J. Appl. Comput. Mech., 5(4) (2019) 647-651
DOI: 10.22055/JACM.2018.26794.1358

ISSN: 2383-4536
jacm.scu.ac.ir

M&MoCS
Shahid Chamran University of Ahvaz

Journal of Applied and Computational Mechanics

Research Paper

Failure Procedure in Adhesive Composite Joints under Different Types of Loading

Dara Fazel[1], Mohammad Hassan Kadivar[2], Hassan Zohoor[3], Mohammad Rahim Hematiyan[2], Mehrdad Farid[2]

[1] Department of Mechanical Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran
[2] School of Mechanical Engineering, Shiraz University, Shiraz, Iran
[3] Mechanical Engineering Department, Sharif University of Technology, Tehran, Iran

Received August 17 2018; Revised November 05 2018; Accepted for publication November 05 2018.
Corresponding author: M.H. Kadivar, kadivar@yahoo.com

Abstract. In this paper, we have used numerical simulation to study failure of adhesive joints in composite plates. To determine the failure load, adhesive joints are subjected to different types of loading and gradual failure of the joint is studied using the finite element method. The composite material failure theory is implemented into the FEM software. Also different geometries for the joint edge are considered and effect of these geometries and fillet chamfer angle on the failure load are investigated.

Keywords: Composite, Adhesive joint, Failure, Tsai-Wu criterion, Chamfer angle.

1. Introduction

Adhesive joints are one of the most common connection methods in composite materials. In late 19th century, herbal and natural adhesives were replaced by synthetic adhesives. Adhesive joints are being used in many different industries and there are few modern products that adhesive joints are not used in them. Examples are from a simple box to an advanced airplane like Boeing 747. Adhesives are also used in different medical applications. In dentistry adhesives are known as cement and are cured using ultra violet light, and in bone surgery acrylic adhesives are used.

Study of the mechanical behavior of adhesive joints and estimation of the failure load is of great importance in the design of composite materials. In this paper, gradual failure of the joint under different types of loading with different adhesive edge [illegible] ure of the plates can be in the matrix or fiber, so to estimate the failure load and study failure mechanism in an adhesive joint, composite plates and adhesive layer should be analyzed simultaneously. For this, failure theories of matrix, fiber, and adhesive material are used together to obtain the failure pattern. The first study on adhesive joints was done by Volkerson [1]. He considered two homogeneous and isotropic plates with a layer of adhesive and assumed that the adhesive deforms under shear loading where both adherends deform under axial loading. Adams and Peppiatt [2] used FEM for linear analysis of adhesive joints. Herris and Adams [3] used non-linear FEM with elasto-plastic behavior of adhesive joint using the vonMises failure theory. Oplinger [4] used beam theory and included shear strain that Goland and Risner [5] considered. Thickness and deformation of the adhesive material and continuity of the edges, and stress distribution in the joint zone where not considered. Tsai and Morton [6] obtained the non-linear deformation and stress distribution in the adhesive experimentally. They concluded that if the joint zone is small, effect of moment at the edges is negligible. Kadiglou and Es-Soun [7] considered aluminum and steel plates under bending loading and studied failure in the adhesive material. Shahin and Taheri [8] investigated deformation in an asymmetric single strap joint. Afendi et al. [9] studied scarf joint under axial loading at different angles. In this study adhesive was considered as brittle material. Da Costa Mattos et al. [11] studied adhesives with quasi-brittle behavior and highly

Published online: April 30 2019

resistance adherends, where adhesive was modeled as a spring.

In this paper, composite plates under axial and shear loading and torsion are studied. Also change in the geometry of the joint because of the failure and its effect on the stress distribution is investigated. ABAQUS is used for the FEM analysis where the failure theory is implemented as a code into the FEM software. This code can be used to study failure of adhesive joints in different industries.

2. Problem Description and Theory

Two composite plates are connected using a 3 mm thick adhesive material as shown in Fig. 1. Width of the adhesive is the same as the width of the plates and the length of the adhesive is 50 mm. Composite plates with different lay-up are considered in this study. The top plate or right side plate has the stacking sequence [0, 90, -45, 30, -60, 30, 10, 0, -60, 90], and the bottom or left one is [0, -45, 60, 45, 90, 0, 30, -10, 0, -60, 45, 10, 30, 90].This joint is considered asymmetric to study the most general case of failure. Mechanical properties of the adhesive and adherends are mentioned in Tables 1 and 2.

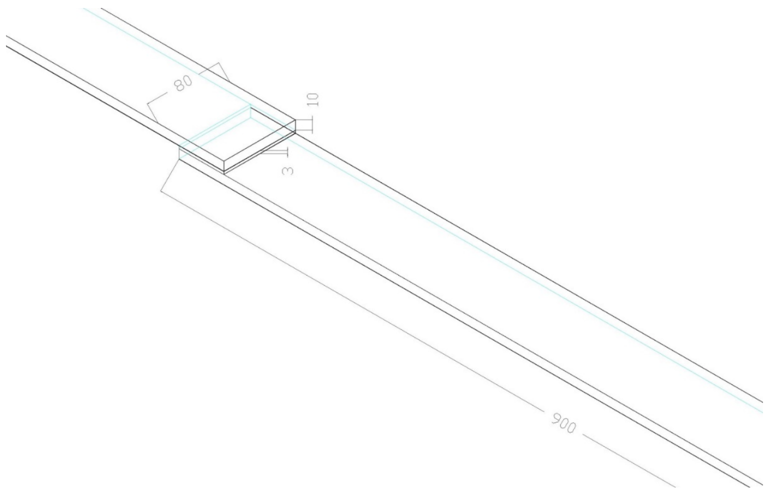

Fig. 1. Geometry of the composite joint

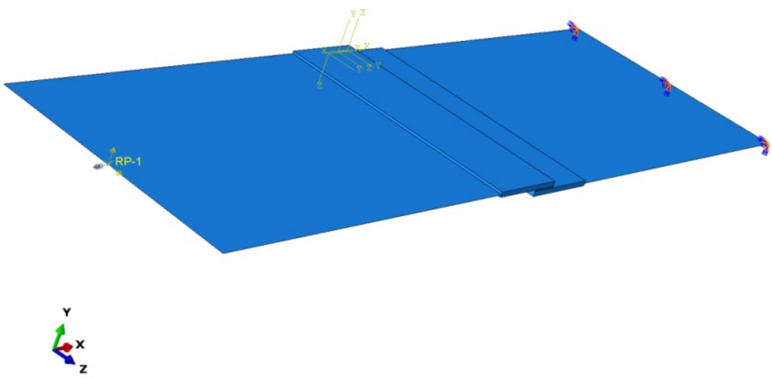

Fig. 2. Loading and boundary condition

Applied loads and boundary conditions are shown in Fig. 2. The von Mises theory is used as the failure criteria for adhesive material. For the composite plates the Tsai-Wu failure criterion is used as follows to predict the failure.

$$F_i\,\sigma_i + F_{ij}\,\sigma_i\,\sigma_j + F_{ijk}\,\sigma_i\,\sigma_j\,\sigma_k + \cdots \geq 1 \quad , \quad i,j,k = 1,\cdots 6 \tag{1}$$

where

$$\begin{gathered} F_1 = 0, \quad F_2 = 0, \quad F_3 = 0, \quad F_{11} = \frac{1}{X_T X_C}, \quad F_{22} = \frac{1}{Y_T Y_C}, \quad F_{33} = \frac{1}{Z_T Z_C} \\ F_{44} = \frac{1}{R^2}, \quad F_{55} = \frac{1}{S^2}, \quad F_{66} = \frac{1}{T^2}, \quad F_{12} = \frac{-F_1\,F_2}{2}, \quad F_{13} = \frac{-F_1\,F_3}{2}, \quad F_{23} = \frac{-F_2\,F_3}{2} \end{gathered} \tag{2}$$

Solution procedure is shown in Fig. 3. After the stress analysis, all elements are checked for failure, and if some elements have failed, those are labeled failed and are removed from model in next step of the analysis. If no elements are failed, load is increased until failure is observed. This procedure is repeated until connectivity condition is not met anymore.

Table1. Properties of adhesive material

Property	Modulus of Elasticity (E)	Poisson's Ratio(ν)
Value	4 GPa	0.35

Table 2. Properties of lamina (adherends composite material)

Property	E_1	E_2	E_3	ν_{12}	ν_{13}	ν_{23}	G_{12}	G_{13}	G_{23}
Value	109 GPa	8.819 GPa	8.819 GPa	0.342	0.342	0.32	4.315 GPa	4.315 GPa	3.2 GPa

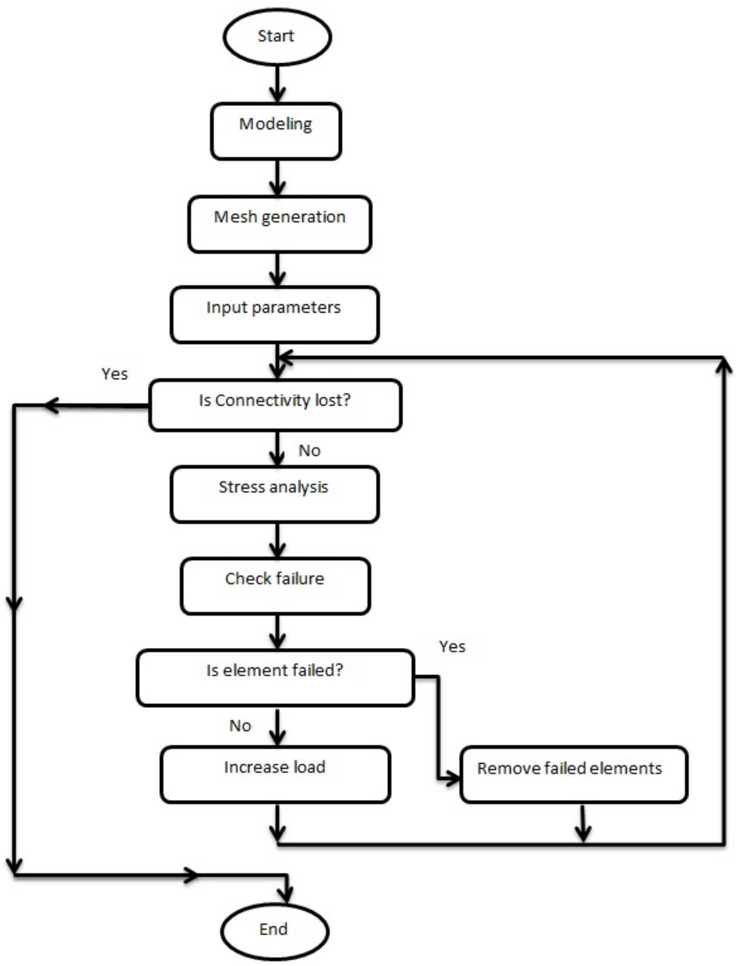

Fig. 3. Process algorithm

3. Results

Chamfer angle of the joint is shown in Fig. 4, which can be changed using jig and fixture during manufacturing. Failure load at different chamfer angles is shown in Fig.5. In axial loading and torsion, maximum and minimum failure loads occur at 0° and 60° respectively (Fig. 5-a and Fig. 5-b), while under shear loading (in Y- and Z-direction) maximum and minimum occur at 30° and 60° respectively (Fig. 5-c and Fig. 5-d). In axial loading the increase of the chamfer angle decreases the failure load because of the increasing stress concentration effect. Also at larger chamfer angles the contact area is increased and consequently shear stress in the adhesive material is decreased. Also it is observed that the failure loads under F_z are much larger than those under F_y. This is because under F_y loading, bending is developed in the joint and the tensile bending stress is the dominant effect which causes failure whereas under F_z torsion about Z-axis developed and failure is due to shear stress. Percentage of change in failure loading at different chamfer angle is listed in Table 3. So we can improve the failure load up to 28% by appropriate choice of chamfer angle.

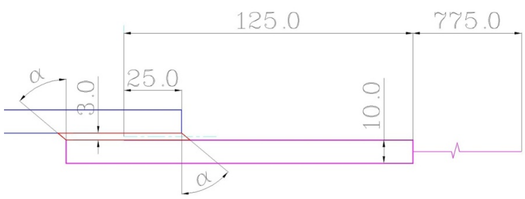

Fig. 4. Chamfer angle of the joint

Table 3. Percentage of change in applied loads

Chamfer Angle (degree)	F_x	F_y	F_z	T_x
30	24.3%	27.83%	8.81%	-7.65%
60	13.53%	19.09%	-6.18%	-16.57%

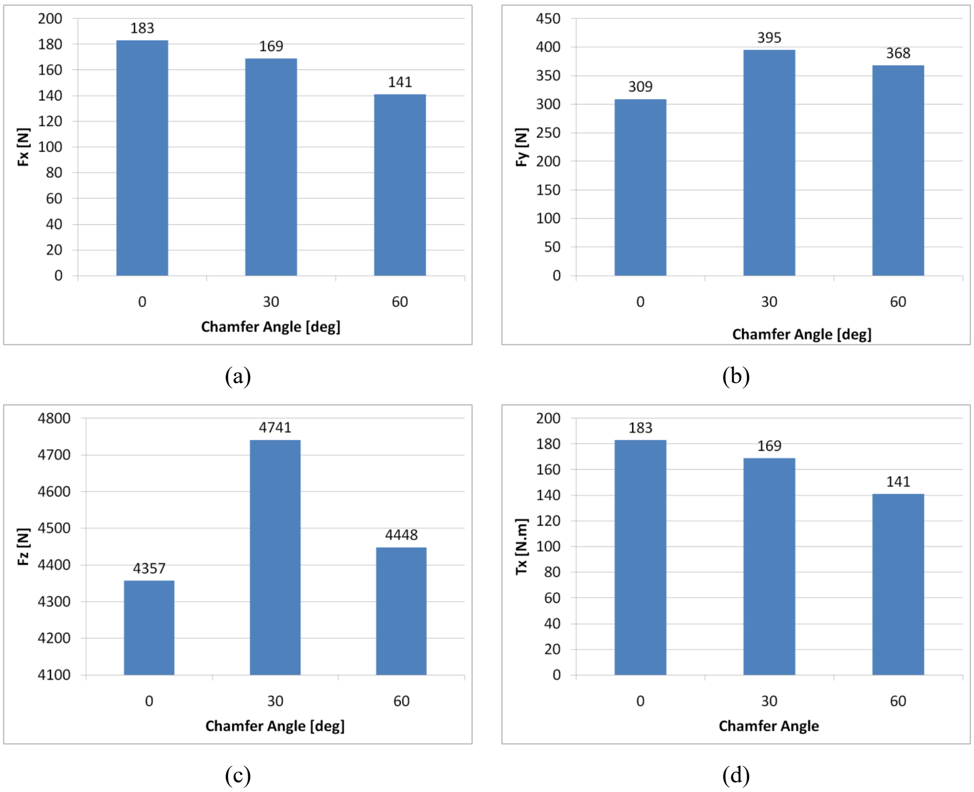

Fig. 5. (a) Axial load, F_x (b) Shear load, F_y (c) Shear load, F_z (d) Torsional load, T_x.

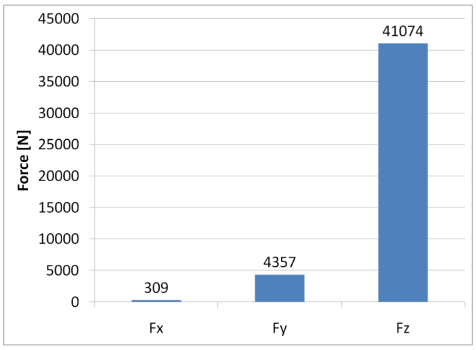

Fig. 6. Chamfer angle 0°

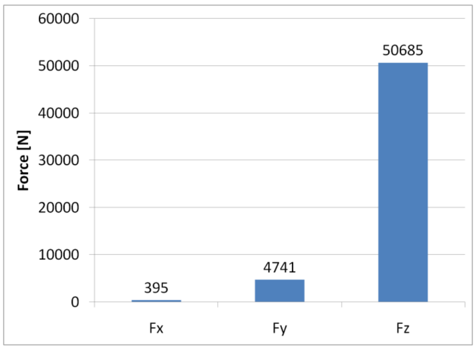

Fig. 7. Chamfer angle 30°

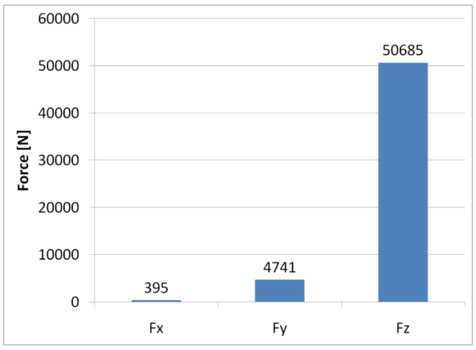

Fig. 8. Chamfer angle 60°

Figs. 6-8 show the effect of loading type at different chamfer angles on the failure load. At all chamfer angles maximum failure load occurs under shear load, F_z. Under axial loading, F_x the forces are not aligned which causes rotation of joint about the Z-axis, and peeling stresses are developed. This is the reason for low failure load under axial loading at all chamfer angles (Fig. 9).

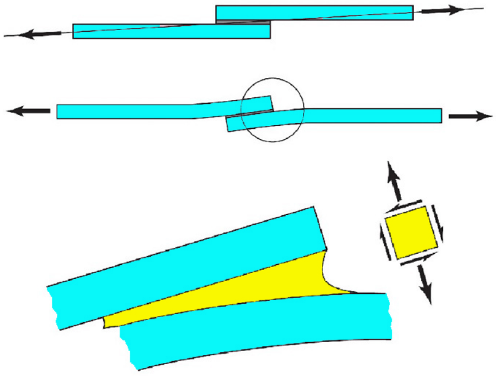

Fig. 9. Peel and shear stress

4. Conclusions

In this paper, we studied effect of chamfer angle on the failure load in single-lap joints. Tsai-Wu criterion and the von Mises theory are implemented into FEM software to study failure of composite joint. Our results show that failure load under F_z shear loading can be increased up to 28% with appropriated choice of chamfer angle. Since there are many joints in complex a composite structure, the weight of this type of structure can be reduced considerably.

Conflict of Interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship and publication of this article.

Funding

The author(s) received no financial support for the research, authorship and publication of this article.

References

[1] Volkersen, O., Die Niektraftverteilung in Zugbeanspruchten mit Konstanten Laschenquerschritten, *Luftfahrtforschung*, 15 (1938) 41-68.

[2] Adams, R.D., Peppiatt, N.A., Effect of Poisson's ratio strains in adherends on stresses of an idealized lap joint, *Journal of Strain Analysis*, 8 (1973) 134-139.

[3] Herris, J.A., Adams, R.D., Strength prediction of bonded single lap joints by non-linear finite element methods, *International Journal of Adhesion and Ad*hesives, 4 (1984) 65-78.

[4] Oplinger, D.W., Effects of adherend deflections in single lap joints, *International Journal of Solids and Structures*, 31(18) (1994) 2561-2587.

[5] Golang, M., Reissner, E., The stress in cemented joints, *Journal of Applied Mechanics*, 66 (1974) 17-27.

[6] Tsai, M.Y., Morton, J., An evaluation of analytical and numerical solutions to the single-lap joint, *International Journal of Solids and Structures*, 31(18) (1994) 2537-2563.

[7] Kadioglu, F., Es-Soun, E., Use of thin adherends in adhesively bonded joints under different loading modes, Science and *Technology of Welding and Joining*, 8(6) (2003) 437-442.

[8] Shahin, K., Taheri, F., Analysis of deformations and stresses in balanced and unbalanced adhesively bonded single-strap joints, *Composite Structures*, 81 (2007) 511-524.

[9] Afendi, M., Teramoto, T., Bakri, H.B., Strength prediction of epoxy adhesively bonded scarf joints of dissimilar adherends, *International Journal of Adhesion & Adhesives*, 31 (2011) 402-411.

[10] Da Costa Mattos, H.S., Sampaio, E.M., Monteiro, A.H., Static failure analysis of adhesive single lap joints, *International Journal of Adhesion & Adhesives*, 31 (2011) 446-454.