A COMPARATIVE STUDY OF WOODEN AND HYRBID COMPOSITE CROSSARMS OF AN ELECTRIC UTILITY POLE

By

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Abstract

Comparative study of Wooden and Hybrid composites Crossarms of an Electric Utility pole

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Most of the cross arms in the country are currently made from wood. Wood, although easily accessible, has its own defects. Environmental effects which includes the expansion and contraction of wood over the years which will disrupt its structural integrity, the presence of termites and other insects which dig into wood and destroy it from the inside, Materials wastage when it comes to improving the structural strength by increasing the cross-sectional thickness and height

The replacement of wood with composites seems like a logical idea and also a solution to most of the problems. The applications of composites in our day to day life has increased exponentially over the past decade. They have proven to be a great substitute to other materials in terms of longevity, structural integrity, and manufacturing. The current study deals with a comparative analysis of hybrid composites as substitutes to wood in cross arms on a utility poles. The present study is done by applying Finite Element Analysis to both wooden and hybrid composites cross arms by considering real-time geometry of the object.

Results from Static structural analysis of the wood such as Spotted gum, southern pine, and western red cedar have been considered from an existing paper. A very detailed analysis of the hybrid cross arms section has been done in ANSYS Workbench V17 software. The models were created using CATIA V5 software. A set of characteristics like Mass per unit length, stresses, Factor of safety and deformation were used to compare the cross arms using the simulated results. The position different composites in hybrid combination of the fibers have been done in different fashions. The composites used here were E-glass, Carbon fiber, S-Glass.

The result was then used to determine an optimized design for the study.

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Chapter 1

1.1 Introduction to cross arms

Cross arms are beams mounted on a utility pole normally used to hold on to the ceramic bearings and pins upon which the wires are held on. Most of the forces acting on the utility poles act on the cross arms which are intron transmitted to the pole in contact. The most popular material used nowadays to produce cross arms is wood. Normally because of its availability and its inexpensiveness.

Figure 1.1.1

In most cases, Cross arms come in two varieties. Tangential Cross arms and dead-end cross. A tangential cross arm is normally connected on both sides of the pin and thus is affected in both directions with strong opposing forces which in turn produce a torque about the center of the cross arm.

Figure 1.1.2a

Figure 1.1.2b

A dead-end assembly cross arms are fewer in number than a regular tangential cross arm since they are assembled only towards the ends of the transmission lines generally to ground the poles. The forces on this cross arm are in one direction and generally the highest along its longitudinal direction.

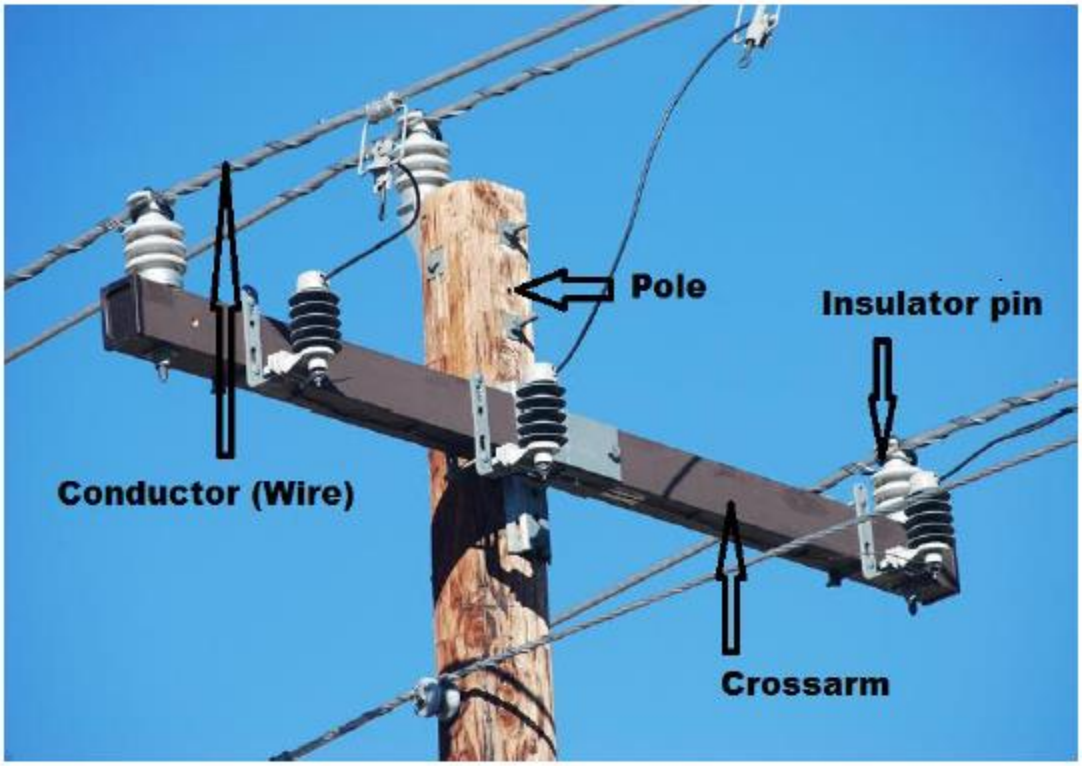


Figure 1.1.3

A Cross arms has variations in terms of the positions and connections of the pins on it. For this study purpose, a regular double pin cross arm has been analyzed.

1.2 Back ground

About 20 different kinds of wood were studied and based on their structural characteristics, a group of three were selected. The results taken from a previous including the present one accounted to carry sufficient information to perform a comparative analysis against the Composite Cross arms that are of essence here. A total of variation of thickness, variation of fiber positions, architecture and compositions were considered for the study. A total of 150 simulations were performed and results were plotted and tabulated in MATLAB and Excel respectively.

1.3 Motivation

The need for lighter equipment has been an everlasting problem since the industrial age. The electric poles and cross arms are made of wood, concrete and steel which are a lot heavy and cause major issues when they are moved to remote areas. Composites are a wonderful alternative for such an issue. With the need for electricity increasing around the world, even in the remote corner, the need for better management of electric poles and lines have increased. Composites provide a wonderful solution.

The idea behind a hybrid combination of composites come from a simple idea of combining positive traits together to form a better bond. The stiffness of carbon fiber, S-glass and E-glass are combined in different ratios to provide better structural characteristics in the cross arms. A comparative study of deformation, Maximum stress, cost of material and safety factors are introduced and studied.

1.4 Objective

The objective behind this study is to compare and correlate results obtained from analysis of hybrid composites vs wood. The selection of the best design for a wooden cross arm has been inducted from a preexisting study whereas the design of composites arms is varied with the design parameters.

The results are then studied to conclude the best combination of fiber and to introduce an alternative design of cross arms which is optimized to achieve best possible result.

1.5 Composites

The basic definition of a composite is that a composite is a material which is composed of two or more distinct phases. Thus, a composite is heterogeneous. Along the same lines, Fibrous composites (the ones used in this study) are martials in which one phase acts as a reinforcement of a second phase. The second phase is called matrix. The challenge is to combine fibers and the matrix to form the most efficient material for the intended application. [14]

Each layer is called a lamina, a group of them are called laminae. When laminae are stacked upon each other in required angles, they form a laminate. A fiber can be oriented in any angle, the most prominent of them all are ±30, ±45, ± 60 and ± 90 degrees. Since a combination of 0° and 45° provides a longitudinal and shear stiffness, they were considered over the other angles.

A select version of laminae was taken. The position was such that the laminate was symmetrical which assured a balanced force acting on the body which will not be the case during an unsymmetrical laminate. [2]

Unsymmetrical laminate induces bending when axial load is applied which cause unnecessary stresses on the laminate.

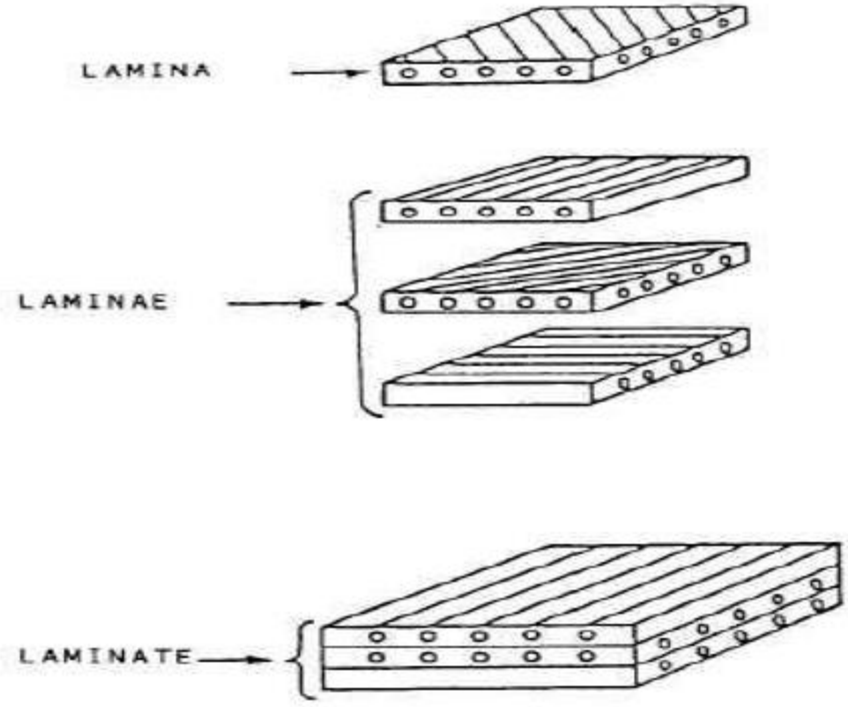


Figure 1.5.1

Advantages of Composites[3]

1. Composites are lighter when compared more the commonly used materials like steel.
2. They have high strength to weight ratio
3. Non- Carbon-based composites conduct electricity
4. Higher durability and life
5. Good structural stability when compared to wood.
6. Manufacturing composites can promise a uniform structural integrity unlike wood, which might show variable characteristics depending on Temperature, humidity and type of wood.

Disadvantages of composites.

1. Expensive when compared to wood.
2. Manufacturing can be a bit tedious and expensive
3. The laminates might slip if the matrix between then is weak.
4. Damage and fatigue occurs internally which need to be examined by expensive instruments.

Chapter 2

Methodology

The existing geometry were modelled in CATIA V5. The dimensions of the washer and the pin were given a value that was assumed to be the best for the dimension of the beam. The material properties of wood were taken from an existing data after a thorough study of some literature.

The Geometry and properties were input in ANSYS V17 workbench. Loads were applied on the pin and the cross arm was bisected in to two sections. The mid-section of each half was then fixed, i.e. remote displacement was zero on six degrees of freedom.

Post processing was carried out in ANSYS. A variation in characteristics in normal stress, shear stress, deformation and factor of safety was plotted and tabulated for each of the composite cross arms and wood. A simple box type criterion was used to predict the failure mode of the Cross arm.

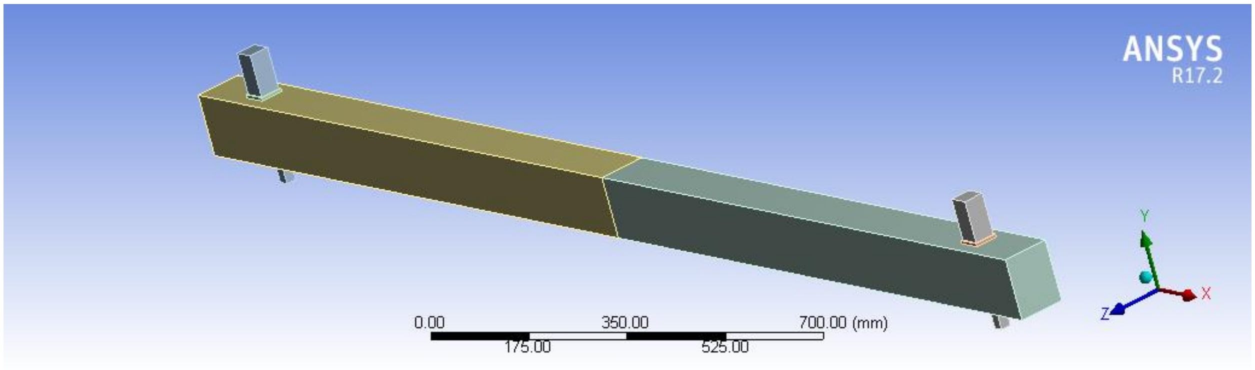


Figure 2.1

Chapter 3

3.1. Geometry used for wood. [15]

This Chapter gives the details of the geometry that has been used for the study. The geometry of beam is as per the dimensions used in industries today

Figure 3.1.1

Figure 3.1.1 shows a rendered image of cross arm, modeled on Catia V5 software. The assembly consists of a wooden beam, two porcelain pins and two washers. The dimensions taken for the present beam are shown in the following image.

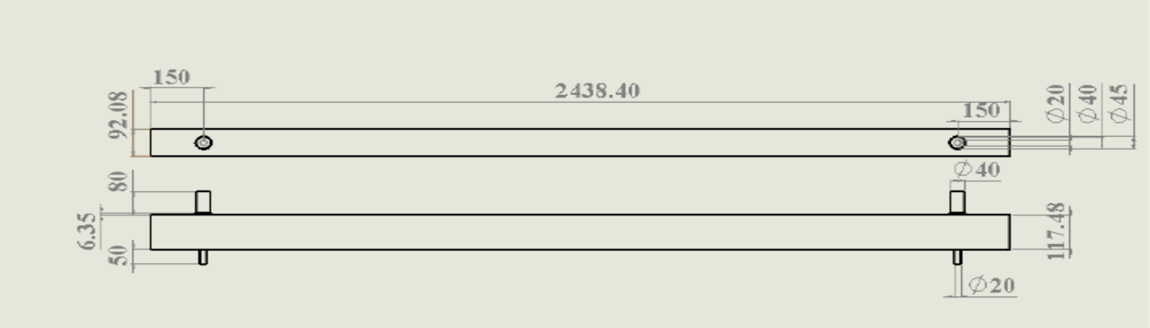


Figure 3.1.2 All dimensions are in mm

3.2 Geometry used for composite Cross arms

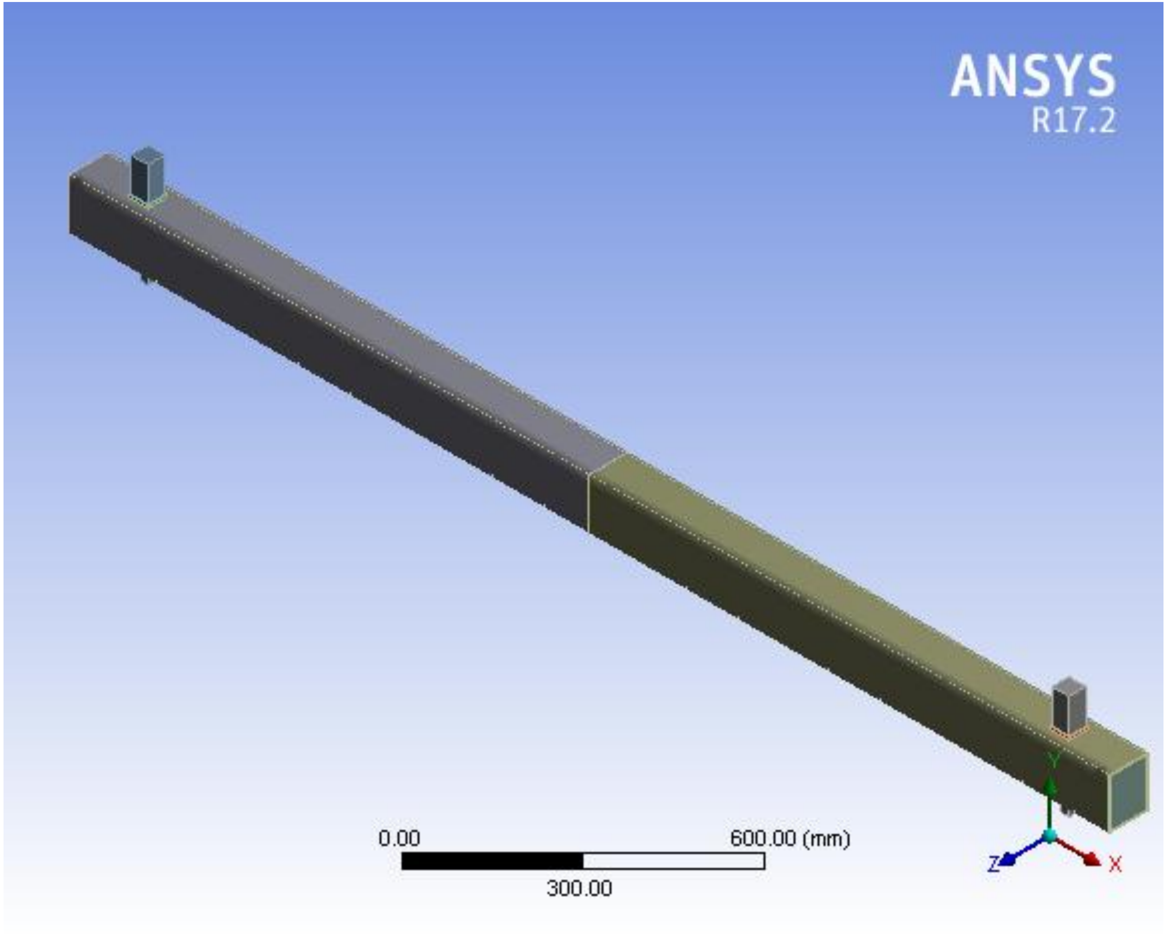


Figure 3.2.1

Figure 3.2.1 shows a rendered image of the cross arm, modeled in Catia V5 and analyzed in ANSYS. In case of composite cross arms, stacking procedure was carried on ANSYS for the hollow section. For this reason, all the components of the cross arm were modelled separately Catia V5 and then exported to ANSYS.

There are two types of stacking. One termed as ‘’ Square Stack’’, wherein all the surfaces of the hollow part was considered as on part and stacked. The other type was termed as ‘’Plate Stack’’ wherein the four sides of the hollow part were considered separately and stacking was done separately in each plate.

The former method was considered for this study.

A change on the geometry was assumed, it helped to analysis each ply precisely and separately on each face.

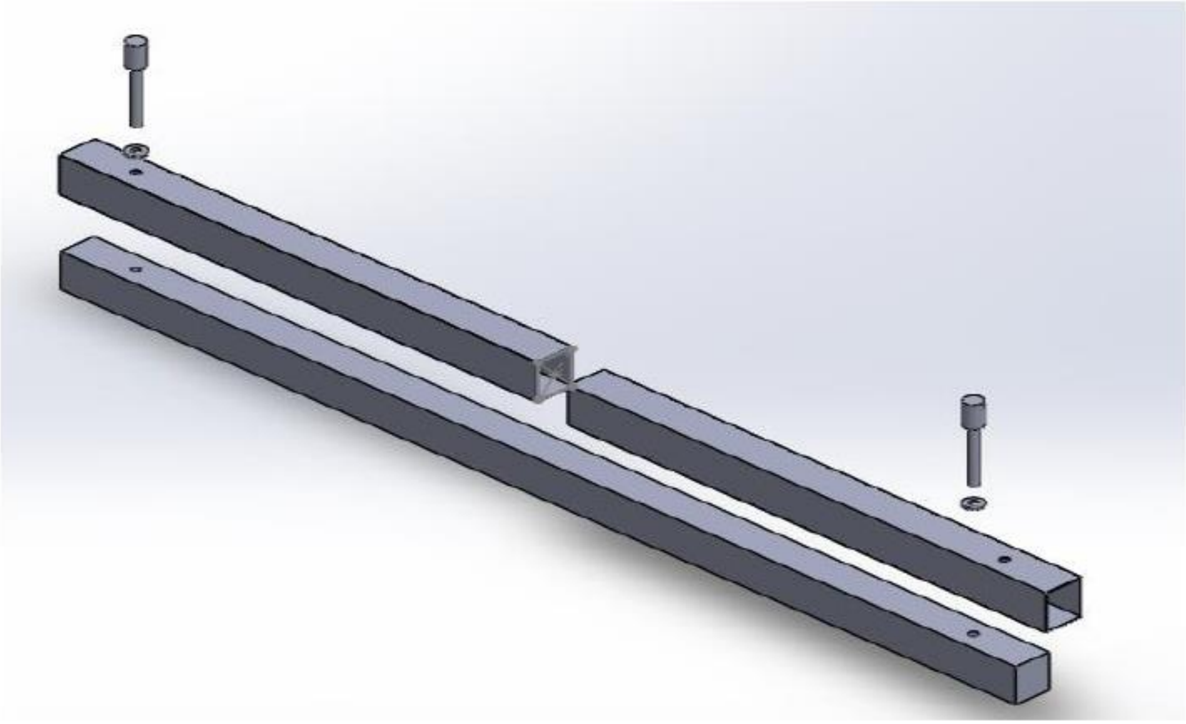


Figure 3.2.2

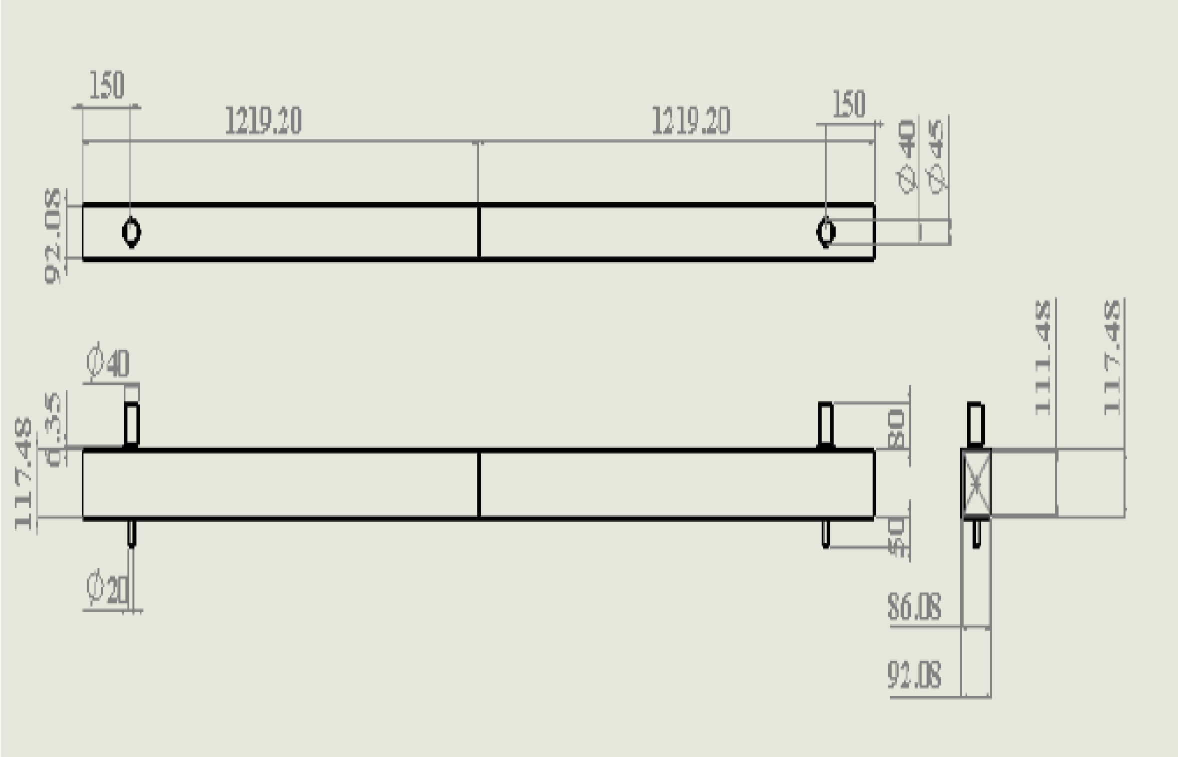


Figure 3.2.3

Figure 3.2.2 and 3.2.3 show a square stacked geometry of (92.08 X 117.48 X 2438.4) mm , with a 3mm thickness wall of the hollow part.

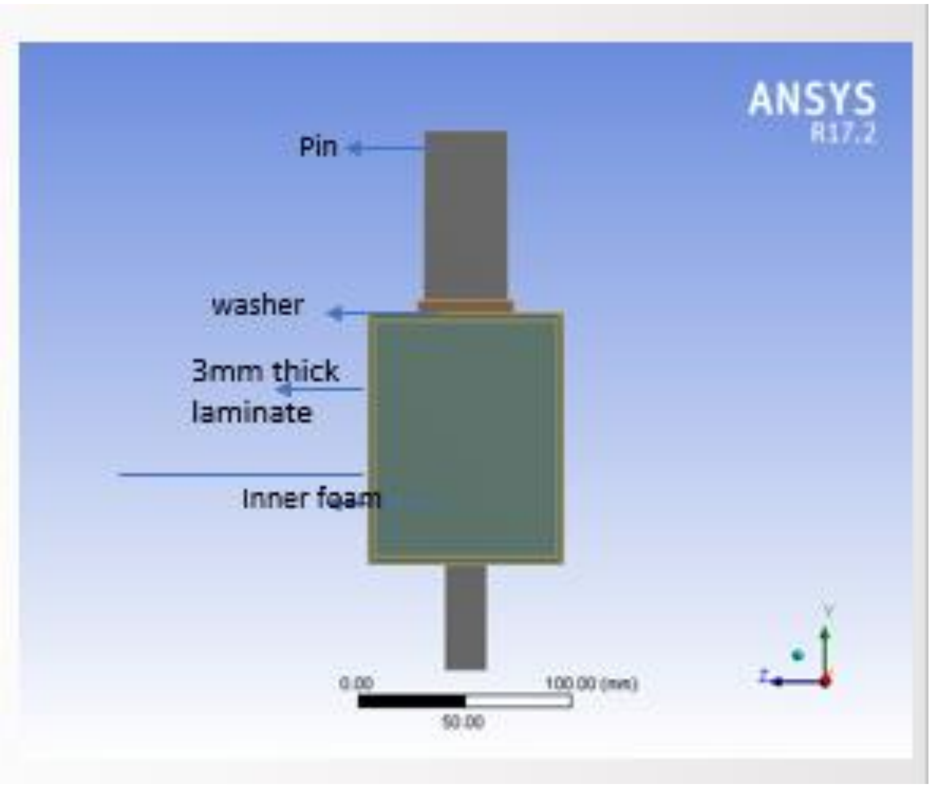


Figure 3.2.4

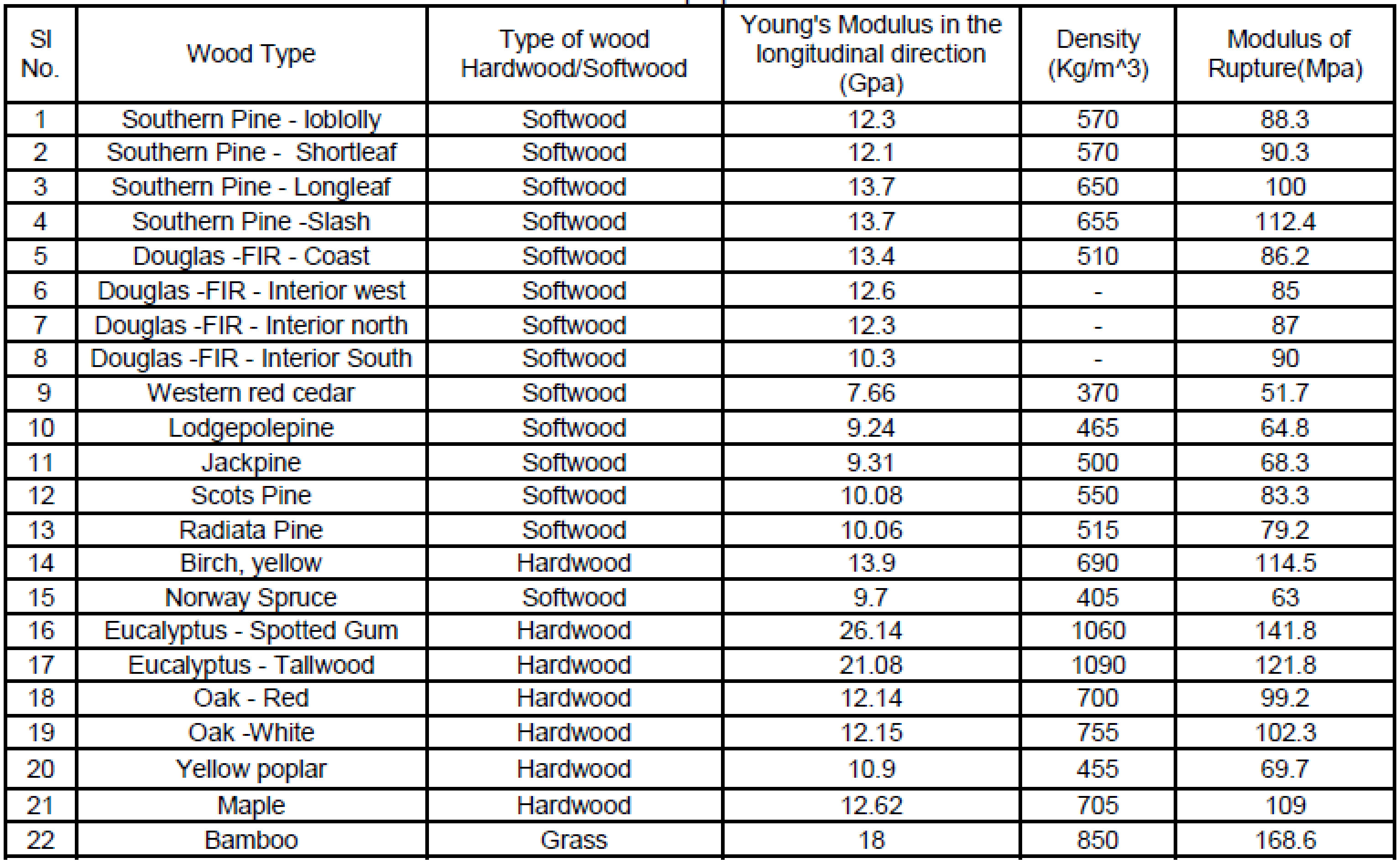
Figure 3.2.4 gives an idea of how the assembly will turn out to be and showcases the thickness of the cross arms with position of the foam, Porcelain pin and washer being used.

(92.08 X 117.48 X 2438.4) mm			
Thickness of the outer wall (mm)	Dimensions of foam (mm)		
	Length	Height	Width
3	2438.4	111.48	86.08
4	2438.4	109.48	84.08
6	2438.4	105.48	80.08

Table 3.2.1

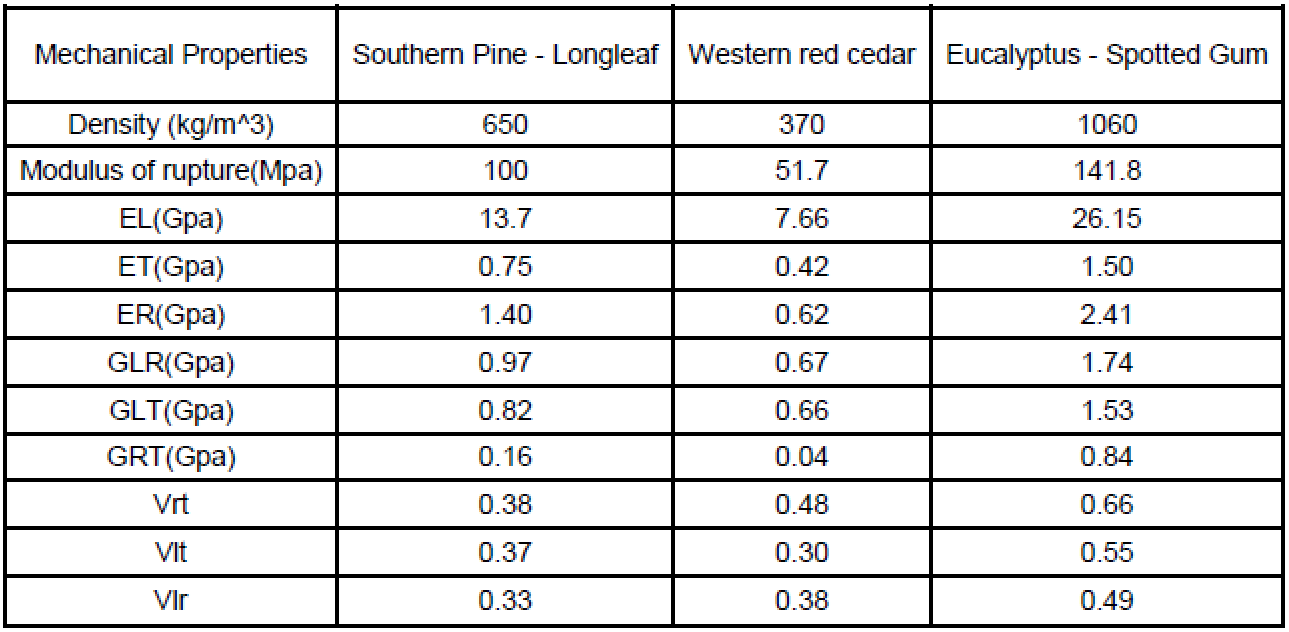
Chapter 4

4.1 Mechanical properties of wood



Sl No.	Wood Type	Type of wood Hardwood/Softwood	Young's Modulus in the longitudinal direction (Gpa)	Density (Kg/m^3)	Modulus of Rupture(Mpa)
1	Southern Pine - loblolly	Softwood	12.3	570	88.3
2	Southern Pine - Shortleaf	Softwood	12.1	570	90.3
3	Southern Pine - Longleaf	Softwood	13.7	650	100
4	Southern Pine -Slash	Softwood	13.7	655	112.4
5	Douglas -FIR - Coast	Softwood	13.4	510	86.2
6	Douglas -FIR - Interior west	Softwood	12.6	-	85
7	Douglas -FIR - Interior north	Softwood	12.3	-	87
8	Douglas -FIR - Interior South	Softwood	10.3	-	90
9	Western red cedar	Softwood	7.66	370	51.7
10	Lodgepolepine	Softwood	9.24	465	64.8
11	Jackpine	Softwood	9.31	500	68.3
12	Scots Pine	Softwood	10.08	550	83.3
13	Radiata Pine	Softwood	10.06	515	79.2
14	Birch, yellow	Hardwood	13.9	690	114.5
15	Norway Spruce	Softwood	9.7	405	63
16	Eucalyptus - Spotted Gum	Hardwood	26.14	1060	141.8
17	Eucalyptus - Tallwood	Hardwood	21.08	1090	121.8
18	Oak - Red	Hardwood	12.14	700	99.2
19	Oak -White	Hardwood	12.15	755	102.3
20	Yellow poplar	Hardwood	10.9	455	69.7
21	Maple	Hardwood	12.62	705	109
22	Bamboo	Grass	18	850	168.6

Table 4.1.1 [4][5][6]



Mechanical Properties	Southern Pine - Longleaf	Western red cedar	Eucalyptus - Spotted Gum
Density (kg/m^3)	650	370	1060
Modulus of rupture(Mpa)	100	51.7	141.8
EL(Gpa)	13.7	7.66	26.15
ET(Gpa)	0.75	0.42	1.50
ER(Gpa)	1.40	0.62	2.41
GLR(Gpa)	0.97	0.67	1.74
GLT(Gpa)	0.82	0.66	1.53
GRT(Gpa)	0.16	0.04	0.84
Vrt	0.38	0.48	0.66
Vlt	0.37	0.30	0.55
Vlr	0.33	0.38	0.49

Table 4.1.2[5][6]

Table 4.1.1 shows the different types of wood that has been used around the world and its mechanical properties. Table 4.1.2 shows the properties of wood that has been used in the study. The moisture content was 12 % for all the wood. Eucalyptus has the highest mechanical properties in terms of Young's modulus, density and modulus of rupture while western cedar has the least. This was the reason for their selection. Southern pine was chosen as its properties lies in between Eucalyptus and Red Cedar. Also, most of the cross arms are made out this material.

4.2 Properties of composites

Mechanical properties	**Epoxy E-glass (hollow part)**	**S2-glass (Hollow part)**	**Carbon Fiber UD (Hollow part)**
Density(Kg/m^3)	2000	2000	1490
Exy(Gpa)	13.3	12.4	19.1
Ex(Gpa)	45	50	121
Ey(Gpa)	10	8	8.6
Ez(Gpa)	10	8	8.6
Vxy	0.3	0.3	0.27
Vyz	0.4	0.4	0.4
Vxz	0.3	0.3	0.27
Gxy(Gpa)	5	5	4.7
Gyz(Gpa)	3.85	3.85	3.1
Gxz(Gpa)	5	5	4.7

Table 4.2.1[7][8]

Table 4.2.1 shows the properties of different composites that have been used for this research. About 60 % fiber concentration per volume was used for the composites.

4.3 Properties of Porcelain and Foam

The porcelain used is of a higher grade whose application could be found in electrical appliances. A high density closed cell rigid polyurethane foam is used which not only provides strength for the hollow surface but also does not let water seep in and affect the hollow surfaces.

Properties	Rigid polyurethane foam	Insulating porcelain
Density (kg/m^3)	77	2400
Young’s Modulus (Mpa)	26.2	110000
Poisson’s Ratio	0.37	0.17

Table 4.3.1[9][10][11]

Table 4.3.1 shows the properties of the foam and porcelain used in research

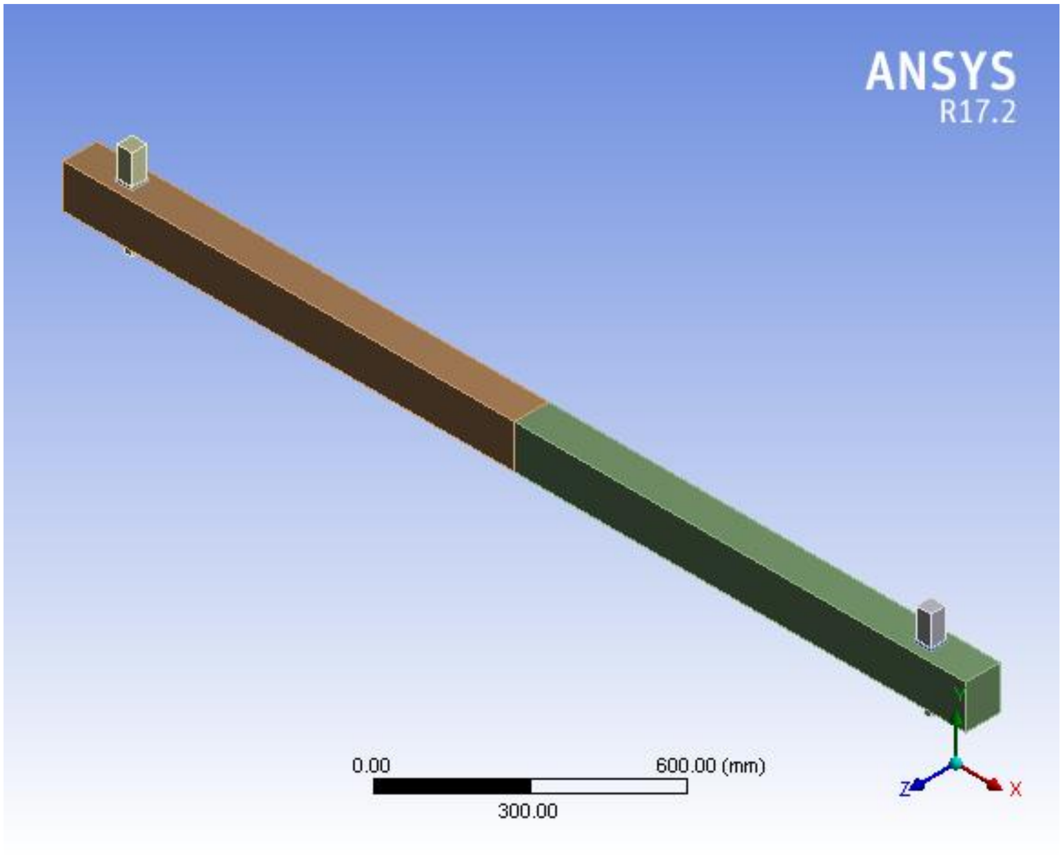


Figure 4.3.1

Figure 4.3.1 shows the coordinate axis considered for the material properties. Variation in this would result in disastrous results, hence a lot of attention must be paid when organizing the axis in leu with the properties of the materials taken.

In total, X axis is for transversal direction, Y axis for vertical direction and Z axis for longitudinal direction.

Chapter 5

Boundary Conditions [15]

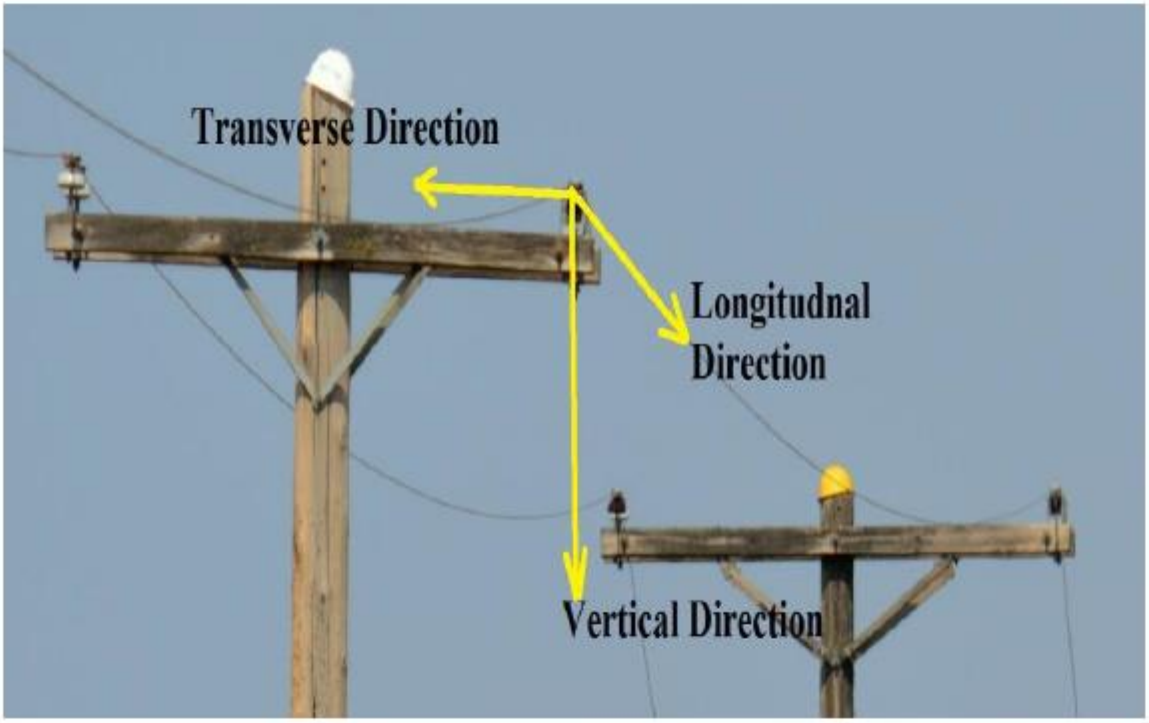


Figure 5.1.1

The forces applied in the Crossarms is shown in figure 5.1.1 namely longitudinal, transverse and vertical loads. The longitudinal loads run along the wires, the transverse loads run along the Crossarms, the vertical loads run perpendicular on the Crossarms. The longitudinal forces cancel each other out however, a force of 50N is still applied on the Crossarms pin due to the differential torque. The vertical loads were calculated according to the NESC Standards for 1-inch Ice around 7/16 strength steel with a span of 120 feet between two poles.

The transverse load was taken around 1500 N

Calculations:

Vertical Load – 2.18 lbf/ft.

Load for 120 feet – 120 X 2.18 = 261.6 lbf/ft. = 1164 N

For Design purpose the load is considered to be 1200 N

From the manual transverse load is 1.25 times the vertical load.

Thus, Transversal load = 1500 N

Final Loads	
Type of Loads	Loads Acting (N)
Longitudinal	1500
Vertical	1200
Transversal	50

Table 5.1.1

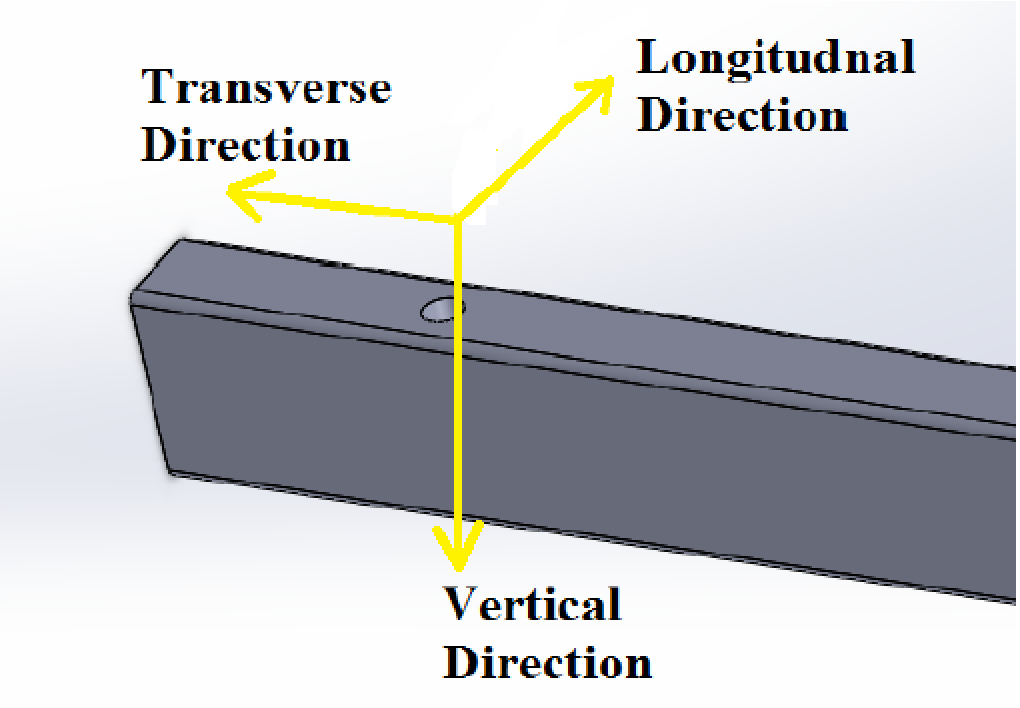


Figure 5.1.2

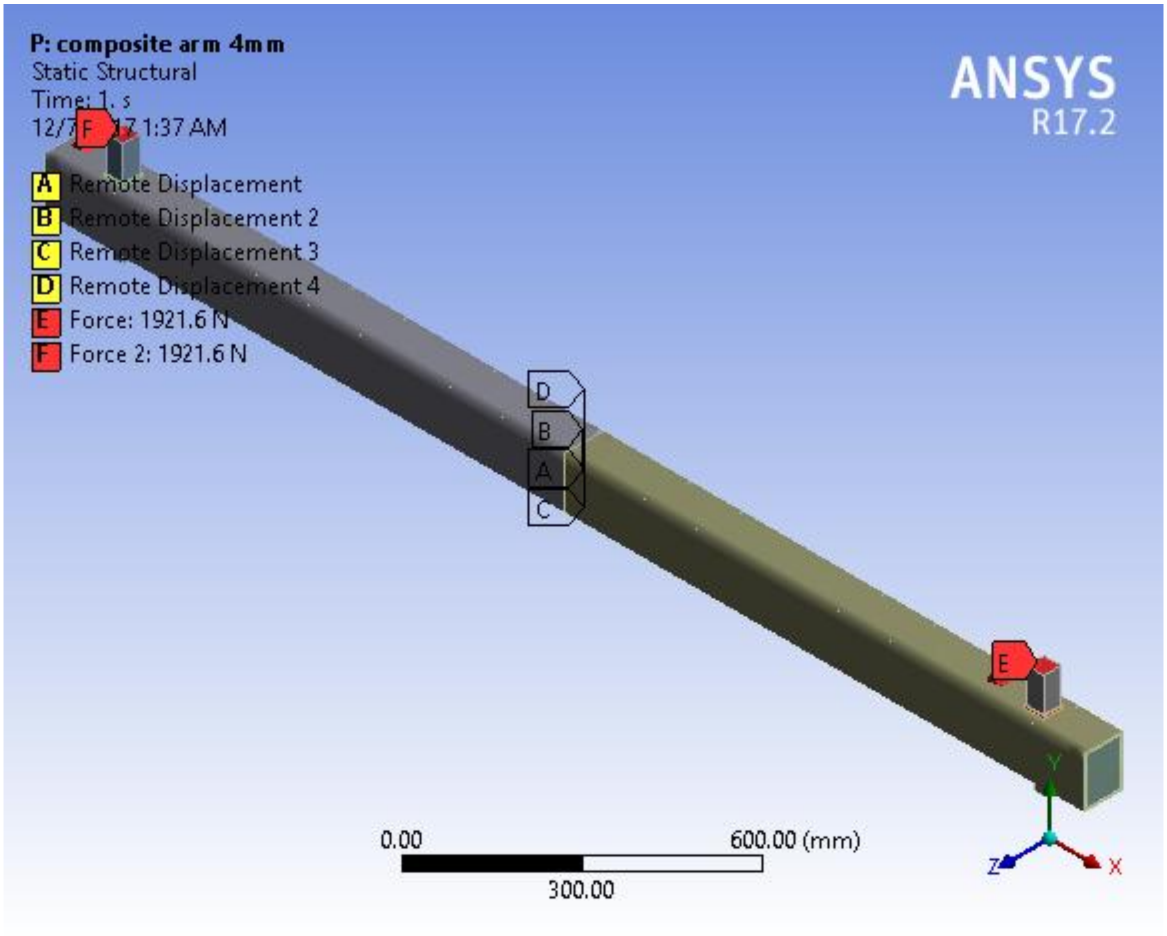


Figure 5.1.3

The forces acting on the poles were taken to be the same for both the wooden and hybrid composite Crossarms for the comparative analysis. Remote displacement was applied in the central face to avoid any unnecessary motion. This fixes all the six degrees of freedom to zero.

The central face of both the wooden and hybrid composite Crossarms underwent similar application of boundary conditions. All the analysis was done in ANSYS Workbench.

Chapter – 6

Meshing

For wood,

The mesh element size considered for this study was 20 mm for the Crossarms part, 8mm for pins. This particular element size was used for both wood and Composite beam. A body method called Hex dominant meshing with fine smoothing, fast transition and fine span angle was used.

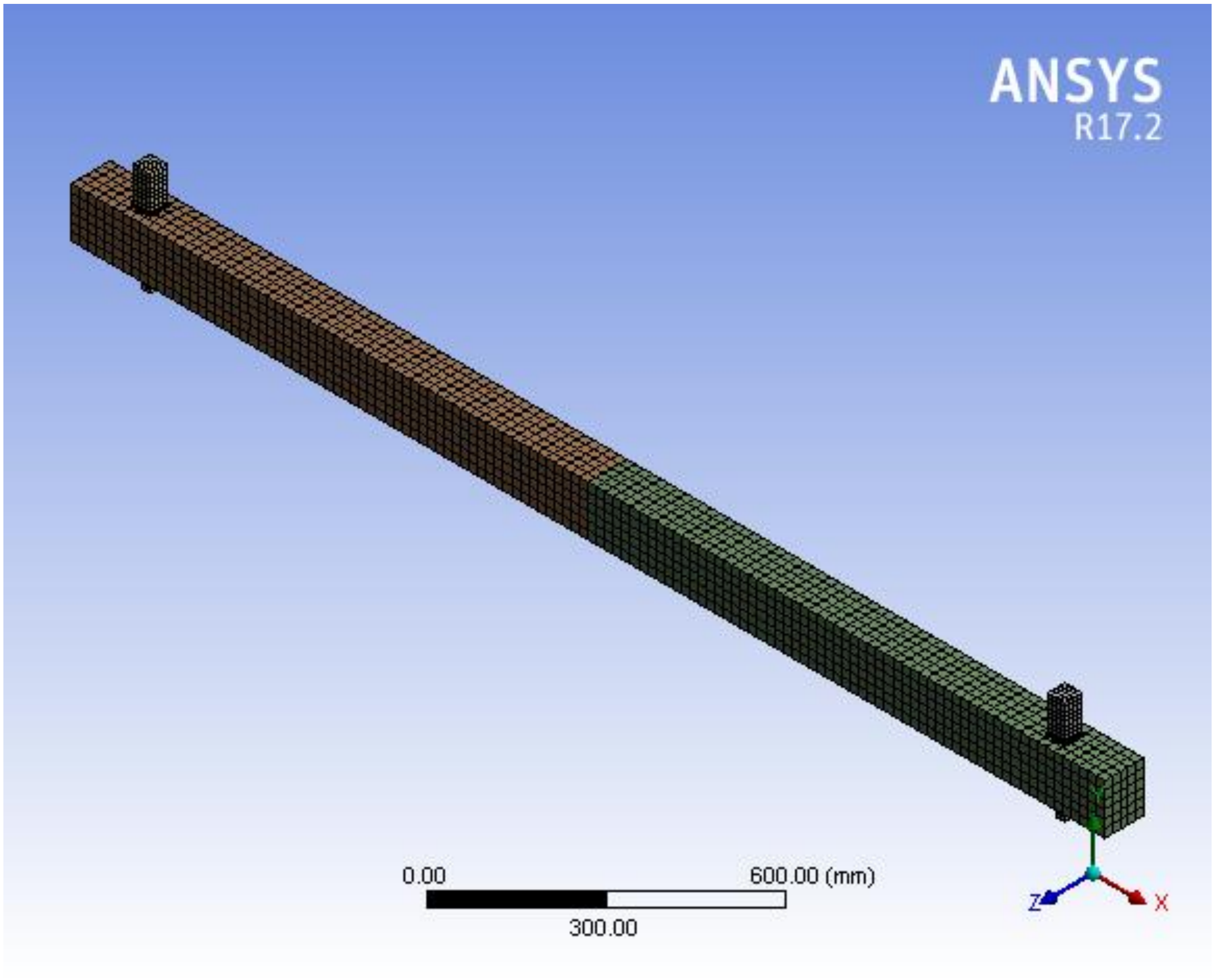


Figure 6.1.1

Figure 6.1.1 shows the element size and the type of element considered for wooden Crossarms. The number of elements used was 5542 and the number of nodes were 28358. The dimensions of wood 92.075 X 117.45 X 2438.4 (all dimension in mm).

For composites,

Meshing sizes of 20 mm was used for the Crossarms part. Fine smoothing, fast transition and fine span angle was used.

Material	Element sizes
Crossarms Composite part	20 mm
Crossarms foam	20 mm
Pin	8 mm
Washer	3 mm

Table 6.1.1

Dimensions (mm)	Thickness of wall (mm)	Number of elements	Number of nodes
92.075 X 117.475 X 2438.4	3	48442	74791
92.075 X 117.475 X 2438.4	4	48044	73369
92.075 X 117.475 X 2438.4	6	47776	71965

Table 6.1.2

Table 6.1.2 shows the number of elements used for different thickness of material used in the study with thickness varying from 3 mm to 6 mm.

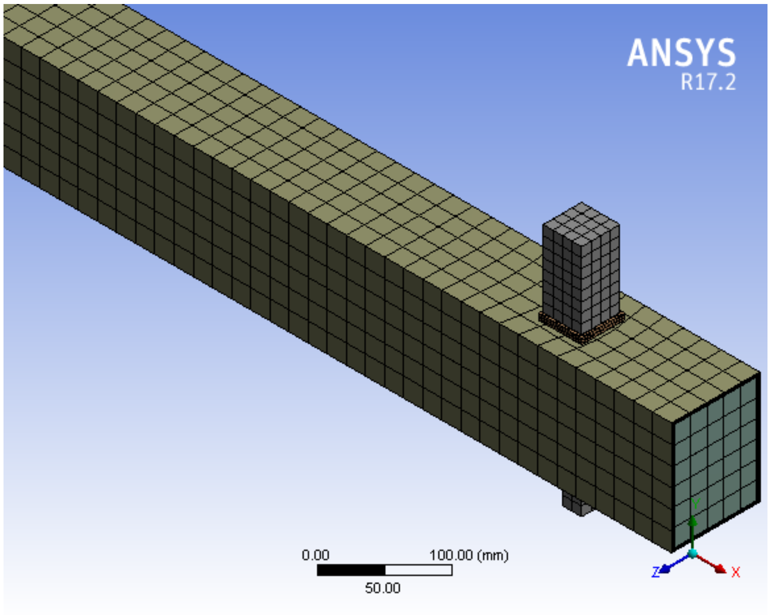


Figure 6.1.2

Chapter 7

7.1 Simulation and Design Parameters

In this chapter the various simulations carried out in this study have been explained as follows.

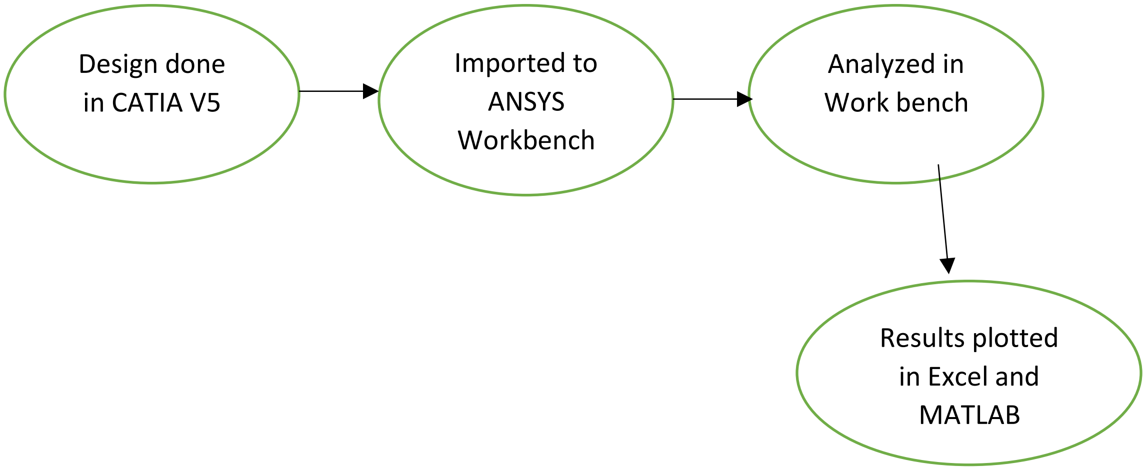


Figure 7.1.1

Simulations were carried out in ANSYS workbench 17. Static structural, ACP-pre and ACP-post work modules were used.

1. Pre-Processing – Input files containing geometry, material properties, boundary conditions and meshing are determined. This part is considered the most crucial during simulation since a minute variation would provide wide range of results.
2. Solution – The problem statement uses all the pre-processing function to establish a result.
3. Post-Processing – The results are plotted and results that are useful are then used such as total Deformation, Shear Stresses and Normal stress.

7.2 Variation in Design Parameters

For wood,

- Type 1 – Analysis conducted for wooden Crossarms made of Eucalyptus wood. The dimensions used were as noted in chapter 6 i.e. (92.075 x 117.475 x 2438.4) mm config. The normal Stress, Total deformation and factor of safety were calculated for this configuration.

- Type 2 - Analysis conducted for wooden Crossarms made of Southern pine wood. The dimensions used were as noted in chapter 6 i.e. (92.075 x 117.475 x 2438.4) mm config. The normal Stress, Total deformation and factor of safety were calculated for this configuration.

- Type 3 - Analysis conducted for wooden Crossarms made of Red Cedar wood. The dimensions used were as noted in chapter 6 i.e. (92.075 x 117.475 x 2438.4) mm config. The normal Stress, Total deformation and factor of safety were calculated for this configuration.

For Composite beams,

The following combinations and variations were considered to even consider the material a composite and a variation in thickness to identify the variation in Total Deformation, normal stress and factor of safety for a tangential force application on the beam was considered.

The variations are as follows

1. Variation in ply thickness
2. Variation in ply material
3. Variation in Orientation

7.2.1 Variation of ply thickness

No.	Number of plies	Thickness (mm)	Lamina Thickness (mm)
1	16	0.1875	3
2	16	0.25	4
3	16	0.375	6

Table 7.2.1.1[15]

- A variation in the thickness of ply was considered over the number of plies to provide a better strength along the layers of the composite.
- If the number of plies were let's say less than 8, to provide the 3mm thick lamina. each ply would be twice as thick. This would increase the material cost and introduce unwanted shear stress in the material.

7.2.2 Variation in ply material

The ply is set in the format shown in the figure below. The new material that is being introduced in the lamina is Carbon fiber UD and S2-Glass fiber. The percentage of combination of hybrid variety of material was changed for each model. Ply number 6 to ply number 11 were used a default variation ply and changed as material was being added or removed.

E glass	Ply 1
E glass	Ply 2
E glass	Ply 3
E glass	Ply 4
E glass	Ply 5
New material	Ply 6
New material	Ply 7
New material	Ply 8
New material	Ply 9
New material	Ply 10
New material	Ply 11
E glass	Ply 12
E glass	Ply 13
E glass	Ply 14
E glass	Ply 15
E glass	Ply 16

Table 7.2.2.1

E glass	Ply 1
E glass	Ply 2
E glass	Ply 3
E glass	Ply 4
E glass	Ply 5
E glass	Ply 6
New material	Ply 7
New material	Ply 8
New material	Ply 9
New material	Ply 10
E glass	Ply 11
E glass	Ply 12
E glass	Ply 13
E glass	Ply 14
E glass	Ply 15
E glass	Ply 16

Table 7.2.2.2

E glass	Ply 1
E glass	Ply 2
E glass	Ply 3
E glass	Ply 4
E glass	Ply 5
E glass	Ply 6
E glass	Ply 7
New material	Ply 8
New material	Ply 9
E glass	Ply 10
E glass	Ply 11
E glass	Ply 12
E glass	Ply 13
E glass	Ply 14
E glass	Ply 15
E glass	Ply 16

Table 7.2.2.3

E glass	Ply 1
E glass	Ply 2
E glass	Ply 3
E glass	Ply 4
E glass	Ply 5
E glass	Ply 6
E glass	Ply 7
E glass	Ply 8
E glass	Ply 9
E glass	Ply 10
E glass	Ply 11
E glass	Ply 12
E glass	Ply 13
E glass	Ply 14
E glass	Ply 15
E glass	Ply 16

Table 7.2.2.4

Table 7.2.2.1 – 7.2.2.4 show the variation of ply material used in the study. The number of layers of foreign material was varied symmetrically to make sure there are no extra stresses internally that would deform the component.

7.2.3 Variation in Orientation

The variation of orientation was carried out in the form of 45-degree changes in the angles. The introduction of 45 ° was to reduce the shear stresses that are prevalent due to torsional stress.

The orientation is as follows.

Ply number	Ply Orientation			
1	0°	0°	0°	0°
2	0°	0°	0°	0°
3	0°	0°	0°	0°
4	0°	0°	0°	0°
5	0°	0°	0°	0°
6	0°	0°	0°	-45°
7	0°	0°	45°	45°
8	0°	-45°	-45°	-45°
9	0°	45°	45°	45°
10	0°	0°	-45°	-45°
11	0°	0°	0°	45°
12	0°	0°	0°	0°
13	0°	0°	0°	0°
14	0°	0°	0°	0°
15	0°	0°	0°	0°
16	0°	0°	0°	0°

Table 7.2.3.1

The combination of the various parameters mentioned above were in the following manner

Case 1 – 3mm thickness with varying ply material and ply angle.

Case 2 – 4mm thickness with varying ply material and ply angle.

Case 3 – 6mm thickness with varying ply material and ply angle.

It gives a total of about 12 simulations with different results in total deformations, Normal stress and Factor of safety.

Chapter 8

8.1 Numerical Results

The simulations run on ANSYS workbench 17 for the three cases of wood namely Eucalyptus, Southern pine and Red cedar has been tabulated and compared accordingly.

An idea as to how the analysis would show the result to be has been shown in the following figures. (taken for red Cedar)

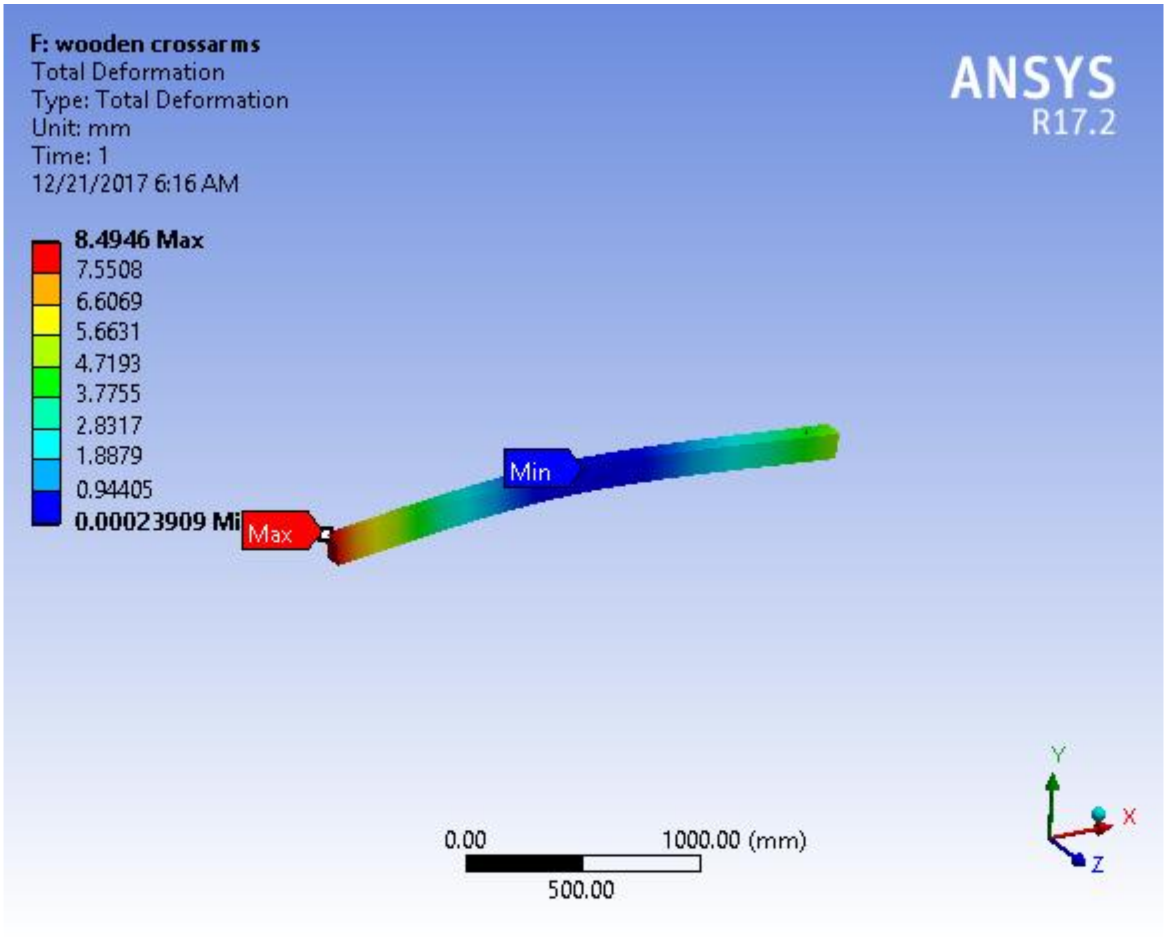


Figure 8.1.1

Total deformation of the Crossarms	8.49 mm

Red cedar was observed to have the highest deformation when compared to the other wood. A tabulated data would be shown in the following pages in this chapter.

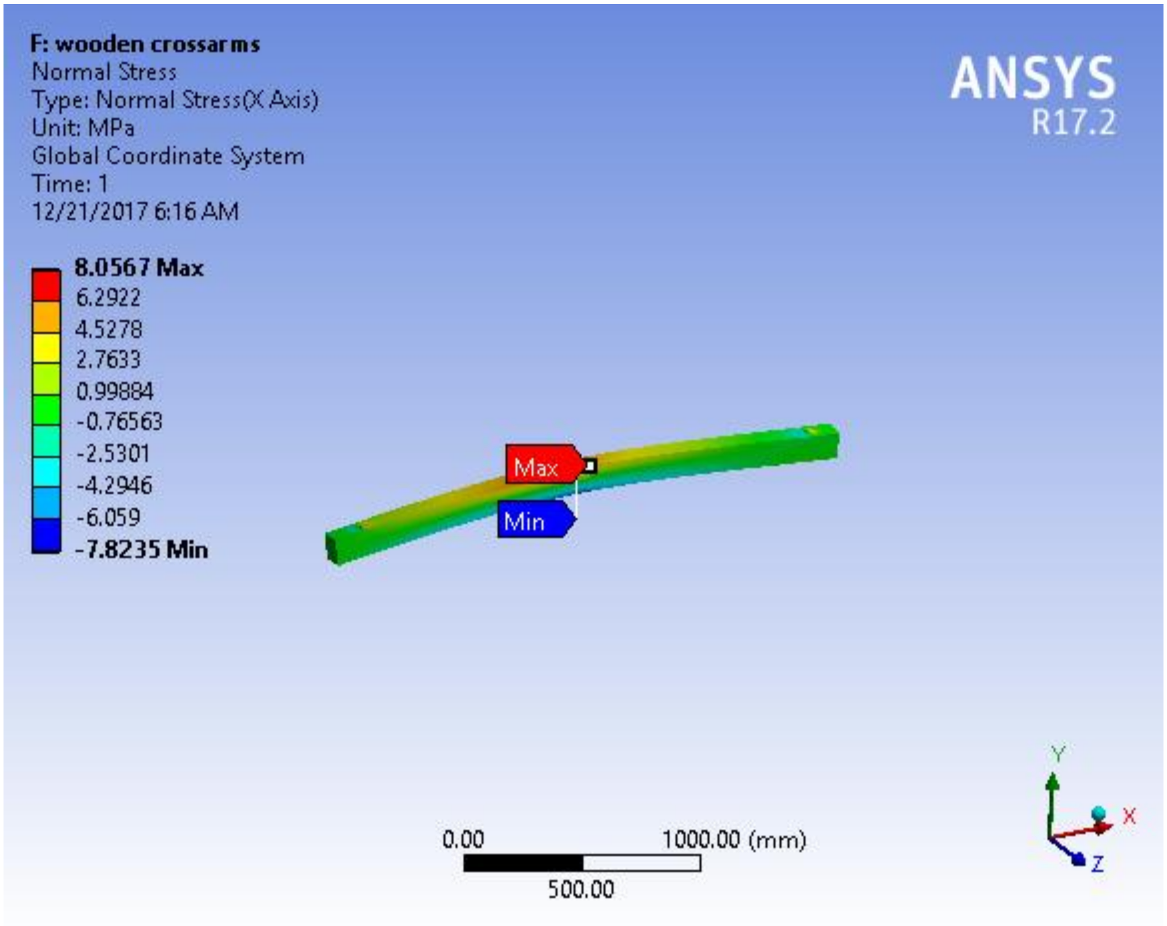


Figure 8.1.2

The maximum Normal stress on the cantilever part of the cross arm is around 8.057 Mpa. The values acquired via the usage of ANSYS are then compared with analytical data which are procured via calculations and procedure by hand or by MATLAB.

8.2 Results for Wooden Crossarms

Material	Deformation (mm)	Factor of Safety	Max-Normal Stress(Mpa)
Eucalyptus	2.45	6.34	22.35
Southern Pine	4.80	5.26	18.99
Red Cedar	8.49	2.67	19.33

Table 8.2.1

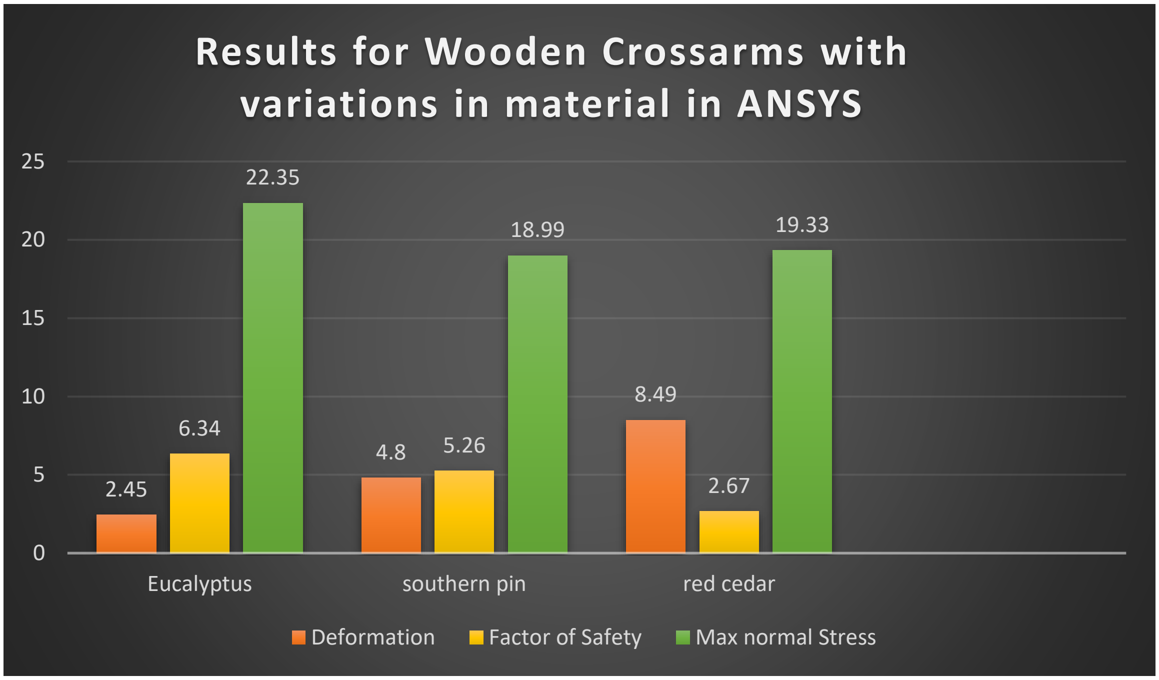


Figure 8.2.1

It can be seen from the plots that, the deformation is maximum in Red cedar, least in Eucalyptus and Southern pine lies in between.

The Normal stress is maximum for southern pine, Red Cedar is in second highest and that of Eucalyptus is at the least.

The Factor of safety is best for Eucalyptus, second best for Southern pine and least for Red Cedar.

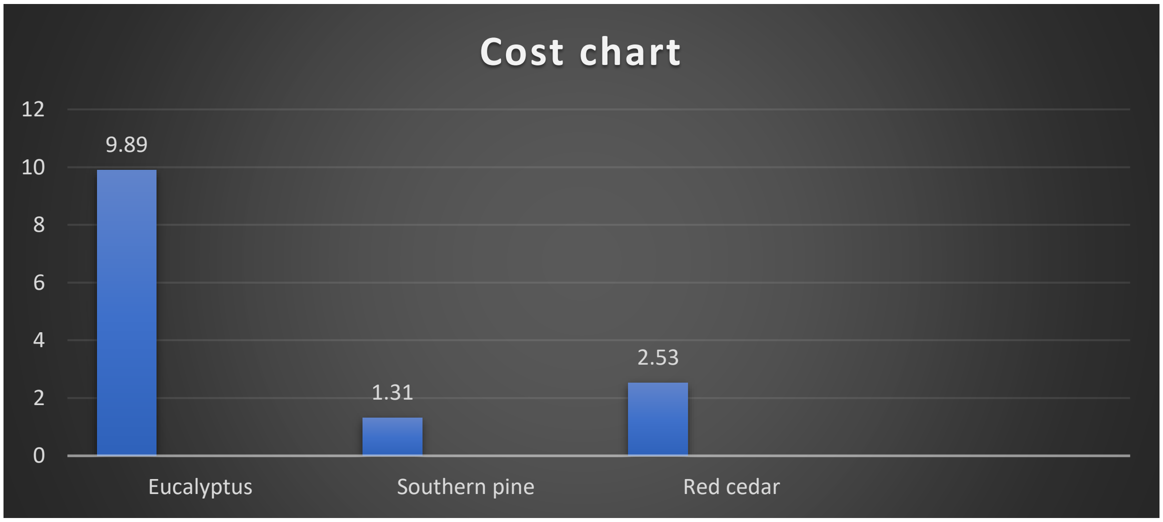


Figure 8.2.2

The cost of Eucalyptus is the highest followed by red cedar and southern pine. Clearly, Southern pine is the best suited option for making wooden Crossarms. This conclusion can be made after comparing the structural characteristics and making an industrial decision to keep the manufacturing economical.

8.3 Analytical for wooden Crossarms [13][8]

- Moment of inertia – I = $\frac{b\,\mathrm{d}^3}{12}$
- Considering half cross arm, deformation of cantilever was found using

  W = $\frac{2PL^3+3ML^2}{6EI}$
- The total deflection at the end of beam was W_t = W + $\left[\frac{PL+M}{EI}\right]L^2$
- The stress was calculated using σ = $\left[\frac{M}{I}\right]y_{max} + \frac{P}{A}$

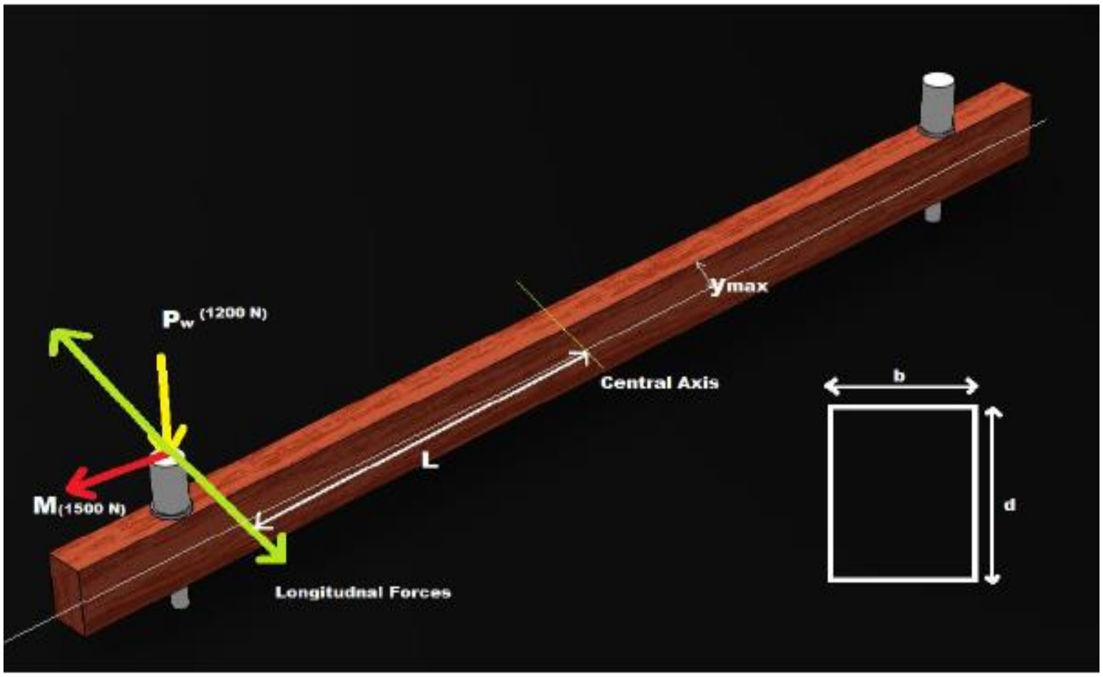


Figure 8.3.1

A comparative study between Analytical solution obtained from the above formula and the results obtained from ANSYS were compared. Although stress concentration areas were taken out of the pictures and the Crossarms were made into two cantilevers. The formula used here are the same for the cantilever beams in strength of materials.

Dimensions of the Crossarms - 92.075 x 117.475 x 2438.4 (mm)						
Type of wood	Analytical Values		Numerical Values		Error %	
	Deflection(mm)	Normal Stress(Mpa)	Deflection(mm)	Normal Stress(Mpa)	Deflection(mm)	Normal Stress(Mpa)
Southern pine	4.98	8.2	4.804	8.03	2 %	1.7%
Eucalyptus	2.6	8.2	2.456	7.97	2.7 %	1.7%
Red Cedar	8.9	8.2	8.4946	8.05	4%	1.7%

Table 8.3.1

Chapter 9

Results for Composite beams.

9.1 Analytical results for composite Crossarms

Just like the wooden Crossarms, the composite Crossarms were subjected to analytical calculations. The method used was that of a simple cantilever beam fixed at one end. The end term here signifies the center part of the composite which has be cut to facilitate such a design.

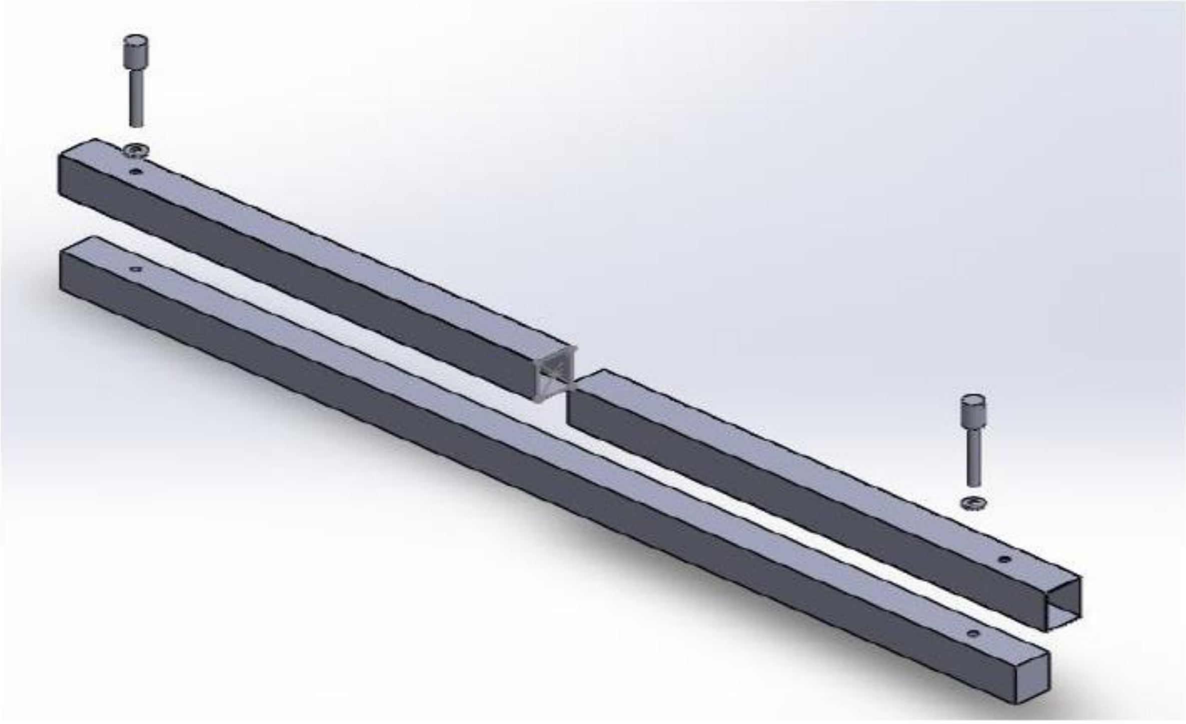


Figure 9.1.1

The formulations for calculating the normal stress and deformations for composite Crossarms are as follows [13]

- Moment of inertia – I = $\frac{bd^3-((b-2t)(d-2t)^2)}{12}$
- Considering half cross arm, deformation of cantilever was found using

  W = $\frac{2PL^3+3ML^2}{6EI}$

- The total deflection at the end of beam was W_t = W + $\left[\frac{PL+M}{EI}\right]L^2$

- The stress was calculated using $\sigma = \left[\frac{M}{I}\right] y_{max} + \frac{P}{A}$
- Where t is the thickness of the composite material. (shown in figure 9.1.2)

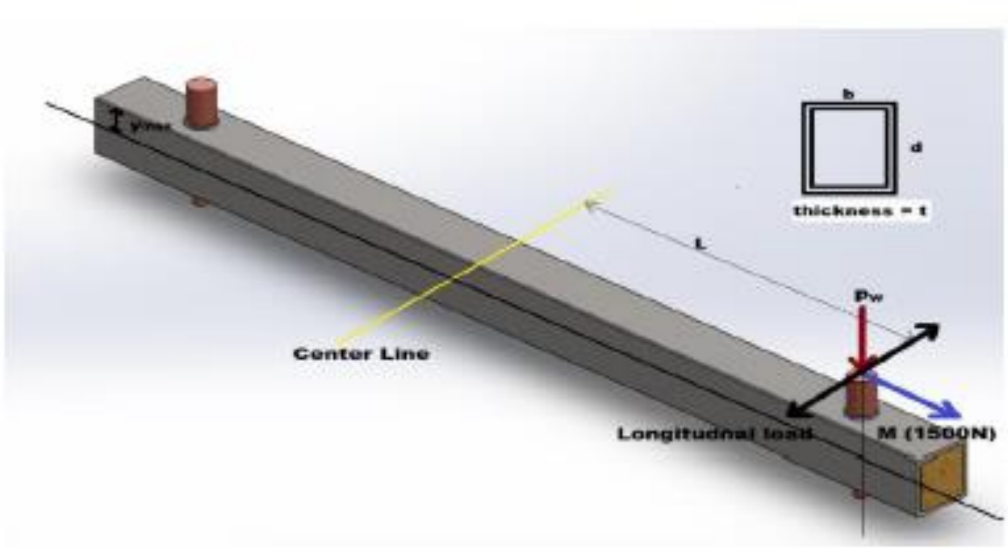


Figure 9.1.2

Since, the young’s modulus required in this case would be different, due to the fact that it is a combination of hybrid composites and foam in between.

We have used the rule of mixture[8] to find the young’s modulus required for each case.

- Effective young’s modulus – The effective young’s modulus of the cross arm along X direction changes due to the addition of ply from different materials
- Hence, rule of mixture was used to determine the effective young’s modulus of the cross arm.

$v1 (E1) + v2(E2) + v3(E3) + v4(E4)$

where v1, v2, v3, v4 are the volume fractions of the different fiber materials

- Effective tensile yield strength of composite

$= (\text{Л}_c * v_{cf}) + ((\text{Л}_g * v_{fg}) * E1/E2)$

Л_c = Yield strength of carbon

E1 = Young’s modulus of glass fiber

E2 = Young’s modulus of carbon fiber

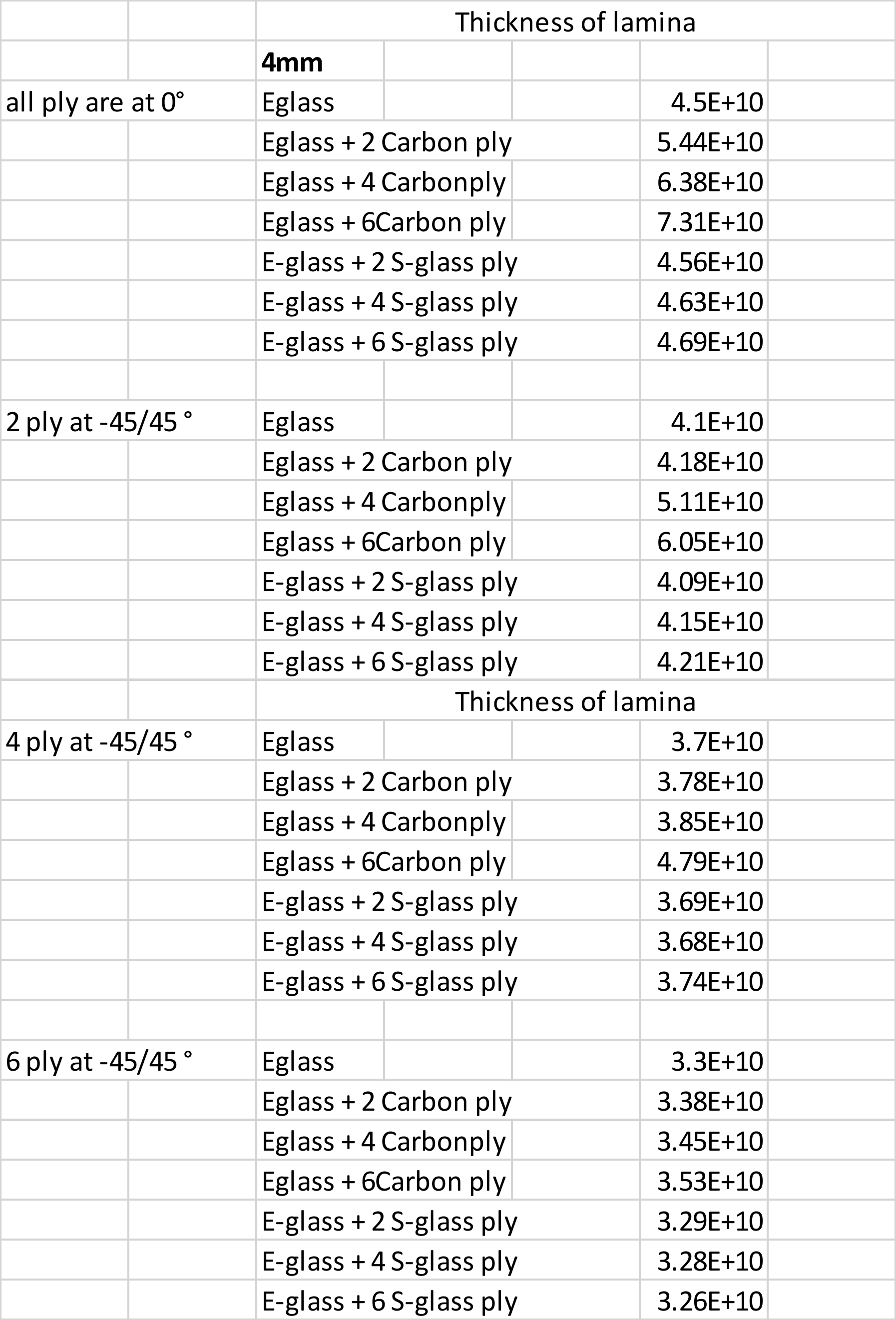
v = volume fractions of fiber with the entire cross arm materials.

The following tables will show the values of the new Young’s modulus. [8]

Ply orientation	Thickness of lamina	
	3mm	
all ply are at 0°	E-glass	4.5E+10
	E-glass + 2 Carbon ply	5.44E+10
	E-glass + 4 Carbonply	6.38E+10
	E-glass + 6Carbon ply	7.31E+10
	E-glass + 2 S-glass ply	4.56E+10
	E-glass + 4 S-glass ply	4.63E+10
	E-glass + 6 S-glass ply	4.69E+10
2 ply at -45/45 °	Eglass	4.1E+10
	Eglass + 2 Carbon ply	4.18E+10
	Eglass + 4 Carbonply	5.11E+10
	Eglass + 6Carbon ply	6.05E+10
	E-glass + 2 S-glass ply	4.09E+10
	E-glass + 4 S-glass ply	4.15E+10
	E-glass + 6 S-glass ply	4.21E+10

Ply orientation	Thickness of lamina	
4 ply at -45/45 °	Eglass	3.7E+10
	Eglass + 2 Carbon ply	3.78E+10
	Eglass + 4 Carbonply	3.85E+10
	Eglass + 6Carbon ply	4.79E+10
	E-glass + 2 S-glass ply	3.69E+10
	E-glass + 4 S-glass ply	3.68E+10
	E-glass + 6 S-glass ply	3.74E+10
6 ply at -45/45 °	Eglass	3.3E+10
	Eglass + 2 Carbon ply	3.38E+10
	Eglass + 4 Carbonply	3.45E+10
	Eglass + 6Carbon ply	3.53E+10
	E-glass + 2 S-glass ply	3.38E+10
	E-glass + 4 S-glass ply	3.28E+10
	E-glass + 6 S-glass ply	3.26E+10

Table 9.1.1 shows the new Young’s modulus for 3mm thick laminate



		Thickness of lamina				
		4mm				
all ply are at 0°		Eglass			4.5E+10	
		Eglass + 2 Carbon ply			5.44E+10	
		Eglass + 4 Carbonply			6.38E+10	
		Eglass + 6Carbon ply			7.31E+10	
		E-glass + 2 S-glass ply			4.56E+10	
		E-glass + 4 S-glass ply			4.63E+10	
		E-glass + 6 S-glass ply			4.69E+10	
2 ply at -45/45 °		Eglass			4.1E+10	
		Eglass + 2 Carbon ply			4.18E+10	
		Eglass + 4 Carbonply			5.11E+10	
		Eglass + 6Carbon ply			6.05E+10	
		E-glass + 2 S-glass ply			4.09E+10	
		E-glass + 4 S-glass ply			4.15E+10	
		E-glass + 6 S-glass ply			4.21E+10	
		Thickness of lamina				
4 ply at -45/45 °		Eglass			3.7E+10	
		Eglass + 2 Carbon ply			3.78E+10	
		Eglass + 4 Carbonply			3.85E+10	
		Eglass + 6Carbon ply			4.79E+10	
		E-glass + 2 S-glass ply			3.69E+10	
		E-glass + 4 S-glass ply			3.68E+10	
		E-glass + 6 S-glass ply			3.74E+10	
6 ply at -45/45 °		Eglass			3.3E+10	
		Eglass + 2 Carbon ply			3.38E+10	
		Eglass + 4 Carbonply			3.45E+10	
		Eglass + 6Carbon ply			3.53E+10	
		E-glass + 2 S-glass ply			3.29E+10	
		E-glass + 4 S-glass ply			3.28E+10	
		E-glass + 6 S-glass ply			3.26E+10	

Table 9.1.2 shows the new Young's modulus for the 4mm thick laminate

The Young's modulus is calculated along the longitudinal direction only since the bending stressing considered here only form against the longitudinal direction of the Crossarms.

		Thickness of lamina	
		6mm	
all ply are at 0°		Eglass	4.5E+10
		Eglass + 2 Carbon ply	5.44E+10
		Eglass + 4 Carbonply	6.38E+10
		Eglass + 6Carbon ply	7.31E+10
		E-glass + 2 S-glass ply	4.56E+10
		E-glass + 4 S-glass ply	4.63E+10
		E-glass + 6 S-glass ply	4.69E+10
2 ply at -45/45 °		Eglass	4.1E+10
		Eglass + 2 Carbon ply	4.18E+10
		Eglass + 4 Carbonply	5.11E+10
		Eglass + 6Carbon ply	6.05E+10
		E-glass + 2 S-glass ply	4.09E+10
		E-glass + 4 S-glass ply	4.15E+10
		E-glass + 6 S-glass ply	4.21E+10
		Thickness of lamina	
4 ply at -45/45 °		Eglass	3.7E+10
		Eglass + 2 Carbon ply	3.78E+10
		Eglass + 4 Carbonply	3.85E+10
		Eglass + 6Carbon ply	4.79E+10
		E-glass + 2 S-glass ply	3.69E+10
		E-glass + 4 S-glass ply	3.68E+10
		E-glass + 6 S-glass ply	3.74E+10
6 ply at -45/45 °		Eglass	3.3E+10
		Eglass + 2 Carbon ply	3.38E+10
		Eglass + 4 Carbonply	3.45E+10
		Eglass + 6Carbon ply	3.53E+10
		E-glass + 2 S-glass ply	3.29E+10
		E-glass + 4 S-glass ply	3.28E+10
		E-glass + 6 S-glass ply	3.26E+10

Table 9.1.3 shows the new Young’s modulus for the 6mm thick laminate

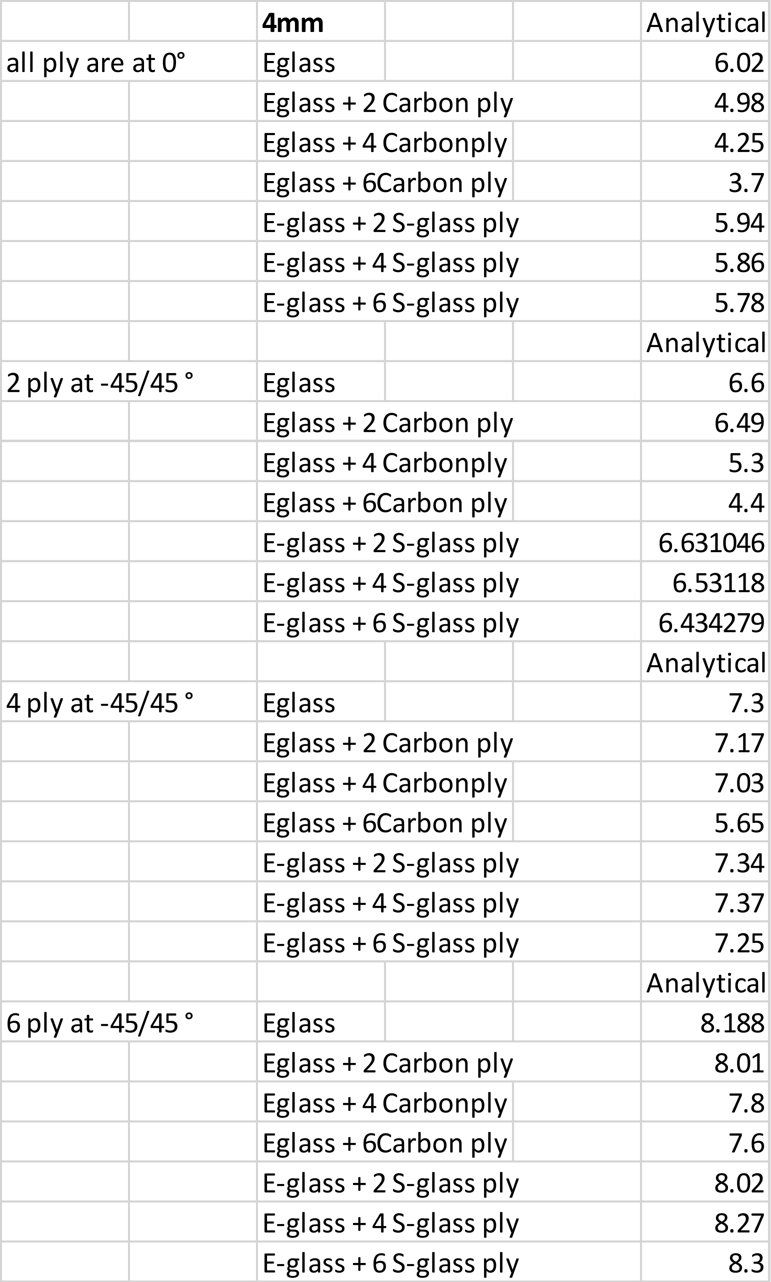
The analytical formulations used in this chapter were used to produce the following tabulations with values.

Case 1 – for 3mm thick laminate. Analytical value for deformation. (in mm)

	3mm	Analytical
all ply are at 0°	E-glass	7.7
	E-glass + 2 Carbon ply	6.4
	E-glass + 4 Carbonply	5.4
	E-glass + 6Carbon ply	4.7
	E-glass + 2 S-glass ply	7.67
	E-glass + 4 S-glass ply	7.57
	E-glass + 6 S-glass ply	7.47
		Analytical
2 ply at -45/45 °	Eglass	8.53
	Eglass + 2 Carbon ply	8.38
	Eglass + 4 Carbonply	6.8
	Eglass + 6Carbon ply	5.7
	E-glass + 2 S-glass ply	8.571052
	E-glass + 4 S-glass ply	8.44197
	E-glass + 6 S-glass ply	8.316718
		Analytical
4 ply at -45/45 °	Eglass	9.44
	Eglass + 2 Carbon ply	9.26
	Eglass + 4 Carbonply	9.09
	Eglass + 6Carbon ply	7.3
	E-glass + 2 S-glass ply	9.497574
	E-glass + 4 S-glass ply	9.533109
	E-glass + 6 S-glass ply	9.373692
		Analytical
6 ply at -45/45 °	Eglass	10.5
	Eglass + 2 Carbon ply	10.35
	Eglass + 4 Carbonply	10.13
	Eglass + 6Carbon ply	9.928
	E-glass + 2 S-glass ply	10.36898
	E-glass + 4 S-glass ply	10.69338
	E-glass + 6 S-glass ply	10.73844

Table 9.1.4 Analytical deformation values.

Case 2 – 4mm thick laminate. Analytical values for deformation (in mm)



	4mm	Analytical
all ply are at 0°	Eglass	6.02
	Eglass + 2 Carbon ply	4.98
	Eglass + 4 Carbonply	4.25
	Eglass + 6Carbon ply	3.7
	E-glass + 2 S-glass ply	5.94
	E-glass + 4 S-glass ply	5.86
	E-glass + 6 S-glass ply	5.78
		Analytical
2 ply at -45/45 °	Eglass	6.6
	Eglass + 2 Carbon ply	6.49
	Eglass + 4 Carbonply	5.3
	Eglass + 6Carbon ply	4.4
	E-glass + 2 S-glass ply	6.631046
	E-glass + 4 S-glass ply	6.53118
	E-glass + 6 S-glass ply	6.434279
		Analytical
4 ply at -45/45 °	Eglass	7.3
	Eglass + 2 Carbon ply	7.17
	Eglass + 4 Carbonply	7.03
	Eglass + 6Carbon ply	5.65
	E-glass + 2 S-glass ply	7.34
	E-glass + 4 S-glass ply	7.37
	E-glass + 6 S-glass ply	7.25
		Analytical
6 ply at -45/45 °	Eglass	8.188
	Eglass + 2 Carbon ply	8.01
	Eglass + 4 Carbonply	7.8
	Eglass + 6Carbon ply	7.6
	E-glass + 2 S-glass ply	8.02
	E-glass + 4 S-glass ply	8.27
	E-glass + 6 S-glass ply	8.3

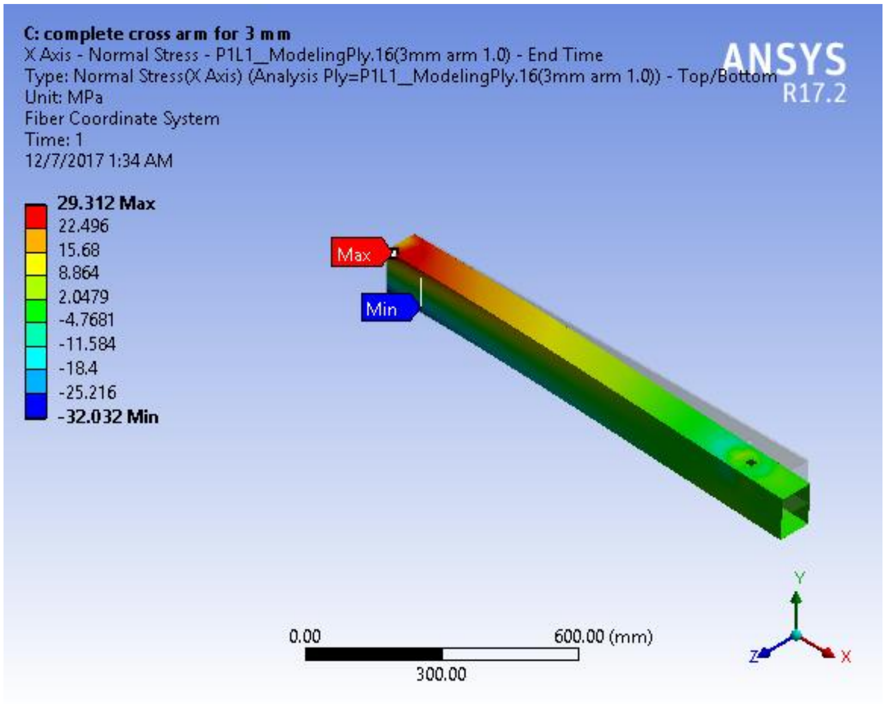
Table 9.1.5 deformation for 4mm thick laminate

Case 3 – 6mm thick laminate – analytical values for deformation (in mm)

6mm						Analytical
	all ply are at 0°		Eglass			4.27
			Eglass + 2 Carbon ply			3.53
			Eglass + 4 Carbonply			3.01
			Eglass + 6Carbon ply			2.62
			E-glass + 2 S-glass ply			4.21
			E-glass + 4 S-glass ply			4.15
			E-glass + 6 S-glass ply			4.1
						Analytical
	2 ply at -45/45 °		Eglass			4.68
			Eglass + 2 Carbon ply			4.61
			Eglass + 4 Carbonply			3.76
			Eglass + 6Carbon ply			3.178
			E-glass + 2 S-glass ply			4.7
			E-glass + 4 S-glass ply			4.63
			E-glass + 6 S-glass ply			5.56
						Analytical
	4 ply at -45/45 °		Eglass			5.18
			Eglass + 2 Carbon ply			5.08
			Eglass + 4 Carbonply			4.992
			Eglass + 6Carbon ply			4.01
			E-glass + 2 S-glass ply			5.213645
			E-glass + 4 S-glass ply			5.233152
			E-glass + 6 S-glass ply			5.145641
						Analytical
	6 ply at -45/45 °		Eglass			5.8
			Eglass + 2 Carbon ply			5.6
			Eglass + 4 Carbonply			5.56
			Eglass + 6Carbon ply			5.4
			E-glass + 2 S-glass ply			5.691996
			E-glass + 4 S-glass ply			5.870075
			E-glass + 6 S-glass ply			5.894815

Table 9.1.6 Deformation for 6mm laminate.

9.2 ANSYS Results / Simulations.



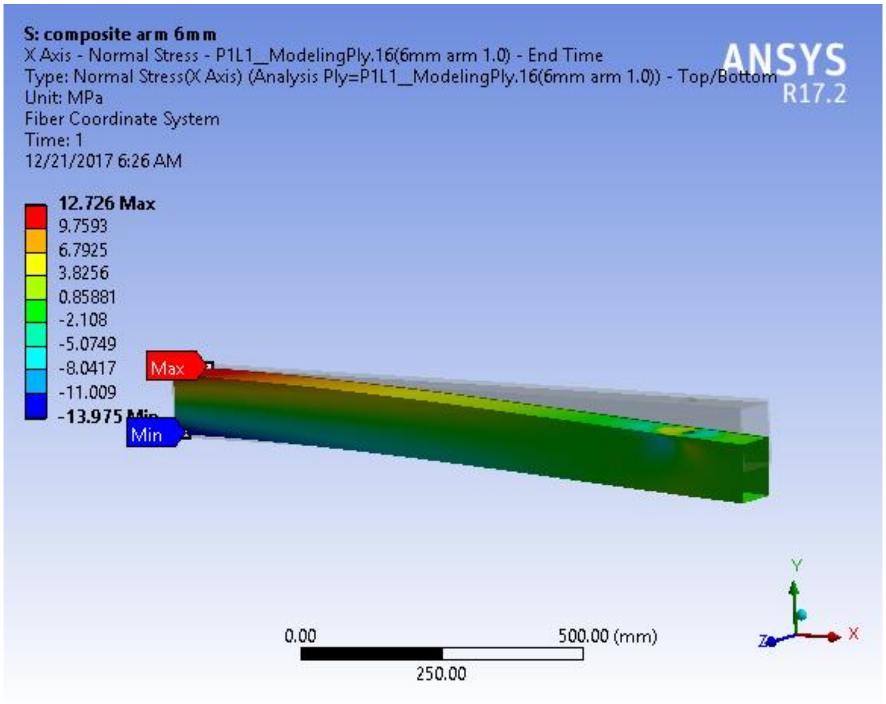


Figure 9.1.3 and Figure 9.1.4 represent an example of how the normal stress was calculated to compare with the analytical solution part. The cantilever also provides an easier evaluation by neglecting the shear stress as we are only calculating the normal stress due to bending forces.

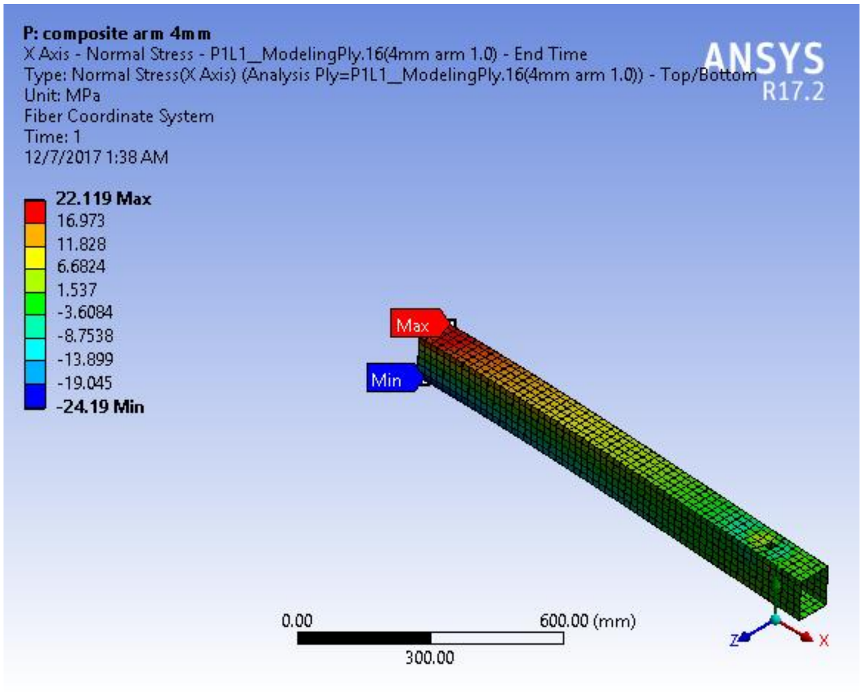


Figure 9.1.5

The figure shows both the meshing and the max normal stress on the cross and the position/location of the maximum stress.

The following tabulations contain results from numerous simulations based on the figures shown above. The next part of the chapter will also deal with a comparitive study between the analytical and numerical results, the benefits of hybrid fiber composition over homogenous fiber composition.

9.2.1 Deformation results for 3mm thick laminate.

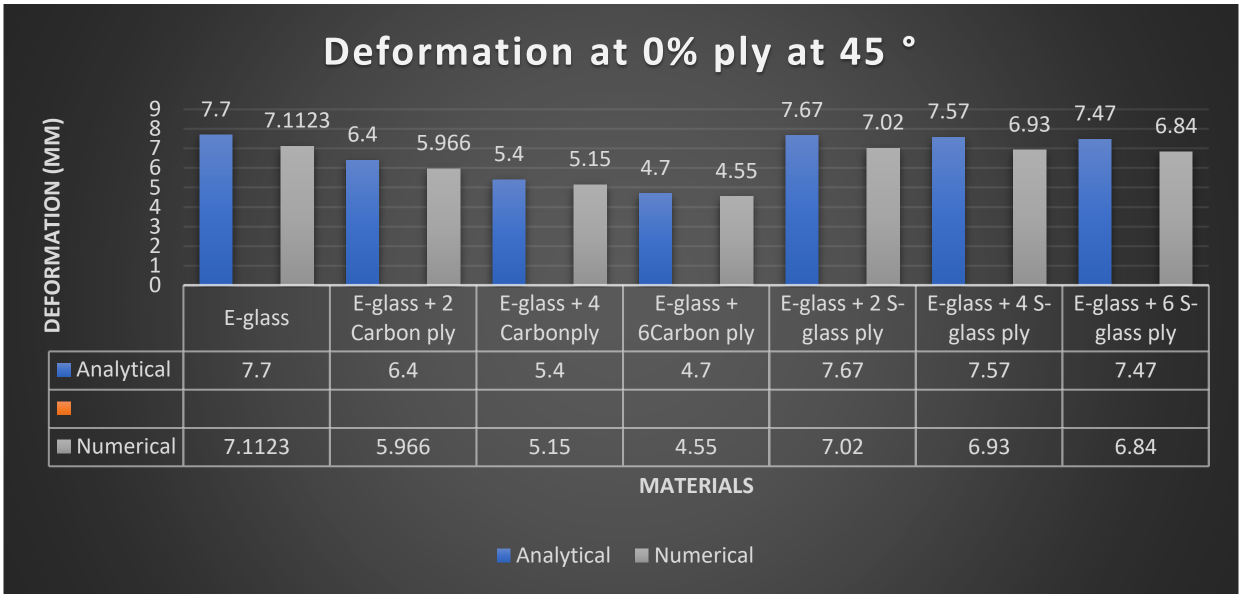


Figure 9.2.1.1

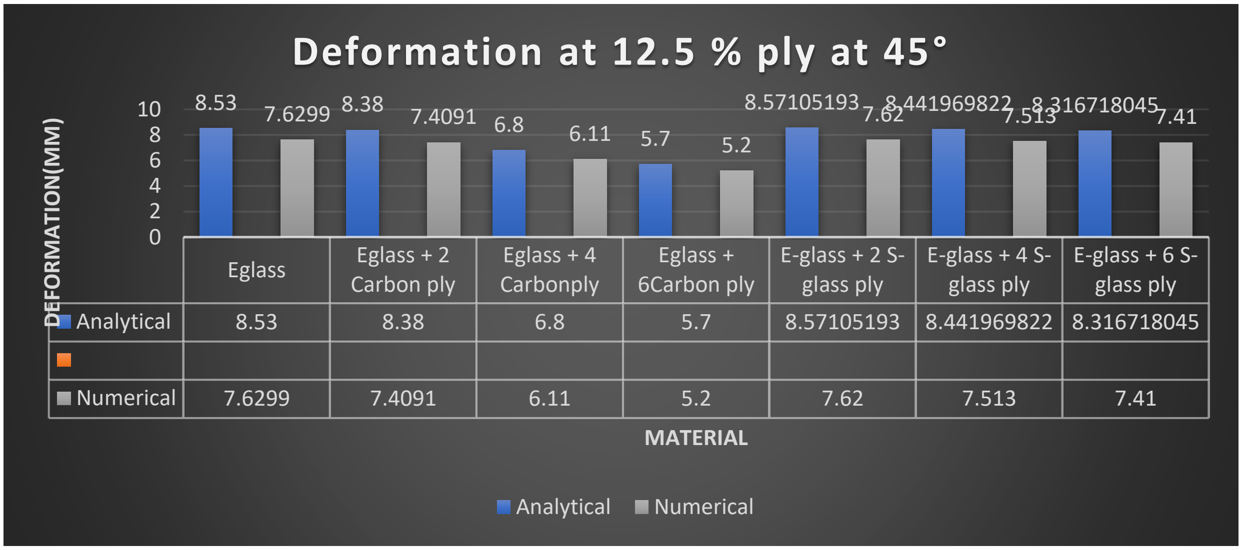
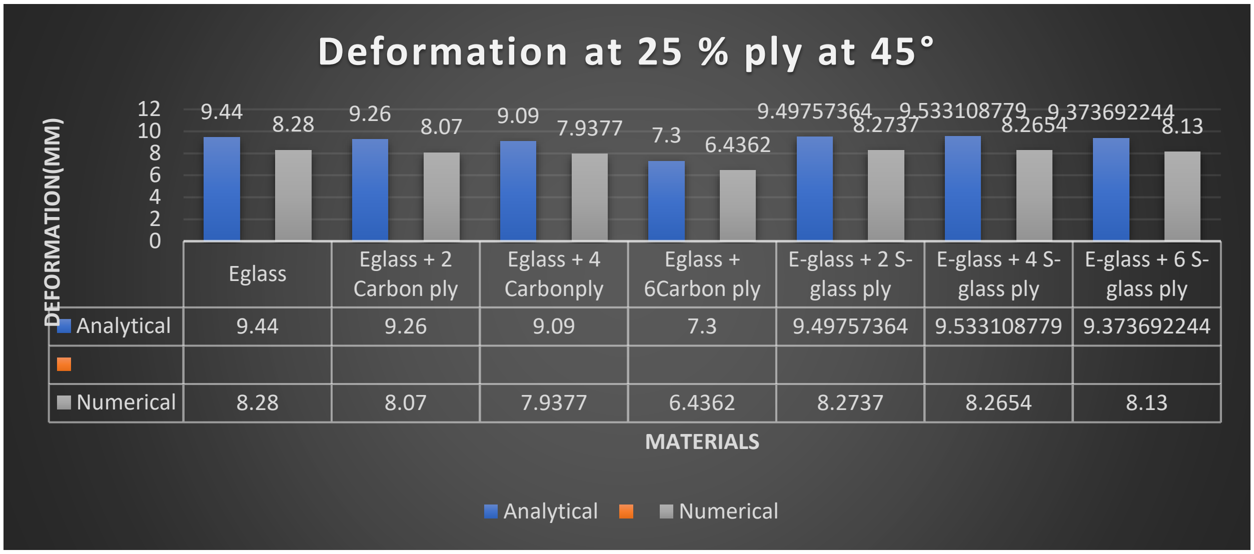


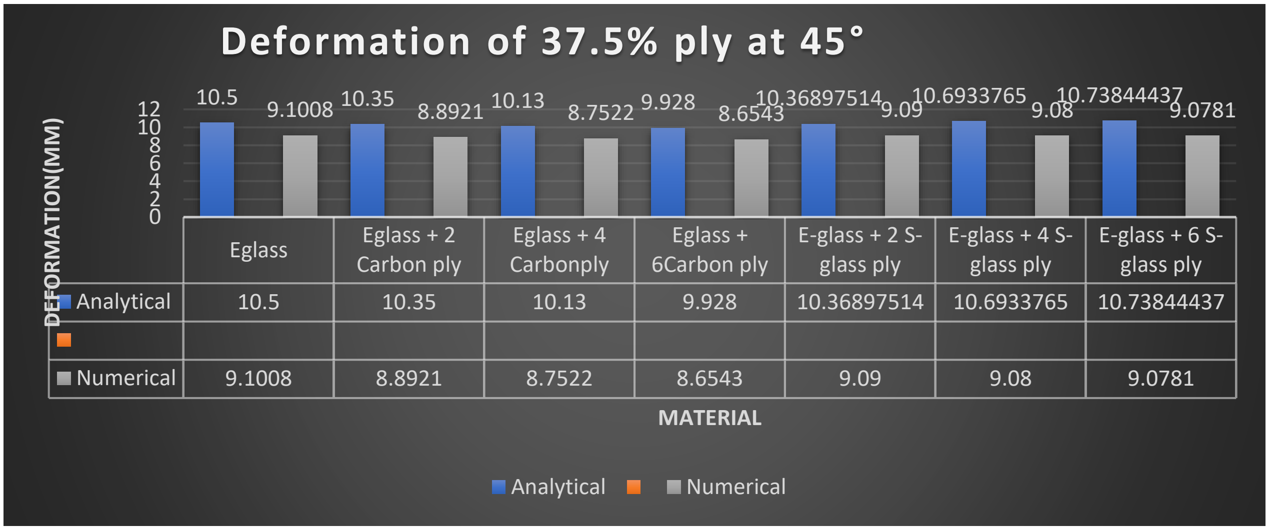
Figure 9.2.1.2

The figure above shows the deformation of a 3mm thick laminate in leu with various design parameters. There is quite noticeable change when it comes to it. In the first case, the deformation drastically decreases as we add the carbon fiber, due to its superior longitudinal young’s modulus. We can see that at 6 layers of carbon the deformation is almost halved. When it comes to S2 glass, the deformation is almost same.



	Eglass	Eglass + 2 Carbon ply	Eglass + 4 Carbonply	Eglass + 6Carbon ply	E-glass + 2 S-glass ply	E-glass + 4 S-glass ply	E-glass + 6 S-glass ply
🟦 Analytical	9.44	9.26	9.09	7.3	9.49757364	9.533108779	9.373692244
🟧							
⬜ Numerical	8.28	8.07	7.9377	6.4362	8.2737	8.2654	8.13

Figure 9.2.1.3

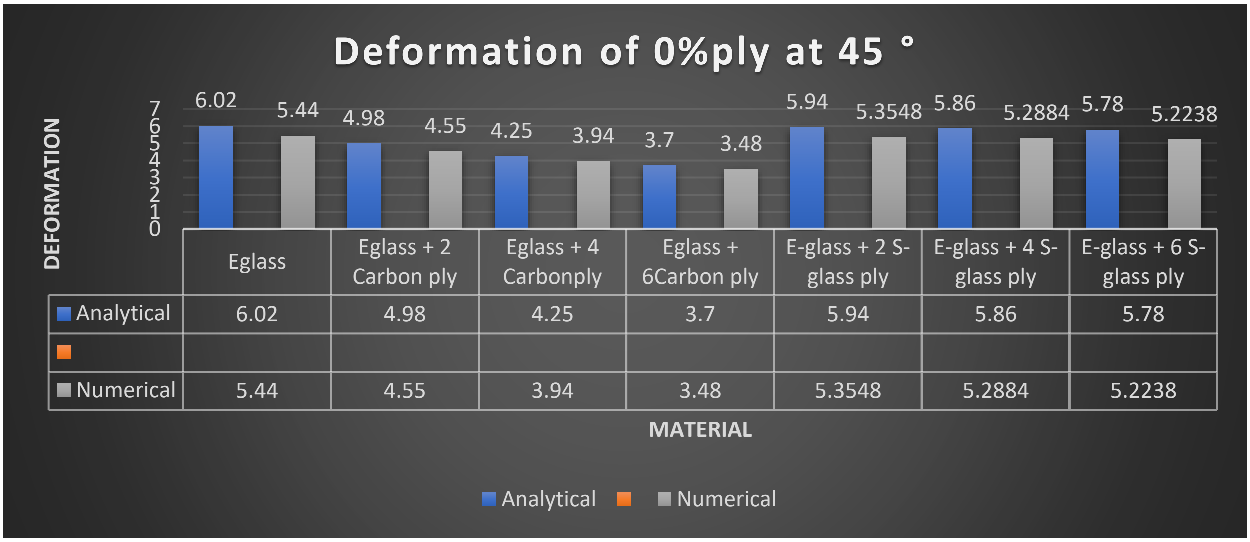


	Eglass	Eglass + 2 Carbon ply	Eglass + 4 Carbonply	Eglass + 6Carbon ply	E-glass + 2 S-glass ply	E-glass + 4 S-glass ply	E-glass + 6 S-glass ply
🟦 Analytical	10.5	10.35	10.13	9.928	10.36897514	10.6933765	10.73844437
🟧							
⬜ Numerical	9.1008	8.8921	8.7522	8.6543	9.09	9.08	9.0781

Figure 9.2.1.4

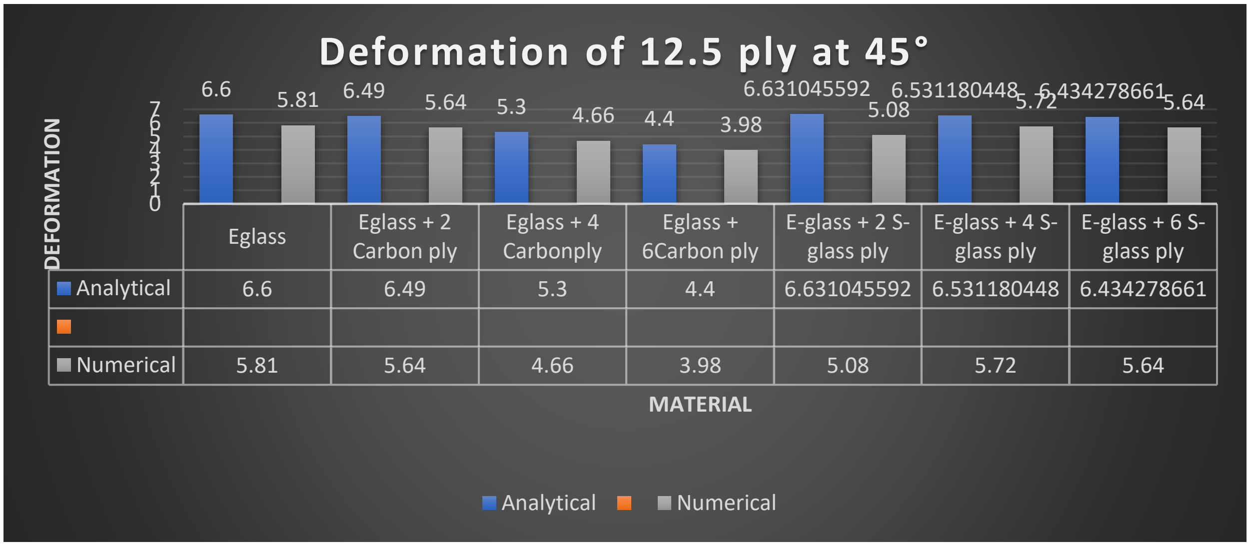
The variation in deformation increases as we increase the amount of 45° ply. The 45 ° ply helps to reduce the torsional strain got upon by the torsional stress.at the same time it reduces its help along the longitudinal direction of the composite. Hence, Deformation increase with increase in 45° ply angle but helps in improving torsional stability.

9.2.2 Numerical result for 4mm thick Laminate



	Eglass	Eglass + 2 Carbon ply	Eglass + 4 Carbonply	Eglass + 6Carbon ply	E-glass + 2 S-glass ply	E-glass + 4 S-glass ply	E-glass + 6 S-glass ply
🟦 Analytical	6.02	4.98	4.25	3.7	5.94	5.86	5.78
🟧							
⬜ Numerical	5.44	4.55	3.94	3.48	5.3548	5.2884	5.2238

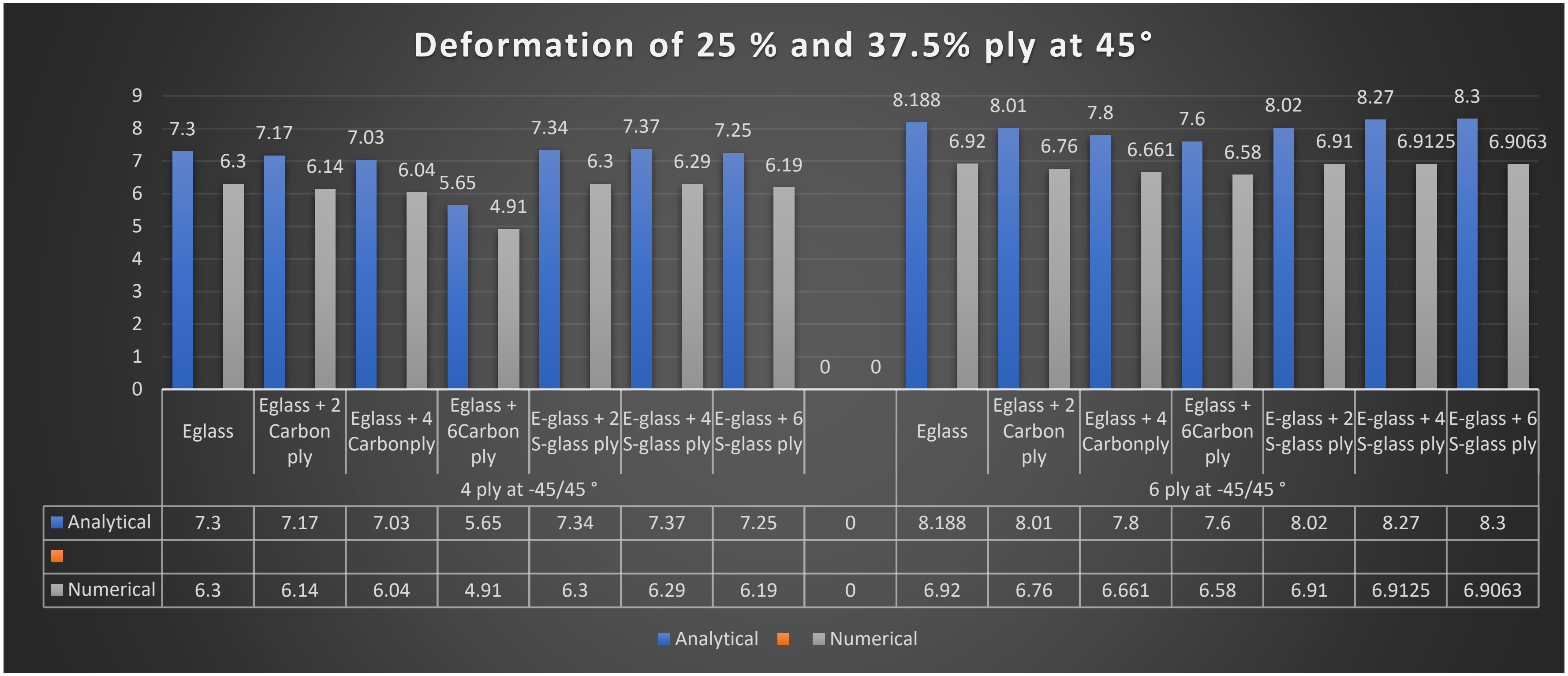
Figure 9.2.2.1



	Eglass	Eglass + 2 Carbon ply	Eglass + 4 Carbonply	Eglass + 6Carbon ply	E-glass + 2 S-glass ply	E-glass + 4 S-glass ply	E-glass + 6 S-glass ply
🟦 Analytical	6.6	6.49	5.3	4.4	6.631045592	6.531180448	6.434278661
🟧							
⬜ Numerical	5.81	5.64	4.66	3.98	5.08	5.72	5.64

Figure 9.2.2.2

The figures above show the variation of deformation in 4mm thick laminate. The increase in thickness has shown a drastic decrease in deformation. Although, the main characteristics mentions in 9.2.1 such as involvement of carbon fiber and S2 glass fiber has been the same. This gives us a reason to consider 4mm thick laminate over 3mm thick laminate as it provides a better reassurance when it comes to deformation in high wind / high force prone areas



	4 ply at -45/45 °								6 ply at -45/45 °						
	Eglass	Eglass + 2 Carbon ply	Eglass + 4 Carbonply	Eglass + 6Carbon ply	E-glass + 2 S-glass ply	E-glass + 4 S-glass ply	E-glass + 6 S-glass ply		Eglass	Eglass + 2 Carbon ply	Eglass + 4 Carbonply	Eglass + 6Carbon ply	E-glass + 2 S-glass ply	E-glass + 4 S-glass ply	E-glass + 6 S-glass ply
🟦 Analytical	7.3	7.17	7.03	5.65	7.34	7.37	7.25	0	8.188	8.01	7.8	7.6	8.02	8.27	8.3
🟧															
⬜ Numerical	6.3	6.14	6.04	4.91	6.3	6.29	6.19	0	6.92	6.76	6.661	6.58	6.91	6.9125	6.9063

Figure 9.2.2.3

A very peculiar trait can be observed in the figure 9.2.2.3 above, they show almost the same deformation as in that of 3mm thick laminate but the best part is that, they have a higher number of 45 ° ply which can provide a sound stability against torsional stress. A much better comparison can be made and understood as we move on to safety factor and normal stress results.

9.2.3 Deformation results for 6 mm thick laminate

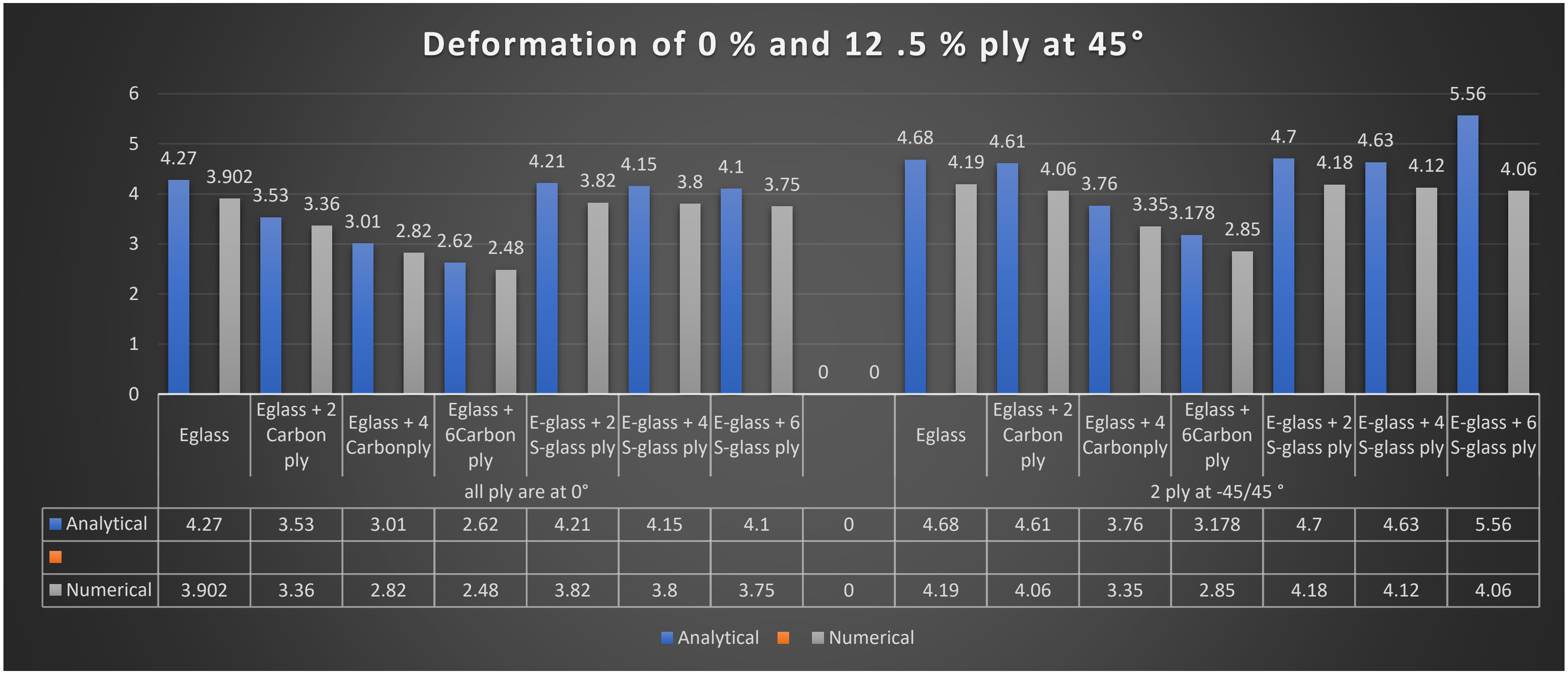
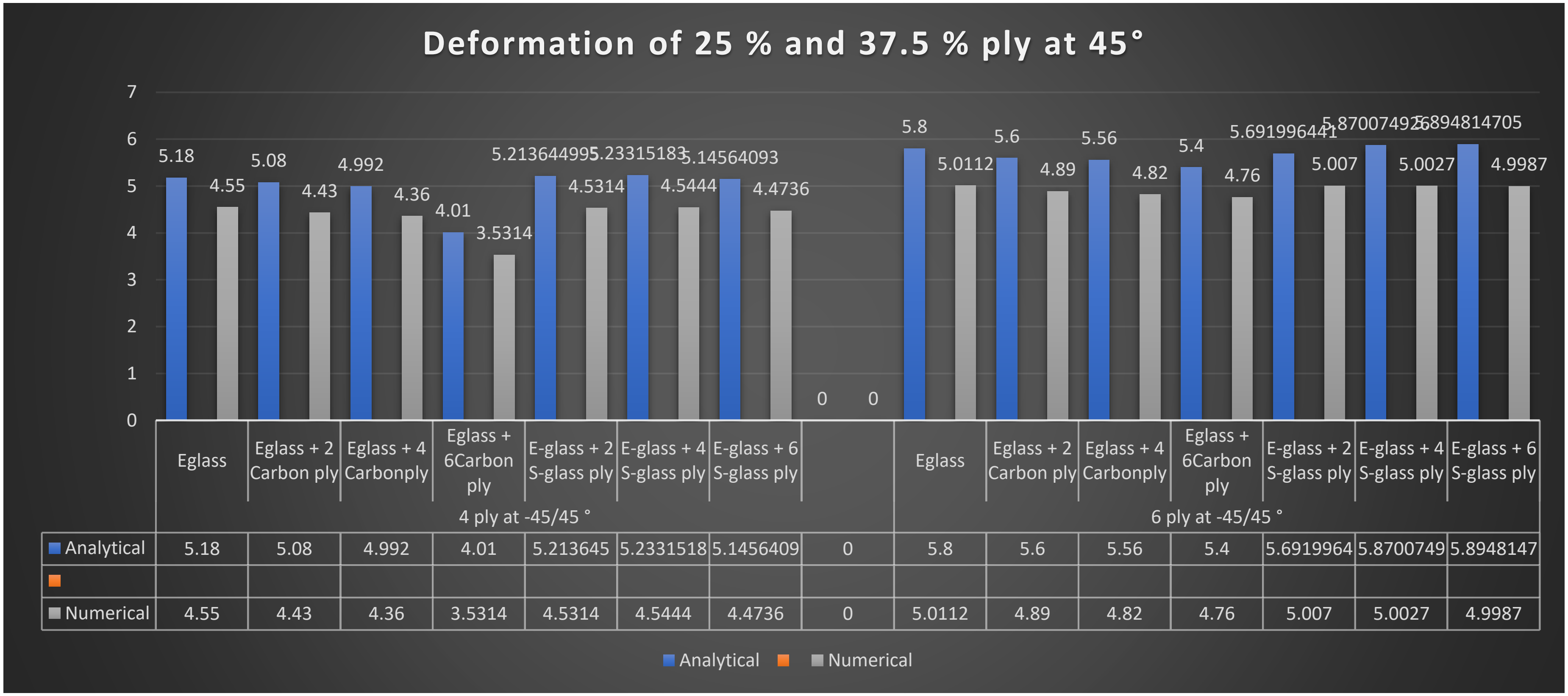


Figure 9.2.3.1

The increase in thickness of composite material seems like overkill sometimes. In figure 9.2.3.1, it is seen that the deformation in the case of carbon fiber has drastically gone down almost to 2.5 mm deflection which is as much as Eucalyptus wood. If cost would not be hinderance here, this thickness will be right suited for high win prone areas. A much better understanding can be done after we review FOS and normal stress.

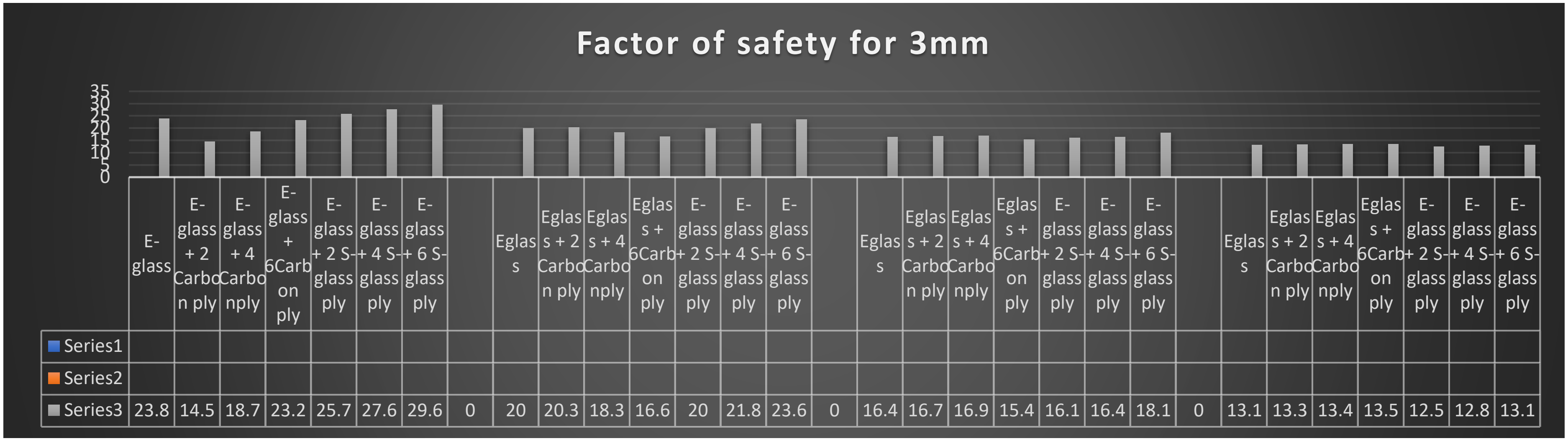


	Eglass	Eglass + 2 Carbon ply	Eglass + 4 Carbonply	Eglass + 6Carbon ply	E-glass + 2 S-glass ply	E-glass + 4 S-glass ply	E-glass + 6 S-glass ply		Eglass	Eglass + 2 Carbon ply	Eglass + 4 Carbonply	Eglass + 6Carbon ply	E-glass + 2 S-glass ply	E-glass + 4 S-glass ply	E-glass + 6 S-glass ply
	4 ply at -45/45 °								6 ply at -45/45 °						
■ Analytical	5.18	5.08	4.992	4.01	5.213645	5.2331518	5.1456409	0	5.8	5.6	5.56	5.4	5.6919964	5.8700749	5.8948147
🟧															
■ Numerical	4.55	4.43	4.36	3.5314	4.5314	4.5444	4.4736	0	5.0112	4.89	4.82	4.76	5.007	5.0027	4.9987

Figure 9.2.3.2

The variation in deformation i.e. increase in deformation with increase in 45° ply and decrease in deformation with increase in thickness of ply is clearly demonstrated in figures 9.2.3.1 and 9.2.3.2.

9.2.4 Factor of safety for 3mm thick laminate.



	E-glass	E-glass + 2 Carbon ply	E-glass + 4 Carbonply	E-glass + 6Carbon ply	E-glass + 2 S-glass ply	E-glass + 4 S-glass ply	E-glass + 6 S-glass ply	
■ Series1								
■ Series2								
■ Series3	23.8	14.5	18.7	23.2	25.7	27.6	29.6	0

	Eglass	Eglass + 2 Carbon ply	Eglass + 4 Carbonply	Eglass + 6Carbon ply	E-glass + 2 S-glass ply	E-glass + 4 S-glass ply	E-glass + 6 S-glass ply	
■ Series1								
■ Series2								
■ Series3	20	20.3	18.3	16.6	20	21.8	23.6	0

	Eglass	Eglass + 2 Carbon ply	Eglass + 4 Carbonply	Eglass + 6Carbon ply	E-glass + 2 S-glass ply	E-glass + 4 S-glass ply	E-glass + 6 S-glass ply	
■ Series1								
■ Series2								
■ Series3	16.4	16.7	16.9	15.4	16.1	16.4	18.1	0

	Eglass	Eglass + 2 Carbon ply	Eglass + 4 Carbonply	Eglass + 6Carbon ply	E-glass + 2 S-glass ply	E-glass + 4 S-glass ply	E-glass + 6 S-glass ply
■ Series1							
■ Series2							
■ Series3	13.1	13.3	13.4	13.5	12.5	12.8	13.1

Figure 9.2.4.1

Factor of safety is one of the most important value in structural characteristics of the material. It determines the yielding of the composite material being used in the scenario. It is noticeable that the factor of safety increases with increase in addition of different ply. There is dip when carbon fiber is first added, but as we increase in the number of carbon fiber ply, the value increases thereby telling us that the composite Crossarms have a increases factor of safety with increase in addition of additional ply. Factor of safety increases with increase in thickness of ply material and at the same its decreases as we increase the number 45 ° ply in the between. The values obtained here clearly show that it is almost 4 times that of the ones found with wooden Crossarms. Keeping all the structural characteristics in mind, we choose the better values so that we can come up with the best setup. In figures 9.2.4.1 – 9.2.4.3 we notice the values of FOS increasing with thickness and decreasing with increase in 45 °ply.

9.2.5 Factor of safety for 4mm thick laminate.

	Eglass	Eglass + 2 Carbon ply	Eglass + 4 Carbonply	Eglass + 6Carbon ply	E-glass + 2 S-glass ply	E-glass + 4 S-glass ply	E-glass + 6 S-glass ply		Eglass	Eglass + 2 Carbon ply	Eglass + 4 Carbonply	Eglass + 6Carbon ply	E-glass + 2 S-glass ply	E-glass + 4 S-glass ply	E-glass + 6 S-glass ply		Eglass	Eglass + 2 Carbon ply	Eglass + 4 Carbonply	Eglass + 6Carbon ply	E-glass + 2 S-glass ply	E-glass + 4 S-glass ply	E-glass + 6 S-glass ply		Eglass	Eglass + 2 Carbon ply	Eglass + 4 Carbonply	Eglass + 6Carbon ply	E-glass + 2 S-glass ply	E-glass + 4 S-glass ply	E-glass + 6 S-glass ply
■ Series1																															
■ Series2																															
■ Series3	30.8	19.2	24.6	30.4	23.6	25.3	27	0	25.9	19.2	24.1	21.9	18.8	20.4	22	0	21.3	16.1	16.2	20.2	15.4	15.7	17.3	0	17	13.1	13.2	13.2	12.2	12.5	12.8

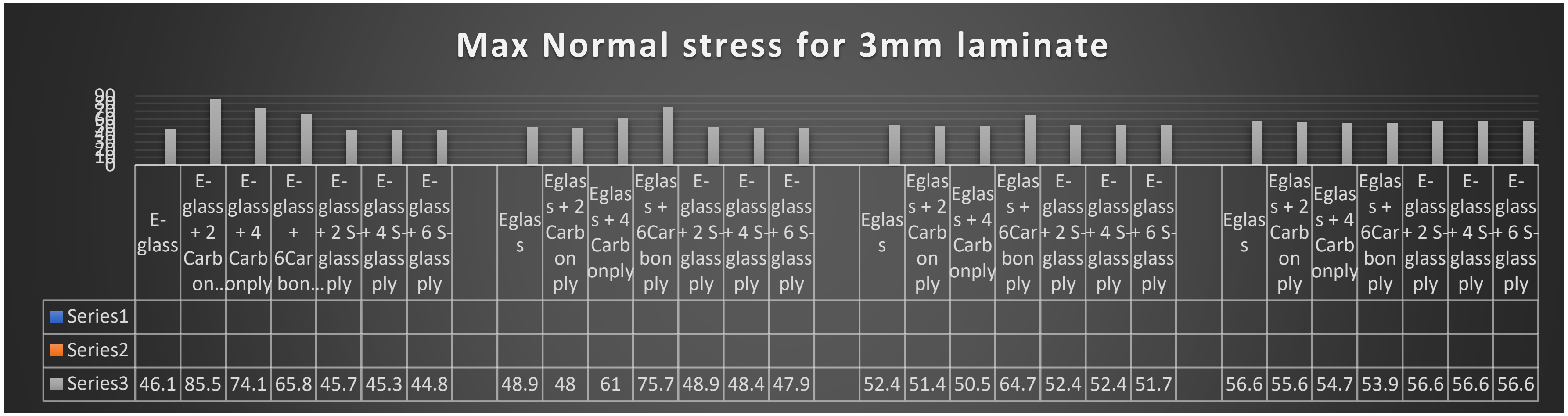
Figure 9.2.5.1

9.2.6 Factor of safety for 6mm thick laminate

	Eglass	Eglass + 2 Carbon ply	Eglass + 4 Carbonply	Eglass + 6Carbon ply	E-glass + 2 S-glass ply	E-glass + 4 S-glass ply	E-glass + 6 S-glass ply		Eglass	Eglass + 2 Carbon ply	Eglass + 4 Carbonply	Eglass + 6Carbon ply	E-glass + 2 S-glass ply	E-glass + 4 S-glass ply	E-glass + 6 S-glass ply		Eglass	Eglass + 2 Carbon ply	Eglass + 4 Carbonply	Eglass + 6Carbon ply	E-glass + 2 S-glass ply	E-glass + 4 S-glass ply	E-glass + 6 S-glass ply		Eglass	Eglass + 2 Carbon ply	Eglass + 4 Carbonply	Eglass + 6Carbon ply	E-glass + 2 S-glass ply	E-glass + 4 S-glass ply	E-glass + 6 S-glass ply
■ Series1																															
■ Series2																															
■ Series3	41.9	27.6	35.5	43.4	45.1	48.2	51.3	0	37.3	35.8	34.5	31.2	36.3	39.2	42.2	0	30.6	30.7	30.7	29	30	30.6	33.7	0	24.4	24.7	25.1	25.1	23.2	23.8	24.4

Figure 9.2.6.1

9.2.7 Max normal stress for 3mm thick laminate



	E-glass	E-glass + 2 Carbon..	E-glass + 4 Carbonply	E-glass + 6Carbon...	E-glass + 2 S-glass ply	E-glass + 4 S-glass ply	E-glass + 6 S-glass ply		Eglass	Eglass + 2 Carbon ply	Eglass + 4 Carbonply	Eglass + 6Carbon ply	E-glass + 2 S-glass ply	E-glass + 4 S-glass ply	E-glass + 6 S-glass ply		Eglass	Eglass + 2 Carbon ply	Eglass + 4 Carbonply	Eglass + 6Carbon ply	E-glass + 2 S-glass ply	E-glass + 4 S-glass ply	E-glass + 6 S-glass ply		Eglass	Eglass + 2 Carbon ply	Eglass + 4 Carbonply	Eglass + 6Carbon ply	E-glass + 2 S-glass ply	E-glass + 4 S-glass ply	E-glass + 6 S-glass ply
■ Series1																															
■ Series2																															
■ Series3	46.1	85.5	74.1	65.8	45.7	45.3	44.8		48.9	48	61	75.7	48.9	48.4	47.9		52.4	51.4	50.5	64.7	52.4	52.4	51.7		56.6	55.6	54.7	53.9	56.6	56.6	56.6

Figure 9.2.7.1

The normal stress in the laminate is another of the main characteristics being used to determine the physical traits of the Crossarms. From the figures 9.2.7.1 -9.2.7.2 we notice that there is an increase when we introduce the 2-carbon ply in the 3mm section of the Crossarms, but as we go on adding it over 2, the normal stresses reduce. This phenomenon is seen with increase in thickness. Another notable feature is that the normal stress decreases with increase in thickness and increases with increase with addition of the 45° ply. The normal stresses also decrease relatively when we compare 45° ply of E glass and carbon fiber. This particular feature is noteworthy and plays an important role during selection of the better combinations of hybrid composites as we try and compare the physical traits of wood to determine how they are much better than the latter.

Another feature to be noticed is that as we increase the addition of 45° ply, the value of normal stress doesn’t differ a lot from themselves. Like in part 4 of every figure in chapter 9.2.7.

9.2.8 Max normal stress for 4mm thick laminate

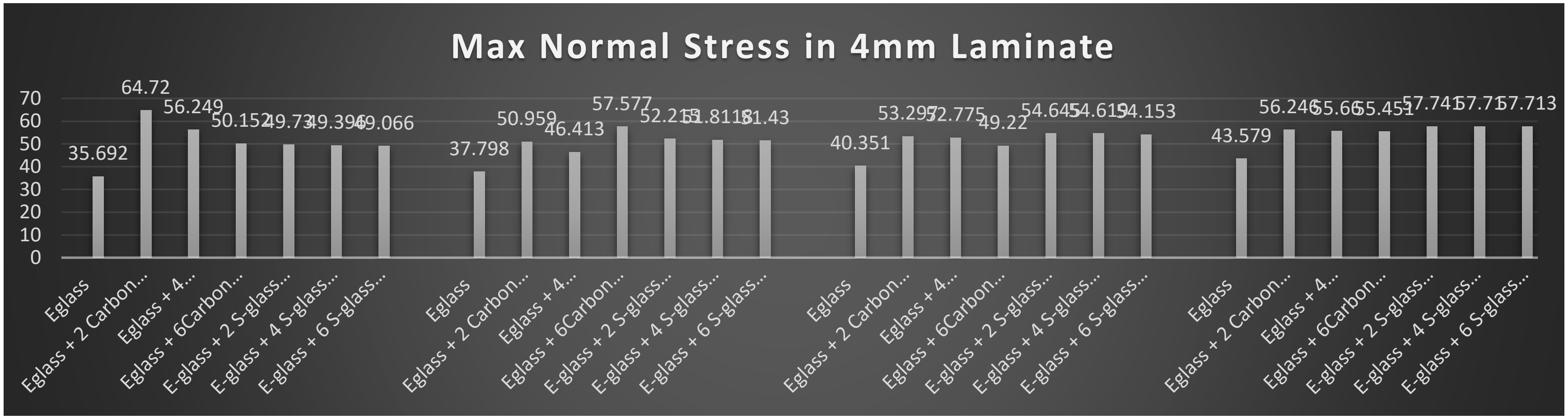


Figure 9.2.8.1

9.2.9 Max normal stress for 6mm laminate

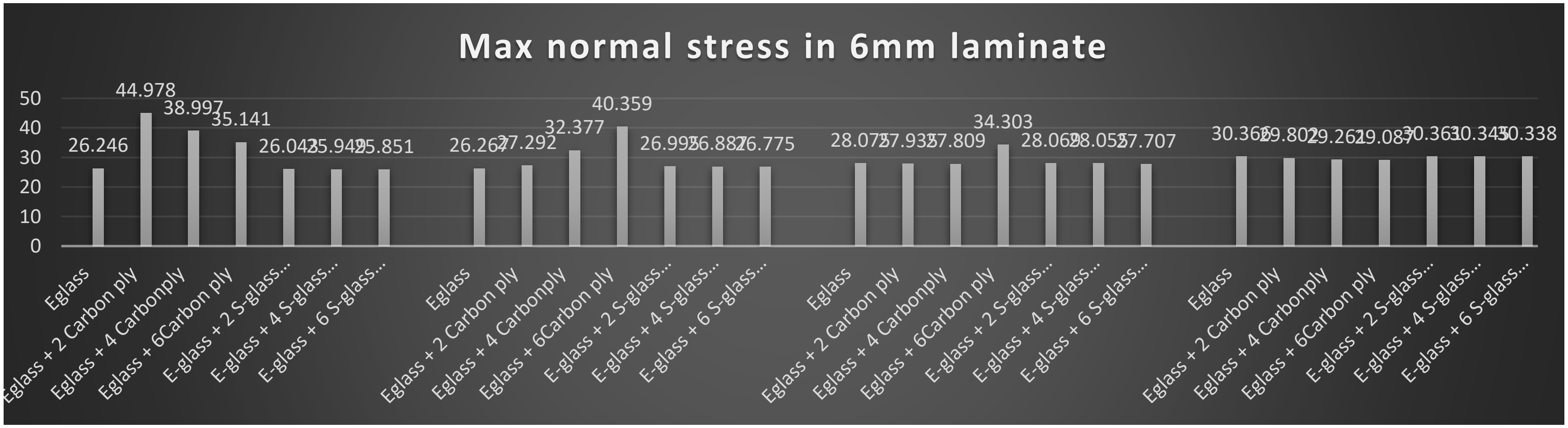


Figure 9.2.9.1

By taking into account the values of each laminate at different design parameters, about 4 laminate combinations are chosen to go on to be compared against wooden composites.

The reasons are based on whether the FOS, deformation and Normal stress are maximum or minimum. Since excess FOS would only mean a wastage of material and since material cost is one of the tradeoff factors, great care has been taken to choose the following laminates.

Laminate composition	Thickness of laminate	Factor of safety	Deformation(mm)	Max normal stress(Mpa)
E glass + 4 carbon @2 45° ply	3 mm	18.3	6.11	61
E glass + 6 carbon @ 2 45° ply	3mm	16.6	5.2	75
E glass + 4 carbon @4 45° ply	3 mm	16.9	7.9	50.5
E glass + 6 carbon @ 4 45° ply	3mm	15.4	6.4	64.7
E glass + 6 carbon @2 45° ply	4 mm	21.9	4.66	32.3
E glass + 4 carbon @ 4 45° ply	4 mm	16.2	4.91	27.801

Table 9.2.1

9.3 Results / conclusion

9.3.1 Comparison of wood and hybrid composite based on deformation

Material	**Max Deformation (mm)**
Eucalyptus	2.45
Southern pine	4.80
Red Cedar	8.46
E-glass + 4 carbon (@ 2 ply 45°) 3mm	6.11
E-glass + 6 carbon (@ 2 ply 45 °)3mm	5.2
E-glass + 4 carbon (@4 ply 45 °) 3mm	7.9
E-glass + 6 carbon (@4ply 45 °) 3mm	6.4
E glass + 6 carbon (@2 ply 45 °) 4mm	4.66
E glass + 4 carbon (@4 ply 45 °) 4mm	4.91

Table 9.3.1

It can be observed that the deflection in case of proposed combination of materials is closer to the deflection of southern pine wood. It is about 15 % less than southern pine wood and about 50 % more than eucalyptus. It should be observed that in case of wood higher the mechanical properties, lesser in deflection. In case of composites, increasing the stack of 45° we see an increased deflection but at the same time increasing the amount of carbon fiber or S2 glass provides lesser deformation. The 0 ° ply provide better stability longitudinally because its property to resist longitudinal stress, whereas 45° play help to provide a torsional stability against torsional stresses

9.3.2 Comparison of wood and hybrid composite based on factor of safety

Material	**Factor of safety**
Eucalyptus	6.34
Southern pine	5.26
Red Cedar	2.67
E-glass + 4 carbon (@ 2 ply 45°) 3mm	18.39
E-glass + 6 carbon (@ 2 ply 45 °)3mm	16.627
E-glass + 4 carbon (@4 ply 45 °) 3mm	16.908
E-glass + 6 carbon (@4 ply 45 °) 3mm	15.376
E glass + 6 carbon (@2 ply 45 °) 4mm	24.008
E glass + 4 carbon (@2 ply 45 °) 4mm	20.21

Table 9.3.2

The factor of safety for hybrid composites is higher than the wood by almost a factor of 3. Which says that the amount stress it can take is much higher than that of wood. When compared to the strongest wood, that is eucalyptus, hybrid composites provide a better factor of safety. according to the thumb rule for life expectancy, hybrid composites can stay longer i.e. almost 3 times longer than that of wooden Crossarms. This is a major factor in determining the effectiveness of composites over wooden materials.

9.3.3 Comparison of wood and hybrid composite based on mass

Material	**Mass (Kg)**
Eucalyptus	27.88
Southern pine	17.10
Red Cedar	9.73
E-glass + 4 carbon (@ 2 ply 45°) 3mm	7.85
E-glass + 6 carbon (@ 2 ply 45 °)3mm	7.26
E-glass + 4 carbon (@4 ply 45 °) 3mm	7.85
E-glass + 6 carbon (@4 ply 45 °) 3mm	7.26
E glass + 6 carbon (@2 ply 45 °) 4mm	7.26
E glass + 4 carbon (@2 ply 45 °) 4mm	7.85

Table 9.3.3

Mass of the Crossarms was compared keeping volume constant i.e. using the same dimensions for all Crossarms (92.08 X 177.48 X 2438.4) mm. It can be observed that the mass of eucalyptus wood is highest. The model designed via the study is almost 65% lesser in weight while offering better structural characteristics. The variation in mass along that characteristics of wood show that southern pine is almost 2.25 times that of eucalyptus while showing good amount of structural benefits.

In conclusion, hybrid composites weigh almost as close to plane E-glass composite while providing better structural benefits and hybrid composites provide better structural benefits while weighing almost 3 times lesser than wood.

9.3.4 Comparison of wood and hybrid composites based on cost.

Materials	**Cost of material ($/ft)**
Eucalyptus	9.89
Southern pine	1.31
Red Cedar	2.53
E-glass + 4 carbon (@ 2 ply 45°) 3mm	12.57
E-glass + 6 carbon (@ 2 ply 45 °)3mm	13.34
E-glass + 4 carbon (@4 ply 45 °) 3mm	12.57
E-glass + 6 carbon (@4 ply 45 °) 3mm	13.34
E glass + 6 carbon (@2 ply 45 °) 4mm	13.34
E glass + 4 carbon (@2 ply 45 °) 4mm	12.37
E glass + S glass (@ any orientation)	10.58

Table 9.3.4

It should be noted that the cost here for wood seems much less in bulk volume whereas composite if manufactured at right dimensions will cut down costs. The tradeoff between factor of safety and cost is what provides an upper hand. The cost of manufacturing can be cut down as we use fabrics since we are not filling the entire volume with the fabric rather using only 3mm to produce the hybrid composites.

Chapter 10

Conclusion

- Laminates with better structural characteristics based on Deformation, Factor of safety and normal stresses.
- A combination of thickness and ply orientation was considered for the selection of the following laminates.
- The selection was done considering the type of load applied.
- Since the safety factor is higher than wood. (almost 4 – 5 times).
- It shows a potential to be considered even in high load circumstances like tornado.
- Higher safety Factor.
- Lesser deflection.
- Life expectancy almost twice as wood.
- Weighs almost half as much as wood.
- Cost of the composite can be optimized by changing the thickness of the fiber laminate.

Future work

Composites show immense potential due to their superior characteristics. This study only paves open an opportunity to show the idea about usage of composites in different aspects such as in Crossarms of utility poles.

Some future work that can be done on this would be

- Dynamics analysis and Fatigue failure mode of the Crossarms.
- Static analysis of the entire pole made of hybrid composites
- Variation in design parameters to provide better physical traits
- Doing an FMEA, DFM and DFA study on the manufacturing of hybrid Crossarms.

Chapter 11

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Biographical Information

Rohit Avadhani was born in Warangal, Telangana, India on January 27th, 1994.He Received his Bachelor of Technology in Aerospace Engineering from SRM University, India in 2015. He worked on various projects in his undergrad, most prominent ones include, Design and development of water propelled resisto jet, which was also his senior year thesis topic. He also participated in AIAA Design, build and fly competition in which he was part of a team that represented the University in 2014. He interned at Bharat Dynamics Limited in 2013 and finished his internship in Sree Trio Poly after a period of six months in India. He enrolled into masters of science in Aerospace engineering in spring 2016. He started working on topic related to design and development of materials using static structural analysis, he developed a likeness towards composites and decided to start his thesis on Composite materials under Dr. Andrey Beyle in spring 2017. He is proficient in ANSYS workbench ACP pre-post , static structural , CATIA V5 and other necessary design software. He graduated in December 2017.