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RESEARCH ARTICLE

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FABRICATION AND ANALYSIS OF MECHANICAL PROPERTIES OF E-GLASS BI-DIRECTIONAL FABRIC COMPOSITE MATERIAL

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ABSTRACT

Composites play a vital role in aerospace, land transportation and consumer goods due to their high specific strengths and stiffness's, leading to reduction in the mass of moving objects. Glass epoxy composites are an unique materials for some of the important hardware such as pressure vessels of commercial applications, Storage of chemicals, sewage treatment plants, chemical industrial applications.

Initially to manufacture a laminate with appropriate finishing and maintaining uniform thickness a Match-Die-Mold is designed and fabricated. In the present investigation, I am going to use three different resin matrix systems in conjunction with E-Glass bidirectional fabric. The epoxy LY556 (resin system - 1) the epoxy LY 556 with 5%reactive diluents (resin system - 2) and Epofine 1555(modified epoxy resin with high elongation (resin system - 3)). Finally after obtaining the testing results, those will be evaluated using **ANSYS** software package.

Key Words: E-birectional fabric 13mil, Ansys 16, Epoxy LY 556, Epofine 1555, Match die mould

1. OBJECTIVE

The objective of this paper is the basic idea is to choose a compatible resin system with E-Glass bidirectional fabric in such a way that the best combination of mechanical properties are achieved. The mechanical properties are determined by carrying out tests on specimens in tension and flexure in accordance with the test procedure laid down in ASTM-D specifications D-3039 and D-790. $\pm 45^0$ specimens has prepared in accordance with D-3518 to study the in-plane shear properties. Inter laminar shear strength will be determined by conducting short-beam shear test with span to thickness ratio less than 4 in accordance with D-2544. Finally after obtaining the testing results, those will be evaluated using **ANSYS** software package.

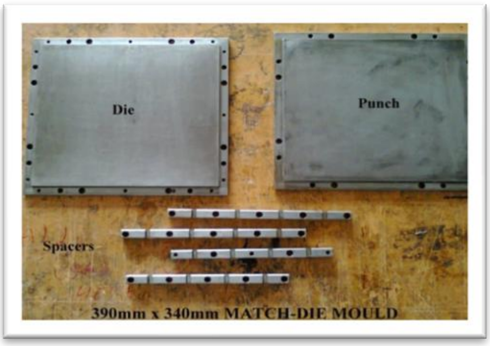
2. MATERIAL PREPARATION

A single layer of a laminated composite material is generally referred to as a ply or laminate. It usually contains a single layer of reinforcement, unidirectional or multidirectional. A single lamina is generally too thin to be directly used in any engineering application. Several laminae are bonded together to form a structure termed as laminate. Properties and orientation of the laminae in a laminate are chosen to meet the laminate design requirements. Properties of a laminate may be predicted by knowing the properties of its constituent laminae.

In this experimental work the following types of laminates were made with different orientations:

1. **0˚/0˚-** (all plies are in 0˚ direction)
2. **±45˚**

The fabric is laid on work bench covered with polythene sheet. Marking is taken by using 0° and ±45° with mould dimensions 390mmx340mm respectively. Resin is weighed as per specifications of fabric that is 100 gms resin, pigmented (5%) for colored surface typically white is chosen and hardener is added in the ratio of 1/3rd. Epoxy is stirred well & bonding agent (epoxy resin) is applied to create bonding between layers. This is usually accomplished by rollers or brushes, with an increasing use of roller type impregnators for forcing resin into the fabrics by means of rotating rollers. The surface of the mould is cleaned with 0-grade Emery paper, the clearance holes are cleaned with jewellery files, also cleaned with acetone and a release agent (waxpol) is applied. If the surface is not clean, then the release agent will not function properly.

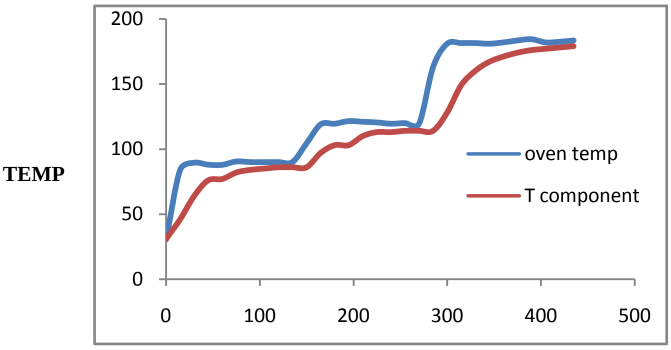


An optional sacrificial layer (Surface mat) is laid up on the mould surface. This layer is usually a fiberglass fabric made with the same resin system as the composite laminate. The sacrificial layer protects the laminate from surface abrasion and surface irregularities during manufacturing.Impregnated piles are cuted into the required size. The first prepreg ply is oriented and placed upon the mould. A roller or other small hand tool is used to compact the plies and remove entrapped air that could later lead to voids or layer separations. Now the polythene sheet is peeled from the ply. It is important that the pre impregnated material have sufficient tack so that it sticks slightly to the peel ply and to the adjacent plies. Thermocouple bead is placed on middle ply just about 3mm from the spacer clearance hole to get the exact temperature reading of the laminate.

Subsequent plies are placed one upon another. These plies are stacked layer by layer of about 12 layers to attain the thickness of 5mm as per the ASTM Standard Specimen. Another surface mat is placed on the top of laminate to protect the laminate surface. Then the mould is closed with punch. The mould is clamped by tightening the bolts with specified torque.

Torque is applied to the clamping bolts on the tool (Mould), causing the excess resin to flow of the clearance holes. The resin flow is critical, since it allows the removal of entrapped air and volatiles from the prepreg and thus reduces the void content in the cured laminate. The mould is now placed in the oven for curing, The process of polymerization is called "curing", and can be controlled through temperature and choice of resin and hardener compounds; the process can take minutes to hours. Some formulations benefit from heating externally supplied during the cure period, whereas others simply require time, and cure on account of mild increase in internal temperatures on account of chemical reactions. IN the first stage in this cure cycle consists of increasing the temperature up to 80 °C and dwelling at this temperature for nearly 60 minutes when the minimum resin viscosity is reached. During this period of temperature dwell, 30KN/m Torque is applied on the tool (Mould), causing some more resin to flow of the clearance holes, indicating that the lay-up inside has further become pliable, and takes compression. After that the oven temperature is increased to 120°C and the component is allowed to reach that temperature. Once the component has reached 120°C, a dwell of one hour is allowed. Finally the oven temperature is raised to 180°C and the component is allowed to reach it. Once the component has reached 180°C then a dwell of 4 Hrs is followed and finally it is allowed to cool for overnight. When the part is sufficiently cured, the mold is opened and the part is removed. Finished molding must usually be trimmed with a handsaw to size outside edges.

The graph for curing cycle of each laminate:



Final Laminate of E-glass bidirectional Fabric – 13 mil

Cured Laminate Trimming the edges of Cured Laminate

3. PREPARATION OF TABBED SPECIMENS

Cutting Specimens:

1. Clamp the laminate appropriately so that it does not shift during cutting.
2. Clamp the specimen with a rubber pad (or) wooden block to absorb vibration from the operation.
3. Begin the cut with a lower load to set the blade.
4. Use largest appropriate blade flanges to prevent the blade from becoming distorted.

The laminate fabricated is cut as per ASTM-D3039 (length 250mm and width 15mm) using Handsaw.

Materials Used to Prepare A Composite Laminate:

1. E-Glass 13mil bi-directional fabric
2. Epoxy Resin
3. Hardener

Selection of Composite Materials

1. E-Glass 13mil bi-directional fabric
2. Epoxy Resins

a) Epoxy LY556 (Resin System 1)

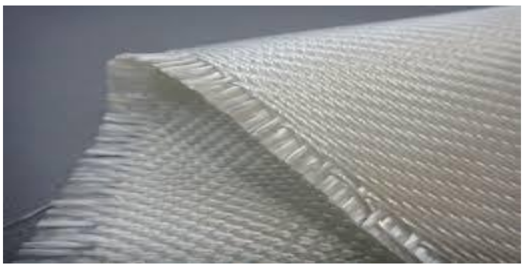
b) Epoxy LY556 with 5 % reactive diluent (Resin System 2)

c) Epofine1555 (modified epoxy resin with high elongation, Resin System 3)

3. Hardener (Aradur HT5200)

E-Glass 13mil bi-directional fabric Properties

Variety : 13 mil fiber glass fabric
Type of weave : 4H - Satin
Thickness: 0.36mm
Width : 40"
Construction: Warp: 48Threads/ Inch
Weft: 36Threads / Inch
Weight per Sq. Meter: 455.4 gms
Breaking strength per 50 mm:
Warp:383 Kgs
Weft: 258 Kgs



Fabric Made of Woven E-Glass Filaments

Selected Specimen Specifications as per (ASTM):

S.NO	Type of Test	Relevant ASTM	Number of specimens	Specimen size(mm)	Selected Specimen size(mm)
1	UD-Tensile	D-3039	5	250x15x1	250 X 15 X 3
2	Transverse Tensile	D-3039	5	175x25x2	250 X 15 X 3
3	Flexural	D-790	5	50x25x1.6	60 X 25 X 3
4	ILSS	D-2344	5	24x12x6	40 X 10 X 6
5	In-plane shear	D-3518	5	300x25x3	300 X 25 X 3

Testing Condition:

1. The specimens were tested at a strain rate (displacement) of 2mm/min
2. Co-axiality of the specimen axis and the machine loading axis was ensuring.
3. Two layers of emery cloth were used on either end of the specimen to hold between the grips.
4. Cognizes was taken in respect of the results in which explosive failure within the gauge length was absorbed.

4. TESTING & ANALYSIS RESULTS

Observed results in respect of specimen derived from Resin System -1(R1), Resin System -2(R2) and Resin System -3(R3) composite plates are placed in

4.1 RESIN SYSTEM-1 PROPERTIES:

Tensile Properties:

S. No	Geometry (mm)	Breaking load(KN)	σ (MPa)
1	250 X 15 X 3	12.82	284.8
2	250 X 15 X 3	12.76	283.5
3	250 X 15 X 3	12.54	278.6
4	250 X 15 X 3	12.70	282.2
5	250 X 15 X 3	12.68	281.7

Tensile Properties - Resin System-1

Average Tensile Strength =282 MPa

Transverse Tensile Properties:

S.No	Geometry (mm)	Breaking load (KN)	σ (MPa)
1	250 X 15 X 3	10.1	224.4
2	250 X 15 X 3	9.8	208.8
3	250 X 15 X 3	9.9	220.0
4	250 X 15 X 3	10.3	228.8
5	250 X 15 X 3	10.25	227.7

Transverse Tensile Properties - Resin System-1

Average Transverse Tensile Strength = 224

Flexural Properties (Span: 51mm):

S. No	Geometry (mm)	Breaking load	σ_f (MPa)
1	60 X 25 X 3	2.35	80
2	60 X 25 X 3	2.41	82.1
3	60 X 25 X 3	2.29	78
4	60 X 25 X 3	2.32	79
5	60 X 25 X 3	2.39	81.5

Flexural Properties - Resin System-1

Average Flexural Strength = 80.12 MPa

Inter Laminar Shear Properties (Span: 18mm):

S.No	Geometry (mm)	Breaking load	τ_{12} (MPa)
1	40 X 10 X 6	4.54	56.8
2	40 X 10 X 6	4.6	57.5
3	40 X 10 X 6	4.47	55.9
4	40 X 10 X 6	4.42	55.3
5	40 X 10 X 6	4.56	57.1

Inter Laminar Shear Properties - Resin System-1

Average Inter Laminar Shear Strength (ILSS) = 56.52 MPa

In-Plane Shear Properties:

S.No	Geometry (mm)	Breaking load	τ (MPa)
1	300 X 25 X 3	27.1	180.66
2	300 X 25 X 3	25.8	172
3	300 X 25 X 3	27.3	182
4	300 X 25 X 3	25.9	172.6
5	300 X 25 X 3	26.4	176

In-Plane Shear Properties - Resin System-1

Average In- Plane Shear Strength =176.65 Mpa

4.2. Resin System-2 Properties:

Tensile Properties:

S.No.	Geometry (mm)	Breaking load (KN)	σ (MPa)
1	250 X 15 X 3	13.6	302.22
2	250 X 15 X 3	13.7	304.4
3	250 X 15 X 3	13.2	293.3
4	250 X 15 X 3	13.5	300
5	250 X 15 X 3	13.75	305.5

Tensile Properties - Resin System-2

Average Tensile Strength = 301.10 MPa

Transverse Tensile Properties:

S.No	Geometry (mm)	Breaking load (KN)	σ (MPa)
1	250 X 15 X 3	11.1	246.66
2	250 X 15 X 3	10.9	242.22
3	250 X 15 X 3	11.3	251.11
4	250 X 15 X 3	10.8	240.00
5	250 X 15 X 3	10.7	237.77

Transverse Tensile Properties - Resin System-2

Average Transverse Tensile Strength = 243.5 MPa

Flexural Properties (Span: 51mm):

S.No	Geometry (mm)	Breaking load (KN)	σ_f (MPa)
1	60 X 25 X 3	2.53	86.3
2	60 X 25 X 3	2.49	84.7
3	60 X 25 X 3	2.60	88.5
4	60 X 25 X 3	2.45	83.4
5	60 X 25 X 3	2.5	85.2

Flexural Properties - Resin System-2

Average Flexural Strength = 85.62 MPa

Inter Laminar Shear Properties (Span: 18mm):

S.No	Geometry (mm)	Breaking load (KN)	τ_{12} (MPa)
1	40 X 10 X 6	4.92	61.5
2	40 X 10 X 6	4.87	60.9
3	40 X 10 X 6	4.84	60.5
4	40 X 10 X 6	4.90	61.3
5	40 X 10 X 6	4.83	60.4

Inter laminar Shear Properties - Resin System-2

Average Inter Laminar Shear Strength (ILSS) =60.92 MPa

In -Plane Shear Properties:

S. No	Geometry (mm)	Breaking load (KN)	τ (MPa)
1	300 X 25 X 3	27.8	185.3
2	300 X 25 X 3	27.1	180.6
3	300 X 25 X 3	27.5	183.3
4	300 X 25 X 3	28.1	187.3
5	300 X 25 X 3	27.6	184

In-Plane Shear Properties - Resin System-2

Average In- Plane Shear Strength =184.10 Mpa

4.3.Resin System-3 Properties:

Tensile Properties:

S.No	Geometry (mm)	Breaking load (KN)	σ (MPa)
1	250 X 15 X 3	16.9	375.5
2	250 X 15 X 3	16.5	366.6
3	250 X 15 X 3	17.2	382.22
4	250 X 15 X 3	16.8	373.3
5	250 X 15 X 3	16.4	364.4

Tensile Properties - Resin System-3

Average Tensile Strength = 372.40 MPa

Transverse Tensile Properties:

S.No	Geometry (mm)	Breaking load (KN)	σ (MPa)
1	250 X 15 X 3	14.4	320
2	250 X 15 X 3	14.6	324.4
3	250 X 15 X 3	14.1	313.3
4	250 X 15 X 3	13.9	308.8
5	250 X 15 X 3	14.25	316.6

Transverse Tensile Properties - Resin System-3

Average Transverse Tensile Strength = 316.62 MPa

Flexural Properties (Span: 51mm):

S.No	Geometry (mm)	Breaking load (KN)	σ_f (MPa)
1	60 X 25 X 3	3.33	113.5
2	60 X 25 X 3	3.26	110.9
3	60 X 25 X 3	3.30	112.5
4	60 X 25 X 3	3.35	114.2
5	60 X 25 X 3	3.28	111.6

Flexural Properties - Resin System-3

Average Flexural Strength = 112.54 MPa

Inter Laminar Shear Properties (span: 18mm):

S.No	Geometry (mm)	Breaking load (KN)	τ_{12} (MPa)
1	40 X 10 X 6	6.07	75.9
2	40 X 10 X 6	6.12	76.5
3	40 X 10 X 6	6.02	75.3
4	40 X 10 X 6	6.13	76.6
5	40 X 10 X 6	6.08	76.1

Inter Laminar Shear Properties - Resin System-3

Average Inter Laminar Shear Strength (ILSS) = 76.08 MPa

In -Plane Shears Properties:

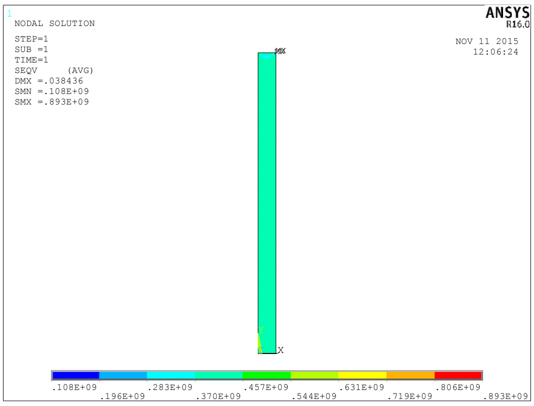
S.No	Geometry (mm)	Breaking load (KN)	τ (MPa)
1	300 X 25 X 3	32.1	214
2	300 X 25 X 3	31.9	212.6
3	300 X 25 X 3	32.3	215.3
4	300 X 25 X 3	31.6	210.66
5	300 X 25 X 3	31.75	211.66

In-Plane Shear Properties - Resin System-3

Average In- Plane Shear Strength =212.8 Mpa

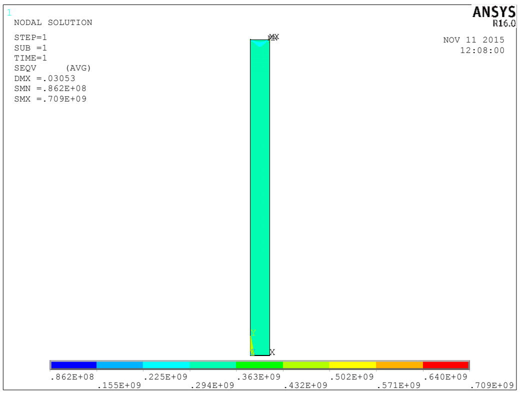
5. ANALYTICAL RESULTS FOR RESIN SYSTEM 1:

Tensile Strength



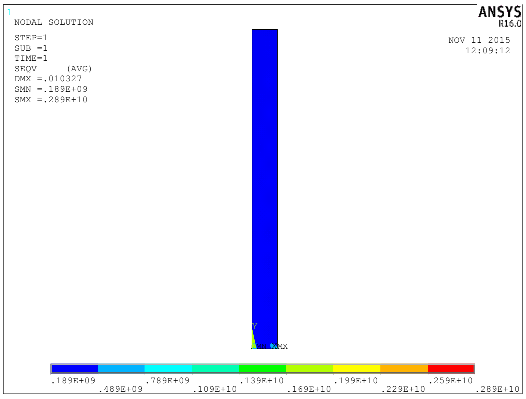
Maximum Stress = 382 MPa

Transverse Strength



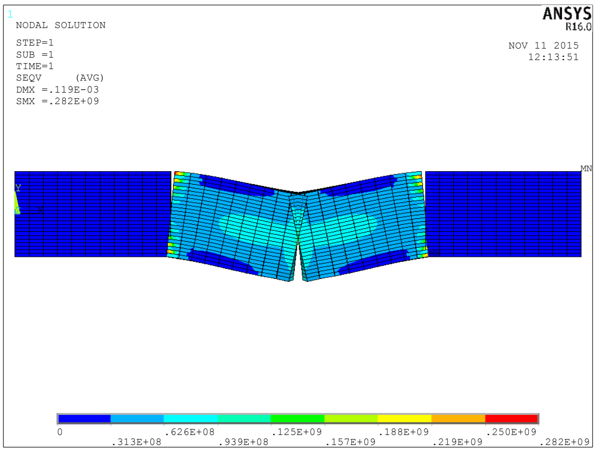
Maximum Stress = 304 MPa

In-plane shear strength



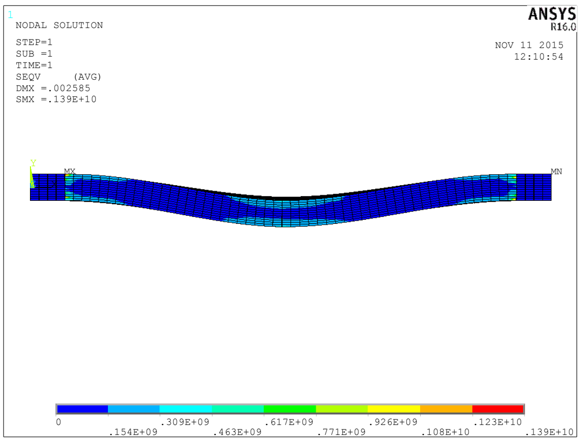
Maximum Stress =369 MPa

Inter Laminar Shear Strength

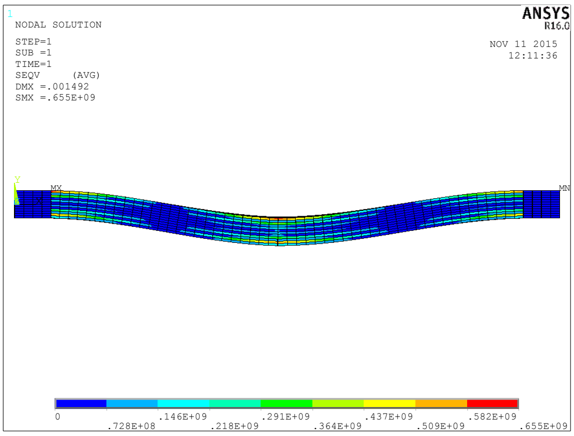


Maximum Stress =57 MPa

Flexural Strength



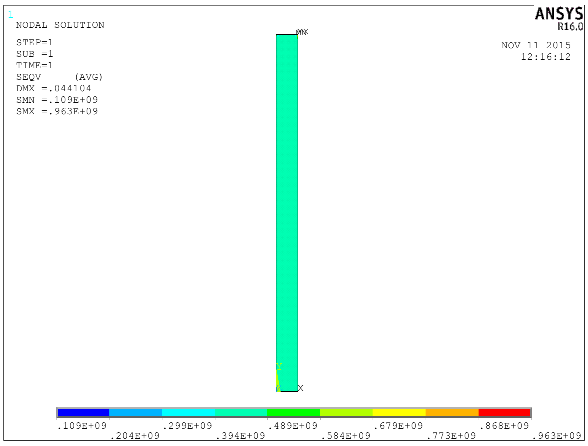
Maximum Stress = 72 MPa (for ± 45^{o})



Maximum Stress

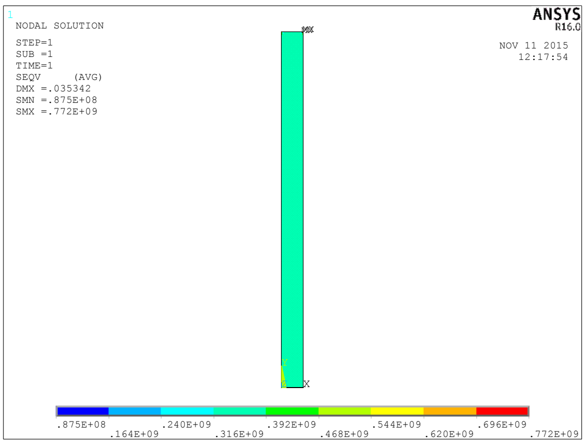
6. ANALYTICAL RESULTS FOR RESIN SYSTEM 2

Tensile strength



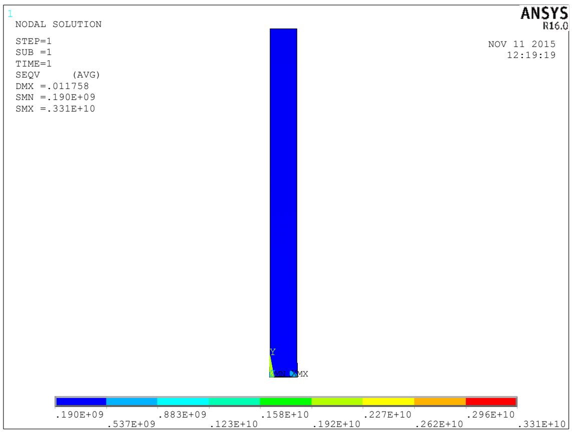
Maximum Stress = 414 MPa

Transverse strength



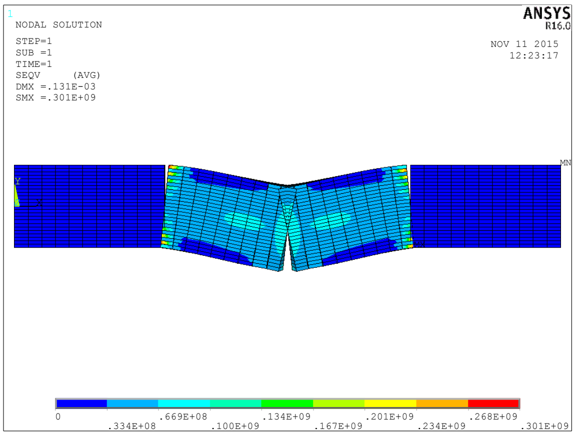
Maximum Stress = 331 MPa

In-Plane Strength



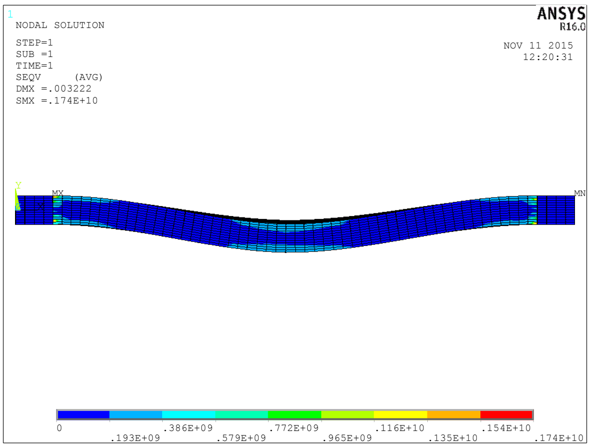
Maximum Stress = 388 MPa

Inter Laminar Shear Strength

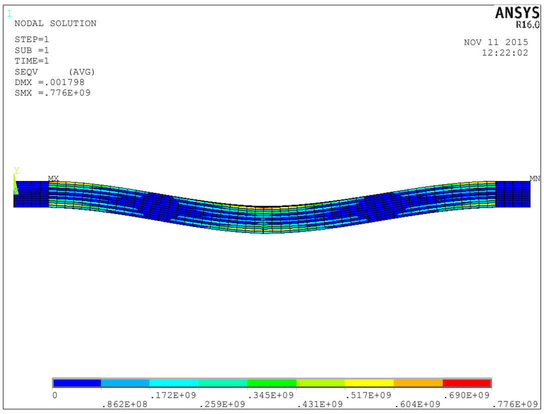


Maximum Stress = 59 MPa

Flexural Strength



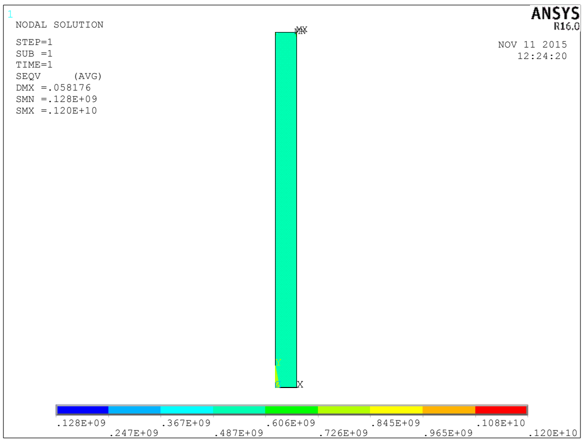
Maximum Stress = 83 MPa (for ± 45^{o})



Maximum Stress =91 MPa (for 0^{o}/90^{o})

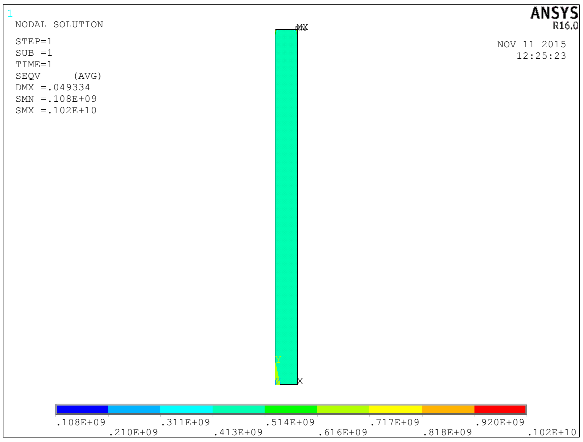
7.ANALYTICAL RESULTS FOR RESIN SYSTEM 3

Tensile Strength



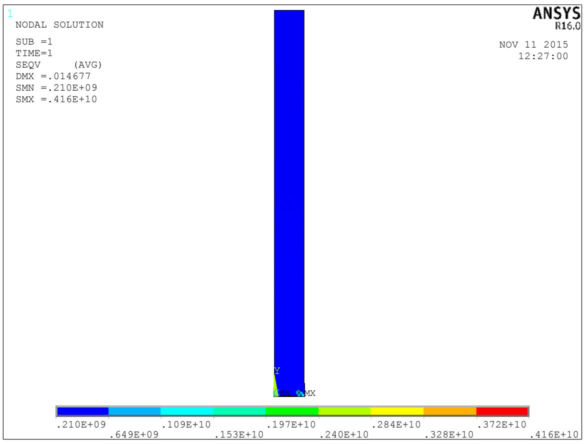
Maximum Stress =518 MPa

Transverse strength



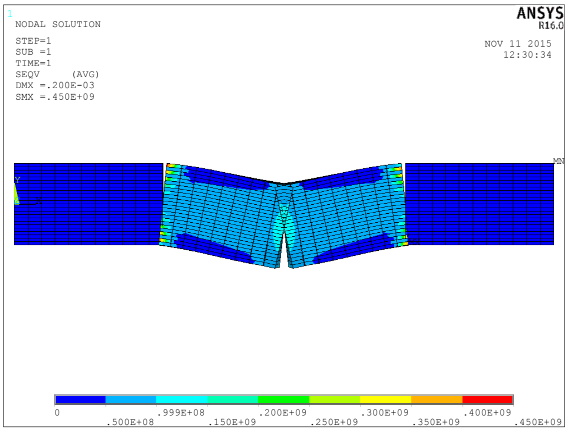
Maximum Stress =440 MPa

In-plane strength



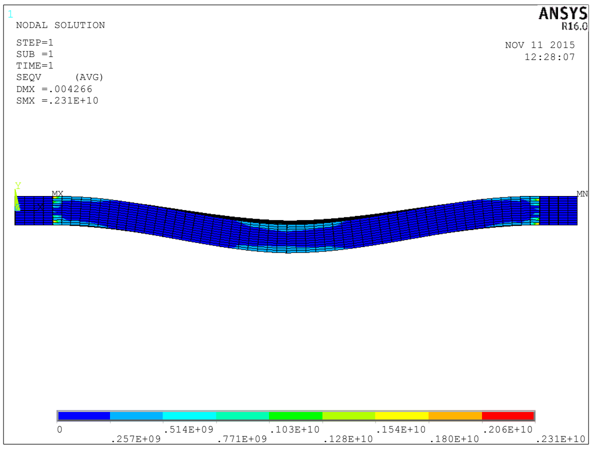
Maximum Stress =449 MPa

Inter Laminar Shear Strength

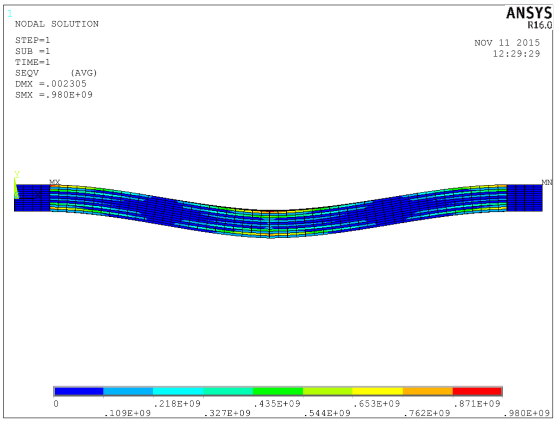


Maximum Stress =84 MPa

Flexural Strength



Maximum Stress =103 MPa (for ±45°)



Maximum Stress =125 MPa (for 0°/90°)

8.THE OVERALL TESTED RESULTS OF ALL FOUR RESIN SYSTEMS ARE TABULATED BELOW:

S.No.	TEST	AVERAGE STRENGTH (MPa)		
		RESIN SYSTEM 1	RESIN SYSTEM 2	RESIN SYSTEM 3
1	TENSILE TEST	282	302	372.4
2	TRANSVERSE TEST	224	242	318
3	FLEXURAL TEST	80	87	112
4	INTER LAMINAR SHEAR STRESS	56	61	76
5	IN-PLANE STRESS	177	185	213

Comparison of tested results of all resin systems

The analytical Results from ANSYS are tabulated below

S.No.	TEST	AVERAGE STRENGTH (MPa)		
		RESIN SYSTEM 1	RESIN SYSTEM 2	RESIN SYSTEM 3
1	TENSILE TEST	382	414	518
2	TRANSVERSE TEST	304	331	440
3	FLEXURAL TEST	72	83	103
4	INTER LAMINAR SHEAR STRESS	57	59	84
5	IN-PLANE STRESS	369	388	449

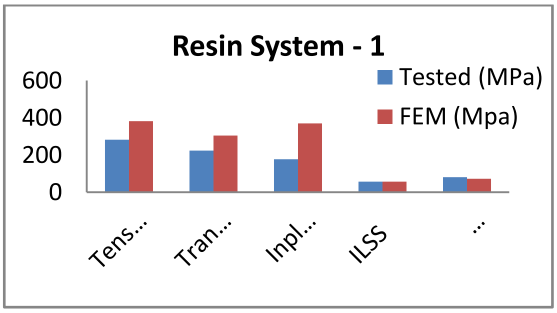
Comparison of FEM results of all resin systems

So, in this present investigation after introducing the reactive diluents the strength has increased to some extent (20MPa) resulting in higher strength. But the toughened Epoxy resin resulted in best bonding strength between fiber and matrix which in turn resulted in higher tensile strength. According to the tested results Resin system 3 resulted in high strength.

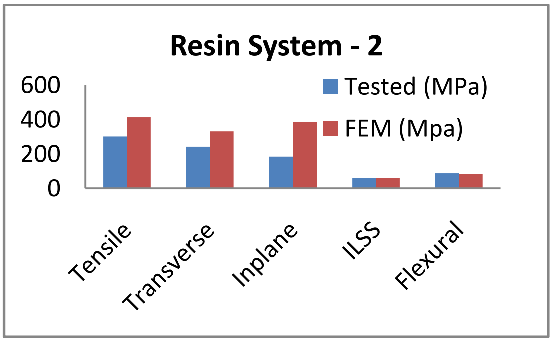
As the transverse strength is resin dominant property, after introducing reactive diluents the strength also increase slightly. For the resin system 3 because of the good compatibility between fiber and matrix it has resulted in high transverse strength compared to other resin systems. Whenever we discussed about flexural strengths the Resin System 3 has resulted in highest.

From the analytical point of view, the boundary conditions given are the replication of the tested results i.e. breaking loads, the resulted stresses at the gauge length are compared. The obtained tensile stresses are lesser compared to the FEM stresses because in the FEM software there is no provision of defining the fiber form i.e. if it is of continuous fiber / woven fabric / chopped strand mat.

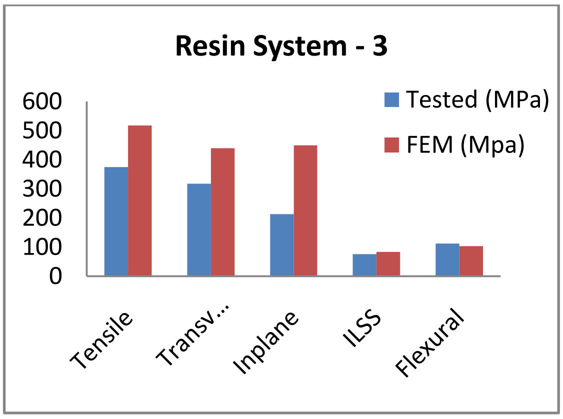
When compared with the pure fiber form laminate, the resulting in-plane shear for the present case will be higher i.e. in the first case the property is purely dominant by matrix and the bonding strength between fiber and matrix. But in the second case it is also affected by the interlock between longitudinal and transverse fibers because of weaving.



Comparison of Resin system 1 Properties



Comparison of Resin system 2 Properties



Comparison of Resin system 3 Properties

CONCLUSION

Full advantage of the enhanced mechanical properties of the fibers like E-Glass can be fully exploited if a judicious choice of matrix system is made. This investigation was aimed at zeroing on an appropriate epoxy resin composition from among a limited number of choices resulting the following observations

- Resin System appears to be compatible with E-Glass fibers for the sizing given on it.
- Resin system 1 to resin system 3 the elastic limit of resin is increasing then resulting in higher strength.
- In conclusion this experimental investigation brings out the need for compatible matrix material particularly used in conjunction with high strength fibers. The potential of high strength of the fibers can be exploited fully only when a compatible matrix is zeroed out.
- Resin system besides having an elastomer as its constituent, its functionality is 3.5 as against 2 of the other resin systems. This is a crucial factor in enhancing the compatibility of matrix with fiber.

Among all the resin compositions tried out, Resin System - 3 is most preferred one since it has given consistent values of tensile strength at an average in excess of **375 Mpa**. This resin system is also given reasonable good flexural, transverse tensile, in-plane shear, inter laminar shear stress.

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