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Certificate of Participation

This is to certify that **Prof. Masoud TAHANI,** has attended the Twenty-Fifth Annual International Conference on Composites/Nano Engineering (ICCE-25) from July 16 to 22, 2017 in Rome, Italy and made an oral presentation entitled:

"Interfacial Void In Adhesively Bonded Composite Joint Integrated With Piezoelectric Patch "

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INTERFACIAL VOID IN ADHESIVELY BONDED COMPOSITE JOINT INTEGRATED WITH PIEZOELECTRIC PATCH

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Introduction

Piezoelectric patches are often bonded to composite substrates using adhesives. Performance of an adhesive bonding is highly related to the degree of integration between the bonded materials. Therefore, appropriate pre-bonding operations like cleaning the joining surfaces, controlling the temperature and humidity, etc. are so important. During joining by adhesive, also, care should be taken to prevent entering extra particles within the adhesive layer as well as formation of interfacial voids which may cause premature failure.

Detachment of adhesive bonding due to high interfacial stress concentrations around a void is a major challenge, and therefore, it is important to accurately determine peak stress values for further failure analyses. As a previously approved analytical framework, the full layerwise theory is used in this study to determine the accurate distributions of interfacial stresses at mid-surface of the adhesive layer containing a void in a composite joint integrated with a piezoelectric actuator. The present method is shown to be fast convergent as well.

Methodology

A piezoelectric actuator is joined to a composite substrate via a thin adhesive layer containing a void, as depicted in Fig. 1. In the full layerwise theory, the joint thickness, *H*, is divided through the thickness into a large number of mathematical sub-layers, *N*, with equal thicknesses.

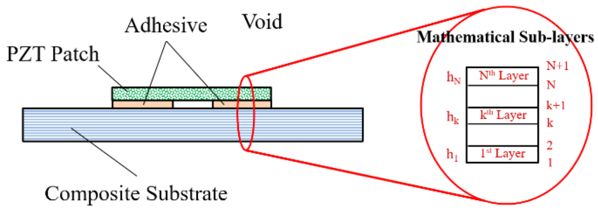

Fig. 1 Schematic of the adhesive joint

Without loss of generality of the mathematical formulations presented in details in Ref. [1], we suppose here that the void is in the middle of the adhesive layer in order to simplify the geometry using symmetry property, as illustrated in Fig. 2, and the symmetrical boundary conditions are imposed.

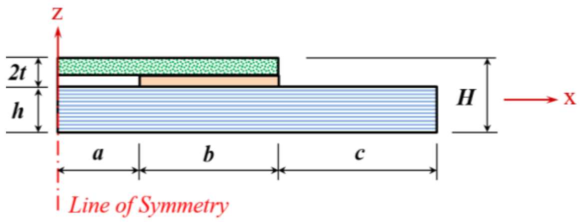

Fig. 2 Half-joint model

The half-joint shown in Fig. 2 should be partitioned into three regions with lengths of *a*, *b*, and *c*. As described in Ref. [1], the displacement field of the full layerwise theory can be written as:

$$\begin{aligned} u_1(x,y,z) &= U_k(x)\Phi_k(z) \\ u_2(x,y,z) &= V_k(x)\Phi_k(z)\,, \quad k = 1,2,\ldots,N+1 \\ u_3(x,y,z) &= W_k(x)\Phi_k(z) \end{aligned} \tag{1}$$

where Φ is a global interpolation function with C^0 order of continuity at the interface of each two mathematical sub-layers [1]. Generally, we suppose that C_{ij} and e_{ik} are the elastic and piezoelectric moduli, respectively, and E_k is the electric field vector. Then the stress-strain relationship for the composite joint can be written as:

$$\sigma_{ij} = C_{ijkl}\varepsilon_{kl} - e_{ijk}\mathrm{E}_k = C_{ij}\varepsilon_{ij} - e_{ik}\mathrm{E}_k \tag{2}$$

The principle of minimum total potential energy gives the equilibrium equations for each region as:

$$\begin{aligned} \delta U_k &: \quad d(M_x^k)/dx - Q_x^k = 0 \\ \delta V_k &: \quad d(M_{xy}^k)/dx - Q_y^k = 0 \\ \delta W_k &: \quad d(R_x^k)/dx - N_z^k = 0 \end{aligned} \tag{3}$$

and the corresponding boundary conditions as well as relations for continuity of displacement components and equilibrium of stresses between each two adjacent regions (details in Ref. [1]). Three fully coupled sets of equations like Eq. (3) for whole the joint then are written in the matrix notation and solved by introduction of state space variables. For more details on the analytical solution procedure, interested readers are referred to Ref. [1]. The proposed method has been previously verified via comparison with finite element simulation [2].

Results and Discussion

The objective is to study how an interfacial void can affect the peeling and shear stresses in the adhesive layer, particularly near the end point of the void where edge effects increases the stresses. Suppose the adhesively bonded joint shown in Fig. 2 undergoes an electrical charge of E = 50V. The joint dimensions (in millimeter) are a = 3, b = 10, c = 20, $2t$ = 2, and h = 3 (i.e., H = 5 mm). The electro-mechanical properties are listed in Table 1.

Table 1 Electro-mechanical properties

Composite (Graphite-Epoxy)	**Adhesive (AY103)**
E_1 = 137.9, E_2 = E_3 = 14.48, G_{12} = G_{23} = G_{13} = 5.86, ν_{12} = ν_{13} = ν_{23} = 0.21	E = 2.8, ν = 0.4
Piezoelectric Patch (PZT-4)	
Elastic Stiffness (GPa)	Piezo Coefs. (C/m^2)
C_{11} = 137, C_{12} = C_{13} = 3.75, C_{23} = 3, C_{22} = C_{33} = 10.9, C_{44} = 3.97, C_{55} = C_{66} = 5	e_{31} = e_{32} = -5.4, e_{33} = 15.8, e_{24} = e_{15} = 12.3

The interfacial shear and peel stresses at the lower bond-line of the adhesive layer of the proposed half-joint are plotted in Figs. 3 and 4. To better show how presence of the void affects the interfacial stress distributions, a perfect half-joint without void is also studied and the stress distributions are plotted in these figures. As it can be seen in Figs. 3 and 4, the presence of a void within the adhesive layer can locally increase the interfacial stresses caused by edge effects. Although the pick stress values at x = a (i.e., the edge of the void) are smaller than the values at x = a+b, it was shown in Ref. [3] that these pick values are strongly dependent on the void size, and greater voids can result in pick stress values governing the failure load.

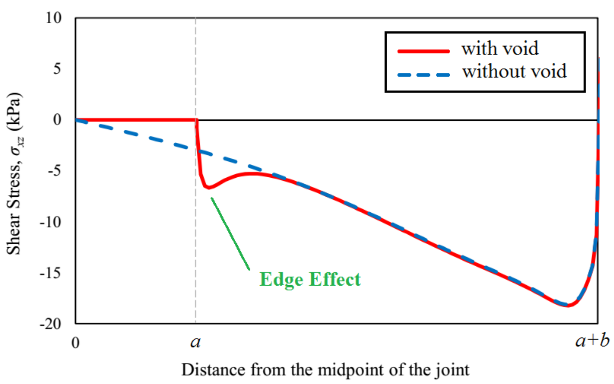

Fig. 3 Interfacial shear stress on lower bond-lines of the half-joints with and without interfacial void

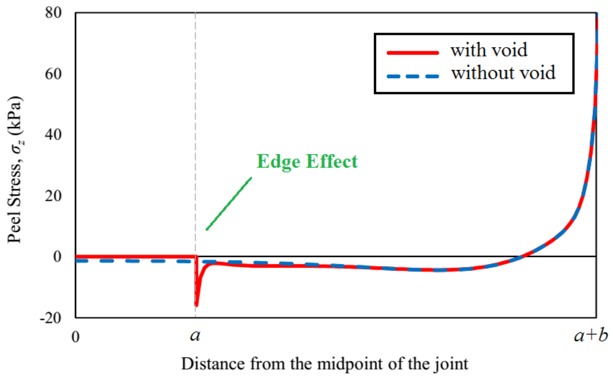

Fig. 4 Interfacial peel stress on lower bond-lines of the half-joints with and without interfacial void

The fast convergence speed of the proposed analytical method is also demonstrated in Fig. 5 for peel stress distribution. As it can be observed, even for small numbers of mathematical sub-layers, the interfacial stress distributions rapidly converge.

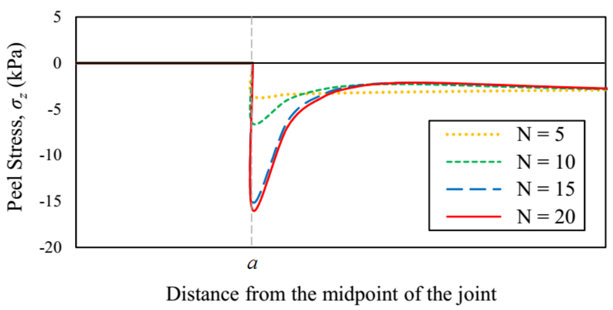

Fig. 5 The interfacial peel stress distribution for different numbers of mathematical sub-layers

Conclusions

It is concluded that presence of a void in the adhesive layer locally increases the interfacial stresses due to edge effects, and thus care should be taken during bonding processes to prevent void formation.

References

[1] Yousefsani, S.A., Tahani, M., International Journal of Adhesion & Adhesives, 43 (2013) 32–41.

[2] Yousefsani, S.A., Tahani, M., “Accurate analysis of adhesively bonded piezoelectric actuators using full layerwise theory” ICMCSF, May 17-22, 2015, Lille, France.

[3] Tahani, M., Yousefsani, S.A., Composite Structures, 130 (2015) 116–123.