STRESS ANALYSIS OF GLASS FIBRE REINFORCED COMPOSITES USED IN WIND TURBINES

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Abstract—Wind turbines transform kinetic energy in the wind into electrical energy. Glass fiber Reinforced Polymer Composite (GFRP) have seen to be the best option for the wind turbines blades due to their high impact strength, light weight and high strength to weight ratio, etc. The objective of this of this paper is to study and analyze the mechanical behavior of GFRP composite specimen subjected to three point flexural loading conditions. GFRP was modeled in ANSYS using SHELL 91element. Loading conditions were simulated and results were recorded. GFRP specimens were fabricated as per ASTM D790 dimensions using hand lay-up process and subjected to three point loading conditions in Instron material testing machine and results were recorded. Simulation results were validated with the experimental results. Study confirms that defining matrix and fiber bonding properties in SHELL 91 element may lead to good agreement between the simulation and experimental results.

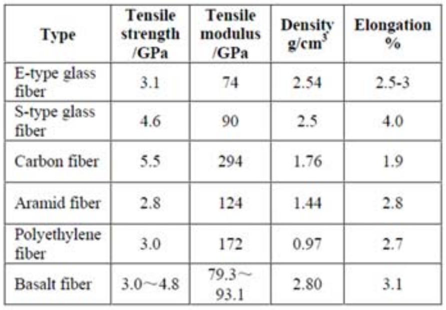
Index Terms—Ansys, composite, glass-fiber, hand lay-up, Instron, material testing, matrix.

I. INTRODUCTION

Composites are materials consisting of two or more chemically distinct constituents on a macro-scale, having a distinct interface separating them and with properties which cannot be obtained by any constituent working individually. Composite contains matrix and reinforcement materials. The reinforcing fibre provides strength and stiffness to the composite, whereas the matrix gives rigidity and environmental resistance. Typically, composite material is formed by reinforcing fibres in a matrix / resin. The reinforcements can be fibers, particulates, and the matrix materials can be metals, plastics, or ceramics.

Polymer composites use thermoset or thermoplastic resins. In case of GFRP composites, glass fibres are reinforced in the polyester resin the reinforcing fibres constitute the backbone of the material and they determine its strength and stiffness in the direction of fibres. The main advantage that enables the widespread use of glass fibres in composites are its competitive price, availability, good usability, ease of processing, high strength and other convenient properties [1]. The most common glass fibres are made of E-glass and S-glass. E-glass is the least expensive of all glass types and it has a wide application in fibre reinforced plastic industry. S-glass has higher tensile strength and higher modulus than E-glass. However, the higher cost of S-glass-fibres makes them less popular than E-glass. The E-glass fibre is a kind of glass fibre with low alkali, excellent strength, stiffness, ductility, insulation, heat resistance and moisture resistance. E glass is the primary reinforced material of wind turbine blades, having low cost and good applicability. It is a better match with many resins, and the molding process. However, as the density of the E-type fiber is large, it is generally used in smaller blades about 22 meters [2].

Table 1.1 shows the mechanical properties of different glass fibres.



Type	Tensile strength /GPa	Tensile modulus /GPa	Density g/cm^3	Elongation %
E-type glass fiber	3.1	74	2.54	2.5-3
S-type glass fiber	4.6	90	2.5	4.0
Carbon fiber	5.5	294	1.76	1.9
Aramid fiber	2.8	124	1.44	2.8
Polyethylene fiber	3.0	172	0.97	2.7
Basalt fiber	3.0～4.8	79.3～93.1	2.80	3.1

Table 1.1 Mechanical properties of different glass fibres.

Wind turbine blades are subjected to external loading which includes flap-wise and edge-wise bending loads, gravitational loads, inertia loads due to pitch and acceleration, as well as torsional loading. The flap-wise loads are caused mainly by wind pressure, while edge-wise load is caused by gravitational force and torque load.

The flap-wise and edge-wise bending loads cause high longitudinal tensile and compressive stress in the blade material. The up-wind side is subjected to tensile stresses, while down-wind side is subjected to compressive stresses [3]. Also environmental conditions such as moisture, icing, heat, rain, chemical corrosions etc. have considerable effect on the life of wind turbine materials.

Because of the above prevalent different types of loads acting on wind turbine blades advanced composites like GFRP are commonly used in blade construction. Traditional E-glass fiber (70-75% by weight) bonded with epoxy or unsaturated polyester resin is the most common resin because it is easier to process, needs no post-curing and is less expensive, Carbon fibre bonded with polyester provides high stiffness and less weight but mainly used for longer turbine blades. Epoxy resin is preferred to polyester for fabricating longer blades for its better tensile and flexural strength. Polyester is easier to process, needs no post-curing and is less expensive. Polypropylene is a new emerging trend in thermoplastic wind turbine blades as it is having an advantage of recyclability [1].

II. FINTE ELEMENT ANALYSIS

Finite element analysis is used to study the behavior of an actual GFRP composite material. Element, SHELL 91 of ANSYS has the following features

- 8-Node Element.
- Non-Linear Structured Shell.
- Layers Permitted-100(Max.)
- Large Strain Capabilities.
- Suitable for laminates and sandwich structures

To ensure that the model created is an accurate mathematical model of a physical prototype, Glass fiber is laid up in a uni-directional manner in the matrix. CADEC Matlab based software *is used to* calculate mechanical properties like Young's *Modulus,* shear *m*odulus*,* and poisson's *r*atio*.* Rules *of* mixtures are applied to calculate the effective mechanical properties. Graph 2.1 shows the young's modulus for Polyester-E-Glass composite for various fibre volume fractions.

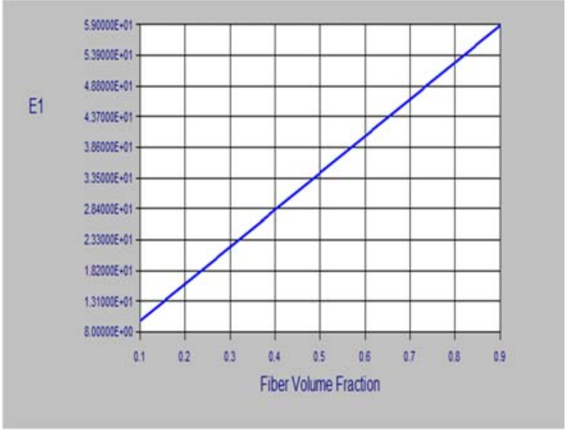


Table 2.1: Polyester-E Glass Young's Modulus for different volume fractions

Polyester-E-Glass composite was modeled in accordance with the Instron Machine setup used for Flexural Analysis. Therefore a 3-point Bending test setup was applied in ANSYS. The load applied was 364.92 N at the middle nodes while at the supporting nodes all DOF are constrained. The composites were modeled using volume fractions of 0.16 and 0.30. Figure 2.2 and 2.3 shows the stress analysis of 0.16 and 0.3 volume fraction Polyester-E-Glass composite performed in ANSYS. The ANSYS model and fabricated specimen have same dimensions, number of layers, fiber orientation, volume fraction and thickness. Subsequently the models were subjected to loads and the nodal solution such as Von Mises Stress was obtained. Figures 2.2 and 2.3 show that the colour pattern observed is in alignment to the stress intensity at that particular region. Ex: Red indicates a highly stressed region whereas the dark blue represents a low intensity region.

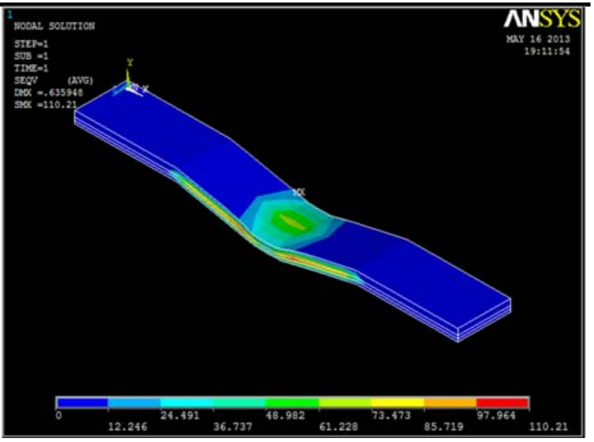


Figure 2.2: Finite element analysis of 0.16 volume fraction Polyester-E-Glass composite

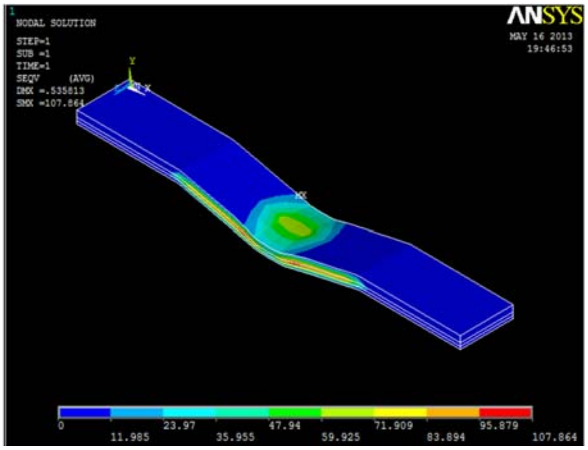


Figure 2.3: Finite element analysis of 0.16 volume fraction Polyester-E-Glass composite

III. Specimen Preparation and Testing

The Polyester-E Glass specimens were prepared by hand layup process which is low-cost and the most common processes employed for manufacturing wind turbine blades using fiberglass composites. A release agent, usually in either wax or liquid form, is applied to the chosen mold. This will allow the finished product to be removed cleanly from the mold. Resin – typically a 2-part polyester or epoxy is mixed with its hardener and applied to the surface. Sheets of glass-fibre matting are laid onto the mold, then more resin mixture is added using a brush or roller. The material must conform to the mold, and air must not be trapped between the fibre- glass and the mold. Additional resin is applied and possibly additional sheets of fibre-glass. Hand pressure, vacuum or rollers are used to make sure the resin saturates and fully wets all layers, and any air pockets are removed before the resin starts to cure. Figure 3.2 shows the hand layup process.

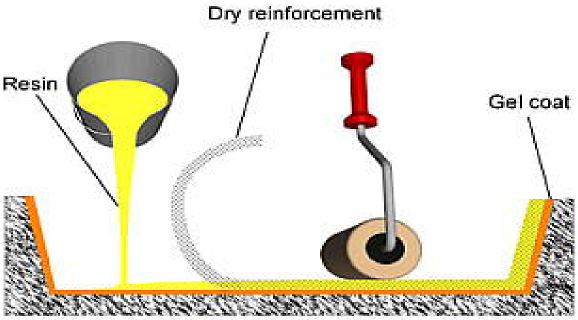


Figure 3.2: Schematic of hand layup process

Figure 3.3 shows the photograph of Polyester-E-Glass composite specimen having 0.16 and 0.3 volume fraction of fibres oriented along the length of the specimen. As per ASTM D790 specimens of dimensions 127×17.5×3.9 mm were prepared by hand lay-up process as discussed above.

Figure 3.3: Photograph of Polyester-E-Glass composite specimen

Instron Universal Testing Machine (UTM) was used for experimental stress analysis of the Polyester-E-Glass composite samples prepared by hand lay-up process. This testing machine meets the testing standards according to ASTM D790. The machine is also used for testing various types of polymer matrix composite specimens according to the necessary type of loading requirement. Various jigs are provided for suitable mounting arrangements of the different specimens like tensile, shear, bending, short beam etc. Figure 3.4 shows the photograph of UTM. The machine consists of a cross head jaw which is fixed between two railings. The cross head is used for applying weight on the specimen when subjected to a particular loading. This crosshead weight applied on the specimen is controlled by a parameter called cross head speed or jaw speed. The crosshead is pneumatically controlled.

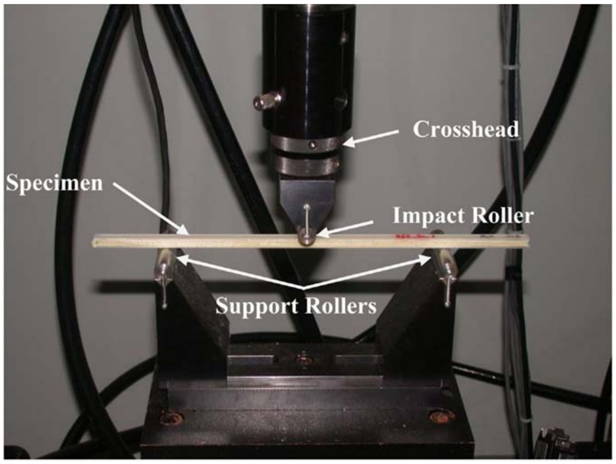


Figure 3.4 Photograph of Instron UTM

The machine is integrated with a computer and software called “Instron Suite”. This is used to run the test machine by using input parameters of the sample test specimen such as span length, width, thickness and cross head speed (Z). The cross head speed, when set, will start the cross head to impinge downwards onto the surface of the specimen and the moment it makes contact with the surface, the software will display real time bending strength variation up to the point of fracture. The variation can be observed clearly by looking onto the computer screen where the material deformation is monitored at each instant of time period. For this study, the jig of standard three point flexural test was selected; the specimen is placed on the two supports at a particular span length as shown in figure 3.4. The span length of 64 mm was used for the experimentation. Once the specimen is placed, the cross head jaw is brought in contact with the surface and the jaw speed is set into motion at a particular feed rate (mm/min). Here for the experimentation, feed rate was set at 1.8 mm/min. Experimental values of flexural strength, flexural modulus, graph of flexural stress vs flexural strain, maximum load up to the point of fracture were recorded.

Three Polyester-E-Glass composite samples with fibre volume fraction of 0.16 were named as specimen A, B and C and were subjected to a 3 point Flexural/Bending Test in the Instron machine. The load was applied up to the point of fracture and the parameters such as flexural strength, flexural modulus, and maximum load at the point of fracture for each specimen was obtained from the machine were recorded. The specimen D without fiber reinforcement was also prepared and subjected to testing to confirm the influence of the fibre in increasing the strength of the composite. All the data obtained during experimentation and simulation are recorded and tabulated in section IV.

IV. Results

The simulation results and experimental results obtained for 0.16 fibre volume fraction were recorded. Figure 4.1,4.2 ,4.3 and 4.4 shows the Instron UTM plot of flexure stress vs flexure strain for sample A, sample B, sample C and sample D respectively. Table 4.1, 4.2, 4.3 and 4.4 shows the Instron UTM stress analysis data of sample A, sample B, sample C and sample D respectively. Table 4.5 shows the CADEC software results which were used for ANSYS analysis. Table 4.6 shows the stress analysis results of ANSYS simulation and table 4.7 shows the summary of stress analysis results obtained by Instron UTM machine.

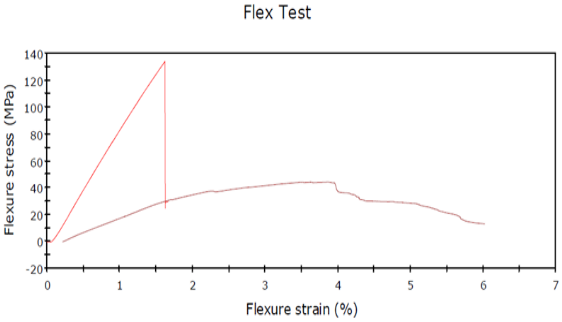
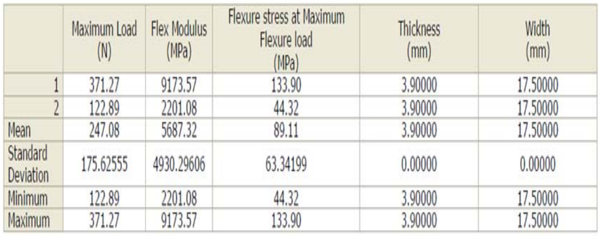


Figure 4.1: Instron UTM plot of flexure stress vs flexure strain for sample A



	Maximum Load (N)	Flex Modulus (MPa)	Flexure stress at Maximum Flexure load (MPa)	Thickness (mm)	Width (mm)
1	371.27	9173.57	133.90	3.90000	17.50000
2	122.89	2201.08	44.32	3.90000	17.50000
Mean	247.08	5687.32	89.11	3.90000	17.50000
Standard Deviation	175.62555	4930.29606	63.34199	0.00000	0.00000
Minimum	122.89	2201.08	44.32	3.90000	17.50000
Maximum	371.27	9173.57	133.90	3.90000	17.50000

Table 4.1: Instron UTM stress analysis data of sample A

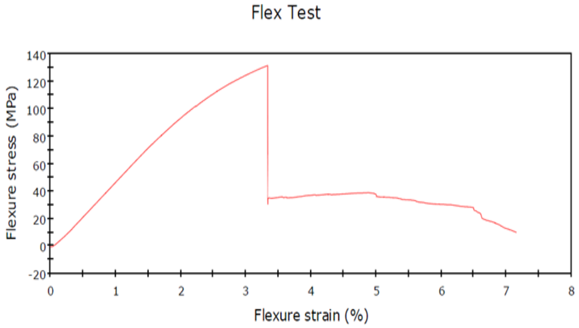
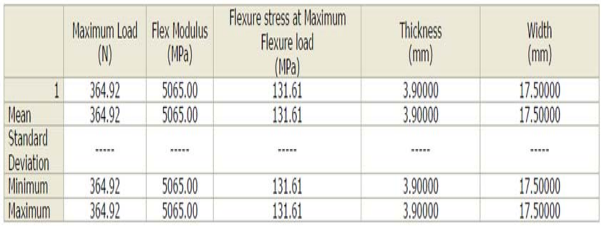


Figure 4.2: Instron UTM plot of flexure stress vs flexure strain for sample B.



	Maximum Load (N)	Flex Modulus (MPa)	Flexure stress at Maximum Flexure load (MPa)	Thickness (mm)	Width (mm)
1	364.92	5065.00	131.61	3.90000	17.50000
Mean	364.92	5065.00	131.61	3.90000	17.50000
Standard Deviation	-----	-----	-----	-----	-----
Minimum	364.92	5065.00	131.61	3.90000	17.50000
Maximum	364.92	5065.00	131.61	3.90000	17.50000

XTable 4.2: Instron UTM stress analysis data of sample B

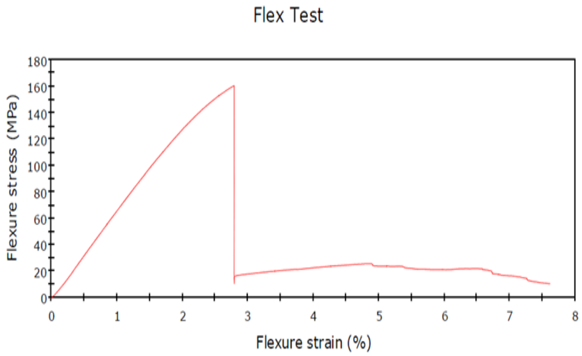
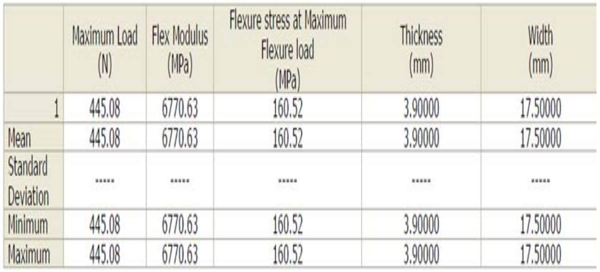


Figure 4.3: Instron UTM plot of flexure stress vs flexure strain for sample C



	Maximum Load (N)	Flex Modulus (MPa)	Flexure stress at Maximum Flexure load (MPa)	Thickness (mm)	Width (mm)
1	445.08	6770.63	160.52	3.90000	17.50000
Mean	445.08	6770.63	160.52	3.90000	17.50000
Standard Deviation	-----	-----	-----	-----	-----
Minimum	445.08	6770.63	160.52	3.90000	17.50000
Maximum	445.08	6770.63	160.52	3.90000	17.50000

Table 4.3: Instron UTM stress analysis data of sample C

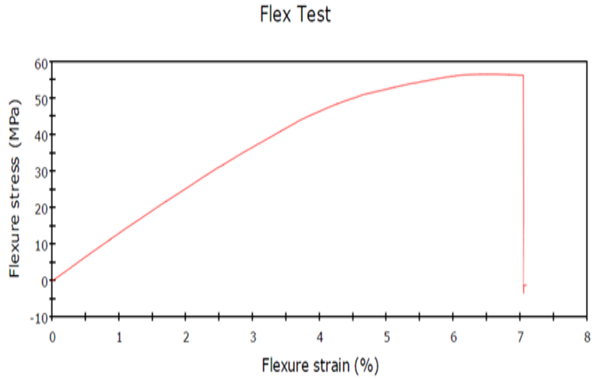
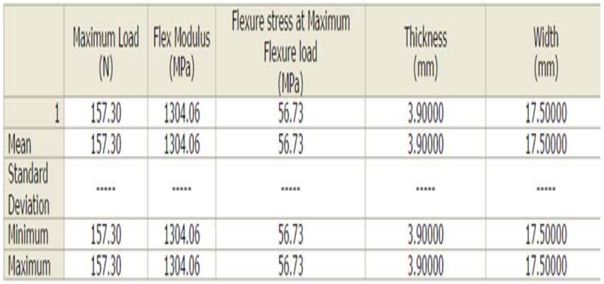


Figure 4.4: Instron UTM plot of flexure stress vs flexure strain for sample D



	Maximum Load (N)	Flex Modulus (MPa)	Flexure stress at Maximum Flexure load (MPa)	Thickness (mm)	Width (mm)
1	157.30	1304.06	56.73	3.90000	17.50000
Mean	157.30	1304.06	56.73	3.90000	17.50000
Standard Deviation	-----	-----	-----	-----	-----
Minimum	157.30	1304.06	56.73	3.90000	17.50000
Maximum	157.30	1304.06	56.73	3.90000	17.50000

Table 4.4: Instron UTM stress analysis data of sample D

Composite	E1	E2=E3	G12=G13	G23	NU12=NU13	NU23
Polyester-E-Glass	14.024	4.508	2.050	1.931	0.245	0.165

Table 4.5: Mechanical Properties Obtained fromCADEC

E1=Young's Modulus in X-direction (GPa)
E2=Young's Modulus in Y-direction (GPa)
E3=Young's Modulus in Z-direction (GPa)
G12=Shear Modulus in XY plane (GPa)
G23=Shear Modulus in YZ plane (GPa)
G13=Shear Modulus in XZ plane (GPa)
NU12=Poisson's Ratio in XY plane
NU23=Poisson's Ratio in YZ plane
NU13=Poisson's Ratio in XZ plane

Composite	Von Mises Stress(MPa)	XY Shear Stress (MPa)	YZ Shear Stress (MPa)	XZ Shear Stress (MPa)
Polyester-E-Glass	110.21	62.882	23.714	6.348

Table 4.6:Stress analysis results of ANSYS.

Specimen	Flexural Strength(MPa) (at max. load)	Flexural Modulus(MPa) (at max. load)	Maximum Load, N (at point of fracture)
Specimen A	133.90	9173.57	371.27
Specimen B	131.61	5065.00	364.92
Specimen C	160.52	6770.63	445.08

Table 4.7: Summary of Stress analysis results obtained by Instron UTM machine

V. CONCLUSION

Test specimens were subjected to standard flexural 3 point bending load using instron testing machine. Loading is of vertical type, in between the span length. The average flexural strength of all three readings of each specimen is considered in order to obtain the most correct value of the flexural strength. The flexural strength of E-glass-fibre reinforced Polyester matrix composite was observed to be around ~143 MPa. The values obtained for the flexural stress obtained from testing the specimen in machine and ANSYS differs by 10-12 MPa due to following shortcomings. In fabrication of specimen by hand layup method, it is impossible to remove voids and cracks inside specimen. Raw materials obtained were not of standard quality. Shortcoming in ANSYS model may be because of no provision for feeding matrix-Fiber bonding for the considered SHELL 91 element. Exact environment setup is not possible to simulate in ANSYS.

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