Investigation of the impact behavior for composite materials reinforced by glass fibers

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Abstract. In this present work, a non-straight Shear-lag model has been created to anticipate the pressure centralization of a customary hexagonal cell containing a two-bundled fiber. This work is concretized by the advancement of a hypothetical plan of the micromechanical redistribution of the anxieties produced by the transverse burst along the strands in a unidirectional composite as an element of the number and the air of the messed up and flawless filaments. The scientific improvements utilized are introduced to legitimize the state of the conveyance of the worries around the messed up fiber and the adjoining filaments. The limit and coherence conditions are considered by this model to evaluate the exchange pace of the strands, imperatives through the lattice between the fiber broken and the neighboring filaments ublemished.

1. Introduction

These days, the shear-lag methodology is one of the most broadly utilized techniques for displaying the fiber/grid communication. At the point when a fiber stacked the longitudinal way breaks in a unidirectional composite material, there will be a dispersion of this heap to the neighboring flawless filaments [1].

This new dissemination is called neighborhood redistribution of endeavors around the messed up fiber. Utilizing the shear-lag model, more research has been led to anticipate the pressure fixation in the region of broken strands just as the longitudinal quality of a unidirectional composite with fiber breakage. Putting together itself with respect to shear-lag shear lag suspicions, a few specialists have examined the shear disappointment at the fiber/framework interface, characterizing a shear parameter used to depict the total versatile fiber/lattice conduct with a splendidly plastic network strip. The models Rosen [2] and Zweben [3] which view themselves as among the most seasoned models for the expectation of the opposition of composites with polymer lattice. Phoenixetal. [4] had the option to decide the pressure and term of viestattique of break of the unidirectional carbon fiber.

Accordingly, the model of Landis et al. [5] was improved via Landis and Mc Meeking [6] considering the impacts of pivotal sliding at the fiber-network interface and the situating of unblemished filaments on firmness by assessing the pressure fixation around the wrecked fiber. Goda [7] proposed a probabilistic model of obstruction dependent on the Markov chain process for unidirectional fiber composites in hexagonal course of action. The model accepts a gathering of filaments with a hexagonal plan. At the
purpose of match of the break of the main fiber, the harm of this gathering develops with the expansion of
the heap. Bouhamida et al. [8] decided the impact of the arbitrary area of the strands on the pressure fixation
around a wrecked fiber. Most as of late Bouhamida et al. [9] proposed a limited distinction model for the
instance of irregular dividing between filaments. The present work endeavors to foresee the compelled
fixation factor in a unidirectional composite cell having a messed up fiber. Contrasted and Bandorawalla
[10], the Shear Lag model was created to evaluate the impact of the messed up fiber on the development of
the pressure focus factor on unblemished neighboring filaments. So as to check the precision of our
outcomes, a correlation was made with the aftereffects of the various methodologies given by the writing.

2. Materials of the study

2.1. Shear-lag model applied to a unidirectional composite

So as to examine the condition of worry in the region of a messed up fiber, the Nearest Neighbor Load
Sharing (NNLS) model was utilized to decide the pressure focus factor of a unidirectional composite under
uniform malleable stacking, as indicated by figure 1.

![Figure 1. Appropriation of worries at the degree of the messed up fiber and the neighboring filaments.](image)

The filaments are masterminded in a hexagonal game plan. The dividing between the filaments is
standard. A messed up fiber is encompassed by six unblemished filaments (figure 2).

According to [10], the distance between the centers of the fibers is given by:

\[ S = \frac{\pi}{\sqrt{V_f \sin 60^\circ}} r_f \]  

To be steady with the portrayal given in reference [10], the messed up fiber and its six neighbors are
numbered 1-7 as appeared in Figure 2. It ought to be noticed that the hexagonal course of action of the
strands is important to ascertain all the impact powers of the messed up fiber \( q_1 \) and those of the neighboring
filaments flawless \( q_2(x), q_3(x), q_4(x), q_5(x), q_6(x) \) and \( q_7(x) \) expressed by the function:
\begin{equation}
\{Q\} = \begin{bmatrix}
q_1(x) \\
q_2(x) \\
\ddots \\
q_7(x)
\end{bmatrix}
\end{equation}

Figure 2. The hexagonal arrangement with fiber numbering.

Similarly, for the displacement vector of the seven fibers constituting the hexagonal cell \(v_1(x), v_2(x), v_3(x), \ldots, v_7(x)\).

\begin{equation}
\{V\} = \begin{bmatrix}
v_1(x) \\
v_2(x) \\
\ddots \\
v_7(x)
\end{bmatrix}
\end{equation}

Using the Shear-lag hypothesis, we can write:

\begin{equation}
\{Q\} = E_f \frac{d}{dx} \{V\}
\end{equation}

As has just been shown in figure 2, the distance between the centers of the fibers \(i\) and \(j\) is denoted by \(d_{ij}\), with \(w_{ij} = d_{ij} - 2.0\ \text{r}_i\). The Shear-lag speculation is applied for the seven-fiber cell and the framework overseeing conditions for fiber removals are gotten:

\begin{equation}
\frac{d^2}{dx^2} \{V\} + [A] \{V\} = 0
\end{equation}
\[ A = C \]

\[
A = \begin{bmatrix}
A_{11} & \frac{1}{w_{12}} & \frac{1}{w_{13}} & \frac{1}{w_{14}} & \frac{1}{w_{15}} & \frac{1}{w_{16}} & \frac{1}{w_{17}} \\
\frac{1}{w_{12}} & A_{22} & 0 & 0 & 0 & \frac{1}{w_{27}} \\
\frac{1}{w_{13}} & 0 & A_{33} & 0 & 0 & 0 \\
\frac{1}{w_{14}} & 0 & 0 & A_{44} & \frac{1}{w_{45}} & 0 \\
\frac{1}{w_{15}} & 0 & 0 & \frac{1}{w_{45}} & A_{55} & \frac{1}{w_{56}} \\
\frac{1}{w_{16}} & 0 & 0 & \frac{1}{w_{56}} & A_{66} & \frac{1}{w_{67}} \\
\frac{1}{w_{17}} & 0 & 0 & 0 & \frac{1}{w_{67}} & A_{77}
\end{bmatrix}
\]

\([A]\) is a square matrix of 7x7. The elements of this matrix are expressed by:

\[
A_{11} = -\left(\frac{1}{w_{12}} + \frac{1}{w_{13}} + \frac{1}{w_{14}} + \frac{1}{w_{15}} + \frac{1}{w_{16}} + \frac{1}{w_{17}}\right);
\]

\[
A_{22} = -\left(\frac{1}{w_{12}} + \frac{1}{w_{23}} + \frac{1}{w_{27}}\right);
\]

\[
A_{33} = -\left(\frac{1}{w_{13}} + \frac{1}{w_{23}} + \frac{1}{w_{37}}\right);
\]

\[
A_{44} = -\left(\frac{1}{w_{14}} + \frac{1}{w_{34}} + \frac{1}{w_{45}}\right);
\]

\[
A_{55} = -\left(\frac{1}{w_{15}} + \frac{1}{w_{45}} + \frac{1}{w_{56}}\right);
\]

\[
A_{66} = -\left(\frac{1}{w_{16}} + \frac{1}{w_{56}} + \frac{1}{w_{67}}\right);
\]

\[
A_{77} = -\left(\frac{1}{w_{17}} + \frac{1}{w_{67}} + \frac{1}{w_{67}}\right);
\]

\[
C = \frac{hG_m}{A_m E_m}
\]

\(h\) is the thickness of the matrix expressed by \(h = (\pi r f) / 3\).

According to Hedgepeth and Van Dyke [11], local stress of each fiber is given by:

\[
\sigma_i = \sigma_f + \sum_{k=1}^{L} q_i (x - x_k) u_k
\]

The limitations for every fiber is important to ascertain the uprooting vector, \((u_i, j=1, L)\), by solving the system of equations for \(\sigma = 0\), the stress concentration factor is given by:
\[ C_i = 1 + \sum_{k=1}^{L} \frac{\sigma_r(x)}{\sigma_f} \left( x - x_k \right) u_k \] (7)

\( \sigma_f \): is the uni-axial stress applied at a distance L of the fiber group.

2.2. Validation of application

So as to check the nature of the outcomes acquired by this model, an approval was made with investigative models from the book reference. Approval was finished with the geometry of the nearby dispersion of the charge for one and two strands broken in a hexagonal cell. This approval was put forth for the defense of a messed up fiber with the model geometric [7] and shear-lag [11].

For our application, a graphite/PPS composite is utilized. Unsettling influence good ways from the messed up fiber is \( x_p = 60^\circ r_f \). The accompanying table records the mechanical and geometrical qualities of the graphite/PPS unidirectional composite.

| Quality                                      | Value   |
|----------------------------------------------|---------|
| Young’s modulus of fiber \( E_f \) (GPa)      | 234.4   |
| Young’s matrix module \( E_m \) (GPa)         | 1.1     |
| Fiber reference resistance \( \sigma_0 \) (GPa) | 3.17    |
| Shear stress \( \tau_0 \) (MPa)              | 25.8    |
| Poisson's ratio of the matrix \( \nu \)        | 0.43    |
| Fraction volume of fibers \( V_f \)          | 0.53    |
| Shear parameter \( \eta \)                   | 1.0     |
| Ray of fiber \( r_f \) (μm)                  | 3.5     |
| Disturbance distance \( x_p \)               | 60°r_f  |

3. The results of the study

3.1. Cell with a single broken fiber

The arrangement of filaments of every cell is kept up with a network which guarantees the exchange of the charges and the dispersion of worries around the flawless strands in the event of breakage of the focal fiber. To have the option to speak to the pressure focus factor along the wrecked fiber and the contiguous unblemished filaments, a subdivision should be made along the longitudinal hub (60°r_f).

To start with, the approval was finished with the consequences of [11]. The pressure fixation factor of a messed up fiber encompassed by the six unblemished filaments is given by \( 1 + \frac{1}{6} = \frac{7}{6} = 1.167 \). In this way, the heap that was at first upheld by the focal fiber, it is appropriated equitably among the six nearby strands, since the last has lost its inflexibility totally (Figure 3). Then again, in our model, the pressure focus factor relies basically upon the mechanical and geometrical attributes of the fiber and the lattice which guarantees the exchange of burden between them. From Figure 4, we note that our outcomes are in ideal concurrence with those of [10]. Additionally, the dividing between the strands has no impact on the pressure focus factor at the purpose of breakage (x = 0.0), in light of the fact that all the filaments are uniformly dispersed.

**Figure 3.** SCF of the six neighboring fibers according to [10].
In Figures 5 and 6, an approval of our outcomes (Model NNLS) was made with the heap circulation model of [12] for a straightforward separation of a fiber situated in a unidirectional fiber composite under a standard hexagonal plan. Figure 5 shows the advancement of the pressure fixation factor as an element of the length of the wrecked fiber. It is unmistakably obvious that our outcomes (Model NNLS) are in phenomenal concurrence with those of the HVDLS. At the position $x = 0$, the pressure fixation factor (SCF) is zero. Going towards a genuinely long length, the SCF takes a level worth equivalent to 1. While for FIG. 6, it speaks to the advancement of the pressure fixation factor as an element of the length of the six flawless neighboring filaments. A fairly momentous distinction is seen between our model and the HVDLS model, particularly for $x = 0$. Towards genuinely long lengths, the two bends join to a similar worth (SCF = 1.0).

From this figure, we can say that our model guarantees a superior conveyance of the charges around the messed up fiber on the grounds that roughly 100% of the pressure is partitioned on the six unblemished neighboring filaments which gives us a 16.66% rate for each nearest neighbor fiber. Then again, the HVDLS anticipates a lower pressure fixation factor around neighboring unblemished filaments about 60%, or 10.95% for each nearest neighboring fiber. Thus, the remainder of the focus discharged by the messed up fiber is disseminated past the outskirt of the closest neighbors.
Figure 6. Comparison between HVDLS and NNLS for the closest neighbor fibers.

Figure 7 shows the development of the pressure fixation factor of the six neighboring filaments as an element of the separation between the strands along the longitudinal pivot. It is noticed that the presence of the SCF is indistinguishable for the six neighboring unblemished strands. The variety out there between the filaments doesn't influence the SCF values at $x = 0$ (break line) and $x = \lambda$ (far separation). A basic unsettling influence exists between these two separations. So more than, this separation is exceptionally little (strands near one another), the state of the bend unites rapidly to the level worth (SCF = 1.0). In this way, the impact of the shear-lag is decreased in light of the fact that we have an expansion in the fiber volume part, thus a decrease in the measure of network that is liable for the postponement of stress move (shear-lag wonder).

Figure 7. Evolution of the stress concentration of the six neighboring fibers as a function of the distance between the fibers along the longitudinal axis.
Figure 8. Evolution of the stress concentration of the six neighboring fibers as a function of the diameter of the fibers of the cell along the longitudinal axis.

### 3.2. Two cells with two broken fibers

As indicated by the semi LLS model [3], the breakage of the subsequent fiber gives us a reasonable dissemination of the heap between the six neighboring filaments, SCF = 1.166, see figure 9.a. Also, a proportion of 1/5 is transmitted to the accompanying five strands (A, B, F, G, H). This doesn't correspond with the standard of LLS created by [6], see figure 9.b. To test the exhibition of our model (NNLS), three sorts of fiber dividing are assessed (dispersed filaments, respectively separated strands, and minimized filaments). From Figure 10, obviously our outcomes are near model [3] on account of respectfully dispersed strands. Then again, they are in acceptable concurrence with the consequences of [6] on account of compacted filaments.

For filaments that are dispersed and organized in an ordinary hexagonal game plan, it is noticed that the most extreme estimations of the SCF are given by the fiber 2 and 6 (SCF = 1.22), in light of the fact that these two strands are encompassed by two broken filaments. The four strands 1, 3, 5 and 7 are in this manner found, with SCF = 1.17. At long last, the two residual strands 4 and 8, where the SCF = 1.16.

![Figure 9](image)

**Figure 9.** Concentration of stress in the case of two broken fibers according to the model [3] and [6].
Discussion and Conclusions
The present work comprises in following the development of the convergence of worries at the degree of the messed up fiber and the neighboring strands unblemished. Our outcomes are in acceptable concurrence with the writing. For the wrecked fiber, the pressure focus is at the zero an incentive at the limit, and afterward it increments to arrive at the estimation of 1.0 by moving ceaselessly in the length. For the closest neighboring strands, the pressure fixation is higher. High on the point \( x = 0 \) with estimation of 1.166 for the six strands. Despite the fact that the exertion of the wrecked fiber is similarly conveyed over the six filaments, the separation between the messed up fiber and the flawless strands doesn't change the incentive at the point \( x = 0 \), all things considered the corruption of the factor over the length fiber contrasts. Subsequently, on account of a little separation, the pressure fixation diminishes all the more quickly, dissimilar to when the separation is more prominent. The dispersion of the SCF for the unblemished filaments isn't indistinguishable, if the quantity of broken strands is higher. Accordingly, the most extreme SCF values are limited for filaments encompassed by two broken strands.

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