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# Maximum Bending Stress Analysis of Jute/Epoxy and Glass/Epoxy Polymer Composites

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**Abstract:** A surge in the use of fibre reinforced composites for biodegradable materials, which include both synthetic and natural fibres, to fulfil the strength requirements of composites while also being environmentally friendly has resulted in the use of these materials becoming increasingly popular. Researchers have been working to improve natural fibre qualities to partially replace synthetic fibre, even though not entirely. The research can be accomplished by modelling and simulation techniques, which are becoming more prevalent as technology advances. The approaches have the benefits of being efficient in addressing any material model, boundary conditions, and complicated form structure that may be encountered. This study uses ANSYS APDL, a finite element analysis tool, to carry out flexural test. These factors, as well as the fibre ply orientation, lay-up sequence, and fibre volume percentage, have an impact on the maximum stress of each composite, which are investigated in this study. In the lay-up sequence of $[(+\theta, -\theta)_2]_s$, with fibre ply orientation of 0˚ the maximum flexural stress obtains for glass/epoxy (vf=60%), glass epoxy (vf=30%), and jute/epoxy (vf=30%) is 214.64 MPa, 153.77 MPa, and 82.91 MPa and for fibre ply orientation of 90˚ the maximum bending stress is 55.41 MPa, 18.39 MPa and 8.37 MPa respectively. Furthermore, the impact of off-axis plies in the 0° fibre ply orientation can be observed in the maximum bending stress of the $[\theta_{4,}0_4]_s$ lay-up sequence, which is a function of the number of off-axis plies in the 0° fibre ply orientation. When using the lay-up sequence $[90_{4,}0_4]_s$, the maximum flexural stress for glass/epoxy (vf=60%), glass/epoxy (vf=30%), and jute/epoxy (vf=30%) is 83.39 MPa, 23.04 MPa, and 17.92 MPa, respectively. When bending tests are performed, the 0° fibre ply orientation produces the highest maximum stress, followed by 45° and 90°. When comparing 0° plies composites with off-axis angles to plies composites, the lay-up sequence of 0° plies with off-axis angles exhibits the highest maximum stress.

**Keywords:** Flexural, jute, ANSYS APDL, off-axis ply, glass fibre

## 1. Introduction

Fibre-reinforced-plastic composites (FRP composites) are common engineering materials used in various applications such as aircraft, spacecraft, ships, submarines, automobiles, and construction. FRP composites are prevalent in such applications because of their outstanding features, which include high stiffness, high strength,

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excellent fatigue and corrosion resistance, and low weight. In addition, FRP is used to produce directional mechanical characteristics, low thermal expansion qualities, and excellent dimensional stability. When it comes to applications where thermal or mechanical attributes are critical and weight management is required, fibre glass reinforced plastic composites (FRP) are frequently utilized [1]. When subjected to transverse stresses, the performance of a composite laminar structure with varying fibre orientations was feasible to quantify the greatest distortion by laminating patterns.

In terms of cost-effectiveness, strength, thermal conductivity, and affordability are important considerations, and jute fibre is a suitable choice. It is also environmentally beneficial and cost-effective natural fibre accessible. India and Bangladesh are the world's largest producers of jute fibre. It is derived from the stems of plants belonging to the genus Corchorus, a member of the Tiliaceae family [2]–[4]. It is possible that the properties of jute, which are now used in low-value and basic textile goods, may be modified to favour high-value and advanced textiles, which would benefit both the economy and the environment. Jute fibres are principally composed of cellulose (45-71.55 %), hemicellulose (13.6-21 %), and lignin (12-26 % ) [5], [6]. Lignin, which includes a high concentration of aromatic rings, provides mechanical support. Because of the fundamental impact qualities of jute fibre, it has a great deal of promise for use in ballistic armour applications [7].

An epoxy matrix is required to achieve good qualities, especially in high-performance materials, which is the most prevalent thermoset composite matrix available. Composites with an epoxy matrix reinforcement that are randomly oriented or laminated offer good physical and mechanical properties that are attractive in various applications [8]. Furthermore, the microstructure of jute composites is varied in nature. The flexural test may be used to examine the mechanical properties of composites when they are bent. The composite will bend and buckle with enough force, creating compressive strain on the concave side, the tensile strain on the convex side, and shear along the mid-plane. The flexural modulus of a composite shows the greatest amount of flexing it can withstand before undergoing irreversible deformation. Delamination, matrix microcracking, and micro buckling are the types of damage that can occur during the flexural testing process [9].

Delamination can occur in a variety of forms and patterns depending on the general manner the laminates are stacked, as well as the shape, velocity, and mass of the impactor used. According to research, flexural strength decreases significantly over time [10]. The amount of energy required to propagate a crack by delamination is inversely proportional to the square root of the crack's characteristic length. Due to the torsional stiffness they provide, angle-ply laminates with a ±45° angle are suggested for various applications, including helicopter rotor blades [11]. A ±45° angle laminate exhibited the largest non-linearity and strain to failure because the angle plies were scissored on the compressive and tensile sides, respectively. High edge free interlaminar stresses caused significant matrix cracking and delamination, which started on the tensile side and progressed to the compressive side, resulting in pseudo-ductile behaviour [12]. Micro buckling of the fibers may result in a catastrophic failure at an early stage. The shear instability of the fibers in the surrounding matrix drives plastic micro buckling, which is the primary cause of compressive failure. It is very sensitive to fibre misalignment and waviness.

The stress-state-dependent strength and fracture stress of the epoxy resin was found to be connected to the outcomes of the mechanical tests. It is crucial in fibre-reinforced composites because the matrix is subjected to triaxial residual stress after being cooled to ambient temperature. The reduction in the load-bearing capacity of the matrix occurs because of the inhibition of the plasticity of the matrix. The low strain to failure of unidirectional laminates when subjected to transverse tensile stress can be explained by the mechanical characteristics of the simple resin used in the laminate. When subjected to low tensile loads, the plain resin shows brittle fracture behaviour, but it yields and displays substantial plastic deformation while subjected to pure shear. Because of its popularity as a computational approach for modelling and optimization in many technical disciplines of study, finite element analysis (FEA) has reached its pinnacle since its conception [13]. Simulation techniques are utilised to analyse composite materials that would be impossible to test experimentally because of their constraints, such as the type of matrix and fibre used, composition, the manufacturing process, and the applications. Furthermore, finite element analysis (FEA) has gained popularity in the analysis of natural fiber-reinforced polymer (NFRP) composites. ANSYS is the most extensively used finite element analysis programme.

The simulation and predicted values might be useful in designing NFRP composites if they are correctly used. As a result, it may be possible to reduce the expense of destructive testing while also shortening the time required to analyse the qualities of the NFRP following testing. Furthermore, the orientation of fibers in composites and the number of off-axis plies can have an impact on their mechanical characteristics. Therefore, this project will assist in determining whether the mechanical properties of FRP jute will be altered due to one-way lamination through modeling and simulation activities.

## 2. Methodology

### 2.1 Numerical Validation

Numerical modeling (or numerical validation) is an important early step in demonstrating that the original Finite Element (FE) design and implementation are acceptable. The usage of FE software was crucial, and the findings generated by ANSYS were verified to confirm that they were consistent with the actual results. As in previous studies, numerical validation was necessary to confirm that the produced result was acceptable. For composite laminate plates with dimensions of 279 x 279 x 2.16 mm and a ply thickness of 5.55555x$10^{-6}$ mm, analytical validation is carried out on the plates. The plate was meshed using the SHELL281 element type, consisting of eight nodes. The present FE findings from ANSYS have been validated following the precise solution. The current model has been validated by comparing its results to the precise answer from past researchers[14][15]. The findings are acceptable since the error margin is less than 2 percent.

## 2.2 Convergence Analysis

A convergence analysis is performed to establish the optimum mesh size for the analysis. A smaller mesh size will improve accuracy, but it will also increase the computation time required by the computer to do the study [16]. For this convergence analysis, 2×2, 4×4, 8×8, 16×16, 32×32, 32×32, 64×64, 128×128, and 256×256 mesh sizes were tested on unidirectional glass fibre reinforced polymer (GFRP) for three angles of fibre which are 0°, 50°, and 90° under tensile load. The deformation values remained the same even when the mesh size was increased. Therefore, a mesh size of 8×8 was selected for better accuracy of results and faster data computation.

## 2.3 Modeling and Failure Analysis of Composite Laminates

The flexural test was simulated using the Finite Element Model (FEM) approach executed in ANSYS software using a specimen with dimensions of 13 mm width, 60 mm length, and 2.5 mm thickness. This study opted for symmetric angle-ply sequences with and without supporting ply angle 0o to be implemented throughout 16 layers of fiber-reinforced laminate. For the specimen without supporting ply angle $0^o$, the laminates were arranged in the sequences of $[0/0]_{4s}$, $[\pm15]_{4s}$, $[\pm30]_{4s}$, $[\pm45]_{4s}$, $[\pm60]_{4s}$, $[\pm75]_{4s}$, and $[90/90]_{4s}$ while the specimen with supporting ply angle $0^o$ were arranged in the sequences of $[0/0]_{4s}$, $[(\pm15)_2,0_4]_s$, $[(\pm30)_2,0_4]_s$, $[(\pm45)_2,0_4]_s$, $[(\pm60)_2,0_4]_s$, $[(\pm75)_2,0_4]_s$, and $[(90/90)_2,0_4]_s$. Fig. 1 shows the mesh elements and boundary conditions used in this analysis.

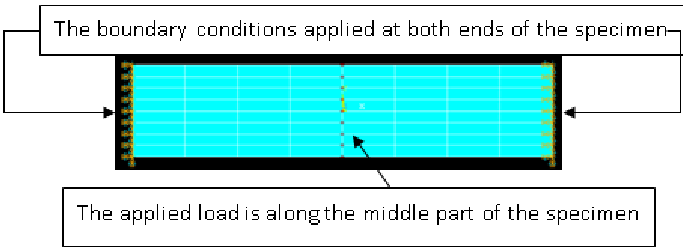



**Fig. 1 - The modelled specimen with mesh element, boundary conditions, and load applied**

The pre-processor is the first step in the simulation process using ANSYS APDL. The pre-processor is essential for determining the model dimensions, element type, material properties, failure criteria, layup sequence, and mesh size. The materials parameters of the specimen were input to determine the maximum stress and deformation of the laminate composite. The dimension is by the ASTM standard for a flexural test using the ASTM D7264 standard. The mechanical parameters of the fibre-reinforced composite, that are used as input materials data in ANSYS, are shown in Table 1. Various stacking layup directions are employed to the fibre. With the SMX value equal to one, the boundary condition and load applied to the model were implemented, and the imposed load was solved with this value. The mechanical properties of the fibre reinforced composite are plotted. The present study utilises the value of mechanical properties of different volume fractions (vf) of glass/epoxy fibre with 60 percent and 30 percent as reference material. It is compared with the properties of natural fibre jute/epoxy, which comprises about 30 percent of the overall volume of fibre reinforcement.

**Table 1 - Mechanical properties of fibre reinforced of polymer composite [17], [18], [19]**

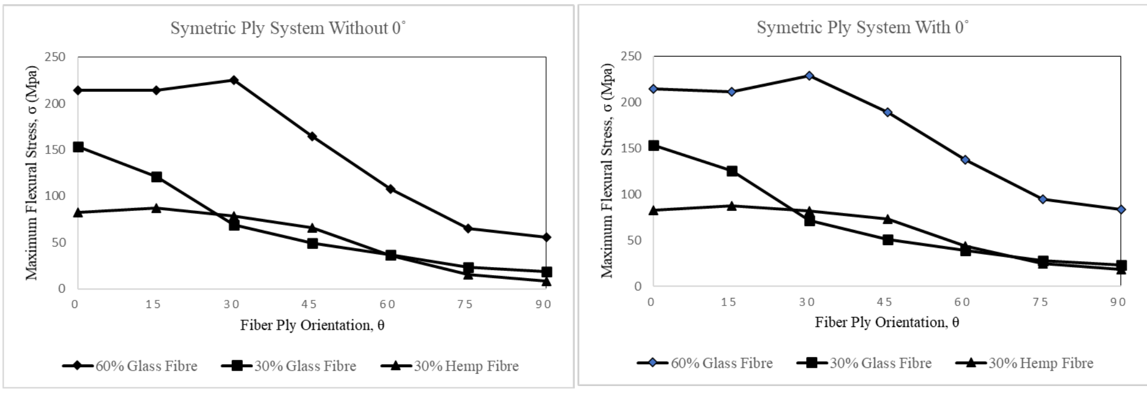
| Mechanical Properties | Symbol | Glass/epoxy (vf=60%) | Glass/epoxy (vf=30%) | Jute/epoxy (vf=30%) |
|---|---|---|---|---|
| Longitudinal modulus (0°) | $E_1$ (GPa) | 54.00 | 6.47 | 4.50 |
| Transverse Modulus (90°) | $E_2$(GPa) | 10.80 | 2.16 | 0.45 |
| Shear Modulus | $G_{12}$ (GPa) | 9.00 | 2.59 | 1.65 |
| Poisson's Ratio | $\nu_{12}$ | 0.25 | 0.25 | 0.36 |
| Shear Strength | $S_{12}$ (MPa) | 41.00 | 41.00 | 27.70 |
| Tensile Strength (0°) | $X_T$ (MPa) | 1035.00 | 342.56 | 42.44 |
| Tensile Strength (90°) | $Y_T$ (MPa) | 28.00 | 9.25 | 4.20 |
| Compression Strength (0°) | $X_C$ (MPa) | 621.00 | 77.29 | 57.26 |
| Compression Strength (90°) | $Y_C$ (MPa) | 103.00 | 10.31 | 5.70[4] |

## 3. Results and Discussion

This section discusses the effects of fibre ply orientation of unidirectional fibre-reinforced epoxy composites under flexural load. The test was conducted using ANSYS simulation on specimens with a thickness of 4 mm, and the thickness of each layer is 0.25 mm. The lay-up sequences used are ($[(+\theta, -\theta)_4]_s$) and ($[(+\theta,-\theta)_{2,}0_4]_s$), in which θ is 0°, 15°, 30°, 45°, 60°, 75°, and 90°. The simulation outcomes include maximum bending stress and deformation analysis contour. Generally, from the results, the maximum flexural stress decreases from 0° to 90° fibre ply orientation.

### 3.1 Results of Flexural Strength with Different Fibre Direction

The results show the stress is measured using the ANSYS APDL software for various layup stacking and fibre orientations of varying volume fractions of synthetic glass and natural jute fibre. Fig. 2 shows the results of maximum flexural stress with different angle of fibre orientation while (a) and (b) shows the effect of 0˚ of angle ply that will affect the value of flexural stress of the fibre. For the glass composite fibre, when comparing volume fractions of 60 percent (vf=0.6) and volume fractions of 30 percent (vf=0.3), the greatest value of flexural stress is obtained from the glass FRP composite with the maximum flexural stress for glass/epoxy (vf=60%) composite at the highest is 225.43 MPa with a fibre ply orientation of 30°, and the lowest is 55.41 MPa at 90° fibre ply orientation. However, Fig. 2 proves that the declining trend coincides with the increasing number of fibre orientations. It demonstrates that greater volume fractions are much more effective in performance. When comparing the two types of materials, such as synthetics and natural fibres, the percentage of volume fractions is the same in both cases, but the maximum flexural strength gives a different value. The value of synthetic fibre is greater than that of natural fibre because synthetic fibre has better mechanical behaviour in terms of strength, impact resistance, thermal conductivity, and other characteristics than natural fibre [20]. Furthermore, while the decreasing trend for the glass fibre is not significantly different from the decreasing trend for the natural fibre when comparing the two layups with and without 0˚ stacking sequences, the decreasing trend for the natural fibre is significantly different when comparing the two layups with and without 0˚ stacking sequences.




(a) (b)

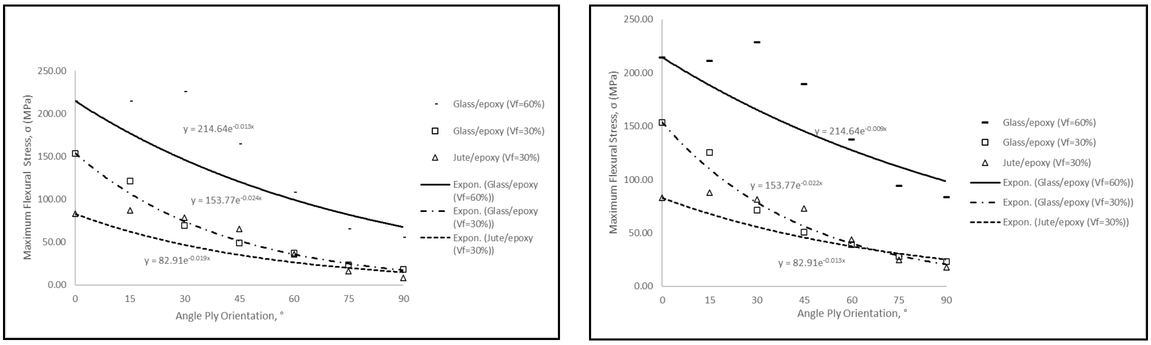
**Fig. 2 - Maximum flexural stress of fibre-reinforced polymer composite with different ply orientations (a) symmetric ply system $[(\pm\theta)_4]_s$ and (b) symmetric ply system with 0˚ $[(\pm\theta)_2,(0)_4]_s$**

### 3.2 The Strength Reduction Index of the Composites

According to the exponential graphs shown in Fig. 3, the strength reduction index of each composite is calculated and analysed. As the ply angle orientation rises, the maximum flexural stress decreases. Increase in the angle of the fibre ply orientation reduces the maximum flexural stress of each material which is glass/epoxy (vf=60%), glass/epoxy (vf=30%), and jute/epoxy (vf=30%). With $y=214.64e^{-0.013x}$, $y=214.64e^{-0.013x}$, and $y=214.64e^{-0.013x}$, where 0.013 is referred to as a fraction in the equation, glass/epoxy (vf=60%) is obtained. Using ($[(+\theta,-\theta)_4]_S$) the percentage strength reduction for glass/epoxy (vf=60 %), glass/epoxy (vf=30%), and jute/epoxy (vf=30%) composites is 1.3, 2.4, and 1.9 percent, respectively. Using ($[(+\theta,-\theta)_{2,}0_4]_s$), the percentage strength reduction for glass/epoxy (Vf=60%), glass/epoxy (vf=30%), and jute/epoxy (vf=30%) composites is 0.9, 2.2, and 1.3, respectively. It demonstrates that the orientation of the fibre ply in the lay-up sequence at 0° has an impact on the flexural stress of the composites since it results in a greater value of the percentage of strength decrease index for the composite.

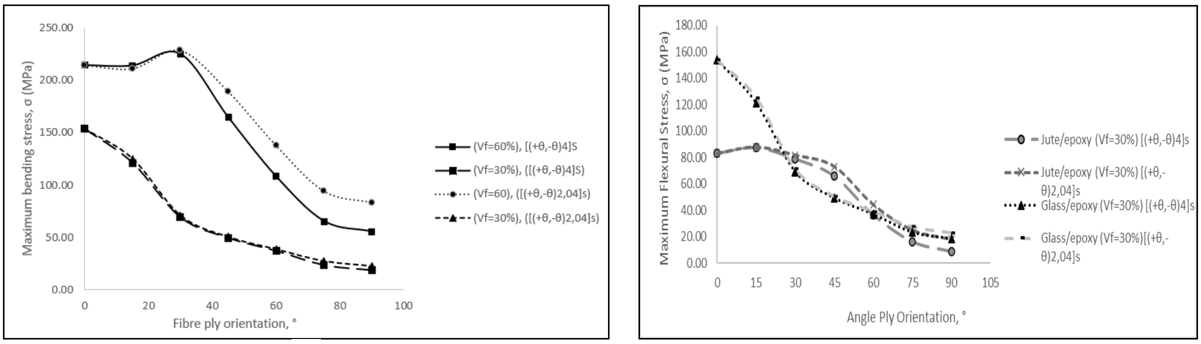
### 3.3 Effects of fibre volume fraction on the maximum flexural test of the fibre-reinforced epoxy composites

Composite materials' flexural strength is significantly influenced by the strength and volume content of the fibre reinforcement. In terms of flexural stress, glass/epoxy (vf=60%) has the greatest value, 214.64 MPa at the 0° fibre ply orientation, while glass/epoxy (vf=30%) has the lowest value, which is 153.77 MPa. In Fig. 4(a), the considerable variation in maximum bending stress of the glass/epoxy can be observed depending on the volume percent of the glass/epoxy fibre. Compared to glass/epoxy with a lower fibre volume percent, a greater fibre volume fraction has a higher maximum bending stress than a lower fibre volume fraction. Significantly, the same volume fraction of fibre with different types of materials also results in varying stress values, with jute having the lowest value of stress as shown in Fig. 4(b). The percentage of volume fractions affects the final qualities of the materials because the fibre can sustain load transfer to the fibre more effectively than the matrix itself [21]. It demonstrates that the load-bearing capability rises as the number of fibres in the composite increases. In comparison, the impact of 0˚ does not provide a significant difference in the maximum bending stress.




(a) (b)

**Fig. 3 - The exponential graph of the effect of fibre ply orientation of the composites on maximum bending stress with lay-up sequence of (a) $[(+\theta, -\theta)_4]_S$ and (b) $[(+\theta,-\theta)_{2},0_4]_s$**



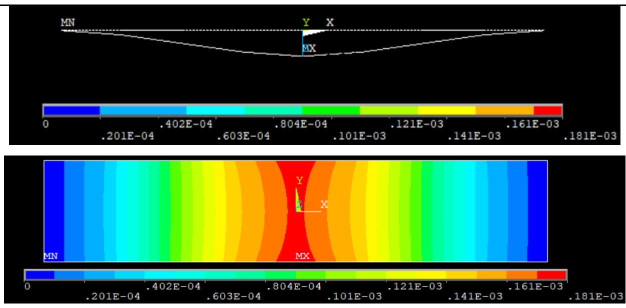
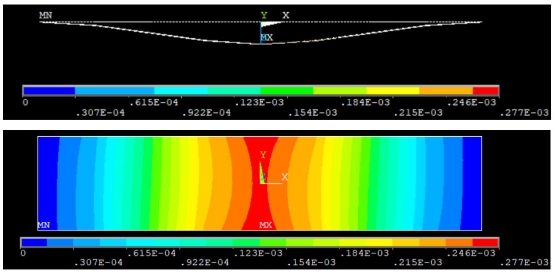
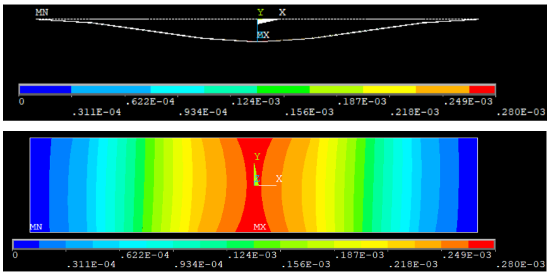
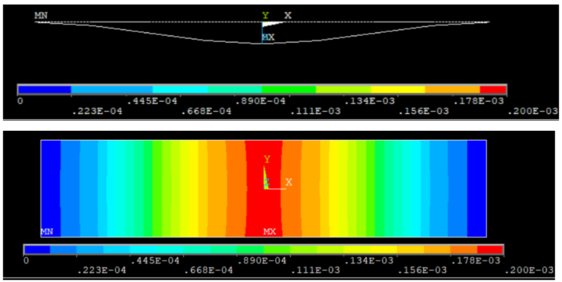
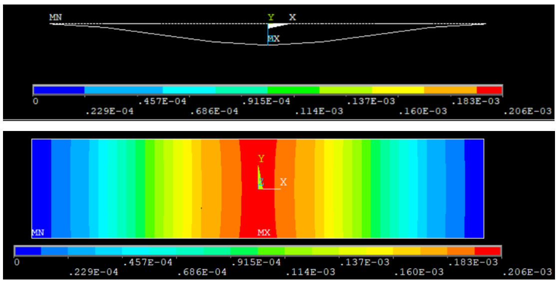
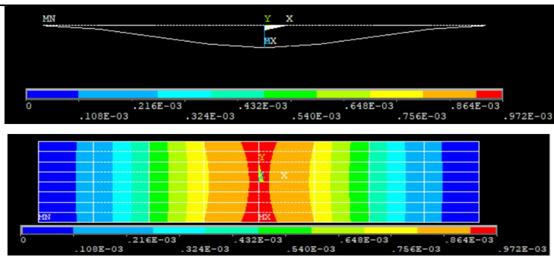
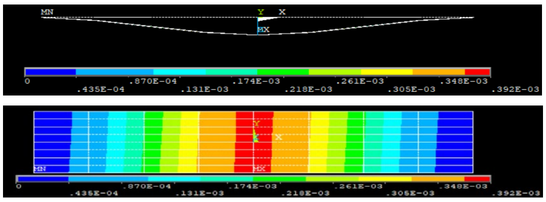
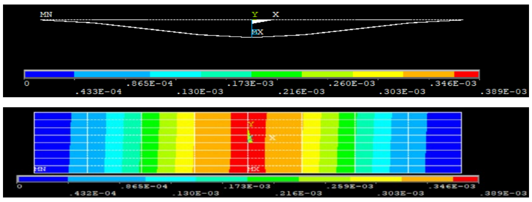
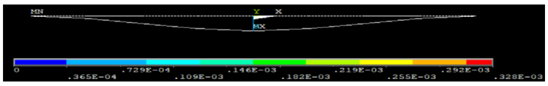
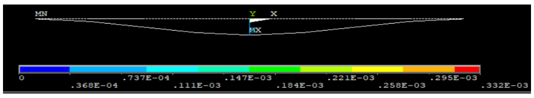

(a) (b)

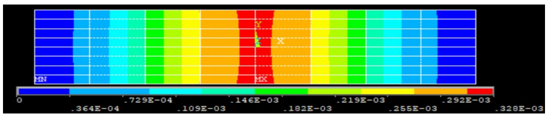
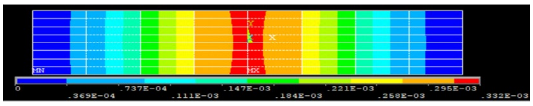
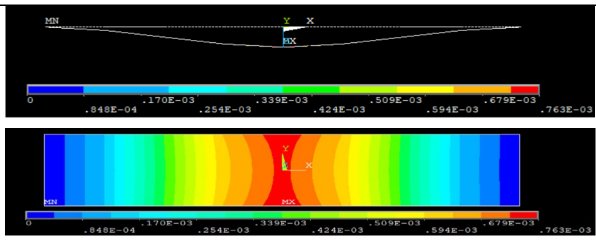
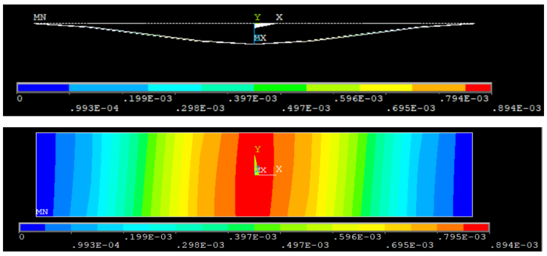
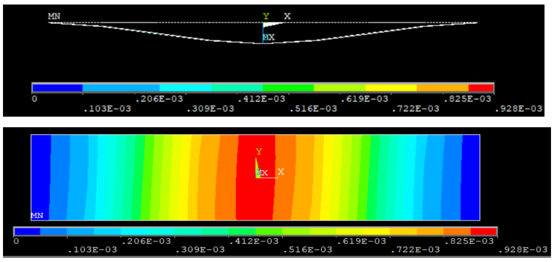
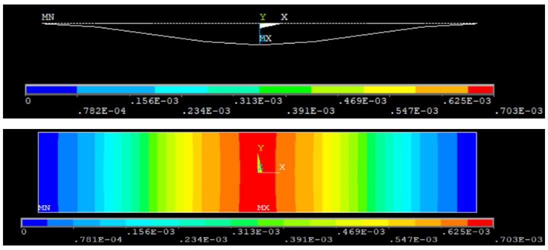
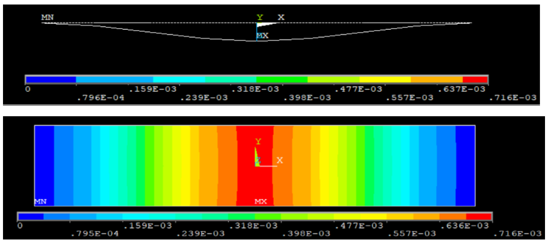
**Fig. 4 - Effects of fibre ply orientation on the maximum bending stress of (a) Different volume of glass/epoxy composites (b) glass/epoxy and jute/epoxy with same volume fraction**

## 3.4. Effects of fibre ply orientation on the deflection before failure load of the fibre-reinforced epoxy composites

The simulation of deformation contours of the composite before failure is analysed at a point load of 2 N/m with fibre ply orientation of 0°, 45° and 90° and a lay-up sequence of $[(+\theta,-\theta)_4]_S$ and $[(+\theta,-\theta)_{2},0_4]_s$. Once the flexural test load is applied, the deformation contours at the z-component throughout the lay-up procedure have been evaluated, and the overall value of deflection is used to determine the maximum value that the material can tolerate before failing. A point load of 2 N/m applied to glass/epoxy (vf=60%) demonstrates that it deforms less when compared to the other two composites, indicating that it has better mechanical capabilities because of its fibre volume fraction. Furthermore, it demonstrates that the highest volume fraction of fibre results in the lowest deformations. It also reveals that the 60˚ composition of glass fibre will result in the highest maximum flexural stress. Despite this, the deflection of glass/epoxy (vf=30%) is less than that of jute/epoxy (vf=30%), with deflections of 0.112 mm and 0.311 mm respectively. The type of fibre used in the composites has a significant impact on the mechanical characteristics of the composites in this context. Both composites contain the same volume proportion of fibre, but synthetic fibre offers superior mechanical qualities over natural fibre and vice versa. In addition, finite element studies are used to determine the value of the strength and stiffness of the materials, and it has been utilised to determine the value of flexural stress in the materials by other studies [22][23]. Table 2 presents the deformation contour of fibre with different fibre ply orientations, volume fractions, and fibre types being utilised to create the deformation contour.

**Table 2 - Maximum deformation contour of fibre-reinforced polymer composite under flexural load for fibre ply orientation [(±θ)4]s and [(±θ)2,(0)4]s**

| | [(+θ,-θ)4]s | [(+θ,-θ)2,04]s |
|---|---|---|
| Glass/epoxy (vf=60%) | | |
| θ = 0° |   Z-component deformation (ANSYS) = 0.181 mm | |
| θ = ±45° |   Z-component deformation (ANSYS) = 0.277 mm |   Z-component deformation (ANSYS) = 0.280 mm |
| θ = 90° |   Z-component deformation (ANSYS) = 0.200 mm |   Z-component deformation (ANSYS) = 0.206 mm |
| Glass/epoxy (Vf=30%) | | |
| θ = 0° |   Z-component deformation (ANSYS) = 0.972 mm | |
| θ = ±45° |   Z-component deformation (ANSYS) = 0.392 mm |   Z-component deformation (ANSYS) = 0.389 mm |
| θ = 90° |   |   |

| | | |
|---|---|---|
| |  Z-component deformation (ANSYS) = 0.328 mm |  Z-component deformation (ANSYS) = 0.332 mm |
| Jute/epoxy (Vf=30%) | | |
| θ = 0° |  Z-component deformation (ANSYS) = 0.763 mm | |
| θ = ±45° |  Z-component deformation (ANSYS) = 0.894 mm |  Z-component deformation (ANSYS) = 0.928 mm |
| θ = 90° |  Z-component deformation (ANSYS) = 0.703 mm |  Z-component deformation (ANSYS) = 0.716 mm |

## 4. Conclusion

The maximum flexural stress is determined by varying the volume fractions and fibre-reinforced polymer used from the simulation and modelling method. In the lay-up sequence of $[(+0,-0)_2]_s$ and $[(+90,-90)_2]_s$, the maximum bending stress for glass/epoxy (vf=60%), glass epoxy (vf=30%), and jute/epoxy (vf=30 %) is 214.64 MPa, 153.77 MPa, and 82.91 MPa and 55.41 MPa, 18.39 MPa and 8.37 MPa, respectively. It shows almost half of the value of 0˚angle fibre direction. Since the value of 0 degree will always be the same, the maximum bending stress for glass/epoxy (Vf=60%), glass/epoxy (Vf=30%), and jute/epoxy (Vf=30%) of the $[(+90,-90)_{2,}0_4]_s$ lay-up sequence is 83.39 MPa, 23.04 MPa, and 17.92 MPa, respectively. The orientation of the fibre ply in the composite influences the maximum flexural stress of the composite, with the value decreasing as the orientation of the fibre ply rises in the composite. Furthermore, in the flexural test, the composite with the $[(+\theta,-\theta)_{2,}0_4]_s$ lay-up sequence exhibited the highest maximum stress when compared to the composite with the $[(+\theta,-\theta)_2]_s$ lay-up sequence. The volume percentages of the fibre also have significant impact on maximum flexural stress. For example, a glass/epoxy composite with a volume fraction of 60% would have a more considerable maximum stress for the flexural test than a glass epoxy composite with a volume fraction of 30%. Therefore, a glass/epoxy composite with a volume fraction of 60% has greater maximum stress for the flexural test than a glass epoxy composite with a volume fraction of 30%. The percentage of strength reduction in the lay-up sequence for $[(+\theta,-\theta)_{2,}0_4]_s$ laminate is less than that of $[(+\theta,-\theta)_2]_s$ laminate, but it is still significant.

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