Finite Element Modeling Failure Prediction of Hybrid Composite CFRP/GFRP

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***Abstract*—This study deals with the effect of different layup and orientation of carbon fiber reinforced plastics (CFRP) and glass fiber reinforced plastics (GFRP) composite materials and predict on the deformation and failure of CFRP and GFRP composite materials using finite element modelling (FEM) method using ANSYS. In this study, the composite is modelled in eight different arrangement of cases in terms of different plies arrangement and different angle of orientation. This paper focuses on the simulation for tensile test and failure prediction. For all the cases of a different arrangement of the composite coupon is generated using the CFRP and GFRP which based on standard on the manufacturer data sheet. The mesh convergence analysis is carried out before starting the simulation. Next, the validated method is implemented to proceed with the composite specimen for the tensile test with displacement control and failure prediction which is last ply failure. The last ply failure is used to find the maximum load of the composite that can withstand with the apply loads by using maximum stress theory and maximum strain theory.**

***Index Terms*—Finite Element Modelling, CFRP, GFRP, Hybrid Composite, Last Ply Failure.**

I. INTRODUCTION

A fiber reinforced composite is a composite that makes from fiber (Discontinuous phase), matrix (Continuous phase) and interphase. The fiber of the composite is normally made from the cellulosic waste streams to form strong composite materials. The main function of the fibers is to hold and withstand the weight of the load on the longitudinal direction in order to obtain the maximum tensile strength and stiffness of the material [1]. The carbon fiber reinforced plastic and the glass fiber reinforced plastic are the most common example of the fiber reinforced composite. The composite laminate is build up by a fiber-reinforced composite lamina. In order to study the mechanical behavior, constructing the constitutive equation of a lamina is required. The mechanical properties of the composite are based on the arrangement of the laminas. To construct the constitutive equation of a lamina (Hooke's Law) requires to assume the lamina is in ideal condition. Therefore, the assumptions demonstrated by scholars [2].

a) The lamina is a continuum
b) Lamina must behave in linear elastic material

From the first assumption, it shows that the macro-mechanical behavior of the lamina. If the composite materials experience fiber breakage, the formulation equation will lapse. Whereas, the second assumption shows the generalized Hooke's law is valid. This two assumption can be eliminated if develop micromechanical constitutive models with inelastic types of a lamina. From the microscopic view, the composite material is considered as an inherently heterogeneous and the properties of the composite materials are normally derived from average weighted of the constituent materials, fiber and matrix, the composite material is assumed to be homogeneous. Whereas the constitutive equations are not affected by the materials is homogeneous or not. This is because the body is held with the stress-strain relations. Therefore, the equation for generalized Hooke's law with an anisotropic material under constant temperature (isothermal) conditions as demonstrated by research is [2]:

$$\sigma_i = C_{ij}\varepsilon_j \tag{1}$$

where σ_i = Stress components ; ε_j= Strain components ; C_{ij} = Material coefficients (Referred to orthogonal Cartesian coordinate system [x_1, x_2, x_3])

II. MODELING TENSILE TEST OF COMPOSITE MATERIALS

The tensile test is a basic of mechanical or material science testing for a coupon or specimen is subjected to control of load until the coupon or specimen failed. Research has studied the tensile test deal with the numerical simulation on the test coupon of CFRP with 16 plies that stack with a different orientation. There are two methods of modeling the composite materials. From research [3], it is obtained an analysis of multi-layered for composite in 3D solid-shell element and performed investigation on two 3D solid-shell element which is element per layers as shows in Figure 1 and some layers per element as shows in Figure 2. For element per layer is modeling the composite model with single desirable physical thickness and stack each layer together. Whereas for some layer per element is modelling the composite model with total desirable physical thickness into the same element. From the research finding, the method of some layer per element is better than the element per layers. This is because it is more easy, convenience and general to use due to requiring one element of the thickness of structures. Besides that, this modelling also gives the advantage for all the numerical integration and simulation of stiffness matrix is based on one single layer of the element and without any delaminates effect which approaches identical. In another study have explored the disadvantage of using the method of layer per element is the element kinematic cannot show and measure the effect of delaminates of the plies [4].

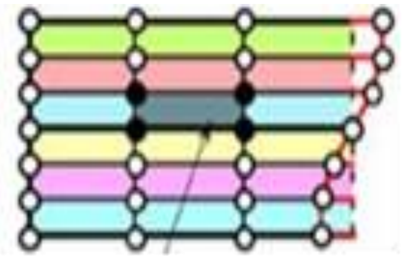


Figure 1: One layer per element

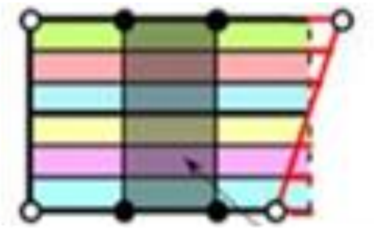


Figure 2: Some layers per element

A. Mesh Convergence Analysis

Mesh convergence analysis is used as a tool that will provide good guidance to get quality of a finite element model. This research, 12 different sizes of the mesh are implemented on a composite layup for CFRP and GFRP. The parameters for the composite layup are varied with the meshing size which are 6 mm, 5 mm, 4 mm, 3 mm, 2 mm, 1 mm, 0.9 mm, 0.8 mm, 0.75 mm, 0.7 mm, 0.65 mm and 0.6 mm. This analysis tool can help to identify the requirement of the mesh refinement in order to get accurate or precise results in the area of high stress or strain for the simulation by shows the small changing or maintain at the same level of the measurement, the size of mesh or element must be small enough. From this, a suitable mesh size can be determined and applicable for the next in tensile test simulation. Graph of maximum stress against the number of an element is plotted for GFRP and CFRP and shows as Figure 3 and Figure 4 respectively. From both of the graph, the mesh convergence trends show a not uniform of increasing. This show that the mesh convergence is not achieved yet due to the uniformly increase the slope of the trend when the mesh size keeps in decreasing. Whereas the result of the mesh convergence become more stable when the mesh size keeps decreasing. For GFRP, the mesh size is achieved stable in between of 0.6 mm and 0.7 mm. Whereas for CFRP, mesh size is achieve stable in between of 0.6 mm and 0.8 mm. With these result, the mesh size of 0.6 mm is selected to develop the numerical simulation in the tensile test for GFRP, CFRP and different arrangement of the composite specimen. Figure 5 depicts the tensile test simulation geometry, boundary and loading condition. Meanwhile Figure 6 shows the stress against strain plot for CFRP and GFRP for baseline/reference for anticipated hybrid composite CFRP/GFRP stress against strain relation.

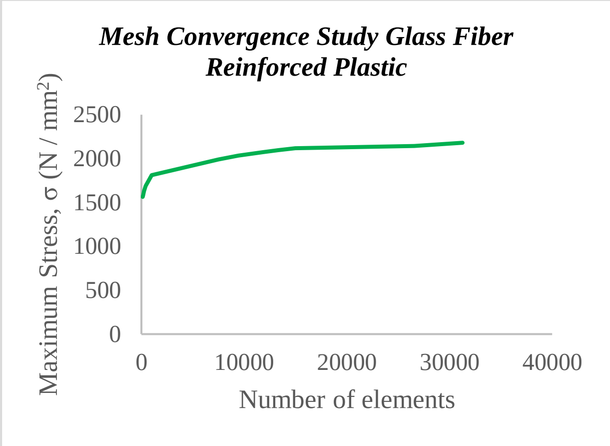


Figure 3: Mesh Convergence Study GFRP

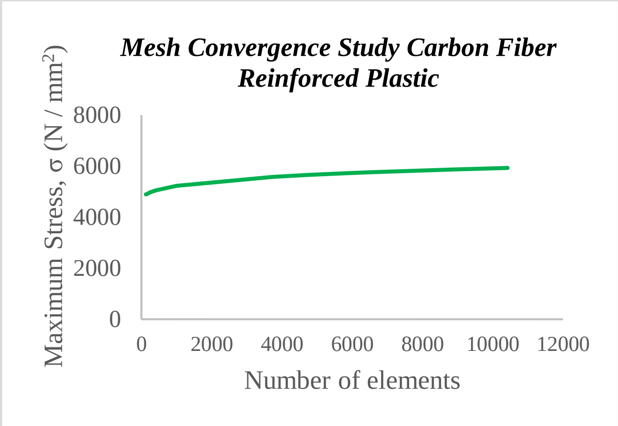


Figure 4: Mesh Convergence Study CFRP

Figure 5: General tensile test set up a diagram

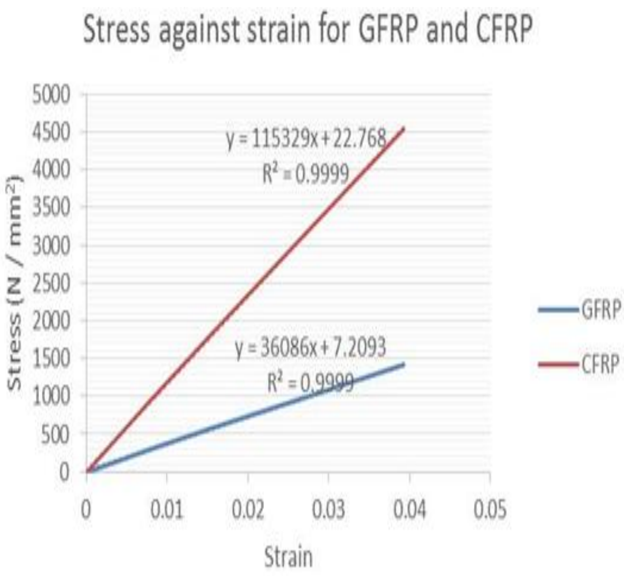
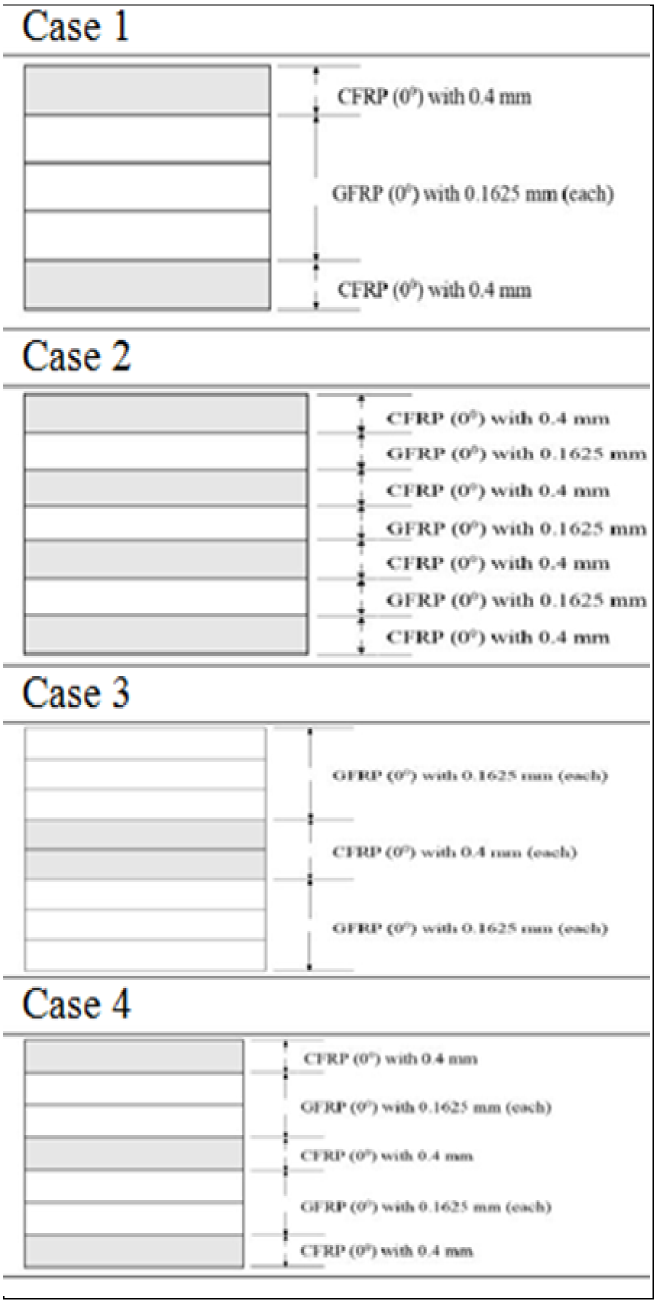


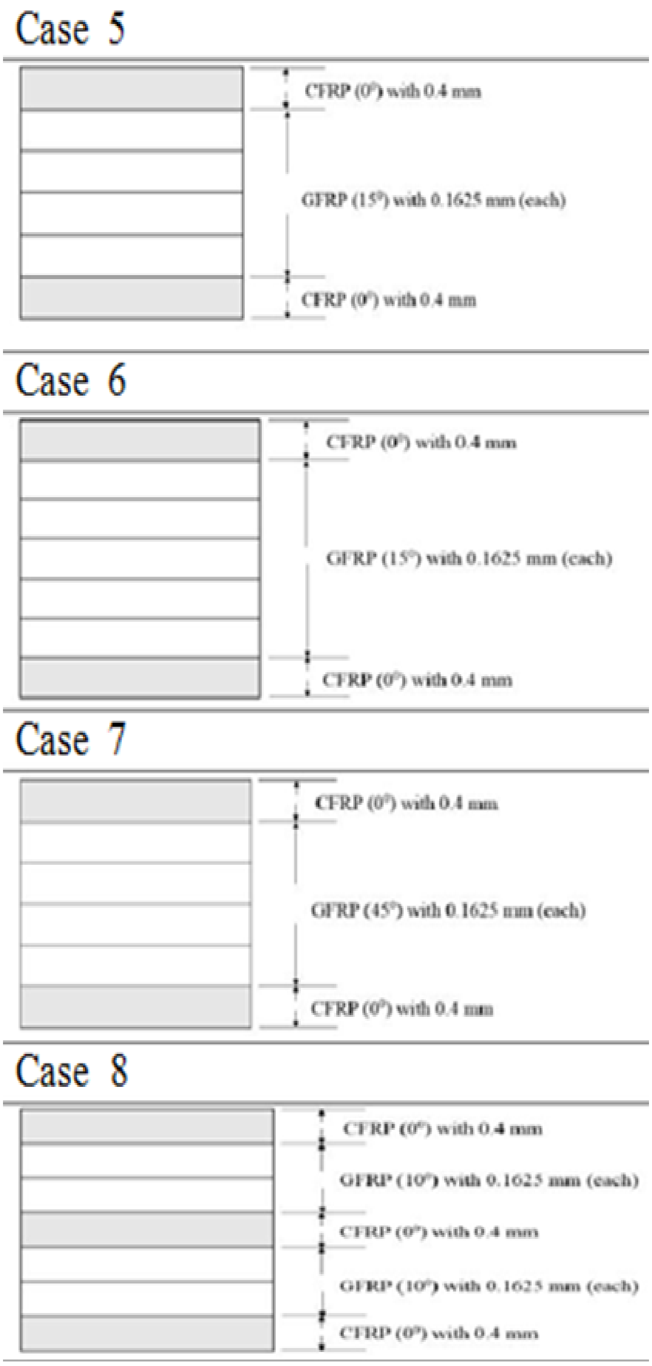
Figure 6: FEA result from a tensile test for CFRP and GFRP

III. Results

All the test specimens are using continuum shell and conventional shell for the modelling the model. An eight different arrangement of cases of the test specimen is modelled and were tested with the tensile test. The dimension for each test specimen (different arrangement of composite) was 250 mm in length, 15 mm in width and the thickness will be shown in Table 1 for Case 1 to Case 8. The result of the Young's Modulus for continuum shell and conventional shell for each different arrangement of the composite is obtained from plotting the stress against strain graph as shown for arrangement case 1 to case 8.

Table 1
Different Layup/Configuration of Hybrid Composite





A. Last Ply Failure Analysis

The tensile test is a basic of mechanical or material science testing for a coupon or specimen in uniaxial direction with subjected to control of load until the coupon or specimen failed. With this, a tensile test normally carries out to obtain the maximum load on the specimen or coupon that able to withstand. In this study is focus on the strength or strain of the plate. When applying the then tensile loading excess the ultimate tensile strength or maximum loading, the coupon will experience structural failure this stage is known as last ply failure (LPF) [5]. So at this stage, the last ply failure (LPF) for the laminate composite coupon is taken into account once failure index of any last layer is more than or equal to one, the ply is accounted structure failed. In this section, the eight different arrangement and different angle orientation of the composite coupon are carried out the tensile test in uniaxial direction for the LPF [6]. All the different arrangement of the composite specimen is modeled. All the methods of modeling the eight arrangement cases are the same as the tensile test on the composite but the fail stress and fail strain need to be specified in the materials of properties for GFRP and CFRP. For the last ply failure analysis, the maximum load for each case of the composite specimen can be identified.

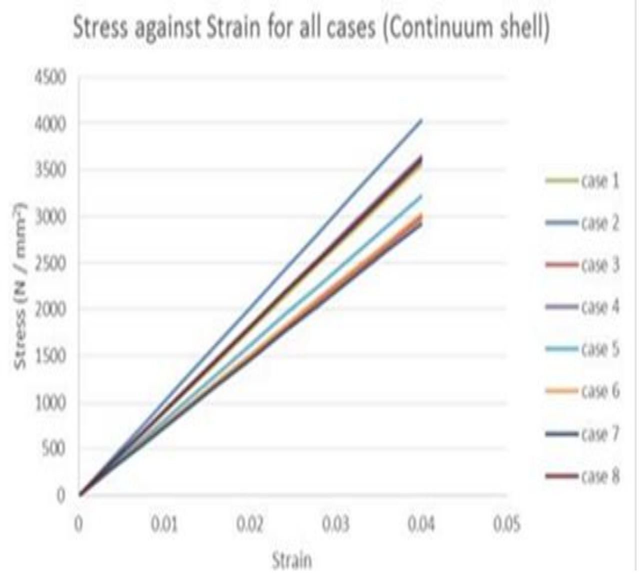


Figure 7: The trend for continuum shell in case 1 to 8

In the comparison between case 1 and case 3, case 3 arrangement requires more loading force to achieve LPF when compare to case 1 which is 41.41 KN in term of maximum stress theory failure measure and 35.04 KN in terms of maximum strain theory failure measure respectively. This result is similar by implementing the conventional shell that shows the case 3 is higher that the case 1 in terms of maximum stress theory and maximum strain theory. This is because of the case 3 consists of 8 numbers of plies when compare to case 1 only have 5 numbers of plies. So, the more the number of plies present in the composite arrangement will lead to more loading force is required to fail the composite structural. In the comparison between the case 1, case 2, case 3 and case 4, the arrangement case 2 shows the largest total reaction force that required to achieve the LPF in the composite specimen. This is due to the case 2 consist a lot of plies and more carbon fiber plies present in the arrangement when compare to other arrangement cases. On the other hand, for the case 1 shows the lowest total reaction force is requiring for LPF in the composite. This is because case 1 consist less number of plies and less carbon fiber plies present in the arrangement when compare to other arrangement cases.

This result is the similar within the conventional shell that shows the case 2 is higher whereas the case 1 is the lower in terms of maximum stress theory and maximum strain theory. Next, the comparison in between arrangement case 5 and case 6. From case 5 and case 6, the only different is case 6 have 5 GFRP plies with arranging in 15 angle orientation which is more than case 5 with only 4 GFRP plies for arrange in 15 angle orientation. From the comparison, case 6 shows the higher of the total reaction force that required to achieve LPF in the composite which is 35.05 MPa and 31.04 MPa for maximum stress theory failure measure and maximum strain theory failure measure respectively. Whereas the case 5 only shows 32.21 KN and 29.41 KN for maximum stress theory failure measure and maximum strain theory failure measure respectively. This shows that the more plies present in the arrangement of the composite specimen, the total reaction force required to fail the composite specimen. This result also proved by implement the conventional shell which shows the same results. Apart from that, the next comparison will be in between arrangement case 5 and case 7. From case 5 and case 7, the only different between these two cases is a different angle of orientation.

This comparison is same as the comparison in between the case 4 and case 8. For arrangement case 5 have 4 plies of GFRP that arrange with the orientation angle of 15 angles. Whereas the arrangement for case 7 has 4 of GFRP plies that arrange with the orientation angle of 45 angles. From the comparison, case 5 shows the higher of the total reaction force that required to achieve LPF in the composite structural which are 32.21 KN and 29.41 KN for maximum stress theory failure measure and maximum strain theory failure measure respectively. Whereas for the case 7 only shows 28.29 KN and 26.38 KN in terms of maximum stress theory failure measure and maximum strain theory failure measure respectively. This is due to case 7 have 4 of the plies is arrange with 45 angle of orientation which is largely deviated from the loading direction when compared to case 5. Hence, the loading force is not fully loaded in the fiber direction. So, it becomes a partial load in longitudinal and transverse direction. For this reason, the angle of orientation between the ply will affect the mechanical properties especially the strength in loading direction and cause decrease significantly in terms of the stiffness of the model in case 7 which compare to case 5. The results obtained by implement the conventional shell also shows the same in case 5 and case 7.

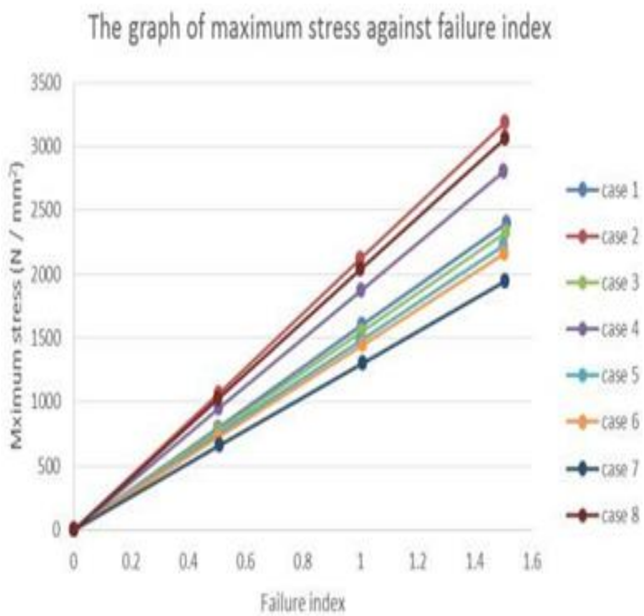


Figure 8: The graph of maximum stress against failure index for continuum shell

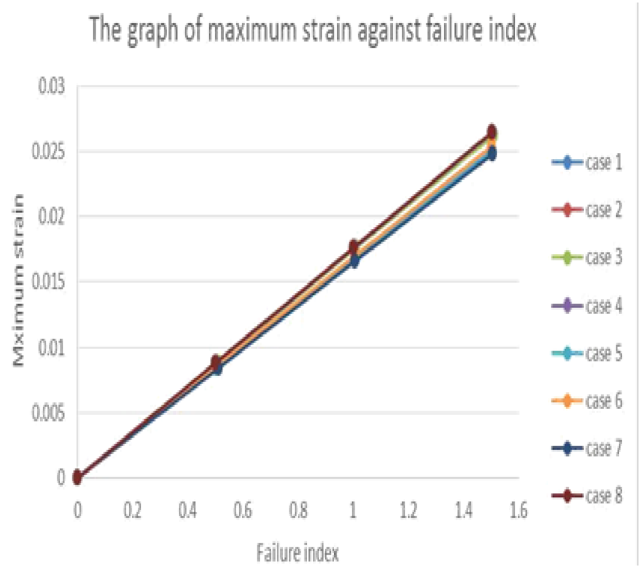


Figure 9: The graph of maximum strain against failure index for continuum shell

Table 2
The Total Reaction Force Measure by Maximum Stress Theory and Maximum Strain Theory for Continuum Shell And Conventional Shell

Cases	Continuum shell		Conventional shell	
	RF obtain from MSTRS (kN)	RF obtain from MSTRN (kN)	RF obtain from MSTRS (kN)	RF obtain from MSTRN (kN)
Case 1	30.88	28.82	38.76	29.84
Case 2	66.28	55.55	71.31	54.90
Case 3	41.41	35.04	44.98	33.04
Case 4	52.07	44.49	57.11	41.44
Case 5	32.21	29.41	32.22	32.57
Case 6	35.05	31.04	33.24	33.24
Case 7	28.29	26.38	29.24	27.34
Case 8	56.55	44.04	48.53	43.03

IV. CONCLUSION

Finite element modelling of tensile test and failure prediction for the last ply failure have been performed. For the tensile test, this research is to determine the stress-strain relation between different types of the composite. From the comparison in between continuum and conventional shell shows the results are almost the same. LPF is a type failure prediction that can be used to estimate the maximum load on the composite of the specimen that can withstand when all the plies of the coupon are failed completely through the tensile test. This failure prediction is predicted by using Ansys software with its built-in failure theory which is Maximum Stress and Maximum Strain Theory. The total reaction force of the composite can be affected by the ratio for the composition of the materials, the number of the specified types of materials, the number of plies and the angle of orientation that present in the composite model. From the overall study shows that the composite for arrangement case 2 is the highest value in terms of Young's Modulus, the total reaction force predict by maximum stress theory and maximum strain theory. Whereas the composite for arrangement case 7 shows the lowest value in terms of Young's Modulus value, total reaction force predicts by maximum stress theory and maximum strain theory. From the overall comparison in between all the cases found that the total reaction force predicted using Maximum Stress Theory and Maximum Strain differ with each other except for certain layup/cases.

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