Validation of Experimental Hybrid Natural/Synthetic Composite Laminate Specimen Using Finite Element Analysis for UAV Wing Application

Nur Marini Zainal Abidin, M. T. H. Sultan, Ernnie Illyani Basri, Adi Azriff Basri, and A. U. M. Shah

Abstract In this day and age, there are high demand for the utilisation of hybrid composite materials in industrial and aerospace applications due to its advantages over the common composite material and other materials. In this case, engagement of natural fiber with synthetic fiber to form a hybrid lamination composite to become a partially eco-friendly material had been studied and analysed to pursuit a properties requirement for UAV wing profile. In experimental study, glass and kenaf were fabricated in two variations of GKG and KGK and were tested under tensile test properties. The result obtained was compared by validation of finite element analysis using ANSYS 18.2 workbench. From the validation results, it showed a good agreement in stress and strain but percentage error in deformation due to several factors will be discussed. In term of composite strength, GKG have the maximum stress of 120.89 MPa compared to KGK with 79.787 MPa maximum stress.

Keywords Natural/synthetic laminate composite · Laminate composite wing · Finite element analysis

N. M. Z. Abidin · M. T. H. Sultan (✉) · E. I. Basri · A. A. Basri · A. U. M. Shah
Department of Aerospace Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
e-mail: thariq@upm.edu.my

M. T. H. Sultan
Aerospace Malaysia Innovation Centre (944751-A), Prime Minister's Department, MIGHT Partnership Hub, Jalan Impact, 63000 Cyberjaya, Selangor Darul Ehsan, Malaysia

M. T. H. Sultan · A. U. M. Shah
Laboratory of Biocomposite Technology, Institute of Tropical Forestry and Forest Products, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

M. T. H. Sultan et al. (eds.), *Impact Studies of Composite Materials*, Composites Science and Technology, https://doi.org/10.1007/978-981-16-1323-4_10

1 Introduction

1.1 Hybrid Composite Laminates

Hybrid composite laminates consisting two or more of types of fibers which together produce desirable properties of strength and modulus fibers in a matrix material. This composite is more advanced than conventional fiber reinforced composite in term of flexibility. Nowadays, engagement of natural fiber in hybrid composite giving a lot of advantages and had been done in several research works. Ramesh and Nijanthan (2016) mentioned that mixing of natural fiber using polymer resins with the synthetic fiber will reduce the cost of production and the harmful destruction. As we known, natural fiber is a renewable source and it can be an alternative solution for environmentally friendly. Salleh et al. (2018) also claimed that natural fiber is a biodegradable and relatively inexpensive compared to synthetic fiber. However, product of natural fiber for structural applications are still limited due to their poor mechanical properties. Compare to synthetic fiber which giving its own advantages such as low weight, high strength, less heat and electrical conductivity and also resistance of chemical agents (Saravanan and Vetrivel 2016). Solving this problem, natural and synthetic fibers are mix together to make the composite hybrid and produce new properties.

In structural applications, fiber-reinforced composite material is form in a lamination of fiber or stacking by a collection of lamina. Hybrid laminate composite term was described as a mixing than one type of fiber in composite laminate. Reddy (2003) claimed that stacking sequence of each fibers and also the orientation can be chosen to achieve desired strength and stiffness. The fiber use in lamination can be continuous or discontinuous, unidirectional, bidirectional, woven or randomly distributed. In this case study, a hybrid composite laminates of E-Glass/Kenaf/E-Glass (G-K-G) fiber and Kenaf/E-Glass/Kenaf (K-G-K) fiber had been fabricated with epoxy resin matrix. The stackup fiber orientation choose is 90/0/90 (Fig. 1). This orientation was applied to both hybrid composite fabricated, G-K-G and K-G-K.

Composite materials which are involved two or more layered materials and have different properties when combining can make this material high strength and superficial with greater manufacturing of complex parts especially in aircraft applications. Some of the product based composite laminate which have complex shapes, will be challenging to analyse or predict the performance of the finished product under real-world working conditions. One of the important component in aircraft using composite laminate as its material is a wing part. Basri et al. (2019b) described that structural analysis in finite element analysis is an effective numerical solution and optimization method in aerospace engineering. In ANSYS workbench, composite lamination material must go through on ANSYS Prepost (ACP) domain where this interface has dedicated tool for composite layup modelling and failure analysis.

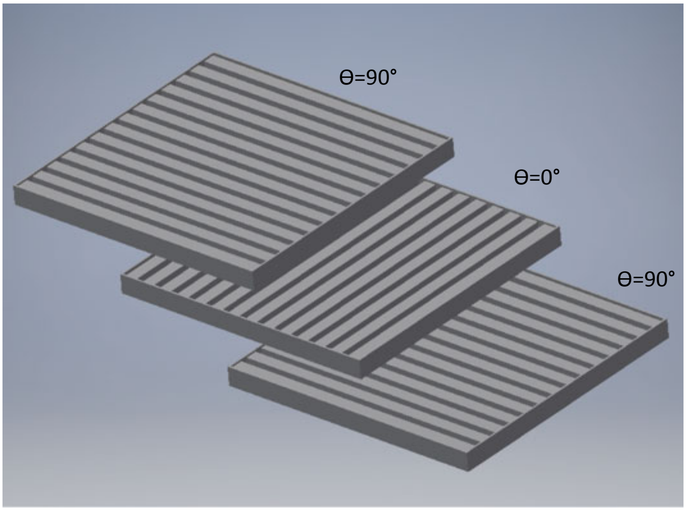


Fig. 1 Fiber orientation of laminate composite

1.2 Finite Element Analysis

A Finite Element Analysis (FEA) is to obtain approximate solutions of Boundary Value Problem using computer technique which based on numerical method solution. A boundary value problem is a solution sought in the domain (or region) of a body subject to the satisfaction of prescribed boundary (edge) conditions on the dependent variables or derivatives (Rao 2004). Three major categories in Boundary Value Problem is Equilibrium problems, Eigenvalue problems and Propagation problems. For example, in aircraft, Equilibrium problem is referring to a static analysis of aircraft wings, fuselage, fins, rockets, etc. while Eigenvalue problems analyse on natural frequencies, flutter and stability on aircraft. Propagation problems is response of aircraft structures to random loads, dynamic response of aircraft (Rao 2004). FEA actually was first developed in the aerospace and nuclear industries where the safety of structures was a main issue to be focused. Nowadays, FEA is widely used in other industries even the simplest products rely on FEA for design evaluation. In the present case study, hybrid composite laminate fabricated was analysed using FEA in order to validated result obtained from the experiment. To perform the simulation, a knowledge of analysis theory of hybrid composite laminate as shown in Fig. 2 is required. The orthotropic elasticity equation (such as Young's Modulus, Poisson's ratio, Shear modulus, Tensile Stress and Strain, Compressive Stress and Strain and Shear Stress and Strain), structural theories (geometry, modelling and ANSYS Composite PrepPost setup), analytical and computational methods to determine the solutions (eg. deformation, stress and strain) and damage or failure theories to predict failure modes and failure loads is the compulsory component or data in finite element analysis (Cook 1995).

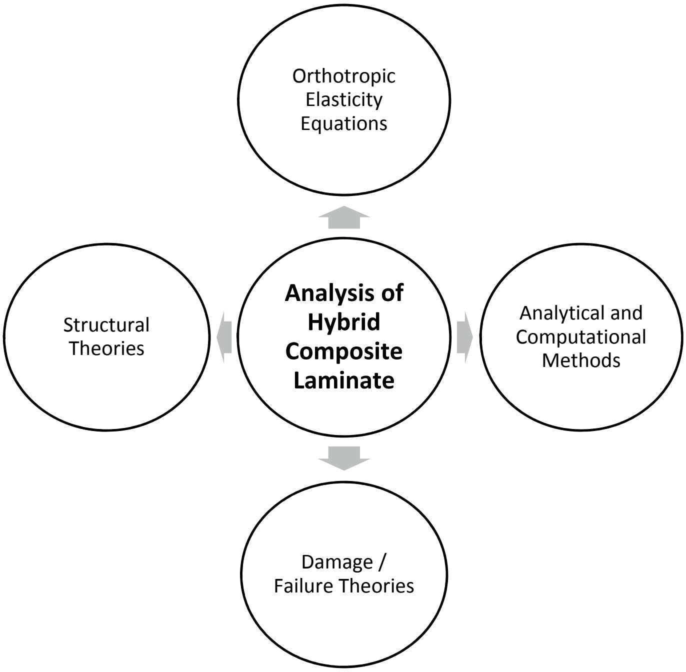


Fig. 2 Analysis of hybrid composite laminate

2 Experimental of Hybrid Natural-Synthetic Laminate Composite

2.1 Material and Methodology

The most widely used and easiest method for laminate composite fabrication is a hand lay-up. For this experiment, the sample size 300 mm width and 300 mm length were prepared. There are two variations of sample were developed which are lamination of Glass-Kenaf-Glass (GKG) and lamination of Kenaf-Glass-Kenaf (KGK). E-Glass and Kenaf fiber were cut properly then measured and recorded all the fiber's weight. In preparation of the mould, a wax was rubbed in a surface of the mould to prevent sticking and enable easy removal of the finished part (Fig. 3).

Next process is mixing epoxy with the hardener (curing agent) with a suitable proportion ratio. Both of the sample were decided using 20:80 proportion ratio of fiber and matrix. The rule of mixture formula calculating as following (Alger 1997):

$$E_c = f E_f + (1 - f) E_m \quad (1)$$

where;

(a) E-Glass fiber (b) Kenaf fiber

Fig. 3 Material used in fabrication of hybrid natural-synthetic laminate composite

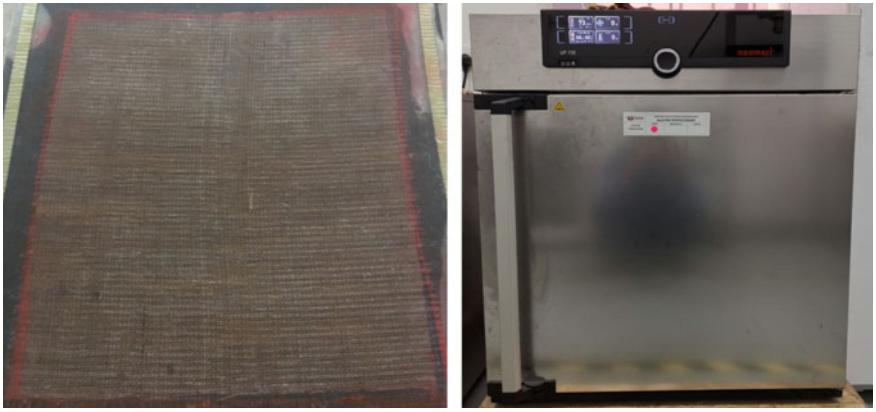
$f = \frac{V_f}{V_f + V_m}$ (the volume of the fibers).
E_f is the material property of the fibers.
E_m is the material property of the matrix.

The mixture of matrix is poured into the mould and spread it uniformly before placed a fiber onto it. Then put the fiber on the matrix and scrub the fiber with the help of brush or roller. The purpose using brush or roller is to remove the extra resin and ensure uniform distribution of resin to whole surface (Biswas and Anurag 2019). The process is repeated for all layers of reinforcements until the required number of layer was achieved. A covering plate of fabrication mould will applied on the top of surface in order to avoid from flying dust falling into the composite laminates sample surface. The sample was left it with standard atmospheric temperature about 24 h before opened and taken out. Then the sample was going to a curing process in the oven with 180° in 2 h (Fig. 4).

Once finished the fabrication process, the samples were cut to a several number of specimens with a specific dimension from ASTM D3039 standard test. The dimension for ASTM D3039 as per Fig. 5.

2.2 Testing and Result

The most important of mechanical testing is determination of material properties of the material which subjected to elasticity, stress and strain data profile. Therefore, the fabricated specimens were undergoing a Tensile Properties Test by followed ASTM D3039 Standard which also known as tension test. ASTM standards were used in



(a) Hybrid laminate composite (b) Oven for curing process

Fig. 4 Hand layup composite and manufacturing process for hybrid laminate

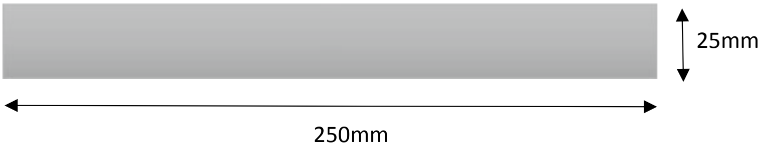


Fig. 5 ASTM D3039 standard dimension

producing data of material specifications, research and development, quality assurance and structural design and analysis. When the material was loaded in tension, the maximum strength will be determined from the maximum force before its failure. Result derived from this test including of tensile stress, tensile strain, Modulus Young's, displacement and maximum load which can be initially chosen from the list of mechanical properties in the machine. As usually, before testing the thickness and width each specimen was taken and recorded. Figure 6 showing a 30kN Universal Testing Machine has been used for a tensile test.

During tensile loading, the stress–strain curve was directly generated from the universal testing machine until the composite breaks. As illustrated in Fig. 7a and b, there have a total of 9 samples for GKG and 11 samples for KGK due to defect of GKG sample when in fabrication process. However, both of the curve for each sample which show a brittle material characteristic, demonstrate a minor nonlinear curve until the maximum strength before failures occurred. All the composite samples within its variation also show a good match and similar behaviours. Compared to both of material, a hybrid composite of GKG have a tensile strength and tensile strain more than KGK. The slope of the graph represents the Young's modulus of the composite. In Table 1 is a tabulated data of each composite specimen translated from the stress–strain curve. The average of maximum strength value of GKG is

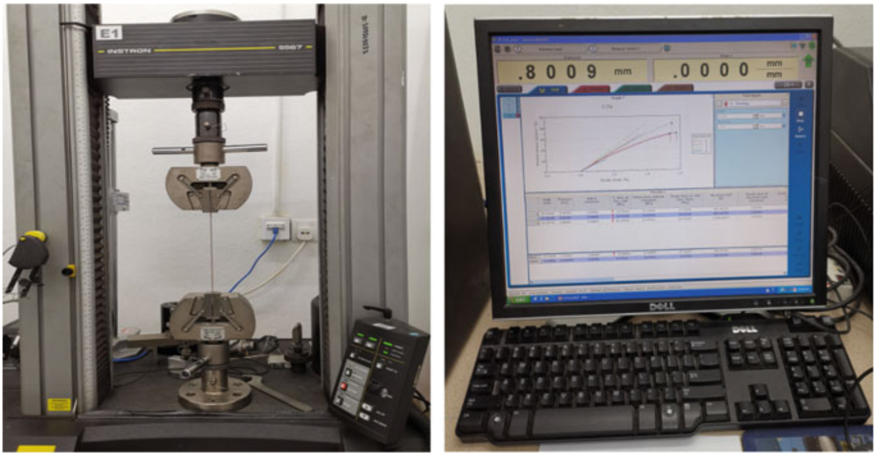


Fig. 6 A 30kN universal testing machine (Instron) and equipment used for the testing

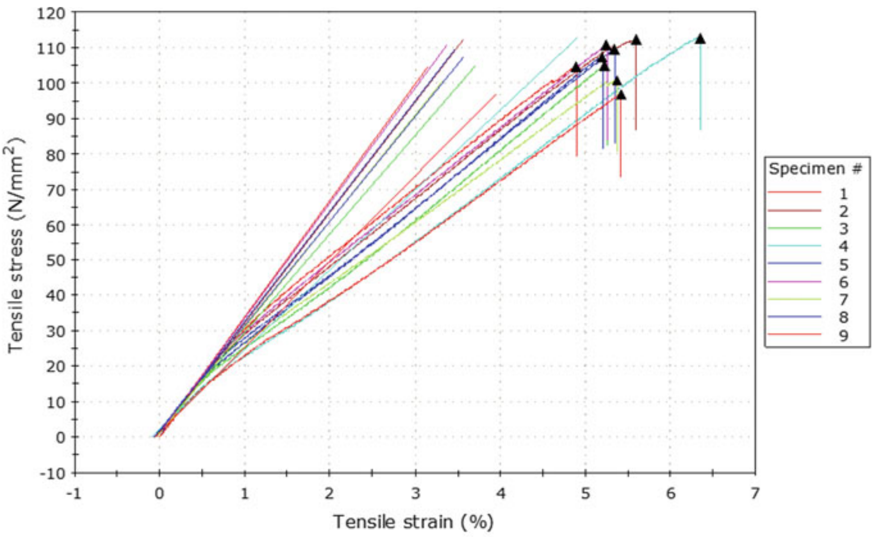
106.648 MPa with an average maximum load of 11,820.874 MPa while KGK have an average maximum strength of 70.17 MPa in average tension force of 7627 MPa.

3 A Development of Laminate Composite Using Finite Element Analysis

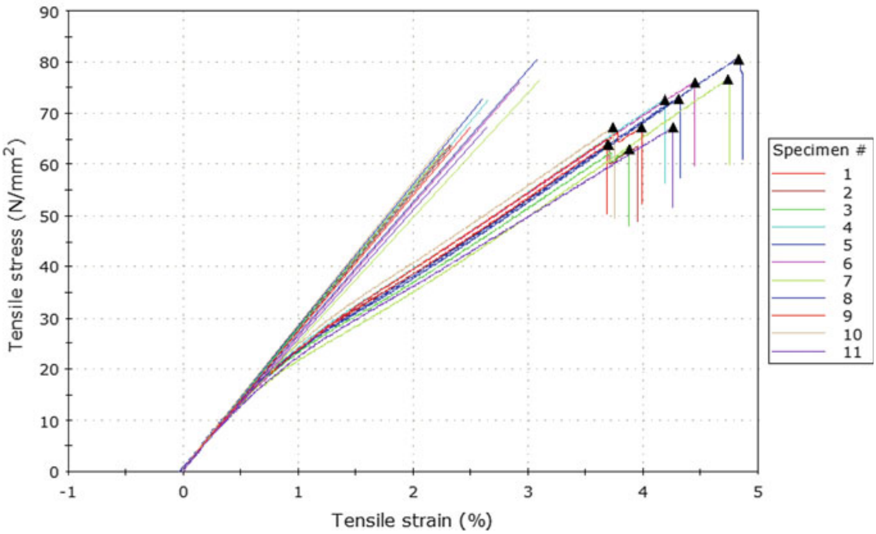
Analysis of the composite elastic behaviour in term of material deformation and applied loading conditions were carried out with the help of ANSYS 18.2 Workbench. It is important to note that composite materials analysis quite complex and have a several factors might be affect the analysis (Al-Qrimli et al. 2015). Therefore, validation is required to use a similar ASTM D3039 standard to ensure the analysis and physical testing are accurate. The results obtained must be within 15% differences to consider the parameters is validated (Prasad and Ramachandran 2017). All the variables from experiment were inserted into the data needed from the simulation. For the hybrid composite case, it must be analyse in ANSYS Composite Pre-Post (ACP) 18.2. ACP is an add-on module of ANSYS dedicated to the modelling of layered composite structures. A schematic view of static structural was shown in Fig. 8 below is a subsequent step of the modelling.

3.1 Geometry

The tensile test sample was modelled in geometry step by following ASTM D3039 standard size requirement. The final geometry of the sample shown in Fig. 9.



(a) Glass-Kenaf-Glass (GKG)



(b) Kenaf-Glass-Kenaf (KGK)

Fig. 7 Tensile test result for all samples of GKG and KGK laminate composite

Table 1 Summarise of G-K-G and K-G-K tensile test result

No.	Thickness (mm)	Maximum load (N)	T. stress at max load (MPa)	T. strain at max load (mm/mm)	Modulus Young's (MPa)
(a) Tensile test result for Hybrid Glass-Kenaf-Glass lamination composite					
1	4.033	12,397.981	104.623	0.049	3287.366
2	3.843	12,797.241	112.299	0.056	3111.967
3	3.97	12,022.857	104.971	0.052	2769.767
4	3.763	11,941.661	112.705	0.064	2250.534
5	3.85	11,986.564	109.407	0.053	3110.088
6	3.777	12,022.252	110.637	0.052	3244.908
7	4.043	11,416.833	100.805	0.054	2996.642
8	3.973	11,644.989	107.443	0.052	2956.592
9	3.74	10,157.483	96.938	0.054	2415.361
Mean	3.888	11,820.874	106.648	0.054	2904.803
(b) Tensile test result for Hybrid Kenaf-Glass-Kenaf lamination composite					
1	3.733	6976	63.85	0.037	2724.80
2	3.733	6726	63.88	0.037	2700.67
3	3.84	7301	63.11	0.039	2747.00
4	3.84	8022	72.74	0.042	2720.88
5	3.847	7938	72.94	0.043	2775.41
6	3.68	8241	76.1	0.045	2577.91
7	3.72	8029	76.72	0.047	2439.16
8	3.813	9079	80.78	0.048	2597.10
9	3.743	7340	67.19	0.040	2672.15
10	3.733	7429	67.26	0.037	2800.94
11	3.74	6813	67.26	0.043	2525.82
Mean	3.7656	7627	70.17	0.042	2661.98

Fig. 8 Schematic view of static structural for hybrid laminate composite

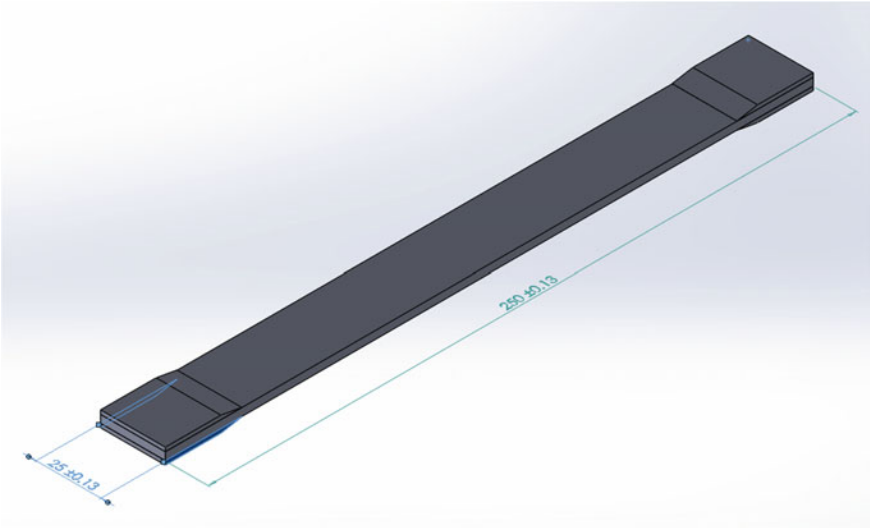


Fig. 9 Isometric view of tensile test sample using ASTM D3039 standard

Thickness of the sample initially was set 1 mm. The real thickness of the sample composite will be defined in the ANSYS Composite PrepPost model based on the composite layup. Then, assigned the type of material for the sample to be analysed. All the properties of chosen material were earlier defined in engineering data module. In this case study, a Glass and Kenaf fiber were assigned as a material of hybrid composite laminate.

3.2 Material Properties

Material properties is located in engineering data step is a compulsory information in analysis. By following a subsequent, the material properties must be defined earlier before modelled the sample in geometry. In this study, the material involved in hybrid laminate composite, E-Glass and Kenaf fibres, will be defined their properties in engineering data. The hybrid laminate E-Glass and Kenaf are categorized in orthotropic material which has three orthogonal symmetry planes. Therefore, a new material was created with new properties which obtained from the experimental. Inserted all the data such as density, orthotropic elasticity and also orthotropic stress and strain limit. The tabulation material properties data of each fiber is shown on Table 2.

Table 2 Material properties of E-Glass and Kenaf fibre

Properties	E-glass	Kenaf
Density (g/cm^3)	1.9	1.3
Exx (MPa)	48,750	13,919
Eyy (MPa)	12,000	22,800
Ezz (MPa)	12,000	22,800
Vxy	0.19	0.324
Vyz	0.31	–
Vxz	0.30	–
Gxy (MPa)	5500	2800
Gyz (MPa)	5000	2677
Gxz (MPa)	5500	2800

3.3 Generating the Mesh

Meshing is the most critical part of pre-processing in simulation. An effective mesh can give maximum accuracy result and reduce the computational time. For this case, the composite sample is rectangular simple plate, therefore, a quadrilateral with 245 elements for both GKG and KGK were used. The total number of nodes is 300. For the validation, a fine meshed was used since it will give an accurate results compared than coarse and medium. So, in order to get more accuracy result for this laminate composite sample, meshing should be finer and therefore mesh it with own parameter. The mesh element of the composite sample is depicted in Fig. 10.

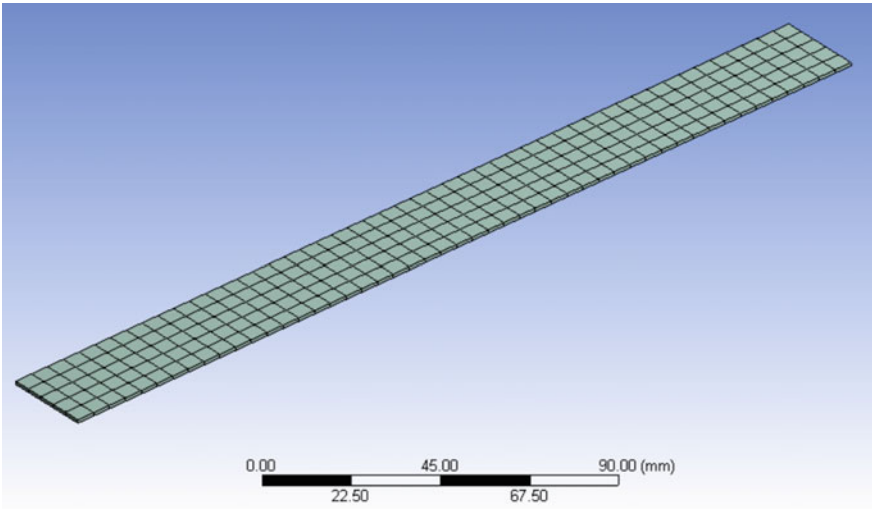


Fig. 10 Mesh generated with parameters set as per requirement

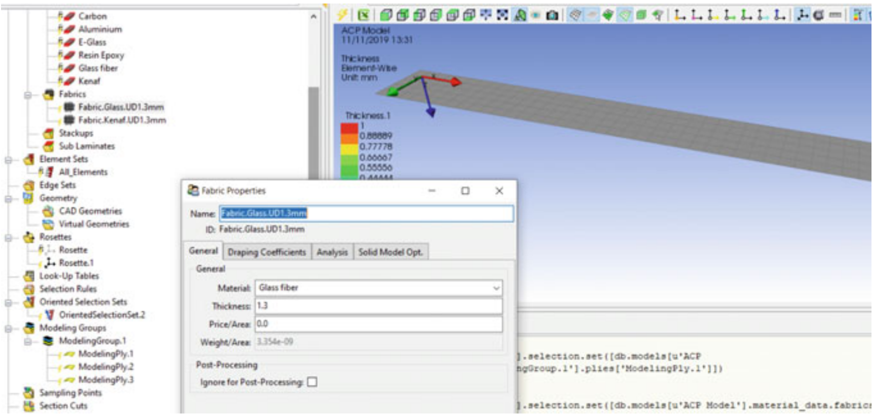


Fig. 11 Define a fabric used and the thickness

3.4 *ACP PrepPost Setup*

As it is known that, composite laminate has numerous layers of materials, different thicknesses and different ply orientation. In subsequent step, ANSYS Prepost (ACP) will be defined all that criteria such as a material used and its thickness, each lamina arrangement and fibre orientation. For this case study, there are two variations of composite lamination, Glass-Kenaf-Glass and Kenaf-Glass-Kenaf. Both of the sample thickness are 4 mm and have the ply orientation of 90°, 0° and 90°. A purpose of rosette is to define a fiber direction reference of 0° while oriented selection set is to define the direction of layup (Basri et al. 2019a). For this composite laminate, rosette with parallel type was chosen and oriented selection set was in *Y*-direction which is area to apply layers on. In modelling ply, all materials were arranged layer by layer similar to experimental of composite lamination. The number of modelling ply was represented a number of composite layer. Figures 11, 12, 13 and 14 shown sequence step contained in ACP setup.

Composite pre-processing part was completed for tensile test sample analysis. Further step is to find the solution needed from the composite laminate. This method will be solved in static structural analysis that linked with ACP (Pre) domain.

3.5 *Result and Discussion*

Static Structural Analysis is the basic types of analysis solver. Before run solution of the analysis, boundary conditions and loads was applied to the sample. In experimental of tensile test, the sample was pulled slowly until it breaks so the load applied in simulation should be similar to the experiment. This concept of stress will categorize as normal stress which is the force was applied in x-direction at one side while

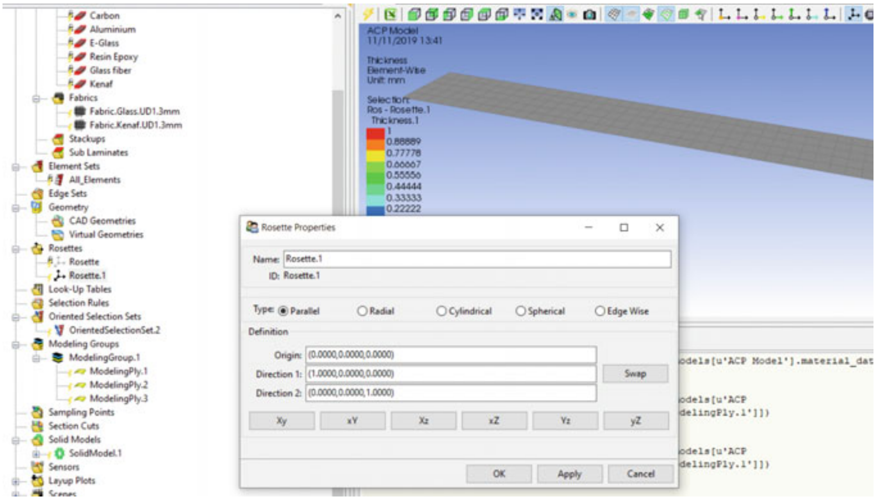


Fig. 12 Set the rosette of the sample

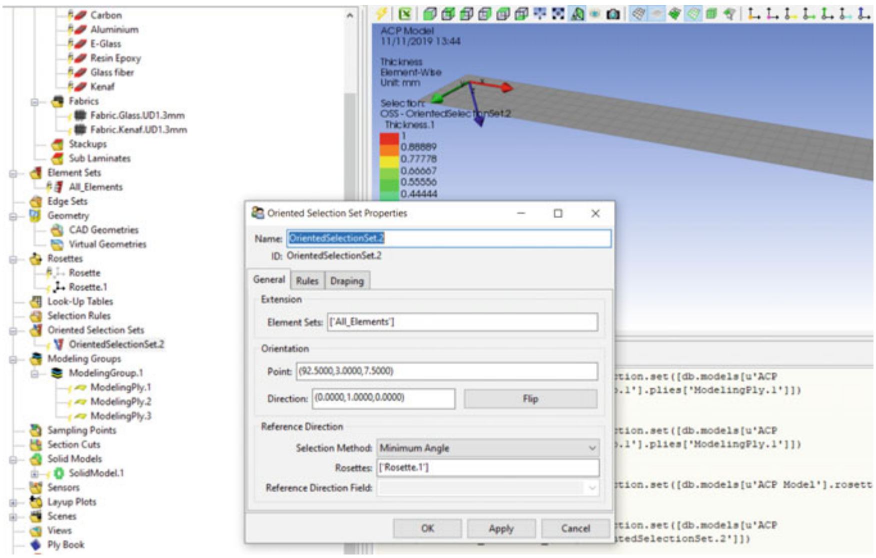


Fig. 13 Define the direction of oriented selection

boundary condition was put at another side in same direction. From the analysis of finite element and experimental for both specimen, result stress and strain (Table 3) are successful in validation range of 15% while percentage error for deformation result of both specimens achieved 100%. The simulation result is more accurate than experimental result. It will be supported with a several factors were occurred when

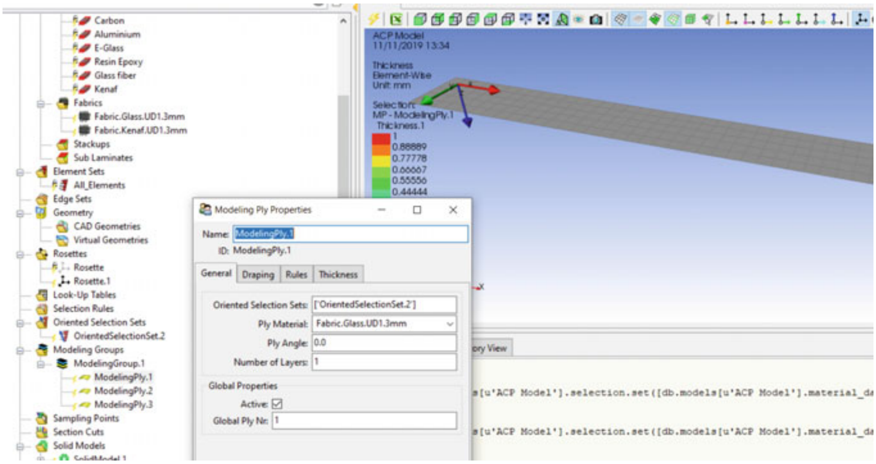


Fig. 14 Define a ply orientation and layers

Table 3 Comparison of analysis result from experiment and finite element analysis

	GKG			KGK		
	Experimental	FEA	Differences (%)	Experimental	FEA	Differences (%)
Stress (MPa)	106.64	120.89	13.4	70.17	79.787	13.7
Strain	0.054	0.057	5.6	0.042	0.036	14.3
Deformation	5.406	13.869	156	4.163	8.581	106

performed the experimental and simulation work. In experimental, it is possible that environmental or human error influence the result obtained such as the strength of specimen grip, a temperature applied in curing process, improper binding for each layer of fibre, etc. (Cook 1995). Compare to simulation process, it can be considered as a perfect process which is zero deformity. Based on Table 3, it clearly shows that composite of GKG have a high strength compare to KGK. Thus, in term of high strength and stiffness, a composite of GKG is most suitable for UAV wing skin. All finite element results of stress and strain for both specimens are shown in Figs. 15, 16, 17, 18, 19 and 20. The loads can get from the raw data of testing performed. Table 3 shown a comparison analysis result of experiment and finite element analysis for both hybrid laminate composite.

Glass-Kenaf-Glass Laminate Composites
See Figs. 15, 16 and 17.

Kenaf-Glass-Kenaf Laminate Composites
See Figs. 18, 19 and 20.

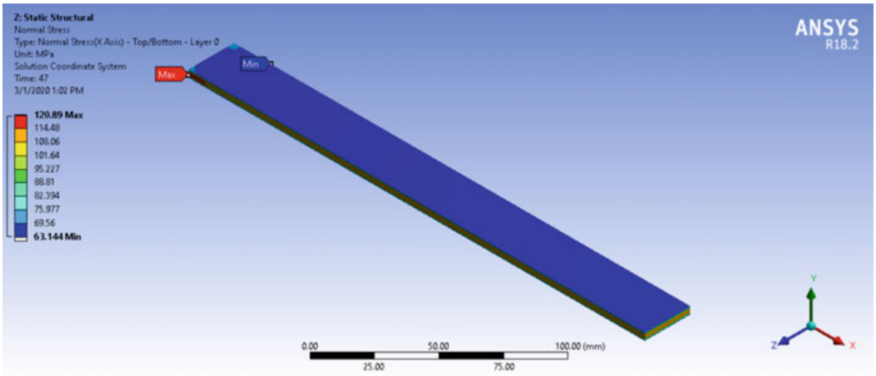


Fig. 15 Normal tensile stress of GKG

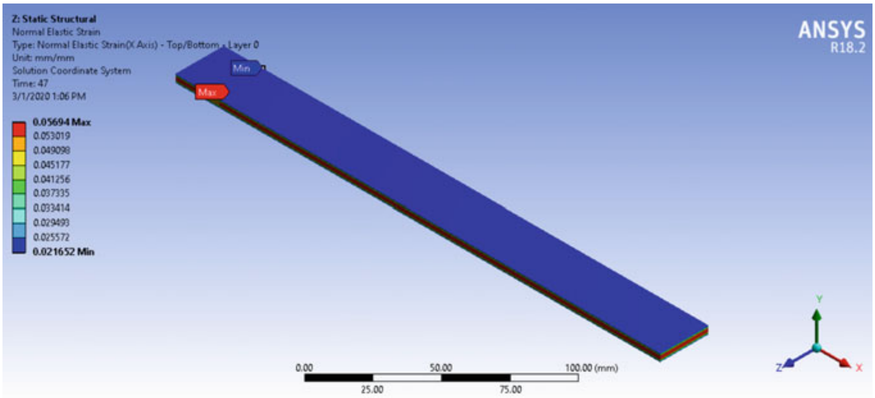


Fig. 16 Normal elastic strain of GKG

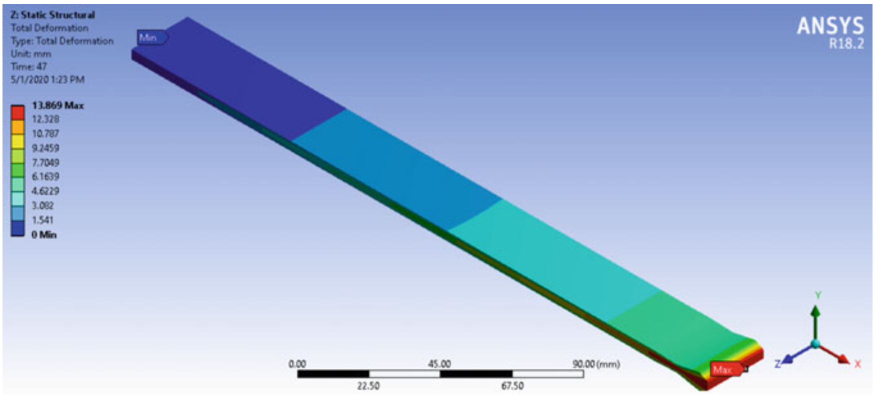


Fig. 17 Total deformation of GKG

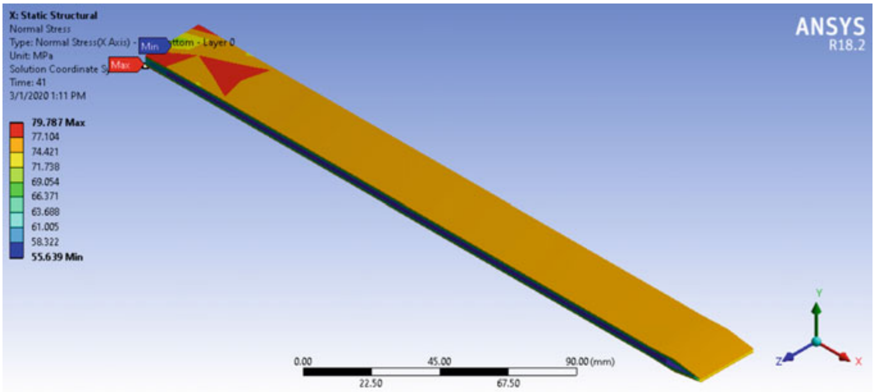


Fig. 18 Normal tensile stress of KGK

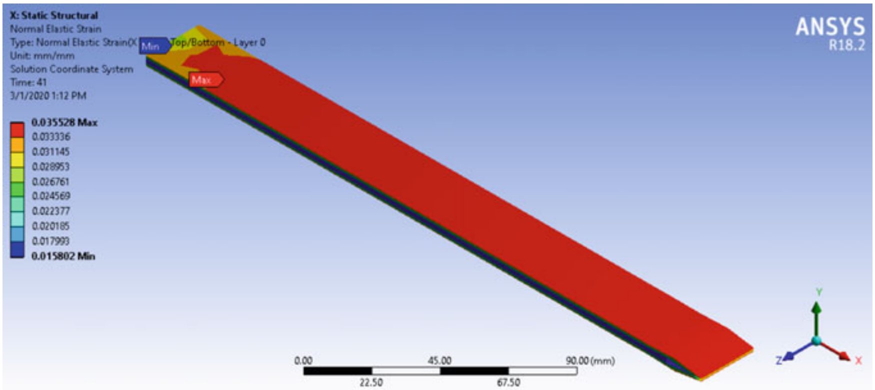


Fig. 19 Normal elastic strain of KGK

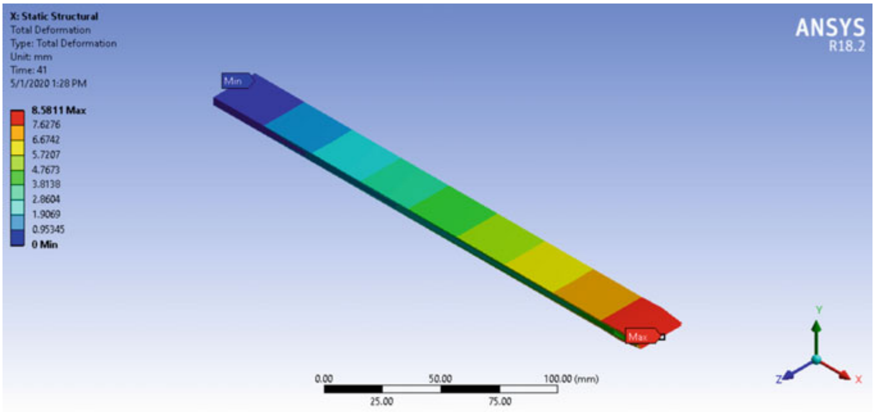


Fig. 20 Total deformation of KGK

4 Conclusion

In this study, it has been focused on engagement of natural composite in a hybrid laminate composite by fabricating two variations of GKG and KGK sample and validated the result obtained from experimental using finite element analysis. Both of the composites were compared in order to define which have the high strength to applied in UAV wing skin. From the finite element analysis, it was found that composite laminate of GKG have a maximum strength of 120.89 MPa compared to KGK which only have 79.787 MPa of maximum stress. In validation between same variation, it was showed a good agreement in stress and strain results in range of 5–15% differences but giving a percentage error for deformation due to the several factors was discussed before. Therefore, from the overall result was observed, it was showed that a hybrid natural-synthetic composite of glass-kenaf-glass giving better properties for applying this composite to a UAV wing skin.

ACKNOWLEDGMENTS The authors would like to thank Universiti Putra Malaysia for financial support through the Geran Putra Berimpak, GPB 9668200. The authors would like to thank the Department of Aerospace Engineering, Faculty of Engineering, Universiti Putra Malaysia and Laboratory of Biocomposite Technology, Institute of Tropical Forestry and Forest Product (INTROP), Universiti Putra Malaysia (HICOE) for the close collaboration in this research.

References

Al-Qrimli HF, Mahdi FA, Ismail FB (2015) Carbon/epoxy woven composite experimental and numerical simulation to predict tensile performance. Adv Mater Sci Appl 4:33–41. https://doi.org/10.5963/amsa0402001

Alger M (1997) Polymer science dictionary, 2nd edn. Springer Publishing

Basri EI, Mustapha F, Sultan MTH et al (2019) Conceptual design and simulation validation based finite element optimisation for tubercle leading edge composite wing of an unmanned aerial vehicle. J Mater Res Technol 8:4374–4386. https://doi.org/10.1016/j.jmrt.2019.07.049

Basri EI, Sultan MTH, Faizal M et al (2019) Performance analysis of composite ply orientation in aeronautical application of unmanned aerial vehicle (UAV) NACA4415 wing. J Mater Res Technol 8:3822–3834. https://doi.org/10.1016/j.jmrt.2019.06.044

Biswas S, Anurag J (2019) Fabrication of composite laminates. Reinf Polym Compos 39–53. https://doi.org/10.1002/9783527820979.ch3

Cook RD (1995) Finite element modeling for stress analysis. Wiley

Saravanan SK, Vetrivel R (2016) Experimental analysis of carbon/glass fiber reinforced epoxy hybrid composite with different carbon/glass fiber ratios. Int J Innov Res Sci Eng Technol (An ISO Certif Organization)

Prasad N, Ramachandran A (2017) Numerical analysis of hybrid carbon fiber composite specimen and validation of results. Int J Mech Eng Technol 8:75–88

Ramesh M, Nijanthan S (2016) Mechanical property analysis of kenaf-glass fibre reinforced polymer composites using finite element analysis. Bull Mater Sci 39:147–157. https://doi.org/10.1007/s12034-015-1129-z

Rao SS (2004) The finite element method in engineering, 4th edn. Elsevier, Butterworth-Heinemann

Reddy JN, (2003) Mechanics of laminated composite plates and shells theory and analysis, pp 840. https://doi.org/10.1007/978-1-4471-0095-9

Salleh Z, Yunus S, Masdek NRNM, et al (2018) Tensile and flexural test on kenaf hybrid composites. IOP Conf Ser Mater Sci Eng 328. https://doi.org/10.1088/1757-899X/328/1/012018