5th International Science Congress & Exhibition APMAS2015, Lykia, Oludeniz, April 16–19, 2015

Joint Strength Optimization of Bi-Adhesively Bonded Composite-Aluminum Sandwich Structure

M.U. Uysal*
Yildiz Technical University, Department of Mechanical Engineering, 34349 Istanbul, Turkey

Adhesively bonded joint strength optimization can be obtained through the modification of the overlap length and bi-adhesively bonded technique. In this technique, the joints have two different types of adhesive in the overlap length. In the present paper, the effects of bi-adhesively bondline on the shear stress, peeling stress and von-Mises stress of tongue and groove joints were investigated by using finite element analysis. The joint models were consisted of thick woven E-glass/vinyl ester laminate composite groove geometry together with aluminum 5083 tongue geometry. Finite element analyses were performed for three different tongue lengths (75, 150, 225 mm). The distribution of shear and peeling stresses were investigated on adhesively bonded tongue and groove joints subjected to longitudinal tensile loads. The results indicated that the joint strength can be improved by selecting appropriate design parameter values with bi-adhesive bonded technique.

DOI: 10.12693/APhysPolA.129.445
PACS/topics: 81.05.–t

1. Introduction

The tongue and groove joints technique has been the subject of considerable research in the literature. Tensile strength estimation has been experimentally investigated for this joint technique in [1–3]. The stress distribution of joint changes with adhesive properties and geometric dimensions. Also, even when relatively low modulus adhesives are employed, the stress is never uniformly distributed through the bond line. For this reason, bi-adhesively bonded joints have been studied in the literature [4, 5] to increase the performance of the joints and to improve the uniformly stress distribution. In the bi-adhesive technique, a stiff adhesive is applied in the middle portion of the overlap, while a low modulus adhesive is applied towards the edges prone to stress concentrations. Pires et al. [6] presented the result of study of that application of two adhesives with different stiffness along the overlap length in aluminum single lap joints. They indicated that a measurable increase in strength of the bi-adhesively bonded joints compared with those in which single adhesives were used over the full length of the bond line. Indeed, a numerical simulation was improved for mono- and bi-adhesively aluminum lap joints by Pires et al. [7]. In addition, Bavi et al. [8] research was to optimize geometry of the overlap in bi-adhesively single and double lap joints and Kumar and Pandey [9] presented both the two-dimensional and three-dimensional finite element analyses of adhesively bonded single lap joints having bi-adhesive bond line.

The aim of the present study is to investigate possible gains in the joint strength through the use of bi-adhesive technique and varies bond-line lengths. This paper presents the results of the application on two adhesives with different stiffness along the overlap length in tongue and groove joints. Linear elastic finite element analyses were carried out for identification of effective bondline length to maximize joint strength in bi-adhesive joints models. The shear and peeling stresses on the adhesive were investigated. All bi-adhesively finite element models were analyzed and correlated with experimental results in literature [2, 3].

2. Description of the bi-adhesive tongue and groove geometry

Figure 1 shows a typical bi-adhesive design of tongue and groove joint geometry and its dimensions. Three tongue lengths (L_0) were selected as 75, 150, and 225 mm in order to study the effect of the tongue length.

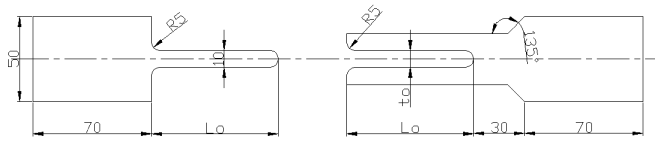

Fig. 1. Tongue and groove geometry configuration and dimensions (mm).

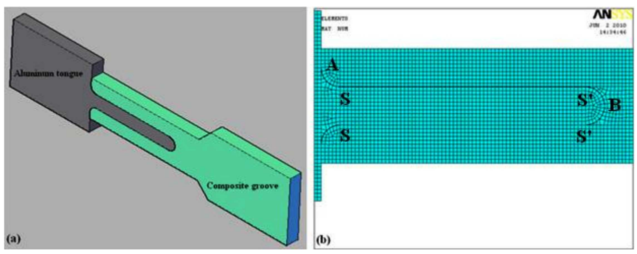

Fig. 2. Modeling of bi-adhesive tongue and groove: (a) 3D geometry, (b) finite element model.

*e-mail: mineuslu@yildiz.edu.tr

The laminated composite material was chosen for groove geometry and the material of the tongue geometry was chosen aluminum alloy as aluminum 5083. Two types of the adhesive were used in this study. The stiff adhesive Loctite-Hysol EA 9394 and the flexible adhesive Loctite-Hysol 9464 were chosen for all adhesive bond lines. The 3D geometry of bi-adhesively tongue and groove modeling can be seen in Fig. 2a. The stiff adhesive is located in middle of the flexible adhesive layer, it is showed by using S–S' paths in Fig. 2b. The material properties of the stiff/flexible adhesive, the laminated composite and the aluminum alloy are shown in Table I.

TABLE I

Mechanical properties of groove/tongue geometries and adhesives [2].

Tongue geometry (aluminum 5083)	Groove Geometry (E-glass vinyl ester)	Flexible Adhesive (Loctite-Hysol 9464)	Stiff Adhesive (Loctite-Hysol EA9394)
$E = 70.00$ GPa	$E_{11} = E_{22} = 22.00$ GPa $E_{33} = 9.00$ GPa	$E = 1.78$ GPa	$E = 4.42$ GPa
$\upsilon = 0.25$	$G_{12} = 5.3$ GPa; $G_{23} = G_{13} = 3.1$ GPa $F_{1t} = F_{2t} = 350$; $F_6 = 95$ MPa	$\upsilon = 0.376$	$\upsilon = 0.30$

3. Analysis of bi-adhesively bonded sandwich structure

Finite element models were developed based on the real sizes of the experimental joint specimen [2, 3] and the finite element analyses were performed using ANSYS® commercial finite element analysis software. The finite element model of the bi-adhesively tongue and groove geometry was shown in Fig. 2b. The tongue/groove geometry and adhesive were meshed by using Shell 99 elements. Also in the adhesive layer, a refined mesh was used in order to achieve the convergence and get more contact detection point. Finally, all elements in the adhesive layer were of equal size. This was important in order to prevent any problems especially in the bi-adhesively bonded joints. The groove geometry material was defined as specific laminate using 24 plies with lay up of [0/+45/90/–45]. The joint model has contact pairs and contact elements were set as the overlap between adhesive and tongue/groove adherents. Sliding is not permitted and debonding of two surfaces was not considered in present paper.

4. Analysis results and discussion

The most important step on the present study is development of finite element analyses for bonded joints based on experimental fail loads. The experimental fail loads for only flexible adhesive layer [2, 3] were used for longitudinal tensile load in the related analyses. For instance, experimental fail load were 26.9 kN on 75 mm tongue length, and this value was used as 44.83 N/mm^2 tensile load on the composite groove lateral area (12 mm joint thickness ×50 mm). The similar fail loads were 29.1 kN and 29.48 kN for 150 mm and 225 mm tongue length, respectively. These values were used as 48.50 N/mm^2 and 49.13 N/mm^2, respectively. From analyses results, three different stresses values were measured for both design of tongue length and bi-adhesive technique.

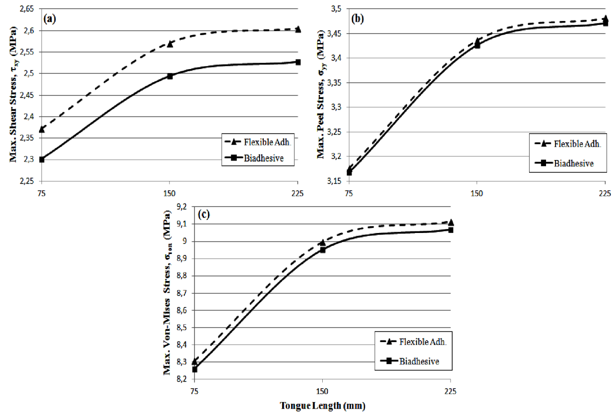

Fig. 3. Effects of the bi-adhesive on A–B path of the adhesive layer: (a) shear stress, (b) peel stress, (c) von-Mises stress.

Figure 3 clearly shows the benefit provided by the change of the adhesive layer as bi-adhesively instead of only flexible layer. The results are given that maximum shear stress, maximum peel stress and maximum von-Mises stress on the A–B path (seen in Fig. 2b) of the adhesive layer for all vary tongue lengths. All stress values decrease with using bi-adhesively layer, especially maximum shear stress on the A–B path. The maximum shear stress value (Fig. 3a) was 2.37 MPa for joint having only flexible adhesive and this value was 2.30 MPa for joint having bi-adhesive layer on the 75 mm tongue length and all adhesive thickness was chosen as 0.1 mm. This decrement was calculated as nearly 3% for the 150 mm and 225 mm tongue length. These result revealed that the adhesive layer only flexible/stiff-flexible properties plays a major role in the shear stress on adhesive layer of joint. The similar less decrement trends are seen in the peel stress (Fig. 3b) and von-Mises stress (Fig. 3c) in the tongue and groove joint having bi-adhesively adhesive layer.

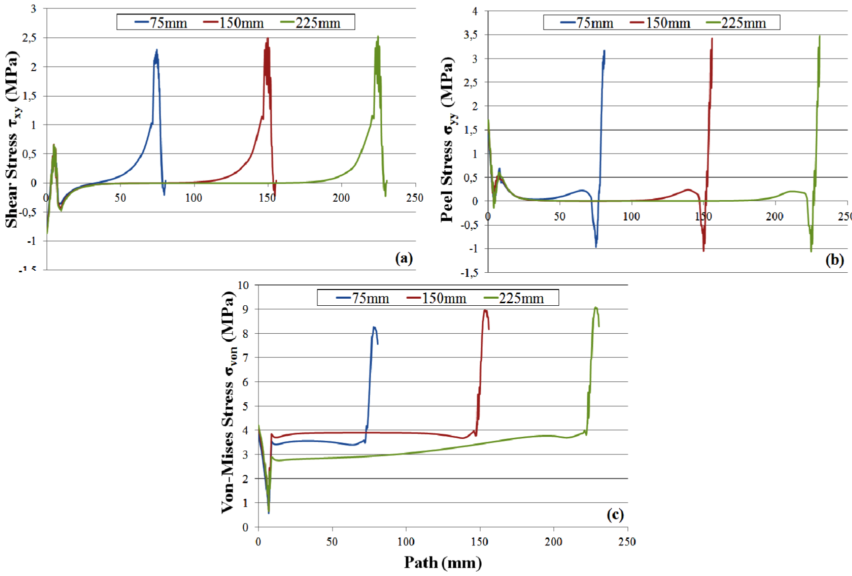

Fig. 4. Effects of the tongue length on *A–B* path of bi-adhesive layer: (a) shear stress, (b) peel stress, (c) von-Mises stress.

The stresses on the *A–B* path of the adhesive layer were also affected from the length of the tongue. The distribution of the shear stress, peel stress, and von-Mises stress on the *A–B* path for tongue and groove bonded joints having bi-adhesive layer can be seen in Fig. 4a–c, respectively. When the tongue length increased, all stress distributions behaviors and values were changed. As seen in Fig. 4c, the von-Mises stress increased by 8.39% when the tongue length changed 75 mm to 150 mm. Also, the von-Mises stress increased by 9.81% when the tongue length changed from 75 mm to 225 mm. This result presented that tongue lengths affected all stress values and their distribution on the adhesive layer. Finally, the joint strength and stress values can be significantly improved by selecting the tongue length as a design parameter and bi-adhesively bonded technique.

5. Conclusion

In this study, finite element model was used to estimate the strength of the bi-adhesively bonded tongue and groove geometry for investigating shear, peel and von-Mises stresses on the adhesive layer. Firstly, the adhesive layer was chosen full flexible adhesive as experimental joint specimens and also two different types of adhesive on the bond line were described as bi-adhesively bonded joints. The experimental fail loads were used for longitudinal tensile load of finite elements models. Comparing the obtained results from the numerical investigation, it is seen that the joint strength increases with using the bi-adhesively joint technique on the tongue and groove geometry. Also finite element models were investigated for three different tongue lengths and their stress distribution for obtain the maximum stress values. The results indicate that a strong aluminum and composite tongue groove joint can be achieved by selecting proper design parameter as tongue length and bi-adhesively bonded technique.

References

[1] G.J. Dvorak, J. Zhang, O.E. Canyurt, *Compos. Sci. Technol.* **61**, 1123 (2001).

[2] O.E. Canyurt, C. Meran, M. Uslu, *Int. J. Adhes. Adhes.* **30**, 281 (2010).

[3] M. Uysal, M.Sc. Thesis, Pamukkale University, 2010 (in Turkish).

[4] E.A.S. Marques, L.F.M. da Silva, *J. Adhesion* **84**, 917 (2008).

[5] P.J.C. das Neves, L.F.M. da Silva, R.D. Adams, *J. Adhes. Sci. Technol.* **23**, 1 (2009).

[6] I. Pires, L. Quintino, J.F. Durodola, A. Beevers, *Int. J. Adhes. Adhes.* **23**, 215 (2003).

[7] I. Pires, L. Quintino, R.M. Miranda, *J. Adhes. Sci. Technol.* **20**, 19 (2006).

[8] O. Bavi, N. Bavi, M. Shishesaz, *J. Adhesion* **89**, 948 (2013).

[9] S. Kumar, P.C. Pandey, *J. Adhes. Sci. Technol.* **24**, 1251 (2010).