STRESS ANALYSIS OF THIN ADHESIVE BONDING DISSIMILAR ADHERENDS SINGLE LAP JOINTS

Thongchai Fongsamootr[1] & Charoenyut Dechwayukul[2]
[1]Department of Mechanical Engineering, Faculty of Engineering, Chiang Mai University THAILAND
[2] Department of Mechanical Engineering, Faculty of Engineering, Prince of Songkhla University, THAILAND

ABSTRACT

In recent years, adhesives have been widely used to bond dissimilar material members particularly in aircraft and automobile structures. If the adhesive layer is very small compared with adherends, a more refined mesh model is needed for FEA modeling. That will take a lot of CPU-time to compute solution. However, there is a method to solve the adhesive lap joints by simulating the adhesive layer with spring elements called the TALA (Thin Adhesive Layer Analysis) method. The objective of this paper is to demonstate a way to analyze the stress distrubution in generalized single-lap adhesive joints of dissimilar adherends by using the FEA and TALA method. First, to validate the FEA-TALA models, the FEA-TALA results will be compared with existing results. Second, the adhesive layer of lap joints of dissimilar adherends will be studied under variation of the Young's modulus ratio between the adherends E_3/E_1 (0.5, 1.0, 2.0, and 3.0) and the adherend thickness ratio h_3/h_1 (0.5, 1.0, 1.5, and 2.0) to understand their effects on the interface stress distribution. The use of the TALA method with adhesive lap joints has been validated and shows good agreement with Sawa's solution. Futhermore, the results show that stresses increase sharply at the edge of the lap interface and that the peak normal stresses and peak shear stresses are increased when the difference in the value of Young's modulus between the upper and lower adherend is increased. The results also show that the both peak stresses at the edge of thicker adherend side is higher than another. Therefore, the best way to minimize the singular stress in adhesive layer is to keep the Young's modulus ratio and adherends ratio near to unity.

1 INTRODUCTION

In recent years, adhesives have been widely used to bond similar and dissimilar material members, particularly in mechanical, aircraft and automobile structures. Research on adhesive lap joints has been undertaken since 1944 by Goland and Reissner [1]. With some limitation of the Goland and Reissner's classical equations, there are several researchers [2-6] who have modified and corrected the classical equation. All of these studies involve adhesive lap joints that have similar adherends. Other researchers have tried to study adhesive lap joints with dissimilar adherends. Wu [7] has modified the classical equation for solving the problem of single-lap adhesive joints of dissimilar adherends. Sawa [8-9] has also analyzed a two-dimensional stress of single-lap adhesive joints of dissimilar adherends subjected to bending moment and tensile loading. The FEA method was used in Sawa's work to analyze these problems. The joints were modeled with quadrilateral elements. The upper adherend was divided into 2452 elements and the element number of the lower adherend was the same as the upper adherend. The adhesive was also divided into 480 elements. However, in this paper, we deal with thin adhesive lap joints. When the adhesive layer is very small compared with adherends, a more refined mesh model is usually needed. This will take a lot of CPU-time to complete analyses. However, there is a method to solve the thin adhesive lap joints by simulating the adhesive layer with spring elements. This method is called TALA: Thin

Adhesive Layer Analysis (see Appendix). Dechwayukul [10-11] used the TALA method solve problems in the aircraft stuctures.

The objective of this paper is to illustrate a way for analyzing the stress distribution in generalized single-lap adhesive joints of dissimilar adherends by using FEA-TALA method. First, to validate the FEA-TALA models, the FEA-TALA results will be compared with the existing results. Second, the adhesive lap joints of dissimilar adherends will be studied under variation of Young's modulus ratio and the adherend thickness ratio between the upper and lower adherends to understand their effect on the interface stress distribution.

2 FEA MODEL

To validate the FEA-TALA method, a two dimensional adhesive single-lap joint model suggested by Sawa [9] (Figure 1) was created using the FEA-TALA method. The problem is treated as linear elastic two-dimensional plane strain finite element analysis. Upper adherends and lower adherends were divided into 160 elements. The joint was subjected to tensile loading, 238.64 N at the center of right side lower adherend surface. By using TALA method, the adhesive layer was transformed to 17 linear normal spring elements and 17 linear shear spring elements connecting the lower surface to the upper surface. The details of mechanical properties of both adherends and adhesive are shown in Table 1.

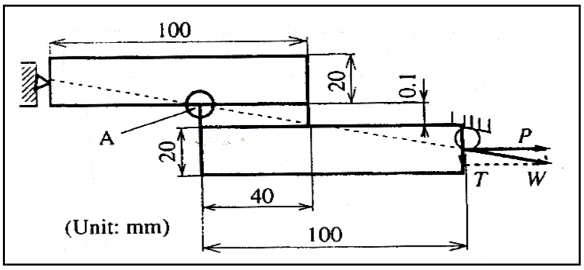


Figure 1: A Sawa's FEA model and the dimensions of the joints

Table 1: Mechanical properties of adherends and adhesive

	E (GPa)	G (GPa)	ν
Upper Adherend	210	80.76	0.30
Lower Adherend	70	26.92	0.30
Adhesive	3.5	1.27	0.38

The adhesive layer of lap joints of dissimilar adherends will now be studied with different Young's modulus ratio between the adherends E_3/E_1 (0.5, 1.0, 2.0, and 3.0) and adherend thickness ratio h_3/h_1 (0.5, 1.0, 1.5, and 2.0). The validated FEA-TALA model was modified by changing the values of E_3 (35, 70, 140, and 210 GPa) and the values of h_3 (10, 20, 30, and 40 mm).

3 RESULTS

3.1 The validation of the FEA-TALA method

To validate the FEA-TALA method for two-dimensional single-lap adhesive joints with dissimilar adherends, the normalized normal stress distributions in the adhesive layer obtained using the FEA-TALA method were compared with the results from Sawa's calculation as shown in Figure 2.

The normal stresses (σ_y) obtained from each spring were divided by τ_m to get normalized normal stresses ($\sigma_{y/}\tau_m$), where τ_m is the mean shear stress $P/2l_2$. The results show good agreement with Sawa's results in term of both shape and magnitude along the overlapping length.

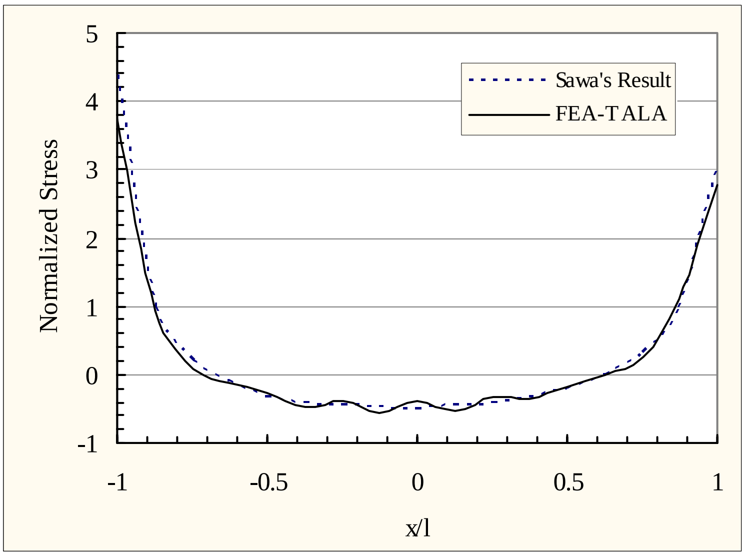


Figure 2: The normalized normal stress

3.2 The effect of the Young's modulus ratio (E_3/E_1) and the adherend thickness ratio (h_3/h_1)

Figure 3 and 4 show the FEA-TALA results along the lap interface under variation of Young's modulus ratio and adherend thickness ratio, respectively. The results are showed in term of relationship between the normalized stresses, normal and shear stresses, and dimensionless distances (x/l) to illustrate the stress distribution along the lap interface.

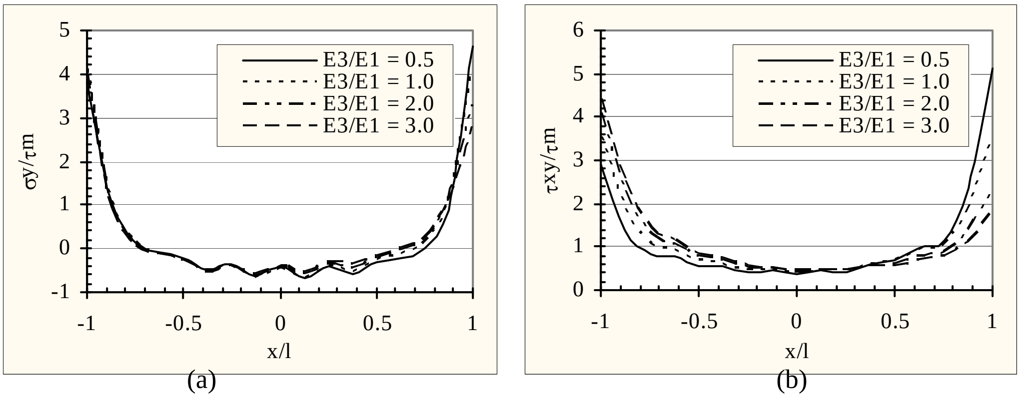
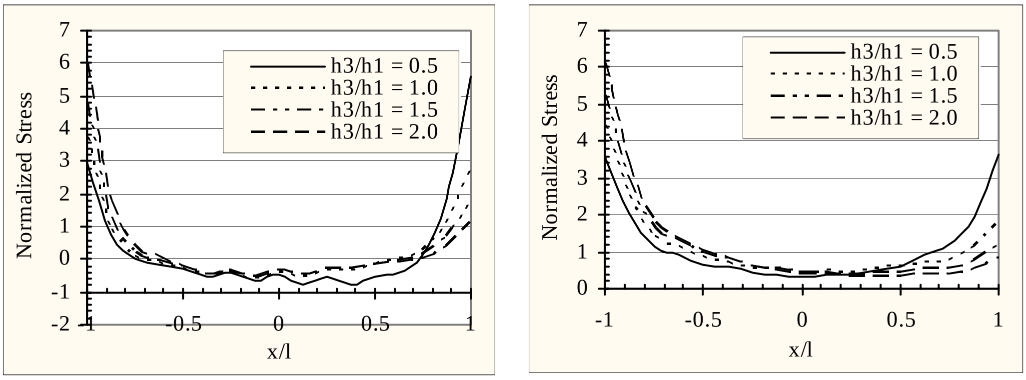


Figure 3: Effect of Young's modulus ratio E3/E1 on the normalized stress distributions (a) normalized normal stress ($\sigma_{y/}\tau_m$) (b) normalized shear stress ($\tau_{xy/}\tau_m$)



(a) (b)

Figure 4: Effect of adherend thickness ratio h_3/h_1 on the normalized stress distributions (a) normalized normal stress ($\sigma_{y/}\tau_m$) (b) normalized shear stress ($\tau_{xy/}\tau_m$)

4 DISCUSSION

The using of TALA method on adhesive lap joint has been validated and it has been shown that good agreement between FEA-TALA method and Sawa's solution is possible. The FEA-TALA method is a practical means to represent the stiffness of two dimensional FEA models of the joints. Futhermore, this method was used to study the effect of Young's modulus ratio and adherend thickness ratio on the stress distribution along the lap interface. All of the results showed that the stresses increase sharply (this phenomenon is so called stress singularity) at the edge of the lap interface. The stresses at the edge of lap interface were summarized in Table 2. The peak normal stresses and peak shear stresses are increased when the differences in the values of Young's modulus and adherend thickness between the upper and lower adherend are increased. Figure 3 and 4 also show that the both peak stresses at the edge of thicker adherend side is higher than another. Therefore, the best way to minimize the singular stress in adhesive layer is to keep the Young's modulus ratio and adherends ratio near to 1.

Table 2: The stresses at the edge of lap interface of each case

E3/E1	h3/h1	$\sigma_{y/}\tau_m$		$\tau_{xy/}\tau_m$	
		Left edge	Right Edge	Left edge	Right Edge
0.5	1.0	3.79	4.63	2.89	5.11
1.0	1.0	4.15	4.15	3.54	3.54
2.0	1.0	4.01	3.31	4.13	2.34
3.0	1.0	3.74	2.79	4.43	1.81
3.0	0.5	2.96	5.56	3.58	3.62
3.0	1.0	3.74	2.79	4.43	1.81
3.0	1.5	4.80	1.76	5.28	1.18
3.0	2.0	5.99	1.15	6.11	0.83

5 CONCLUSION

This paper has studied with a two-dimensional stress analysis of a generalized thin adhesive single lap joint of dissimilar adherends by using the FEA-TALA method. The following conclusions can be made:

(1) A FEA-TALA method can be used to analyze the stresses of generalized thin adhesive single lap joints of dissimilar adherends.

(2) The results show that the peak normal stresses and peak shear stresses are increased when the difference in value of Young's modulus between the upper and lower adherend is increased. The results also show that the both peak stresses at the edge of thick adherend side is higher than another side. These results also showed that the best way to minimize the singular stress is to keep the Young's modulus ratio and adherends ratio near to 1.

6 REFERENCES.

1. Goland M and Reissner E., The Stresses in Cemented Joints, Trans. ASME, Journal of Applied Mechanics, 11, A17-A27, 1944.
2. Cornell, R. W., Determination of stresses in Cemented Lap joints, Trans. ASME, Journal of Applied Mechanics, 75, 355-364, 1953
3. Hart-Smith, L. J., Adhesive-bonded single lap-joints, NASA, CR-112236.
4. Ojalvo, I. U., and Eidinoff, H. L., Bond Thickness effect upon in Single-Lap Adhesive Joints, AIAA Journal, 16, 204-211, 1977
5. Dalale, F. E., and Aydinoglu, M. N., Stresses in Adhesively bonded Joints: A closed form Solution, Journal of Composite Materials, 15, 249-271, 1981.
6. Kalamkarov, A. L., Stress Analysis in Elastic Joint Structures, International Journal of Mechanical Science, 39, 873-883, 1997
7. Wu, Z. J., Romeijn, A., and Wardenier, J., Stress expressions of single-lap adhesive joints of dissimilar adherends, Composite Structures, 38, 273-280, 1997.
8. Liu, J., Sawa, T. and Toratani, H., A Two-dimensional Stress Analysis and Strength of Single-lap Adhesive Joints of Dissimilar Adherends Subjected to External Bending Moments, Journal of Adhesion, 69, 263-291, 1999
9. Sawa, T., Liu, J., Nakano, K. and Tanaka, J., A two-dimensional stress analysis of single-lap adhesive joints of dissimilar adherends subjected to tensile loads, Journal of Adhesion Science and Technology, 14, 43-66, 2000.
10. Dechwayukul, C., Rubin, C. A., and Hahn, G. T., Analysis of the Effect of Thin Sealant Layers in Aircraft Structures Joints, AIAA Journal, 41, 2216-2218, 2003.
11. Dechwayukul, C., Thongruang, W., Suwannao, J. and Fongsamootr, T., Spring Element for modeling of 2-D adhesively bonded lap joints, The 17th Conference on Mechanical Engineering Network of Thailand, 47-51, 2003.

7 APPENDIX

TALA METHOD: Figure 5 illustrates the general idea of TALA (Thin Adhesive Layer Analysis) is that each pair of coincident nodes between two contacting surfaces in the FEA models is connected by spring elements. The stresses (σ_x, σ_y, τ_{xz}, τ_{xy}, τ_{yz}, τ_{yx}), strains (γ_{xz}, γ_{xy}, γ_{yz}, γ_{yx}) as shown in Figure 1 and Poisson's ratio effect are neglected because the adhesive layer is very thin. There are only σ_z, τ_{zx} and τ_{zy} acting between the two nodes. The normal stress (σ_z) and shear stresses (τ_{zx}, τ_{zy}) are changed to normal force, and shear force, respectively. The normal and shear strains (ε_z, γ_{zy}, γ_{zx}) are changed to normal and shear relative displacements in spring i. The equations used for converting the stresses and strains in the solid element to forces and displacements to define the properties of the spring element are presented below.

- In the normal direction : $F_{n,i} = K_{n,i} * v_{n,i}$, and $K_{n,i}=E*(A_i/h)$
- In the shear direction : $F_{f,I} = K_{f,I}*u_{f,,I}$ and $K_{f,i}=G*(A_i/h)$

where:

$F_{n,i}$	is the normal force transmitted in spring element i,
$v_{n,i}$	is the relative displacement of spring element i in the normal direction,
$K_{n,i}$	is the local stiffness of spring element i in the local normal direction
E	is the Young's modulus of the adhesive.
$F_{f,i}$	is the shear force transmitted in spring element i,
$u_{f,i}$	is the relative displacement of spring element i in the shear direction,
$K_{f,i}$	is the local stiffness of spring element i in the shear direction, and
G	is the shear modulus of the adhesive.

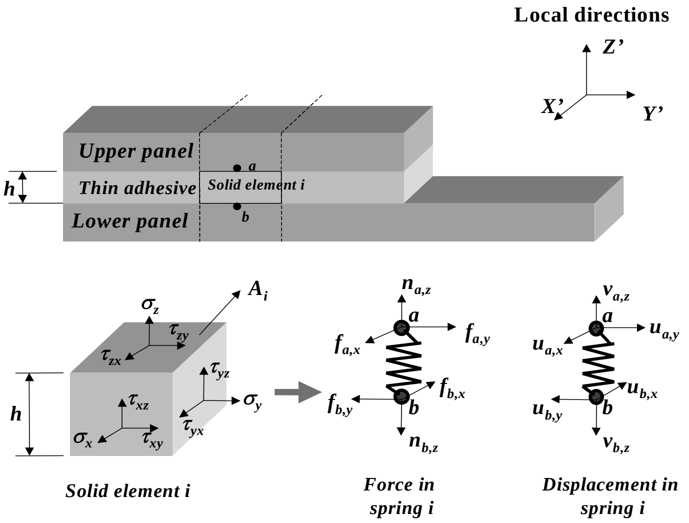


Figure 5: Schematic of spring representation of solid adhesive element.