



Research Paper

DEVELOPMENT OF MATHEMATICAL MODELS FOR DETERMINATION OF FAILURE LOADS OF GLASS EPOXY COMPOSITE PLATES WITH TWO PARALLEL HOLES

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This paper deals with the development of mathematical models to study the failure loads of fiber glass reinforced woven epoxy composite plates with two parallel holes subjected to traction forces by two rigid pins. To understand the effect of joint geometry on the failure loads the geometrical parameters like the edge distance to the hole diameter (E/D), the distance between center of two holes-to-hole diameter (K/D), the distance from the upper or the lower edge of the specimen to the centre of the hole-to-hole diameter (M/D) were varied. Mathematical models have been developed for wet and dry specimens to determine the failure loads of different geometry plates. Wet specimens are specimens immersed in seawater for 3 months. The unimmersed specimens are called dry specimens. Here Full Cubic models have proved to be very efficient. A comparison of the results from mathematical models with the experimental results from existing literature shows high values of correlation co-efficient, Root Mean Square Error and Maximum Absolute Error. For estimation of the failure loads within the range of E/D, K/D and M/D considered for the study, the mathematical models developed are found to be efficient.

Keywords: Composites, Failure load, Pin loading

INTRODUCTION

The use of composite materials in structural components of mechanical and civil applications has grown steadily in recent years. Composite materials have a wide range of applications because of their high strength-to-weight ratio, stiffness, low density, and long fatigue life. As a result, composite-

to-composite or composite-to-metal joining is required widely in industrial applications. Most of these joints are formed by using mechanical fasteners such as pins because of their low cost, simplicity and easy assembly and disassembly. Multiple fasteners can also be used in many applications. But stress concentrations are generated in the vicinity

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of the hole making the joint a weak one. The knowledge of failure strength of a joint helps in selecting the appropriate joint size for a given application. Advanced computer techniques can be used to determine the failure strengths of joints after some experiments are done. Several authors examined the effect of geometric parameters on the failure strength, fibre orientation and failure mode of a laminated composite plate with mechanically fastened joints.

Aktas and Uzen (2008) have experimentally studied the effect of seawater on glass fiber composites with single hole for different time periods by tying the specimens in the ship and making a voyage in the sea. The study showed that the failure distance of pin displacement increased with the increase in immersion period due to the softening of the specimen. Seawater had a degrading effect on the failure strength of the specimens. (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) have studied the effect of seawater on glass epoxy composite specimens with two serial holes subjected to a serial pin loading. The specimens were considered dry and also wet i.e. immersed for 24 hours in seawater. (Orcen et al., 2012) have studied the effect of seawater on the first failure load on glass epoxy composite joint with two parallel holes. Dry specimens and also wet specimens immersed in seawater for 3 months were

studied. Different specimens were considered by varying the geometrical parameters. Finite element analysis models were developed in ANSYS and the results obtained were compared with the experimental results. (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. (Sridevi, 2013) has developed mathematical models for determining the failure loads of glass epoxy composite plates with two serial holes. The results obtained from mathematical models were compared with experimental results and they were found to have high correlations. In the present work, mathematical models have been developed to predict the failure loads of composite pin joints under both dry and wet conditions. The results obtained from the mathematical models are compared with the experimental results of (Orcen et al., 2012).

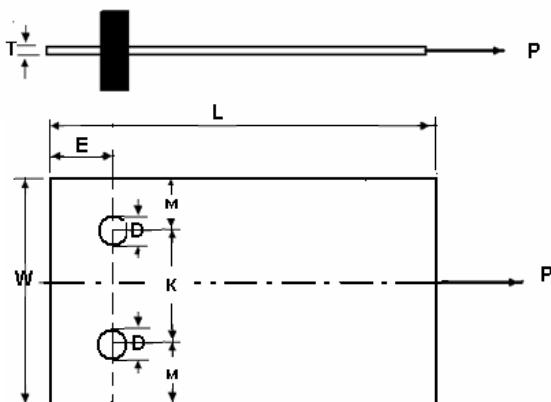
MATERIALS AND METHODS

Problem Definition

To understand the effect of joint geometry on the failure loads the geometrical parameters like the distance from the upper or the lower edge of the specimen to the centre of the hole-to-hole diameter (M/D), the distance between center of two holes-to-hole diameter (K/D) and the edge distance to the hole diameter (E/D) were varied from 1-2, 2-4 and 2-5 respectively. Here specimens are

considered both dry and wet i.e. specimen held in sea water for 3 months.

Figure 1: Geometry of the Specimen



The geometry of the composite specimen is shown in Figure 1. Here W represents the width of the plate, L is the total length of the plate, E the edge distance of the holes from one end of the plate, K is the distance between the two holes, M the distance from the upper or the lower edge of the specimen to the centre of the hole and T is the thickness of the plate. The diameter of the holes is shown as D . The diameter of the holes, thickness of the plate and the total length of the plate are taken constant as 5mm, 1.6mm and 95mm respectively. A load P is applied to the plate along the longitudinal axis. The plate is symmetric with respect to the longitudinal axis.

Table 1: Material Properties of the Composite Plate

MODEL	E_1 (GPa)	E_2 (GPa)	G_{12} (GPa)	S_{12} (MPa)	μ_{12}	$X_t=Y_t$ (MPa)	$X_c=Y_c$ (MPa)
DRY	25.90	25.90	6.32	92.00	0.16	258	216.5
WET	23.97	23.97	5.40	90.80	0.16	218	195.5

The material properties considered, that are given by Orcen *et al.* (2012), are shown in Table 1. Different models are obtained by varying M/D , K/D and W/D but keeping the parameters D , T and L as constant. Mathematical models are developed to obtain the failure loads of different specimens. A comparison with experimental results is made and correlations are observed.

MATHEMATICAL MODELLING

Mathematical models have been developed to predict the failure loads of specimens with different geometries using curve expert. The models are built with the available experimental results. The equation has two independent variables in K/D ratio as x_1 and E/D ratio as x_2 . 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. Full Cubic model is found to be best suited to determine the failure loads for the existing problem. Equations are developed for dry and wet specimens with M/D ratio equal to 1 and 2 wherein each case K/D varies from 2-4 and E/D varies from 2-5. These equations can be used to predict the failure load of specimens with other geometric parameters within the given range i.e. for M/D , K/D and E/D ratios for which experiments have not been done. It thereby saves the cost and time in carrying out the tests. Hence, the mathematical models are best suited to obtain the results for failure loads. The Full-cubic equation developed is found to be

$$P = a + b*x_1 + c*x_2 + d*x_1^2 + e*x_2^2 + f*x_1^3 + g*x_2^3 + h*x_1*x_2 + i*x_1^2*x_2 + j*x_1*x_2^2$$

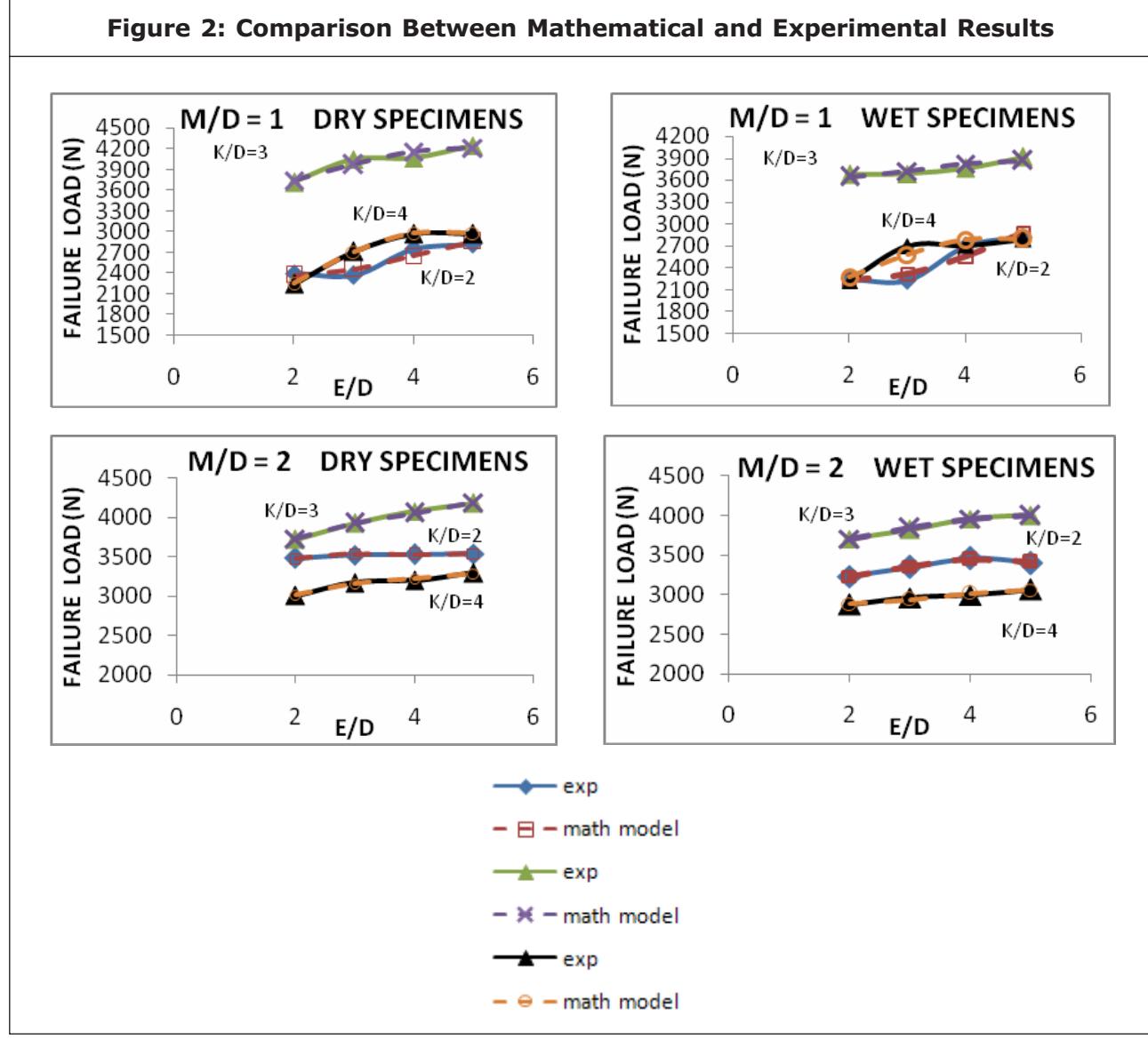
Wherein the value of the co-efficients a, b, c, d, e, f, g, h, i and j are given in Table 2.

Here model 1 represents dry specimens with M/D=1, model 2 for wet specimens with M/D=1, model 3 for dry specimens with M/D=2 and model 4 for wet specimens with M/D=2.

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

MODEL	a	b	c	d	e	f	g	h	i	j
1	1480.3	-1630.7	-1227.8	1910	316.6	-381.4	-13.9	267.7	45	-71.4
2	-14880	15635.1	-648.3	-3869	348.1	249	-14.9	-266.7	118.9	-66.9
3	3185.6	-778.6	-316.2	462.5	-151.8	-83.3	13.9	651.6	-98.7	-3.5
4	2029.5	-401	-82.8	756	36.9	-146.9	-11.1	107	-40.2	18.9

Figure 2: Comparison Between Mathematical and Experimental Results



RESULTS AND DISCUSSION

Composite specimens with two parallel pin holes subjected to traction forces by rigid pins are studied. The specimens are considered both dry and wet i.e. soaked for 3 months in seawater. Mathematical models have been separately developed for both dry and wet specimens. Figure 2 represents the graphs showing the comparison between the results obtained from the mathematical models with the existing experimental results for different E/D, K/D and M/D ratios. Mathematical models follow the same trend as that of experimental results.

- When M/D=1 as K/D increases from 2 to 3 load increases but between K/D variation 3 to 4 the failure load decreases. This is because the distance between the holes increases but the holes are coming close to the outer edge of the plate. So it becomes weak.
- When M/D=2 as K/D increases from 2

to 3 load increases but as K/D increases from 3 to 4, the failure load values are clearly below that at K/D=2. So the specimens are weak for this geometric combination.

- In all cases K/D=3 shows maximum failure load.
- In all cases for constant K/D, with increase in the E/D ratio the failure load increases as the distance from the edge of the plates increases.
- Wet specimens show a decrease in the failure loads compared to dry specimens due to degradation of material properties.
- The correlation between the mathematical models and experimental results is found to be high.

Table 3 shows the Correlation Coefficient, Root Mean Square Error and Maximum Absolute Error.

Table 3: Correlation Coefficient, Root Mean Square Error and Maximum Absolute Error

MODEL	Maximum absolute error	Root mean square error	Correlation coefficient
1	94	54	0.9968
2	133	71	0.9932
3	23	11.5	0.9994
4	25	13	0.9994

CONCLUSION

- Keeping the total width of the specimen constant, with the increase in E/D ratio the failure load increases.
- For a constant E/D ratio, increasing the width of the specimen by increasing the distance between the holes (K) increases the failure load first from K/D=2 to 3 and later decreases from 3 to 4

which shows that K/D=3 is a critical value.

- When the specimens were soaked for 3 months in seawater, then they are found to fail at lower loads compared to the dry specimens. So, seawater was observed to have a negative effect on the failure loads of the specimens.

- 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.

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