STUDY OF FAILURE LOADS OF CARBON EPOXY COMPOSITE PLATES WITH SINGLE PIN HOLES

K. Sridevi

Department of Mechanical Engineering, Faculty of Technical and Engineering, The M.S. University of Baroda, Vadodara, Gujarat, India

ABSTRACT

This paper deals with the study of failure loads of carbon epoxy composite plates with a circular hole subjected to a traction force by a rigid pin using mathematical model. These are investigated for two variables, the ratio of distance from the free edge of the plate (E) to the diameter of the hole (D) and the ratio of width of the plate (W) to the diameter of the hole (D). The effect of joint geometry on the failure loads has been studied and a comparison of experimental, numerical and mathematical models is made. The results obtained by mathematical model are found to be close to the experimental results.

***KEYWORDS**: Failure loads, carbon epoxy composite plates, single pin holes.*

1.0 INTRODUCTION

Composite materials are popularly used because of their light weight, high strength to weight ratio, good fatigue resistance, corrosion resistance etc. compared to metals. Fiber-reinforced laminated composite materials have been gaining a wide application area in aircraft, aerospace, and marine industries because of their advanced properties. Pinned connections are commonly used in joining composites either to composites or to metal. But the presence of a hole in a laminated plate subjected to external loading introduces a disturbance in the stress field. Stress concentrations are generated in the vicinity of the hole making the joint a weak one. The knowledge of failure strength of a joint helps in selecting the appropriate joint size in a given application. The capability of a composite structure to withstand any physical load can be evaluated either by physical testing or by any advanced computational method. Performing physical tests on composites is destructive and costly. So, implementing advanced computational techniques to determine the failure loads and failure modes are preferred after some experiments are done.

* Corresponding author email: srikavirayani@gmail.com

Nanda et al. (2009) studied the effects of various geometric parameters on the behaviour of three and four-pin joints in glass fiber/epoxy composite laminate with emphasis on pitch-to-diameter ratio. Numerical analysis was performed using a two-dimensional finite element model to study the propagation of damage by implementing Tsai–Wu failure criteria to predict failure load and to differentiate failure modes. Experiments were conducted to validate the results obtained from finite element analysis. Aktas (2011) has done experimental and numerical study to determine the failure behaviour of glass epoxy composite plates with single pinned hole and two serial pinned holes. The numerical study was performed by using ANSYS and Yamada-Sun failure criteria were used. Ozen and Sayman (2011) investigated experimentally and numerically the first failure load and the bearing strength behaviour of pinned joints of glass fibre reinforced woven epoxy composite prepregs with two serial holes subjected to traction forces by two serial rigid pins. Soykok et al. (2013) have carried experiments to understand the effect of thermal condition and tightening torque on the failure load and failure behavior of glass epoxy composite joints. It was observed that the load carrying capacity of the joint decreased by increasing the temperature level. The tightening torque was observed to increase the joint strength. Khashaba et al. (2013) has dealt with the failure and reliability analysis of composite pinned-joints using theoretical models based on Weibull distribution functions with experimental results for a guideline of safe design strength. Sridevi and Satyadevi (2013) have studied the failure of glass vinylester composite plates for different geometries using ANSYS and also through mathematical modeling. Here the results obtained by mathematical models were found to be close to the experimental results when compared with the ANSYS results. Kadir Turan et al. (2014) have studied experimentally and numerically the failure loads of carbon epoxy composite plates for different geometric parameters. In the present work mathematical model is developed to predict the failure loads of different geometric specimens. The results obtained from mathematical model are found to be close to the experimental results.

2.0 PROBLEM DEFINITION

In the present work a composite rectangular plate, shown in Figure. 1, of length L+E, width W and thickness T is considered. A hole of diameter D is present at a distance E from one edge of the plate. A rigid pin is located at the centre of the hole. A load P is applied to the plate along the longitudinal axis. The plate is symmetric with respect to the longitudinal axis. The diameter of the hole is taken as 6mm and thickness of the plate T as 1.235mm.

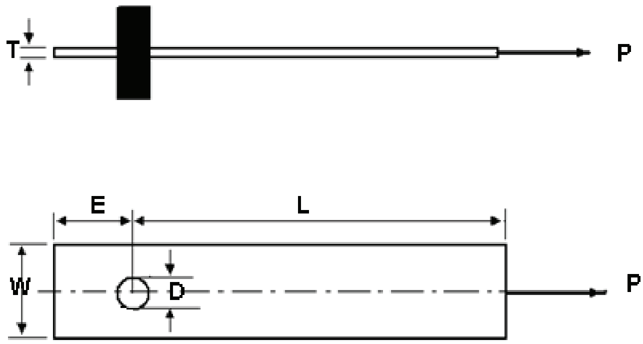

Figure 2. Geometry of the Specimen

The material properties considered are shown in Table 1 given by K. Turan et al. (2014). Different models are obtained by varying E/D and W/D but keeping the parameters D and T as constant. A mathematical model is developed to obtain the failure loads of different specimens. A comparison of results obtained from mathematical models with experimental and numerical results is made and correlations are observed.

Table 1. Material properties of the plate.

Longitudinal Young's module	E1 (MPa)	172,891
Transverse Young's module	E2 (MPa)	10,797
Shear module	G12 (MPa)	3638
Poisson's ratio	v12	0.32
Longitudinal tensile strength	Xt (MPa)	1441
Transverse tensile strength	Yt (MPa)	37
Longitudinal compressive strength	Xc (MPa)	420
Transverse compressive strength	Yc (MPa)	116
Shear strength	S (MPa	57

2.1 Mathematical Modeling

A mathematical model has been developed to predict the failure loads of specimens with different geometries using curve expert. The model has been built with the available experimental results of Kadir Turan et al. (2014). The equation has two independent variables in W/D ratio as x1 and E/D ratio as x2. The dependent variable considered here is the failure load P. The thickness of the specimen and the diameter of the hole are constant for all the specimens. A Full Cubic polynomial equation is found to be best suited to determine the failure loads for the existing problem. This equation can be used to predict the failure load of specimens with other geometric parameters within the given range i.e. for E/D and W/D ratios for which experiments have not been done. The limitation with the model is that the failure mode is not predicted. But, we know that for higher values of E/D and W/D the shear strength and normal strength of the plates increase, so specimen tends to fail in bearing mode only. Hence, the mathematical model is best suited to obtain the results for failure loads. The equation developed is found to be

$$\begin{gathered} P = a + b*x_1 + c*x_2 + d*x_1^2 + \ldots\ldots \\ \ldots\ldots + e*x_2^2 + f*x_1^3 + g*x_2^3 + h*x_1*x_2 + \ldots\ldots \\ \ldots\ldots + i*x_1^2*x_2 + j*x_1*x_2^2 \end{gathered} \tag{1}$$

Where in the values of the co-efficients a, b, c, d, e, f, g, h, i and j are given in Table 2

Table 2. Co-efficients of the Full Cubic Model Developed

a	b	c	d	e	f	g	h	i	j
896.12	-1037.76	465.34	267.51	-123.72	-20.01	7.45	183.98	-21.23	-2.68

The results obtained by mathematical model are compared with the experimental and numerical results. The graphical representation is shown in Figure.2.

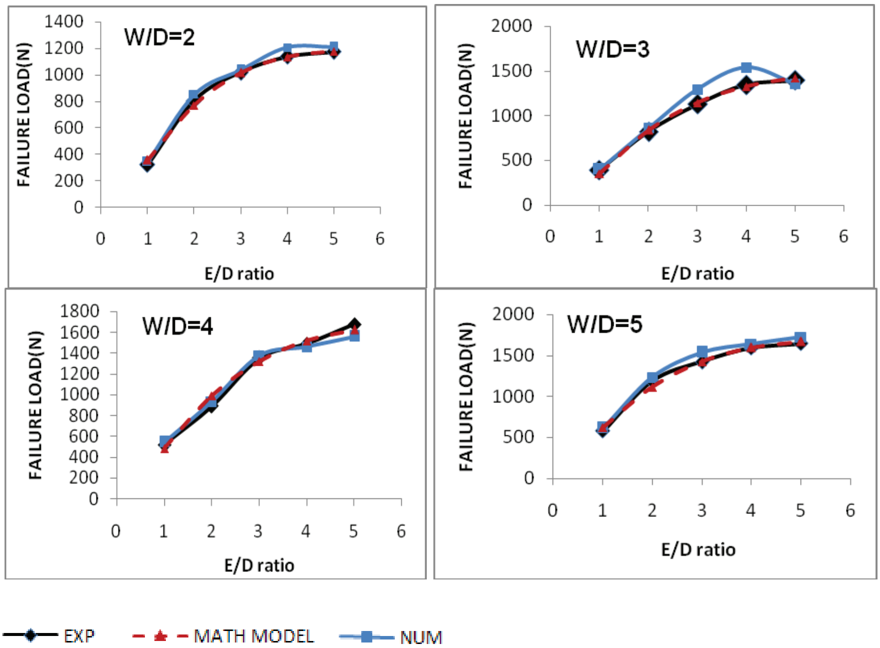

Figure. 2 Comparison of results for constant W/D

3.0 RESULTS AND DISCUSSIONS

The failure loads of specimens obtained by varying the E/D and W/D ratios are found from mathematical model. Results from numerical models found using ANSYS are available. A comparison of the failure loads obtained from experimental, numerical and mathematical model have been made. Shown in the Figure. 2 are the graphs plotted for the failure loads of specimens obtained from experimental, numerical and mathematical models for different W/D ratios and E/D ratios. All the three methods show the same trend in the failure loads but the results obtained by the mathematical model are close to the experimental results. It is observed from the results obtained that

- For a constant W/D ratio, the failure strength of the specimen increases with increase in E/D. This is because keeping the diameter of hole constant, when E/D increases, the distance of the hole from one edge of the plate increases and so the shear strength of the specimen increases.

- With the increase in W/D ratio, keeping E/D ratio constant, the failure load of the specimens increase. This is because as W/D increases and hence the width of the specimen, the normal strength of specimen increases.

- Both numerical and mathematical models show the same trend in failure loads with varying E/D and W/D ratios.

- A comparison of the experimental results with the mathematical model shows that the mathematical model gives results with Correlation Co-efficient 0.9956, Maximum Absolute Error as 176N and Root Mean Square Error as 80N.

4.0 CONCLUSIONS

In the present work, failure loads of carbon epoxy composite plates with singe pin holes were studied mathematically for the geometrical parameters W/D and E/D. A comparison with the experimental results show that

- The specimen is weak for lower values of E/D and W/D and so failure occurs at small loads.

- E/D ratio has a greater effect on the failure load of the specimen.

- As for higher values of E/D and W/D ratios, the specimen generally fails in bearing mode only, and hence the failure loads are the important parameters to be analyzed, wherein the mathematical models prove to be more efficient.

- Mathematical models show the same trend in the failure loads of specimens, when compared with the experimental models. So, for estimation of the failure loads within the range considered for the study, the mathematical models developed, i.e., Full Cubic Models proves to be efficient with the given values of Correlation Co-efficient, Maximum Absolute Error and Root Mean Square Error.

REFERENCES

Nanda, A.K., Malhotra, S.K. and Prasad, N.S., (2009). Failure analysis of multi-pin joints in glass fibre/epoxy composite laminates. *Composite Structures, 91*. 266-277

Aktas, A., (2011). Failure analysis of serial pinned joints in composite plates, *Indian Journal of Engineering and Material Sciences, 18*. 102-110

Ozen, M. and Sayman, O., (2011). Failure loads of mechanical fastened pinned and bolted composite joints with two serial holes, *Composites: Part B 42*, 264-274

Soykok, I.F., Sayman, O., Ozen, M., Korkmaz, B., (2013). Failure analysis of mechanically fastened glass fiber/epoxy composite joints under thermal effects, *Composites: Part B 45*, 192-199

Khashaba, U.A., Sebaey, T.A., Alnefaie, K.A., (2013). Failure and reliability analysis of pinned-joints composite laminates: Effects of stacking sequences, *Composites: Part B, 45* (2013) 1694-1703

Sridevi, K., and Satyadevi, A., (2013). Model development for estimation of failure loads: A case study of composite plates with single pin-loaded hole, *International Journal for Scientific Research & Development 1(05)*, 1268-1271

Kadir Turan., Mustafa Gur., Meta Onur Kaman., (2014). Progressivef analysis of pin-loaded unidirectional carbon-epoxy laminated composites, *Mechanics of Advanced Materials and Structures 21*, 98-106