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Analysis and Fabrication of Composite Wing Spar

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ABSTRACT

To increase the structural properties of aircraft components like spar web by replacing the individual materials with the composite material. Composite material is combination of two or more materials having compositional variations and depicting properties distinctively different from those of the individual materials of the composite.

A composite material provides much better benefits against bending when applying loads. The composite materials are prepared with 1:10 epoxy hardener and epoxy resin. These are laminated by the glass fiber and mild steel rods. The mild steel rods provide structural strength to the wing spar. Finally we obtained the opened fiber glass epoxy.

Initially the spar web is considered with individual and composite materials. To find the bending moment, three different approaches has been done: numerical, analytical and experimental approaches. When some external loads acts on a beam a shear force and bending moment are set up at all sections of the beam. Due to the sheer force and bending moment, the beam undergoes certain deformation. The material of the beam will offer resistance or stresses against these deformations. These stresses with certain assumptions can be obtained by three approaches.

Thus, composite material fibre glass epoxy provides more efficient structural properties than the individual metal alloys.

***Keywords:** Wing Spar, Composite Materials, Analysis, FRP, Epoxy Resin, Fibre Process, Aircraft, Hardner, Analysis.*

1. INTRODUCTION

COMPOSITES

The advent of technology has lead manufacture to fabricate aircraft components using composite materials. There many advantages provided by composite materials. In this project, due to the advantage of composite materials, is selected for use to fabricate aircraft wing.

Composite materials have been utilized to solve technological problems for a long time but only in the 1960's did these materials start capturing the attention of industries with the introduction of polymeric-based composites. Since then, composite materials have been common engineering materials and are designed and manufacture for various applications including automotive components, sporting goods, aerospace parts, consumer goods, and in the marine be and oil industries awareness regarding product performance and increased competition in the global market for lightweight components. Among all materials, composite materials have the potential to replace widely used steel and aluminum, and many times with the better performance. Replacing steel components composite components can save 6-80% in component weight, and 20-50% weight by replacing aluminum parts. Today, it appears that composite are the materials of choice for many engineering applications.

Fibre-reinforced plastic (**FRP**) (also *fibre-reinforced polymer*) is a composite material made of a polymer matrix reinforced with fibers. The fibers are usually glass, carbon, basalt or aramid, although other fibers such as paper or wood or asbestos have been sometimes used. The polymer is usually an epoxy, vinyl ester or polyester thermosetting plastic, and phenol formaldehyde resins are still in use. FRPs are commonly used in the aerospace, automotive, marine, and construction industries.

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Figure 1 EPOXY FIBRE GLASS

PROCESS DEFINITION

A polymer is generally manufactured by Step-growth polymerization or addition polymerization. When combined with various agents to enhance or in any way alter the material properties of polymers the result is referred to as a plastic. Composite plastics refer to those types of plastics that result from bonding two or more homogeneous materials with different material properties to derive a final product with certain desired material and mechanical properties. Fibre reinforced plastics are a category of composite plastics that specifically use fibre materials to mechanically enhance the strength and elasticity of plastics.

The original plastic material without fibre reinforcement is known as the matrix. The matrix is a tough but relatively weak plastic that is reinforced by stronger stiffer reinforcing filaments or fibers. The extent that strength and elasticity are enhanced in a fibre reinforced plastic depends on the mechanical properties of both the fibre and matrix, their volume relative to one another, and the fibre length and orientation within the matrix. Reinforcement of the matrix occurs by definition when the FRP material exhibits increased strength or elasticity relative to the strength and elasticity of the matrix alone

FIBRE PROCESS

The manufacture of fibre fabric

Reinforcing Fibre is manufactured in both two dimensional and three dimensional orientations

1. Two Dimensional Fibre Reinforced Polymer are characterized by a laminated structure in which the fibers are only aligned along the plane in x-direction and y-direction of the material. This means that no fibers are aligned in the through thickness or the z-direction, this lack of alignment in the through thickness can create a disadvantage in cost and processing. Costs and labor increase because conventional processing techniques used to fabricate composites, such as wet hand lay-up, autoclave and resin transfer moulding, require a high amount of skilled labor to cut, stack and consolidate into a preformed component.
2. Three-dimensional Fibre Reinforced Polymer composites are materials with three dimensional fibre structures that incorporate fibers in the x-direction, y-direction and z-direction. The development of three-dimensional orientations arose from industry's need to reduce fabrication costs, to increase through-thickness mechanical properties, and to improve impact damage tolerance; all were problems associated with two dimensional fiber reinforced polymers.

EPOXY RESIN

Epoxy is both the basic component and the cured end product of epoxy resins, as well as a colloquial name for the epoxide functional group. Epoxy resins, also known as polyepoxides are a class of reactive prepolymers and polymers which contain epoxide groups. Epoxy resins may be reacted (cross-linked) either with themselves through catalytic homo polymerization, or with a wide range of co-reactants including polyfunctional amines, acids (and acid anhydrides), phenols, alcohols, and thiols. These co-reactants are often referred to as hardeners or curatives, and the cross-linking reaction is commonly referred to as curing. Reaction of polyepoxides with themselves or with polyfunctional hardeners forms a thermosetting polymer, often with high mechanical properties, temperature and chemical resistance. Epoxy has a wide range of applications, including metal coatings, use in electronics / electrical components, high tension electrical insulators, fiber-reinforced plastic materials, and structural adhesives. Epoxy resin is employed to bind gutta percha in some root canal procedures.

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Figure 2 epoxy resin

Epoxy resin chemistry

Epoxy resins are low molecular weight pre-polymers or higher molecular weight polymers which normally contain at least two epoxide groups. The epoxide group is also sometimes referred to as a glycidyl or oxirane group. A wide range of epoxy resins are produced industrially. The raw materials for epoxy resin production are today largely petroleum derived; although some plant derived sources are now becoming commercially available (e.g. plant derived glycerol used to make epichlorohydrin).

Epoxy resins are polymeric or semi-polymeric materials, and as such rarely exist as pure substances, since variable chain length results from the polymerisation reaction used to produce them. High purity grades can be produced for certain applications, e.g. using a distillation purification process. One downside of high purity liquid grades is their tendency to form crystalline solids due to their highly regular structure, which require melting to enable processing.

An important criterion for epoxy resins is the epoxide content. This is commonly expressed as the epoxide number, which is the number of epoxide equivalents in 1 kg of resin (Eq./kg), or as the equivalent weight, which is the weight in grams of resin containing 1 mole equivalent of epoxide (g/mol). One measure may be simply converted to another:

Equivalent weight (g/mol) = 1000 / epoxide number (Eq./kg)

The equivalent weight or epoxide number is used to calculate the amount of co-reactant (hardener) to use when curing epoxy resins. Epoxies are typically cured with stoichiometric or near-stoichiometric quantities of curative to achieve maximum physical properties.

As with other classes of thermoset polymer materials, blending different grades of epoxy resin, as well as use of additives, plasticizers or fillers is common to achieve the desired processing and/or final properties, or to reduce cost. Use of blending, additives, and fillers is often referred to as formulating.

Figure 3 Epoxy resin (Lapox-12)

Bisphenol A epoxy resin

The most common and important class of epoxy resins is formed from reacting epichlorohydrin with bisphenol A to form diglycidyl ethers of bisphenol A. The simplest resin of this class is formed from reacting two moles of epichlorohydrin with one mole of bisphenol A to form the bisphenol A diglycidyl ether (commonly abbreviated to DGEBA or BADGE). DGEBA resins are transparent colourless-to-pale-yellow liquids at room temperature, with viscosity typically in the range of 5-15 Pa.s at 25°C. Industrial grades normally contain some distribution of molecular weight, since pure DGEBA shows a strong tendency to form a crystalline solid upon storage at ambient temperature.

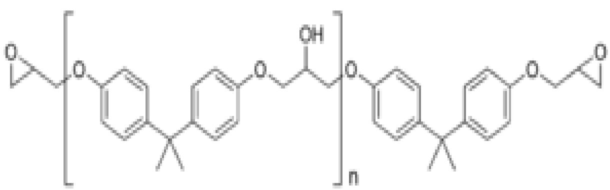

Figure 4 Structure of bisphenol-A diglycidyl ether epoxy resin

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Increasing the ratio of bisphenol A to epichlorohydrin during manufacture produces higher molecular weight linear polyethers with glycidyl end groups, which are semi-solid to hard crystalline materials at room temperature depending on the molecular weight achieved. As the molecular weight of the resin increases, the epoxide content reduces and the material behaves more and more like a thermoplastic. Very high molecular weight polycondensates (ca. 30 000 – 70 000 g/mol) form a class known as phenoxy resins and contain virtually no epoxide groups (since the terminal epoxy groups are insignificant compared to the total size of the molecule). These resins do however contain hydroxyl groups throughout the backbone, which may also undergo other cross-linking reactions, e.g. with aminoplasts, phenoplasts and isocyanates.

HARDNER:

The hardener used in the composite structure is hardener K-6with LAPOX epoxy resin. lapox epoxy resin have the following outstanding properties excellent adhesion to many different materials. Great strength, toughness and resilience. Excellent resistance to chemical attack and to moisture outstanding electrical insulating properties. Absence of volatilize on curing. Negligible shrinkage.

Figure 5 Hardener (K-6)

3 IMPORTANCE OF SPAR IN AIRCRAFT

In a fixed-wing aircraft, the **spar** is often the main structural member of the wing, running span wise at right angles (or thereabouts depending on wing) to the fuselage. The spar carries flight loads and the weight of the wings while on the ground. Other structural and forming members such as ribs may be attached to the spar or spars, with stressed skin construction also sharing the loads where it is used. There may be more than one spar in a wing or none at all. However, where a single spar carries the majority of the forces on it, it is known as the main spar.

Spars are also used in other aircraft aerofoil surfaces such as the tail plane and fin and serve a similar function, although the loads transmitted may be different to those of a wing spar.

Figure 6 : Main spar of a de Havilland DH.60 Moth

SPAR LOADS

The wing spar provides the majority of the weight support and dynamic load integrity of cantilever monoplanes, often coupled with the strength of the wing 'D' box itself. Together, these two structural components collectively provide the wing rigidity needed to enable the aircraft to fly safely. Biplanes employing flying wires have much of the flight loads transmitted through the wires and interplane struts enabling smaller section and thus lighter spars to be used

FORCES

Some of the forces acting on a wing spar are:

- Upward bending loads resulting from the wing lift force that supports the fuselage in flight.

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These forces are often offset by carrying fuel in the wings or employing wing-tip-mounted fuel tanks; the Cessna 310 is an example of this design feature.

- Downward bending loads while stationary on the ground due to the weight of the structure, fuel carried in the wings, and wing-mounted engines if used.
- Drag loads dependent on airspeed and inertia.
- Rolling inertia loads.
- Chord wise twisting loads due to aerodynamic effects at high airspeeds often associated with washout, and the use of ailerons resulting in control reversal. Further twisting loads are induced by changes of thrust settings to under wing-mounted engines. The "D" box construction is beneficial to reduce wing twisting.

Many of these loads are reversed abruptly in flight with an aircraft such as the Extra 300 when performing extreme aerobatic manoeuvres; the spars of these aircraft are designed to safely withstand great load factors.

4. ANALYSIS

My Analysis of wing spar is done in two ways:

1. Experimental approach
2. Analytical approach

Experimental approach:-

Experimental approach is done using the experimental data. Various loads are added and the strength of the material is calculated using manual calculations. The average of the loads is taken as the final result.

Analytical approach:-

Analytical approach includes creating the model in software and finding out the deflection, shear centre, and shear flow.

XPERIMENTAL APPROACH

PREPARING TRAYS

For preparing spar of channel section and Z section we require the channel and Z section trays. We prepared these trays with aluminum sheet. The dimension of required sheet is 510*210 mm of two pieces. One is used to channel and another is Z section.

The channel section is made from aluminum sheet, by using straight cutter, hammer, tape, sharp channel and long steel scale. First we marked the sheet as 50 mm, 100mm and 50 mm along the width. The length of the section is 500 mm.

By using hammer and channel we mould the aluminum sheet into channel section. The same process is used for preparing Z- section also. To cover the composite after pouring in trays we used another set of trays, these are small compared to main trays to fix into the main trays on composite material. These trays are used to get smooth surface of spar sections.

The dimensions of sections are

Length: 500 mm

Web: 100 mm

Flanges: 50 mm.

Figure 8: Preparing Tray

Preparing of composite material:

The composite material is prepared with the epoxy hardener and epoxy resin in ratio of 1:10. First the resin is pour in bowl and mix hardener with gently until that seems to be one material.

After mixing the epoxy resin and hardener, take the aluminum trays and epoxy fibre glass. Keep a cover on

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trays to avoid damage when removing composite structure from trays. Use glouses when working with these composite materials to avoid skin diseases.

First apply the mixture to cover using scrubber that is bottom surface of the structural component, on that keep one layer of epoxy fibre glass and apply the composite solution. The same process will do up to 4 – 5 layers.

Do the same process for all layers until channel section is completed with required thickness.

For the Z-section also prepared in same way, the figure shows the preparation of Z-section

Experimental approaches include finding out the shear centre of C- section and Z- section.

Figure 9: Preparing of composite material

SHEAR CENTRE OF C- SECTION

AIM: Shear centre of an C- section determination.

THEORY**:** For any unsymmetrical section there exists a point at which any vertical force does not produce a twist of that section. This point is known as shear centre.

The location of this shear centre is important in the design of beams of open sections when they should bend without twisting, as they are weak in resisting torsion. A thin walled channel section with its web vertical has a horizontal axis of symmetry and shear centre lies on it. The aim of the experiment is to determine its location on the axis if the applied shear to the tip section is vertical (i.e. along the direction of one of the principal axis of the section) and passes through the shear centre tip, all other sections of the beam do not twist.

Figure 10: shear center calculations on channel section

PROCEDURE:

1. Mount two dial gauges on the flange at a distance apart at the free end of the beam. set the dial gauge readings to zero.
2. Place a total say 1.3Kgs load at A (loading hook and six load pieces will make up this value).note the dial gauge readings (hooks also weigh a 100gms each).a side dial gauge rotate in anticlockwise direction. B-side dial gauge rotate in

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anticlockwise direction. Note down the dial gauge readings.

3. Now remove one load piece from the hook at A and place in hook B. This means that total vertical load on this section remains 1.4kg. Record the dial gauge readings.
4. Transfer carefully all the load pieces to B one by one. Noting each time the dial gauges readings. This procedure ensures that while the magnitude of the resultant vertical force remains the same its line of action shifts by a known amount along AB every time a load piece is shifted. Calculate the distance 'e' of the line of action from the web thus:
5. For every load case calculate the algebraic difference between the dial gauge is (u-v) readings as the measure of the angle of twist (ϴ) suffered by the section.
6. Plot θ against e and obtain the meeting point of the curve (a straight line in this case) with the e-axis (i.e., ϴ ,the twist of the section is zero for this location of the resultant vertical load). This determines the shear center.

Though a nominal value of 1.2kgs for the load is suggested it can be less. In that event the number of readings taken will reduce proportionately.

Dimensions of the beam and the section

Length of the beam (L) : 500

Height of the web (b) : 100

Width of the flange (b) : 50

Thickness of the sheet (t) : 4

Distance between the hook stations (AB) : 300

Theoretical location of the shear center (e) : 18.75

Vertical load w_v= (w_a+w_b), 0.2kgs-6nos

S. No	Wa	W_b	d1	d2	d1-d2	E=AB(w_a − w_b)/(2*w_v)
1	1.3	0.1	-393	-70	-323	128.5714
2	1.1	0.3	-335	-110	-225	85.714
3	0.9	0.5	-275	-152	-123	42.857
4	0.7	0.7	-214	-195	-19	0
5	0.5	0.9	-150	-245	95	-42.857
6	0.3	1.1	-79	-320	241	-85.714
7	0.1	1.3	-4	-392	388	-128.571

Calculations:

$$e_{the}=\frac{3b}{6+\frac{h}{b}}$$
$$=\frac{3*50}{6+\frac{100}{50}}$$
=18.75 mm

$$e_{exp}=\frac{AB(W_a-W_b)}{2*W_v}$$

Where AB =length of the centre to centre hook distance. From centre to centre of load.

$$=\frac{300*1.2}{2*1.4}$$
=128.5714

And applied same process for all readings

Draw the graph: deflection –$(d_1 - d_2)$ vs e_{exp}.

Plot e, versus (d1-d2) curve and determine where this meets the e axis and locate the shear center.

Conclusion:-

$e_{the} > e_{exp}$ And nearer to the value.

The difference due to both backlash and slippages at the points of contact between the dial gauges and the sheet surface and can induce errors if not taken care of.

Repeat the experiment with identical settings several times to ensure consistently in the readings.

Graph of channel section

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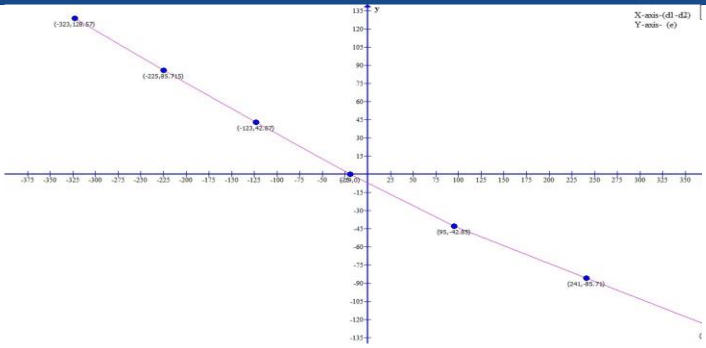

Graph of channel section

UNSYMMETRICAL BENDING OF BEAMS

AIM**:** principal axes of an unsymmetrical section determination.

THEORY**:**

The flexure formula $\sigma = \frac{M_y}{I}$ based on the elementary theory of bending beams assumes that the load is always applied through one of the principal axes of the section. Actually, even if the applied load passes through the centroid and /or the shear centre of the section the plane of loading need not necessarily be the same. Therefore, a knowledge of the location of the principal axes is required for the determination of the stress distribution in beams (of any arbitrary cross section) using flexure formula. The determination of the principal axes experimentally is described here.

If the Ix, Iy and Ixy are the moments and product of inertia of any section about an arbitrary orthogonal centroidal axes OX and OY then the inclination θ of the principal axes to OX is given by

$$\text{Tan}2\theta = \frac{2I_{xy}}{I_y - I_x} \quad ; \quad \theta = 1/2 \tan^{-1}\frac{2I_{xy}}{I_y - I_x}$$

The experimental determination if the principal axes of a given section is based on the fact that when the load passes through the shear centre and is in the direction of the principal axes of the section, the entire section under the load deflects in the direction of the load only.

Figure 11: shear centre calculations on Z-section

Procedure**:**

1. Mount two dial gauges on the section to measure the horizontal and vertical deflections of a point (u/v) .set dial gauges to zero.
2. Apply the vertical load W_v (about 2.2 kg include two hooks each pan 1kg+100gm pan weight) = (w_a+w_b)= W_v
3. Read u and v horizontal and vertical deflections respectively, and note down the reading in the tabular column.
4. Increase the loadW_h in steps of about 200gm (for the first case 200gm + 100gm hook) from zero to maximum about 1.1kg noting down in

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each case the values of u and v. Repeat the procedure and check for consistently in measurements . Every time before taking reading hit gently the beam for settling of reading in dial gauge.

5. Plot the graphs (u/v) vs $(\frac{W_h}{W_v})$ and find the intersection of this curve with a straight line to the origin at 45°(note: the X and Y scales must be chosen to be same for the graph).
6. The inclination of the principal axes to the web as $\theta_{exp} = \tan^{-1}\frac{W_v}{W_h}$

   Where W_v and W_h correspond to the point of intersection. (from the graph).
7. Calculate the inclination ϴ using eqn.

   Vertical load W_v = $(w_a + w_b)$ specimen = l= 22cm

Table-1

S. no	W_h	Dial gauge readings		$\frac{W_h}{W_v}$	u/v
		u	v		
1	0.1	-43	290	0.045	-0.148
2	0.3	22	12	0.136	1.833
3	0.5	22	8.5	0.227	2.588
4	0.7	30	16	0.318	1.875
5	0.9	38	16	0.409	2.375
6	1.1	25	13	0.500	1.9230
7	1.3	44	13	0.591	3.3846

CALUCLATIONS:-

$\frac{W_h}{W_v} = \frac{0.1}{2.2}$ =0.045

$\frac{U}{V} = \frac{22}{12}$ = 1.833

Like this all the calculations are done by using the dial gauge readings.

The values are tabulated above.

Conclusion:

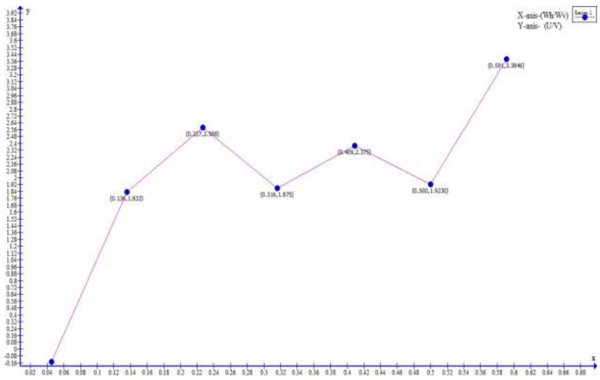
$e_{the} > e_{\ exp}$ and nearer to the value.

The difference due to error may be noted down in the readings.

This shift happens due to both backlash and slippages at the points of contact between the dial gauges and the sheet surfaces and can induce errors if not taken care of.

Repeat the experiments with identical settings several times to ensure consistency in the readings

Z-section graph



TENSION TEST

AIM**: -** Universal testing machine is used to find Young's modulus, Ultimate stress, breaking stress, percentage elongation, percentage reduction in cross section area.

APPARATUS: - 40 Tone UTM, calipers, gauge marker, scale, and rectangular fiberglass epoxy composite material with thickness 3.6mm.

THEORY: - UTM is machine designed to test specimen in tension, compression, flexure, shear, machine comprises of

1. Machine frame that is loading unit.
2. Hydraulic system
3. Electronic control panel

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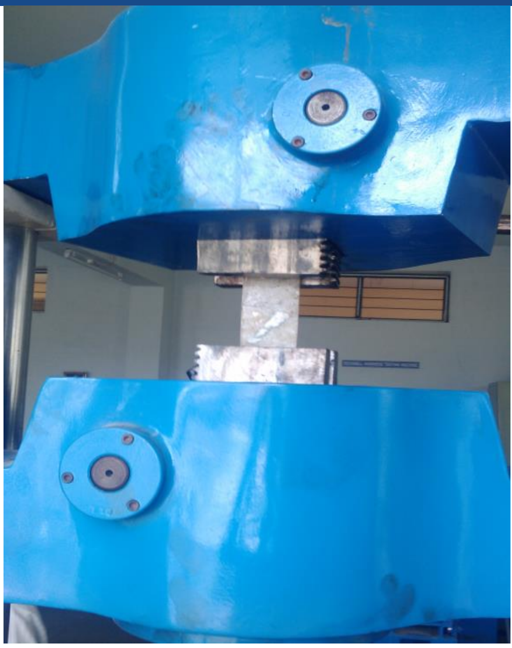

Figure 12 UTM and specimen

PROCEDURE:-

1. The dimension of the composite rectangular plate is measured.
2. The specimen is firmly fixed between jaws for a known gauge length.
3. The left valve is kept fully closed and right valve in normal open position.
4. The centre cross head is now operated to move downward, to elongate the bar.
5. The right jaw is opened and load allowed to increase steadily till specimen breaks, intermittent valves of load and elongation are noted and values tabulated.
6. The data is recorded electronically and graph is plotted. From the graph, yield stress, UTS, breaking strength ,percentage elongation can be calculated.

Original dimensions:-

Length = 23.6cm

Width = 4.6cm

Thickness = 0.36cm

Sample calculations

Stress =load/area

Strain = change in dimensions/original dimension

Young's modulus = stress / strain

Figure 13: Breaking of test piece

CALCULATIONS:-

Load (p) =12.5KN

Area (A) = $162mm^2$

Stress (σ)=$\frac{p}{A}$ =$\frac{12.5*10^3}{162}$ =77.1 N/mm^2

Strain :-

Original length l_1 =236mm

Final length l_2= 237mm

Change in length $\Delta l = l_1 - l_2$

Δl= 1mm

$\varepsilon = \frac{\Delta l}{l_1} = \frac{1}{236} = 4.23 * 10^{-3}$

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Young's modulus:-

$E = \frac{\sigma}{\varepsilon} = \frac{77.1}{4.23*10^{-3}} = 18.22 KN/mm^2$

Poisson's ratio:-

$\gamma = \frac{lateral\ strain}{longitudinal\ strain}$

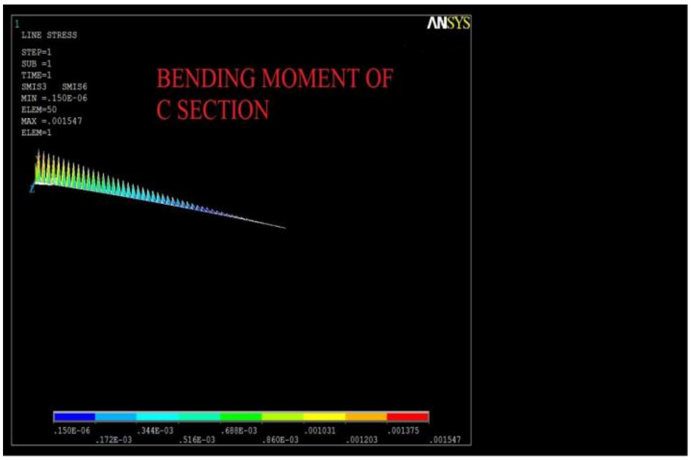
γ= 0.5244

Density:-

Density= mass/ volume

=104.25Kg/m^3

5. ANLYTICAL APPROACH BENDINGMOMENT



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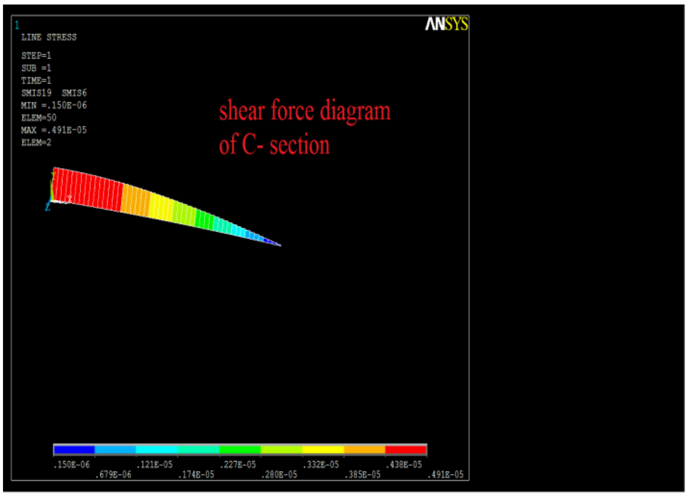

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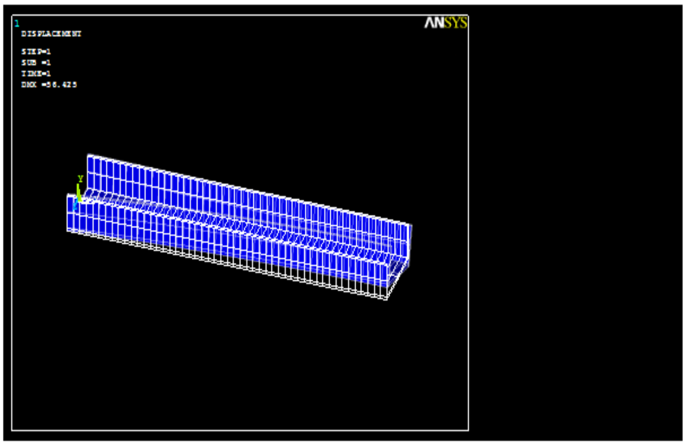

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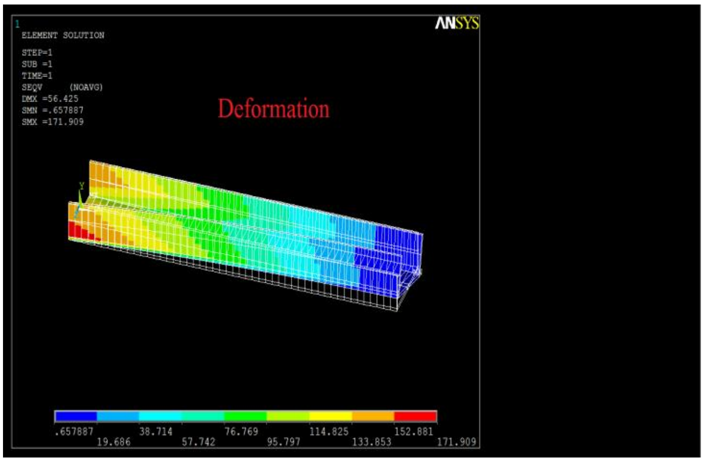

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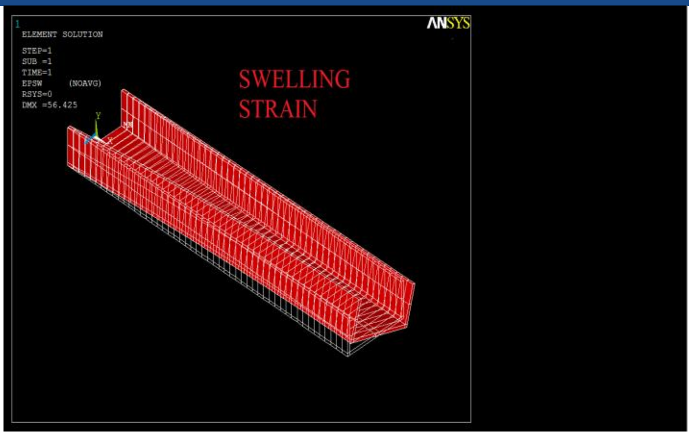

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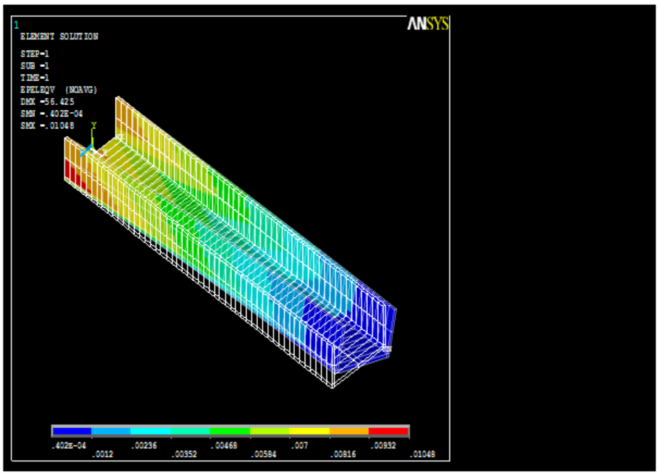
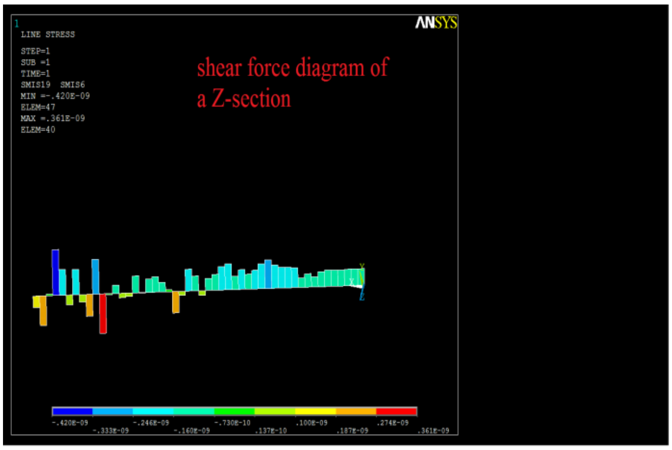
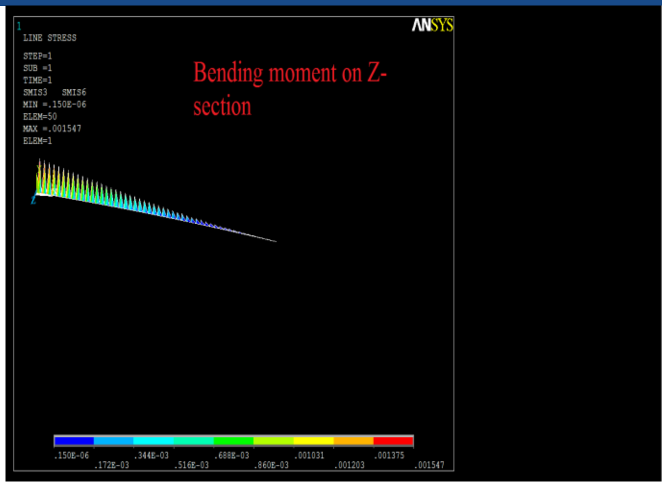
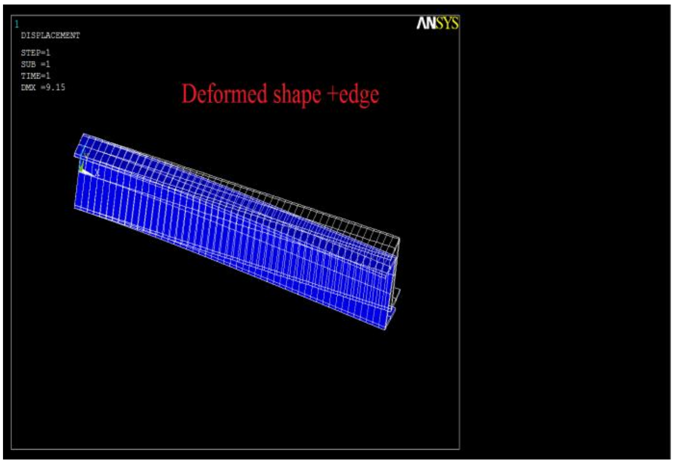
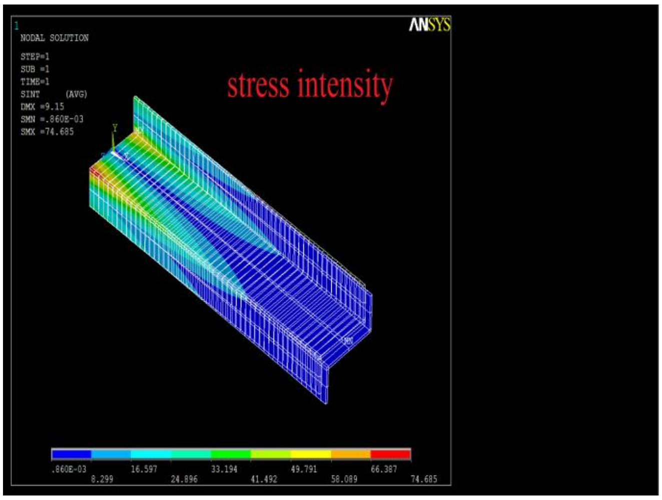


ANALYTICAL APPROACH ON Z- SECTION USING ANSYS









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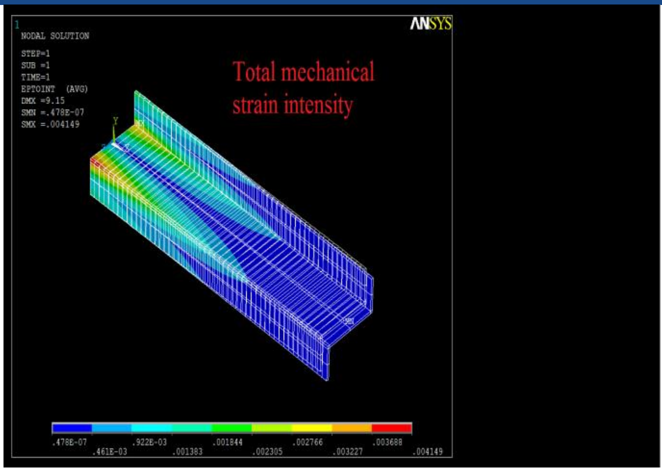

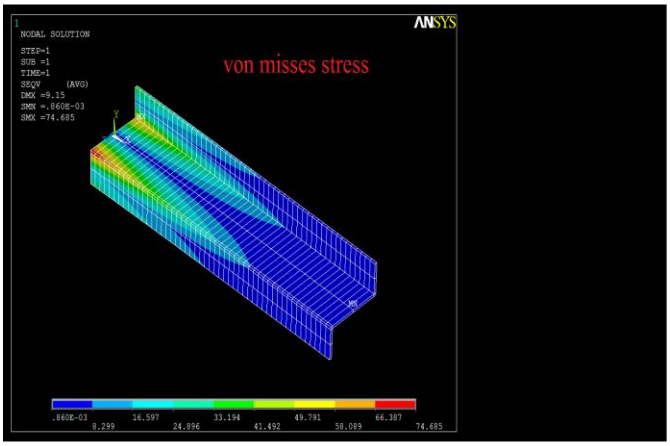

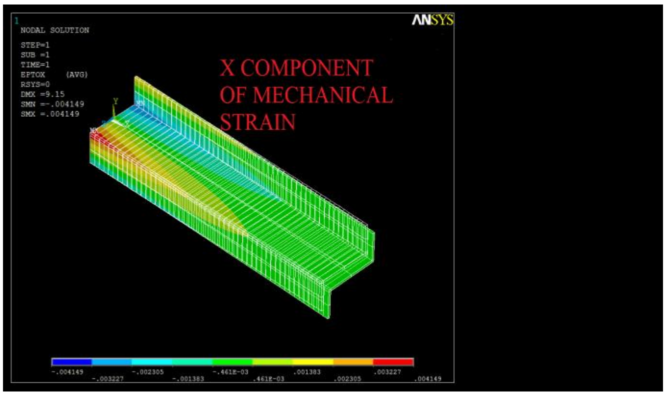

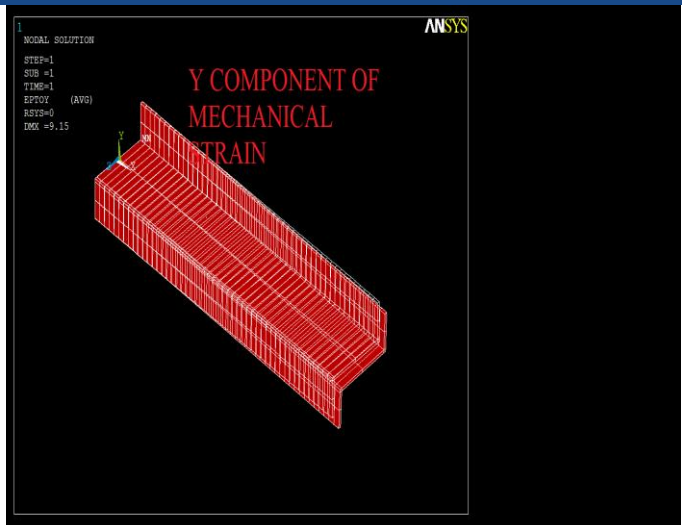

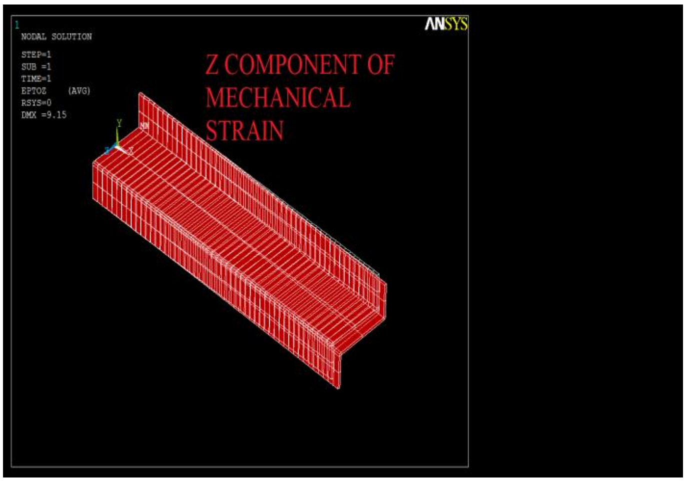

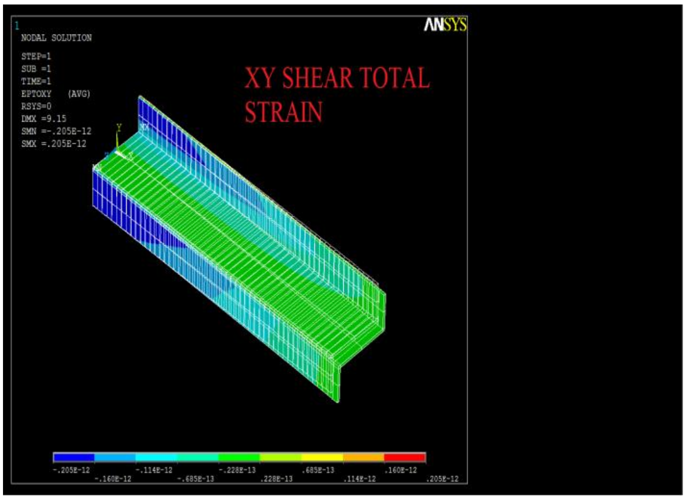

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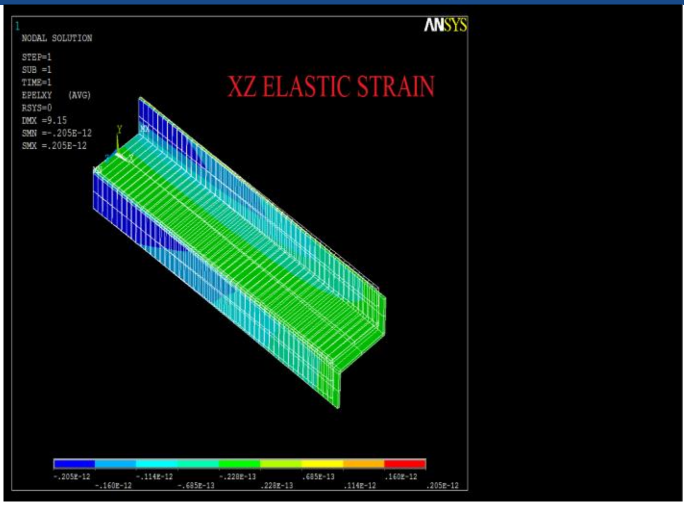

6 CONCLUSION

This composite structural component is made with epoxy fibre glass and epoxy resin. This composite has more strength, toughness and stiffness. For increasing stiffness we used mild steel structure along with the composite material.

We prepared channel section and Z-section with the fibre glass (4 mills), epoxy resin and hardener K-6.we analyzed these structures in theoretical, experimental and analytical approaches. We observed that the shear centre, shear flow and bending moment of the structural component is nearer or almost equal in three approaches.

From this structure we observed that it has more stiffened than metal component. It withstand equal to a mild steel component. And this composite has very less in weight. Due to this the weight ratio is decreases greatly.

We observed that by experimental and analytical calculations this composite structure has more strength to weight ratio than all other individual metal components.

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