A STUDY ON THE OPEN HOLE TENSION OF THE UNIDIRECTIONAL FLAX YARN REINFORCED COMPOSITES

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Abstract
Growing interest of the global community towards the recyclable products would provide the wonderful opportunities for natural fiber reinforced composites. Natural fiber composites are having many advantages compared to the petroleum based fiber reinforced composites such as recyclability, low cost, low density, good specific mechanical properties, low CO_2 emission, biodegradability, easy incineration at the end of the life cycle, less irritation to the skin and inner respiratory system. Natural fiber reinforced composites are mostly used in the field of automobiles, in which door panel, rear window shelves, spare wheel covers, car roofs are noticeable application of the natural fiber composites. Furthermore, the natural fiber composites are also having the applications in civil construction and noise absorbing panels. In this work, pretreated flax and polypropylene yarns are used as a weft and warp respectively for the preparation of interwoven fabric. Finally, unidirectional flax fiber reinforced composites are produced from interwoven fabric stacking by hot pressing machine, where the flax and Polypropylene act as a reinforcement and matrix respectively. The notched composite laminate is prepared by drilling the hole with the diameters of 2 and 4 mm. The influence of the different stacking sequence and different hole diameter on the tensile strength of notched and unnotched specimen are explained in detail.

1 Introduction

Drilled hole on composites plates for joints and bolts are unavoidable for structural application which will induce the discontinuity and strength reduction in the composite structure. It is used to happen because of the stress concentration development around the notched area. In the last 30 years, a wide range of research is being carried out to propose the optimized design for notched sample. Notch sensitivity describes how sensitive laminate is against notch and geometrical discontinuity. It has been influenced by many factors such as, laminate thickness, laminate ply number, ply orientation angle, notch diameter and shape, material thermal expansion, material constituents and their interfacial strength [1, 2, 3, 4].

Many researchers so far investigated the performance and failure trend of notched laminates made from synthetic fiber reinforcement. Pinnell has investigated the effect of reinforcement and matrix on the notched strength of graphite fiber reinforced composites. This work concludes that the high strength fiber with thermoplastic matrix is having the better resistance against tensile fracture for notched and unnotched laminates compared to the thermo set composites [1]. Stacking sequences and laminate thickness have significant influence on the notched strength value of composites. O'Higgins et.al reported that higher number of 0º ply occupied and thickness reduced laminates are showing the good performance in open hole

strength test [5]. 45º ply dominated composites can protect the sample from delamination failure during shear coupling effect and also provides the balanced layup structure with higher strength value [6, 7]. Chang et al. observed the propagation of the damage from open hole to off axis layer through matrix failure in quasi isotropic laminates. Finally, this work concludes the ply orientation is playing a vital role in the fracture mode of notched samples [8].
Harris and Morris found that quasi isotropic laminates are showing the decreasing notched strength while increasing the sample thickness. Moreover, fracture surface of thin laminate is not more uniform and non self similar compared to the thick laminates [9].
Many works has revealed the effect of hole diameter and hole shape on the strength of composites. Whitney and Nuismer studied the open hole strength of notched laminates with the diameter range from 0 to 1 inches. Notched strength of sample is decreased with increasing the hole diameter [10]. Sristava and Kumar have reported the effect of circular or elliptical hole size and specimen width on the fracture behavior of different kind of woven fabric composites. They predicted that the charactertistic length in point stress criterion is mainly depends on hole size and width of the plate [11].
Chang et al. tried to enhance the woven fabric laminate notched strength by using drilled and moulded-in circular holes. It is shown that the moulded-in holes samples exhibits 2.7–38.3% higher failure strengths than those of drilled specimens [12]. Woven E-glass fiber reinforced composites notched strength and damage or crack development with various types of notches has been studied by Khashaba .This work concluded that load–elongation curve of notched and unnotched glass fiber reinforced polyester (GFRP) specimens have a nonlinear behavior and lowest notched strength is obtained for single edge notch specimens [13].
At the junction, application of natural fiber composites in the automobile sector has extensively increased in the last few decades [14]. It is mainly due to the following promising benefits from natural fiber, such as low density, easy process ability, renewable raw material sources and low cost [15, 16]. Flax fiber is found as a most suitable candidate for the structural application because of their higher strength and stiffness compared to other natural fiber [17]. There is a lot of unanswered question about the damage propagation mode of notched natural fiber composites during structural application. This work try to reveal the above problem by introducing different kind of notch in the unidirectional flax reinforced composites during tensile test, and also discuss the effect of different stacking sequence on the notched sample.

2 **Materials and testing methods**

2 .1Materials

Interwoven fabric was made from flax and polypropylene yarn for composites production. 105.4 Tex count flax and 72.2 Tex count polypropylene yarn was used as a weft and warp respectively for interwoven fabric production. Flax ring spun yarn and polypropylene draw textured yarn were provided by Tai Yuang Textile and Sanyo Textile Company respectively. Fabric particulars are given in Table 1.

Table 1. Fabric particulars of flax/PP interwoven fabric

Fabric nomenclature	**Warp Yarn**	**Weft Yarn**
Material	Polypropylene draw textured yarn	Flax ring spun yarn
Threads/cm	22	13
Yarn count (Tex)	72.2	105.4
Fabric tensile strength (N)	970.36	532.37

Fabric elongation (%)	12	2

2.2 Methods

Prior to composites preparation, fabric was preheated by hot oven at 160 ºC for 30 min. It will be help to avoid the fabric shrinkage and place the fabric in same position during composites production. It is named as heat setting process of interwoven fabric. Preheated fabric was placed in hot pressing machine for single lamina production and it was pressed at 180ºC for 1 min. Composite laminate was prepared by ºcomprising six lamina at 190 ºC for 3 min under 100 kg/cm^2 pressure. The different stacking sequence was used to prepare the composite laminates including (0_6), $(\pm 45_6)$, $(0/90/0)_S$, which was found as a good stacking sequence from our previous work. Consequently, the notched laminates were prepared by drilling the hole with 2 and 4 mm diameter.

2.3Tensile test of composites

Tensile strength of notched and unnotched laminates was measured by universal testing machine (Trapezium X (AG-100 KNX)). Testing standard was obtained from ASTM D-D3039. Average of tensile test results were calculated from five samples for each combination. Sample size and testing speed were used as follows: 250×25×2mm^3 and 5 mm/min. Drilled hole was made at the center of the specimen for notched sample.

3 Results and discussion

3.1 Effect of different orientation on tensile properties

Type of orientation	Unnotched strength (σ_{UN}) (MPa)	Notch diameter (mm)	Notched strength (σ_N) (MPa)	σ_N/σ_{UN} (%)
(0_6)	71.87	2	66.78	93
		4	57.53	80
$(0/90/0)_S$	57.23	2	51.87	91
		4	48.33	84
$(\pm 45_6)$	47.27	2	31.21	66
		4	25.57	54

Table 2. Tensile strength of unnotched and notched sample for different orientation

Tensile strength of different orientation laminate is given in Table 2. Tensile strength of notched and unnotched sample is having higher value for (0_6) parallel oriented laminates. It is possible due to the axial arrangement of flax yarn in the composite laminates. Cross ply laminates ($(0/90/0)_S$) is also exhibiting the moderate tensile strength for notched and unnotched condition. Here, tensile strength was contributed by the combination of 0º and 90º laminates. $(\pm 45_6)$ is helped to understand the shear behavior of flax yarn reinforced composites. Tensile values of 45º samples are very lower than other combination which

confirms the non availability of yarn reinforcement in the axial direction. It gives the shear properties of flax yarn reinforced composites. Normalized strength (%) of Parallel and cross laminated notched sample is around 80-93%. It confirms that notch is insensitive for (0_6) and $(0/90/0)_s$ laminates. But, $(\pm 45_6)$ oriented notched laminates is having the normalized strength (%) between 54-66 %, which shows higher sensitivity towards failure. This result confirms that the importance of different stacking sequence on the composite laminate notched strength.
Moreover, it helps to understand the notched natural fiber reinforced composite behavior during tensile test. It is important because the drilling hole in the composite is unavoidable during the structural application.

3.2Effect of different hole size on tensile properties

The effect of different hole diameter on notched strength is illustrated in Figure 1. Notched strength results explains that the increase in hole diameter has showing the drastic reduction in tensile strength value. Here, Notch strength failure is mainly attributed by stress concentration around the hole. More specifically, 4 mm diameter notches are obtained very low strength for different orientation. This is mainly due to the higher notch sensitivity development on the sample and it can be caused by larger discontinuity created from drilled hole.

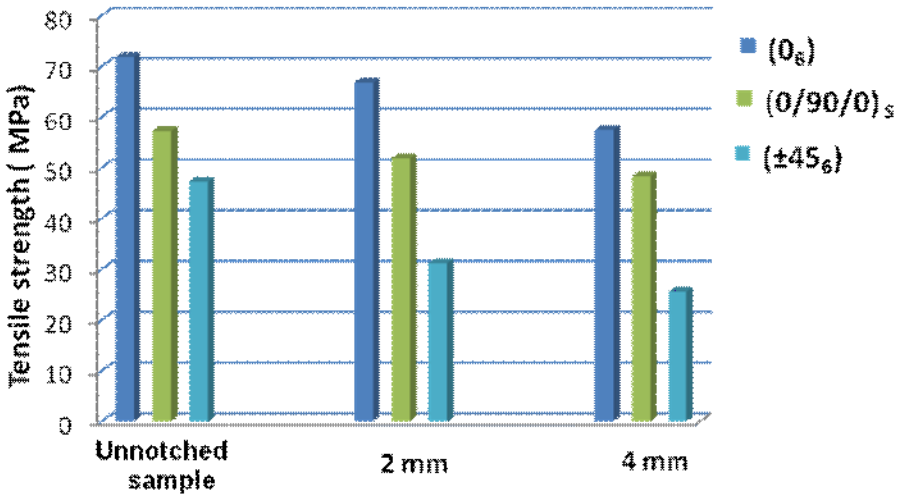

Figure 1. Tensile strength of notched sample for different hole diameter

3.3 Fractography analysis of damaged sample

Figure 2 shows the damaged sample of different layup laminates with different diameter hole. Damaged sample confirms the stress development and failure around the notch. There is no delamination occurred around the damaged area in the tested sample. Unexpected and invisible damage is also not found from different kind of the sample. The sample was mostly end with fiber breakage during tensile test. When the stress is reached to the maximum, the sample starts matrix crack and tend to form the failure around the notched portion.

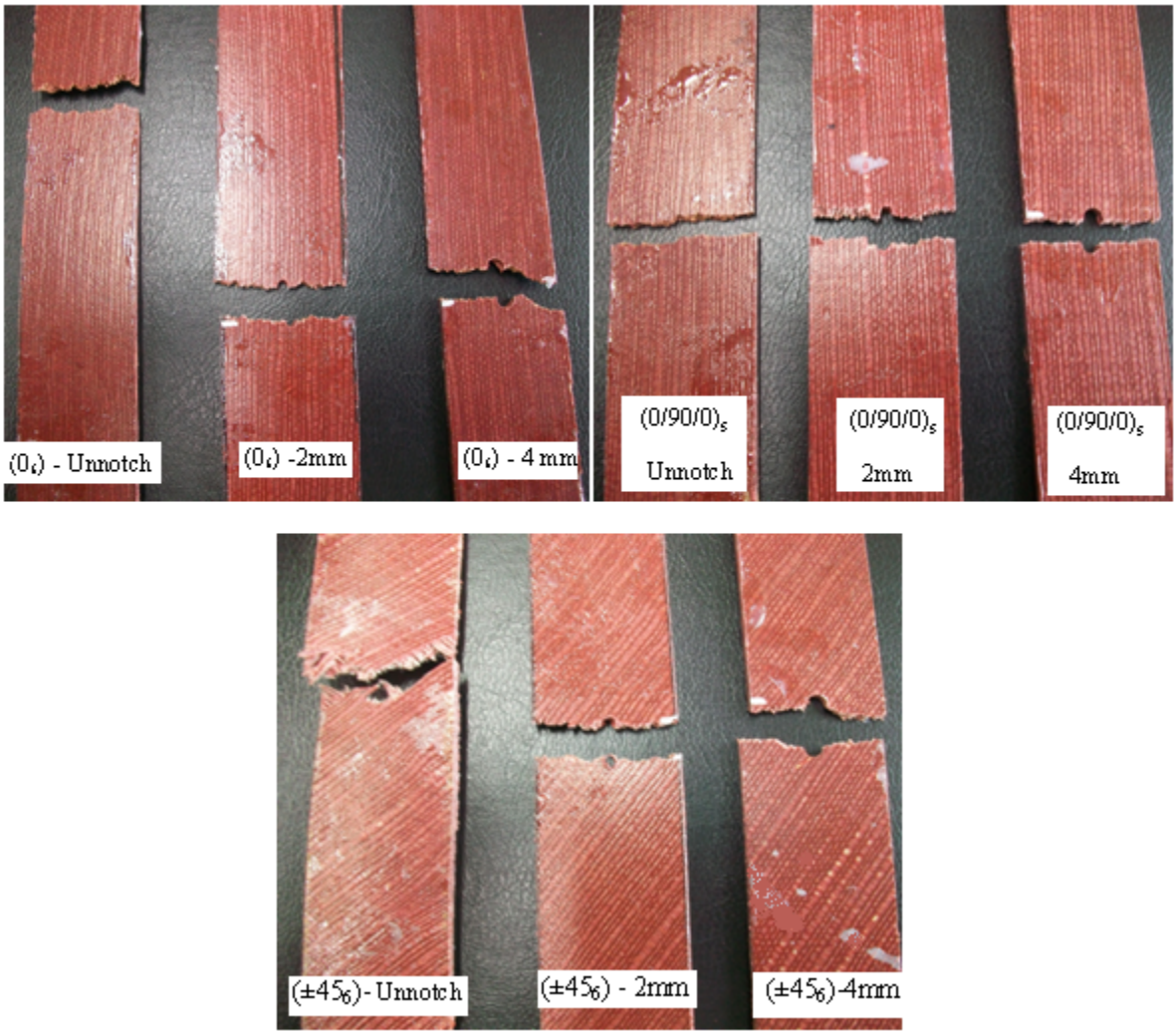

Fig.2. A photo image of tensile damaged sample for different orientation direction with different notch diameter.

4. Conclusion

Flax/PP unidirectional yarn reinforced composites were produced from interwoven fabric. The effect of different orientation and drilled hole on the tensile strength was explained in detail.

Experimental results were concluded that the different orientation has significant influence on the tensile properties of laminates. Highest strength and lowest strength were observed for (0_6) and ($\pm45_6$) oriented laminates respectively. Sample with large hole diameter (4mm) was found very low performance during tensile test. It has also been concluded that the stress concentration development is very high for the large diameter hole laminates. Finally, this work suggested that the (0_6) oriented flax reinforced laminates is recommended for structural application such as automobile and construction sector.

Further work is underway to improve the interface behavior of laminates with chemical and physical treatment. The different type of model will be used to simulate the experimental results of notched sample.

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