"Analysis of Unidirectional Carbon-Epoxy Laminar Composites to be Used In Light Weight Automobile Leaf Spring Model"

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Abstract: Composite is mixture of two or more materials, these constituents of composite defines its properties composite as a whole. Slight change in one leads to vary structural properties of composite and this justifies dependability of structural properties of composites on its constituents. Constituents define properties of lamina, and properties of lamina define properties of laminate ultimately, thus any faulty or wrong proportion chosen of constituents for a structure leads to produce something unwanted and unexpected which is of no use at all. Manufacturing of laminate is accurately addressed if and only if, manufacturing of lamina has happened accurately by selecting right and appropriate proportion of required basic ingredients.

Paper is written to study parameter dependability on each other which at ultimately affects the performance of lamina and laminate. The analysis of lamina accommodates investigation of constituent properties on lamina properties, and lamina properties on laminate properties. Paper is written to chain such dependability between various parameters which are playing unique role in unique structure of composite (Lamina or Laminate).

***Index Terms*- Lamina, laminate, analysis, composite etc.**

1. Introduction: Composite material is mixture of two or more than two material which is physically distinct, mechanically separable from each other; still one can gain advantage of its constituents together which otherwise not possible constituent as alone. Composite material considered as Anisotropic/Heterogeneous which requires eighty one independent elastic constant in its detailed analysis. Symmetry of stress-strain reduces these constant numbers to thirty six. Energy consideration further takes this figure down to twenty one. Orthotropic material which has three mutually perpendicular planes of material symmetry can put forth in analysis considering only nine elastic constants; transversely isotropic material reduces theses constants to five. Isotropic material whose engineering properties are same in all directions needed only two independent elastic constants in its complete analysis. Isotropic material is the simplest case of analysis which involves only two independent parameters referring to which third engineering elastic constant can chalk out.

Composite is mixture of fibre and matrix, fibre are stiff and strong element which surrounded by matrix, matrix are though soft and flexible, they hold fibre to their right position when deformation is over. Load is transferred from matrix to fibre by shear force.

Lamina is mixture of fibre, matrix and resin. Fibres oriented for definite sequence defines strength of lamina/ply/plate structure. Several such lamina's with same or different orientations stacked one above the other for required thickness and laminate structure is formed.

Behaviour of laminate is different from lamina behaviour under similar loading conditions. Failure of composite structure considered at micro and macro level, in micro failure of composite structure failure is considered at constituent level which includes failure in fibre, matrix, fibre-matrix interface etc. In Macro level of failure, structure failure is considered at ply level which includes failure of type such as, ply delamination due to excessive in-plane shear force, delamination initiated from edge etc.

Performance and strength of lamina is the function of fraction or fibre and matrix maintained during its manufacturing, strength of several such laminas with same or different fibre orientation defines strength of laminate. Properties of laminate are different from properties of lamina, but properties and arrangement of laminas are maintained in such a way that, they all together define an average properties of laminate. Properties of lamina vary with respect to fibre orientation, for certain orientation it found optimized but for few they reach below average level. Stacking sequence of lamina also affect overall strength of laminate. For example, laminate defined for lamina stacking sequence [0/45/90] exhibits different strength than laminate which defined for lamina stacking sequence [90/45/0].

Factors which leads to vary properties and behaviour of lamina or laminate structure are fibre volume fraction, matrix volume fraction, fibre orientation, lamina thickness, lamina stacking sequence etc. more the percentage of fibre, strong the lamina and laminate too, but there is certain limit beyond which packaging of fibre in to matrix is not possible, and thus choosing the right pattern of imbibing the fibre in to matrix address this issue satisfactorily. Fibre is stiff and strong in the direction of load acting so maximum amount of total load acting is shared only by fibres. Matrix arranged in structure surrounding of the fibres, they have good damping capacity; they transfer the load to fibres by shear and protect the structure from ultimate damage. The holding of fibres to proper positioning is also addressed by matrix element in composite structure. Stacking sequence affects lot on properties and behaviour of laminate, for example, lamina which are orthotropic in nature when organized for specific sequence in to laminate for special recognition and arrangement, the nature of laminate would be isotropic rather being orthotropic which was the nature of laminas stacked in to laminate structure otherwise.

2. Methodology: Composite leaf spring is to be manufactured for Mahindra Bolero which is an expected a replacement for conventional leaf spring in the time to come. The work is undertaken keeping benefit of this replacement in mind such as, weight reduction, operational efficiency enhancement, cut down on the cost of maintenance and part replacement, cut down on the cost on designing of various accessories needed in the instalments and support of conventional leaf spring, superior fatigue behaviour and high reliability etc. the work is undertaken in to following step/road map of work.

1. Materials chosen for replacement of conventional leaf spring material are Carbon/Epoxy, E-glass/Epoxy, and Kevlar/Epoxy etc.

2. Above composites are put forth for uniaxial testing on UTM to determine basic engineering elastic properties such as Young’s Modulus, Shear Modulus and Poisons Ratio. Later value of Young s Modulus in transverse direction and poisons ratio in two-one plane are calculated through proper mathematical formulas used.

3. Lamina fibre orientations considered are 0, 90, 30 and 45 degrees. For fibre and matrix volume fraction, first standard value is considered between the optimized ranges defined.

4. Value of off-axis stress and strains are obtained by making use of experimental data processed through mathematical formulae.

5. Value of on-axis stress and strains are obtained by using transformation matrices.

6. Value of stiffness components, stiffness and compliance matrices are calculated by using mathematical formulae and relationship.

7. In final stage, effect of fibre orientations/Lamina orientation has studied on engineering elastic properties, value of off-axis and on-axis stress, value of off-axis and on-axis strains etc.

3. Properties of lamina: After Uni-axial test on UTM (Universal Testing Machine) following properties of Uni-Directional lamina have predicted,

Material	E_1	E_2	G_{12}	μ_{12}
Carbon/Epoxy	135	9	5	0.28

Following few lamina configurations shows orientation of fibre and thus naming of lamina happened after it. Following are the lamina with standard orientation used to address need of various applications and each lamina as depicted below carries its unique work functionality towards load sustaining.

0 degree lamina recommended to sustain load in the longitudinal direction, 90 degree lamina’s recommended for transverse load sustaining, 30 and 45 degree lamina used to sustain shear load and in plane bending. Orientation of fibres is measured with respect to standard principal plane in counter clockwise direction.

Analytical work of this paper is center towards consideration of all the fibre orientations from 0 to 90 degrees and their impact on various mechanical preppies of the structure.

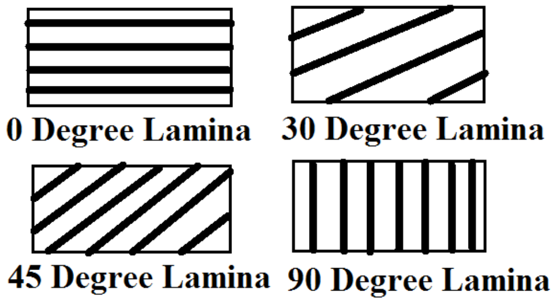
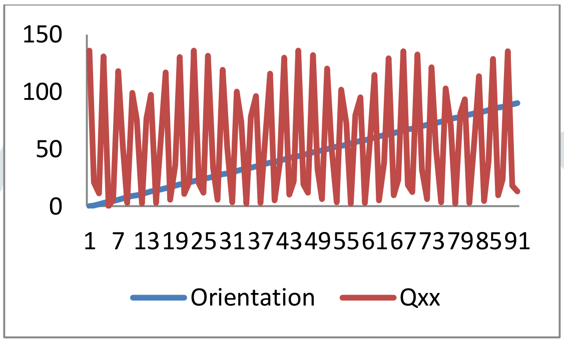
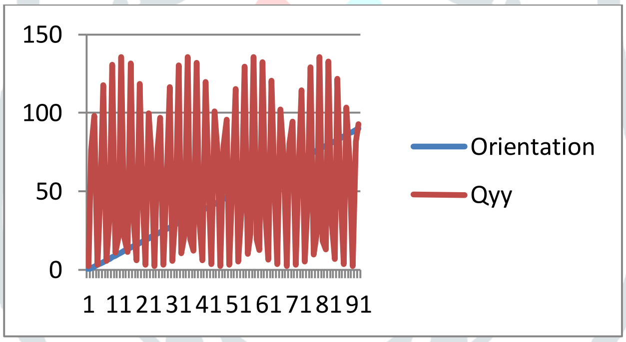


Fig (3.1): Few laminas with fibre oriented in different directions.

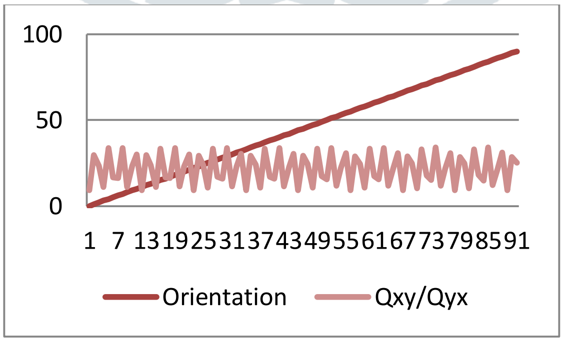
4. Lamina Analysis: Effect of fibre orientation is considered on various parameters associated with lamina which defines its performance and stability under mechanical and thermal loadings either acts individually or combinely. Various graphs below depict this parameters dependability on fibre orientation and among themselves as well.



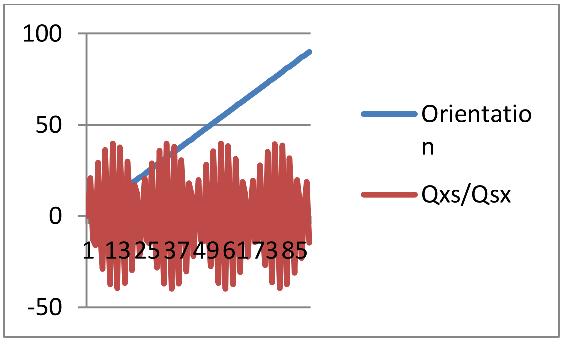
Graph (4.1): Fibre orientation vs stiffness in xx plane.



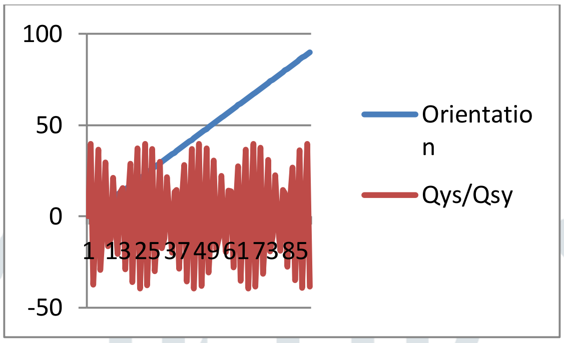
Graph (4.2): Fibre orientation vs stiffness in yy plane.



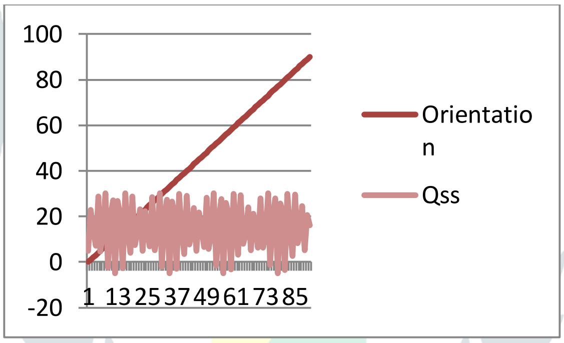
Graph (4.3): Fibre orientation vs stiffness in xy/yx plane.



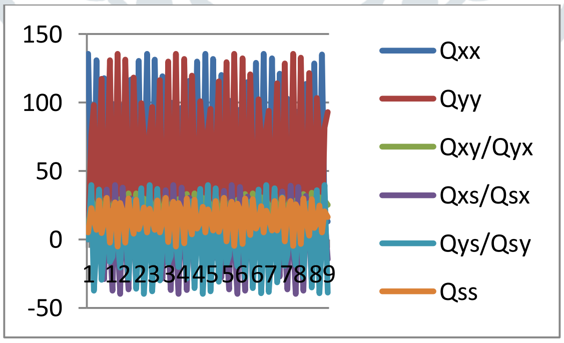
Graph (4.4): Fibre orientation vs stiffness in xs/sx plane.



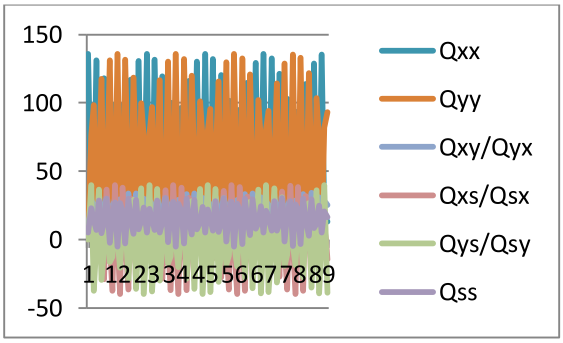
Graph (4.5): Fibre orientation vs stiffness in ys/sy plane.



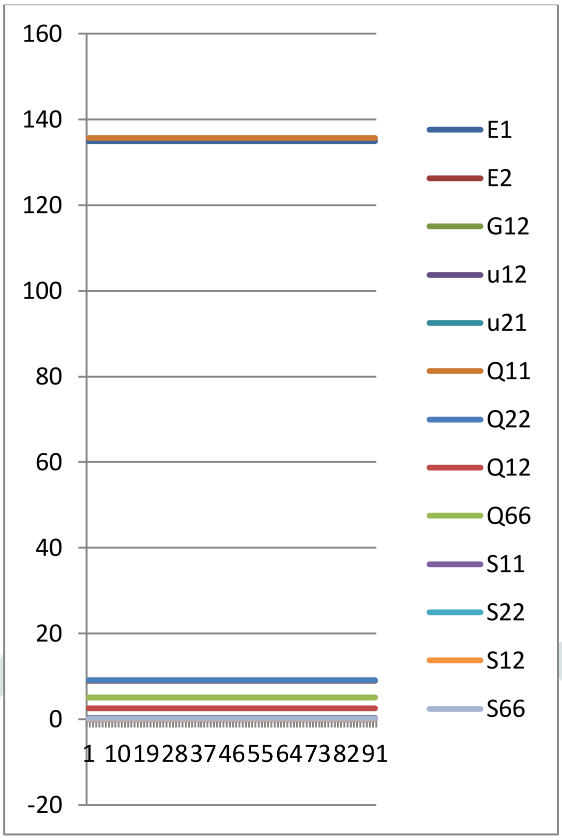
Graph (4.6): Fibre orientation vs stiffness in ss plane.



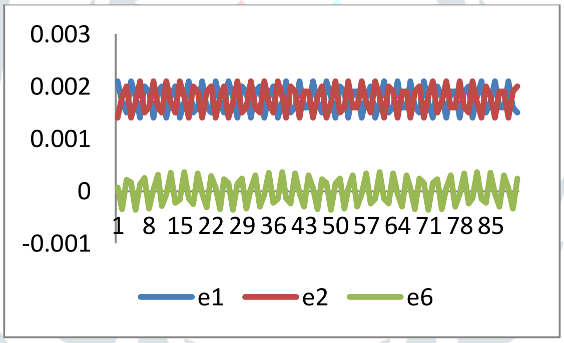
Graph (4.7): Overall representation of dependency of stiffness parameters on fibre orientation.



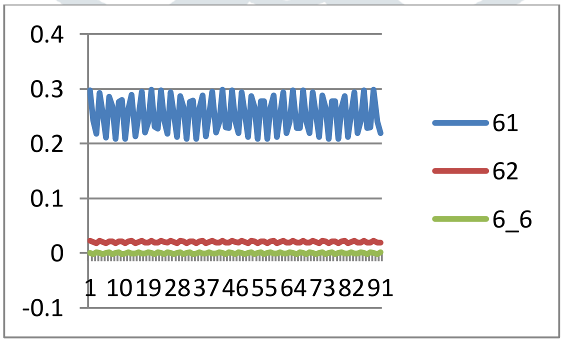
Graph (4.8): effect of fibre orientation on compliance and stiffness parameters.



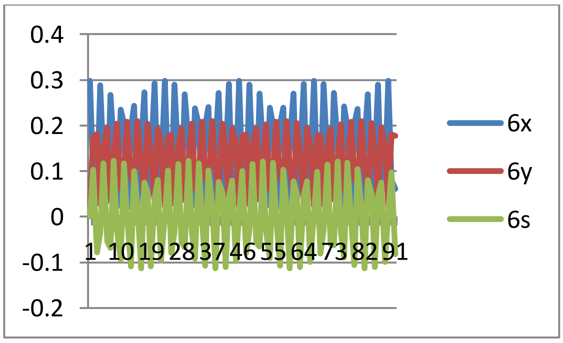
Graph (4.9): Graph showing on-axis engineering elastic constants are unaffected by fibre orientations



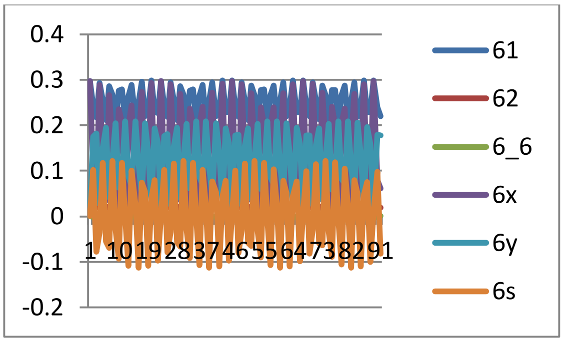
Graph (4.10): Varying value of on-axis strain with respect to fibre orientation



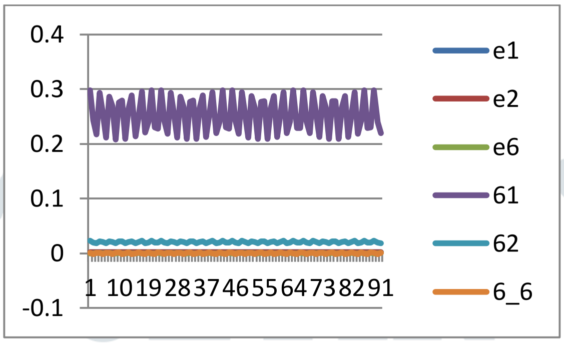
Graph (4.11): Varying value of on-axis stress with respect to fibre orientation



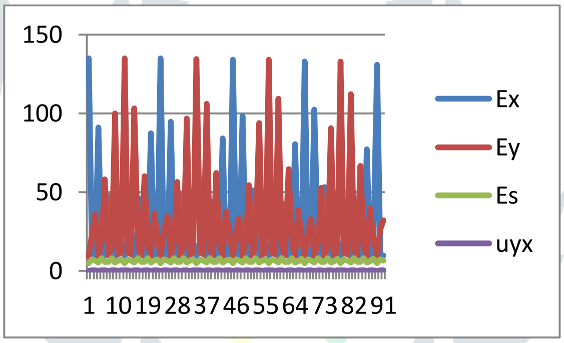
Graph (4.12): Varying value of off-axis stress with respect to fibre orientation



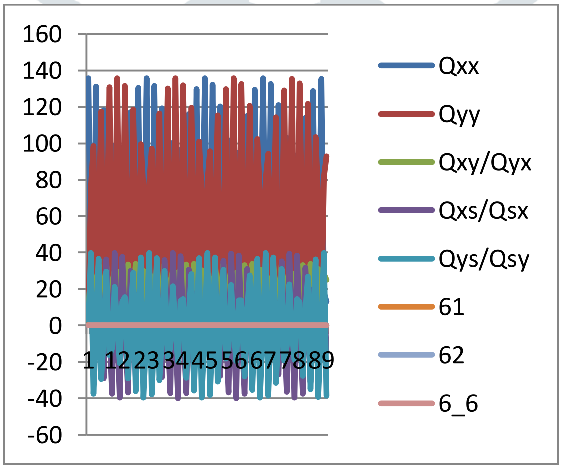
Graph (4.13): Effect of fibre orientation on the on-axis and off-axis stress.



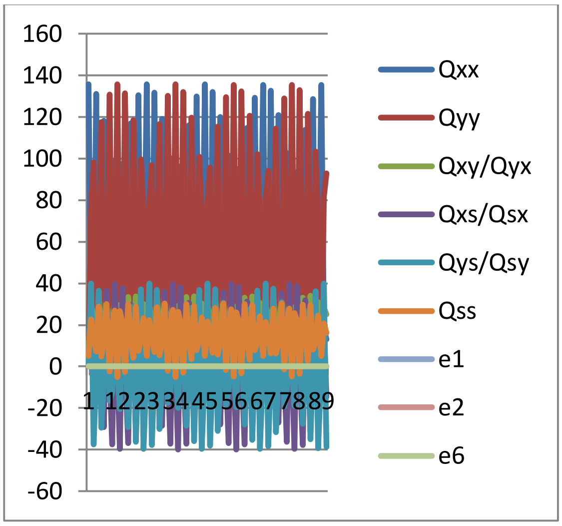
Graph (4.14): Dependability of on axis strain and on axis stress on fibre orientation



Graph (4.15): Effect of fibre orientation on off-axis engineering elastic properties.



Graph (4.16): Dependability of stress on stiffness components considered with varying fibre orientation from 0 to 90.



Graph (4.17): Dependability of strain components on stiffness considered with varying fibre orientation from 0 to 90.

5. Result, conclusion & Discussion:

Parameters	Maximum value	Minimum value	Orientation (Degrees), Respectively
Q_{xx}, GPa	135.70	2.53	0 & 11,33
$Q_{yy,}$ GPa	135.70	2.53	11,33 & 0
Q_{xy}, GPa	33.94	9.04	84 & 0
Q_{xs}, GPa	39.72	-39.79	10 & 56
Q_{ys}, GPa	39.79	-39.79	45 & 21
$Q_{ss,}$ GPa	30.24	-4.99	73 & 11
e_1	0.0021	0.0014	[0,3,16,19,22,25,38,41,44,47,60,63.66,69.82,85,88] & [5,8,11,14,27,30,33,36,49,52,55,58,71,74,77,80]
e_2	0.0021	0.0014	[5,8,11,14,27,30,33,36,49.52,55,58,71,74,77,80] & [3,16,19,22,25,38,41,44,47,60,63,66,69,82,85,88]
e_6	3.57*10^-4	-3.57*10^-4	[15,37,59,81] & [26,48,70]
σ_1, GPa	0.298	0.2083	19 & 8
σ_2, GPa	0.0226	0.018	[19,22,41,44,63,66,85,88] & [8,11,30,33,52,55,74,77]
σ_6, GPa	1.80*10^-3	-1.80*10^-3	[0] & [4,26,48,70]
σ_x, GPa	0.2978	0.018	[22,44,66,88] & [11,33,55]
σ_y, GPa	0.2093	0.0225	80 & 0
σ_s, GPa	1.22*10^-1	-1.14*10^-1	[0] & [15,37]
$E_{x,}$ GPa	135	9	0 & 11
$E_{y,}$ GPa	134.95	9	11 & 0
$E_{s,}$ GPa	8.12	5	84 & 0
μ_{yx}, GPa	0.452	0.0187	[86] & [0,22]

With respect to above results, following conclusions and discussion can steer up,

1. Longitudinal stiffness of lamina is noted highest in 0 degree orientation.
2. Transvers stiffness of lamina is noted lowest in 0 degree orientation.
3. Shear stiffness of lamina is noted highest along 84 degree, where, it is noted less along 0 degree.
4. On-axis longitudinal and transverse strains are found equal and more than shear strain.
5. On-axis longitudinal stress is found more than transverse stress, which was further more than shear stress.
6. Maximum stress in shear plane indicates failure sensitivity of lamina due to excessive shear load.
7. Off axis stress too like on axis stress noted from higher to lower magnitude in longitudinal, transverse and shear direction.

8. Maximum value of on axis longitudinal stress found equal to maximum value of off axis longitudinal stress, but assumption is not true in case of minimum stress values, and it shows, minimum value of on axis longitudinal stress is more than minimum value of off axis longitudinal stress.
9. Value of engineering elastic constant, modulus of elasticity found maximum along 0 degree, where it noted less in transverse plane which represented by location of fibres inclined at an angle 11 degrees to the material principal axis.
10. Value of transverse young's modulus is noted maximum in the plane, i.e. 11 degrees where value of longitudinal young's modulus was noted minimum.
11. Value of shear modulus noted highest along plane located at an angle 84 degrees, and it found less along plane located at 0 degrees.
12. Poisons ratio is noted highest in value along plane located at 86 degrees, where, it is noted less long planes holding location 0 and 22 degrees respectively.

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