# Investigation of Stresses & Deflection of Composite Wind Turbine Blade Spar With and Without Delamination for Different Orientation of Fiber's

Karthik.S[1], Sachin Prabha[2], Pradip gunaki[3], Shivsharanayya swamy[4]

**Abstract**—Stresses and deflection's are more important in any type of composite structures, especially when we come across the wind turbine blade spar which acts like a cantilever beam. A spar is a member of the turbine blade where it acts as a supportive structure of the blade which carries blade on one end and the other end is rigidly attached to the hub of wind turbine. Spar is first considered as a cantilever beam and analysed for stresses & deflection under given loading conditions and also the spar itself is analysed for stresses and deflection for normal specimen's and delaminated specimens as well and the results are compared to observe the deviation of results from normal to delaminated specimens.

***Keywords*—**3D-Model, Spar, Boundary Conditions, Layup sequence, Delamination, ANSYS.

## 1. INTRODUCTION

Wind energy is one of the renewable means of electricity generation that is part of the worldwide discussion on the future of energy generation. This renewable technology is still in its early stage of development and maturation .The need for improved knowledge of materials properties and advanced, economical, high-volume manufacturing process becomes more important during this stage of development. Hence in this work we concentrated on backbone of the wind turbine blade called Spar. Spar is the supportive structure which connects the turbine blade to the rotating hub. This spar itself takes atmospheric forces which are acting on the aerofoil shaped blade. Hence it is very important to analyse the spar for given loading conditions and design the best by optimizing the fiber orientations. Hence here we analyse the spar for both normal and defective specimens for extracting the best design in order to increase the toughness of the composite structure.

Delamination is a mode of failure for composite materials due to repeated cyclic stresses, impact etc...can cause layers separate causing a mica like structure with significant loss in mechanical toughness. Delamination failure may bedetected primarily by sound, the delaminated area sounds dull while the normal reinforced composite sounds solid.

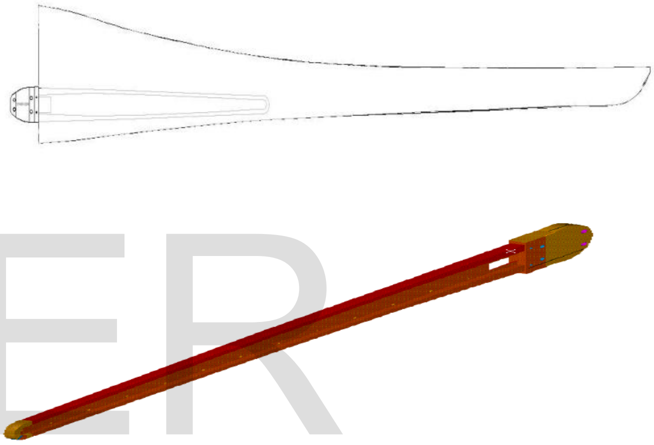

Fig.01. Spar model

## 2. ANALYSIS OF CANTILEVER BEAM.

### Case:1: Analysis of cantilever beam with isotropic material.

Due to the larger length to cross section ratio the spar is considered as a beam. The beam perhaps the most common type of structure found in engineering design on their behaviour under host of applied load and boundary conditions as well documented for a beam constructed from isotropic material.

Consider a beam subjected to a pure bending. The bending equations for a beam is

$$\frac{M}{I} = \frac{\sigma}{y} = \frac{E}{R}$$

Considering isotropic material properties, we have
E= 2 x 105.

Poisson's ratio = 0.3.

Force= 100N.

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TABLE: 1: ISOTROPIC STRESS AND DEFLECTION.

| | Theoretical Results | | Ansys Results | |
|---|---|---|---|---|
| | Stress(Mpa) | Deflection(mm) | Stress(Mpa) | Deflection(mm) |
| Solid | 240 | 1.59 | 241.26 | 1.579 |
| Shell | 240 | 1.59 | 235.29 | 1.586 |
| Beam | 240 | 1.59 | 237.05 | 1.593 |

### Case: II: Analysis of cantilever beam with orthotropic material.

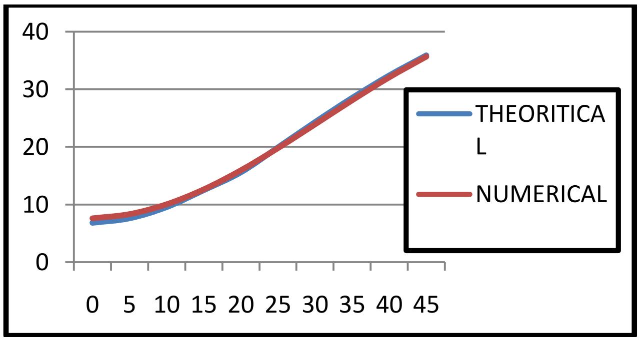
Essentially this provides the first stage in composite design that is tailoring the constituent material to suit operating conditions. Hence calculating the stresses & deflection for different orientation of fiber layers ranging from 00- 450 each.

Hence considering the orthotropic properties for analysis given below.

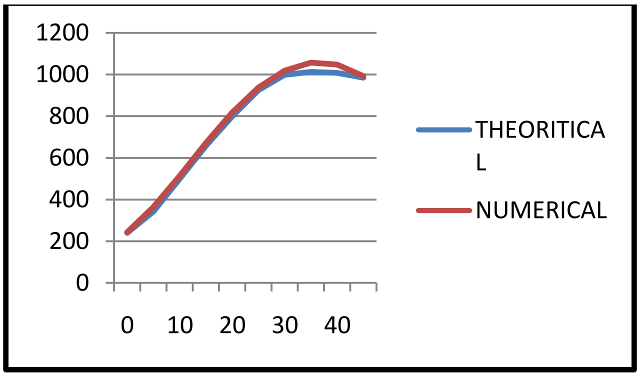
EL = 4.14 × 10 4 N/mm2
Et = 6.9 × 10 3 N/mm2
γLT = 0.15
ρ = 1.94 × 106 Kg/m3

TABLE: 2: ORTHOTROPIC STRESSES & DEFLECTION

| | Theoretical | | Numerical | |
|---|---|---|---|---|
| | *Deflection* | *Stress* | *Deflection* | *Stress* |
| $0^0$ | 6.82 | 240 | 7.636 | 243.663 |
| $5^0$ | 7.60 | 342.32 | 8.368 | 364.75 |
| $10^0$ | 9.55 | 498.88 | 10.072 | 514.224 |
| $15^0$ | 12.49 | 656.9 | 12.657 | 671.338 |
| $20^0$ | 15.59 | 799.01 | 15.97 | 817.389 |
| $25^0$ | 19.92 | 923.97 | 19.809 | 937.143 |
| $30^0$ | 24.32 | 998.66 | 23.939 | 1019 |
| $35^0$ | 28.53 | 1012 | 28.113 | 1057 |
| $40^0$ | 32.42 | 1008 | 32.098 | 1048.1 |
| $45^0$ | 35.92 | 984.32 | 35.696 | 992.075 |



Graph.1. Comparison of Deflection for different orientation's of Glass Fibres.



Graph.2. Comparison of Stresses for different orientation of Glass Fibers.

## 3. ANALYSIS OF CANTILEVER BEAM WITH DELAMINATION.

### Case: 1: Delamination at the Fixed End of the beam.

Here we introduce delamination of certain area into the model at the fixed end of the model and analyse for stresses & deflection.

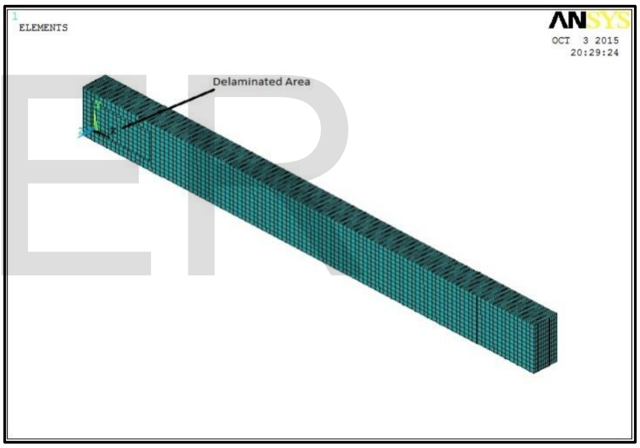


Fig: 2: Delamination at Fixed end of the beam.

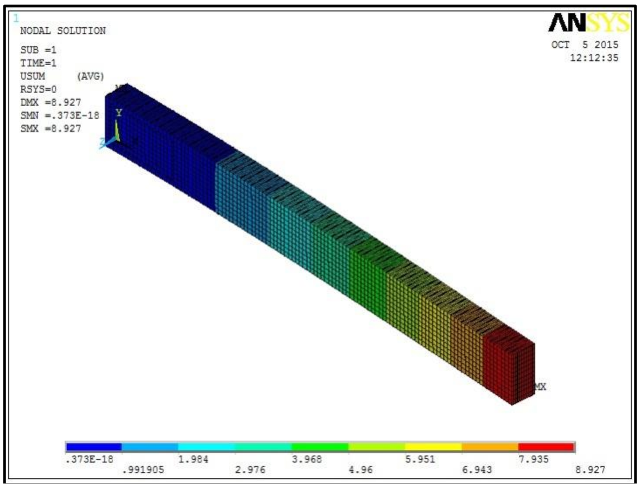


Fig: 3: Deflection of beam with delamination at fixed end.

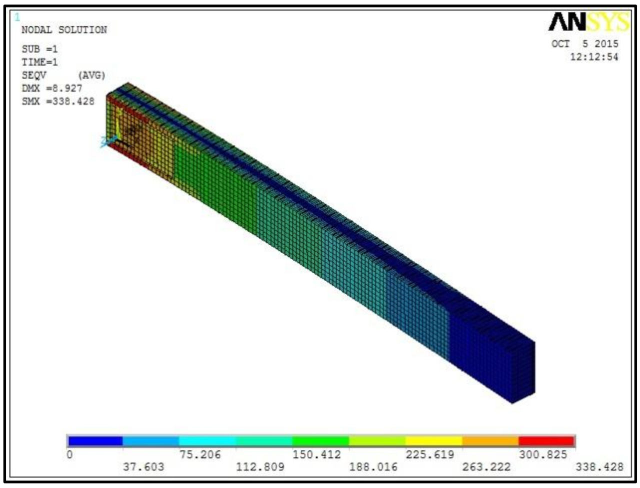
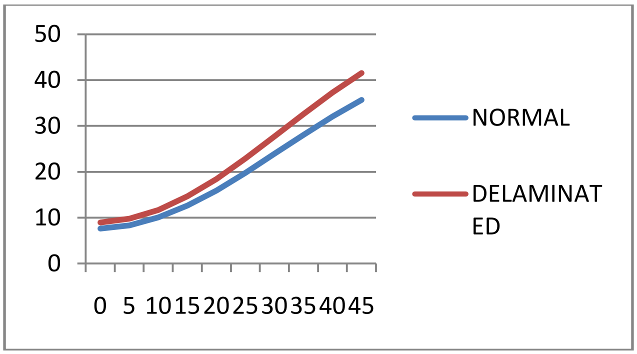


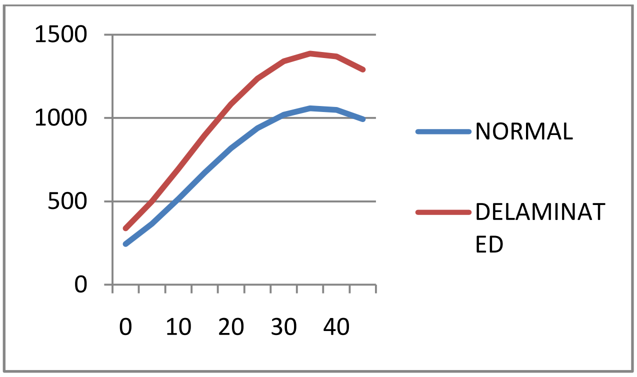
Fig. 4. Stress of beam with delamination at fixed end

TABLE: 3: COMPARISON OF DELAMINATION FOR STRESSES & DEFLECTION AT FIXED END OF THE BEAM.

| | NORMAL | | DELAMINATED | |
|---|---|---|---|---|
| | Deflection | Stress | Deflection | Stress |
| $0^0$ | 7.636 | 243.663 | 8.927 | 338.428 |
| $5^0$ | 8.368 | 364.75 | 9.745 | 500.099 |
| $10^0$ | 10.072 | 514.224 | 11.675 | 694.367 |
| $15^0$ | 12.657 | 671.338 | 14.622 | 896.032 |
| $20^0$ | 15.97 | 817.389 | 18.425 | 1083 |
| $25^0$ | 19.809 | 937.143 | 22.864 | 1236 |
| $30^0$ | 23.939 | 1019 | 27.671 | 1340 |
| $35^0$ | 28.113 | 1057 | 32.559 | 1386 |
| $40^0$ | 32.098 | 1048.1 | 37.251 | 1369 |
| $45^0$ | 35.696 | 992.075 | 41.51 | 1291 |



Graph: 3: Representation of deflection of delaminated model at fixed end.



Graph. 4. Representation of Stress of delaminated model at fixed end.

### Case: 2: Delamination at the Centerof the beam

The delamination is introduced at center of the beam and analysed for stresses and deflection for different orientation.

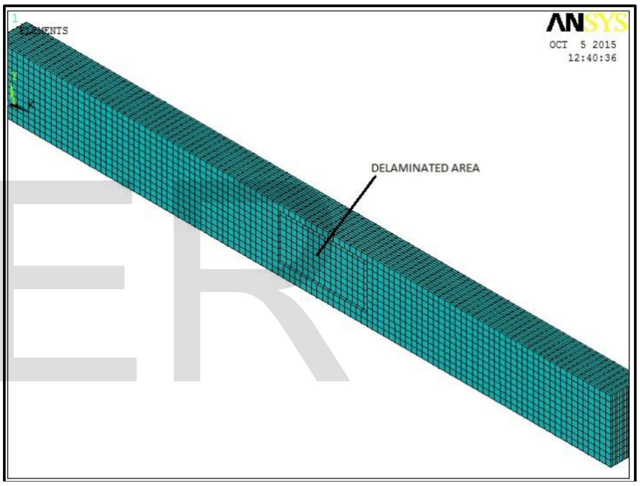


Fig. 5. Delaminated area at Center.

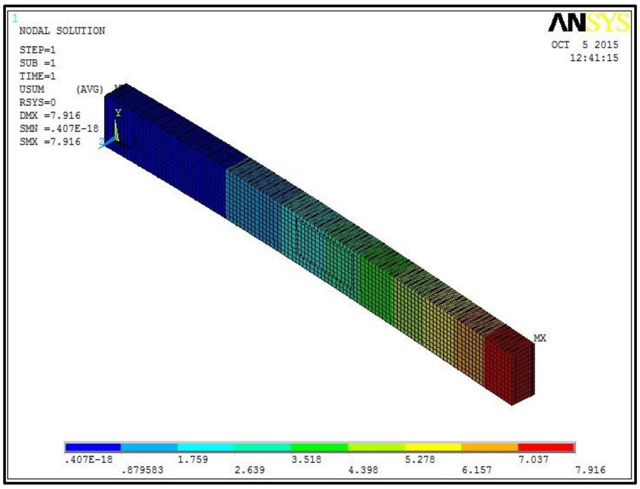


Fig: 6: Deflection of beam with delamination at center.

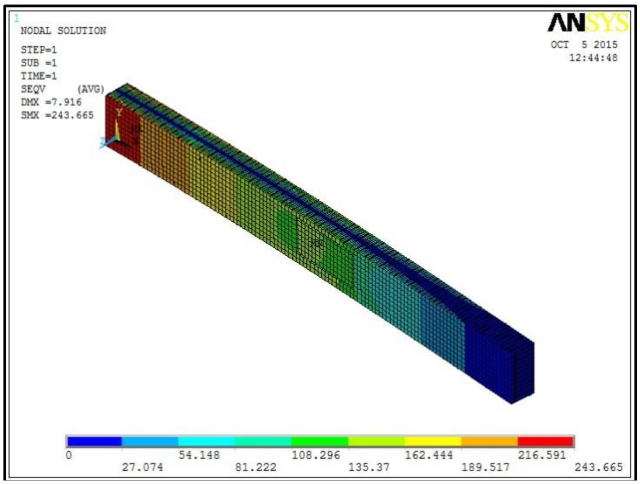
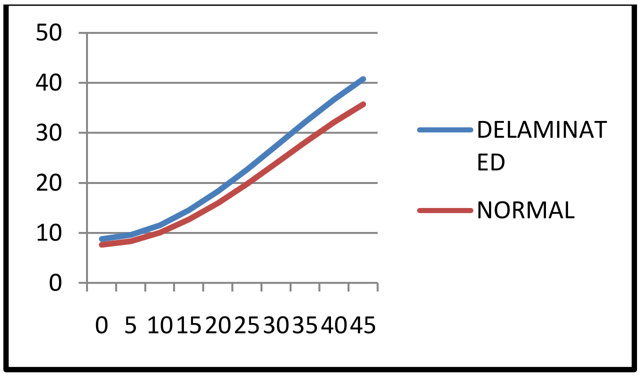


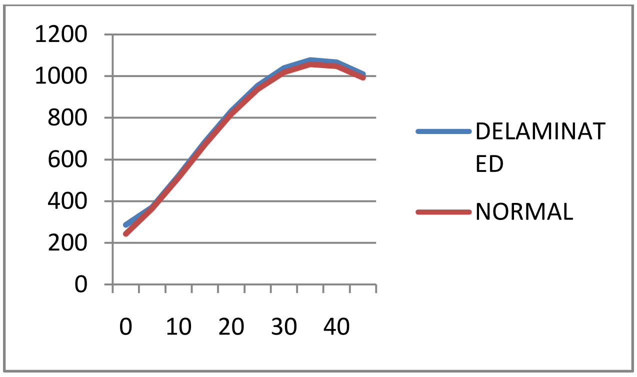
Fig: 7: Stress of beam with delamination at center.

TABLE: 4: COMPARISON OF STRESSES & DEFLECTION OF BEAM WITH DELAMINATION AT CENTER.

| | NORMAL | | DELAMINATED | |
|---|---|---|---|---|
| | Deflection | Stress | Deflection | Stress |
| $0^0$ | 7.636 | 243.663 | 8.775 | 286.234 |
| $5^0$ | 8.368 | 364.75 | 9.611 | 370.765 |
| $10^0$ | 10.072 | 514.224 | 11.557 | 522.854 |
| $15^0$ | 12.657 | 671.338 | 14.509 | 682.706 |
| $20^0$ | 15.97 | 817.389 | 18.292 | 831.321 |
| $25^0$ | 19.809 | 937.143 | 22.674 | 953.214 |
| $30^0$ | 23.939 | 1019 | 27.384 | 1037 |
| $35^0$ | 28.113 | 1057 | 32.14 | 1076.11 |
| $40^0$ | 32.098 | 1048.1 | 36.676 | 1066.02 |
| $45^0$ | 35.696 | 992.075 | 40.769 | 1009 |



Graph: 5: Representation of deflection of delaminated model at Center.



Graph. 6. Representation of Stress of delaminated model at fixed end.

## Case: 3: Delamination at the Free End of the beam.

The delamination is introduced at Free end of the beam and analysed for stresses and deflection for different orientation.

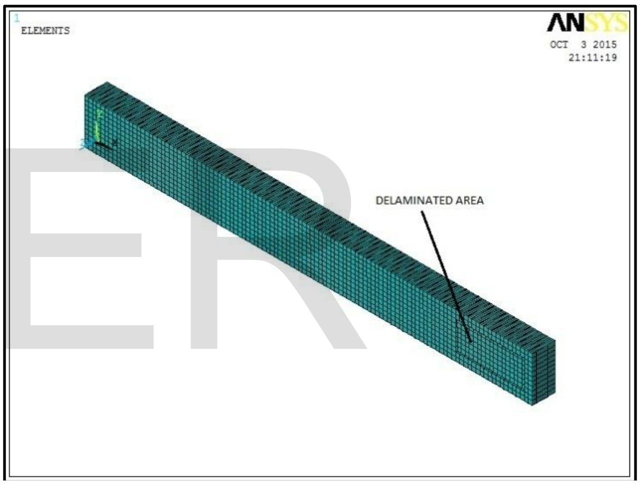


Fig.8. Delaminated area at Free End.

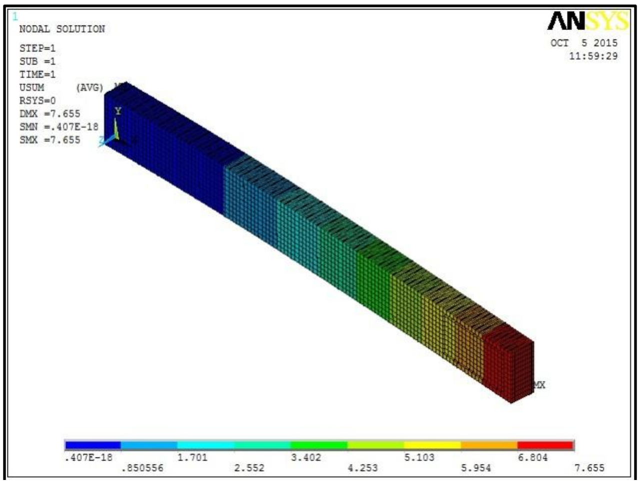


Fig.9. Deflection of beam with delamination at Free End.

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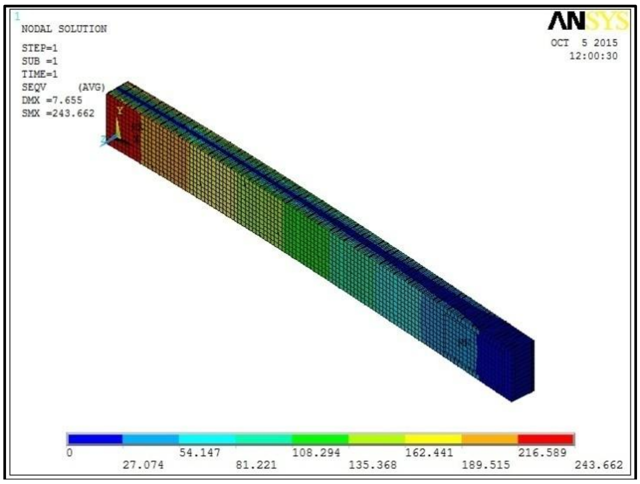
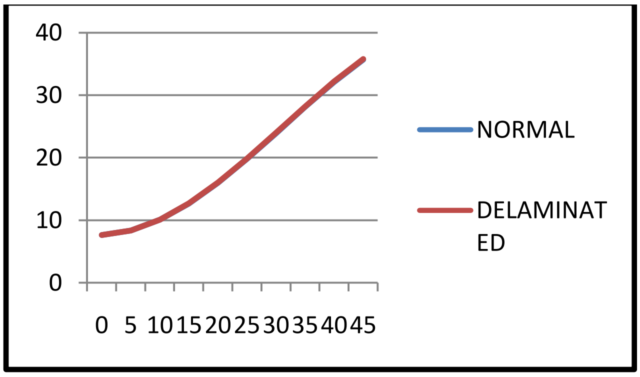


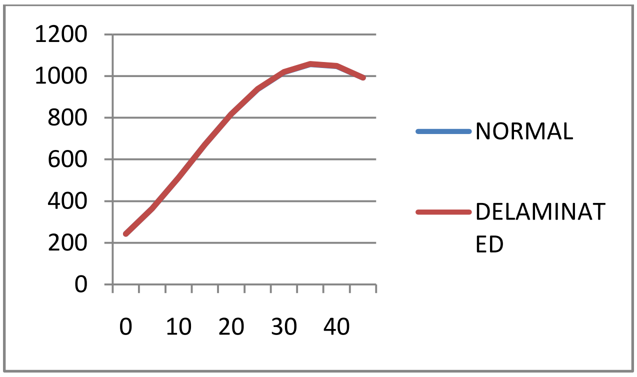
Fig: 10: Stress of beam with delamination at Free End

TABLE: 5: COMPARISON OF STRESSES & DEFLECTION OF BEAM WITH DELAMINATION AT CENTER.

| | NORMAL | | DELAMINATED | |
|---|---|---|---|---|
| | Deflection | Stress | Deflection | Stress |
| $0^0$ | 7.636 | 243.663 | 7.655 | 243.662 |
| $5^0$ | 8.368 | 364.75 | 8.391 | 364.948 |
| $10^0$ | 10.072 | 514.224 | 10.103 | 514.022 |
| $15^0$ | 12.657 | 671.338 | 12.697 | 671.2 |
| $20^0$ | 15.97 | 817.389 | 16.02 | 817.5 |
| $25^0$ | 19.809 | 937.143 | 19.869 | 937.46 |
| $30^0$ | 23.939 | 1019 | 24.009 | 1019.77 |
| $35^0$ | 28.113 | 1057 | 28.193 | 1057.56 |
| $40^0$ | 32.098 | 1048.1 | 32.186 | 1048 |
| $45^0$ | 35.696 | 992.075 | 35.792 | 992 |



Graph: 7: Representation of deflection of delaminated model at Free End.



Graph: 8: Representation of Stress of delaminated model at free end.

## 4. ANALYSIS OF SPAR

Spar is made using glass fiber epoxy composite. Its cross-section is like I-beam. Web is made using glass-epoxy laminates. Rim sections at top and bottom of the web are made using Unidirectional roving or bundle of fibers. The fiber in the rims is laid out along the spar length. Both web and rim regions are stimulated using composite shell element. Theweb thickness is about 6.5mm and the same is stimulated using 11 layers of 0.6mm thick each. The lay-up sequence is ± 450 with respect to spar length. The elements in the rim is assumed to have 68 layers and each is of 0.1,, thickness. All 68 layers are unidirectional, i.e. fibers are laid out along the span length of the spar.

TABLE:6: MATERIAL PROPERTIES OF SPAR.

| Properties | Unidirectional Glass Epoxy |
|---|---|
| Axial Modulus(GPa) | 41.4 |
| Transverse Modulus(GPa) | 6.90 |
| Shear Modulus(GPa) | 3.45 |
| Poisson's ratio | 0.15 |
| Density kg/m3 | 1940.00 |
| Ultimate Axial Strain(Tensile) | 0.033 |
| Ultimate Axial Strain (Compressive ) | 0.0266 |
| Ultimate Transverse Strain(Tensile) | 0.005 |
| Ultimate Transverse Strain(Compressive ) | 0.025 |
| Ultimate Shear strain | 0.010 |
| Axial Expansion Coefficient (με/oC) | 3.5 |
| Transverse Expansion Coefficient (με/oC) | 20.0 |

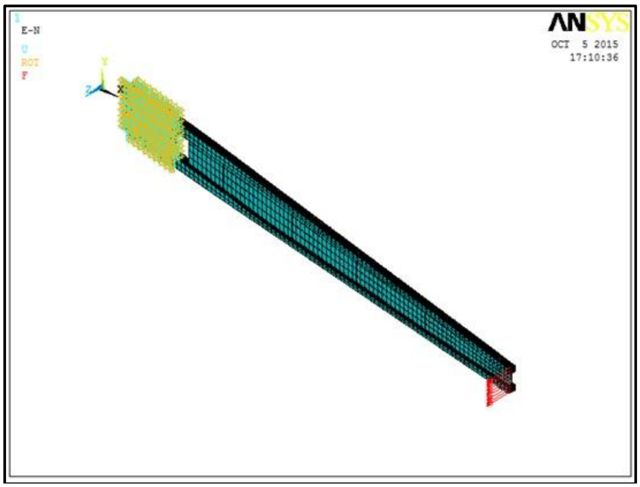


Fig. 11.Boundary conditions of Spar.

In fig 4.1 the base of the spar is constrained in all degrees that is translation in x,y,z and rotation in x,y,z is arrested and analysed for stresses and deflection.

Wind speed –exceeding 36m/s is termed as gust. When the speed of the air is above 36m/s, both the aerodynamic and mechanical brake is applied and wind turbine is arrested. This condition is called parking of blade. Under this condition high-speed wind exerts a force, which depends on the shape of the structure. The load on the blade during gust is calculated as below.

Vgust= 36m/s
Dynamic pressure = ½(ρVgust2)
Solidity = σ = Blade area/ πR2
Drag Co-efficient = CD = 1.3
ρ = Density of air = 1.25 kg/m3
σ = Blade area/πR2 =0.843783*107*2/π*(11350)2=0.041698
We know that,
Gust Force = Cd [½(ρVgust 2)]*σ*πR2 / number of blades.
Force= 1.3*[1/2(1.25*722)*0.041*π*(11.350)2 ]/2
= 9429.9N

This force acts uniformly over the plane form area of the blade

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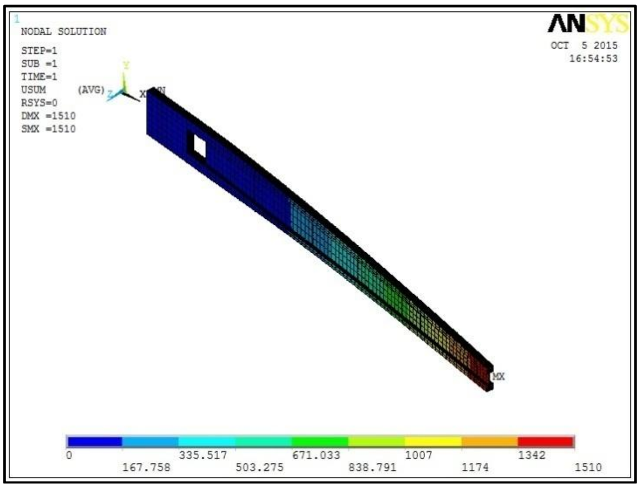

Fig: 12: Displacement of Spar.

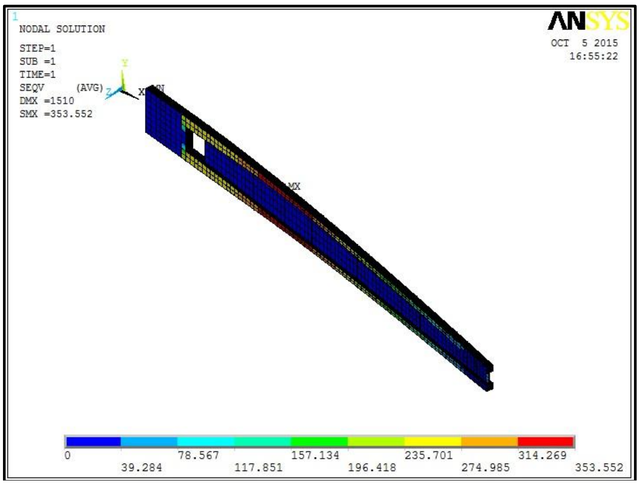

Fig. 13. Stress on the Spar.

## 5. ANALYSIS OF DELAMINATED SPAR

Delamination is introduced at the center of the spar and analysed for stresses and deflection under gust load condition of 9429.9N.

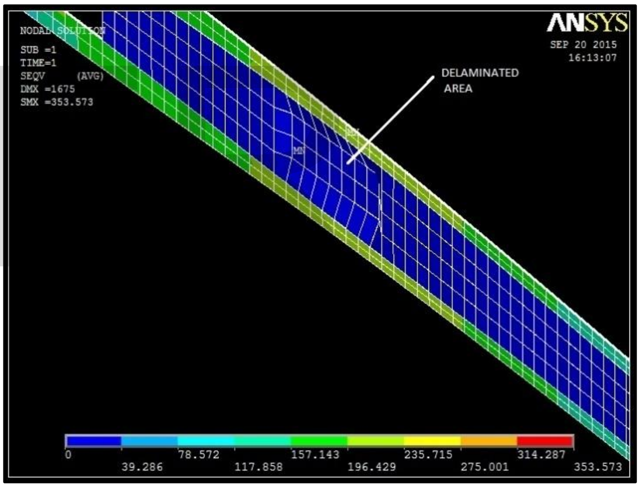

Fig. 14. Delaminated Spar model .

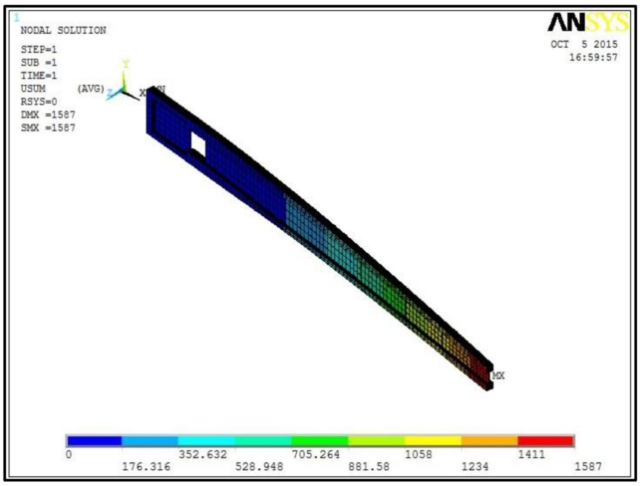

Fig.15.Deflection of delaminated spar

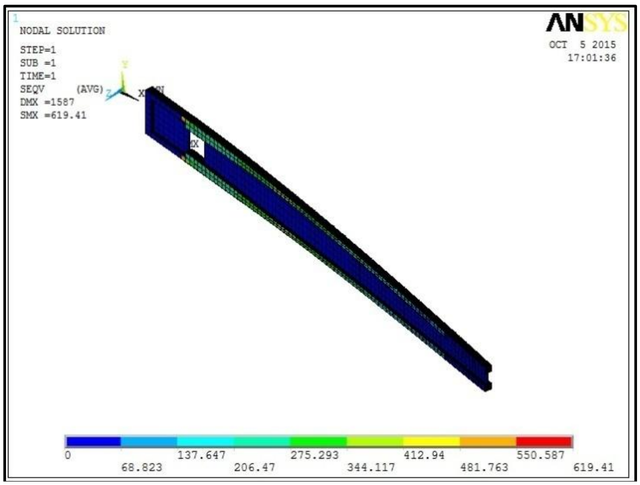

Fig. 16. Stress in delaminated Spar.

TABLE:7: COMPARISON OF STRESS& DEFLECTION.

| | NORMAL | | DELAMINATED | |
|---|---|---|---|---|
| | Stress | Deflection | Stress | Deflection |
| Spar | 353.552 | 1510 | 619.41 | 1587 |

## 6. CONCLUSION

Numerical analysis was performed to study the behaviour of Uni-directional glass fiber reinforced polymer composite beam and spar as using finite element analysis software Ansys. Undelaminated composite specimen was compared against delaminated composite specimen for deflection and stress under bending. In that the values of stress & deflection of different fiber orientation were varied because of delamination defect which are introduced in the specimen. The delamination reduces the toughness of the beam and spar which inturn results in variation of stresses & deflection. It is also concluded that the results obtained from analytical and numerical methods compares very well with less percentage of error.

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