EFFECT OF FIBRE PACKAGING PATTERN ON PERCENTAGE OF FIBRE, MATRIX VOLUME FRACTION AND STRENGTH OF COMPOSITE LEAF SPRING MODEL

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Abstract: Fibre, matrix and resin are important constituents of composite structure. Presence of these constituents with varying percentage affects the structure properties ultimately. Fibre are stiff and strong elements than matrix and always makes structure to sustain the load in the direction it applied. More the percentage of fibre more load sustaining occurs in respective direction and vice versa, but presence of fibre in structure is limited to specific value and that is 80%, beyond which packing of fibres in to structure is not possible, but in the case of cylindrical geometry of fibres this figure can raise up to 90%. Fibre packing in possible in multiple way and few can be listed, triangular, rectangular, pentagonal, hexagonal etc.

Paper describes one such aspect of fibre packing in to leaf spring model to be used in Mahindra Bolero. The ultimate aim of work is finding out the good pattern of fibre packing in to matrix which would lead to maintain optimum percentage of fibre in to structure and thus leads further to enhance strength of the leaf spring to sustain maximum magnitude of load which would act under un-described circumstances.

Keywords: Leaf spring, composite, Fibre, Packaging, Mahindra Bolero etc.

1. Introduction: Use of composite in various domains is widely popular which is obviously not hidden from the one who wish to bring innovation in to product and technology. Though replacement of metal is not possible throughout, still, researchers are looking towards composite with very wide scope.

Strength of composite is the function of strength of its constituents which imparts combine advantage and benefit of every such individual ingredient added as a part of composite structure. Fibre are stiff element and thus one would believe to add more percentage of it to achieve required strength under the conditions of uncertainty, but there is limit to maximum inclusion of it in to matrix structure and that made one to analyse best possible way or pattern to add optimum percentage of fibre to achieve said property configuration with priority given to strength enhancement.

There are multiple patterns available referring to which fibre reinforcement in to matrix make happened, but method can materialize remains within set of few restrictions such as, fibre must be long and continuous, fibres must be organized parallel to each other, optimum spacing maintained between fibres etc. the optimum percentage of fibre in to structure would lead to exhibits high load sustaining capacity in to that structure and that is all time beneficial; if one would think from mechanical point of view.

2. Leaf spring dimensions and proposed model: The figure below depicts the basic model of composites along with dimensions. The dimensions of conventional leaf spring which is made of steel carry forwarded as it is, only the difference between composite and conventional spring is that, the model of leaf spring made of composite is manufactured as continuous structure with no plates stacked one above the other. The model gains advantage such as weight reduction, strength enhancement, size reduction, manufacturing easiness etc.

The fibre orientations are maintained parallel in each lamina, several such lamina until thickness 8 mm won't reach keep added in to laminate structure.
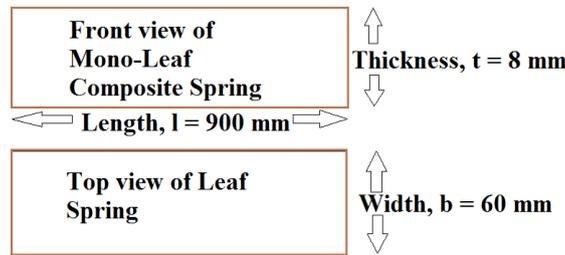
Fig (2.1): Laminate spring structure modelled in composite material

Fibre contributes 75% of load sharing of total load acting, in this view, it is beneficial to add more percentage of fibre in to structure but because of restriction to maximum fibre volume fraction structure with excess fibre fraction is not possible to manufacture.

The equation below justifies the importance and contribution of fibre and matrix volume fraction in load carrying.

Total load on structure = Load carried by fibre + load carried by matrix.

$P_T = P_f + P_m$…………(1)

But, according to the equation of stress,

$\sigma = \frac{P}{A}$…………..(2)

Thus, Load, $P = \sigma * A$……….(3)

Let put up the value of load from equation three in to equation one.

$\sigma_T * A_C = \sigma_m * A_m + \sigma_f * A_f$

$\sigma_T = \sigma_m * A_m / A_C + \sigma_f * A_f / A_C$

$\sigma_T = \sigma_m * v_m + \sigma_f * v_f$.........................(4)

Above equation represents load sustaining capacity and ability to withstand against failure is the function of fibre and matrix volume fraction contents of that respective structure.

Matrix is flexible elements which never sustain the load longer but transfer it to fibre to deal further. This load transfer happens through Shear Force. Thus presence of fibre in structure in optimum percentage is beneficial always. Type of packaging pattern recommended for fibre reinforcement in to matrix decides and vary this percentage from pattern to pattern. Paper investigates two patterns, namely, Triangular and Square to chalk out best possible percentage of fibre that can be imbibe in to structure to achieve the optimum property balance as an operational requirement.

3. Objectives of the study:

1. To find optimum fibre and matrix volume percentage for composite leaf spring.

2. To find optimum pattern of fibre packaging for maximum fibre accommodation inside the matrix.

4. Hypothesis considered:

H₁: Only triangular and rectangular patterns have considered for study purpose.

H₂: Percentage of fibre is calculated only for unit cell and based on same calculations later percentage fibre for entire leaf spring has calculated.

H₃: Fibre distribution for entire spring geometry is considered as homogenous and same.

5. Methodology: The methodology followed by paper described trough following few steps,

1. Structure of leaf spring is finalized by considering dimensions of composite spring as similar as conventional leaf spring.

2. Fibre volume percentage is calculated by considering Triangular and Square pattern of fibre packaging in to matrix.

3. Total fibre volume percentage in to leaf spring is calculated taking in to account geometry of leaf spring. Total fibre volume percentage for entire leaf spring geometry is calculated for unit fibre volume percentage calculated for Triangular and Square pattern.

4. Based on total fibre volume fraction, strength, mass of the leaf spring calculated and compared for Triangular and Square pattern.

6. Fibre volume fraction by Square arrangement of fibre in to structure:
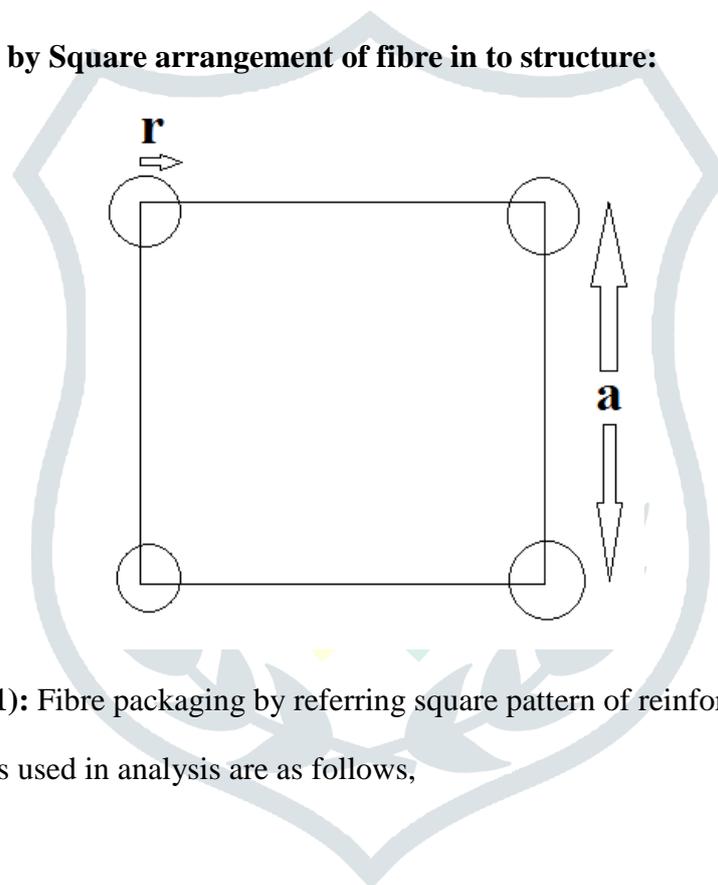

Fig (6.1): Fibre packaging by referring square pattern of reinforcement.

Meanings of abbreviations used in analysis are as follows,

r- Radius of fibres, mm
d- Diameter o fibres, mm
a- Fibre spacing, mm
V$_f$- Fibre volume fraction, mm^3

Step 01: Fibre packaging factor, x = (60*4/360) = 2/3

Step 02: Fibre cross sectional area, A = x*$\frac{\pi}{4}d^2$ = (2/3)*($\frac{\pi}{4}$)*d^2

Step 03: Unit cell area, A$_u$ = (2/3)*(a)*(a) = (2/3)*a^2

Step 04: Fibre volume fraction, V$_f$ = (Fibre) cross sectional area/(Unit cell area)

V$_f$ = (2/3)*($\frac{\pi}{4}$)*d^2/(2/3)*a^2

$$a = \frac{\sqrt{\pi}*d}{2*V_f^{1/2}} \ldots\ldots\ldots\ldots(1)$$

Equation (1) represents possible spacing can be marinated between fibres to accommodate maximum fibre volume in unit cell with chosen pattern.

Step 05: Maximum fibre volume fraction, $= \frac{\sqrt{\pi}*d}{2*V_f^{1/2}}$ - (d)

Step 06: $V_{f\_max}= 0.78\%$ is maximum fibre volume fraction that can be accommodates in to the structure if fibres are organized in square pattern.

Step 07: Volume of composite leaf spring, $V_s = 900*8*60 = 432000$ mm^3

Step 08: Volume of fibres, $V_f = 0.78*432000 = 336960$ mm^3

Step 09: Volume of matrix, $V_m = 432000- 336960 = 95040$ mm^3

7. Fibre volume fraction by Triangular arrangement of fibre in to structure:

Meanings of abbreviations used in analysis are as follows,

r- Radius of fibres, mm
d- Diameter o fibres, mm
a- Fibre spacing, mm
V$_f$- Fibre volume fraction, mm^3

Step 01: Fibre packaging factor, x = (60*3/360) = 1/2

Step 02: Fibre cross sectional area, A = x*$\frac{\pi}{4}d^2$ = (1/2)*($\frac{\pi}{4}$)*d^2

Step 03: Unit cell area, A$_u$ = (1/2)*$\frac{\sqrt{3}}{2}$*(a)*(a) =$\frac{\sqrt{3}}{4}$*(a^2)

Step 04: Fibre volume fraction, V$_f$ = (Fibre) cross sectional area/(Unit cell area)

V$_f$ = (1/2)*($\frac{\pi}{4}$)*d^2/(1/2)*$\frac{\sqrt{3}}{2}$*(a)*(a) =$\frac{\sqrt{3}}{4}$*(a^2)

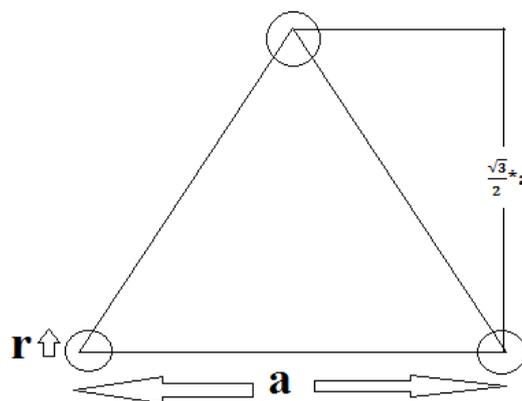$a = \frac{0.952}{V_f^{1/2}}$*d

Fig (7.1): Fibre packaging by referring Triangular pattern of reinforcement.

Step 05: Maximum fibre volume fraction, $= \frac{0.952}{v_f^{1/2}}*d - (d)$

Step 06: V_{f_max} = 0.90 is maximum fibre volume fraction that can be accommodates in to the structure if fibres are organized in triangular pattern.

Step 07: Volume of composite leaf spring, V_s = 900*8*60 = 432000 mm^3

Step 08: Volume of fibres, V_f = 0.90*432000 = 388800 mm^3

Step 09: Volume of matrix, V_m = 432000- 388800 = 43200 mm^3

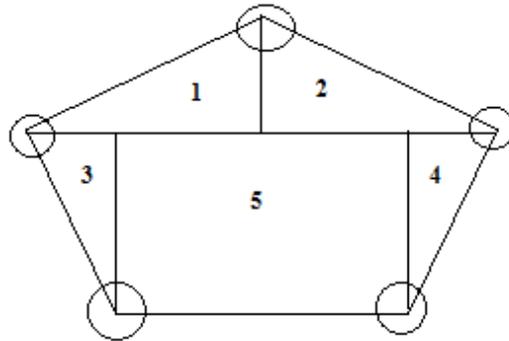## 8. Fibre volume fraction by pentagonal packaging method:

Fig (8.1): Pentagonal arrangement of fibres

As shown above pentagonal geometry is divided in to five sub-standard geometries named from numbers 1 to 5.

As discussed earlier percentage of fibre volume fraction is calculated in the steps as depicted below,

Step 01: Fibre packaging factor, x = (60*5/360) = 5/6

Step 02: Fibre cross sectional area, $A = x*\frac{\pi}{4}d^2 = (5/6)*(\frac{\pi}{4})*d^2 = 0.654166$ d^2

Step 03: Unit cell area, $A_u = 5/6*[\sqrt{3}/2*a*a + \sqrt{3}/2*a*a]+a^2 = 2.276*a^2$

Step 04: Fibre volume fraction, V_f = (Fibre) cross sectional area/(Unit cell area)

$V_f = 0.654166*d^2/3.886*a^2$

$a = 0.410288*d/v_f^{1/2}$

According to the condition of maximum fibre volume fraction, following equation can be written,

   (a) - (d) = 0

   V_f = 0.16

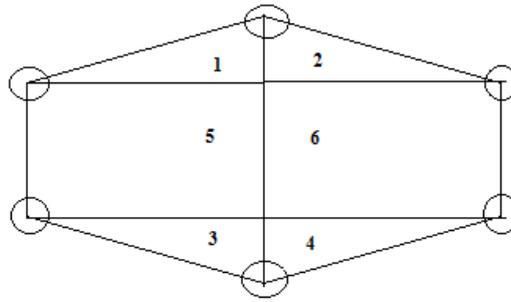## 9. Fibre volume fraction by hexagonal packaging method:

Fig (8.1): Hexagonal arrangement of fibres

Geometry is divided in to six standard geometries, the calculation of fibre volume fraction is processed through following steps,

Step 01: Fibre packaging factor, x = (60*6/360) = 1

Step 02: Fibre cross sectional area, $A = x * \frac{\pi}{4} d^2 = (1)*(\frac{\pi}{4})*d^2 = 0.704257 \ d^2$

Step 03: Unit cell area, $A_u = 1 \ [\sqrt{3}/2*a*a + \sqrt{3}/2*a*a] + 2a^2 = 3.73*a^2$

Step 04: Fibre volume fraction, V_f = (Fibre) cross sectional area/(Unit cell area) = $0.704257 \ d^2/3.73*a^2$

$$a = (\sqrt{\frac{0.704257}{3.73}} * d)/v_f^{1/2}$$

According to the condition of maximum fibre volume fraction, following equation can be written,

$$(a) - (d) = (\sqrt{\frac{0.704257}{3.73}} * d)/v_f^{1/2} - d = 0$$

$V_f = 0.18$

10. Result: The different fibre packing percentage has found when it refers different patterns of fibre packaging, based on maximum fibre percentage in structure, respective volume of fibre and matrix has calculated.

Sr. No.	Pattern	Fibre volume in percentage	Matrix volume in percentage
1	Triangular	90%	10%
2	Square	78%	22%
3	Pentagonal	16%	84%
4	Hexagonal	18%	82%

11. Conclusion & Discussion:

1. Triangular method of fibre packaging enables maximum percentage of fibre packaging in matrix structure and thus leads to produce strong structure with less density.
2. Despite more volume, weight of fibres noted low than matrix.
3. Triangular, square, pentagonal and hexagonal methods of fibre packaging have studied side by side, the results reveal triangular method of fibre packaging enable maximum accommodation of fibres than others method.
4. Fibre are stiff and strong members than matrix, so maximum fibre inclusions in to structure leads to produce strong and stiff structure which is basic requirement of all the mechanical application.

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