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Prediction of open-hole tensile strength of unidirectional flax yarn reinforced polypropylene composite by analytical and numerical models

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Open-hole tensile strength of unidirectional flax yarn reinforced polypropylene composites has been predicted for different laminates with varying lay-up through analytical and numerical models. Point stress criterion (PSC), modified PSC and finite element modeling (FEM) have been applied to examine the effect of different open-hole sizes on the stress bearing capacity. The characteristic length (d_0) of the composites has been confirmed by PSC which depends on the specimen geometry. The modified PSC has been used with stress concentration factor, notch sensitivity factor, and exponential parameter for evaluating the open-hole tensile strength. The stress distribution and the open-hole tensile strength have also been obtained by finite element simulation. The best correlations between the experimental and predicted results have been achieved from modified PSC model than with traditional PSC and FEM models.

Keywords: Analytical and numerical modeling, Composites, Finite element model, Flax fibre, Open hole tensile strength, Point stress criterion, Polypropylene

1 Introduction

Natural fibre reinforced composites are promising candidates for industrial applications in the last few decades. In comparison with synthetic fibre reinforced composites, natural fibre reinforced composites are preferred for use in many applications due to many specific features, such as high specific strength, low density, low weight, fairly good mechanical properties, non-abrasiveness, bio-degradability, eco-friendliness, sustainability, low CO_2 emission, low cost, renewable bio-resources, etc[1,2]. Natural fibre reinforced composites have recently been used in the load-bearing structural application in automotive industry[3,4], where the use of drilled components is inevitable to accommodate joints and bolts. The stress concentration and notch sensitivity are the primary concerns while using the drilled composite components[5,6], which can be understood from the experimental tests such as tensile and flexural tests. However, these tests are time-consuming and sometimes expensive as well. Alternatively, it is possible to predict the mechanical properties of composites and other influencing factors which are responsible for the successful usage of composites with the help of various mathematical /analytical models. Linear elastic fracture mechanics (LEFM), Average stress criterion (ASC), Point stress criterion (PSC), Modified ASC and PSC are notable analytical models used for the prediction of the open-hole tensile strength of composites.

Waddoups *et al.*[7] made a first attempt to introduce LEFM model for the composite analysis which is a well-known model for homogeneous isotropic and anisotropic materials. In continuation to LEFM, Whitney and Nuismer[8] proposed another model (point and average stress criterion) for predicting the open-hole strength of composites. In this model, it has been assumed that the failure of the open-hole specimen occurs when the tensile strength of drilled sample reaches the tensile strength of undrilled sample at a particular distance from the radius (characteristic length) while applying uniform stress distribution on the radius of an open-hole. This model has assumed that the characteristic length is the material property and provides the same value for different sizes and shapes of notches. This model has also evaluated the failure of open-hole tensile samples by using the

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characteristic length and undrilled sample tensile strength. This criterion was widely accepted and used by the research community for predicting the open-hole and bolted-hole strength of the composites[9-11]. Pipes *et al.*[12] made an effort to modify the Whitney's PSC model by adding three new parameters (stress concentration factor, notch sensitivity factor, and exponential parameter assuming that the characteristic length depends on the hole radius). Hence, Pipes *et al.*[12] have proposed an equation for prediction of notched tensile strength using an exponential relationship by relating the characteristic length and the sample dimensions. Ahmed *et al.*[13] also have shown the possibility of using PSC models for natural fibre reinforced composites. Accordingly, in the present research work, PSC and modified PSC models have been employed to predict the tensile strength and characteristic length of unidirectional flax yarn reinforced polypropylene (PP) composites.

In the numerical approach, the finite element method (FEM) has been used to predict the structural properties of composites. Many researchers have examined the progressive damage of composites by FEM. Chang *et al.*[14] introduced the progressive damage modeling for the prediction of the open-hole strength of composites with the help of FEM. Simulation of notched tip crack pattern and stress distribution map was very clearly demonstrated by Kortschot and Beaumont[15].

In the present work, an attempt is also made to simulate the tensile test by FEM based commercial software (ANSYS) for observing stress distribution and predicting the maximum tensile strength of flax/PP composites. Furthermore, the results are also compared with experiments.

2 Theoretical Consideration

2.1 Point Stress Criterion Model

Whitney and Nuismer[8] have proposed the PSC model for the prediction of open-hole tensile strength of composites. This model assumes that the failure occurs when the sample reaches tensile strength (σ_{UDT}) of the undrilled sample at a fixed distance (d_0) from the edge of an open-hole when the specimen is subjected to the uniform stress (σ_y^{∞}), as shown below:

$$\sigma_y\left(x,0\right)_{x=R+d_0} = \sigma_{UDT} \quad \text{... (1)}$$

The stress distribution (σ_y) for an infinite orthotropic plate along the x-axis can be described as follows:

$$\sigma_y(x,0) = \frac{\sigma_y^{\infty}}{2}\left[2+\left(\frac{R}{x}\right)^2+3\left(\frac{R}{x}\right)^4-(K_T^{\infty}-3)\left[5\left(\frac{R}{x}\right)^6-7\left(\frac{R}{x}\right)^8\right]\right] \quad \text{... (2)}$$

Here, K_T^{∞} is the stress concentration factor for an orthotropic plate which is given as follows:

$$K_T^{\infty} = 1+\sqrt{2\left(\sqrt{\frac{E_y}{E_x}}-\nu_{yx}+\frac{E_y}{2G_{yx}}\right)} \quad \text{...(3)}$$

where E_y is the modulus of elasticity in an axial direction; E_x, the modulus of elasticity in the transverse direction; G_{yx}, the shear modulus; and ν_{yx}, the Poisson's ratio. In the PSC model, normalized notch strength of orthotropic infinite plate has been expressed by substituting Eq. (1) into Eq. (2), as given below:

$$\frac{\sigma_{OHT}^{\infty}}{\sigma_{UDT}} = \frac{2}{2+\zeta_1^2+3\zeta_1^4-\left(K_T^{\infty}-3\right)\left(5\zeta_1^6-7\zeta_1^8\right)} \quad \text{... (4)}$$

where $\zeta_1 = \dfrac{R}{\left(R+d_0\right)}$; d_0, the characteristic length in mm; and σ_{OHT}^{∞}, the tensile strength of the open-hole sample with infinite width. The equation above describes the notch strength of an infinite plate. It needs the correction factor to convert the not strength of infinite width sample to finite width sample, as given below:

$$\sigma_{OHT}^{\infty} = \left(K_T / K_T^{\infty}\right)\sigma_{OHT} \quad \text{... (5)}$$

where σ_{OHT} is the tensile strength of an open-hole sample with the finite width; and K_T, the stress concentration factor. Thus, the finite width correction factor $\left[F = \left(K_T / K_T^{\infty}\right)\right]$ can be expressed as:

$$\frac{1}{F} = \frac{K_T^{\infty}}{K_T} = \frac{3-\left(1-2R/W\right)}{2+\left(1-2R/W\right)^3}+\frac{\left(K_T^{\infty}-3\right)}{2}\left(\frac{2R}{W}S\right)^6\left[1-\left(\frac{2R}{W}S\right)^2\right] \quad \text{... (6)}$$

where

$$S^2 = \frac{\sqrt{1-8\left[\dfrac{3\left(1-{2R}/{W}\right)}{2+\left(1-{2R}/{W}\right)^3}-1\right]}-1}{2\left(\dfrac{2R}{W}\right)^2} \quad \text{... (7)}$$

where W is the width of the sample in mm. Now, Eq. (5) can be rewritten as:

$$\frac{\sigma_{OHT}^{\infty}}{\sigma_{UDT}} = F.\left(\frac{\sigma_{OHT}}{\sigma_{UDT}}\right) \quad \text{... (8)}$$

Whitney's stress criteria assumed that the characteristic length is a material property, which is fully independent of the laminate lay-up and the hole size. However, research has confirmed that the characteristic length is dependent upon the sample dimensions also. An attempt has been made in the present work to findout different values of characteristic length for holes of different sizes by PSC model. Thus, Whitney's PSC model has to be modified, and in connection to this, the d_0 value has been proposed by the exponential function, as shown below[16]:

$$d_0 = C^{-1}\left(\frac{2R}{W}\right)^m \quad \text{... (9)}$$

where C is the notch sensitivity that depends upon the sample geometry (*2R* and *W*); and *m*, the exponential parameter.

2.2 Finite Element Model

Finite element model (FEM) is used to find out an approximate solution to the boundary value problem, where the complex problem is divided into small elements and the final solution is obtained by using the numerical technique. This work has employed a composite modeling by FEM software (ANSYS 13). The 3D geometrical model was analyzed by using 4 noded SHELL181 elements with mapped and free meshes[17,18].

3 Materials and Methods

Interwoven fabric with 40/60 (flax/PP) volume fraction was used to make unidirectional flax yarn reinforced PP composites. It was processed in a hot-pressing machine at 190°C for 3 min under a pressure of 10 MPa. Different stacking sequences such as Axial (0_6), Cross-ply ($\pm45_6$), and Off-axial $(0/90/0)_S$ were used to analyze the tensile properties of composites. Stacking sequences along with fibre and matrix properties were optimised in our previous work[19,20]. Tensile tests of undrilled and open-hole samples were performed in accordance with ASTM D3039 standard by using a universal tensile testing machine (Trapezium X (AG-100 KNX)) with a testing speed of 5 mm/min. The sample dimension was 250×25×2 mm^3. Circular holes with three different diameters (4 mm, 6 mm, and 8 mm) were made on the samples used for the open-hole tensile test. Strength retention % ($\sigma_{OHT} / \sigma_{UDT}$) was used as a normalized strength for comparing samples with different hole sizes. The engineering constants of flax/PP composites were obtained from the tensile test and are given in Table 1.

4 Results and Discussion

In the analytical method, prediction of the characteristic length and the open-hole tensile strength is made. Besides, the strength retention for different laminate lay-ups has also been computed. The finite element results are also studied for comparison and verification.

4.1 PSC Analytical Model

4.1.1 Prediction of Characteristic Length

The finite width correction factors (*F*) of the samples has been obtained from Eq. (6). Consequently, the ratios of the tensile strength of the open-hole samples and the tensile strength of the undrilled samples for indefinite plate are calculated from Eq. (8). The calculated finite width correction factors and experimental variables are given in Table 2. It is found that *F* increases with the increase in diameter of a hole. The increase in *F* is 3.9% for the sample with a hole diameter of 6 mm when compared with the sample with a hole diameter of 4 mm; however, the corresponding increase in *F* is 10.8% for sample with a hole diameter of 8 mm when

Table 1 — Elastic constants of flax/PP composites

Elastic constants	Value
Modulus of elasticity in axial direction (E_y),GPa	5.76
Modulus of Elasticity in transverse direction (E_x),GPa	1.17
Shear modulus in axial direction (G_{yx}),GPa	2.02
Poisson's ratio (ν_{yx})	0.4

compared with the sample of hole diameter 4 mm. This clearly illustrates the dependence of the *F* on the diameter of the hole[21,22]. Finally, the characteristic length has been calculated by using Eq. (4) and is provided in Table 3. It is found that d_0 increases with the increase in diameter of the hole for axial composites which is also confirmed by the other study[23]. The increase in d_0 is 28.8% and 60.9% for samples with hole diameters of 6 mm and 8 mm respectively as compared to the 4 mm diameter samples. The laminatelay out can clearly be attributedto the consistent increase in d_0. However, for the cross-ply composites, the dependence of d_0 on the diameter decreases. Specifically, d_0 decreases by 8.4% and 6.2% for composites with 6 mm and 8 mm holes respectively as compared to 4 mm hole. Further, it is noteworthy that in the case of off-axial composites, the value of d_0 decreases steeply with an increase in hole diameter; more specifically; d_0 decreases by 28.6% and 50.3% for composites with 6 mm and 8 mm holes respectively in comparison with the 4 mm hole.

The dependence of characteristic length can thus be clearly attributed to the diameter of the hole as well as to the composite laminate lay-up. Additionally, it is also evident from the results that d_0 value is highest for cross-ply laminated composites by nearly two-fold as compared to the other two laminated composites. Based on above observations, it is evident that the characteristic length is not constant as stated in Whitney's traditional PSC Model[8]. An average value of d_0 has been calculated for samples of different hole sizes and applied in Eq. (4). On the other hand, modified PSC model with an exponential parameter has been formulated by using Eq. (9). The input values of *C* and *m* for Eq. (9) are calculated from the experimental results so as to predict the tensile strength of the open-hole composites by the modified PSC model. It has been calculated from a line arregression using the least squares method.

Table 2 — Experimental variables and finite width correction factor

Hole diameter (2R), mm	2R/W	S^2	S	1/F	F
4	0.16	2.27	1.50	0.97	1.02
6	0.24	2.01	1.41	0.94	1.06
8	0.32	1.94	1.39	0.88	1.13

R–Radius of open-hole; W–Width of the sample in mm; S–Intermediate value for finding F value; S^2–Square of S; and F–Finite width correction factor

4.1.2 Prediction of Tensile Strength of Open- hole Composite

The tensile strength of the open-hole composite has been calculated from Eq. (5) where the value of σ_{OHT}^{∞} has been derived from Eq. (4). In addition, the relative error between the actual and the predicted tensile strength of the open- hole composite has been calculated and is given in Table 3. It has been seen that σ_{OHT} reduces as the diameter of hole increases for all laminate lay-ups, both experimentally and analytically (PSC)[15,24,25]. The detailed analysis of σ_{OHT} obtained from experiment shows that it decreases by 6% and 12.2% for axial composite laminates respectively for 6 mm and 8 mm hole samples as compared to 4 mm hole sample. Similarly, σ_{OHT} decreases by 7.7% (6 mm hole) and 14.3% (8 mm hole) for cross-ply composite laminates when compared with 4 mm hole sample. Analogously, it reduces by 5.5% (6 mm hole) and 27.4% (8 mm hole) for off-axial composite laminates in comparison with 4 mm hole sample. Similarly, PSC method shows that σ_{OHT} reduces by

Table 3 — Prediction of characteristics length and tensile strength of an open hole composite by traditional PSC

Laminate lay-up	Experimental results			PSC (Point stress criterion)				
	σ_{UDT} MPa	Hole diam mm	σ_{OHT} MPa	σ_{OHT}^{∞}	$\frac{\sigma_{OHT}^{\infty}}{\sigma_{UDT}}$	d_0	Predicted σ_{OHT} MPa	Relative error %
Axial	80.18±3.01	4	71.36±1.63	73.35	0.91	3.40	73.48	2.97
		6	67.09±2.26	71.71	0.89	4.38	69.83	4.08
		8	62.68±2.95	70.95	0.88	5.47	66.25	5.70
Cross-ply	47.15±2.17	4	46.40±3.10	47.69	1.01	10.96	43.51	6.23
		6	42.82±2.83	45.77	0.97	10.04	42.89	0.16
		8	39.76±1.95	45.00	0.95	10.28	42.14	5.99
Off-axial	27.96±1.48	4	25.83±1.07	26.55	1.02	5.69	23.14	10.41
		6	24.40±1.30	26.08	1.06	4.06	21.92	10.16
		8	18.75±1.40	21.22	0.75	2.83	20.72	10.51

5% (6 mm hole) and 9.8% (8 mm hole) in comparison with 4 mm hole sample for axial composite laminates, and it reduces by 1.4% (6 mm hole) and 3.1% (8 mm hole) in comparison with 4 mm hole sample for cross-ply composite laminates. It also reduces by 5.3% (6 mm hole) and 10.5% (8 mm hole) in comparison with 4 mm hole sample for off-axial composite laminates. These findings also show that σ_{OHT} strongly depends on the diameter of the hole as well as the composite laminate lay-up. The relative error between experimental and analytical (PSC) methods does not show any particular trend. For axial and cross-ply arrangements, the variation in σ_{OHT} is relatively small however for off-axial it is large. This finding limits the use of PSC criteria for predicting the experimental results. Hence, the dependence of laminate lay-up on the tensile strength of the open-hole composites is established. The tensile strength of the open-hole composite by modified PSC was computed from Eq. (8) for characteristic length and is given in Table 4. This tensile also follows the same trend as followed by traditional PSC, but it shows comparatively less relative error than the PSC model. Analogous to the results given in Table 3, the findings in Table 4 illustrate that the experimental results of σ_{OHT} for axial, cross-ply, and off-axial composite show a decrease in σ_{OHT} by 6% (6 mm hole) and 12.2% (8 mm hole); 7.7% (6 mm hole) and 14.3% (8 mm hole); and 5.5% (6 mm hole) and 27.4% (8 mm hole) respectively as compared to 4 mm hole samples of respective composite laminates. Similarly, analytical results by modified PSC of σ_{OHT} for axial, cross-ply, and off-axial composite show a decrease in σ_{OHT} by 5.3% (6 mm hole) and 10.4% (8 mm hole); 5.8% (6 mm hole) and 12% (8 mm hole); and 4.5% (6 mm hole) and 22% (8 mm hole) respectively in comparison to 4 mm hole samples of receptive composite laminates. The influence of the diameter of the hole and the composite laminate lay-up on σ_{OHT} is also visible from these findings. The relative error between experimental and analytical modified PSC result points to a comparable agreement between σ_{OHT} for all laminate arrangements. Additionally, it is also obvious that modified PSC is better than PSC criteria.

4.2 Analysis of FEM Results

The tensile strength and stress distribution of flax/PP composites have been studied by employing FEM. The tensile strength results for the open-hole samples with different laminate lay-up are obtained by considering the stress distribution. According to the stress distribution plot, even though none of the principal stresses surpasses the yield stress, it is possible that the yielding (failure) of material takes place due to the combination of the principal stresses. Comparison of the experimental and the simulated tensile test results is given in Table 5. The relative error between the experimental and FE simulated results is maximum for axial composite laminates (12%, 11%, and 14% for 4mm, 6 mm and 8 mm hole composite laminates respectively). However, the relative error is very small for cross-ply composite laminates and it is low for off-axial composite laminates.

Analogous to Tables 3 and 4, it is observed from Table 5 that σ_{OHT} reduces as the diameter of the hole

Table 4 — Prediction of tensile strength of an open hole composite by modified PSC

Laminate lay-up	Experimental results			Modified PSC	
	Hole diameter (2R) mm	2R/W	σ_{OHT} MPa	Predicted σ_{OHT} MPa	Relative error %
Axial	4	0.16	71.36±1.63	71.24	0.16
	6	0.24	67.09±2.26	67.43	0.51
	8	0.32	62.68±2.95	63.85	1.87
Cross-ply	4	0.16	46.40±3.10	45.55	1.83
	6	0.24	42.82±2.83	42.89	0.15
	8	0.32	39.76±1.95	40.10	0.86
Off-axial	4	0.16	25.83±1.07	24.20	6.31
	6	0.24	24.40±1.30	23.10	5.33
	8	0.32	18.75±1.45	18.88	0.68

Table 5 — Prediction of tensile strength of undrilled and an open hole composites by finite element modeling (ANSYS)

Laminate lay-up	Experimental results		ANSYS simulation		
	Hole diam mm	σ_{OHT} MPa	Tensile force N	Predicted σ_{OHT} MPa	Relative error %
Axial	0	80.18±3.01	3675.89	80.32	0.17
	4	71.36±1.63	3271.53	62.80	12.0
	6	67.09±2.06	3116.86	59.58	11.19
	8	62.68±2.95	2895.02	53.90	14.00
Cross-ply	0	47.15±2.17	2533.88	46.43	1.52
	4	46.40±3.10	2201.08	45.45	2.04
	6	42.82±2.83	2155.33	41.85	2.26
	8	39.76±1.95	1829.92	40.15	0.98
Off-axial	0	27.96±1.48	1305.54	28.83	3.11
	4	25.83±1.07	1292.96	23.41	9.36
	6	24.40±1.30	1227.54	23.65	3.07
	8	18.75±1.45	935.63	18.46	1.54

increases for all composite laminate lay-up, both by experiment and by FE simulation. Additionally, it is also clearly visible that σ_{OHT} remains highest for all open-hole composite laminate lay-up. Detailed study shows that simulation results of σ_{OHT} in comparison to 4 mm hole samples of respective composite laminates reduces for all composite laminate lay-up by 5.1% (6 mm hole) and 14.2% (8 mm hole) for axial composites; 7.9% (6 mm hole) and 11.7% (8 mm hole) for cross-ply composites; and 1% (6 mm hole) and 21.1% (8 mm hole) for off-axial composites. Effect of hole diameter and laminate lay-up on the σ_{OHT} is also seen in the simulation results. Based on the relative error between experiment and simulation, it is found that the FE based simulation matches cross-ply composite laminate experiments most accurately and axial laminate least accurately. In a nutshell, the effect of composite laminate lay-up on σ_{OHT} is clearly observed.

The stress distributions of one sample around the open-hole are illustrated in Fig. 1. The open-hole composite sample simulation exhibits the highest stress concentration in the vicinity of the open-hole [Fig. 1(a)] at opposite ends of a hole along the transverse direction of the sample. The simulated images follow the similar damage propagation pattern like experimental ones [Fig. 1 (b)].

It can be seen from the FEM of axial laminates (4 mm, 6 mm, and 8 mm hole) that maximum stress occurs consistently along the transverse direction of the composite laminated sample in the vicinity of the

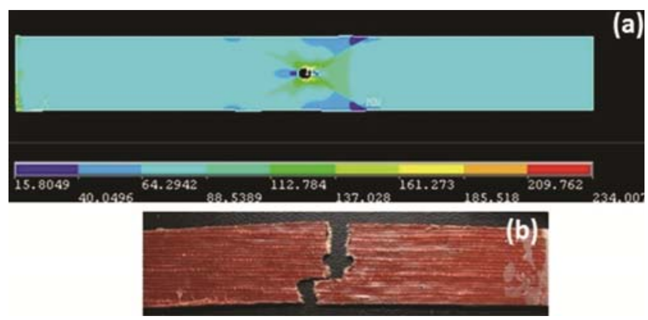

Fig. 1 — Comparison of stress distribution between finite element model (a), and experimental sample (b), for axial laminates 4 mm hole sample

hole as a consequence of stress concentration. Further more, the symmetric stress regions are found to be originated at 45º from the edge of the hole. Similar stress behavior is observed for all the composites with holes; however, it can clearly be seen that stress concentration at the lateral hole edge increases with increase in hole diameter. Additionally, it is also found that the maximum stress magnitude reduces with an increase in the hole diameter. On the other hand, FEM analysis of cross-ply composite laminates (4 mm, 6 mm, and 8 mm hole) also consistently shows maximum stress along the transverse direction of samples in the vicinity of the hole which is clearly attributed to the stress concentration.

It is also found that the same kind of failure pattern appears in the simulation of cross-ply laminates and experimental tests. The symmetric stress regions are found along a 45º direction from the edge of the hole. Similar stress behavior is found for all composites with holes; however, one can clearly see that the stress concentration at the lateral hole edge increases with increase in hole diameter. It is also found that the maximum stress magnitude is highest for 6 mm hole laminate, intermediate for 8 mm hole laminate and lowest for laminate with 4 mm hole. The comparison of results of cross-ply composite laminates with axial composite laminates reveals that there is a drastic reduction in the maximum stress magnitude. The FEM and experimental results respectively of off-axial composite laminates (4 mm, 6 mm, and 8 mm hole) exhibit stress behavior similar to the cross-ply composite laminates. However, the stress magnitude is reduced by nearly 50% for all cases.

Analogous to axial laminates, the stress distribution is similar for all cross-ply composite laminate lay-up; however, it strongly depends on the hole size. Significant observation of FE simulation results is that, for three hole sizes, the maximum stress value is found for composite with 6 mm hole, an intermediate stress value is found for composite with 8 mm hole and a least maximum stress value is found for composite with 4 mm hole.

4.3 Comparison of Tensile Strength of Open-hole Results of Various Models

A comparison of experimental and predicted strength retention for axial, cross-ply, and off-axial laminate lay-up is given in Fig. 2. It is observed that an axial composite laminate's experimental, traditional PSC, and modified PSC results are closely correlated with each other, and hence show very small differences. However, FE results differ significantly due to the idealization of the simulation environment. For cross-ply composite laminates, experimental, modified PSC, and FE results are very close to each other; however, the result of the traditional PSC is significantly lower for 4 mm hole laminate and higher for 8 mm hole laminate. Significantly different results are found for off-axial composite laminates. The findings have revealed that the experimental, traditional PSC, modified PSC, and FE results vary significantly for 6 mm hole laminate. The strength retention percentage is maximum by FE and minimum by traditional PSC method. For 4 mm hole laminate, FE, and experimental results match well and the other two results deviate to a larger extent. On the contrary, for 8 mm hole laminates; FE, and traditional PSC results match with each other and are higher; however, experimental, and modified PSC results match with each other and are lower.

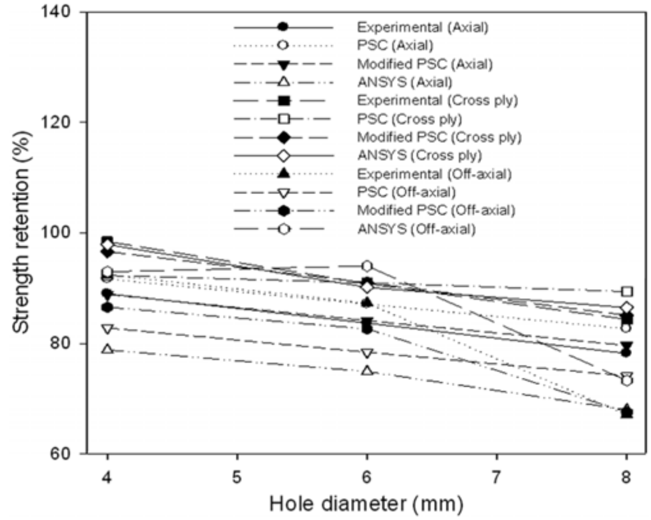

Fig. 2 — Comparison of experimental and predicted strength retention for axial, cross-ply and off-axial laminate lay-up

5 Conclusion

In the analytical model, characteristic length (d_0) of flax reinforced composites having different laminate lay-ups and three different diameter open holes have been calculated by traditional PSC and modified PSC. The characteristic length is found to have the highest value for cross-ply composite laminates with 4 mm hole size as compared to other laminate lay-ups, which confirms that d_0 is dependent upon the sample dimensions and laminate lay-up configurations. The predicted tensile results of PSC model show the relative error with reference to experimental value up to 10%. However, the modified PSC relative error is limited within 6%. The maximum relative error is found to be 14 % for the open-hole tensile strength prediction from FEM. Finally, this work concludes that the best predicted results are obtained with modified PSC model for flax/PP composites.

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