DETERMINATION OF NOTCH SENSITIVITY OF JUTE/ISOPHTHALIC COMPOSITES – AN EXPERIMENTAL STUDY

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ABSTRACT:
Monolithic metals and their alloys cannot always meet the demand of today's advanced technologies. Only by combining several materials one can meet the performance requirements. Composites have the unique property of offering very high strength to weight ratio. The objective of this paper is to investigate the notch sensitivity of notched and unnotched jute-isophthalic polyester subjected to uniaxial tensile loading experimentally. The results are also validated using theoretical models viz, Point Stress Criterion (PSC), Average Stress Criterion (ASC) and Damage Zone Criterion (DZC). Correlation between theoretical models and experimental results is also presented.

KEY WORDS: Notch Sensitivity, Jute/isophthalic Composites, Failure criterion

1. INTRODUCTION

Previous works involved in the field of jute composite consists mainly of jute fibers. Here in this project for the fabrication of composite jute fabric is used and the composite is developed using hand lay up technique using Isophthalic Polyester Resin. The jute fabric composite which is of low cost can be used for all low impact loaded applications. Apart from low cost, the jute fabric also has the advantage of abundant availability.

Most methods currently used for predicting tensile strength of composite laminates containing holes and cracks adopt a characteristic distance approach such as the Point Stress Criterion (PSC) or the Average Stress Criterion (ASC). These and similar approaches are attractive to designers since they are simple to apply. The limitation of such approaches however is that the characteristic distance is not a physical parameter but is an empirically determined constant, dependant on the geometry of the specimen. The Damage Zone Criterion (DZC) is also used in this paper which is based on fundamental physical principles. Therefore, the notch sensitivity of the jute/polyester composites is determined experimentally and they are validated by using theoretical models such as PSC, ASC and DZC.

2. EXPERIMENTATION

The jute fabric consists of yarns in two directions namely warp and weft. In the warp direction, 22 yarns/inch are present and in the weft direction there are 12 yarns/inch. The fabric is the woven jute fabric of unbalanced type (strength is not the same in both the directions). It is woven by keeping the warp yarns longitudinally and weaving the weft across it. The gram per square meter (GSM) of the fabric is 320. The fig.1 shows how the warp and weft yarns are counted.

Jute fabric (Double warp woven unbalanced) and Isophthalic polyester resin with Methyl Ethyl Ketone Peroxide are used to prepare composite specimens. The composite specimens were cut to the ASTM (3039) standard. The dimensions of the specimen as per this standard are (250mmX25.4mm).
The specimens after cutting were drilled to the hole sizes of 3mm, 5mm and 7mm. The drilled composite specimen is shown in fig.2.

The specimens were tested in the ZWICK Universal Testing Machine. The fig.3 shows the stressed specimens, after applying the load. From the experiments it is found that unnotched specimen has an average breaking load of 14.66 kN with an average area of 160.11mm². The notched specimen having a hole of diameter 3 mm has an average breaking load of 11.01 kN which reduces strength by 25%. The notched specimen having a hole of diameter 5 mm has an average breaking load of 9.07 kN which reduces strength by 30%. Similarly, for 5 mm and 7 mm hole notched specimens, the strength values are reduced by 40.8% and 48.05% respectively. One can expect that due to proportional decrease in area, there will be proportional decrease in stress values. But this does not happen due to the notch sensitivity factor. As the holes are produced there will be some residual stress present in the material which is difficult to control.

3. FAILURE ANALYSIS
3.1 Point Stress Criterion

Based on the experimental values some theoretical model calculation was done and the results of these are compared here. For unnoticed specimens, the average load is found to be 15.34 kN. The average stress, \( \sigma_o \) is found to be 96.58 N/mm² for unnoticed specimen.

\[
\frac{\sigma_N}{\sigma_o} = \begin{bmatrix} K_T \\ K_T^* \end{bmatrix} 
\]

where

\[
K_T = 2 + (1 - (D/b))^3 \\
K_T^* = \frac{2}{3(1 - (D/b))} 
\]

Therefore, \( \frac{\sigma_N}{\sigma_o} = 78.06 \times 1.01 = 0.82 \)

Also,

\[
\frac{\sigma_N}{\sigma_o} = \frac{2}{2 + A_1 + 3A_1 - (K_T^* - 3)(5A_1^* - 7A_1^*)} 
\]

where

\[
K_T^* = 1 + \left[ \frac{2}{56.86} \sqrt{(3731.15 - 19.98 + 3731.15 - 399.20)} \right]^{1/2} 
\]

\[
K_T^* = 3.36 
\]

Substituting the above value in equation (3)

\[
\frac{\sigma_N}{\sigma_o} = \frac{2}{2 + A_1 + 3A_1 - (K_T^* - 3)(5A_1^* - 7A_1^*)} \frac{\sigma_N}{\sigma_o} = 0.81
\]
For Ø 5mm hole, the average stress = $\sigma_N = 69.94 \text{ N/mm}^2$. For 5mm diameter notched specimen, $(\sigma_N/\sigma_o)_{\text{theoretical}} = 0.72$ and, $(\sigma_N/\sigma_o)_{\text{experimental}} = 0.68$. For Ø 7mm hole, the average stress = $\sigma_N = 64.50 \text{ N/mm}^2$. For 7mm diameter notched specimen, $(\sigma_N/\sigma_o)_{\text{theoretical}} = 0.58$ and, $(\sigma_N/\sigma_o)_{\text{experimental}} = 0.66$.

### 3.2 Average Stress Criterion

In this failure criterion it is assumed that failure occurs when the average stress, over some distance equals the unnotched laminate strength.

$$\left\{ \frac{\sigma_N}{\sigma_o} \right\} = \left( \frac{2(1-\epsilon^2)}{(2-\epsilon^2)(1-\epsilon^4) + (K^T - 3)(\frac{\epsilon^6}{2} - \frac{\epsilon^8}{2})} \right)^{\frac{1}{2}}$$

For 7 mm diameter notched specimen, $(\sigma_N/\sigma_o)_{\text{theoretical}} = 0.63$ and, $(\sigma_N/\sigma_o)_{\text{experimental}} = 0.66$.

### 3.3 Damage Zone Criteria

A damage zone is assumed to be present in the maximum stress region of the laminate when the tensile stress reaches the tensile strength of the unnotched laminate. The DZC is simple to apply, makes excellent predictions of the strength of specimens made from laminates of different configurations.

$$\frac{\sigma_N}{\sigma_o} = \frac{w - m_2 + m_3 + m_1((w/2) - R - d^*_1)}{w - m_2 + m_3 + m_1((w/2) - R - d)}$$

where,

- $m_1 = 2 + (R/p)^2 + 3(R/p)^4 - (K^T - 3)[5(R/p)^6 - 7(R/p)^8]$
- $m_2 = 2q - (R^2/q) - (R^4/q^3) + (K^T - 3)[(R^6/q^5) - (R^8/q^7)]$
- $m_3 = 2p - (R^2/p) - (R^4/p^3) + (K^T - 3)[(R^6/p^5) - (R^8/p^7)]$
- $p = R + d_1$
- $q = w/2$

The results of these three theoretical models are compared in the table 1 & 2.

### Table 1. Comparison of experimental and theoretical model results

<table>
<thead>
<tr>
<th>Notch diameter mm</th>
<th>PSC model $(\sigma_N/\sigma_o)_{\text{theoretical}}$</th>
<th>ASC model $(\sigma_N/\sigma_o)_{\text{theoretical}}$</th>
<th>DZC model $(\sigma_N/\sigma_o)_{\text{theoretical}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.81</td>
<td>0.81</td>
<td>0.81</td>
</tr>
<tr>
<td>5</td>
<td>0.72</td>
<td>0.68</td>
<td>0.71</td>
</tr>
<tr>
<td>7</td>
<td>0.66</td>
<td>0.58</td>
<td>0.63</td>
</tr>
</tbody>
</table>

### Table 2. Percentage deviation of theoretical results of different models from experimental results

<table>
<thead>
<tr>
<th>Notch diameter mm</th>
<th>PSC model % deviation</th>
<th>ASC model % deviation</th>
<th>DZC model % deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5.56</td>
<td>1.38</td>
<td>2.78</td>
</tr>
<tr>
<td>7</td>
<td>12.00</td>
<td>4.50</td>
<td>6.06</td>
</tr>
</tbody>
</table>

In the figure 4, the hole diameters (3 mm, 5 mm and 7 mm) of the notched specimens are matched with the $(\sigma_N / \sigma_o)$ experimental values.

- The value of $(\sigma_N / \sigma_o)_{\text{experimental}}$ decreases with increase in the value of hole diameter.
- The decrease in $(\sigma_N / \sigma_o)$ is due to the decrease in cross sectional area.

![Figure 4. Comparison of $(\sigma_N / \sigma_o)_{\text{experimental}}$ with hole diameter](image)

Figure 4. Comparison of $(\sigma_N / \sigma_o)_{\text{experimental}}$ with hole diameter

The deviation of the DZC model result from the experimental value is slightly greater than that of the ASC model, but definitely it is lesser deviant than PSC model result.

![Figure 5. $(\Sigma_n / \Sigma_o)_{\text{Exp}}$ Vs various theoretical model results](image)

Figure 5. $(\Sigma_n / \Sigma_o)_{\text{Exp}}$ Vs various theoretical model results
4. CONCLUSIONS

The DZC is simple to apply, makes excellent predictions of the strength of specimens made from laminates. The DZC provides significantly improved accuracy compared with the PSC, and is at least as accurate as the ASC. The maximum stress for unnotched composite laminates will always occur at the edges, where the tensile load is applied, but the decrease in thickness reduces the strength of the specimen at the center causing it to fail. For notched specimens the residual stress along with the stress produced while applying the load causes the specimen to fail exactly at the center where the notch is produced.

REFERENCES