Experimental and FEA Determination of Stress Values for Glass Fiber Composite Plate

P. P. Kamble, N. K. Chhapkhane

Abstract- ***This paper deals with an experimental and FEA determination of stress values for glass fiber composite plate. Composite materials are their high strength and stiffness, low density, as compared with bulk materials, allowing for a weight reduction in the finished part. The use of composite materials for aircraft primary structures can result in significant benefits on aircraft structural cost and performance. Such applications of composite materials are expected to result in a 30–40% weight savings and a 10–30% cost reduction compared to conventional metallic structures.***

Keywords- Composite plate, FEA, Reflection Polariscope, Abaqus software, Stress values.

I. INTRODUCTION

Glass fiber is a light weight, extremely strong, and robust material. Although strength properties are some what lower than carbon fiber and it is less stiff, the material is typically far less brittle, and the raw materials are much less expensive. Its bulk strength and weight properties are also very favorable when compared to metals, and it can be easily formed using molding processes. The plastic matrix may be epoxy, a thermosetting plastic (most often polyester or vinylester) or thermoplastic. Common uses of fiberglass include boats, automobiles, baths, hot tubs, water tanks, roofing, pipes, cladding, casts and external door skins.

II. OBJECTIVES

- To fabricate composite plate by using vacuum bag molding process.
- To produce composite plate with centrally located diagonal notch.
- Testing of composite plate with different loads.
- To find stress values of composite plate with the help of Reflection Polariscope.
- To find stress values of composite plate with the help of Abaqus software.

III. MANUFACTURING OF COMPOSITE PLATE

Manufacture of composite plate by using vacuum bag molding process (see figure 1).

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P. P. Kamble, Department of mechanical Engg. R.I.T. Sakharale
N. K. Chhapkhane, Department of mechanical Engg. R.I.T. Sakharale

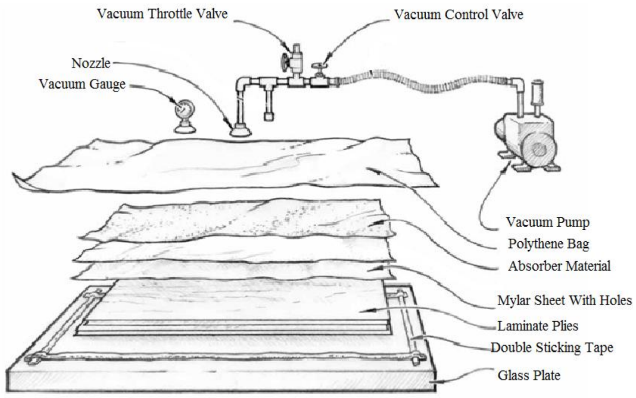

Figure 1. Typical components vacuum bag sysyem

- Place first glass plate on the table and clean it with the help of cloth.
- Stick the double sticking tape on the glass plate in the rectangular pattern.
- On another glass plate, place the glass fiber roving, and cut it with the help of cutter to form the required size of glass fiber sheets.
- Take the polythene sheet or bag and cut it into larger dimensions than the rectangle formed by double sticking tape and make the hole at one of its corner to the bag and attach the nozzle of vacuum pump to it.
- Check the polythene bag for damage, if any leakage or small pin hole presents, it will affect the whole process to the greater extent.
- Now, take the required amount of epoxy resin with the help of weighing machine.
- Take 100ml epoxy resin, 10ml hardener.
- Mix these three elements properly with the help of mixing rod so that proper mixture will be take place.
- Now, on main glass plate, place the larger size Mylar sheet (without holes) inside the rectangle formed by the sticking tape.
- Use the hand layup technique as described to prepare the composite plate as per required orientation of fibers.
- After placing all layers, place the Mylar sheet (with holes) and also place the absorber at the top.
- Place the absorber at the top of mylar sheet (with holes).
- Take the polythene bag with nozzle and stick the bag to the rectangle formed by the double sticking tape in such a way that, no leakage occurs between environments and bag.
- Now, connect the nozzle to the vacuum pump and switch on the pump to create vacuum inside the bag.
- As negative pressure built up into the bag, the pressure on the layers goes on increasing.

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- As the result, excess resin comes out from the holes prepared on Mylar sheet and gets absorbed into the absorber placed at the top.
- This process is carried out up to half an hour and then pump is switched off.
- Now, remove the bag with nozzle and place another glass plate on the layup assembly.
- Remove the glass plate after 30 hours, because curing process takes much time. Also remove the absorber and two Mylar sheets from the composite plate formed. Mylar sheets gives good surface finish to the composite plate and also releases the composite plate easily.
- Now, the composite plate is ready for further machining and the experimentation (see figure 2).

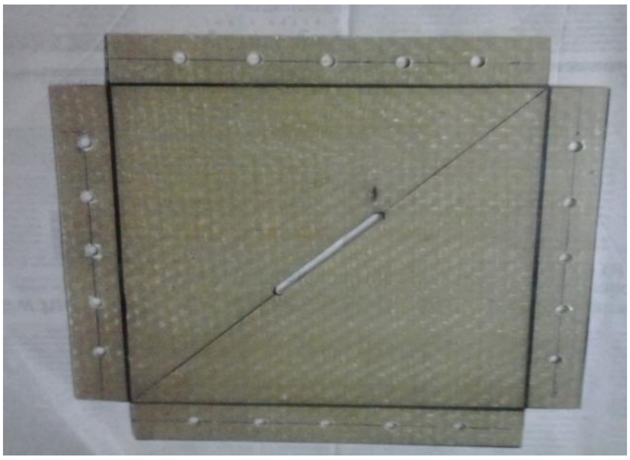


Figure 2. Vacuum bag molding composite plate

IV. CASTING AND CONTOURING PHOTOSTRESS SHEETS

The following procedures are used for casting and contouring Photostress sheets. The procedure can be divided into six principal steps:

- Preparing the casting plate
- Preparing and pouring the plastic resin and hardener
- Polymerization cycle
- Removing plastic sheet from the casting plate
- Contouring the sheet to the test-part surface
- Removing the cured sheet from the test part
- Bonding Procedure for composite plate
-

Determining Amount of Resin and Hardener

The total amount (weight) of plastic is determined by:

$W = d \times A \times t$

Where:

W = total amount needed (in gm)

d = plastic density, [1.13 * 10^{-3} gm/m3]

A = area of sheet to be cast (width x length)

t = desired thickness of sheet

W = 1.13 * 10^{-3} * 180 * 180 * 2.00

W = 73.224 gm

The amount of hardener is indicated in “parts per hundred,” or “pph,” by weight. For example, 20 pph of hardener means 20 gm of hardener for 100 gm of resin. Refer above Coating Materials chart to determine the proper proportion of hardener to resin. Then, continuing with the above example, for a total of 73.224 gm of Type PL-1 plastic, the resin and hardener calculations are made as follows:

PL-1 Resin: 73.224 * $\frac{100}{100+20}$ = **61.02 gm**

PLH-1 Hardener: 73.224 * $\frac{20}{100+20}$ = **12.204 gm**

When the resin and hardener reach the temperature indicated in the Coating Materials table, pour the hardener into the resin, being careful to avoid the introduction of air bubbles. Pour all the hardener into the resin jar. Mixing the resin and hardener is a crucial step in obtaining a quality contoured sheet. It is essential to stir thoroughly, but slowly (see figure 3).

Figure 3. Mixing the hardener and resin

Do not use a whipping action, which will introduce air bubbles. Stirring to produce a clear, non-streaking mixture is best accomplished using the technique illustrated. Non-uniform mixing will most likely occur at the inside surfaces of the mixing container. The stem thermometer should be brought into line contact with the sides of the container several times during mixing. Line contact should be maintained while making several passes around the inside of the container. The temperature increase produced by the exothermic chemical reaction during mixing is easily observed on the stem thermometer. Continue stirring until the pouring temperature is obtained. The mixed plastic is now ready to be poured onto the previously prepared casting plate. Remove the cover from the casting plate and pour the plastic. When pouring, hold the mixing cup close to the casting-plate surface and pour gently. This procedure will minimize bubble formation. While pouring, it is advisable to move the cup to form an “X” or “S” pattern, which will improve flow to fill the mold (see figure 4).

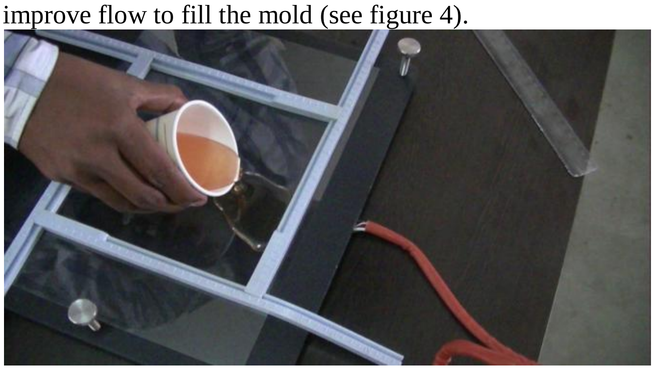


Figure 4. Pouring the mixture to form “S” pattern

This is particularly advantageous when pouring thinner sheets [1.5 mm] or less. Thin sheets do not flow out and cover the casting plate as freely as thicker sheets. The final portion of the plastic should be poured along the outside boundary close to the frame.

Do not scrape excess plastic from the cup sides and bottom onto the casting plate, as these are areas where a non-uniform mix is most likely to occur. The stem thermometer or a wooden tongue depressor may be used to help spread the plastic over the entire plate surface (the liquid will level with time). Place the cover over the poured sheet to protect it from dust and other foreign matter during polymerization and switch the temperature controller off. If air bubbles are present, wait a few minutes and burst them with a dental probe or a similar pointed object. Replace the cover over the casting plate.

When probed, the plastic still behaves as a liquid. It adheres to the probe and no dent is formed; plastic can be pulled up with the probe. The plastic approaches a gel state and adheres to the probe. The surface is easily deformed with little or no pressure on the probe and feels very sticky to the touch. Using a plastic probe or a wooden tongue depressor, apply light to moderate pressure to a corner of the cast plastic. If a dent can easily be formed and the probe does not stick to the plastic, it is time to attempt to remove one section of the rubber frame (see figure 5). Carefully try to separate one section of the rubber frame at one corner; using fast whipping movements.

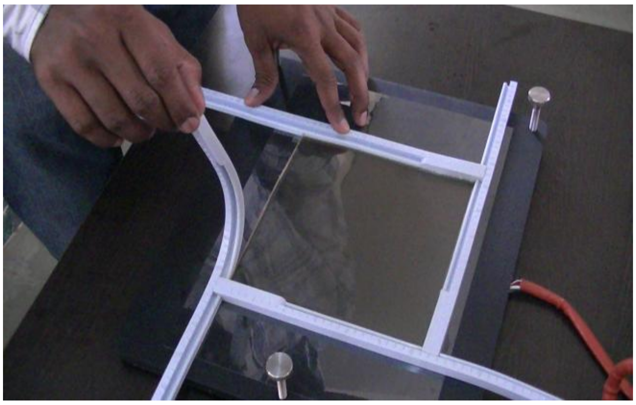


Figure 5. Rubber frame separates from the cast plastic

If the rubber frame easily separates from the cast plastic, keep pulling until it is removed from the casting plate. This last step should be done carefully, avoiding pressure to the cast plastic. Wipe your hands to remove any traces of mineral oil. Hold one free end of the Teflon carrier and lift it slowly (see figure 6). Continue lifting until the Teflon carrier with the cast plastic sheet is completely free of the casting plate.

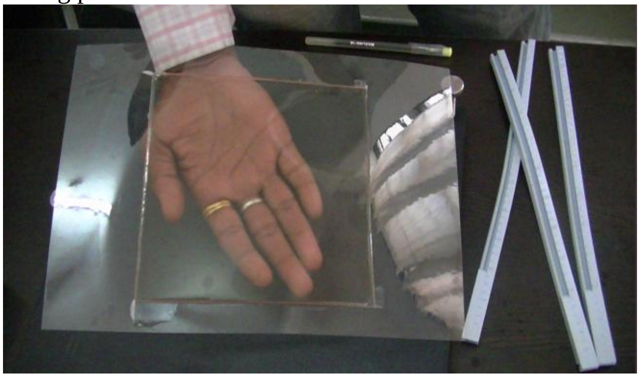


Figure 6. Lifting until Teflon carrier with cast plastic sheet

Immediately place the palm of your other hand under the Teflon carrier. Next cut a strip of slightly more than [23 x 76 mm] and place it flat on the casting plate. These cuts are done by cutting both the Teflon carrier and the cast plastic. If small air pockets form under the plastic, carefully lift the edge of the plastic sheet up to the air pocket and, with oiled fingertips, smooth back the plastic, pushing the air pocket to the edge of the sheet. The working time available for contouring the plastic after removal from the mold is approximately 10 to 20 minutes. After this time, the plastic will begin to stiffen, making it more difficult to manipulate and cut with scissors. After contouring is complete, the formed sheet will retain its shape while final polymerization takes place.

If the plastic has been contoured to a vertical or overhead surface, it may be necessary to mechanically hold it in place for complete cure on composite plate (see figure 7).

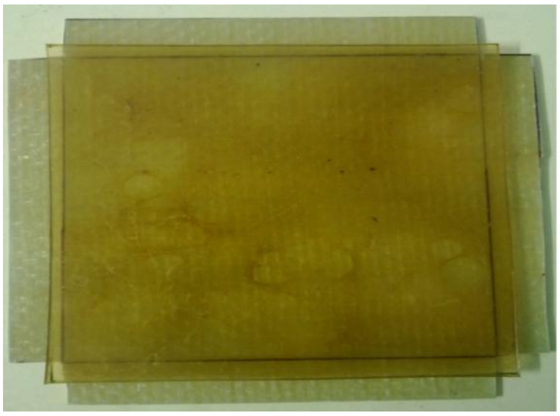


Figure 7. Place plastic sheet on composite plate

Bonding Procedure for composite plate:

Masking tape, applied approximately [5 mm] from the sheet boundaries, will afford a clean and neat adhesive boundary. Pour the mixed adhesive onto the cleaned test part surface and spread it over the entire surface with a brush (see figure 8). Brushing is best accomplished with a mildly stiff brush, which serves to wet (or paint) the surface as well.

Figure 8. Mixture of adhesive material

The adhesive layer should be at least [1 mm] thick. Press down on the contacting edge with moderate finger pressure and slowly work additional contact toward the opposite edge. This technique will allow air to flow out along with the excess adhesive. After full contact is made, additional finger pressure should be applied.

Start near one edge and slowly progress across the sheet to bleed additional adhesive from beneath. Repeat this several times, taking care to brush excess adhesive in contact along all edges of the sheet. This boundary of excess adhesive will prevent air entrapment after finger pressure is released. Do not attempt to squeeze all adhesive from beneath the sheet. If the sheet tends to float or move from the intended position, it can be lightly tacked in place with masking tape. After the entire excess adhesive is squeezed out, apply a thin coating around all edges of the plastic (including diagonal notch that may have been created) to provide a seal against moisture absorption. It is at this point that the adhesive bevel if used can be initiated. Allow the adhesive to polymerize until it thickens and tends to hold its shape (one to two hours for PC-1), then reconstruct the adhesive bevel. Remove the masking tape around the edges of the plastic coating (laid down during the bonding preparation phase). This will leave a neat adhesive line around all the edges of the coating. All traces of adhesive on the outer surface of the coating must be removed at this time. Gauze sponges wetted with the appropriate solvent are recommended. Allow the adhesive to cure in accordance with the time (see figure 9).

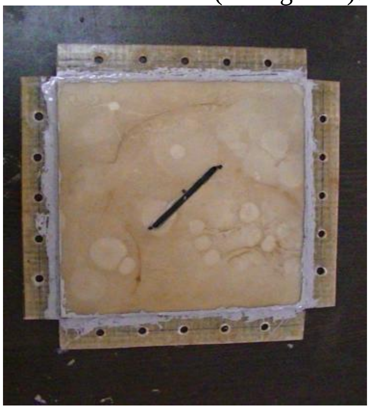


Figure 9. Cured coated glass fiber plate

Calibration Measurements

- Insert the beam all of the way into the mounting clamp, center the free end of the beam between the side rails of the calibrator, and clamp firmly in place (see figure 10).

Figure 10. Standard calibrator

- Using a fine-pointed grease pencil, marking pen, or scriber, mark the coating with a small cross + on the centreline of the beam and directly in line with the index lines on the side rails of the calibrator. This will be the calibration point (see figure 11).

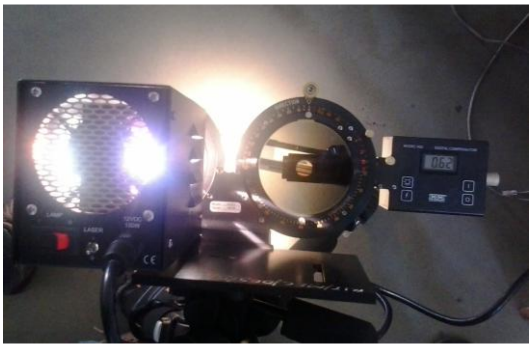
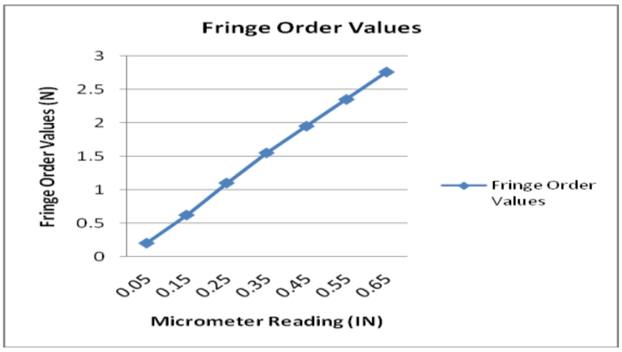


Figure 11. Compensator fringe order value

- Set up the calibrator and LF/Z-2 Polariscope for normal-incidence measurements. Observe the coating at the calibration point while slowly rotating the micrometer head. When the spindle of the micrometer contacts the beam, slight birefringence will start to appear in the coating. Continue rotating until the micrometer reading reaches a convenient round number say, 0.05 inch.
- Accurately measure the fringe order at the premarked calibration point for the initial micrometer setting, and record the result. Rotate the micrometer head four full turns (0.100 inch deflection increment), and make a new fringe order measurement. Repeat the operation, making a measurement after every 0.100 inch increment of deflection, and continuing for four increments to obtain a total of five readings, including the preload measurement at the initial micrometer setting.

Table No.1 Observations table for Fringe order value

Micrometer Reading (in inches)	Fringe Order - N
0.05	0.20
0.15	0.62
0.25	1.10
0.35	1.55
0.45	1.95
0.55	2.35
0.65	2.76



Graph 5.1 Fringe Order Vs Micrometer Reading

From chart we can find out the value of strain-optic coefficient K′ = 0.14

$$K = K' \left[1 + \frac{2(t'_A - t_A)}{t_B + t_C}\right]$$

Where:

K′ = strain-optic coefficient

K = actual (corrected) strain-optic coefficient

t'_A = standard adhesive thickness (*0.075 mm*)

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t_A = actual adhesive thickness (0.87mm)
t_B = beam thickness (*6.35 mm*)
t_C = coating thickness (2mm)
Put these values in above equation no.1 then
We have

$$K = 0.14\ [1+\frac{2(0.075-0.87)}{6.35+2}]$$

$$K = 0.14 * 0.8096$$

$$\mathbf{K = 0.1133}$$

V. EXPERIMENTAL ANALYSIS OF COMPOSITE PLATE

The experimental analysis consists of shear load testing, so the composite laminate panels are pulled for shear load testing. Also the load must be applied gradually in steps of kg. The composite laminate panel is fixed at one end and other end load applied under shear load testing. The main objective of experimental analysis is to find out stress values of composite panel with centrally located diagonal notch (see figure 12).

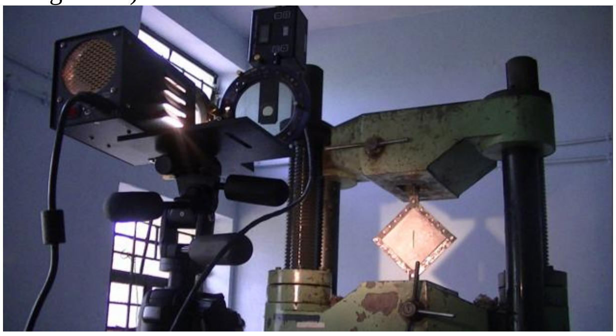

Figure 12. Experimental setup

Place the polariscope on a table and adjust the height of light source and test specimen will be same. Attach the test specimen on the universal testing machine about 2 meters away from the polariscope. Insure that the initial load on the test specimen is zero. Turn on the polariscope light source by flipping the on/off switch to the on. Align the light source to illuminate on the test specimen by loosening the locking screw of the center mounting bracket. Lock the screw after alignment is done. Boot the computer and turn on the video camera by moving the power switch to the camera position.

Figure 13. Computer screen with PhotoStress color pattern

Double click the PS Calc software icon. Apply the load on test specimen by using universal testing machine. The computer screen should show a pattern of color bands. Use the video camera zoom control to fill the computer screen with the PhotoStress color pattern (see figure 13).

The polariscope is set in the direction of the principal stresses at the marked point, with respect to a vertical reference between the polariscope and test specimen. When no load acting on test specimen (see figure 14).

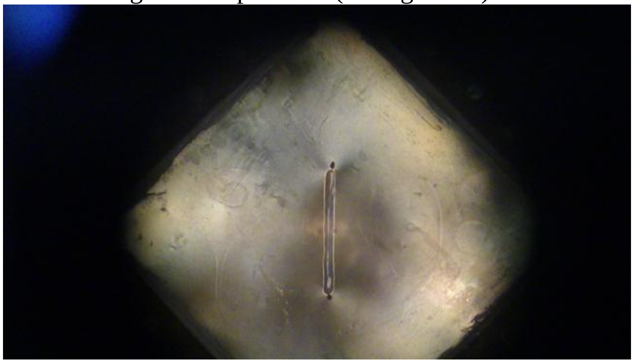

Figure 14. No load acting on test specimen

Insure that the test specimen is under load and stepwise load in kg is increasing on test specimen. While increasing load, change the color band on test specimen (see figure 15).

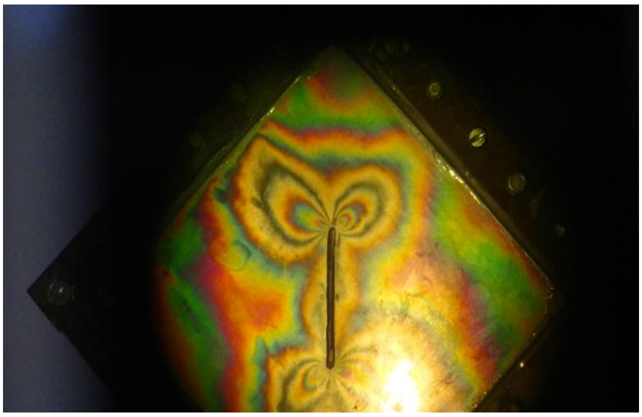

Figure 15. Color band, when load acting

Load (Kg)	Fringe order values (N)
50	0.68
100	1.35
150	2.03
200	2.71
250	3.38
300	4.07
350	4.74

Calculation for Experimental stress values

$$\sigma_1-\sigma_2=\frac{E_s}{1+\vartheta_s}(R_1-R_0)*f_c$$

Where:

f_c = calibration value of coating material

The calibration value f_c may be obtained by

$$f_c=\frac{287.5}{K*\ t_c}$$

$$f_c=\frac{287.5}{0.1133*2}$$

$$f_c=\mathbf{1268.76}$$

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Where K is an optical constant (a number) of the PhotoStress plastic and t_c is the plastic thickness.

But we know that the principal stress perpendicular to the boundary is zero. When the Compensator is positioned tangent to the boundary and compensation can be made, we solve for $\boldsymbol{\sigma_1}$, and the sign is positive ($\boldsymbol{\sigma_2}$ = 0).

$$\sigma_1 = \frac{E_s}{1+\vartheta_s}(R_1 - R_0) * f_c$$

$$\sigma_1 = \frac{9.44}{1+0.26}(0.68-0) * 1268.76$$

$$\sigma_1 = 6.4638 * 10^3 \text{ N/mm}^2$$

Load (Kg)	Experimental Stress values (N/mm^2)
50	$6.4638*10^3$
100	$12.8326*10^3$
150	$19.2964*10^3$
200	$25.7602*10^3$
250	$32.129*10^3$
300	$38.6879*10^3$
350	$45.0566*10^3$

FE ANALYSIS USING ABAQUS SOFTWARE:

Software analysis for stress values of composite plate with centrally located diagonal notch and subjected to in shear loading (see figure 16).

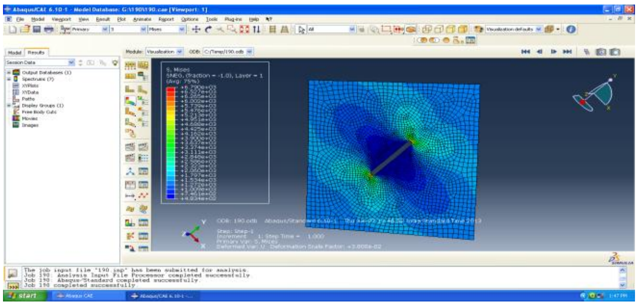

Figure 16. stress values, when load 50kg

Table No. 7.1 Software Stress values (N/mm^2)

Load (Kg)	Software Stress values (N/mm^2)
50	$6.790*10^3$
100	$13.58*10^3$
150	$20.37*10^3$
200	$27.16*10^3$
250	$33.95*10^3$
300	$40.74*10^3$
350	$47.53*10^3$

VI. CONCLUSION

- In this paper experimental and FEA determination of stress values for glass fiber composite plate with centrally located diagonal notch and subjected to shear loading.
- Stress curves are straight lines for experiment and software analysis.
- The errors between experimental result and FEA result are in between 4-6 %.
- The variation in results occurs may be because the PhotoStress coating applied over the surface of composite structure takes some of the applied load.

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