AMM5117	Introduction to Composite Materials	Group Project Team 02

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Analysis of Composite Control Arm for vehicles

Section 1: Case

The object of the project is to design and produce a composite control arm for a car's suspension system, aiming to replace traditional steel or aluminum arms with a lighter, more durable, and potentially better-performing alternative.

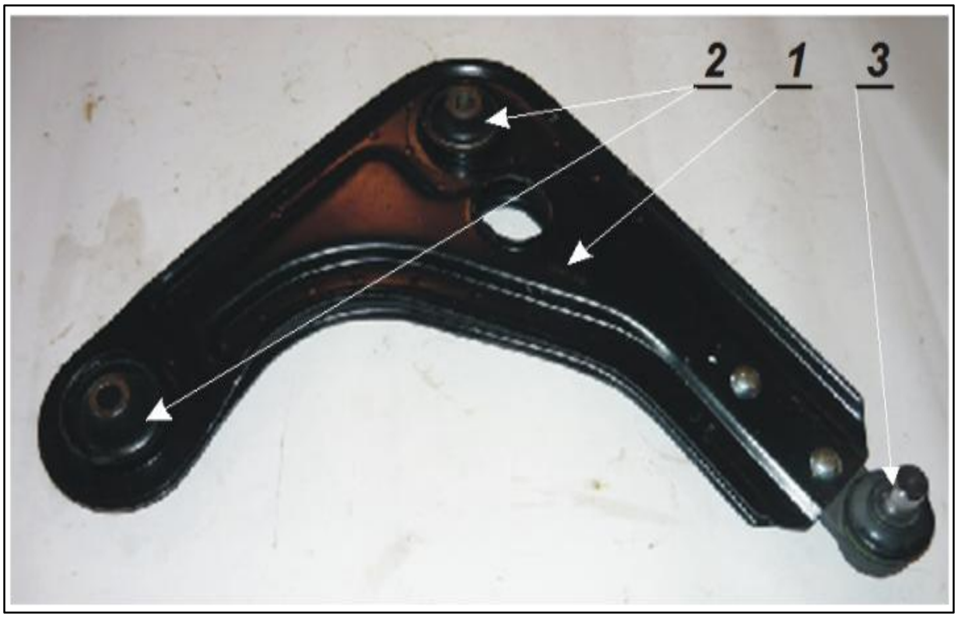

Figure 1: Conventional control arm made of steel[1]

The purpose of this project is to explore the feasibility and benefits of using composite materials, specifically epoxy resin and glass fiber, in the construction of a control arm. The goal is to improve overall vehicle performance, handling, and durability while considering factors such as weight reduction, rust resistance, and customization.

The control arm is described as a crucial part of a car's suspension system, typically resembling the letters "A" or "L." It connects the steering knuckle or wheel hub to the vehicle's frame or chassis, allowing for smooth wheel movement and proper alignment. The control arm has various components, including the control arm body, bushings, and ball joint.

The production process involves creating a mold with dimensions and shapes matching those of the control arm. Prepreg or composite fabric is then cut into appropriate sizes and shapes based on the control arm design. Layers of composite materials are arranged in the mold with a specific orientation and stacking order, considering necessary stiffness and strength in different directions.

The control arm is approximated as a set of flat plates with specific dimensions. The main components include:

Control Arm Body (1): The primary structural element, resembling the letters "A" or "L," connecting the steering knuckle or wheel hub to the vehicle's frame or chassis.

Bushings (2): Rubber or polyurethane bushings located at the attachment points, providing flexibility and reducing noise and vibrations.

Ball Joint (3): Located at the end of the control arm, allowing the wheel to pivot during steering and suspension travel.

In the current study the thickness of the entire laminate is 3.5mm and the entire thickness of the control arm is 15mm.

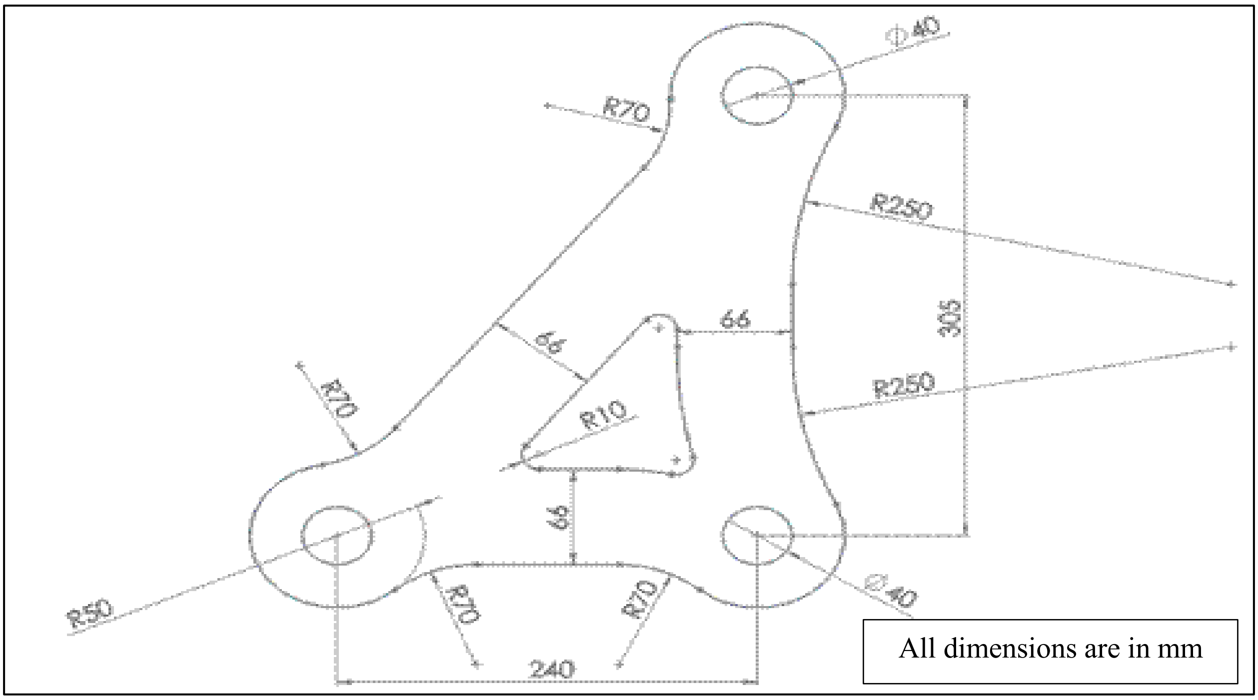

Figure 1.2: Dimensions of the control arm[1]

Section 2: In-plane load cases

2.1 Load Case 1:

In case the vehicle makes a turn at 10km/hr for a radius of 15m there will be a centripetal force acting on the control arm and will be directed in the inward direction. The velocity will be 2.77 m/s and from assumption of the mass of the vehicle to be 1200kg we can get the centripetal force.

$F_1 = \frac{\mathrm{m}v^2}{\mathrm{r}} = \frac{1300\mathrm{x}2.77^2}{15} = \mathbf{665\ N}$

There will also be a reaction force at point C denoted by R_c to keep the part in equilibrium.

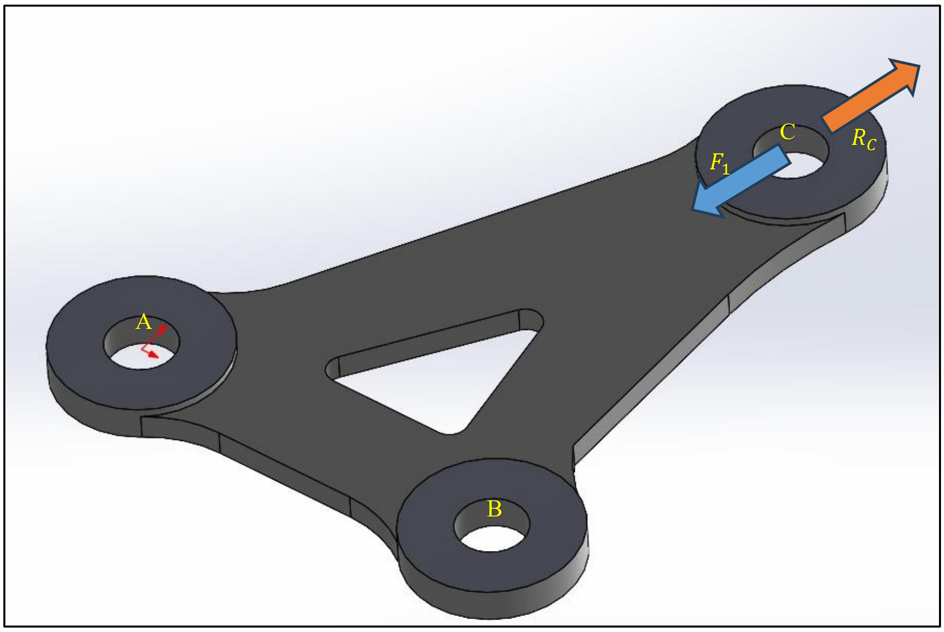

Figure 2.1(a): Load Case 1

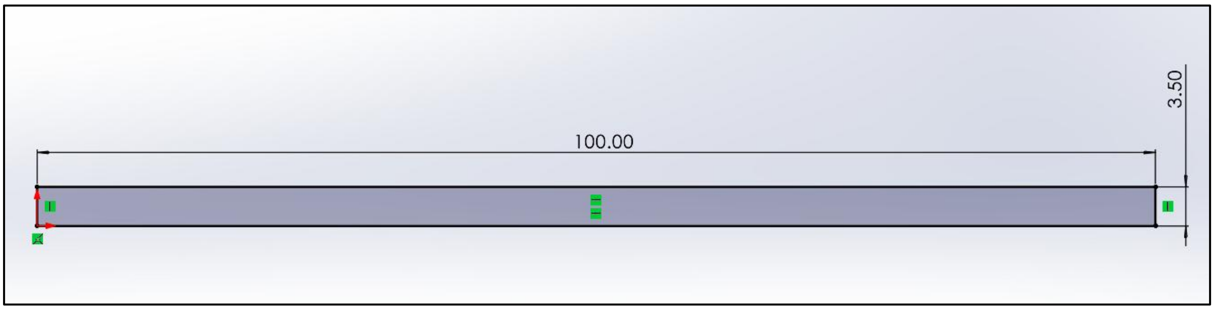

Figure 2.1(b): Dimensions of rectangular face(diameter of ball joint viewed from direction of the force) for load case 1

Stresses acting at point C are $\sigma_x = F_1/\mathrm{A} = \frac{665}{100\text{x}15\text{x}10^{-6}}$ = **-0.443MPa** , $\sigma_y = \sigma_z = 0$

2.2 Load Case 2: Force caused by the acceleration of the vehicle.

Considering the vehicle accelerates from 0-50km/hr in 5 seconds, the acceleration will be 2**.776 m/s^2.** From previous assumptions the mass of the vehicle is **1300 kg**. Therefore, the in-plane force acting on the control arm is **3608 N.**

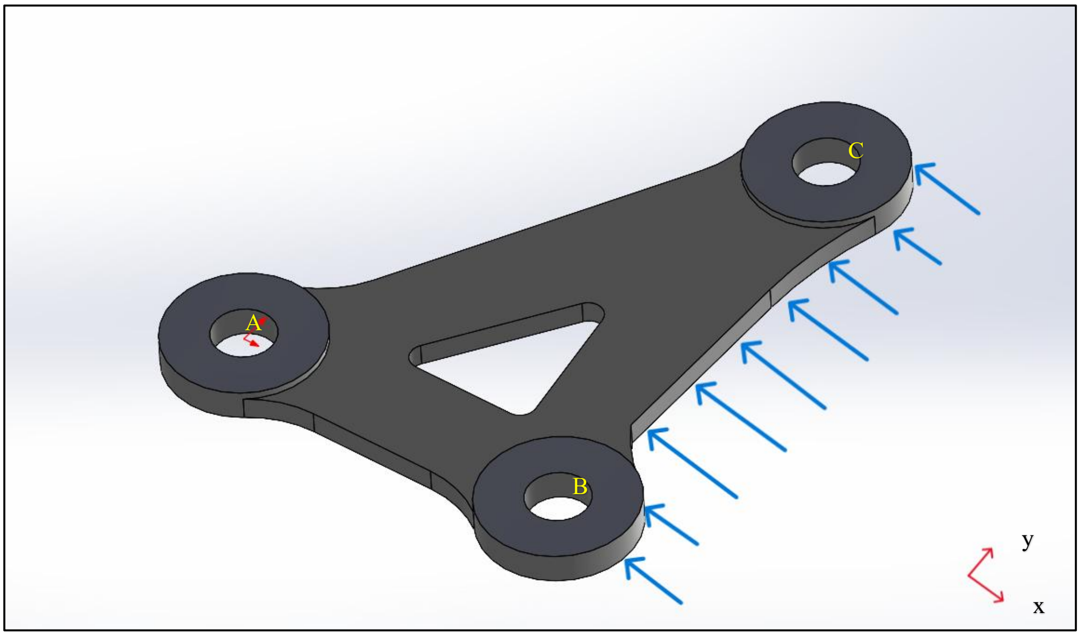

Figure 2.2 (a) Load Case 2

The stresses resulting to this force will be acting on a rectangular face.

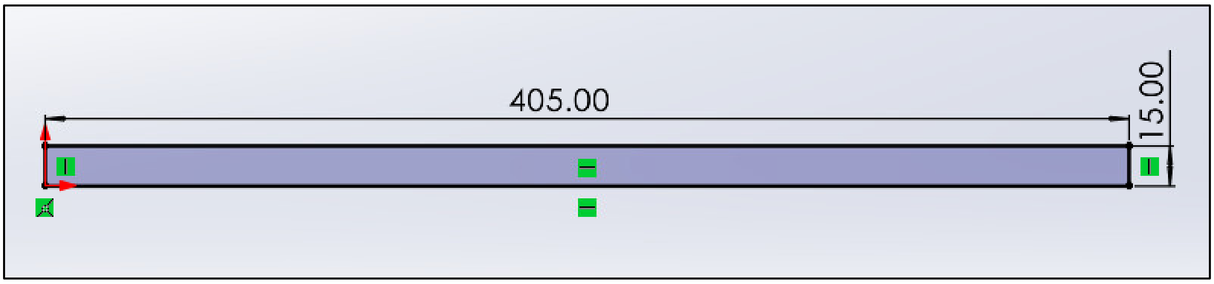

Figure 2.2 (b): Dimensions of rectangular face(from point B to point C viewed in the direction of force) for load case 2

Stress acting for this load case is σ_x = F/A $= \frac{3608}{405x15x10^{-6}}$ = **-0.594 MPa**, $\sigma_y = \sigma_z = 0$

2.3 Bending:

In the context of a vehicular system with a specified mass of 1300 kg, the gravitational force acting on the vehicle at its centre of gravity is determined by the product of its mass and the acceleration due to gravity, yielding a value of 14715 N, as per the equation W = mg, where “W” represents weight, “m” signifies mass, and “g” denotes the gravitational acceleration constant of 9.81 m/s².

Concurrently, a presumption is made regarding the wheelbase length, established at 2.5 meters, with an additional assumption that the centre of gravity is positioned precisely at the midpoint of the vehicle.

Therefore, the load acting on the front axle = $\frac{W x \, Distance \, from \, CG}{\text{Length of wheelbase}} = \frac{14715 \text{ x } 1.25}{2.5}$ = **6376.5 N**

There are two wheels on an axle the load acting on the control arm on one wheel is, F= $\frac{6376.5}{2}$ = **3188.25 N**. This load would create a bending moment in the vertical direction. The control arm is connected to the chassis of the vehicle at points A and B and the force is acting on the part which is connected to the wheel hub at point C.

Bending Moment M_1=$F \ x \ L$=3188.25 x 0.405 = **1291 Nm**

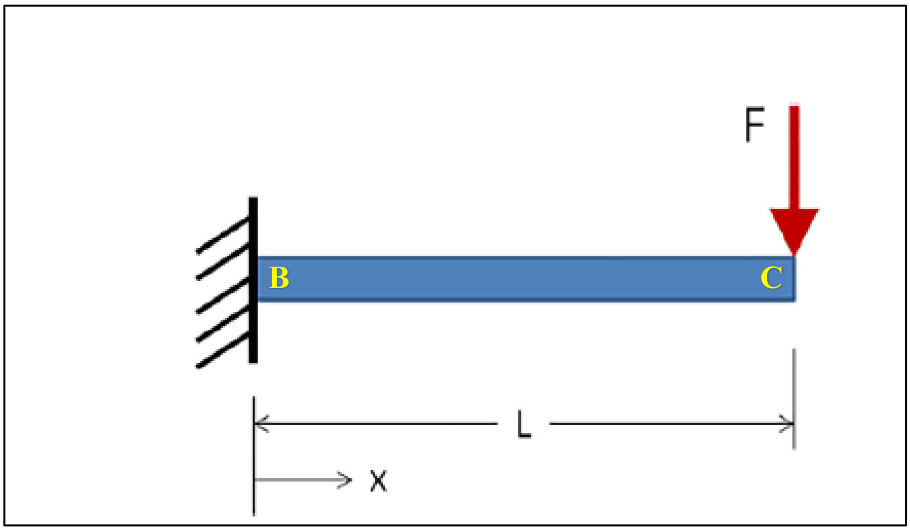

Figure 2.3 (a): Control arm acting as a cantilever beam with point load at point C

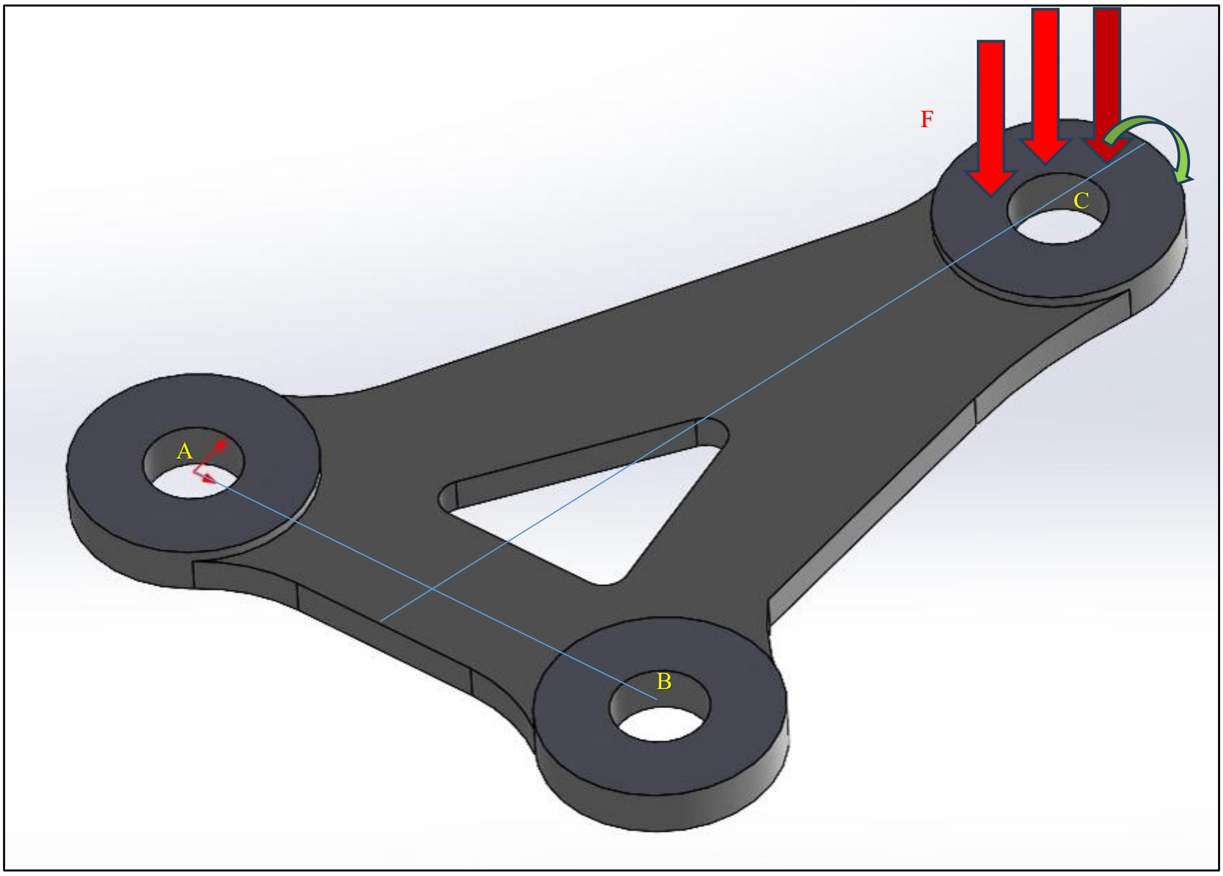

Figure 2.3: Bending Moment resulted by weight of the car.

Section 3: Production run, process and vf

The envisioned production plan for the lower control arm involves manufacturing up to 100 units, initially starting with a minimum run of 10 units for testing and market feedback. The selected overbraiding process is expected to efficiently produce each item, with an estimated production cycle time reflecting its compatibility with the intricate geometry of the control arm. The time frame for the entire production will depend on the cycle time and the capacity of the manufacturing process. Cost-effectiveness is a critical consideration, prompting the choice of overbraiding over alternatives like Resin Transfer Moulding (RTM), which, while offering superior surface finish and accuracy, is deemed less suitable for the control arm's complex geometry and less economically viable for smaller production volumes. Reduction in unit cost is prioritized, and the targeted fiber volume fraction of 65% is set to ensure the desired balance of strength, stiffness, and weight characteristics in the final product, aligning seamlessly with market demands for high-performance automotive components.

Section 4: Materials

Fibre: AGY S-2 Glass Fiber[3]

Resin: Solvay CYCOM 890 RTM Epoxy Neat Resin[4]

For calculations, the selected fibre volume fractions 50% and 65% were studied. After which the latter provided better results.

The on-axis stiffness and compliances matrices for 65% vf are as follows:

Input parameters	
0.65	Fibre volume fraction vF
2.46	Density, fibres: ρF
1.22	Density, resin: ρR
86.9	Young's modulus, fibre: EF
3.1	Young's modulus, resin: ER
0.23	Poisson's ratio, fibre: vF
0.37	Poisson's ratio, resin: vR
35.3252	Shear modulus, fibre: GF
1.131387	Shear modulus, resin: GR

Figure 4.1 Input paramaters

2.026	Density, composite: ρC
57.57	Longitudinal Young's modulus, composite: EC,x
0.981153	Proportion of axial load borne by fibres
8.306815	Transverse Young's modulus (simpler model), composite: EC,y
9.444381	Transverse Young's modulus (more exact model), composite: EC,y
3.051057	Shear modulus (simpler model), composite: EC,s
4.665485	Shear modulus (more exact model), composite: EC,s
0.279	Major Poisson's ratio, composite: vC,x
0.040257	Minor Poisson's ratio (simpler model), composite: vC,y
0.04577	Minor Poisson's ratio (more exact model), composite: vC,y

Figure 4.2 Material Properties

3) Material properties as stiffness, single layer on-axis		
Qxx	(GPa)	58.224
Qyy	(GPa)	8.401
Qxy	(GPa)	2.344
Qss	(GPa)	3.051

Figure 4.1 Stiffness terms for 65%vf

Sxx	(TPa^{-1})	17.370
Syy	(TPa^{-1})	120.386
Sxy	(TPa^{-1})	-4.847
Sss	(TPa^{-1})	327.761

Figure: 4.2 Compliance terms for 65%vf

Section 5: Lamination sequences

From our previous analysis using $\left[0_{3,}90_{4}\right]_{s}$ and $[30_{2,}\ 45_{2,}{-30}_{2},{-45}_{1}]_{s}$ laminating sequences, better properties were observed in $\left[0_{3,}90_{4}\right]_{s}$ this sequence.

5.1 Stacking Sequences:

A. First Laminating Sequence $\left[0_{3,}90_{4}\right]_{s}$

In this lamination sequence plies are each located at 0 and 90 degrees respectively and the sequence is repeated.

B. Second Laminating Sequence $[30_{2,}\ 45_{2,}{-30}_{2},{-45}_{1}]_{s}$

In this lamination sequence 2 plies are each located at +30, +45, -30 and -45 degrees respectively.

The thickness of the plate is 3.5mm. Assuming the thickness of each ply to be 0.25 mm the plates will consist of total 14 plies.

Section 6: Calculations

6.1 Stiffness and Compliances:

At 65% volume fraction for $\left[0_{3,}90_{4}\right]_{s}$ laminating sequence:

Ply At angle	Vf	cos(2θ)	cos(4θ)	sin(2θ)	sin(4θ)
0	0.4285	1	1	0	0
90	0.57142	-1	1	0	0

To calculate the geometric factors, we use the following equation,

$$V_1^* = v_{f,1}\cos(2\theta_1) + v_{f,2}\cos(2\theta_2) + \ldots + v_{f,m/2}\cos(2\theta_{m/2})$$

$$V_2^* = v_{f,1}\cos(4\theta_1) + v_{f,2}\cos(4\theta_2) + \ldots + v_{f,m/2}\cos(4\theta_{m/2})$$

$$V_3^* = v_{f,1}\sin(2\theta_1) + v_{f,2}\sin(2\theta_2) + \ldots + v_{f,m/2}\sin(2\theta_{m/2})$$

$$V_4^* = v_{f,1}\sin(4\theta_1) + v_{f,2}\sin(4\theta_2) + \ldots + v_{f,m/2}\sin(4\theta_{m/2})$$

Equation 1: Relation between Normalized geometric factors and ply angle.

From equation 1 we have,

V1* = vf,$_1$ cos($2\theta_1$) + vf,$_2$ cos($2\theta_2$)

= 0.4285(1)+0.57142(-1)

= **-0.14292**

V2* = vf,1 cos($4\theta_1$) + vf,2 cos($4\theta_2$)

= 0.4285(1)+0.57142(1)

= 1

V3* = vf,1 sin($2\theta_2$) + vf,2 sin($2\theta_2$)

= 0.4285(0) + 0.57142(0)

= **0**

V4* = vf,1 sin($4\theta_1$) + vf,2 sin($4\theta_2$)

= 0.4285(0) + 0.57142(0)

$= \mathbf{0}$

Now, to calculate the values of U's from on axis stiffness terms we use the following relation,

$$
\boxed{
\begin{aligned}
U_1 &= \frac{1}{8}\left(3Q_{xx} + 3Q_{yy} + 2Q_{xy} + 4Q_{ss}\right) \\
U_2 &= \frac{1}{2}\left(Q_{xx} - Q_{yy}\right) \\
U_3 &= \frac{1}{8}\left(Q_{xx} + Q_{yy} - 2Q_{xy} - 4Q_{ss}\right) \\
U_4 &= \frac{1}{8}\left(Q_{xx} + Q_{yy} + 6Q_{xy} - 4Q_{ss}\right) \\
U_5 &= \frac{1}{8}\left(Q_{xx} + Q_{yy} - 2Q_{xy} + 4Q_{ss}\right)
\end{aligned}
}
$$

Equation 2: Relation between U's and on-axis stiffness properties

The values of U's can be obtained by putting the values of on-axis properties in equation 2,

The following values were obtained using the spreadsheet provided.

Q_{xx}	(GPa)	58.244
Q_{yy}	(GPa)	8.401
Q_{xy}	(GPa)	2.344
Q_{ss}	(GPa)	3.051

U_1	27.1034
U_2	24.9215
U_3	6.2191
U_4	8.5631
U_5	9.2701

GPa

Finally, using the conversion method, we obtained the values of the Normalised stiffness term Aij/h using the below equation and by inverting the matrix of Aij/h we can obtain the values of aij*h.

$$\begin{bmatrix} A_{11}/h \\ A_{22}/h \\ A_{12}/h \\ A_{66}/h \\ A_{16}/h \\ A_{26}/h \end{bmatrix} = \begin{bmatrix} U_1 & V_1* & V_2* \\ U_1 & -V_1* & V_2* \\ U_4 & 0 & -V_2* \\ U_5 & 0 & -V_2* \\ 0 & \frac{1}{2}V_3* & V_4* \\ 0 & \frac{1}{2}V_3* & -V_4* \end{bmatrix} \cdot \begin{bmatrix} 1 \\ U_2 \\ U_3 \end{bmatrix}$$

Equation 3: Relation between Normalized stiffness terms and material properties.

$$\Delta = \frac{(A_{11}A_{22}A_{66} + 2A_{12}A_{26}A_{61} - A_{22}A_{16}^2 - A_{66}A_{12}^2 - A_{11}A_{62}^2)}{h^3}$$

$$a_{11}h = \left(A_{22}A_{66} - A_{26}^{\ 2}\right)/\Delta h^2 \qquad a_{66}h = \left(A_{11}A_{22} - A_{12}^{\ 2}\right)/\Delta h^2$$

$$a_{22}h = \left(A_{11}A_{66} - A_{16}^{\ 2}\right)/\Delta h^2 \qquad a_{16}h = \left(A_{12}A_{26} - A_{22}A_{16}\right)/\Delta h^2$$

$$a_{12}h = \left(A_{16}A_{26} - A_{12}A_{66}\right)/\Delta h^2 \qquad a_{26}h = \left(A_{12}A_{16} - A_{11}A_{26}\right)/\Delta h^2$$

Equation 4: Relation between Normalized stiffness terms and Normalized compliance terms

Considering the following laminating sequence [0_3 / 90_4]$_S$ at 65% fibre volume fraction. From using the above-mentioned equations 3 & 4, we can calculate the Normalized Stiffness and Normalized Compliance matrices. They are as follows:

$$\boldsymbol{Normalized\ Stiffness\ Matrix} = \begin{bmatrix} \mathbf{29.7502} & \mathbf{2.3440} & \mathbf{0} \\ \mathbf{2.3440} & \mathbf{36.8748} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{3.0510} \end{bmatrix} \mathbf{GPa}$$

$$\boldsymbol{Normalized\ Compliance\ Matrix} = \begin{bmatrix} \mathbf{33.7825} & \mathbf{-2.1473} & \mathbf{0} \\ \mathbf{-2.1474} & \mathbf{27.25553} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{327.7614} \end{bmatrix} \boldsymbol{TPa^{-1}}$$

6.2 Elongation and Shear:

We have stress in the plate, and we need constant strains, therefore we require normalised compliance terms aij *h.

$$\begin{bmatrix} \varepsilon_1^{\;0} \\ \varepsilon_2^{\;0} \\ \varepsilon_6^{\;0} \end{bmatrix} = \begin{bmatrix} a_{11} * h & a_{12} * h & a_{16} * h \\ a_{21} * h & a_{22} * h & a_{26} * h \\ a_{61} * h & a_{62} * h & a_{66} * h \end{bmatrix} \cdot \begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_6 \end{bmatrix}$$

Equation 5: Relation between stress and strain in terms of normalized compliance terms

Axial strains are Ɛ1 & Ɛ2.

Shear Strain is Ɛ6.

Elongation along 1 = Ɛ1* original length along 1

The original length along 1 is from the bushings to the ball joint which is 405mm[1].

Elongation along 2 = Ɛ2* original length along 2

The original length along 2 is the length between both the bushings which is 340mm[1].

From

Lamination sequence [0_3 / 90_4]s + Fibre volume fraction 65 % with load case 1

$$\begin{bmatrix} \text{Ɛ}1 \\ \text{Ɛ}2 \\ \text{Ɛ}6 \end{bmatrix} = \begin{bmatrix} -14.96E-06 \\ 0.951E-06 \\ 0 \end{bmatrix} \mathbf{m}$$

Elongation along direction 1 = Ɛ1 x length of plate 1 along 1 = -0.01495 x 405mm = **-6mm**

Elongation along direction 2 = Ɛ2 x length of plate 1 along 2 = 0.000951 x 340 mm = **0.3mm**

Shear Strain = Ɛ6 = 0

6.2 Lamination sequence 2 [0_3 / 90_4]s + Fibre volume fraction 65 % with load case 2

$$\begin{bmatrix} \text{Ɛ}1 \\ \text{Ɛ}2 \\ \text{Ɛ}6 \end{bmatrix} = \begin{bmatrix} -0.2006E-04 \\ 1.27E-06 \\ 0 \end{bmatrix} \mathbf{m}$$

Elongation along direction 1 = Ɛ1 x length of plate 1 along 1 = -0.020 x 405 = **-8.1 mm**

Elongation along direction 2 = $\varepsilon 2$ x length of plate 1 along 2 =0.00127 x 340 mm= **0.431mm**

Shear Strain = $\varepsilon 6$ = 0

Section 6.3 Bending:

We use the [0_3 / 90_4 /z_c]$_S$ laminating sequence for the bending scenario with **7** composite layers each side and a core of thickness (z_c)equal to **8** plies totally. The Ply thickness h_o = 0.25 $\times$ 10^{-3} m ,

Zc= 4 x 0.25 x10^-3 mm =**1 mm**

The Number of plies is equal to **22.**

The total thickness h= Number of Plies x Ply thickness = 22 x 0.25 $\times$ 10^{-3} m

Therefore, h = **5.5 mm**

Ply At angle	**Vf**	**cos(2θ)**	**cos(4θ)**	**sin(2θ)**	**sin(4θ)**
0		**1**	**1**	**0**	**0**
90	**3**	**-1**	**1**	**0**	**0**

Now, we must calculate the Dij's we need to find the W* terms from the below mentioned equation,

$$W_1^* = \frac{8}{n^3}\left[\cos(2\theta_1) + 7\cos(2\theta_2) + 19\cos(2\theta_3) + 37\cos(2\theta_4) + \ldots\right]$$

$$W_2^* = \frac{8}{n^3}\left[\cos(4\theta_1) + 7\cos(4\theta_2) + 19\cos(4\theta_3) + 37\cos(4\theta_4) + \ldots\right]$$

$$W_3^* = \frac{8}{n^3}\left[\sin(2\theta_1) + 7\sin(2\theta_2) + 19\sin(2\theta_3) + 37\sin(2\theta_4) + \ldots\right]$$

$$W_4^* = \frac{8}{n^3}\left[\sin(4\theta_1) + 7\sin(4\theta_2) + 19\sin(4\theta_3) + 37\sin(4\theta_4) + \ldots\right]$$

Equation 6: Relation between ply angle and Wi*

t	t^3	$(t-1)^3$	$t^3-(t-1)^3$
1	1	0	1
2	8	1	7
3	27	8	19
4	64	27	37
5	125	64	61
6	216	125	91
7	343	216	127
8	512	343	169
9	729	512	217
10	1000	729	271
11	1331	1000	331
12	1728	1331	397
13	2197	1728	469
14	2744	2197	547
15	3375	2744	631
16	4096	3375	721
17	4913	4096	817
18	5832	4913	919
19	6859	5832	1027
20	8000	6859	1141

Table 6.1 Values of t

Considering the values from t=5 because the core thickness is t=4 on either side

$W1^* = (8/22^3)\ ((61+91+127+169) \cos(2\theta_1) + (217+271+331) \cos (2\theta_2))$

$= 0.00075131\ (448(-1)+819(1)$

$\mathbf{= 0.278736}$

$W2^* = (8/22^3)\ ((61+91+127+169) \cos(4\theta_1) + (217+271+331) \cos (4\theta_2))$

$= 0.00075131 * 1267$

$\mathbf{= 0.95228987}$

$W3^* = (8/22^3)\ ((61+91+127+169) \sin(2\theta_1) + (217+271+331) \sin(2\theta_2))$

$= 0.00075131\ (0)$

$\mathbf{= 0}$

$W4^* = (8/22^3)\ ((61+91+127+169) \sin(4\theta_1) + (217+271+331) \sin(4\theta_2))$

$= 0.00075131\ (0)$

$\mathbf{= 0}$

Now we need to find I*

$I^* = h^* = h^3 /12$

= $(22*0.25)^3/12$

= 166.375/12

= $13.86 * 10^{-9}$ m^3

Now we need to calculate the geometric factors,

W1 = W1* · I*

= 0.278736 * 13.86 * 10^{-9} m^3

= 3.8632* 10^{-9} m^3

W2 = W2* · I*

= 0.95228987* 13.86 * 10^{-9} m^3

= 13.1987375982* 10^{-9} m^3

W3 = W3* · I*

= 0 * 13.86 * 10^{-9} m^3

= **0 m^3**

W4 = W4* · I*

= 0.249849 * 13.86 * 10^{-9} m^3

= 0 m^3

h*= $h^3/12(1-(2z_c/h)^3)$

= 13.86 * 10^{-9} m^3 (0.951915)

= 13.193553719 * 10^{-9} m^3

We obtained the values of the in-plane stiffness matrices Qxx, Qyy, Qxy, and Qss from previous work for each fibre volume fraction and used these stiffness matrix values to calculate Us, which is a function of the on-axis stiffness term. Finally, using the below equation, we obtained the values of the Dij and dij.

$$\begin{bmatrix} D_{11} \\ D_{22} \\ D_{12} \\ D_{66} \\ D_{16} \\ D_{26} \end{bmatrix} = \begin{bmatrix} U_1 & W_1 & W_2 \\ U_1 & -W_1 & W_2 \\ U_4 & 0 & -W_2 \\ U_5 & 0 & -W_2 \\ 0 & \frac{1}{2}W_3 & W_4 \\ 0 & \frac{1}{2}W_3 & -W_4 \end{bmatrix} \cdot \begin{bmatrix} h^* \\ U_2 \\ U_3 \end{bmatrix}$$

Equation 7: Relation between Dij’s and material properties

By using the above equation 7 we can get Dij terms as follows, (refer **Appendix I**)

$$D=\begin{bmatrix} 535.5905 & 30.9291 & 0 \\ 30.9291 & 343.4232 & 0 \\ 0 & 0 & 40.5270 \end{bmatrix} Nm$$

$$d=\begin{bmatrix} 0.0019 & -0.0002 & 0 \\ -0.0002 & 0.0029 & 0 \\ 0 & 0 & 0.0248 \end{bmatrix} Nm^{-1}$$

From previous bending case we have a moment of 1291 Nm. Therefore, the moment per width will be Moment/(width of the laminate) which is equal to **3797Nm/m.**

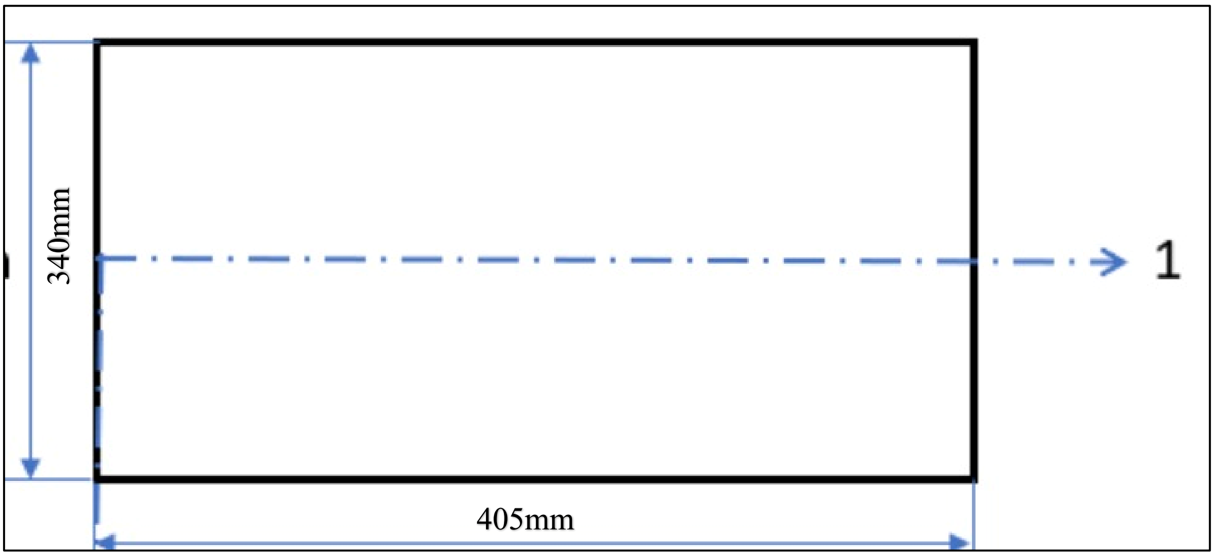

Figure 6.3.1: Top view of the assumed rectangle plate on which the bending force acts vertically.

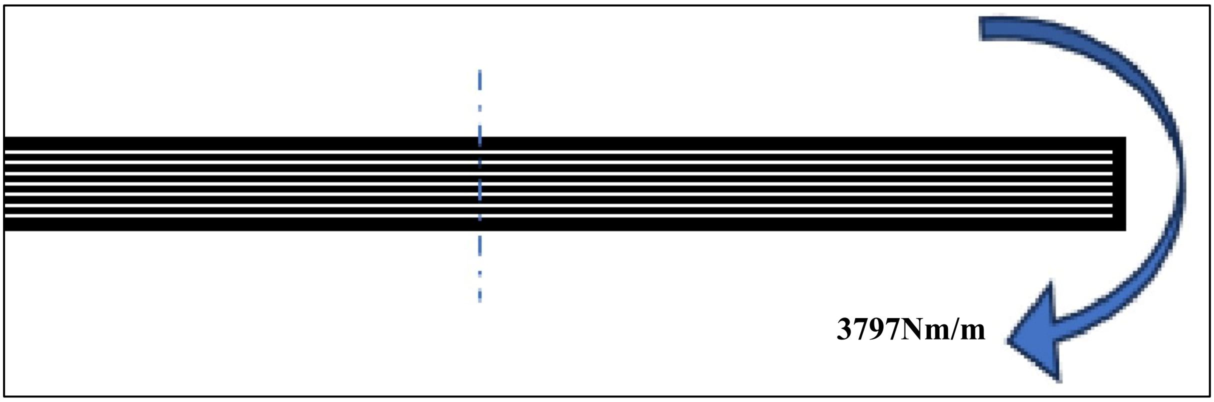

Figure 6.3.2: Representation of Bending moment

$$\begin{bmatrix} k_1 \\ k_2 \\ k_6 \end{bmatrix} = \begin{bmatrix} d_{11} & d_{12} & d_{16} \\ d_{21} & d_{22} & d_{26} \\ d_{61} & d_{62} & d_{66} \end{bmatrix} \cdot \begin{bmatrix} M_1 \\ M_2 \\ M_6 \end{bmatrix}$$

Equation 8: Relation between Moment and curvature "k"

By using equation 8, we can get the value of curvatures as k1, k2 and k3 as mentioned below.

$$\begin{bmatrix} \boldsymbol{K1} \\ \boldsymbol{K2} \\ \boldsymbol{k3} \end{bmatrix} = \begin{bmatrix} \mathbf{7.12} \\ \mathbf{-0.6418} \\ \mathbf{0} \end{bmatrix}$$

Curvature Radii The curvature (k) of a beam is related to the curvature radius (r) by the following formula: r = 1/K

Curvature Radius:

R1 = **140.3 mm**
R2 =**-1558.117 mm**

Elongational strains:

The strains in each ply are obtained by multiplying the curvature by the z coordinate corresponding to that ply.

For Outermost ply with core, value of z = 2.75 x 10^-3m

$$\varepsilon_1(z) = z \cdot k_1 \qquad \varepsilon_2(z) = z \cdot k_2 \qquad \varepsilon_6(z) = z \cdot k_6$$

Equation 9: Relation between z and curvature

By using equation 9, we can get the strains.

$$\begin{bmatrix} \mathcal{E}1 \\ \mathcal{E}2 \\ \mathcal{E}6 \end{bmatrix} = \begin{bmatrix} 19.596E - 03 \\ 1.76495E - 03 \\ 0 \end{bmatrix}$$

Deflection of the cantilever beam:

The moment of inertia about the neutral axis for the rectangle on which the bending force of 3188.25N is given by the formula I = bd^3/12 = 4.25 × $10^{-8} mm^4$, Therefore we get the deflection as,

$$\text{Deflection} = \frac{F \times L^3}{3 \times E \times I} = \frac{3188.25 \times (450 \times 10^{-3})^3}{3 \times 57.57\text{x}10^9 \times 4.25 \times 10^{-8}} = \mathbf{0.346\boldsymbol{mm}}$$

Section 7: Conclusion

1. For the mentioned analysis a **S-2 glass fibre** with a density of **2.46g/cc** was selected. According to our research it is a widely available and relatively cheap commodity material.
2. For the resin we have selected an **Epoxy neat resin** which has good resistance to moisture and polluting elements as well as good mechanical properties.
3. For the in-plane load cases a larger value of stress was observed for the second load case and as result a significantly larger value of elongation was observed along the plate around **-8.1mm**
4. In the first laminating sequence, **$[\ 0_3 / 90_4\ ]_S$** the shear strains are **0** as this is a cross ply laminating sequence.
5. In $[\ 0_3 / 90_4\ ]_S$ ith layers oriented at 0 and 90 degrees; this sequence is comparatively simple and quite easy to manufacture.
6. $[\ 0_3 / 90_4\ ]_S$ has isotropic properties in the laminate's plane, which qualifies it for uses requiring comparable strength in both directions.
7. Less complicated laminates can be produced more cheaply and with greater ease.
8. For bending the stiffness matrix has better values for **$[\ 0_3 / 90_4\ ]_S$** laminating sequence than $[\mathbf{30_2}, \mathbf{45_2}, \mathbf{-30_2}, \mathbf{-45_1}]_s$ laminating sequence.
9. For the selected lamination sequence **$[\ 0_3 / 90_4\ ]_S$** since there plies oriented at 0 degrees at both sides of the skin the contribution to the stiffness is greater and it results in good stiffness parameters.

Section 7: References

[1] Papacz, W. , Kuryło, P. , & Tertel, E. (2013). The Composite Control Arm – Analysis of the Applicability in Conventional Suspension. *American Journal of Mechanical Engineering*, *1*(7), 161-164.

[2] M. Sadiq A. Pachapuri, R. G. (2021). Design and analysis of lower control arm of suspension system. *Elsevier*.

[3]URL of fibre: https://www.matweb.com/search/DataSheet.aspx?MatGUID=881df8cd9bde4344820202eb6d1e7a39 (visited on 12/05/2023)

[4]URL of resin: https://www.matweb.com/search/DataSheet.aspx?MatGUID=595fd56422eb453ba6572c2830714c95 (visited on 12/05/2023)

Appendix I

```
%We use the values form 2nd assignment
u1=27.0959e9
u2=24.9115e9
u3=6.2166e9
u4=8.5606e9
u5=9.2676e9

syms D11 D22 D12 D26 D66 D16
%Values of w1,w2,w3,w4
w1= 3.857e-9
w2= 13.193e-9
w3= 0
w4= 0
D=[D11;D22;D12;D66;D16;D26]
h1= 13.193553719e-9

%Calculating the Dij→s

U =[u1 w1 w2 ;u1 -w1 w2;u4 0 -w2;u5 0 -w2;0 0.5*w3 w4;0 0.5*w3 -w4]
W =[h1;u2;u3]

D = U*W
```

```
D11=535.5905
D22=343.4232
D12=30.9291
D66=40.2570
D16=0
D26=0

DD=[D11 D12 D16;D12 D22 D26;D16 D26 D66]
d=inv(DD)
m1=
M=[m1;0;0]
syms k1 k2 k3

K=[k1;k2;k3]
%k = INVERSE OF d[]*M{}
K= d*M
```