$$

Now replacing the expression of C_2 in equation (2.2) at x = L, and multiplying both sides by K, produces

$$K\frac{\partial \tau}{\partial x} = K\left[C_1\mu \ cosh\mu(L-C) + C_1\mu C \ \mu sinh\mu(L-C)\right] \tag{2.5}$$

Equating for left hand sides of equations (2.3) and (2.5) and rearranging them results in the expression for C_1 as,

$$C_1 = \frac{(\alpha_1 \Delta T_1 - \alpha_2 \Delta T_2)}{K\mu\left[\mu \ Csinh\mu(L-C) + cosh\mu(L-C)\right]} \tag{2.6}$$

At this stage replacing the expressions for C_1 and C_2 from equations (2.6) and (2.4) into (2.2), results in the expression for shearing stress as,

$$\tau = \frac{(\alpha_1 \Delta T_1 - \alpha_2 \Delta T_2)\left[sinh \ \mu(x-C) + \mu C \ cosh\mu(x-C)\right]}{K\mu\left[\mu C \ sinh \ \mu(L-C) + cosh \ \mu(L-C)\right]} \tag{2.7}$$

The expression for peeling stresses for tri-material assembly with partial bonding condition.

$$P = \frac{\left(h_1 D_2 - h_2 D_1\right)}{2D} \frac{(\alpha_1 \Delta T_1 - \alpha_2 \Delta T_2)}{K \ cosh(\mu L)} cosh(\mu x), \tag{2.8}$$

2.2 For partial length

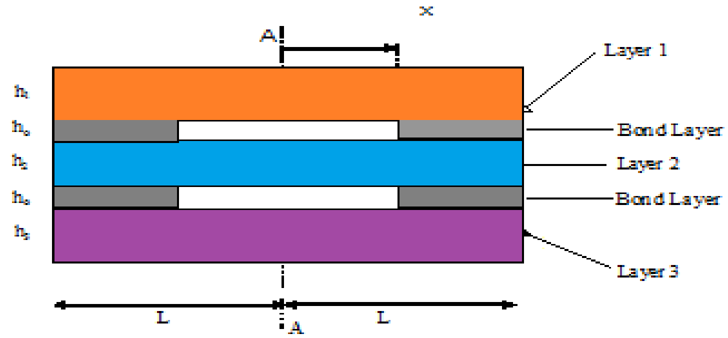

Fig. 2.3: Tri-Material Assembly with Partial Bond Layer on both 1-2 & 2-3 interface

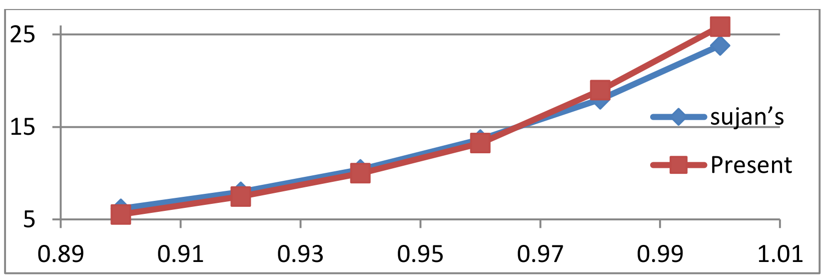

Fig 2.4 shows the Comparison of analytical shear stresses of sujan,s and present for without bond at 1-2 interface.

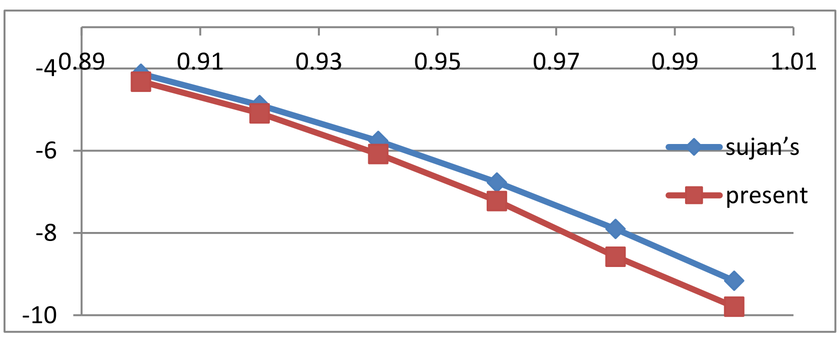

Fig 2.5 shows the Comparison of analytical shear stresses of sujan,s and present for without bond at 2-3 interface.

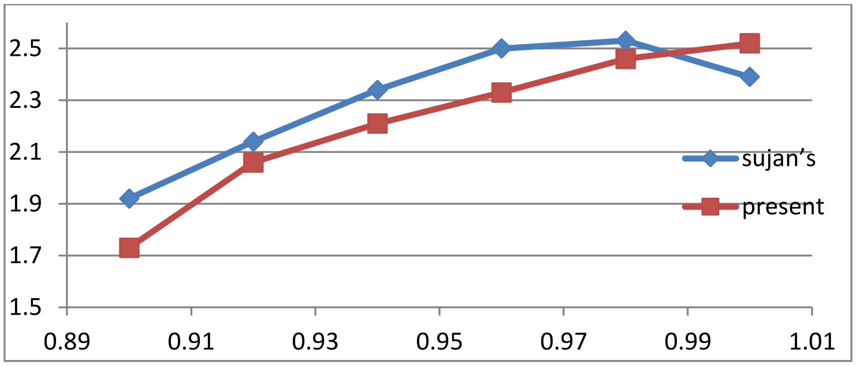

Fig 2.6 shows the Comparison of analytical peeling stresses of sujan,s and present for without bond at 1-2 interface.

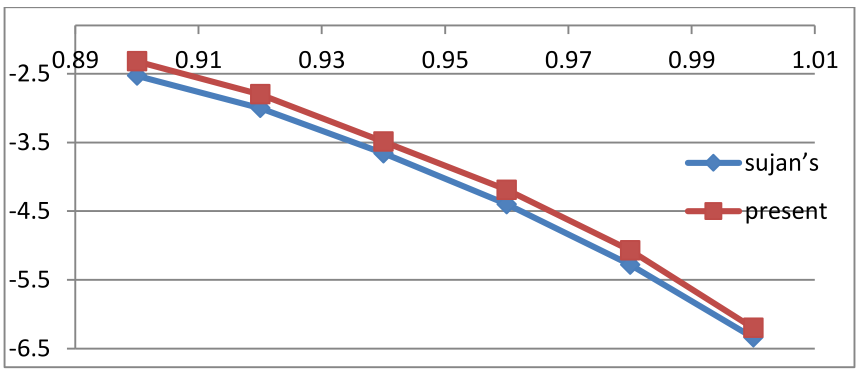

Fig 2.7 shows the Comparison of analytical peeling stresses of sujan,s and present for without bond at 2-3 interface.

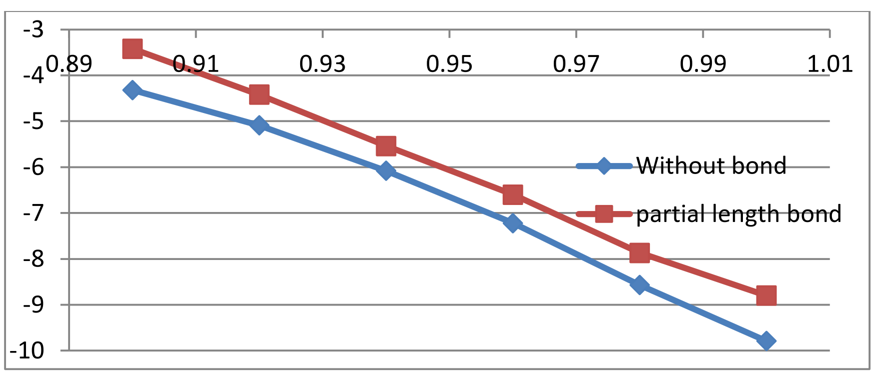

Fig 2.8 shows the Comparison of analytical shear stress for without and partial length bond at 1-2 interface.

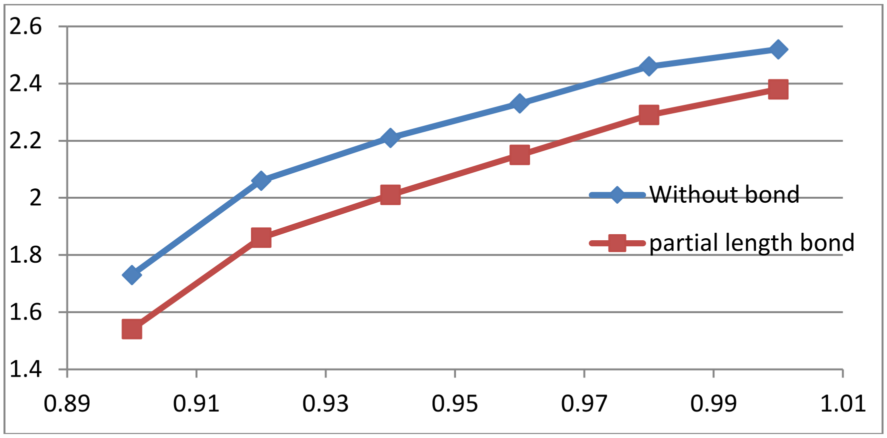

Fig 2.9 shows the Comparison of analytical shear stress for without and partial length bond at 2-3 interface

2.3 The FEM calculation

The finite element method is the best method to calculate shearing and peeling stresses at the Interface, the model has been created by using element brick 8 nodded 45 elements.

2.3.1 Partial length bonding

By taking material properties for tri-layered full length bonding assembly as discussed in table no 3.1,and also 3D model prepared for FEM analysis will have thickness as shown in same table .the fig 2.11 shows the full length bonding at 1-2 interface in tri-layered assembly before meshing, the fig 2.11 shows the full length bonding at 2-3 interface in tri-layered assembly before meshing, the biasing ratio and number of elements will give accurate results, the fig 4.6 shows the meshed tri-layered assembly

The model taken is ¼ th of the full model so the symmetric boundary condition applied at the inner two faces. And the thermal load is applied to model is (120^{0}c) is the change in temperature form the room temperature to the operating temperature.

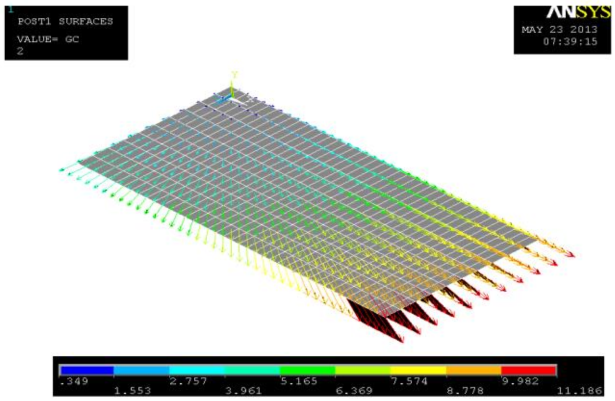

Fig 2.11 shows the cutting plane having shear stress thermal load

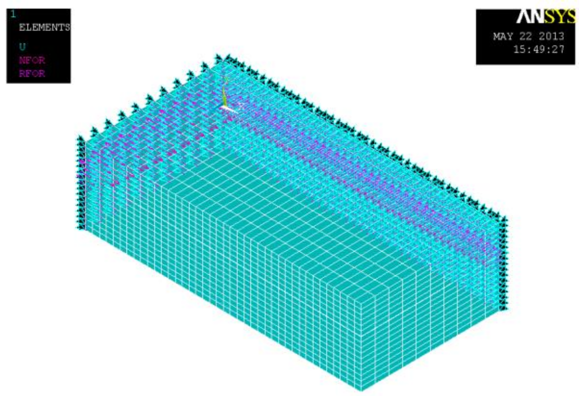

Fig 2.11 shows the symmetric boundary condition with

3 Results and Discussions

The fig 3.1 represents the cutting plane with shearing stress distribution and that can be obtained by offsetting the work plane to the required distance and orientation and the nodes has to select in a path representing the model center inner edge to outer most edge that is [from X/L=0 to X/L=1.0],

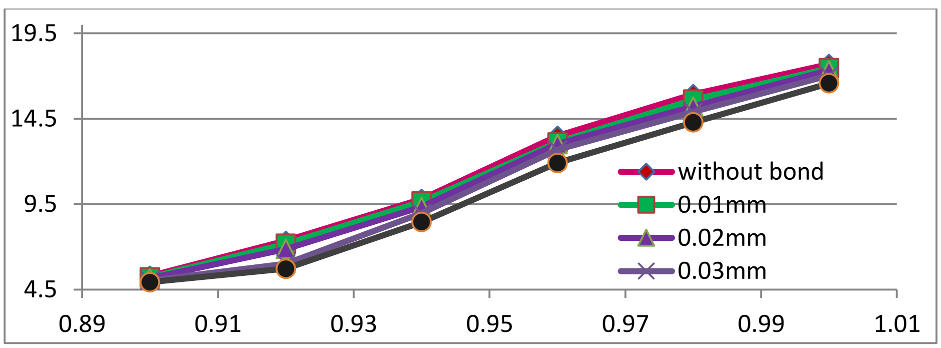

Fig 3.1 Comparison of FEM shear stress for various bond thickness at 1-2 interface

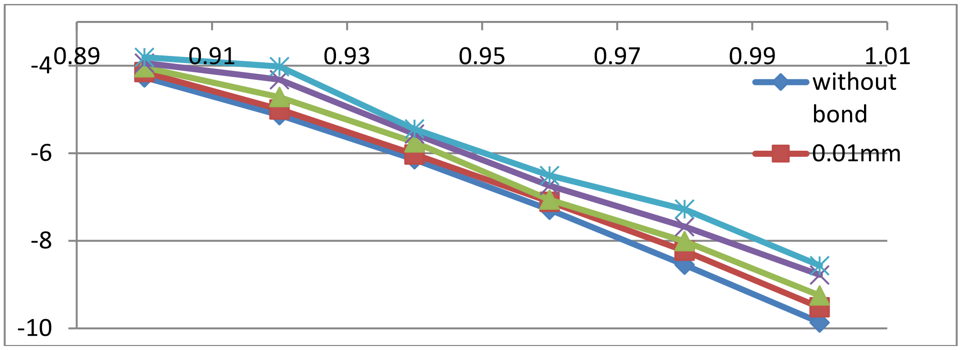

Fig 3.2 Comparison of FEM shear stress for various bond thickness at 2-3 interface

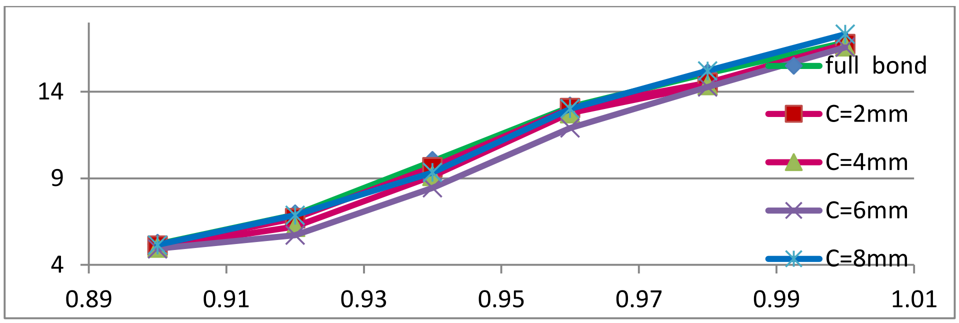

Fig 3.3 Comparison of FEM shear stress for various bond length at 1-2 interface

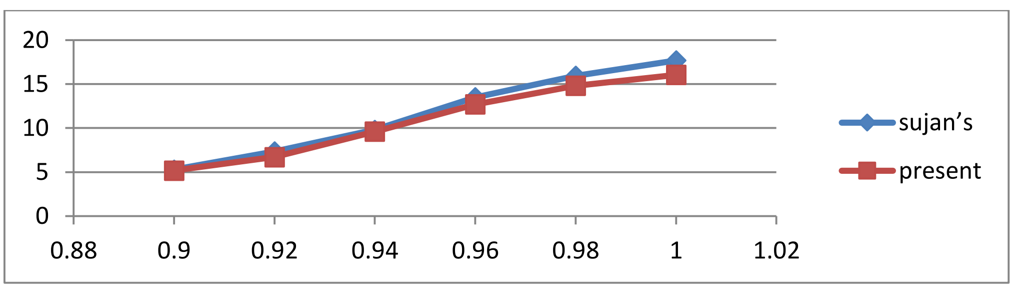

Fig 3.4 Comparison of FEM shear stresses for without bond at 1-2 interface

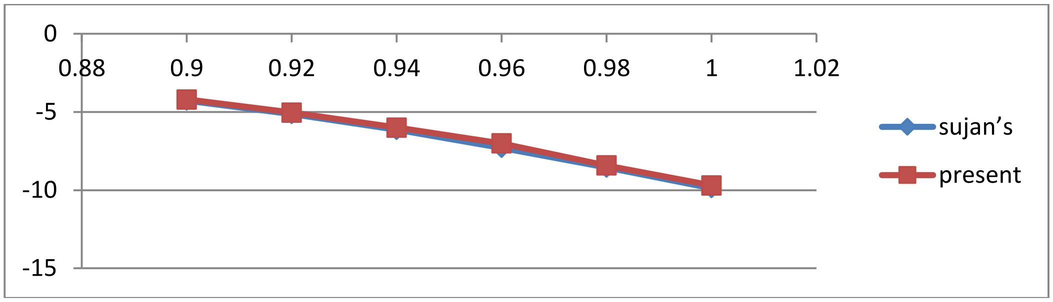

Fig 3.5 Comparison of FEM shear stresses for without bond at 2-3 interface

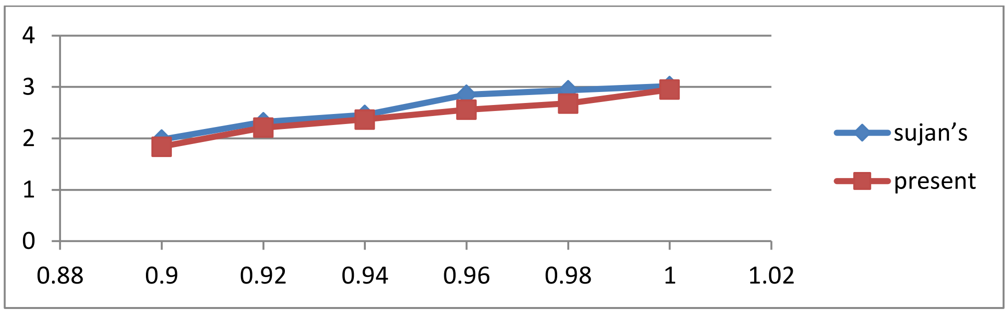

Fig 3.6 Comparison of FEM peeling stresses for without bond at 1-2 interface

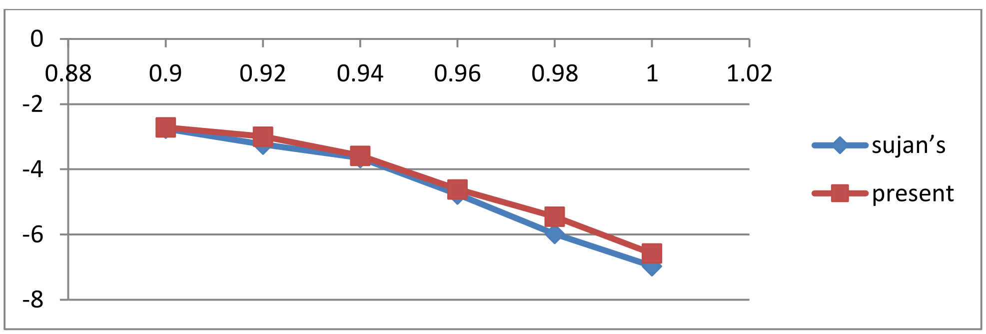

Fig 3.7 Comparison of FEM peeling stresses for without bond at 2-3 interface

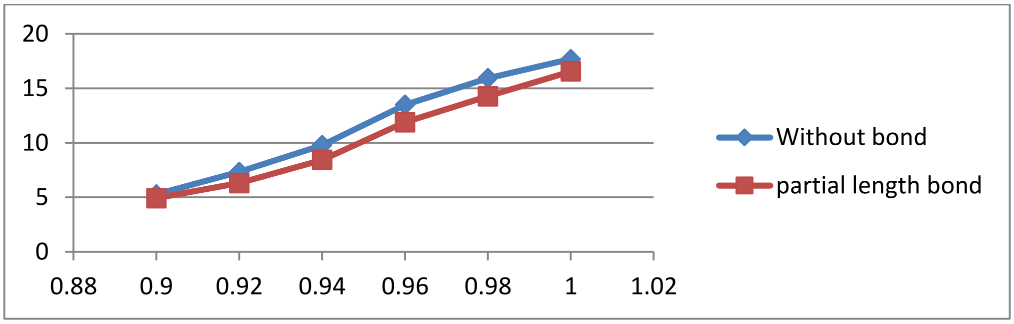

Fig 3.8 Comparison of FEM shear stress for without and partial length bond at 1-2 interface

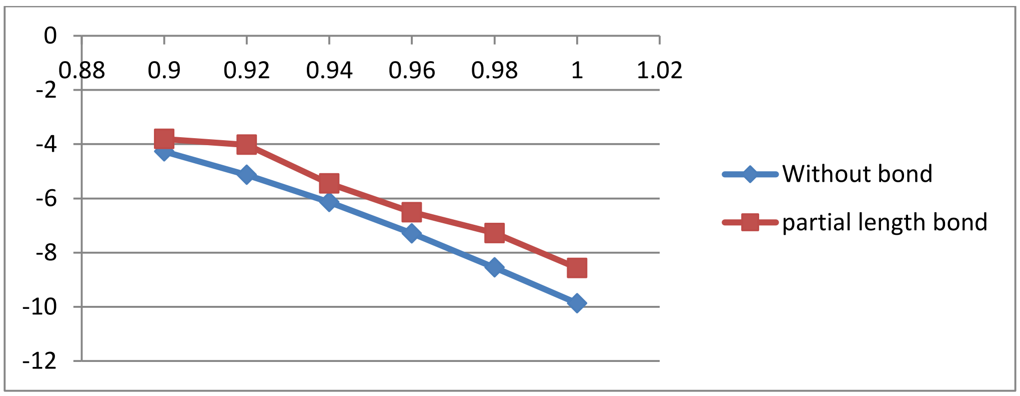

Fig 3.9 Comparison of FEM shear stress for without and partial length bond at 2-3 interface

4. Conclusions

Thorough validation of both analytical and numerical analysis is carried out for both the shearing and peeling stress. The results obtained from the analysis leads to following conclusion.

1. Analytical and Numerical results showed that shearing stress are reduced in the range of 50% - 70% at (1-2) interface and 30% - 40% at (2-3) interface near the free end due to the influence of bond layer. Thus , it indicates that near the vicinity of the free end, the bond layer consideration may influence significantly on interfacial stress.
2. It is observed that, peeling stress are continuously reduced in the range of 12% - 20% at (1-2) interface and 15% - 25% at (2-3) interface due to the influence of bond layer. Thus, it indicates that, the bond layer consideration may influence significantly on interfacial stress.
3. The shearing stresses decreased considerably at the interface with the increase of bond layer thickness. For instance, shearing stress decreased 40% - 50% at (1-2) interface and 30% - 40% at (2-3) interface respectively at the free end for a bond thickness of 0.01mm compared to zero bond thickness.
4. The peeling stresses decreased considerably at the interface with the increase of bond layer thickness. For instance,

peeling stress decreased by 10% - 15% at both (1-2) interface and (2-3) interface respectively at the free end for a bond thicknes s of 0.01mm compared to zero bond thickness.

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