

Experimental and Simulation Investigation of Bending Moment Effect on Hollow Columns of Multi-layers of Hybrid Materials

Ayad A. Ramadhan

Department of Mechanical Engineering, Al-Hawija Technical Institute, Northern Technical University
ayad_almuhndis@yahoo.com

Abstract

This paper presented the effect of bending on multi-layer of hollow columns of Hybrid materials (Carbon-Glass /epoxy-Alumina) composite this effect occurred and volume fraction of fibers. An experimental procedure was developed to study the performance of these effects under bending load using a hydraulic bending device type (MATEST. SRL) testing machine. This study has three forms through the selection of columns hollows width to thickness (a/b) (0.5, 1 and 2) with three types of layers of samples (2,4 and 8) layers. The ultimate load of failure for each Hybrid/epoxy- Al_2O_3 had been determined and specified the optimum volume fraction (V_f) due to the effect of mixing 50% and 60% were low in the case for compared 55% volume fraction. To simulate this problem the researcher used Explicit Mesh for AUTODYN under ANSYS-15 software, it was found that maximum bending load for Hybrid/ Epoxy- Al_2O_3 Specimens, the maximum load of specimens increased with increasing number of layers from 2L to 8L. The results also identified that the maximum load capacity by 55% volume fraction and a/b=0.5 of all composite specimens was highest from the others types of (50% and 60%) volume fractions and (a/b=1 and a/b=2). Also, the Increasing ratio of stress capacity for specimens have 4 to 2 layers (4/2) and 8 to 4 (8/4) for experimental results have maximum value with increasing by 48.19% and 46.84% at (Sp.4#8/Sp.2#4) and (Sp.8#6/Sp.4#6) respectively.

Keywords: Experimental study; Simulation study; AUTODYN; Bending load; Hybrid materials; and Hollow columns.

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1.Introduction

A composite material is made by combining two or more dissimilar materials. They are combined in such a way that the resulting composite material or composite possesses superior properties which are not obtainable with

a single constituent material. So, in technical terms, we can define a composite as 'a multiphase material from a combination of materials, differing in composition or form, which remain bonded together, but retain their identities and properties, without going into any chemical reactions.' The components do not dissolve or completely merge. They maintain an interface between each other and in concert to provide improved, specific or synergistic characteristics not obtainable by any of the original components acting singly[1-3]. Thin cylinders of fiber-reinforced plastic (FRP) material are used in large quantities as a kind of structural material for robot arms, airplanes and aerospace applications because of their light weight and high strength. Limin Bao and Natsuki Kamada [et al] [4] improved the mechanical properties of these cylinders, this study applied the VaRTM method to develop a biomimetic design of a thin cylinder with nodes that imitate a bamboo structure. They studied effects of inserted nodes on the bending properties of a thin FRP cylinder that were examined by the four-point bending test. It is evident that the flexural rigidity and bending buckling load were increased; the validity of the node has also been confirmed. Several researchers found that bending strength was greater than tensile strength in polymeric composite materials[5-8]. Liu [9] tested the bending fatigue lifetime of the aramid fiber by using a sample bending fatigue apparatus and Gu [10] investigated the bending fatigue strength of the wool fiber. Burgoyne and Hobbs [11] used a sheave bending apparatus to investigate the bending fatigue of parallel lay aramid ropes. Todd.[12] got numbers of cycles-to strength degradation curves under a low tension, which proved that the bending fatigue damage of the aramid fibers used for communication cables are small under the low tension. Kohji [et al] [13]. The pultruded polymer matrix composite sections are being increasingly used in structural applications such as bridge decks, panels, railings, gratings, and standard sections (circular, square, rectangular, wide flange, I, channel, etc.). Based on geometry, the composite members can be classified as thin-walled members, and the glass

fiber orientation results in orthotropic material behavior. The behavior of fiber-reinforced composites has been typically explained in the light of Micromechanics and Classical Laminate Theory (CLT), as reported by many researchers, [14-20] wherein the laminate properties of composites are given. During field applications, the pultruded members are subject to different types of loads, including combined torsion and bending, potentially resulting in structural instability, including various modes of buckling. Response of closed Glass Fiber Reinforced Polymer sections under combined bending and torsion was studied by Muhammad AM Qureshi [et al] [21]. Phan and Reddy [22]. applied this theory for the bending, the free vibration, and the buckling of composite plates. Idlbi [et al.] [23]. compared trigonometric or sine functions shear deformable plate theory TSDPT and parabolic shear deformable plate theories PSDPT for the bending of cross-ply plates. Recently, Karama [et al] [24]. proposed an exponential variation for the transverse strain in their investigation of the bending of composite beams. A comprehensive literature review revealed that most of the experimental work done on pultruded composite materials is limited to flexural loading or compressive axial loading (no load interaction) at component level, but mainly at coupons level. However, research on torsional loading of pultruded members is limited, and certainly no prior research work has been reported on testing full-size specimens till failure under combined bending and torsion. Testing full-size specimens can be a challenge because of absence of standard test methodologies. While theories of isotropic material response have also been modified for composite materials and reported in literature, [25 The theory of anisotropic plates also helps define the behavior of fiber-reinforced composites 29] The design manuals of structural members of various cross-sectional shapes have been developed by professional societies and manufacturers.[30-32] Moreover, finite element analysis (FEA) of GFRP composite members was performed here in to compare the response data under complex loading conditions with our experimental data. The bending fatigue behaviors were investigated in glass fiber-reinforced polyester composite plates, made from woven-roving with four different weights., 800, 500, 300, and 200 g/m², random distributed glass-mat with two different weights 225, and 450 g/m² and polyester resin [33]. Portal axle shaft analyzed by Finite Element Analysis considered three different composite materials and varying parameters. i.e rib thickness and hollow shaft thickness are considered. Some of the parameters are kept constant, they are depth of spokes, rib fillet radius, number of spokes.

Torsional strength of the shaft compared for three different materials. When thickness are varied Deformation and Stresses are almost same for Kevlar/Epoxy and Boron/Epoxy materials but varied for E-Glass/Polyester Resin. Similarly When Shaft Thickness is varied the results are same for Kevlar/Epoxy and Boron/Epoxy but varied for E-Glass/Polyester Resin material. the effect of stacking sequence on mechanical properties of untreated luffa cylinder and glass fiber reinforced epoxy hybrid composites has been investigated experimentally by Niharika Mohanta & Acharya [35]. the mechanical properties of three types of composite materials using natural rubber vulcanized, un vulcanized and reinforced rubber have been investigated by Dr. Hani Aziz Ameen.[36] in this study the bending properties of a glass polyester hollow shaft had been studied.

In this work, the experimental study of bending load effect on hollow columns that are mad from hybrid (Carbon-Glass) fiber with epoxy- Al₂O₃ with different (2,4 and 8) number of layers has been studied with two shapes of cross-sectional area of specimen (rectangular and square shape). The effect of bending load different type of volume fraction (50%, 55% and 60%) with different number of layers on the strength of columns is studied via both experimental and simulation approaches by using ANSYS V.15. Experimental investigation of strength in Hybrid materials subjected to bending load is performed by using MATEST S.R.L TREVOLLO 08 24048 ITALY bending device. A comparison between test results is made to demonstrate the suitability of the composite materials in maximum stress capacity.

2. Methodology and Materials Selection

2.1. Materials selection and specimen fabrication

Two kinds of fiber (Carbon and Glass) with (0°/90°) fiber orientations for hollow columns of Hybrid materials (Carbon-Glass/epoxy-Alumina) had been selected to fabricate the composite materials as follow:-

- 1- Woven fiber Carbon
- 2- Woven fiber Glass
- 3- Epoxy + Hardener
- 4- Alumina (Al₂O₃) powder.

The mechanical properties of these materials have been specified in Table 1 as bellow The volume fraction of fiber V_f (fiber volume/total volume) in composites is very often significantly less than 100%, and it was tested by (Hyer, 1998), so the volume fraction was selected by 55% in this work, it was an optimum value

compared with others volume fraction for fabricating the specimens.

Table 1 Properties of materials used.

Properties	Material type		
	Carbon	Glass	Alumina
Diameter(μm)	8-9	—	
Density (Kg/m^3)	1780-1820	2490	3.71
Tensile Modulus (GPa)	228-276	68.9	
Tensile Strength (MPa)	2410-2930	3160	
Elongation (%)	1.0	4.8	
Thermal Expansion Coefficient ($\times 10^{-6}/^\circ\text{C}$)	-	7.2	5.4
Thermal Conductivity ($\text{W/m}^\circ\text{C}$)	20	—	30 - 40
Specific Heat ($\text{J/kg}^\circ\text{K}$)	950	780	

Three shapes of hollow columns; wide to height ratio ($a/b=0.5, 1$ and 2) with three types of samples (2,4 and 8) layers. All the specimens have the same length which is 320 mm, but the active length 280 mm will carry the bending load of the test until failure occurs by bulking the specimen as shown in Figure 1, while failure at mid of the hybrid specimen generated by the

bending test (simply supported beam) would lead to maximum deformation in the center of the specimen. The maximum load and stress of failure for each of the Hybrid/epoxy- Al_2O_3 under bending has been determined. The lower horizontal edges of the plate are loaded at a midpoint of specimen. In all cases, the hollow columns boundary is a simply supported beam as well.

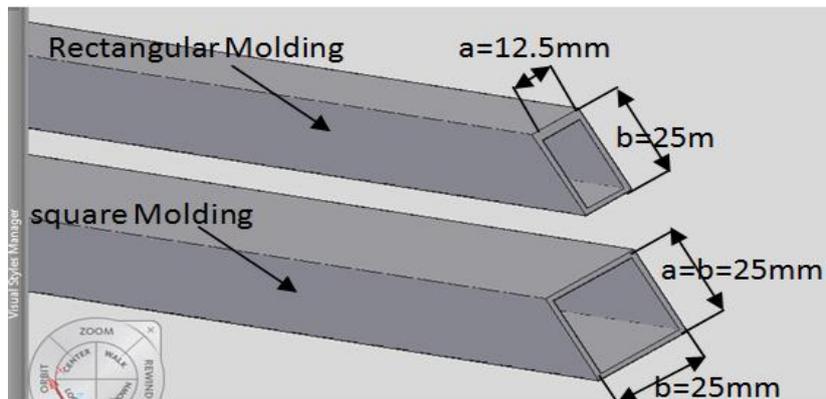


Figure 1: Rectangular and Square shape of specimen drawn by AUTOCAD Program

The specimens specified in the number of layers and volume fraction (V_f) with ($0^\circ/90^\circ$) fiber orientation angle as listed in Table 2. The volume fraction of the woven fiber affects the behavior of orthotropic specimens under an applied bending load. Three types of layers of

samples (2, 4 and 8) layers with different (50%, 55% and 60%) volume fraction V_f has been fabricated in this work. That it is need to paint the fiber textured Epoxy plus the amount of hardener 1.5% of the required amount of Alumina powder.

Table 2 Specimen fabricated of hybrid composite (27 specimens).

Specimen of (2Layers)	V_f	Width/High Ratio (a/b)	Specimen of (4Layers)	V_f	Width/High Ratio (a/b)	Specimen of (8Layers)	V_f	Width/High Ratio (a/b)
Sp.2#1	50%	0.5	Sp.4#1	50%	0.5	Sp.8#1	50%	0.5
Sp.2#2	55%	0.5	Sp.4#2	55%	0.5	Sp.8#2	55%	0.5
Sp.2#3	60%	0.5	Sp.4#3	60%	0.5	Sp.8#3	60%	0.5
Sp.2#4	50%	1	Sp.4#4	50%	1	Sp.8#4	50%	1
Sp.2#5	55%	1	Sp.4#5	55%	1	Sp.8#5	55%	1
Sp.2#6	60%	1	Sp.4#6	60%	1	Sp.8#6	60%	1
Sp.2#7	50%	2	Sp.4#7	50%	2	Sp.8#7	50%	2
Sp.2#8	55%	2	Sp.4#8	55%	2	Sp.8#8	55%	2
Sp.2#9	60%	2	Sp.4#9	60%	2	Sp.8#9	60%	2

Hand lay-up method has been used to fabricate all the specimens. Woven (Carbon and Glass) fibers are wound manually around the mold of plastic, which was coated with wax to easily remove the specimen later, and epoxy with Alumina powder resin brushed over and into the woven roving fiber in this way for (Carbon-Glass)/epoxy+ Al_2O_3 . After preparing all the materials, the first step in fabrication starts with cutting the woven roving fiber manually. The fiber used to fabricate the active area is mixed between the carbon fiber woven roving and glass

fiber woven roving and other things is totally the same, also 27 specimens were fabricated, 9 specimens for each number of layer 2, 4 and 8. Fibers pieces for the active area should cut and prepare before fabricating and also the mandrels should be ready, then in the fabrication of this case the fiber Glass piece must rolled at first then the Carbon fiber were rolled around the glass fiber in order to make the hybrid fiber specimens, the inactive area will be from glass fiber also, Figure 2 will show the fabrication process for hybrid/Epoxy- Al_2O_3 specimens.

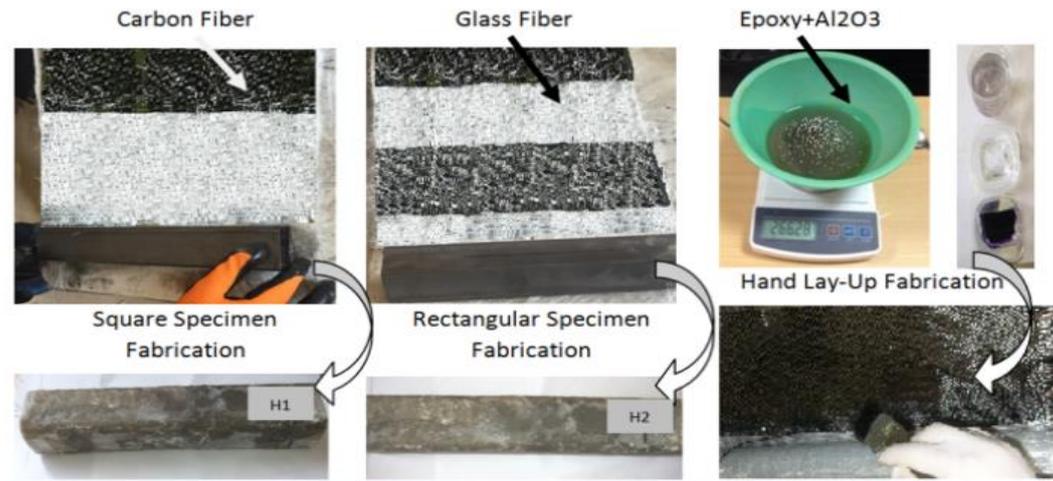


Figure 2: Two and four layers specimen fabrication of hybrid composite

The tests were conducted at room temperature between 25-28 C° and the time required for solidification of all specimens is about 72 h to provide optimum blend.

2.2 Specimens Testing

The device that is used to examine the samples is MATEST S.R.L TREVOLLO 08 24048 ITALY bending device where the sample is horizontally installed, and then is lowered on a sample of bending arm commends the sample down to a case of total failure of the sample where the purpose of the experiment is to examined the maximum load under the influence of bending, bending device is shown in Figure 3.

After conducting laboratory tests on a composite of Carbon-glass fiber / Epoxy + Alumina showed practical results of the effect of bending load on hollow columns that is made of composite material of Hybrid/Epoxy- Al_2O_3 . This study has two forms through the rectangular tube selection (hollow columns) a/b (a / b = 0.5 and 2, square a / b = 1) with 3 types of layers of samples (2,4 and 8) layers. Totally more than 27 specimens were facts of this compound for both forms to take the test. All samples were tested. In this study, a statement bearing capacity of those columns resist bending applied on the central subject of the test sample.

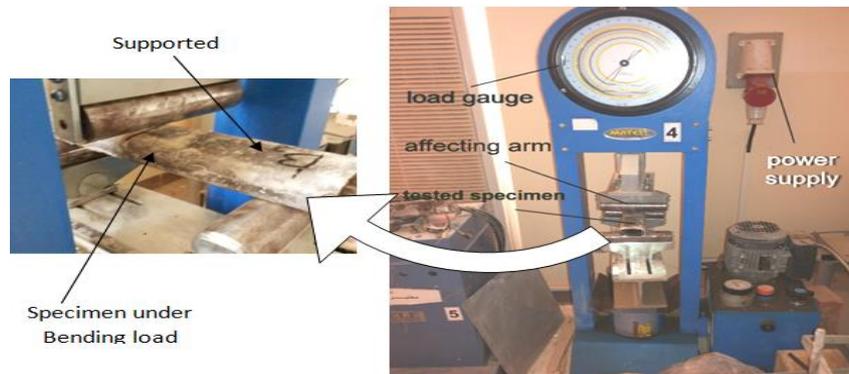


Figure 3: Matest S.R.L trevolo 08 24048 italy bending test device

3. Autodyn Simulation

The standard 3D AUTODYN in ANSYS 15 model was used to investigate this simulation, Lagrange code was used and created, so that cell boundaries occurred at free surfaces and material boundaries. Another point is that during calculations, the mesh would distort to match the distortion of the material, so the mesh assumed in this study was Explicit –Auto-meshing and the standard properties of Hybrid/Epoxy- Al_2O_3 composite laminated plate. The finite element mesh used for the analysis consisted of 1560

QUAD4.elements, as shown in Figure 4. The load cases considered, which were a variety of maximum stress. The 27 hybrid specimens are solved by Explicit Dynamics in AUTODYN 15 to be representative of a lateral Carbon-Glass/ $E-Al_2O_3$ with non-linear analysis of specimen dimensions (length, $L = 320$ mm, high, $a = 12.5$ mm and width, $b = 25$ mm) with 1.25mm, 2.4mm and 4.7mm thickness of specimen. The boundary condition of specimen is simply supported beam on both ends and the loading similar to that of the test specimens as shown in Figure 4.

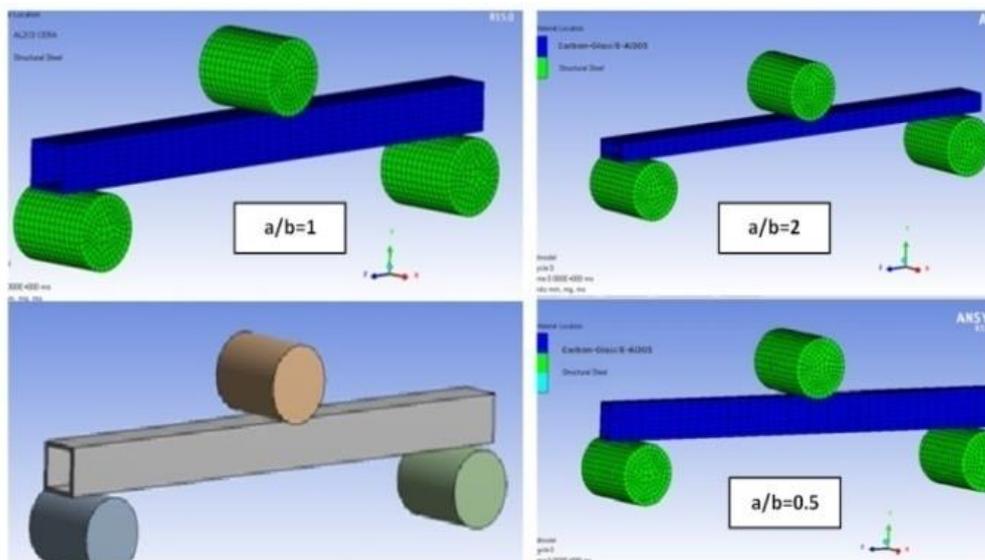


Figure 4: Autodyn V.15 - Geometry modeling for different shape of cross-sectional area of Hybrid specimens

4.Results and Discussions

The bending test applied for the three types of layers of composite specimen sets and the test result will be discussed below and according to maximum bending stress capacity for number of layers and by using volume fraction of composite relations and parameters will find and

discuss. To make a comparison for a maximum stress capacity between 27 types of specimens according to the number of layers, a diagram including all of them has been done. Figure 5 shows the variation of stresses with different cross-sectional area ($a/b=0.5, 1$ and 2) for 2, 4 and 8 layers for all specimens tested.

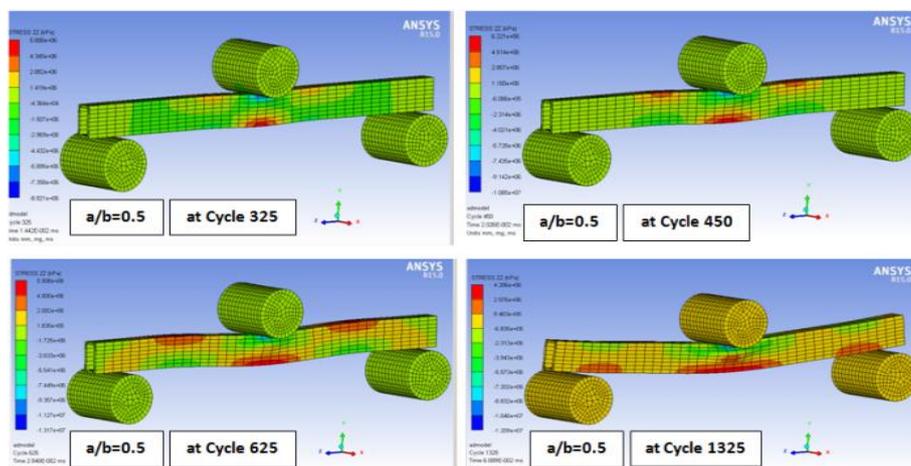


Figure 5: Deformation of Hybrid/epoxy- Al_2O_3 of rectangular cross-sectional area of specimen under test at different cycles

A prescribed incremental bending loading is by applying loading on the mid of the specimen, while the ends are simply supported fixed.

Figure 6 shows the maximum deformed state of rectangular tube of Hybrid specimen under bending load with $a/b=0.5$

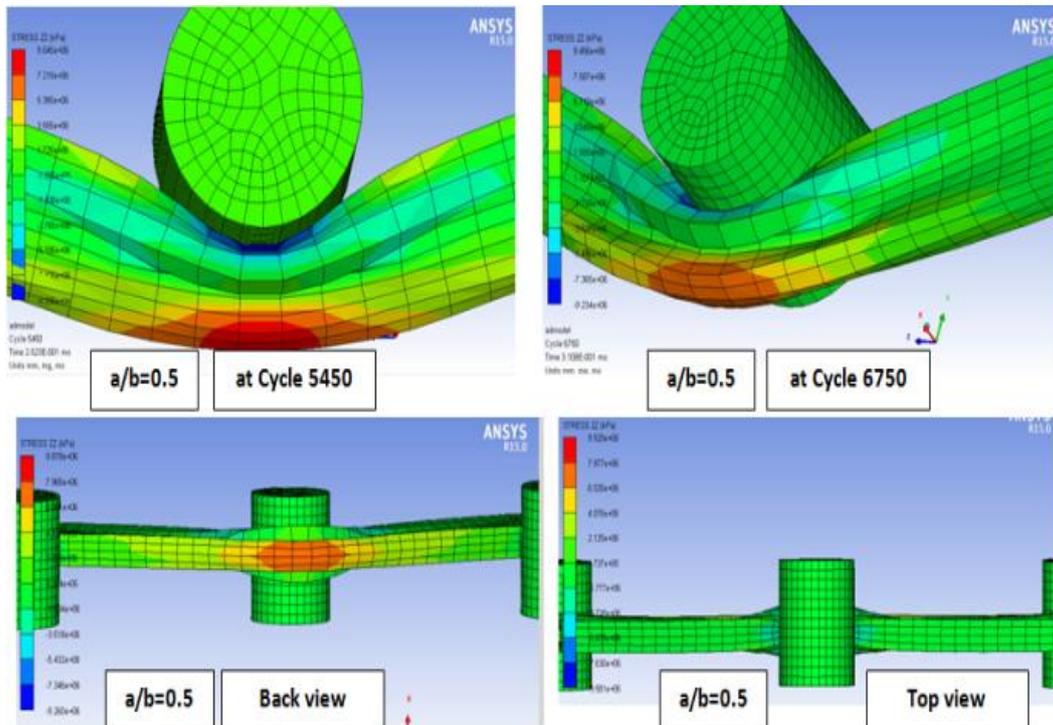


Figure 6: Maximum deformation of Hybrid/epoxy- Al_2O_3 of rectangular cross-sectional area of specimen under test at different cycles

Another example shows the influence of maximum stress loading on specimen was modeled as shown in Fig. 7 below of rectangular

cross-sectional area with $a/b=2$ at different number of cycle.

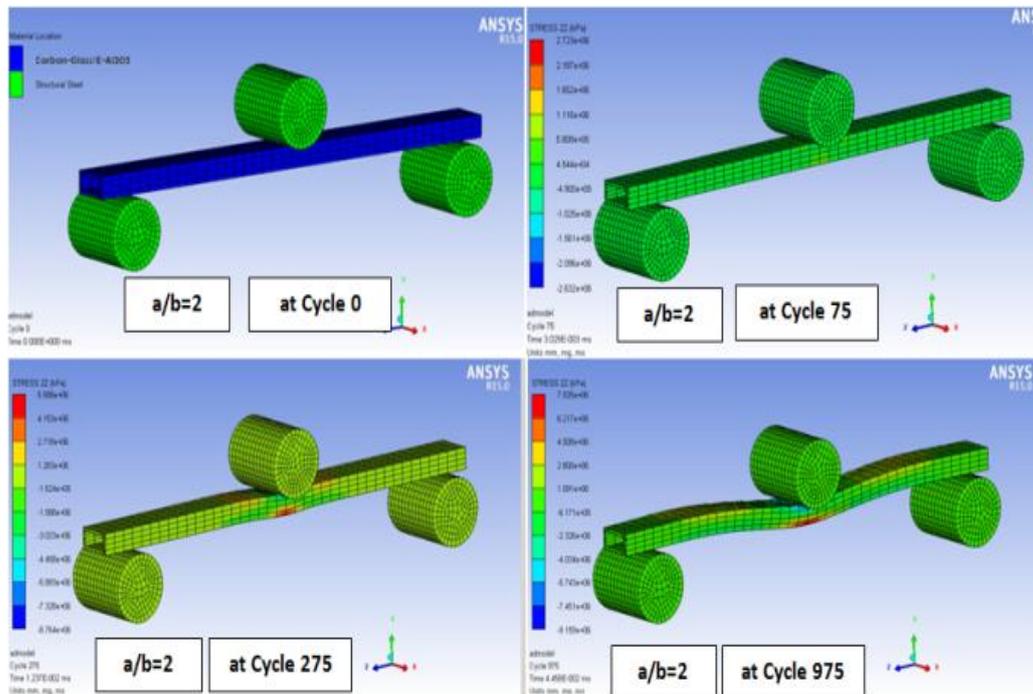


Figure 7: Deformation of Hybrid/epoxy- Al_2O_3 of rectangular cross-sectional area $a/b=2$ of specimen under test at different cycles

The influence of maximum stress loading on specimen was showed as back view as shown in

Fig. 8 below of rectangular cross-sectional area with $a/b=2$ at different number of cycle.

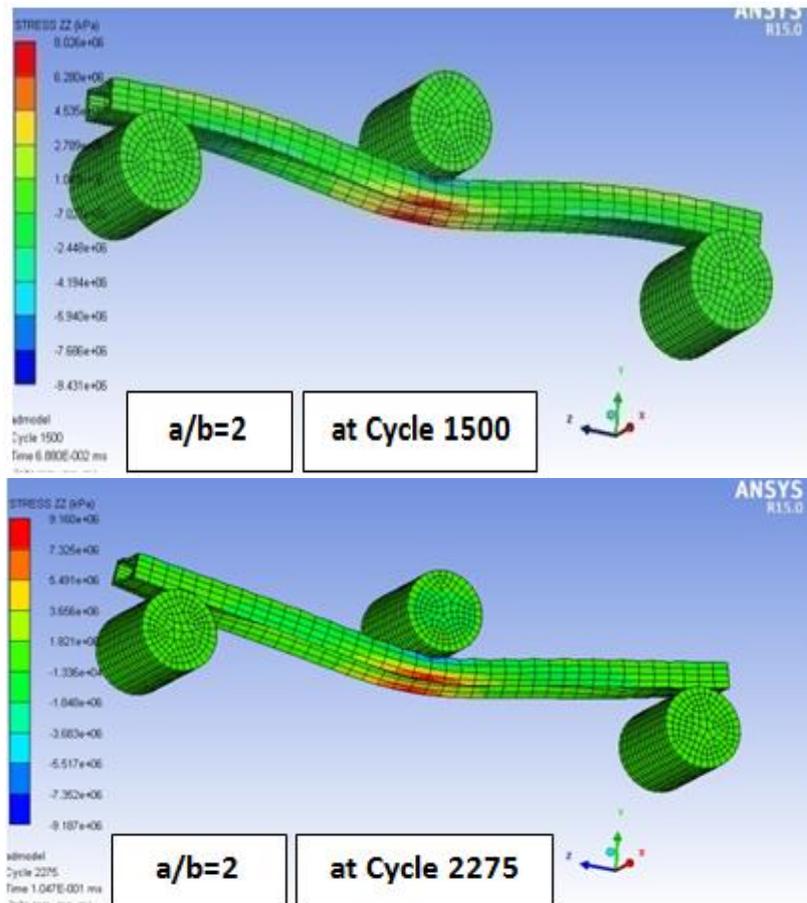


Figure 8: Back view of deformation of Hybrid/epoxy- Al_2O_3 of rectangular cross-sectional area $a/b=2$ of specimen under test at different cycle

The deformation occurred during different time and cycle of bending load variation. A different view showed in Fig. 9 below of rectangular

cross-sectional area with $a/b=2$ at different number of cycle.

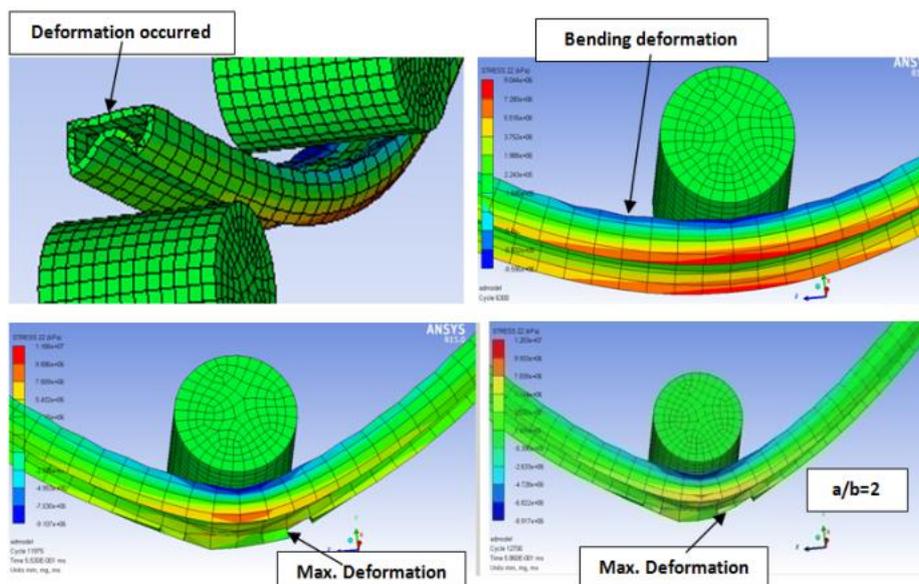


Figure 9: Stress deformation examples of specimens without cut-out at time (0.0678 ms) and with cut-out at time (0.2086 ms) under tensile test

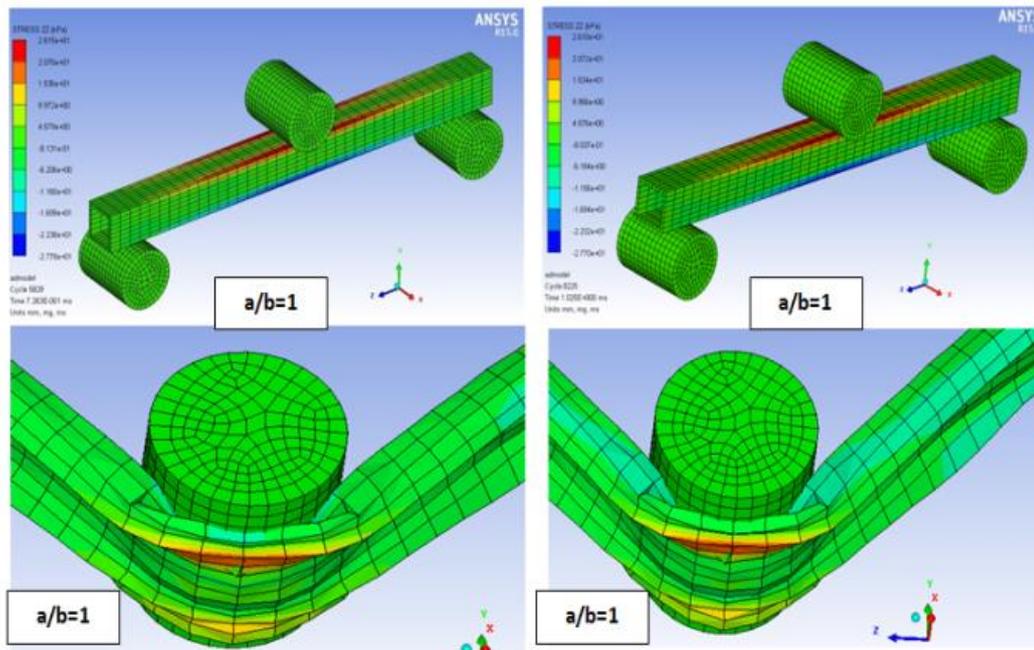


Figure 10: Back view of deformation of Hybrid/epoxy- Al_2O_3 of rectangular cross-sectional area $a/b=1$ of specimen under test at different cycle

The maximum value of the stress obtained is 443MPa and 469MPa of experimental and simulation result respectively at 55% volume fraction of 2 layers of Hybrid/Epoxy- Al_2O_3 specimen at $a/b=0.5$ as shown in Figure 11, while the minimum values of stress capacity are obtained for all specimens that have 50% volume fraction with $a/b=2, 1$ and 0.5 , but the smallest value is occurred at $a/b=2$. The difference in results due to cross-sectional area of the specimens have different shapes, hence the moment of inertia is different, this lead to maximum load capacity of bending has different value. Large different has been occurred in this figure between the simulation and experimental study for the samples made from the composite (Hybrid / Epoxy - alumina) of the two layer is caused by the high sensitivity of the impact of those materials with a low thickness to bear bending, The properties of the hybrid to the virtual library may show a difference in results because the composite is non-standard and is not in the list of materials available in the simulator designed for this purpose.

Figure 12 illustrates the variation of the maximum stress capacity of bending for all specimens with different volume fraction of 4 layers of composite materials. The maximum load capacity increased gradually from the lowest value of volume fraction in Hybrid/Epoxy- Al_2O_3 specimens until the highest value can notice in 55% volume fraction specimens then decreased gradually until reach to 60% volume fraction of specimens. The maximum value is obtained by 866 Mpa and 846 Mpa for simulation and experimental respectively at $a/b=0.5$ with 55% volume fraction of specimen.

The same behavior as before that showed in Figure 12, the curves shown in Figures 13 has peak point at 55% with $a/b=0.5$ and minimum value at 50% volume fraction with $a/b=2$. The maximum values obtained from above Figures are 1597 Mpa and 1557MPa for simulation and experimental results respectively of 8 layers hybrid/Epoxy- Al_2O_3 .

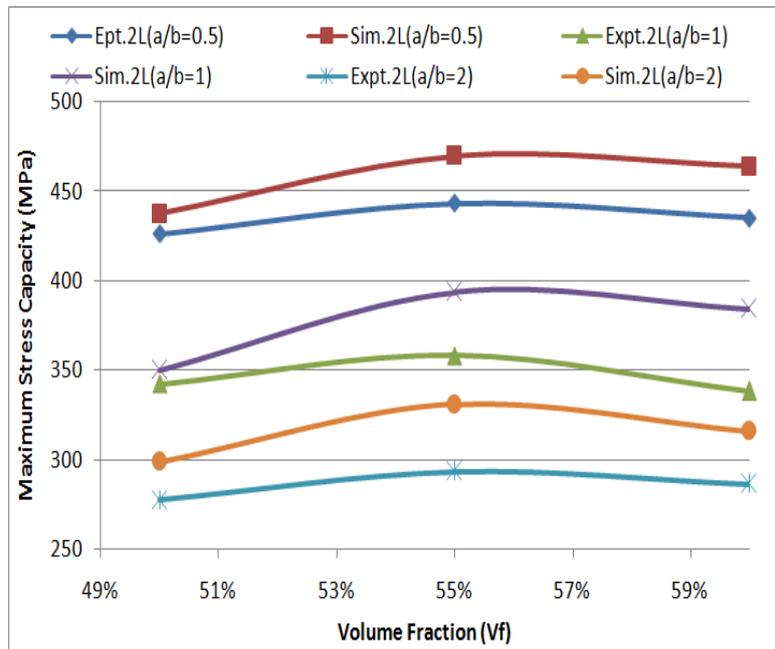


Figure 11: Volume fraction vs maximum stress capacity of 2 layers of Hybrid/Epoxy+Al₂O₃

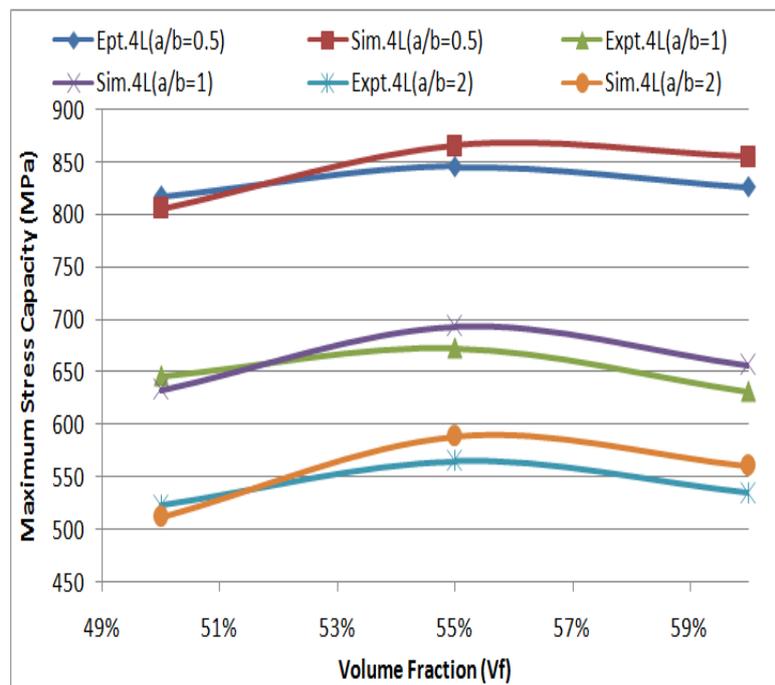


Figure 12: Volume fraction vs maximum stress capacity of 4 layers of Hybrid/Epoxy+ Al₂O₃

The same behavior as before that showed in Figure 12, the curves shown in Figures 13 has peak point at 55% with a/b=0.5 and minimum value at 50% volume fraction with a/b=2. The

maximum values obtained from above Figures are 1597 Mpa and 1557MPa for simulation and experimental results respectively of 8 layers hybrid/Epoxy- Al₂O₃.

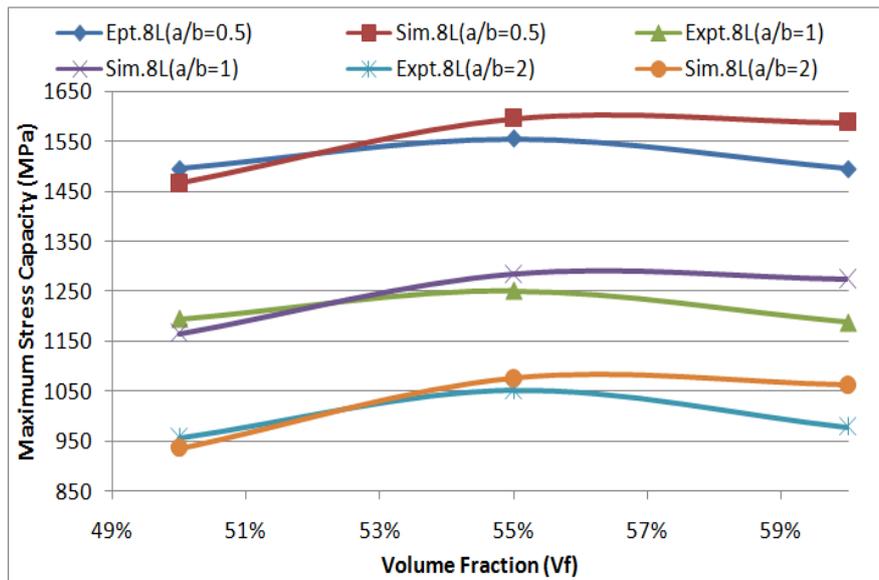


Figure 13: Volume fraction vs maximum stress capacity of 8 layers of Hybrid/Epoxy+Al₂O₃

The maximum load that the 55% volume fraction of composite specimens can carry it always more than other types of volume fractions (50% and 60%) of specimens and the maximum bending load it directly proportional to the number of layers. Also the variation of thickness to high ratio (a/b) of the specimen also effects on the values of maximum stress capacity. The 8 layers (8L) of specimens always can carry the highest load capacity comparing with other specimens that made from two layers (2L) and four layers (4L). Experimental and simulation differences have listed in Table 3. with maximum error 11.98 %, 7.93, 4.67% at specimen Sp.2#6, Sp.8#9 and Sp.4#9 for

specimens that have 2, 8 and 4 layers respectively. Also the Increasing ratio of stress capacity for specimens have 4 to 2 layers (4/2) and 8 to 4 (8/4) for experimental results have maximum value with increasing by 48.19% and 46.84% at (Sp.4#8/Sp.2#4) and (Sp.8#6/Sp.4#6) respectively.

The difference in the results obtained from the output samples are subject to the tests form by applying vertical force on the samples where it is known that the section of the form changes the moment of inertia and consequently change the amount of the maximum load of samples pregnant when exposed to external stresses.

Table 3 Increasing ratio of load capacity with layers ratio.

Volume fraction V _f	Width/ High Ratio (a/b)	Specimen No. 2Layers	Error % Expt. Sim.	Specimen No. 4Layers	Error % Expt. Sim.	Increasing ratio of stress capacity 4/2 Expt	Specimen No.	Error % Expt. Sim.	Increasing ratio of stress capacity 8/4 Expt
50%	0.5	Sp.2#1	2.56	Sp.4#1	-1.48	47.92	Sp.8#1	-2.03	45.36
55%	0.5	Sp.2#2	5.64	Sp.4#2	2.29	47.64	Sp.8#2	2.51	45.65
60%	0.5	Sp.2#3	6.21	Sp.4#3	3.33	47.37	Sp.8#3	5.85	44.75
50%	1	Sp.2#4	2.23	Sp.4#4	-2.11	47.09	Sp.8#4	-2.56	45.95
55%	1	Sp.2#5	9.02	Sp.4#5	3.02	46.81	Sp.8#5	2.58	46.24
60%	1	Sp.2#6	11.98	Sp.4#6	3.80	46.52	Sp.8#6	6.75	46.84
50%	2	Sp.2#7	7.20	Sp.4#7	-2.25	47.09	Sp.8#7	-2.36	45.36
55%	2	Sp.2#8	11.43	Sp.4#8	3.99	48.19	Sp.8#8	2.23	46.30
60%	2	Sp.2#9	9.38	Sp.4#9	4.67	46.52	Sp.8#9	7.93	45.36

Practical results have shown from Table 3, the increase by bending pregnancy with the number of layers for each sample where the results showed that the maximum increasing was by 48.3% of a class of samples (4/2) and 50% for

samples with a layer (8/4). The difference in the results obtained from the output samples are subject to the tests form and way to shed the vertical force on the samples where it is known that the section of the form changes the moment

of inertia and consequently change the amount of the maximum load of samples pregnant when exposed to external stresses. For the theoretical side, the same behavior in the practical side in the form of curves with an acceptable error rate where the properties of the materials used in this research of multi layers of hybrid / Epoxy- Al_2O_3 with different volume fraction as a factor also showed that at 55% . This difference is the result of the fact that known mechanical properties (tensile, compression, strength) are strongest at this volume fraction ratio and gradually decrease by increasing or decreasing by 55%.

In general, a composite would consist of a reinforcing fiber which is the strongest and stiffest component, embedded in a continuous matrix. The main functions of the matrix are to transmit externally applied loads to the fiber and to protect the latter from external mechanical damage. Fiber volume fraction is one of the most important factors controlling the strength, stiffness and many other mechanical properties of the composites.

5. Conclusion

It was found:-

- 1- The maximum load of specimens increased with increasing number of layers from 2L to 8L.
- 2- The results also identified that the maximum load capacity by 55% volume fraction and $a/b=0.5$ of all composite specimens was highest from the others types of (50% and 60%) volume fractions and ($a/b=1$ and $a/b=2$).
- 3- The Increasing ratio of stress capacity for specimens have 4 to 2 layers (4/2) and 8 to 4 (8/4) for experimental results have maximum value with increasing by 48.19% and 46.84% at (Sp.4#8/Sp.2#4) and (Sp.8#6/Sp.4#6) respectively.
- 4- The maximum differences of experimental and simulation errors were obtained by 11.98 %, 7.93, 4.67% at specimen Sp.2#6, Sp.8#9 and Sp.4#9 for specimens that have 2, 8 and 4 layers respectively.
- 5- The Increasing ratio of stress capacity for specimens have 4 to 2 layers (4/2) and 8 to 4 (8/4) for experimental results have maximum value with increasing by 48.19% and 46.84% at (Sp.4#8/Sp.2#4) and (Sp.8#6/Sp.4#6) respectively.

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