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"Analysis Of Unidirectional Glass-Epoxy Laminar Composite"

Gunale Rahul Bhaskarrao[1] , Sarang P. Joshi[2]

[1]Department of Mechanical Engineering JSPM's Imperial College of Engineering & Research, Pune.

[2]Department of Mechanical Engineering JSPM's Imperial College of Engineering & Research, Pune.

Abstract: As already discussed in many papers by authors, composite is mixture of two or more than two materials at micro level, which leads to form mixture of anisotropic material which despite this precise micro level mixing retains its uniqueness which are still physically distinct and mechanically separable from each other, and there is no chemical bond formation during the process of entire curing. Fibre, matrix and resin are few elements which can be added in to the list of such elements. The basic structure and properties of lamina/ply is virtue of percentage combination of all these elements added together. Properties of laminate is function of properties of lamina configure with definite fibre, matrix percentage and stacked in sequence with unique fibre orientation. A thing is very interesting to note, lamina which has its own properties and behaviour before stacking in to laminate structure changes after being the part of laminate and response of behaviour noted is completely different than previous one, so assumption of determining laminate properties from lamina properties do not stand strong and valid all the time. There are several parameters which keeps affecting performance and behaviour of lamina and those are, fibre orientation, fibre and matrix percentage, lamina thickness, processing parameters etc. the most behaviour dominating parameters are fibre orientation and percentage of fibre and matrix added in to the lamina structure. Fibres are strong and stiff in the direction of load acting, and so the orientation of lamina and thus of several such laminas maintained in to laminate structure to impart required strength to it. Lamina/ laminate strengths in various directions is base criterion of design, so the precaution is taken that load acting on laminate should not goes beyond ultimate limit to maintain safety of structure as long as it becomes part of an operation.

Popularity of composite increases day by day, its functioning and applicability enable it to use almost in all field to the extent isotropic material could have been use hardly. Thus researcher keep emphasis to optimize the structure to enhance its applicability and use even high which was never before. Paper focusing on analysis of composites performed for monotonic or uni-axial loading. The characterization and behaviour of composite is studied in the current paper. This analysis is performed to check an applicability of composite which would enable its use in an aeronautical applications. Analysis focuses mainly on understanding the capacity of composite material which would make it more suitable and capable material for the use in aeronautical and relevant applciations.

The paper is written to discuss analysed things of unidirectional composite laminar structure to judge its application versatility. Analysis discusses impacts of fibre orientation on stiffness components, stress, strain, off-axis engineering elastic properties etc. Analysis concludes few laminas associated parameters do not affected by ply orientation and remains same till failure but remaining are strongly affected as an effect of such orientation change.

Keywords: Composite, lamina, laminate, orientation, & Engineering properties etc.

1. Introduction: Past research's which were undertook to investigate the effect of fibre orientation on lamina properties reveals that longitudinal stiffness of lamina is noted high in axial direction, where transverse stiffness noted extremely low in the same direction. As inclination progresses from 0 degree onwards, transverse stiffness goes increasing and noted maximum while getting to 90 degrees, at the same location longitudinal stiffness is noted extremely low. On axis lamina stiffness components are not affected by fibre orientation but it shows considerable impact on off-axis lamina stiffness constants when orientation change occurs. Lamina shear stiffness noted increasing up to 45 degrees and starts declining onwards. Value of poison's ratio observed increasing from 45 degree onwards and noted highest at 86 degrees, and lesser at 0 and 22 degrees.

Despite such behaviour details of lamina, behaviour of laminate cannot be derived inline to the behaviour of laminate. Only the sure things can tell about laminate behaviour are, stress-strain relationship for laminate is linear, the failure is brittle type, failure can happen due to delamination or crack propagation, strain is linear through lamina's, last ply failure of laminate represents ultimate failure of laminate etc. the failure of laminate is studied ply by ply or layer by layer. The failed layer transfer entire load to un-failed lamina's and process of transferring of load continues until failure of last ply is not happened. The subsequent time between failure of lamina's is very short, the moment one has failed the other appears to failure, the failure at such several places forms the crack which propagates with respect to load and brings ultimate failure in to laminate structure beyond which stricter is no more capable to sustain the load, it could be the end point of stress-strain curve.

In laminate Laminas are stacked for definite sequence, and orientation of lamina is the function of overall laminate strength required. Inter laminar strength between lamina's which let keep laminas bonded together is virtue of manufacturing, this strength defines laminate stability, any load which excess this strength brings lamina delamination leads to disintegrate structural stability. As per the effect of voids and discontinuities are concern, crack initiation takes place at the region of flaws or discontinuous, this flaw tends to grow with rise in load magnitude and responsible in bringing an ultimate failure of laminate. Fibre failure is function of fibre strength, when load excess the maximum load sustaining capacity at yield point failure initiates, failure by neck formation is the function of further rise in load and which causes ultimate failure due to neck formation, at this stage scope of load sustaining ends totally. Comparative to fibre, matrix shows enough strain by the time of failure, that indicates capacity of matrix of undergoing deformation, but load sustaining capacity of matrix is less than fibre. As per failure between fibre and matrix interface is concern, it happens under the practice of load transfer from matrix to fibre.

In ply delamination, when inter laminar shear stress reached to its maximum value, delamination starts from edge of laminate. Ply delamination is not failure of laminate but it made laminate (Remaining safe plies in structure) to sustain no more load, and that probably exhibits laminate failure ahead, as delaminated ply do not contribute in load sharing so load is transferred to safe lamina's results in excessive load on each such lamina's than actual what for they have designed.

Graphs pasted below depicts relationship between lamina's orientation and its impact on various components such stiffness, engineering elastic properties, stresses and strains. Few such impacts and parameters dependability is discussed through following graphs.

No doubts composites are gaining popularity day by day due to their high strength to weight ratio, although design of composite is complicated affair so is the fabrication and manufacturing. Once design they are durable and highly reliable in use. Composites has high strength than isotropic material.

2. Literature review:

1. Jean Marie Berthelot (2014): Studied damping analysis of composite structure. Synthesis of damping analysis material which viscoelastic layers and sandwich material. The FEA method is used to study the damping effect. Transverse shear loading is applied on the structure. Beam specimen is used for testing purpose. Impulse technique inculcated. Modelling of material and constituents to study the damping parameters of the material.
2. Jacob Fish (2015): Author has studied multi scale computational procedure based on philosophy of multilevel method.
3. J. F. Chen (2016): Development of combined catastrophic damage model for progressive failure analysis of composite material and structure. Irreversible strain caused due to plasticity effect and material properties degradation due to damage initiation development. Also considered continuous damage mechanics plasticity theory.
4. Ronal F Gibsonn (2018): Model vibration response, measurement to characteristics, characterize mechanical properties of composite material structure. Model testing for single mode or multi-mode of vibration. Used to determine elastic moduli and damping factor of composite material and there constituents. The method and model used for testing was an excitation.

3. Methodology: lamina of the glass/epoxy is formed with fibres oriented in 0 degrees. Lamina has tested for uni-directional loading to predict its mechanical properties such as modulus of elasticity in longitudinal direction, shear modulus and poisons ratio etc. then based on obtained properties lamina and laminate behaviour has been studied for uniaxial loading condition's. The characterization and behaviour of lamina has considered for further recommendation of structure to be used in aerospace and relevant applications. Behaviour and response of lamina and laminate has been studied through various graphs depicted in the paper at various stages of writing.

Composites are widely recommended to use in the domains such as sports, aeronautical, automobiles, biomedical etc.

4. Research gaps and objectives:

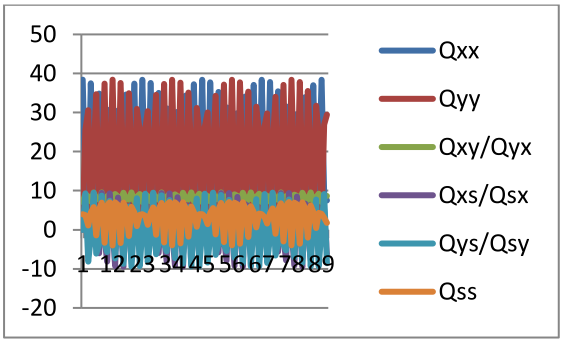
- To study plane mechanical behaviour of lamina and laminate under the influence of mechanical loading.
- Study the characterization of lamina and laminate for uni-axial loading conditions.
- Recommend use of structure for aerospace and relevant application's virtue of its strength and capability to sustain an acting service load during operational tenure.

5. Engineering elastic constants and off axis strains: the material testing on UTM (Unidirectional loading), stress-strain plotting enables to obtain following values of elastic constants.

Glass/Epoxy				
Engineering Elastic Constants	**E1**	**E2**	**G12**	**U12**
Values	**38**	**7**	**4**	**0.24**
Off-Axis strains	**ex**	**ey**	**es**	
Values	**0.0032**	**0.0020**	**0.00012**	

Table (5.1): Value of engineering elastic constants and off axis strain along material principal axis.

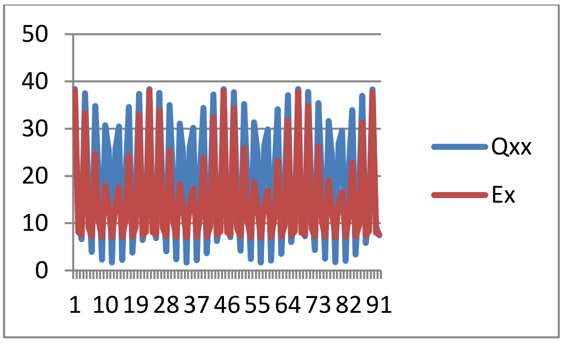
6. Analysis of laminar plates:



Graph (6.1): effect of changed lamina orientation on stiffness properties

Lamina stiffness properties noted maximum in the direction of fibre orientation, the fibre orientation is set for the direction along which maximum load is needed to be carry.

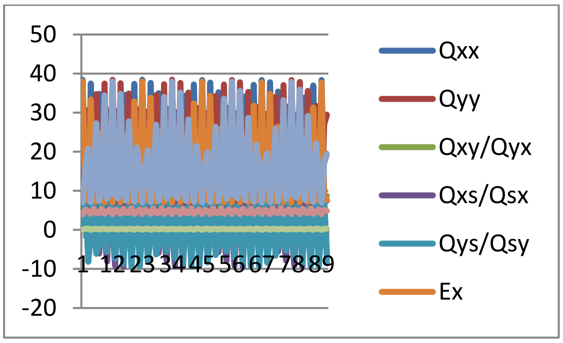
The longitudinal stiffness in xx plane is noted maximum along 0 degree where it is noted less in traverser's plane, which can locate for orientation 11 degrees with respect to lamina principal axis. As per lamina stiffness in yy plane is concern, it is noted less along 0 degree and noted maximum in transverse plane which is located for inclination 11 degrees with respect to material principal axis again.



Graph (6.2): Effect of change of stiffness with respect to orientation on laminas engineering elastic properties

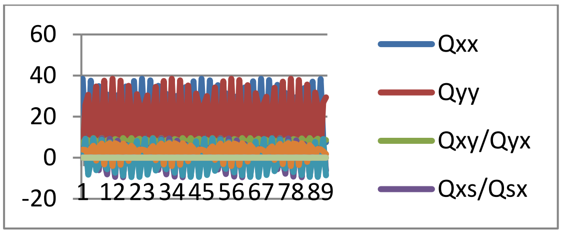
Engineering elastic constants of laminas even affected by change in fibre orientation. Longitudinal modulus found maximum along 0 degree where it noted lowest along 11 degrees. Contrast to this transvers modulus of lamina noted maximum along fibre location, 11 degrees and again noted less along fibre located along 0 degrees.

The observation is enough to conclude that, maximum value of longitudinal modulus of elasticity is noted along 0 degree or longitudinal direction and starts decaying as orientation changes from longitudinal to transverse. In the case, lamina's transverse modulus, value is noted maximum along traverse direction and starts decaying as orientation changes from transverse to longitudinal.



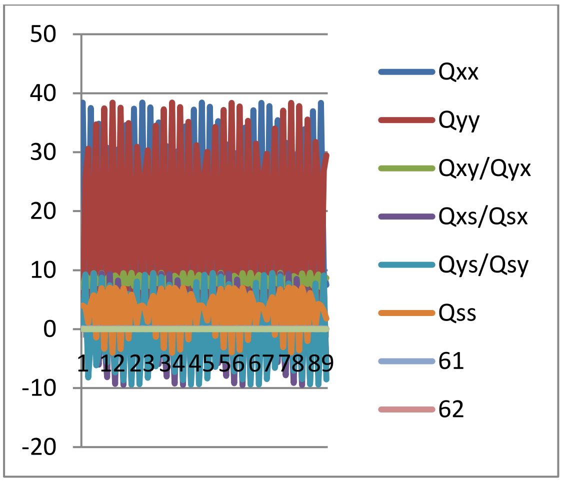
Graph (6.3): Effect of stiffness components on lamina engineering elastic properties.

Value of engineering elastic constants are not only affected by change in fibre orientation occurs but it also impacted by lamina's stiffness components. A relationship between parameters dependency can be stated as, lamina elastic modulus is maximum in respective direction such as longitudinal modulus is maximum in 0 degrees, transverse modulus is maximum along planes which initiates to locate from 45 degrees onwards, so the value of respective stiffness components in respective planes found maximum.



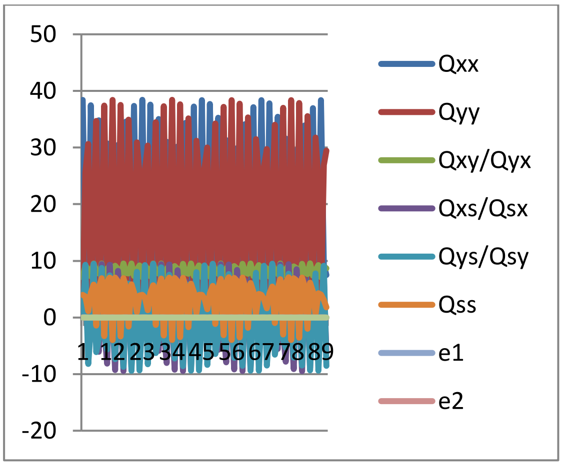
Graph (6.4): Effect of laminas stiffness components on off-axis stress

With increase in stiffness of components, value of induced stresses starts increasing. For example stiffness of component considered in xx plane and effect measured in transverse plane, value of associated stress in same direction is noted negligible.



Graph (6.5): Effect of lamina's stiffness components on on-axis stress.

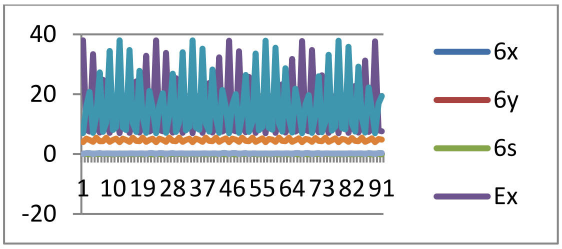
Similar observations were noted for on axis stress too which were noted for lamina's off axis stresses.



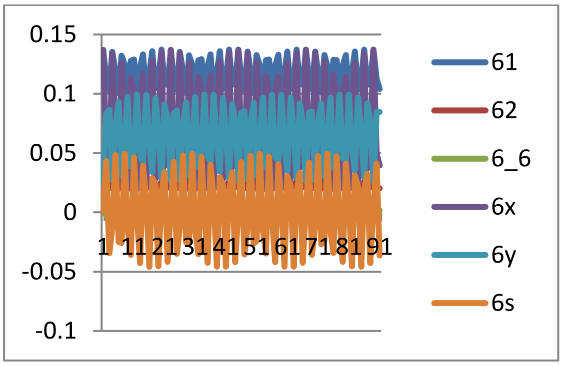
Graph (6.6): Effect of lamina's stiffness components on lamina on on-axis strain

For lamina stiffness considered for respective direction is noted high so high be the stress and lesser will be the deformation.

Idle equation of engineering mechanics states relationship between Elastic constants and respective stresses. Elastic modulus exhibits relation with normal or linear stress, shear modulus exhibits relation with shear stress or planer stress. With increase in the value of these elastic constantan's of respective nature value of stress also increases and vice versa.



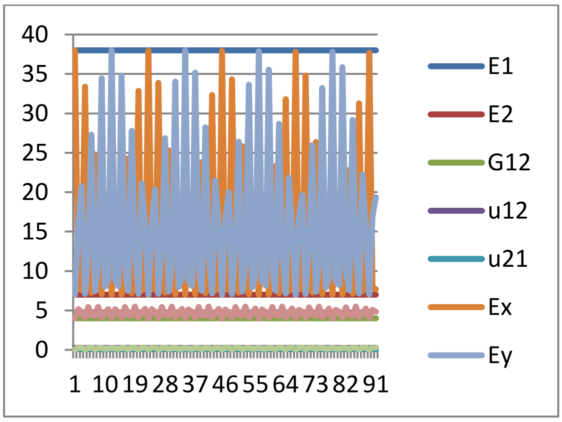
Graph (6.7): Effect of lamina's engineering elastic constants on off-axis lamina stress



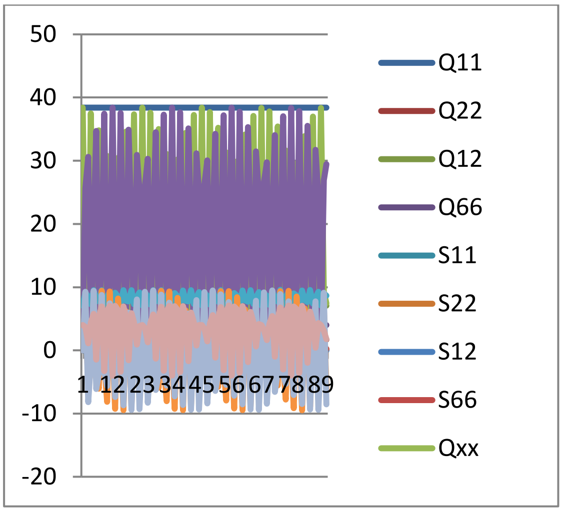
Graph (6.8): Comparison between stress magnitude, off axis and on axis stress.

Value of on axis laminar stresses noted maximum than off-axis stresses.

From following graph conclusion has drawn, With change in orientation of lamina fibres, on axis engineering elastic constants remains un-changed and un-affected but off axis elastic constants tends to vary in their value, this value change is cyclic, for some range of fibre orientation change there is pattern of increasing the value of elastic constants noted and for rest it noted decaying again.



Graph (6.9): Effect of lamina changed orientation on off-axis and on-axis engineering elastic constants.



Graph (6.10): Comparing lamina orientation affectivity on off-axis and on-axis lamina stiffness components.

On axis stiffness components and compliance components are not at all affected by change in fibre orientation of lamina.

7. Result, discussion and conclusion:

Parameters	Maximum value	Minimum value	Orientation (Degrees), Min & Max Respectively
Q_{xx}, GPa	**38.40**	**1.69**	**11 & 0**
Q_{yy}, GPa	**38.40**	**1.69**	**0 & 11**
Q_{xy}, GPa	**9.54**	**7.07**	**0 & 84**
Q_{xs}, GPa	**9.42**	**-9.48**	**81 & 7**
Q_{ys}, GPa	**9.47**	**-9.41**	**18 & 70**
Q_{ss}, GPa	**7.088**	**-3.9993**	**11 & 76**
e_1	**0.002**	**0.0032**	**[5.8.11.27,30,33,49,52,55,58, 71,74,77,80] & [0,16,19,22,38, 41,44,47,60,63**

			,66,69,82,85,88]
e_2	**0.0032**	**0.002**	**[0,16,19,22,38,41,44,47,60,63,66,69,82,85,88] & [5.8.11.27,30,33,49,52,55,58,71,74,77,80]**
e_6	**6.12*10^-4**	**-6.12*10^-4**	**[26,48,70] & [37,59,81]**
σ_1, GPa	**0.1373**	**0.0992**	**[8,30,52] & [19,41,88]**
σ_2, GPa	**0.0261**	**0.01995**	**[8,30,52] & [19,41,44,63,66,85,88]**
σ_6, GPa	**2.4*10^-3**	**-2.4*10^-3**	**[1,4,23,26,45,48,70,73] & [12,15,34,37,56,59,81,84]**
σ_x, GPa	**0.1371**	**0.0196**	**[11,33,55,77] & [0,22,44,66,88]**
σ_y, GPa	**0.0994**	**0.026**	**[0] & [11,33]**
σ_s, GPa	**4.94*10^-2**	**-4.59*10^-2**	**[15,84] & [29,51,73]**
$E_{x,}$ GPa	**38**	**7**	**11 & 0**
$E_{y,}$ GPa	**37.99**	**7**	**0 & 11**
$E_{s,}$ GPa	**5.48**	**4**	**0 & 84**
μ_{yx}, GPa	**0.3092**	**0.0442**	**[0,22] & 24**

8. Conclusion & Discussion:

1. Values of engineering elastic constants and stiffness components are noted maximum in respective directions, for example, stiffness component in xx plane is noted for highest value

in xx plane and value of component starts decaying in transvers plane yy. Similarly value of transverse stiffness component noted maximum in yy plane and its value starts decaying in longitudinal or xx plane.

2. Stiffness components affect the stress and strain components later, maximum stiffness leads to induce maximum stress and thus less deformation come occurs in lamina.

3. Strength of lamina along material principal axis is the function of engineering elastic constant sin respective directions, where, in-plane strength in various directions is the function of stiffness and compliance constants.

4. Stiffness/Compliance components imparts strength to lamina in specific plane, and thus its contribution towards imparting strength to lamina in other planes noted almost nil, and that defines role of various stiffness components proposed to study lamina strength and behaviour in different planes.

5. Longitudinal components (Elastic constants, stiffness, compliance) noted contributing well towards behaviour and load sustaining of lamina in longitudinal direction and planes, i.e. 0 degrees, where, their contribution and impacts is seems to lowered down as orientation change happened from longitudinal to transverse.

6. Similar behaviour of components has noted in transverse plane, and their impact seems lowered down as plane locations changes from transverse to longitudinal direction.

7. Lamina on axis engineering elastic constants, stiffness and compliance components are not affected by fibre orientation but off axis properties defined by transformation matrix were seems affected greatly with such orientation change happened.

8. Deformation, stress, in plane and directional bending in lamina and quite probably in laminate is the function of lamina stiffness components.

9. Strength of lamina is the function of fibre and matrix constituents which enables lamina through its stiffness and compliance component to sustain load of said magnitude by imparting required strength in needy direction.

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