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FAILURE ANALYSIS OF TRAPEZIUM SHAPED CARBON-EPOXY PLATE PINNED-JOINT

Alaattin AKTAŞ
Kırıkkale Üniversitesi, Mühendislik Fakültesi, Makine Mühendisliği Bölümü, Kırıkkale

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ABSTRACT

The aim of this study is to investigate failure strength and failure mode of mechanically fastened carbon-epoxy composite plate which shape is trapezium. The failure load and mode are analyzed numerically. The numerical method includes two steps. First, the stress distribution in the plate is calculated by the use of a finite element method. Second, the failure load and the failure mode are predicted by means of Tsai-Hill and Tensile-compressive failure criterion. A computer code was developed which can be used to calculate the maximum failure load, the mode of failure and the propagation of failure. The edge, E/D, and side, W/D, distances of plate are changed from 1 to 4 and 2 to 4 respectively, while the orientation angle of plate is equal to 0°. It is found that full bearing strength is developed when the edge distance ratio is equal to 3 and side distance ratio is equal to 4.

Key Words : Failure, Pinned-joint, Bearing strength, Carbon-epoxy

İÇİNDE PİM BULUNAN YAMUK ŞEKİLLİ KARBON EPOKSİ PLAKANIN HASAR ANALİZİ

ÖZET

Bu çalışmanın amacı, içinde pim bulunan yamuk şekilli, karbon-epoksi kompozitinin yırtılma mukavemetini ve modunu araştırmaktır. Yırtılma yükü ve modu nümerik olarak analiz edildi. Nümerik metod iki adım içerir: ilk olarak plakadaki gerilme dağılımı sonlu elemanlar metodu kullanarak hesaplandı. İkinci olarak, yırtılma yükü ve modu Tsai-Hill ve Tensile-Compressive Failure kriterleri yardımıyla bulundu. Maksimum yırtılma yükü, Yırtılma modu ve Yırtılma ilerlemesini bulan bir bilgisayar programı geliştirildi. Fiber açısı 0° olmak üzere plakanın kenar oranı E/D ve genişlik oranı W/D sırayla 1 ile 4 ve 2 ile 4 oranında değiştirildi.

Anahtar Kelimeler : Hasar, Pimli bağlantı, Yataklama mukavemeti, Karbon-Epoxy

1. INTRODUCTION

Among the major advantages of composite structures over conventional metal structures are their comparatively high strength to weight and stiffness to weight ratios. As a result, fiber reinforced composite materials have been gaining wide application in joining aircraft and spacecraft construction. These applications require joining composites either to composites or to metals. Most commonly, joints are formed using mechanical fasteners. Therefore, suitable methods must be found to determine the failure strength of mechanically fastened joints. A knowledge of the failure strength would help in selecting the appropriate joint size in a given application.

Owing to the significance of the problem, several investigators have developed analytical procedures for calculating the strength of bolted joints in composite materials: (Akay and Kong Ah Mun, 1991) have investigated failure analysis of pinned-joint kevlar fibre-reinforced epoxy laminates experimentally. Fu-Kuo et all. (1984) and Hiroyuki et all. (1996), have investigated failure analysis using Yamada Sun failure criteria for different fiber angle direction. Fu-Kuo and Kuo-Yen (1987), have investigated nonlinear failure analysis of Yamada Sun failure criteria. They have used T300/1034-C graphite-epoxy composites that have different ply orientation angles. Larry and Mahmood, (1995) have investigated failure analysis using Graphite-epoxy composite. They analyzed laminates, which have different ply angle directions. In addition, they used Fiber tensile-compressive, shearing, Matrix tensile-compressive and fıber-matrix shearing criterion. Larry and Mahmood (1995), have investigated nonlinear tree-dimensional stress of pin -loaded composites which have $[0_4/90_4]_s$ and $[90_4/0_4]_s$ orientation ply angle. Quinn and Mathews (1977), have investigated failure analysis experimentally. They have used glass-fıbre reinforced laminates, which have different ply angle directions. Usama (1996), has investigated the notched and pin-bearing strength of randomly oriented GFRP composites having various values of fiber volume fractions.

In this paper, two dimensional finite element method is used to determine the failure load and mode using Tsai-Hill and fiber tensile-compressive failure criterion. In the calculation a half of the model was taken due to symmetry.

2. PROBLEM STATEMENT

A composite plate which shape is trapezium (length L = 60 mm, width b = 60 mm, thickness t = 1.24 mm and α = 7.12°) is used in this study. A hole of diameter D = l0 mm is located along the centerline of the plate (x = 0) at a distance E from one end of the plate. A rigid pin (diameter D), supported outside the plate, is inserted into the hole and a uniform tensile load P is applied to the plate. (Figure 1). The load is parallel to the plate and is symmetric with respect to the centerline. Hence, the load cannot create bending moment about either the x_1, x_2, and x_3 axes. Moreover, for symmetric plates in plane and bending effects are uncoupled. It is desired to find.

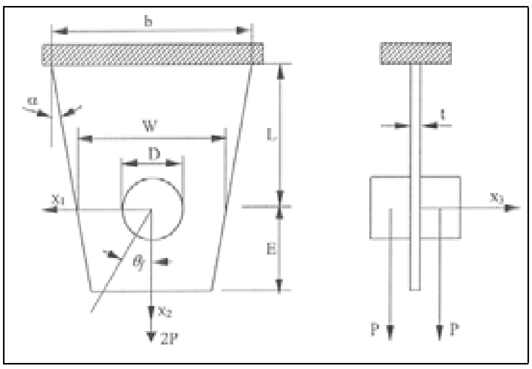


Figure 1. Geometry of the problem

1. The maximum (failure) load (P_f) that can be applied before the joint fails, for each geometries.
2. The mode of failure for each geometry range.

Point 1 refers to the fact that, according to experimental evidence mechanically fastened joints under tensile loads. Generally, fail in three basic modes referred to as net-tension mode, shear mode, and bearing mode. The type of damage resulting from each of these modes is illustrated in Figure 2 (Fu-Kuo et all., 1982; Kaj, 1996; Hong et all., 1996)

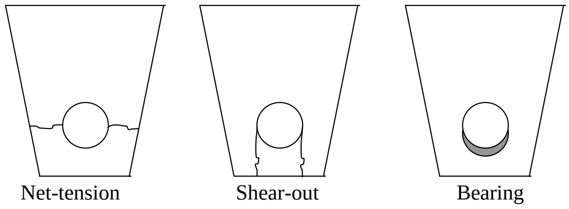


Figure 2. Typical failure mechanisms for the pinned joint configuration.

3. STRESS AND FAILURE ANALYSIS OF COMPOSITE MATERIAL

Linear two-dimensional modeling implies some assumptions: The thickness of the laminate must be small compared with the plate length and width ,and the applied load must be in plane and symmetric with respect to the mid-plane.

The pin is modeled as a perfectly rigid inclusion with zero clearance, thus radial boundary conditions may be used. The contact stresses at these radial boundary conditions are monitored throughout the stress analysis. The initial contact angle is 90°, but when load is increased the contact angle is reduced if contact stresses are no longer compressive.

In order to find the failure analysis of composite material; firstly, the stresses at the nodes are calculated by finite element method.

$$\acute{o} = DBq \qquad (1)$$

where D is stiffness matrix given by;

$$D = \begin{bmatrix} \frac{E_1}{1-\nu_{12}\nu_{21}} & \frac{E_1\nu_{21}}{1-\nu_{12}\nu_{21}} & 0 \\ \frac{E_2\nu_{12}}{1-\nu_{12}\nu_{21}} & \frac{E_2}{1-\nu_{12}\nu_{21}} & 0 \\ 0 & 0 & G_{12} \end{bmatrix} \qquad (2)$$

Secondly stresses is put into failure criteria. If the result of criteria is bigger then the value of unity stiffness matrix loses its all properties. So, **D** is written as follows (Larry and Fu Kuo, 1991a,b; Aktaş and Karakuzu, l998).

$$D = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \tag{3}$$

then, stresses are calculated again and the procedure is, thus, continued.

4. FAILURE CRITERIAS

4. 1. Tsai-Hill Failure Criteria

This criteria says failure occur when the failure index, given by Tsai-Hill Theory, exceeds 1; i.e. the following inequality must be for no failure.

$$\frac{\sigma_1^2}{X^2} - \frac{\sigma_1 \sigma_2}{X^2} + \frac{\sigma_2^2}{Y^2} + \frac{\tau_{12}^2}{S^2} < 1 \tag{4}$$

where $X = X_t$ or X_c and $Y = Y_t$ or Y_c corresponding to the signs of $\sigma_{1,}$ σ_2 (if the applied stress is tension, the tensile strength is used and if the applied stress is compression, the compressive strength is used).

4. 2. Fiber Tensile-Compressive Failure Criteria

This mode of failure is used in two parts for pinned joint problems if $\sigma_1 > 0$ the failure criteria is given follows:

$$\left(\frac{\sigma_1}{X_t}\right)^2 + \left(\frac{\tau_{12}}{S}\right)^2 > 1 \tag{5}$$

and if $\sigma_1 < 0$ the criteria is;

$$\left(\frac{\sigma_1}{X_C}\right)^2 > 1 \tag{6}$$

The mechanical properties of the carbon-epoxy composite material are obtained from tensile test by means of strain gauge, shown in Table 1.

Table 1. Mechanical Properties of Composite Material

E_1 (GPa)	60.2	X_t (MPa)	636.5
E_2 (GPa)	59.2	X_c (MPa)	780.7
G_{12} (GPa)	3.91	Y_t (MPa)	541
ν_{12}	0.25	Y_c (MPa)	693
V_f (%)	16	S (MPa)	112

5. PREDICTION OF FAILURE MODE

The failure criterion mentioned above doesn't indicate the failure mode directly. So, to find the failure mode, θ_f must be found When θ_f is small ($\theta_f \approx 0°$) failure is by the bearing mode. When $\theta_f = 45°$ failure is due to shear-out. When $\theta_f = 90°$ failure is caused by tension. In summary, we take (Fu-Kuo et all., 1984).

-I 5° < θ_f < 15° bearing mode
30° < θ_f < 60° shear-out mode (7)
75° < θ_f < 90° net-tension mode

At intermediate values of θ_f failure may be caused by combination of these nodes.

6. RESULTS AND DISCUSSION

When the bearing strength values and failure modes are investigated, they are taken as functions of two variables; E/D ratio and W/d ratio when orientation angle of fibers is taken constant (θ = 0°). By changing the value of one of the variable while keeping the value of the other constant, the numerical analyses are performed. When E/D = 4 (W/D = 4 is constant) and W/D = 3 (E/D = 4 is constant), the failure modes are found as bearing mode which is the best mode of resisting load. For the small values mentioned above, the modes are found as shear-out and net-tension, which is weak type of failure.

While the value of bearing strength has its smaller value for E/D = 1, It increases with the increasing E/D ratios. For all E/D ratios, the bearing strength values obtained come close for each criterias (Figure 3).

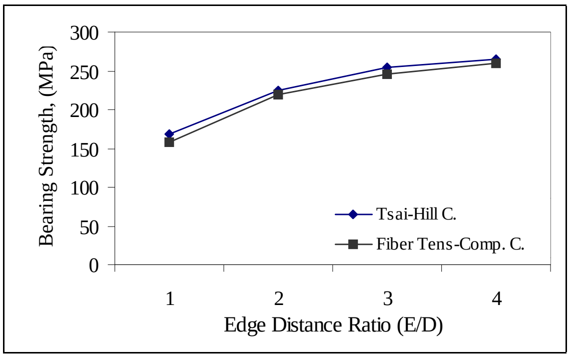


Figure 3. The effect of edge distance ratio on the bearing strength

Table 2. Comparisons of predicted failure mode, N-Net tension mode, S-shear-out mode, B-Bearing mode

θ = 0°, W/D=4	Predicted Failure Mode		Failure Angle	
E/D	Tsai-Hill C.	Fiber Ten.-Com. C.	Tsai-Hill C.	Fiber Ten.-Com. C.
1	S	S	52	56
2	S-N	S	72	45
3	S	S	42	36
4	B	B	0	0
θ=0°, E/D=4	Predicted Failure Mode		Failure Angle	
W/D	Tsai-Hill C.	Fiber Ten.-Com. C.	Tsai-Hill C.	Fiber Ten.-Com. C.
2	N	N	82	84
3	B	B	0	0

If one looks at the variation of the bearing strength values with respect to W/D ratios, it may be concluded that the bearing strength values increases as the W/D ratio increases. In the bearing strength with respect to W/D diagram, the curve has its higher slope in between the W/D ratios of 2 and 3 (Figure 4).

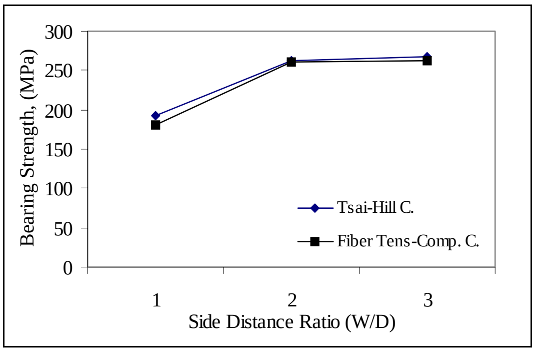
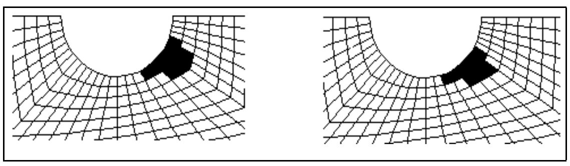


Figure 4. The effect of side distance ratio on the bearing strength

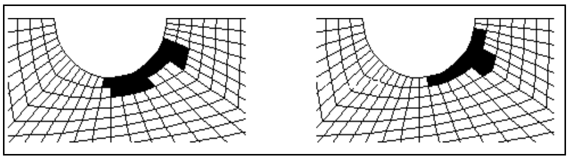
As a result of finite element analysis, failure mode of composite material considered is found to be shear-out and net-tension except for the cases of E/D and W/D ratios of 4 and 3 respectively. For those values the mode is bearing mode. The failure mode summary is given on Table 2.

Although the failure mode is the same, the propagation of failure is a bit different for criterion. Because the angle of first failure areas are different each other (Figure 5). The finite element program is stopped at the given loads due to numerical instability (e. g. excessive element distortion in an element with greatly reduced material properties) at a critical stage before the damage can progress completely towards the specimen edge (Larry and Mahmood, 1995).



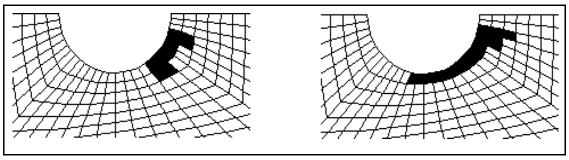
Tsai-Hill criteria
P=2200 N, θ_f=52
E/D=1, W/D=4

Fiber Tensile-Compressive criteria
P=2050 N, θ_f=56
E/D=1, W/D=4



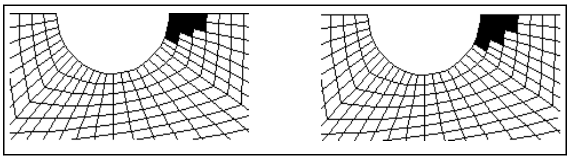
Tsai-Hill criteria
P=2900 N, θ_f=72
E/D=2, W/D=4

Fiber Tensile-Compressive criteria
P=2800 N, θ_f=45
E/D=2, W/D=4



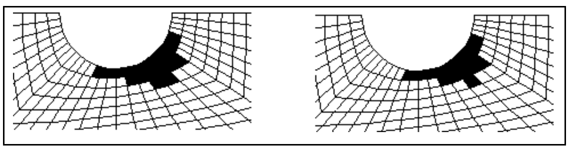
Tsai-Hill criteria
P=3250 N, θ_f=42
E/D=3, W/D=4

Fiber Tensile-Compressive criteria
P=3100 N, θ_f=36
E/D=3, W/D=4



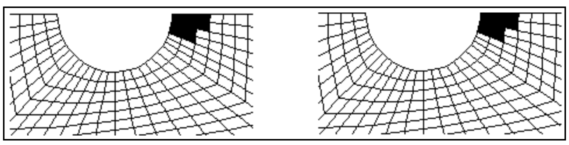
Tsai-Hill criteria
P=3400 N, θ_f=0
E/D=4, W/D=4

Fiber Tensile-Compressive criteria
P=3300 N, θ_f=0
E/D=4, W/D=4



Tsai-Hill criteria
P=2400 N, θ_f=82
W/D=2, E/D=4

Fiber Tensile-Compressive criteria
P=2300 N, θ_f=84
W/D=2, E/D=4



Tsai-Hill criteria
P=2400 N, θ_f=0
W/D=4, E/D=4

Fiber Tensile-Compressive criteria
P=2300 N, θ_f=0
W/D=4, E/D=4

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