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NUMERICAL STUDY OF HYBRID COMPOSITE CFRP/GFRP

Ahmad Fuad Ab Ghani[1], Nurul Najwa[1], Zulkefli Selamat[2], Yongtao Lu[3], Aidah Jumahat[1] and Jamaludin Mahmud[1]

[1]Faculty of Mechanical Engineering, University Technology Mara, Shah Alam, Selangor, Malaysia
[2]Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, Durian Tunggal, Melaka, Malaysia
[3]Department of Engineering Mechanics, Faculty of Vehicle Engineering and Mechanics, Dalian University of Technology, Dalian, China
E-Mail: ahmadfuad@utem.edu.my

ABSTRACT

The project aims to analyze the failure of glass/epoxy and graphite/epoxy laminates and investigates failure behavior of glass-graphite/epoxy hybrid composite with the numerical and experimental approach. Finite element simulation using ANSYS v15 is used to determine the first ply failure (FPF) and last ply failure (LPF) loads. The hybrid effect to glass-graphite/epoxy will be replicated and analyzed using with a various angle of fiber orientation (θ = 0°, 45° and 90°) subjected to the uniaxial tensile test. Maximum Stress Theory and Tsai-Wu Failure Criteria are employed to determine the failure load (failure index = 1). In numerical approach, failure behavior of the two different composite laminates has been analyzed. The failure curves (FPF and LPF) for both theories (Maximum Stress Theory and Tsai-Wu) are plotted and found to be close to each other. Therefore, from the preliminary outcome, it can be concluded that the current study is useful to the failure behavior of composite laminate.

Keywords: hybrid composite, composite laminate, failure behaviour, ANSYS.

INTRODUCTION

Historically, the concept of composite materials has been used for a long time, approximately from the ancient time itself. Some alloys and compound metals can satisfy to some extent, but there are some constraints and limitations. In that case, composite materials have relevant properties to satisfy the present requirements such as weight reduction with excellent toughness, cost reduction and as well as high durability. However, these vision and properties can be further enhanced and improved by introducing hybrid composite.

Hybrid composite is an extension to composite due to the increase in demand of advance material to satisfy the needs of automotive, aerospace and as well as sports industry. The term hybrid composite can be defined as two types of fibers are mixed together into a single matrix. The concept is a simple extension of the composites principle by combining several different types of fiber in order to optimize their engineering value [1]. The purpose of hybridization is to extend the concept of tailoring the material's properties to suit particular design requirements and to offset the limitations of one component by the addition of another [2]. This allows expensive fibers like graphite and boron can be partially replaced by less expensive fibers such as glass and Kevlar [3] [4]. The significance advantages offered by hybrid composite materials are often considered in terms of the improvement in a particular mechanical property resulting from the addition of a second reinforcement type [5].Glass/epoxy laminated composite among the most commonly used composite materials due to its ability to provide good performance at low cost. However, one major drawback of glass/epoxy composite is its brittle property and has a relatively low tensile strength which limits its applications [6]. In addition, another limitation of glass/epoxy is heavy and as compared to graphite/epoxy, it has a lower strength to weight ratio. In terms of graphite/epoxy composite, it has high strength and stiffness properties, however, it cost more [7].By definition, failure occurs in a material when the applied load reached its limit or threshold [8]. There are a few factors can lead to the occurrence of failure such as the effect of longitudinal tensile loads in the fiber direction, longitudinal compressive loads in the fiber direction, tensile loads transverse to the fibers, compressive loads transverse to the fibers, or shear loads. These could resulted in matrix cracks, separation of the fiber and the matrix (debonding), and separation of one lamina from another (delamination) under normal working conditions [9].

First ply failure (FPF) occurs when the first ply in a laminate fails in either the fiber direction or in the direction perpendicular to the fibers. This failure could result to the loss of stiffness and strength of the material. The failure will further propagate to the next weakest plies available until it finally leads to the total rupture when the last ply fails [10]. The load corresponding to this failure can be the design limit load. The relationship between the first ply failure and the last ply (ultimate) failure of a laminate can determine the total number of plies, the relative stiffness of those plies and the overall stress distribution among the plies. Last ply failure (LPF) is said to be occurred after the structure has degraded to the point where it is no longer capable of carrying additional load [9].

In terms of failure criterion, the Maximum Stress Theory is one of the common failure criteria used in foreseeing composite laminate failure. The stresses in the

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principal material directions ($\sigma 1$, $\sigma 2$, $\tau 12$) must be less than the corresponding strength (X, Y, and S), or else failure is said to be occurred at the composite layer. Generally, for tensile stress the limits are ($\sigma 1 < Xt$, $\sigma 2 < Yt$, $|\tau 12| < S$) and failure occurs when onset is marked by any of the loading factors reaching $F \geq 1$ [11]. Tsai-Wu failure criterion is another commonly used failure theory in predicting composite failure. It involves polynomial composite laminate. It is considered to be the general theory of strength for anisotropic materials. However, Tsai-Wu failure criterion not able to identify modes of failure such as fiber failure, matrix failure and shear stress as compared to the Maximum Stress Theory [12]. Therefore, this study aims to analyze failure of graphite/epoxy and glass/epoxy laminates and failure behavior of glass-graphite/epoxy laminate using finite element software prior to the hybridization process of glass-graphite/epoxy composite laminates.

METHODOLOGY

In order to achieve the main objective of this research, there are 3 stages involved:

- Stage 1: Development of finite element (FE) model
- Stage 2: Numerical validation
- Stage 3: Failure analysis

Figure-1 shows the overall workflow of the current study. The workflow repeated with different variations of angle (0°, 15°, 30°, 45°, 60°, 75°, 90°) and using two failure criteria which are Maximum Stress Theory and Tsai-Wu.

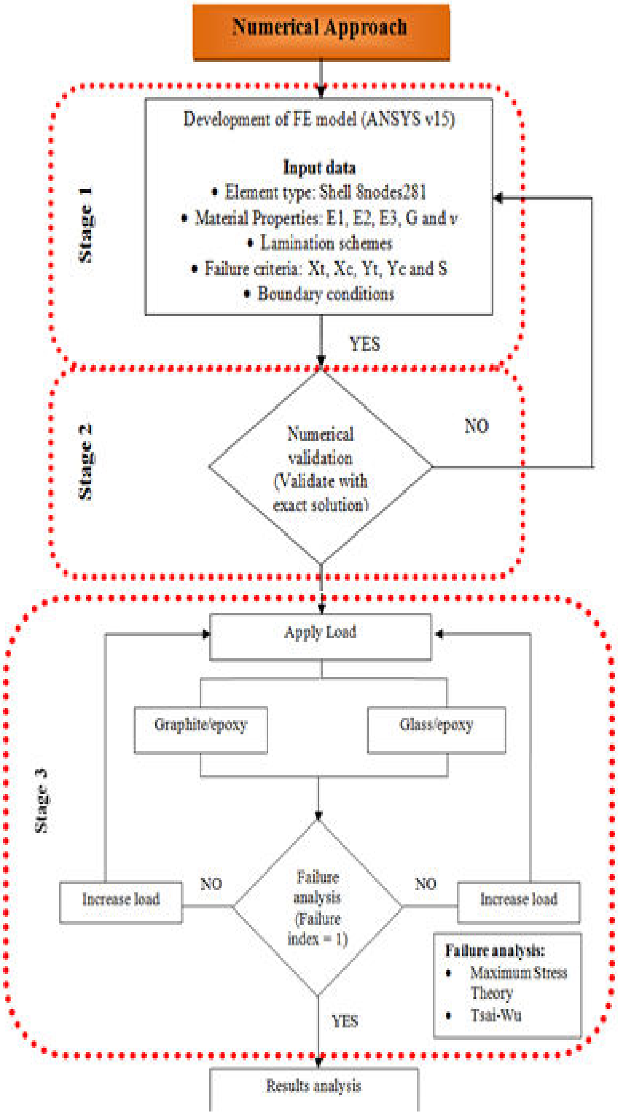

Figure-1. Overall workflow of failure analysis of composite laminates.

Numerical validation

Numerical validation is an important initial step to prove that the current FE model and implementation is acceptable. The current finite element results (ANSYS) have been validated compared to the exact solution. The plate geometry is shown in Figure-5. The material used is T300/5208 graphite/epoxy composite and its properties are tabulated in Table-1. The results are acceptable since the error is found less than 2% (as shown in Table-2). It is found that the FE model was considered valid and able to produce reliable results. Thus further analyses were carried out using FE simulation.

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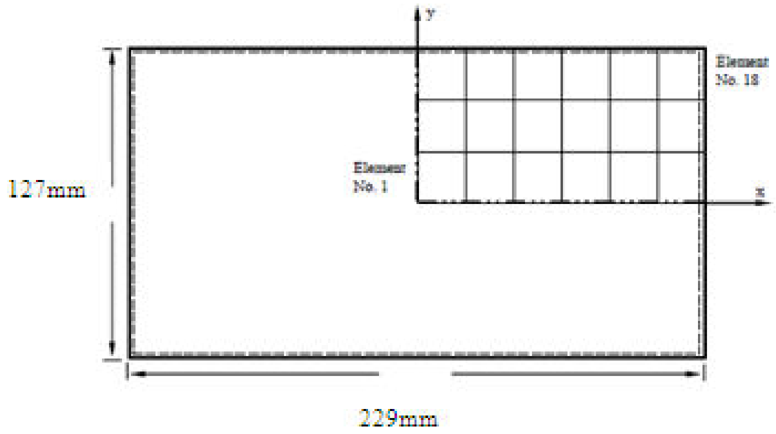

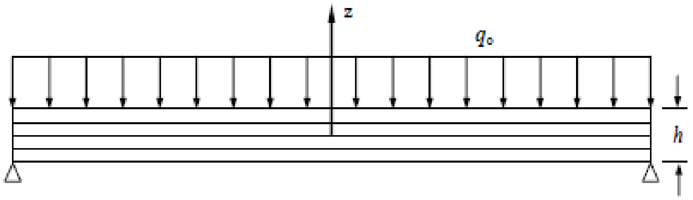

Figure-2. Geometry and computational domain for composite laminate under transverse load.

Table-1. Material properties of T300/5208 graphite/epoxy.

Properties	Values
E_1	138 GPa
E_2	10.6 GPa
G_{12}	6.46GPa
ν_{12}	0.3
X_T	1035 MPa
X_C	1035 MPa
Y_T	27.6 MPa
Y_C	138 MPa
S	41.4 MPa

Table-2. Comparison of exact and finite-element solution, z-displacement (mm) for laminated composite plate (229mm by 127mm).

Lamination scheme	**UDL**(Pa)	**Exact solution**(mm)	**ANSYS** (mm)	**Error (%)**
$[0/90/0/90]_T$	689.5	0.00340	0.00338	0.59
$[0/90/90/0]_T$	689.5	0.00582	0.00579	0.52
$[45/-45/45/-45]_T$	689.5	0.00276	0.00274	0.72
$[15/-15/15/-15]_T$	689.5	0.00639	0.00636	0.43
$[45/-45]_T$	689.5	0.04066	0.04029	0.91
$[15/-15]_T$	689.5	0.06610	0.06576	1.42

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Failure analysis of composite laminates

Symmetric composites plates are modeled as shown in Figure-3 under uniaxial tension. The laminate consists of 24 layers, where the layup studied is (θ4/04/-θ4)s. For this study 2 types of composite materials are analyzed, which are T300/5208 graphite/epoxy and glass/epoxy. The plate is square, with the length of the plate, a, is 20 mm (0.02 m). The laminate is made of having an aspect ratio (S = a/h) of 150. Therefore, the thickness of the plate, h, is 1.33333 x 10-4 m and the cross sectional area (A = ah) is 2.66667 x 10-6 m2. The material and strength properties are shown in Tables 3 and 4.

A finite element failure analysis procedure is carried out using commercial software (ANSYS v15.0). The predictions of failure are based on available built in failure theory and failure criteria functions which are Maximum Stress Theory as in Equation. (1) and Tsai-Wu as in figure Equation. (2).

Plate Geometry:

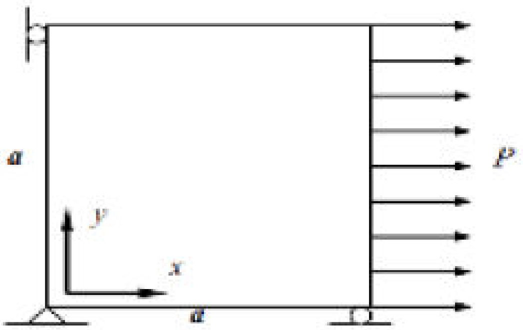

Figure-3. Uniaxial tension model.

Table-3. Material properties of T300/5208 graphite/epoxy composite [13].

Properties	Values
E_1	138 GPa
E_2	10.6 GPa
G_{12}	6.46GPa
ν_{12}	0.3
X_T	1450 MPa
X_C	1450 MPa
Y_T	51 MPa
Y_C	250 MPa
S	93MPa

Table-4. Material properties of glass/epoxy [14].

Properties	Values
E_1	19.94 GPa
E_2	5.83 GPa
G_{12}	2.11 GPa
ν_{12}	0.29
X_T	700.11 MPa
X_C	700.11 MPa
Y_T	69.67 MPa
Y_C	122.12 MPa
S	68.69 MPa

$\sigma_1 = X_t$ or X_C, $\sigma_2 = Y_t$ or $Y_{C,}$ $\tau_{12} = S$ (1)

$$F_1\sigma_1 + F_2\sigma_2 + F_6\tau_{12} + F_{11}\sigma_1{}^2 + F_{22}\sigma_2{}^2 + 2F_{12}\sigma_1\sigma_2 + F_{66}\tau^2{}_{12} \geq 1 \quad (2)$$

RESULTS AND DISCUSSIONS

Case study 1: Graphite/epoxy (T300/5208)

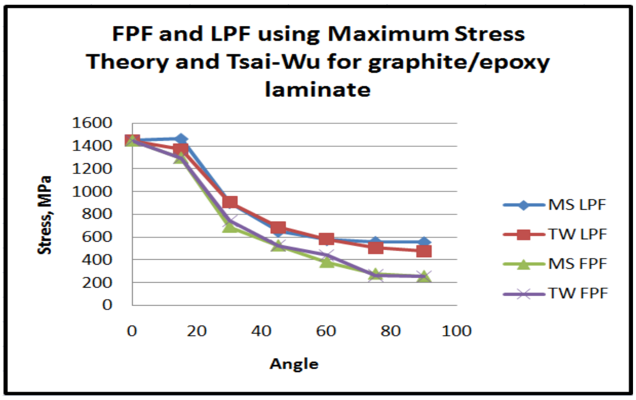

Figure-4. FPF and LPF using maximum stress theory and Tsai Wu in graphite/epoxy graph.

Case study 2: Glass/epoxy

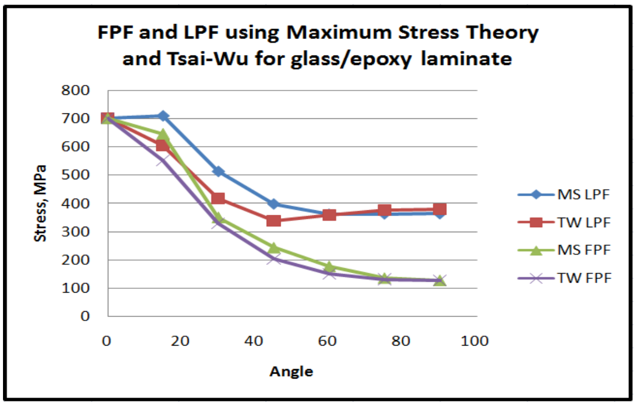

Figure-5. FPF and LPF using maximum stress theory and Tsai Wu in glass/epoxy graph.

Prior to the hybridization process of glass-graphite/epoxy laminates, FE simulation and analysis using ANSYS for each of the composite laminates (graphite/epoxy and glass/epoxy) are performed. In general, the results show that the first ply failure and last ply failure load for both graphite/epoxy and glass/epoxy decreases when the fibers are orientated from 0° to 90°. Stresses value in x-direction shows that Maximum Stress Theory predicts higher stress than Tsai-Wu in most cases. Both of the theories predicts the highest stress occur at angle 0° while the lowest at angle 90° expect for the LPF for both of the laminates which tested using Maximum Stress Theory. The highest maximum stress for them is at angle 15°. Basically, highest stress occurs at angle 0° due to the fibre direction parallels to the direction of the load applied. While at angle 90°, fibre direction perpendicular to the x-axis (global axis) is perpendicular to the load applied. This requires less stress applied for the failure to occur.

Graphite/epoxy laminate

From the results shown in Figure-4 (graphite/epoxy), it could be observed that there is no significant difference of the failure curves when tested using Tsai-Wu and Maximum Stress Theory. At FPF, slight differences occurred at angles 30° and 60° fiber orientation. The failure curves for the rest of angle orientation are almost similar. At LPF, slight differences occurred at angles 15° and between 75° to 90° fiber orientations. The failure curves for the rest of angle orientation are almost similar.

Glass/epoxy laminate

From the results shown in Figure-4 (glass/epoxy), it could be observed that there is no significant difference of the failure curves when tested using Tsai-Wu and Maximum Stress Theory. At FPF, slight differences occurred between angles 15° to 60° fiber orientations. However, the differences in stresses values are small and at 30° the difference was calculated to be only 20.69 MPa or 5.9%. At LPF, slight differences occurred between angles 15° to 45° fiber orientation. The failure curves for the rest of angle orientation are almost similar. The failure curves for the rest of angle orientation are almost similar.

Hybridization process

The outcome of this research will be use in future studies as it will be continue for hybridization process and further tested using tensile test. The variations of angle of 0°, 45° and 90° will be use to determine the hybrid effect of glass-graphite/epoxy hybrid laminate. The expected results for the hybridization process include a reduction in weight and cost of glass-graphite epoxy hybrid laminate.

CONCLUSIONS

This paper presents the application of numerical analysis using commercial software (ANSYS) to analyze the failure of graphite/epoxy and glass/epoxy laminates under uniaxial tension and further hybridize these two composite laminates. The results of the study prove that the main objective of the research has been achieved successfully. The findings show that failure load for both graphite/epoxy and glass/epoxy laminates are highest at angle 0° . The failure curves for FPF and LFP for both of the laminates coincide respectively. In general, it can be concluded that the current study is useful and has contributed significant knowledge to better understand the failure and of composite plate.

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REFERENCES

[1] Kelly A. 1994. Concise Encyclopedia of Composite Materials, 1st Edition.

[2] Inam F., Wong D. W. Y., Kuwata M. and Peijis T. 2010. Multiscale Hybrid Micro-Nanocomposites Based on Carbon Nanotubes and Carbon Fibers.

[3] Chou T. W., Kelly A. 1980. Mechanical properties of composites. Annual. Rev. Material. Science. 10:229-59

[4] Ahmed M. N., Kumar P. V., Shivanand H. K. and Muzammil S. B. 2013. A Study on Flexural Strength of Hybrid Polymer Composite Materials (E Glass Fibre-Carbon Fibre-Graphite) on Different Matrix Material By Varying Its Thickness. International Journal of Mechanical Engineering and technology. 08/2013; 6359(4):274-28.

[5] Dong, C. and Davies, I. J. 2014. Flexural and tensile moduli of unidirectional hybrid epoxy composites reinforced by S-2 glass and T700s carbon fiber, Material & Design. 54, 893-899.

[6] Daryadel S. S., Ray C., Pandaya T. and Mantena P.R. 2015. Energy Absorption of Pultruded Hybrid Glass/Graphite Epoxy Composite under High Strain-Rate SHPB Compression Loading. Material Science and Applications. 6, 511-518.

[7] AF Ab Ghani, J Mahmud.2017. Shear deformation behaviour of hybrid composite

(GFRP/CFRP),Materialwissenschaft und Werkstofftechnik 48 (3-4), 273-282

[8] Nahas M. N. 1986. Survey of Failure and Post-Failure Theories of Laminated Fiber-Reinforced Composites. Journal of Composites Technology & Research. 8: 138-153.

[9] Samsudin A. H., Hussain A. K. and Mahmud J. 2015. Deformation and Failure Analysis of Symmetric and Antisymmetric Graphite/Epoxy Laminate Due To Variations in Fiber Orientation. ARPN Journal of Engineering and Applied Sciences. 10(17). ISSN 1819-6608.

[10] S. Tolson, T. Zabaras. 1991. Finite Element Analysis of Progressive Failure in Laminated Composite Plates. Computers and Structures. 38: 361.

[11] Kam T. Y., Lai F. M. 1999. Experimental and theoretical predictions of first-ply failure strength of laminated composite plates. International Journal of Solid and Structure. 2379-2395.

[12] AF Ab Ghani, S Dharmalingam, NAA Md Zahir, J Mahmud .2017. Study on failure index variation of hybrid composite using finite element modelling method.Proceedings of Innovative Research and Industrial Dialogue 2016.95-96

[13] Reddy J.N. and Pandey A.K. 1987. A first ply failure analysis of composite laminate. Computer and Structures. 25(3): 371-393.

[14] Torabizadeh M. A. and Fereidoon A. 2013. Progressive Failure Analysis of Glass/Epoxy Composites at Low Temperatures. Material Science-Advanced Topics.