ISSN 2228-9860 eISSN 1906-9642 CODEN: ITJEA8

International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies

http://TuEngr.com

A Comparison Study of Hybrid Composite Laminate Failure using Finite Element Analysis and Artificial Neural Network

Noor Idayu Mohd Tahir[1], Mohamad Mali[1], Muhammad Nadiarulah Nanihar[1], Jamaluddin Mahmud[*1]

[1] *School of Mechanical Engineering, College of Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, MALAYSIA.*

**Corresponding Author (Tel: +60355436257,Email: jm@ uitm.edu.my).*

Paper ID: 13A13G

Volume 13 Issue 13

Received 23 July 2022
Received in revised form 18 October 2022
Accepted 25 October 2022
Available online 01 November 2022

Keywords:
Glass/Epoxy; Graphite/Epoxy; Boron/Epoxy; Prediction;-Uniaxial tensile load.

Abstract

A composite material's failure behaviour is difficult to predict because of its spontaneity. Failure prediction of hybrid composite laminates under uniaxial stress was studied using Finite Element Analysis (FEA) and Artificial Neural Network (ANN). Changes in the orientation of the fibres can reveal the failure behaviour of composite laminates. The implementation of constructing finite element models was carried out to replicate physical testing. The Maximum Stress and Tsai-wu Failure Criteria were used in order to predict laminate failure. Uniaxial tensile load tension was applied to composite plates, having 24 layers. The failure condition was attained based on FPF loads. In addition, the ANN tool in MATLAB was also used to predict the failure of the same composite laminates. Finally, the simulated data from ANSYS was compared to ANN model failure data. The predicted failure between ANSYS and MATLAB was caused by the slight percentage inaccuracy of the output. The methods produced more realistic and reliable results, with FEA results closely matching the analytical results. Thus, the advances in knowledge in predicting the failure behaviour of hybrid composite laminates using artificial neural networks (ANNs) in this study are noteworthy.

Discipline: Material Science, Mathematical modelling, Mechanical engineering

Cite This Article:

Mohd Tahir, N.I., Mali, M., Nanihar, M.N., and Mahmud, J. (2022). A Comparison Study of Hybrid Composite Laminate Failure using Finite Element Analysis and Artificial Neural Network. *International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies, 13*(13), 13A13G, 1-9. http://TUENGR.COM/V13/13A13G.pdf DOI: 10.14456/ITJEMAST.2022.259

1 Introduction

Composite materials have been around for a long time, reaching back to prehistoric times. For construction, they used Mesopotamian and Egyptian clay bricks and straw strengthened with glue and created plywood by gluing wood strips at different angles. A composite material is a combination of two or more component elements that enhance mechanical performance and characteristics in multiple directions (Ma et al., 2021). Studies have improved material characteristics like fiberglass, the world's first modern carbon fiber. Glass is both light and strong, yet it is also fragile. Meanwhile, plastic holds the glass together. Aesthetically, fiberglass is utilised to construct boats and pipes.

Recent studies have led to the emergence of a new branch of composite known as hybrid composite. This development is needed in the automobile, aerospace, and sports industries. The term "hybrid composite" refers to combining two fiber kinds into a single matrix. The idea is simple; combine different fibres to increase engineering value (Ghani & Mahmud, 2020). Hybridization is a technique that adds another material to one component to satisfy a design criterion. For example, combining glass/epoxy with a graphite/epoxy combination increases strength while decreasing manufacturing costs.

2 Literature Review

Stress analysis of laminated composites, educational MATLAB software, has been created. The software can be used to investigate both the micro- and macro-mechanics of a lamina or laminate. The software can also be used to analyse laminate failures, making it valuable for designing composite laminates under specific loading situations. The MATLAB failure mechanism is fiber failure, matrix failure, or shear. Composite materials fail when the major material axes are stressed to a certain level (Daryadel et al., 2015). A structure fails if the applied load exceeds the maximum permissible stress.

The neural network has been utilized to investigate novel composite possibilities. Neural networks are made up of simple components that are inspired by the organic nerve system. Similar to nature, the network's operation is heavily influenced by inter-element connections. Frequently, neural networks are retrained such that a given input leads to the desired output. The network is then adjusted till the output matches the target. Supervised learning uses several input/target pairings to train a network. This simulation must be validated before it can be used. This simulation is validated using a MATLAB solution (Dawson & Wilby, 1998). Then ANSYS is used to model and analyse a glass-graphite/hybrid laminate simulation. The outputs of both techniques are compared for validation and documented for future reference (Yeh et al., 2012).

Based on this review, it is found that there is a lack of information related to the comparison of hybrid composite laminate failure using Finite Element Analysis and Artificial Neural Networks.

3 Method

3.1 Finite Element (FE)

Three FE models are constructed based on the literature review of graphite/epoxy laminates, and glass graphite/epoxy hybridization (Wintermantel et al., 2016). This study's strategy combines two approaches of ANNs and numerical methods. The ANN method uses MATLAB. This study also employs the numerical approach with ANSYS software. The numerical method using ANSYS is chosen because it is industrially authorised, and the objective of this study is to help the industry satisfy its need for new material data. Data are collected, and the failure and deformation are computed using two failure criteria of Tsai-Wu (Chen et al., 2021) and Maximum Stress Theory. Figure 1 shows the overall process flow.

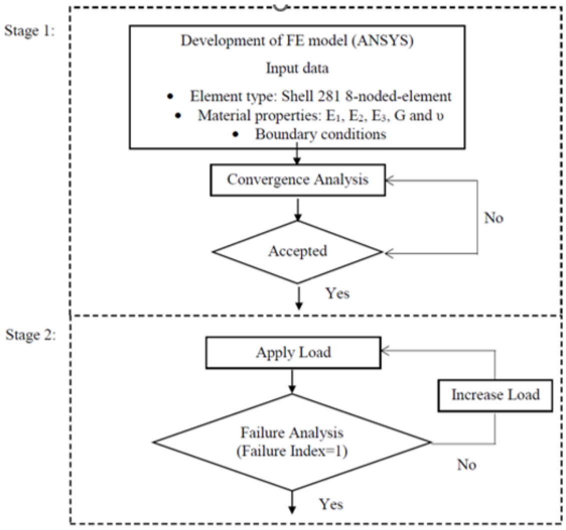

Figure 1: Overall process flow of Finite Element Analysis (FEA) using ANSYS APDL.

3.1.1 Modeling the composite model

The square plate of 0.02m x 0.02m and thickness of 1.33333 x 10^{-4} m is used as shown in Figure 2(a). Figure 2(b) shows the model applied with the uniaxial loads and boundary respectively.

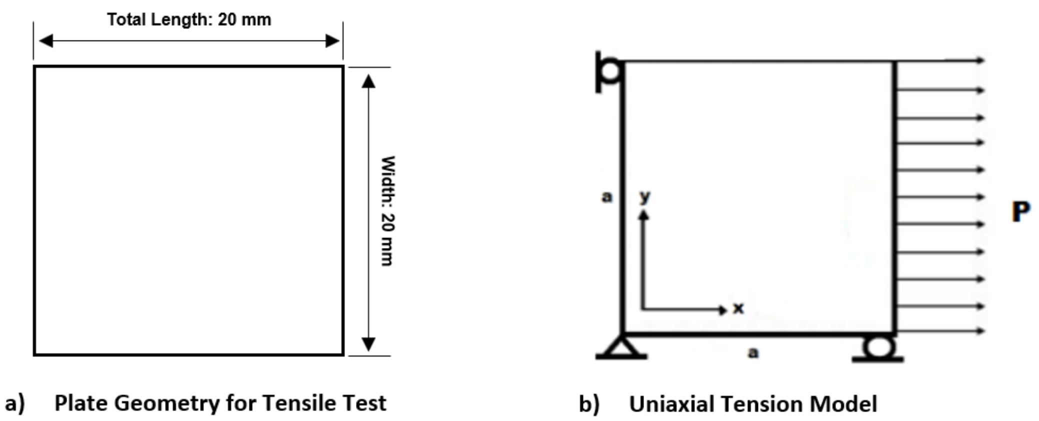

Figure 2: (a) dimension of the plate and (b) loads and boundary of model.

3.1.2 Material Properties

Table 1, Table 2, Table 3 and Table 4 show the material properties of Graphite / Epoxy, Glass / Epoxy, Boron / Epoxy and S-Glass composite laminates which are used to develop the model of this study.

Table 1: Material properties for Graphite / Epoxy (Tolson & Zabaras, 1991).

Elastic Parameter		Strength Data	
E_1	138 GPa	X_t	1450 MPa
$E_2 = E_3$	1.6 GPa	X_c	1450 MPa
ν_{12}	0.3	Y_t	51 MPa
G_{12}	6.46 GPa	Y_c	250 MPa
		S	93 MPa

Table 2: Material properties for Glass / Epoxy (Tolson & Zabaras, 1991).

Elastic Parameter		Strength Data	
E_1	9.94 GPa	X_t	700.11 MPa
$E_2 = E_3$	0.83 GPa	X_c	570.37 MPa
ν_{12}	0.29	Y_t	69.67 MPa
G_{12}	11 GPa	Y_c	122.12 MPa
		S	68.89 MPa

Table 3: Material properties for Boron / Epoxy (Tolson & Zabaras, 1991).

Elastic Parameter		Strength Data	
E_1	204 GPa	X_t	1260 MPa
$E_2 = E_3$	19 GPa	X_c	2500 MPa
ν_{12}	0.25	Y_t	61 MPa
G_{12}	5.6 GPa	Y_c	202 MPa
		S	76 MPa

Table 4: Material properties of S-Glass (Yeh et al., 2011).

Elastic Parameter		Strength Data	
E_1	55.5 GPa	X_t	2500 MPa
$E_2 = E_3$	7.5 GPa	X_c	2000 MPa
ν_{12}	0.32	Y_t	50 MPa
G_{12}	4.55 GPa	Y_c	150 MPa
		S	50 MPa

3.1.3 Numerical Validation

The primary procedure to validate the current FE model and application is adequate by using numerical validation. The FE results are referred to ANSYS which is validated to the exact solution. The model of FE simulation by ANSYS software is validated with the exact solution (Reddy, 2012). Laminated composite plates with various angles of fiber orientation under uniaxial tension are demonstrated and their maximum deformation is determined. The error obtained is less than 2% which makes the result adequate. This is similar to the practice used by past researchers such as Noh et al. (2017).

3.1.4 Failure Analysis

Failure analysis is carried out with commercial FE software (ANSYS). The failure behaviour of the composite laminates is identified using the software built-in failure criteria, Maximum Stress

Theory to determine the failure load of the developed model. The failure criteria which include Xt, Xc, Yt, Yc and S are inserted into the software to determine the strength of composite laminates. The failure index of the model must be equal to or more than 1. Otherwise, the load must be increased continuously to the plate until it reaches the failure index = 1.

3.2 Artificial Neural Network (ANN)

In this study, the ANN is operated using MATLAB based on the availability and capability of this software to do the mass calculation. The software provides the user with a simplified version of how to conduct the ANN. The method is applied by using NNTOOL using flow as shown in Figure 3.

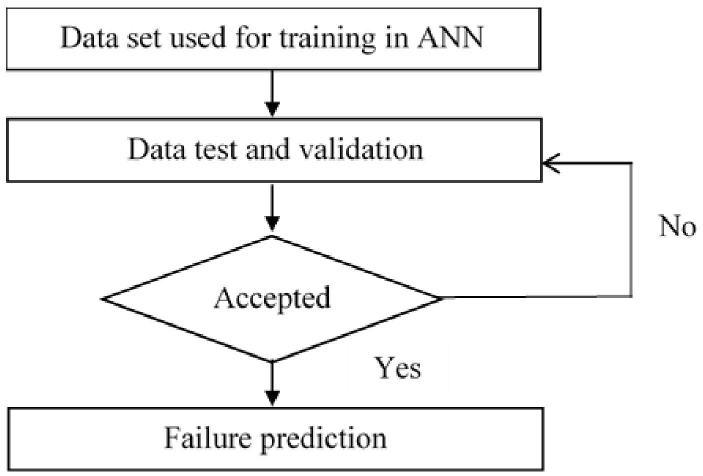

Figure 3: Overall ANN simulation overview.

4 Result and Discussion

4.1 Results

The graphite epoxy technique gains post-data from ANN and FEA as shown in Figure 4. The overall trend of fiber orientation and stress is the same for all methods. At 10˚ ANN, the maximum stress for first ply failure is obtained, while the Tsai-Wu technique yields the lowest. The ANN predicts the same result at 15˚ - 40˚ angles when the strength loss is greater. After that, the graph is kept at 550MPA stress for the first ply failure. The experimental value (Soni, 1983) is 15% different from the expected value, and the value decreases across the orientation. The value for ANN prediction is intercepted at 45˚ and the result is maintained at 65˚.

Data of ANN versus FEA for Glass/Epoxy are shown in Figure 5 while data of ANN versus FEA for Boron/Epoxy are shown in Figure 6. The overall result shows the same trend. As for ANN, the result at the first 3 angles is in between maximum stress and the Tsai-Wu method, but after 30˚ of orientation, the value gains a slightly higher result.

The performance of hybrid composites with composite laminates is compared in Figure 7. The same overall trend is shown in the Glass/Epoxy material, which increases in strength at 10˚ layup and then decreases in stress value until 45˚ layup. Boron/ Glass / Epoxy presents a similar overall trend as Glass/ Epoxy material, which increases in strength at 10˚ layup and then decreases in stress value until 45˚ layup. Then the behaviour of boron/epoxy is revealed at 50˚ and 90˚ layup angles.

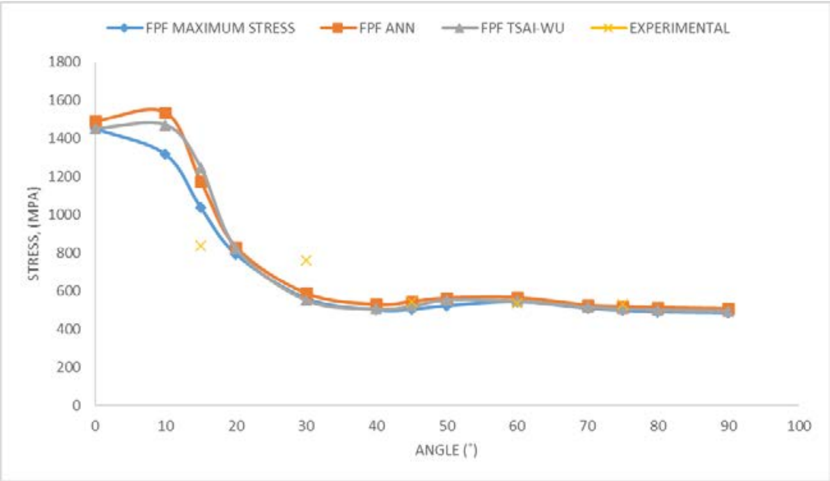

Figure 4: Graph of ANN compared to FEA method for Graphite/Epoxy Glass epoxy.

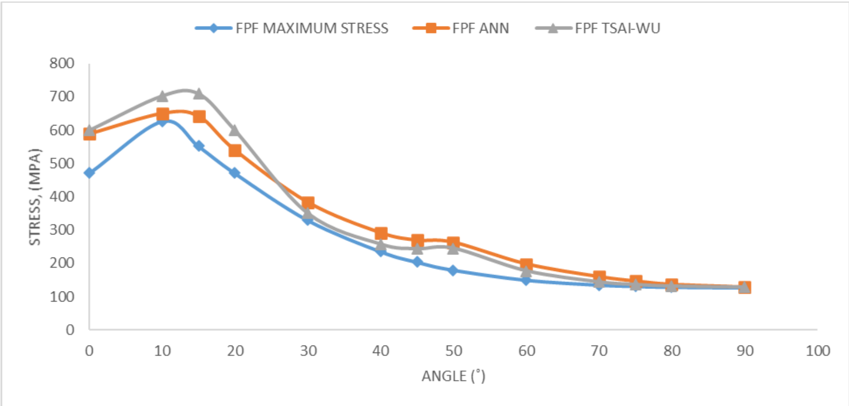

Figure 5: Graph of ANN compared to the FEA method for Glass/Epoxy.

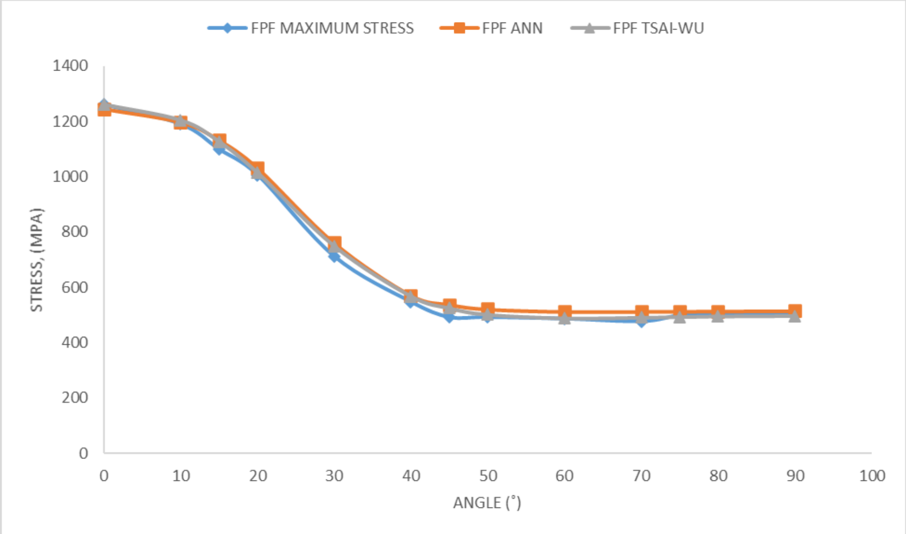

Figure 6: Graph of ANN compared to the FEA method for Boron/Epoxy.

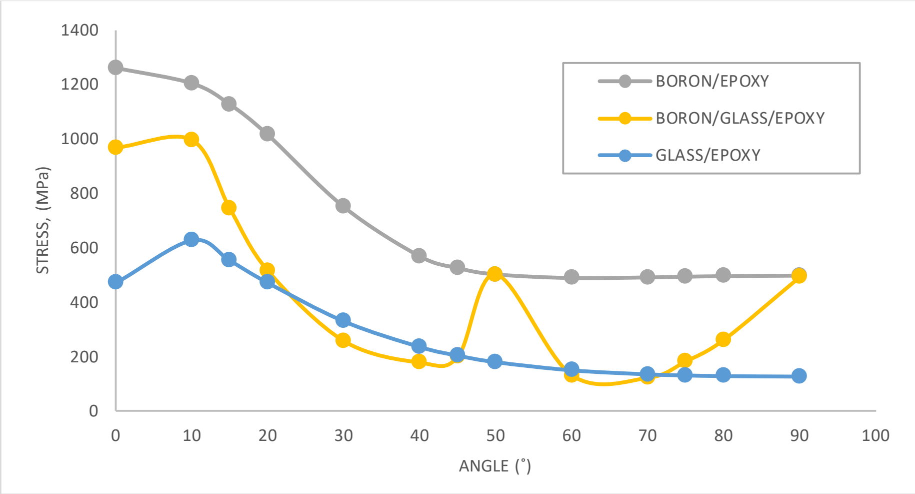

Figure 7: Graph of ANN compared to the FEA method for Boron/Epoxy.

4.2 Discussion

The ANN model's projected data are compared to the ANSYS simulation results. In conclusion, the difference in the percentage of output failures between ANSYS and MATLAB is accepted. Generally, as the degree of fiber orientation rises, all laminate composites display the same tendency. This behaviour is found similar to past studies (Tolson & Zabaras, 1991; Noh et al., 2017). The result of the failure analysis is then compared to the one gained in MATLAB software, which is a neural network simulator. In comparison to the percentage error, the average difference between the input and output is 18.97, 6.25, and 4.04 for Glass/Epoxy, Graphite/Epoxy, and Boron/Epoxy, respectively.

A reduction in error occurs when the value of training is close to 1. However, the approach produced using numerical methods gives more accurate results, with FEA results being quite comparable to those of the analytical approach.

This study presented the details of data prediction utilising analytic methods in depth. According to the results, ANN can produce a better forecast of tensile strength than simulation models. The biggest disadvantage of utilising the ANN model is that it requires more data sets, which means more simulations. By constructing a database once and using it to anticipate the ideal value for each application, this problem can be resolved. When using simulation data instead of experimental data or theoretical calculations, predicting intermediate values is easier.

5 Conclusion

The study was successful in demonstrating the application of numerical analysis by using one of the MATLAB tools to anticipate the outcome. Using MATLAB, the failure analysis is performed to forecast the amount of stress required to cause the first ply failure about the angle orientation. The failure load, lamina failure, displacement, and stress of the First Ply Failure (FPF) are all determined using the Maximum Stress criteria for the first and last plies. The cumulated data predicted by the ANN model is associated to the results of the ANSYS simulation. Furthermore, the minor percentage error of the output failure between ANSYS and MATLAB summarises the outcome. All laminate composites exhibit the same tendency as the degree of fiber orientation increases. On the other hand, the trend for failure analysis of hybrid composites varies according to their orientation. The failure analysis result is then compared to the one gained in MATLAB software, which is an artificial neural network. The findings of the investigation revealed that both numerical approaches provide accurate and dependable results, with the FEA result being quite similar to the results of the analytical approach. According to the research, the FPF loads represent the amount of load required to reach the failure condition. When simulation data is used instead of experiment data or theoretical calculations, predicting intermediate values is easier. Other mechanical properties such as fatigue and creep can be predicted using this technique, as well as a larger number of input variables such as laminate thickness, lamination scheme, and manufacturing variables like pressure and temperature.

6 Availability of Data and Material

Data can be made available by contacting the corresponding author.

7 Acknowledgement

This work is supported by the Ministry of Higher Education (MOHE) Malaysia and Universiti Teknologi MARA, under the Fundamental Research Grant Scheme: Grant No. FRGS/1/2018/TK03/UITM//02/8 and 600-IRMI/FRGS 5/3 (165/2019).

8 References

Chen, X., Sun, X., Chen, P., Wang, B., Gu, J., Wang, W., Chai, Y., Zhao, Y. (2021). Rationalized Improvement of Tsai–Wu Failure Criterion Considering Different Failure Modes of Composite Materials. *Composite Structures*. 256, 113120.

Daryadel, S. S., Ray, C., Pandya, T., Mantena, P. R. (2015). Energy Absorption of Pultruded Hybrid Glass / Graphite Epoxy Composites under High Strain-Rate SHPB Compression Loading. *Material Sciences and Applications*. 6, 511-518.

Dawson, C. W., Wilby, R. (1998). An Artificial Neural Network Approach to Rainfall-runoff Modelling. *Hydrological Sciences Journal*. 43:1, 47-66.

Ghani, A. F. A., Mahmud, J. (2020). Characterisation of Hybrid Carbon Glass Fibre Reinforced Polymer (C/Gfrp) of Balanced Cross Ply and Quasi Isotropic Under Tensile and Flexural Loading. *International Journal of Automotive and Mechanical Engineering*. 17(1), 7792-7804.

Ma, Z., Chen, J., Yang, Q., Li, Z., Su, X. (2021). Progressive Fracture Analysis of The Open-Hole Composite Laminates. *Composite Structures*. 262, 113628.

Reddy, J. N. (2012). Energy and Variational Methods in Applied Mechanics (with and Introduction to the Finite Element Method). *New York: John Wiley*.

Noh, N. N., Samsudin, A. H., Mahmud, J. (2017). Failure Analysis of Glass/Epoxy and Graphite/Epoxy Laminates due to the Effect of Variation in Lamination Scheme and Angle of Fibre Orientation. *Materials Science Forum*. 889, 36-44.

Tolson, S., Zabaras, N. (1991). Finite Element Analysis of Progressive Failure in Laminated Composite Plates. *Computers & Structures*. 38(3), 361-376.

Wintermantel, El, Mayer, J., Goehring, T. N., Aqida, S. N. (2016). Composites for Biomedical Applications. *Reference Module in Materials Science and Materials Engineering*, 1-6.

Yeh, P., Chang, P., Yang, J., Wu, P. H., Liu, M. C. (2011). Blunt Notch Strength of Hybrid Boron/Glass/Aluminum Fiber Metal Laminates. *Materials Science and Engineering: A*. 528(4-5), 2164-2173.

Yeh, P., Chang, P., Wang, J., Yang, J., Wu, P. H., Liu, M. C. (2012). Bearing Strength of Commingled Boron/Glass Fiber Reinforced Aluminum Laminates. *Composite Structures*, 94(11), 3160-3173.

Ir. Noor Idayu Mohd Tahir is a post-graduate student at the School of Mechanical Engineering, College of Engineering, Universiti Teknologi MARA, Selangor, Malaysia. She obtained a Master of Science degree, majoring in Mechanical Engineering from Universiti Teknologi MARA, Malaysia. Her research area involves the Mechanics of Materials using the Finite Element Method and Mechanical Engineering Design.

Dr. Mohamad Mali is a recent PhD graduate from the School of Mechanical Engineering, College of Engineering, Universiti Teknologi MARA, Selangor, Malaysia. He also has a Master of Science in Mechanical Engineering degree from the same university. His research focuses on the Mechanics of Composite Materials, Finite Element Analysis, and Matlab programming.

Muhammad Nadiarulah Nanihar is a post-graduate student at the School of Mechanical Engineering, College of Engineering, Universiti Teknologi MARA, Selangor. He obtained a Master of Science in Mechanical Engineering degree from Universiti Teknologi MARA, Malaysia. His research focuses on Composite Laminate, Finite Element Analysis, and Artificial Neural Networks.

Prof Ir. Dr Jamaluddin Mahmud is a professor at the School of Mechanical Engineering, College of Engineering, Universiti Teknologi MARA, Selangor, Malaysia. He obtained his PhD degree in Engineering (Biomechanics) from Cardiff University, UK. He obtained his Master of Science degree from the International Islamic University, Malaysia, where his MSc thesis focused on the Mechanics of Composite Materials and Finite Element programming. At present, his research focuses on Biomechanical Engineering, Composite Structures, Mechanical Design and Numerical Methods.