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Materials Today: Proceedings XX (2016) XXX–XXX

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PMME 2016

Experimental and numerical analysis of flexural test of unfilled glass fiber reinforced polymer composite laminate

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Abstract

Present investigation focus on flexural strength of unfilled glass fiber reinforced polymer laminate. In this work eight layers (0/90/±45/±45/0/90/0/90/±45/±45/0/90) of glass fiber/ epoxy laminates has been fabricated by hand lay-up and Vacuum bagging method. Flexural tests were peformed on designed fixture according to ASTM D790. Load was applied until first failure occurs by hounsfield tensometer with a capacity of 50 KN. Finite element analysis were also studied by Ansys software by APDL 14.5 model to validate experimental results. Structure and morphology of Fracture samples were also studied using Field emission scanning electron microscope (FE- SEM).

Selection and Peer-review under responsibility of International Conference on Processing of Materials, Minerals and Energy (July 29th – 30th) 2016, Ongole, Andhra Pradesh, India.

Keywords: Glass fiber; flexural properties; Finite element analysis; Ansys

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1. Introduction

Since their introduction, glass fiber reinforced polymer become paramount importance owing to their high specific strength, low weight, low cost and high stiffness. Glass fiber / epoxy laminates is being extensively used in different field like automobile industries, space industries, power industry, oil industries etc. In glass fiber reinforced polymer, glass fiber and thermosetting epoxy acts as reinforcing and matrix phase respectively. Reinforcing phase is called hard phase, while the matrix phase is called soft phase. Combining together composites have better mechanical properties. When a fiber reinforced composite is loaded, the matrix transfers the load to fibers. The interfacial shear stress (τ_i) acts as a bond between the matrix and fiber. The existence of the bond strength develops stresses in the fibers. If there is high shear stress on the ends of fiber mean that polymer matrix will flow plastically. In order to fully utilize the high strength of fiber it is necessary that plastic zone in the matrix should not extend from fiber ends to its middle length before the strain in the fiber reaches its failure strain. Flexural strength is very important in the design of composite material when material is subjected to lateral loads. Similarly flexural modulus measures the stiffness of composite materials. Three point bend test is widely used for finding flexural strength and flexural modulus. In this test composite beam of rectangular cross section is transversely loaded under simply supported condition. When the load is applied to composite specimen, it deflects in such a way that the underside of the specimen will be under tension while the upper side will be subjected to compression. Due to the anisotropic nature of specimen bending failure may be occurred due to tensile, compressive, shear or combination of these stresses.

The finite element analysis using ANSYS software is an important tool to validate experimental data and to analyse any complex design. ANSYS is a comprehensive general purpose finite element programme, which is being used in many engineering field that includes aerospace, automobile, electronics and nuclear [1]. Present work focus on finding the flexural strength of different sample of unfilled glass fiber reinforced polymer laminate and validation of data with APDL 14.5 model by ANSYS. Post failure analysis of fracture samples were also investigated by scanning electron microscope at different magnification.

Hazatul Nabila et al. [1] performed both experimental as well as numerical analysis of tensile samples of glass/ epoxy woven composite laminate. It was observed that the percentage error (5%) was within the acceptable range. Chensong Dong and Ian J Davies [2] studied both experimental as well as numerical analysis on flexural properties of glass and carbon fiber reinforced epoxy hybrid composites. They investigated flexural behaviour and observed that the mode of failure was compressive. Soma Dalbehera and S. K. Acharya [3] studied on the flexural behaviour of natural fiber reinforced woven jute glass hybrid composites. They observed an increased in flexural properties of jute E- glass epoxy and its composites by incorporating glass fiber as extreme fiber. G. Suresh and L.S jayakumari [4] studied on flexural properties of E- Glass fiber/ carbon fiber reinforced interpenetrating polymer networks. They observed a reduction in flexural strength and flexural modulus of the composite by adding polyurethane and vinyl ester matrices. J.Myalski studied [5] on flexural properties of composite laminates containing polymer glass fiber recyclates. He observed a reduction in flexural properties by using polymer composites wastes as filler materials. Yadavalli Basavaraj and Raghavendra H [6] studied on the influence of volume fraction on flexural strength of E-glass epoxy cross ply laminates. They compared experimental data with numerical analysis using Abaqus software and concluded there was an increased in flexural strength for volume fraction of 65:35.

Here we fabricated glass fiber reinforced polymer laminate of eight layers by hand lay- up and vacuum bagging technique. Flexural strength of different specimen was measured using three point bend test on designing a fixture according to ASTM D 790. ANSYS analysis was done on different samples in order to validate the experimental data. Fracture surfaces were also investigated through field emission scanning electron microscope (FE-SEM).

2. Experimental

2.1 Materials

Digycidyl ether of Bisphenol- A (DGEBA) based thermosetting epoxy resin under the trade name of Lapox (L-12) was chosen as a polymer matrix, while an amine based hardener consists of Triethylene tetra amine (TETA) under the trade name of K-6 was chosen as a solvent. Both were manufactured by Atul Industries Limited, Balasad, Gujrat (India). Glass fabric having a weight of 600 gsm and a count of 25x 16 (25 yarns in wrap and 16 yarns in weft direction) was used as reinforcement. The plain weave glass fabric by weight of 600 g/m^2 is supplied by M. S.

Industries, Kolkata (India). Density of glass fibers used was 2540 kg/m^3.

2.2 Composite Laminate fabrication

First of all a plain woven glass fabric of eight layers was cut from the bundle of glass fiber. Then resin and hardener were mixed by mechanical stirrer in the ratio of 10:1 by weight percentage. Each laminates of glass fiber was impregnated with mixture of epoxy resin and curing agent (hardener) by paint brush. The impregnated layers were placed one over the other by hand and then pressed by cylindrical roller to remove entrapped air as well as extra resin. In this way laminates of Plain weave glass fabrics (280 x 240 mm^2) were prepared by hand lay-up technique at laboratory temperature.

Laminates were made with total 8 plies of different stacking sequences $(0/90/\pm45/\pm45/0/90)_2$. Then Vacuum bagging method, which is shown in fig.1, was applied to complete the mould. In this method whole laminates was placed inside the vacuum bag. The vacuum pump was connected to vacuum bag through flexible hoses with nozzle. Vacuum pump was run for a period of 30 minutes. Blanket was used as breather material in order to absorb extra resin. At the end heavy weight was placed on composite laminates for 24 hrs for complete the curing process.

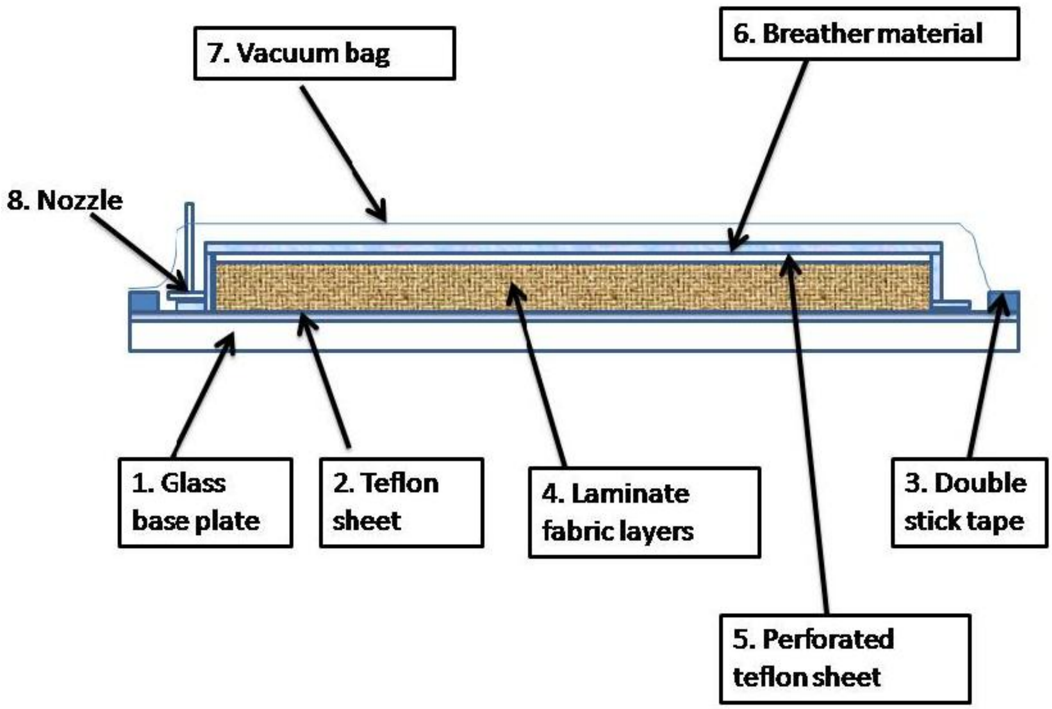

Fig. 1 Vacuum bagging method

2.3 Flexural test

Flexural strength of glass fiber reinforced polymer (GFRP) composites was determined according to ASTM D790. In this process a specimen of 140 mm length and 30 mm wide were carefully cut by a hex blade from laminate (280 x 240 mm^2) and then it was loaded in three points bending with recommended span to depth ratio of 16: 1 as shown in fig. 2 and 3 respectively. Transverse load was applied gradually in the middle until first failure taken place.

Different specimens were tested at a crosshead speed of 1.5 mm/min. Flexural strength was found out by following equation.

$\sigma = 3p_{max}L/2bt^2$, where p_{max} is the maximum load at the first failure, L is the span length, b is the width and t is the thickness (mm) of composite material.

2.4 Fractrography study

Bending fracture surface of glass fiber reinforced polymer composite were examined using Field emission scanning electron microscope (FE- SEM) (model-SUPRA 55, Carl Zeiss) . The cross sections of bending specimens were cut about 10 mm length, 30 mm width and 3.9 mm thickness and sputter gold coated to make specimen conductive. Failed specimens were observed under an electron microscope and different micrograph was taken at different magnification in order to provide insight damage mechanisms and to explain any anomalies into mechanical performance.

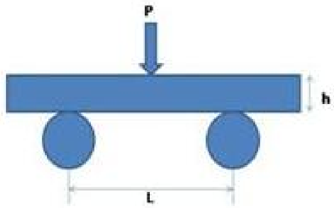

Fig.2 Three point bend test

Fig.3 Sample under deflection

3 Finite element analysis

Finite element method is one of the best method to solve a complex problem and to validate data with experimental results by using ANSYS software. For performing the flexural test material was considered as orthotrophic in nature. Boundary conditions and load was applied accordance with experimental procedure. In ANSYS software APDL 14.5 model of eight layers with the orientation of (0/90/±45/±45/0/90/0/90/±45/±45/0/90) was used. Thickness of each ply was fixed to 0.4875 mm. Therefore 3.9 mm thickness of finite element models of glass fiber/epoxy composite could be achieved. The element type was selected as 8 node and shell 281multilayered shell element, which has six degrees of freedom per node. The orthotropic properties were assigned to composite laminates, which is given in table 1 [7]. Simply supported boundary condition was applied and lateral load was applied at the centre of laminates along y- axis.

Table 1. Mechanical properties of glass fiber/ epoxy laminate

Young's Modulus	Shear Modulus	Poission's ratio
E_1 = 19.1 Gpa	G_{12}= 3.5 Gpa	ν_{12}= 0.17
E_2= 19.1 Gpa	G_{23}= 2.06 Gpa	ν_{23}= 0.28
E_3= 6.72 Gpa	G_{13}= 2.06 Gpa	ν_{13}= 0.28

Table 2. Flexural properties of glass fiber/ epoxy laminate

Specimen No.	Flexural Strength (MPa)Exp.	Flexural Strength (MPa) Num.	% error	Maximum load
1	289.3	272.102	5.944	1600
2	256.6	244.892	4.562	1345.5
3	167.19	179.771	7.524	876.9
4	197.90	207.69	4.946	1038

4. Result and discussion

4.1 Flexural test

In flexural test at least four specimen was taken and tested under three point bend test after taking a span length of 58 mm, result of which is shown in table 2. Average flexural strength for unfilled glass fiber reinforced polymer was found to be 227.74 Mpa. Graph of force vs deflection is shown in fig.3. it is evident from the graph that due to flexural loading on sample, matrix and fiber, both elastically deformed followed by plastic deformation, which is shown by nonlinear graph. After extensive plastic deformation fiber fracture followed by composite fracture.

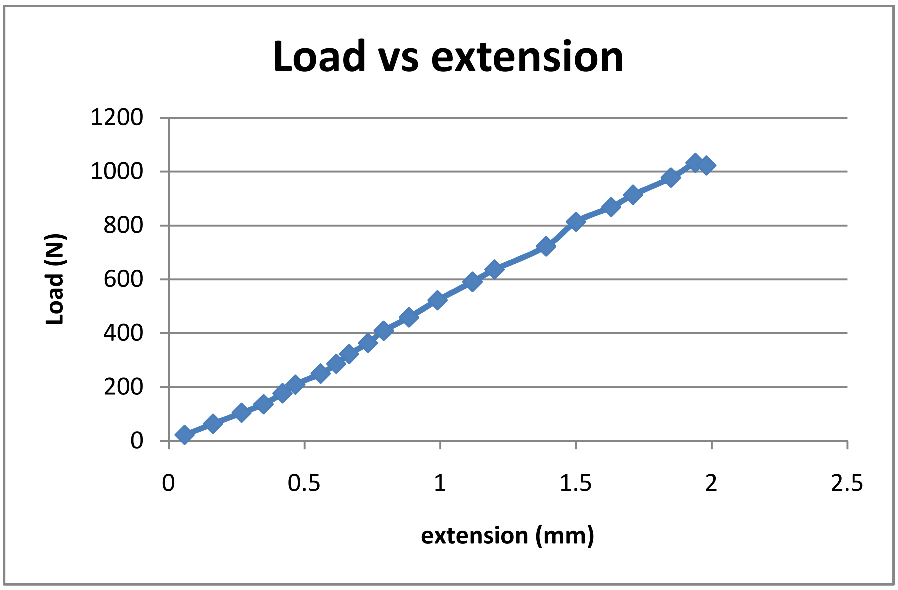

Fig.4. Force (N) vs extension (mm)

4.2 Fractrography

Post failure analysis of all fractured samples of unfilled glass fiber reinforced polymer laminates were carried out to understand the various micro and nano scale failure mechanisms which is responsible for bulk failure of material using field emission scanning electron microscope (FE- SEM), which is shown in fig. 5 to fig. 9.

a b

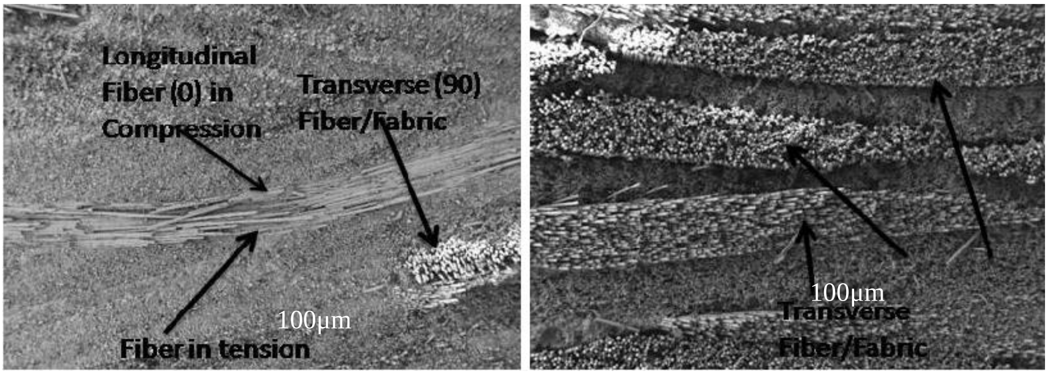

Fig. 5 FE- SEM image of fracture surface of unfilled GFRP composite at 100 μm showing (a) longitudnal fiber; (b) transverse fiber

From figure 5a, It is clearly evident that primary failure mode is bending failure. Upside of the fibers are in compression mode, while bottom side of the fiber/ fabric are in tension mode. Bending failure occurs owing to large span thickness ratio (L/t) of sample. The maximum fiber stress at failure on the tension side in three point bend test (flexural) is considered as flexural strength of the material. Broken fibers in the indentation can be seen in the post failure analysis of specimen. Figure 5b shows transverse fiber/ fabric in different layers, which are well arranged. Besides that fiber pull out and voids can be also seen. Voids is a manufacturing defect, which occurs due to entrapped air into the composite laminate. Some loose fibers can be also seen, which occurs due to weak bonding between fiber and matrix.

a b

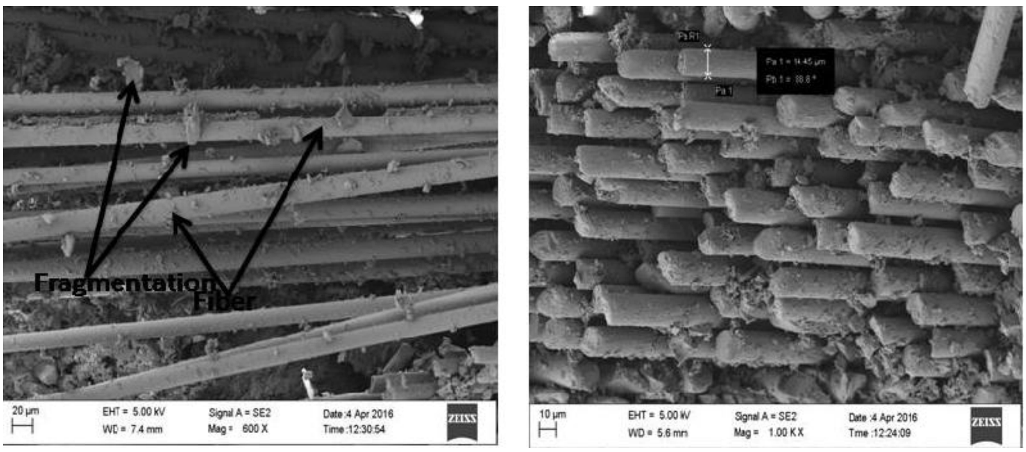

Fig. 6. FE- SEM image of fracture surface of unfilled GFRP composite showing (a) fabric fragmentation; (b) well arranged fiber

From the figure 6a, fiber/ fabric fragmentation and debris can be clearly seen. Fiber/ matrix fragmentation occurs as a result from abrasion of the matrix from fiber fracture surfaces due to flexural loading. Fiber bridging can be also seen. The surfaces of the fibers are devoid of substantial amount of matrix residue, which shows weak fiber-matrix adhesion. The overall fracture surface of matrix/ fiber appears to be cleavage facet. From figure 6b it can be observed that fibers are well arranged in a systematic manner. No breakage of fiber has been found. Some matrix fragmentation can be seen. A thin layer of matrix can be seen which covering the fiber surfaces, which shows good adhesive bonding between matrix and fiber, resulting in better flexural strength.

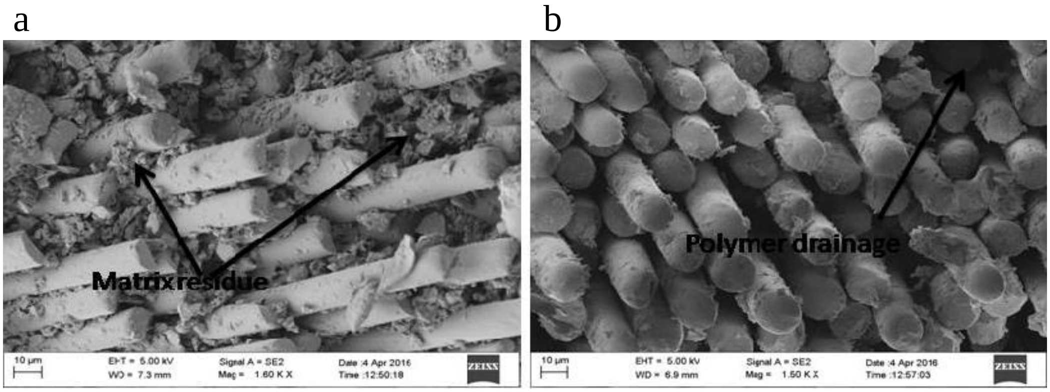

Fig. 7. FE- SEM image of fracture surface of unfilled GFRP composite (a) matrix residue; (b) thin layer of matrix covering the glass fiber

Lot of matrix residue adhering to the fiber surfaces can be seen from figure 7a, which shows good interfacial bonding between matrix and fiber. Figure 7b depicts well arranged fiber. Matrix residue adhering to the fiber surfaces besides that a thin layer of matrix completely covering the fiber surfaces can be seen in post fracture analysis of three point bend test. Fiber pull out can be also seen, which happens owing to weak interfacial adhesion between fiber and matrices.

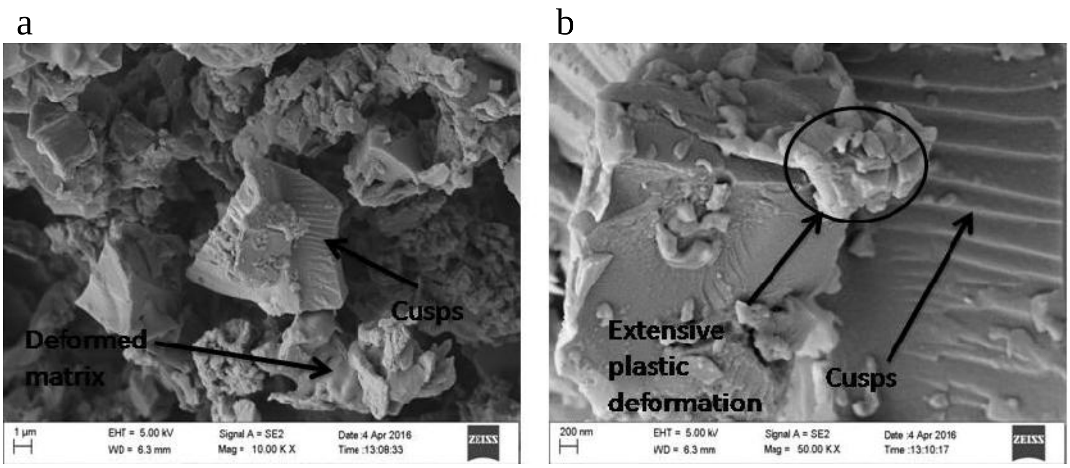

Fig. 8. FE- SEM image of fracture surface of unfilled GFRP composite (a) deformation behaviour of matrix at 1μm; (b) Cusps at 200 nm.

Figure 8a shows that the matrix and fiber after elastically deformation goes to plastic deformation resulting in extensive matrix deformation. Cusps/ hackles can be also seen in figure 8b which is an indicative of effective load transfer from fiber to fiber through matrices[8]. In my opinion these cusps should be observed in short beam shear test, nevertheless it has been found under flexural loading. All the cusps are neither parallel to each other, nor equally spaced. Total approximately seven cusps can be seen. Distance between first cusps to second cusp is approx. 266.4 nm, from second cusps to third cusps is approx. 399.6 nm, from third to four cusps is approx. 199.8 nm, from fourth to fifth cusps is approx. 466.2 nm, fifth to sixth cusps is approx. 399.6 nm and from sixth to seven is approx. 333 nm.

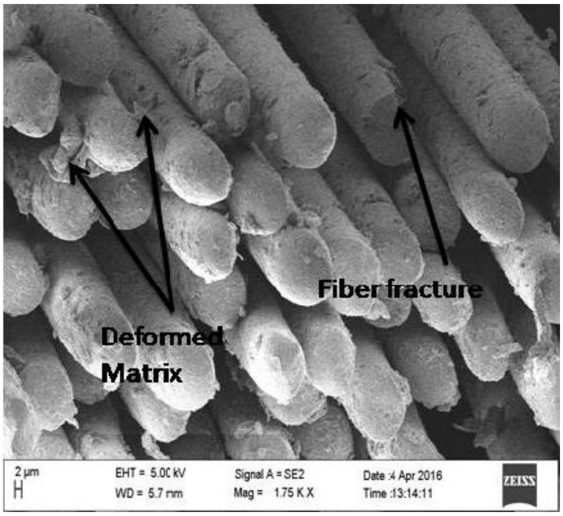

Fig. 9. FE- SEM image of fracture surface of unfilled GFRP composite showing arranged fiber at 2 µm.

Figure 9 reveals that fiber is completely covered by a thin layer of matrix attribute to better interfacial bonding between fiber and matrices and this happens due to better resin adhesion. Fiber fracture surface appears to be cleavage and fibers are well arranged in a systematic manner. Few deformed matrices can be seen, which presents a ductile behaviour of matrices. The overall fracture surface appears to be mixed mode of brittle and ductile facet.

4.3 ANSYS analysis

Numerical results are obtained on Ansys by using a general post- processor. The nodal solutions are obtained for bending stress, which is shown from fig. 10 to 13. The comparison between experimental and numerical results are shown in table 2 for different samples. It can be construed that results obtained from structural analysis are closely related with experimental results. The error obtains show that there is a good agreement between experimental and numerical data.

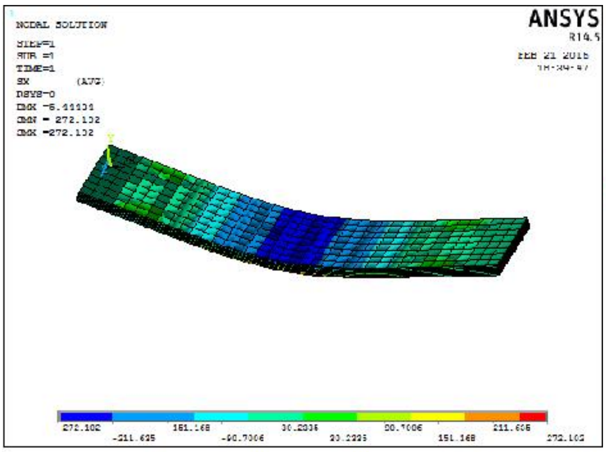

Fig. 10 nodal solution for bending stress for X component (sample1)

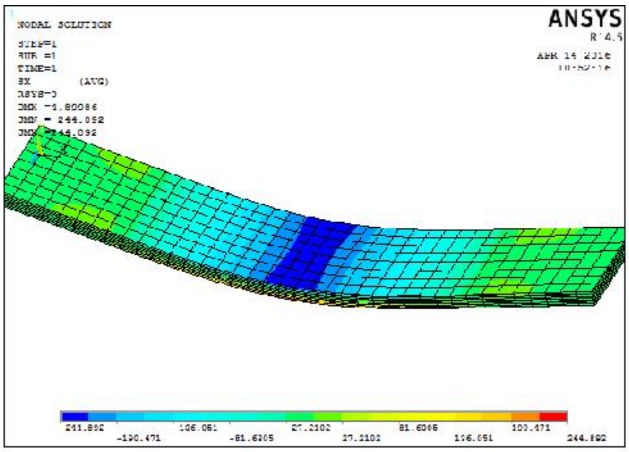

Fig. 11 nodal solution for bending stress for X component(sample2)

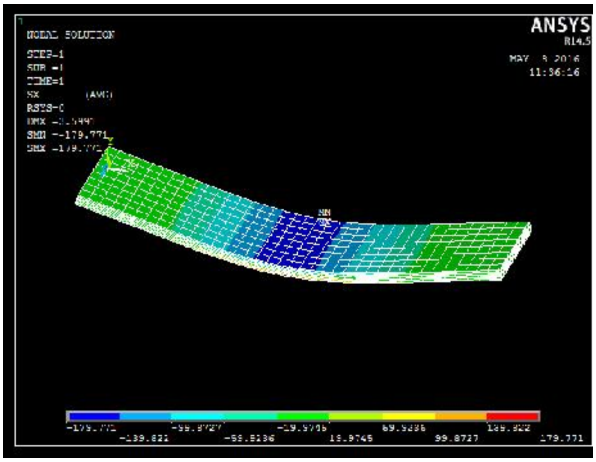

Fig. 12 nodal solution for bending stress for X component (sample 3)

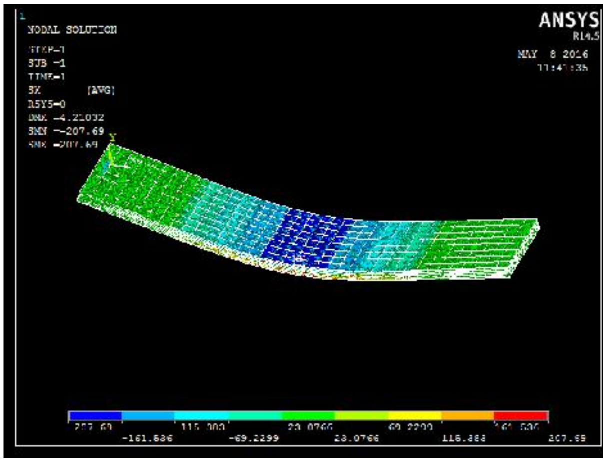

Fig. 13 nodal solution for bending stress for X component (sample 4)

5. Concluding remarks

Eight lamina of (0/90/±45/±45/0/90/0/90/±45/±45/0/90) glass fiber/ epoxy laminate has been manufactured by hand lay-up and vacuum bagging technique. Flexural test was performed on composite samples accordance with ASTM D790 and data was validated with ANSYS software with APDL 14.5. Error was found to be within the range of 10 %, which shows that our results are good agreement with numerical results. Post failure analysis of fracture sample reveals that the mode of failure is bending. Cusps/ hackles have been observed on the fracture sample, which is an indicative of effective load transfer from fiber to fiber through matrices.

Acknowledgement

Author would like to thank Department of mechanical engineering, I.S.M, Dhanbad and Department of Mechanical Engineering, B.I.T, Sindri for providing research facilities.

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