ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
ISSN: 1584 - 2673

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

Mouleeswaran SENTHIL KUMAR

Mechanical Engineering, PSG College of Technology, Coimbatore, INDIA

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 Isopthalic 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.

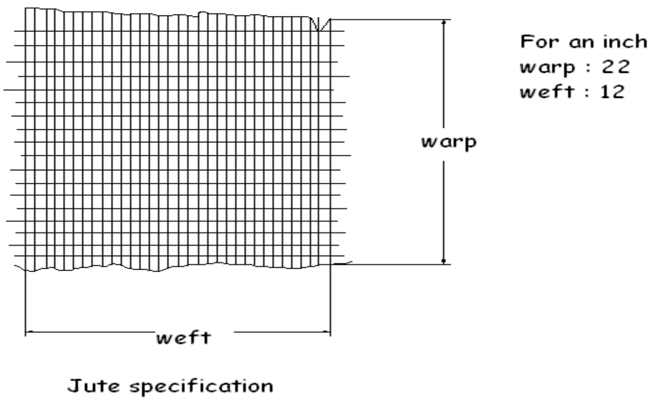

Figure 1 Specification of jute fabric

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.

Figure 2. Notched composite specimen

Figure 3. Tested composite specimens

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, σ_o is found to be 96.58 N/mm² for unnoticed specimen.

$$\frac{\sigma_N{}^{\infty}}{\sigma_o} = \left\{\frac{\sigma_N}{\sigma_o}\right\}\left\{\frac{K_T}{K_T{}^{\infty}}\right\} \tag{1}$$

where

$$\frac{K_T}{K_T{}^{\infty}} = \frac{2+(1-(D/b))^3}{3(1-(D/b))} \tag{2}$$

Therefore, $\frac{\sigma_N{}^{\infty}}{\sigma_o} = \frac{78.06}{96.58} \times 1.01 = 0.82$

Also,

$$\frac{\sigma_N{}^{\infty}}{\sigma_o} = \frac{2}{2 + A_1^2 + 3A_1^4 - (K_T^{\infty} - 3)(5A_1^6 - 7A_1^8)} \tag{3}$$

where

$$K_T^{\infty} = 1 + \left\{\frac{2}{a_{22}}\left[\sqrt{(a_{11} \times a_{22}) - a_{12}} + \frac{a_{11}a_{22} - a122}{2a_{66}}\right]\right\}^{1/2} \tag{4}$$

$$K_T^{\infty} = 1 + \left\{\frac{2}{56.86}\left[\sqrt{(3731.15) - 19.98} + \frac{3731.15 - 399.20}{28.36}\right]\right\}^{1/2}$$

$$K_T^{\infty} = 3.36$$

Substituting the above value in equation (3)

$$\frac{\sigma_N{}^{\infty}}{\sigma_o} = \frac{2}{2 + A_1^2 + 3A_1^4 - (K_T^{\infty} - 3)(5A_1^6 - 7A_1^8)}$$

$$\left\{\frac{\sigma_N{}^{\infty}}{\sigma_o}\right\} = 0.81$$

For Ø 5mm hole, the average stress = σ_N = 69.94 N / mm². For 5mm diameter notched specimen, $(\sigma_N/\sigma_o)_{theoretical}$=0.72 and, $(\sigma_N/\sigma_o)_{experimental}$ =0.68. For Ø 7mm hole, the average stress = σ_N = 64.50 N/mm². For 7mm diameter notched specimen, $(\sigma_N/\sigma_o)_{theoretical}$=0.58 and, $(\sigma_N/\sigma_o)_{experimental}$ =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.

$$\left\{\frac{\sigma_N{}^{\infty}}{\sigma_o}\right\} = \frac{2(1-\xi_2)}{(2-\xi_2^2-\xi_2^4+(K_T^{\infty}-3)(\xi_2^6-\xi_2^8))} \tag{5}$$

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

$$\frac{\sigma_N}{\sigma_o} = \frac{w-2R}{w-m_2+m_3+m_1((w/2)-R-d_1^*)} \tag{6}$$

where, $m_1 = 2 + (R/p)^2 + 3(R/p)^4 - (K_T^{\infty}-3)[5(R/p)^6-7(R/p)^8]$ (7)

$m_2 = 2q - (R^2/q) - (R^4/q^3) + (K_T^{\infty}-3)[(R^6/q^5)-(R^8/q^7)]$ (8)

$m_3 = 2p - (R^2/p) - (R^4/p^3) + (K_T^{\infty}-3)[(R^6/p^5)-(R^8/p^7)]$ (9)

$p = R + d_1$ (10)

$q = w/2$ (11)

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

Table 1. Comparison of experimental and theoretical model results

Notch diameter mm	$(\sigma_N/\sigma_o)_{practical}$	PSC model $(\sigma_N/\sigma_o)_{theoretical}$	ASC model $(\sigma_N/\sigma_o)_{theoretical}$	DZC model $(\sigma_N/\sigma_o)_{theoretical}$
3	0.81	0.81	0.81	0.81
5	0.72	0.68	0.71	0.70
7	0.66	0.58	0.63	0.62

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

Notch diameter mm	PSC model % deviation	ASC model % deviation	DZC model % deviation
3	-	-	-
5	5.56	1.38	2.78
7	12.00	4.50	6.06

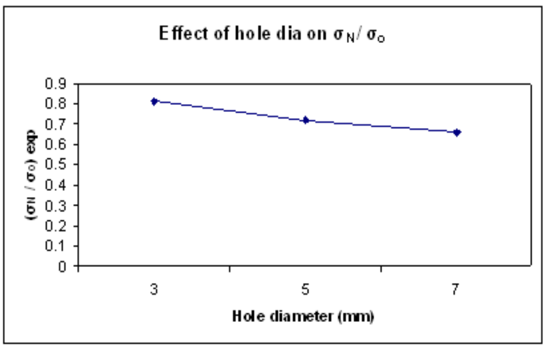

Figure 4. Comparison of (σ_n / σ_o) experimental with hole diameter

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

- The value of (σ_N / σ_o) experimental decreases with increase in the value of hole diameter.
- The decrease in (σ_N / σ_o) is due to the decrease in cross sectional area.

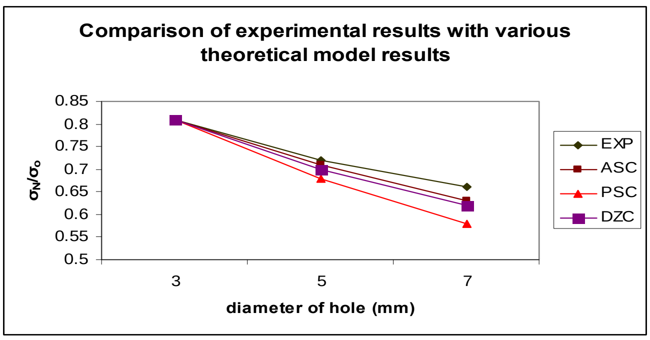

Figure 5. $(\Sigma_n / \Sigma_o)_{Exp}$ Vs various theoretical model results

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.

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

[1.] *Awerbuch, J. and M.S. Madhukar. "Notched Strength of Composite Laminates; Predictions and Experiments – A Review." Journal of Reinforced Plastics and Composites, 4:3-159 (1985)*

[2.] *Whitney,J.M. and R.J. Nuismer. "Stress fracture criteria for Laminated Composites containing stress concentrations" Journal of Composite materials. 8:253-265 (1974)*

[3.] *Nuismer, R.J. and J.M.Whitney, "Uniaxial failure of Composite laminates containing Stress Concentrations." ASTM STP 593. American Society for Testing and Materials, Philadelphia, pp 117-142 (1975)*

[4.] *Backlund, J. "Fracture analysis of Notched Composites." Computers and Structures, 13:145-154 (1981)*

[5.] *Backlund, J. and C.G. Aronsson. "Tensile Fracture of Laminates with Holes." Journal of Composite Materials, 20:259-286 (1986).*

[6.] *Karlak, R.F. "Hole effects in a related series of symmetrical laminates." Proc. 4th Joint ASM-Metallurgical Society of AIME Symposium on Failure Modes in Composites. Chicago, 1977. The Metallurgical Society of the American Institute of Mining. Metallurgical and Petroleum Engineers, Warrendale, PA. pp. 105 – 117 (1979)*

[7.] *Hashin,Z., Analysis of properties of fiber composites with anisotropic constituents, ASME J.Appl.Mech., 46, 543,1979.*

[8.] *Whitney, J.M. and Riley, M.B., Elastic properties of fiber reinforced composite materials, AIAA J., 4, 1537,1966.*

[9.] *Mechanics of Composite Materials – Autar K. Kaw, CRC Press, New York,2003.*

ANNALS OF FACULTY ENGINEERING HUNEDOARA – INTERNATIONAL JOURNAL OF ENGINEERING