Jurnal
Teknologi

Full Paper

Effect of Hybridization on Open-Hole Tension Properties of Woven Kevlar/Glass Fiber Hybrid Composite Laminates

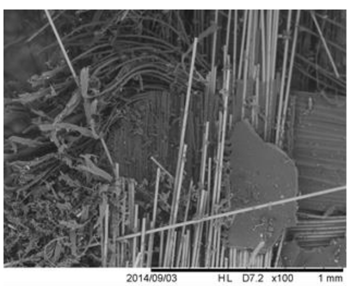
Article history
Received
15 February 2015
Received in revised form
30 April 2015
Accepted
31 May 2015

Norazean Shaari[a,b], Aidah Jumahat[a*], Shahrul Azam Abdullah[a], Ahmad Zariff Hadderi[a]

[a]Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
[b]Faculty of Engineering, Universiti Selangor, Bestari Jaya Campus, Jalan Timur Tambahan, 45600 Bestari Jaya, Selangor, Malaysia

*Corresponding author
aidahjumahat@salam.uitm.edu.my

Graphical abstract



Abstract

Hybrid laminates consisting of woven Kevlar/glass fiber composite plies were studied in terms of their residual tensile strength, stiffness and fracture surface. Residual tensile strength and stiffness were determined from the open hole tension test according to ASTM D5766. The laminates of Kevlar fiber reinforced polymer (KFRP), glass fiber reinforced polymer (GFRP) and hybrid of Kevlar-glass fiber reinforced polymer (KGFRP) were fabricated using a vacuum bagging process. Three different ratios of Kevlar to glass fiber plies were prepared in this study which were 20:80, 50:50, and 80:20. Results showed that hybrid laminate consisting of 80:20 Kevlar to glass fiber plies, produced higher residual tensile strength and stiffness when compared to the other hybrid system. Furthermore, strength and stiffness of hole specimens were reduced within 50-63% when compared to unhole specimens due to existence of the hole. In addition, the effect of adding nanosilica to the hybrid system was also studied. 5 wt% of nanosilica was added to the hybrid composite laminates and results showed that higher tensile strength and stiffness was observed in GFRP and 20:80 KGFRP specimens, while the tensile strength was decreased with an increased number of Kevlar fiber. This research was conducted as there are limited number of studies that have been done on the tensile strength of woven hybrid composite laminates so far, especially on hybridization of Kevlar and glass fiber with consideration on the effect of hole and addition of nanofillers.

Keywords: Kevlar fiber, glass fiber, hybrid composite, open-hole tension, nanosilica

1.0 INTRODUCTION

Hybrid composites are usually prepared by incorporating two or more fibers into a single matrix. The fibers can be either synthetic fibers such as glass fiber, carbon fiber and Kevlar or natural fibers such as Kenaf, jute, coir, banana, hemp, pineapple leaf, abaca, sisal and coconut fiber [1][2]. In this study, Kevlar fiber and glass fiber are incorporated into epoxy matrix to investigate their effect of hybridization on the mechanical properties of FRP composites. In addition, a preliminary study on the effect of nanofillers on the properties of composite laminates is also conducted by adding nanosilica into the epoxy matrix. Kevlar fibers are noted for their extremely high level of toughness and stiffness, resistance to impact damage, low density and flexible but sensitive to moisture and relatively expensive while glass fiber is relatively cheap, good resistance to water and environment but high density [3][4][5]. Both fibers are usually incorporated into a toughened epoxy matrix because these fibres could provide a good lateral support and load transfer, gives better resistance to microbuckling, delays crack initiation and propagation and provides a unique balance of chemical and mechanical properties combined with good processing versatility [6][7]. Therefore, hybridization is possible to design the material to better suit various requirements with reduced costs [4].

There are a number of researches conducted on studying the effect of hybridization on mechanical properties of composite materials. Haery *et al*. [8] studied the influence of hybridization on tensile strength of woven fabric hybrid C-glass/3K-carbon epoxy composite laminates. It was observed that hybridization of carbon fiber to glass fiber improved the tensile strength of C-glass/epoxy composite and reduced the rupture strain of the composites. Guru and Hari [7] investigated the effect of three different angle-ply orientation that are 0°/90°, 45°/45°and 30°/60° on tensile strength, tensile modulus, and peak load of Kevlar/glass fiber hybrid composites. From the result, angle ply orientation of 0°/90° showed significant increase in tensile properties as compared to the other orientations. The effect of stacking sequence on the strength of woven fabric glass/carbon epoxy composite laminate comprising of various ratios of glass to carbon were investigated by Zhang *et al*. [9]. They found that tensile strength of glass/carbon hybrid composite (50:50) was improved by placing the carbon layers at the exterior or by placing both fibers alternately. A study conducted by Pandya *et al*. [10] on hybrid composites which were made using 8H satin weave T300 carbon fabrics and plain weave E-glass fabrics with epoxy resin showed that tensile strength and ultimate tensile strain increased by placing glass fibers in the exterior and carbon fibers in the interior.

Effect of nanofillers on mechanical properties of composite materials also has been studied by some researchers. Nanoclays, carbon nanotubes (CNT) and nanosilica are the examples of nanofillers usually added to the matrix materials. Tang *et al*. [11] added 10 wt% and 20 wt% of nanosilica into carbon fiber/epoxy composite. Results indicated that addition of nanosilica has increased the transverse tensile strength and mode I interlaminar fracture toughness but decreased the interlaminar shear strength and mode II interlaminar fracture toughness with increasing of nanosilica content. Jumahat *et al*. [12] conducted a study by adding 3.6 vol% - 19.7 vol% of nanosilica into unidirectional carbon fiber/epoxy composite materials. Compressive test results showed that the addition of nanosilica improved the compressive modulus and compressive strength of the unidirectional carbon laminates without any significant reduction in failure strain. Nanosilica was also incorporated into a neat epoxy polymer by Jumahat *et al*. [6] to study the effect on tensile properties. Tensile modulus and tensile strength were found to increase by 38% and 24%, respectively by addition of 25 wt% of nanosilica.

In this study, open-hole tension properties of woven Kevlar/glass fiber hybrid composite laminates were investigated. The performance of Kevlar and glass fiber reinforcement and Kevlar-glass fiber hybrid composite specimens via open-hole tension test were evaluated. Both hole and unhole specimens were prepared to determine the effect of hole to the tensile properties of the composite laminates. In addition, a preliminary study on the effect of nanosilica addition on the woven Kevlar/glass fiber hybrid composite laminates was also investigated. Here, 5 wt% of nanosilica was added into the composite laminates.

2.0 EXPERIMENTAL

2.1 Materials

The composite specimens were fabricated using Miracast 1517 A/B resin system supplied by Miracon Industry Sdn. Bhd., 2443 twill weave Kevlar produced by Fibre Glast Developments Corp. and CWR200 plain weave glass fiber as the reinforcement material. Nanopox F400 nanosilica manufactured by Nanoresins, Germany was used as the nanofiller material.

2.2 Specimen Preparation

An average of 2.5 mm specimen thickness of Kevlar fiber reinforced polymer (KFRP), glass fiber reinforced polymer (GFRP) and hybrid of Kevlar-glass fiber reinforced polymer (KGFRP) composites were fabricated using vacuum bagging process. For unmodified composite laminates, epoxy resin and hardener were mixed in a ratio of 3.7:1.3 while for nanomodified epoxy resin; resin and nanosilica were mixed using vacuum mechanical stirrer for an hour before mixing with hardener. For a preliminary study, only 5 wt% of nanosilica was added into the composite system. Three different ratios of Kevlar to glass fiber plies were prepared in this study: 20:80, 50:50, and 80:20 in which the stacking sequences of the laminate are Kevlar fiber in the interior while glass fiber at the exterior. All specimens prepared were cured at room temperature for 24 hours followed by post curing up to 120ºC for about 11 hours and 30 minutes. Then, the specimens were cut into a dimension of 300 mm x 36 mm. Finally, 6 mm hole were drilled on the specimens using vertical drilling machine at a speed of 3000 rpm.

2.3 Open-Hole Tension Test

Tensile test was performed according to ASTM D5766 using INSTRON 3382 Universal Testing Machine. An extensometer with a gauge length of 25 mm was attached to the center of the specimen to measure the strain response. Test was conducted at a cross-head speed of 2 mm/min. For the unhole specimens, tabs were required in order to avoid slippage of the material with the machine's gripper during the testing.

2.4 Scanning Electron Microscope (SEM)

The fractured surface of the specimen was examined using SEM (Hitachi TM 3000) table top microscope manufactured by Hitachi High Technologies, Japan. The specimens were cut into 30 mm x 36 mm and were sputter coated with gold to produce electrically conductive specimens using SC7620 QUORUM sputter coater.

3.0 RESULTS AND DISCUSSION

3.1 Tensile Strength and Stiffness of Unmodified Composite Specimens

Figure 1 and Figure 2 show the results of tensile strength and tensile stiffness for both hole and unhole specimens. From the graphs, KFRP shows the higher tensile strength and stiffness as compared to GFRP. Therefore, hybridization of Kevlar fiber to glass fiber also increases the tensile strength and stiffness of the hybrid composites. Tensile strength of both hole and unhole specimens of 50:50 Kevlar/glass fiber hybrid composite was increased above 60% compared with that of GFRP composite laminates while for the tensile stiffness, an increment of approximately 40% was observed for both type of specimens. Similar finding was obtained by Haery *et al*. [8] which reported that the tensile strength of hybrid composite laminate is higher than that of glass composite laminate. With increasing plies of Kevlar fiber added to glass fiber, the tensile strength and stiffness was increased.

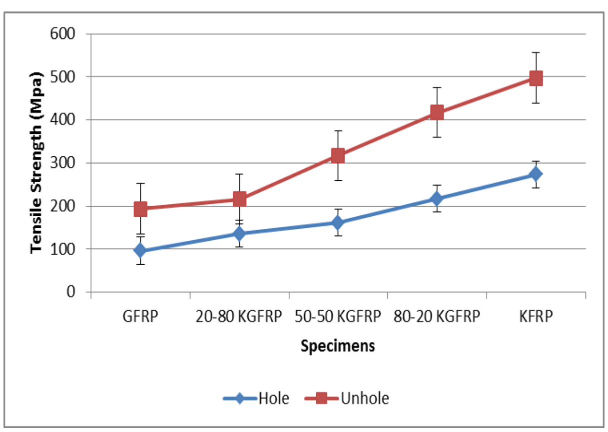


Figure 1 Effect of hybridization Kevlar fiber to glass fiber on tensile strength

This result was supported by Talib *et al*. [13], which stated that Kevlar has more resistance to tensile loading while Guru and Rao[1] reported that Kevlar/glass hybrid laminate can withstand more load and improved flexural strength as compared to carbon/glass hybrid system.

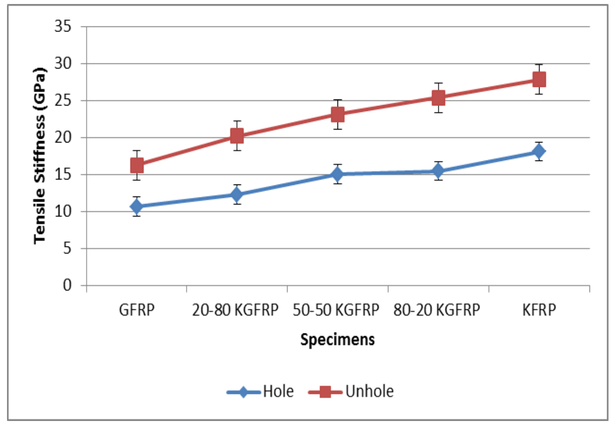


Figure 2 Effect of hybridization Kevlar fiber to glass fiber on tensile stiffness

According to the graphs, hole affected the strength and stiffness of these composites. The unhole strength is seen to be significantly greater than the open hole strength for all laminate specimens. Hole made to the specimen reduced the tensile strength of all specimens within 50-63% as in Table 1. The open hole acts as sufficient stress riser which make the damage zone developed from the hole. According to Salleh *et al*. [14], tensile strength of unhole specimens were greater than hole specimens and the strength is decrease with the increasing of hole sizes. This result also supported by Zheng *et al*. [15], which stated that the open hole tensile strength of unhole specimens are higher as compared to hole specimens.

Table 1 Tensile strength data of unmodified specimens

Specimens	σ_{hole} (MPa)	σ_{unhole} (MPa)	$\sigma_{hole/unhole}$ (%)
GFRP	96.156	193.473	49.7
20:80 KGFRP	135.243	215.652	62.7
50:50 KGFRP	161.409	317.413	50.9
80:20 KGFRP	216.796	416.915	52.0
KFRP	273.613	497.478	55.0

3.2 Scanning Electron Microscope

Microscopic observation was carried out to observe and analyze the condition of the specimen fractured surface. All the specimens were viewed closely at the area of the hole and also the fiber at the fractured line. From the observation, generally the fracture of glass fiber takes place in a brittle fracture mode while Kevlar fiber showed a ductile fracture surface which agrees with the positive hybrid effect in open hole tension test. As Kevlar has higher ductility, it tends to deform and has higher strain under tensile load. Therefore, the fiber of Kevlar could withstand greater tensile stress by deforming until fracture. Meanwhile, the glass fiber shows brittle fracture. It means that, the glass fiber absorbs little energy and fractured with little deformation until failure. In addition, it was observed that the total failure of hybrid laminate can occur by any combination of the primary modes of failure that are fiber pull out, debonding, fiber breakage, and matrix fracture as showed in Figure 3. Low bond strength between matrix and glass fiber is expected since only glass fiber showed debonding and fiber pull out failure mode. On the other hand, higher bond strength between matrix and Kevlar fiber were observed due to ductile fiber breakage of Kevlar fiber. The failure characteristics changed from fiber pull out to fiber breakage with increasing plies of Kevlar fiber in the hybrid system.

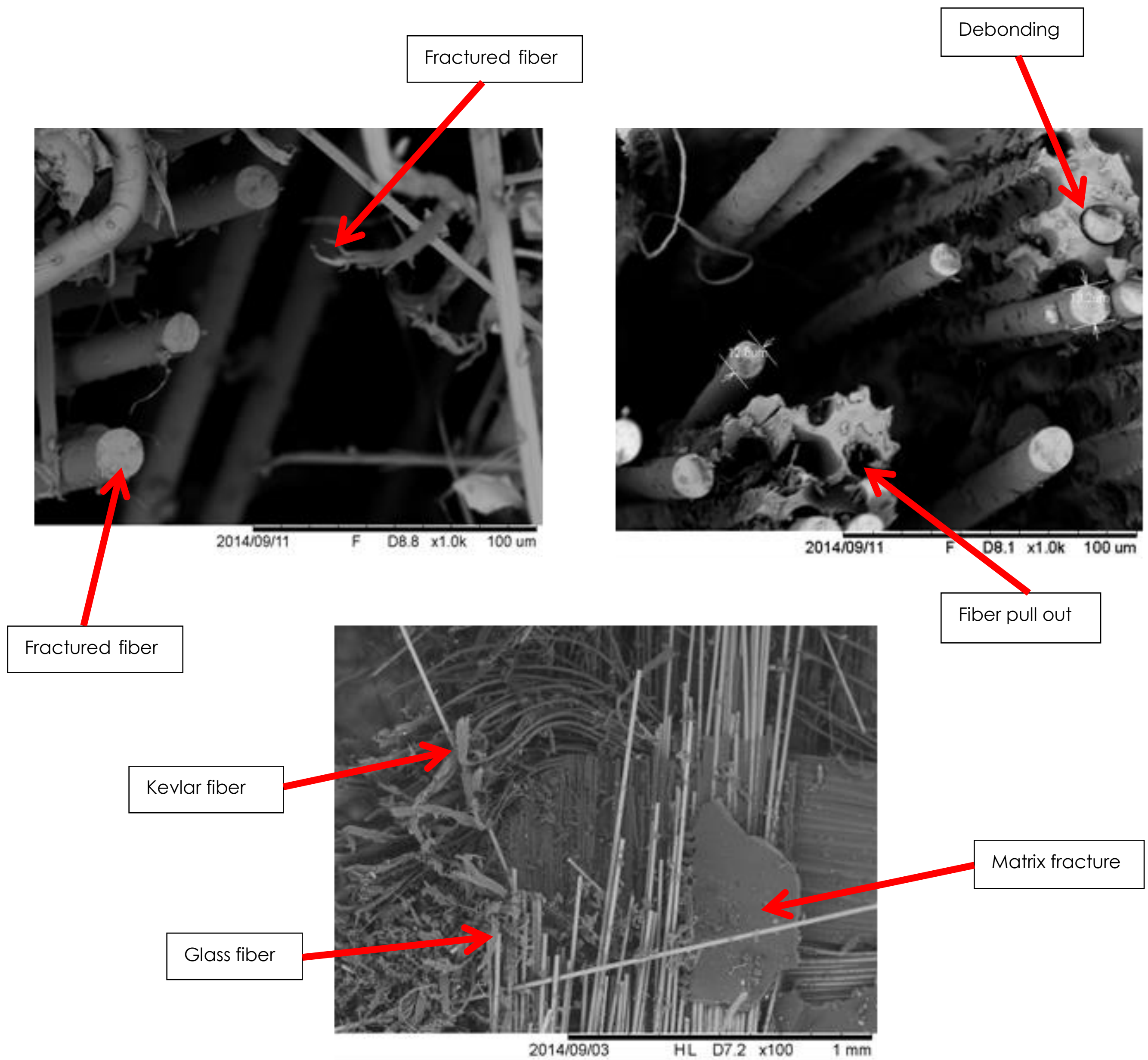


Figure 3 Microscopic observation of fractured surface of Kevlar/glass fiber hybrid composite laminates

3.3 Tensile Strength and Stiffness of Nanomodified Composite Specimens

A preliminary study on the effect of nanosilica addition to the hybrid composite laminates was also conducted in this study. Results of tensile strength, tensile stiffness, and tensile strength ratio between hole to unhole specimens are tabulated in Table 2. According to the results, the addition of 5 wt% nanosilica has increased the tensile strength and tensile stiffness of both hole and unhole of GFRP and 20:80 KGFRP specimens as compared to the unmodified specimens. Tensile strength of hole specimens have increased about 23% and 10% for GFRP and 20:80 KGFRP, respectively while for unhole specimens only slight increment was noticed that are between 2-7%. However, for other system with increasing number of Kevlar plies, tensile strength was lower than the unmodified specimens. In this condition, addition of nanosilica into the epoxy resin may hinder the wetting process, thus affecting the fiber-matrix bonding. Since, Kevlar fiber has lower moisture resistant than glass fiber, it require more matrix or resin for high wettability. However, the existence of nanosilica was hindered the wetting process, and cause less resin to be bonded or wetted the fiber, thus lower the tensile strength. Since in tensile loading, load transfer is focus more on the fiber than matrix, therefore fiber pull out may tends to occur. Besides that, results also showed that tensile strength of hole specimens were found to decrease within 57-68% than unhole specimens which are slightly higher if compared to unmodified specimens.

Table 2 Tensile properties of nanomodified composite specimens

Specimens	Tensile Strength, σ (MPa)		Tensile Stiffness (GPa)		$\sigma_{hole/unhole}$ (%)
	Hole	Unhole	Hole	Unhole	
GFRP	118.709	206.911	13.73	19.46	57.4
20:80 KGFRP	148.831	219.577	12.38	20.59	67.8
50:50 KGFRP	187.924	286.338	16.84	17.75	65.6
80:20 KGFRP	192.556	337.587	12.43	26.50	57.0
KFRP	207.711	360.570	15.61	24.30	57.6

4.0 CONCLUSION

The tensile strength and stiffness properties of glass and Kevlar fiber reinforced polymer composite laminates were investigated. Experimental results showed that hybridization of Kevlar fiber to glass fiber has increased the tensile strength and stiffness of glass fiber reinforced polymer. Microscopic observation of fractured specimens showed that the ductility of Kevlar fibers gave them the ability to deform and stretch under tensile load before failure. Since the presence of hole acts as a sufficient stress riser, hole specimens have lower tensile strength and stiffness compared to unhole specimens. The unhole specimens possessed about double the tensile strength before fractured. The existence of the hole on the specimen increased the stress concentration which caused the damage zone to develop from the hole. Preliminary study on the effect of nanosilica on the tensile properties of composite specimens indicated that a system with more glass fiber plies showed an increment of tensile strength while composite specimens with more Kevlar fiber plies had low tensile strength. Most of the composite system showed an increment in tensile stiffness with the addition of nanosilica. This preliminary results would be used as a reference for future study on the effect of nanosilica to the hybrid system.

Acknowledgement

The authors would like to thank Research Management Institute (RMI) UiTM, Ministry of Education Malaysia and Institute of Graduate Studies (IPSIS) for the financial supports. The research is conducted at the Faculty of Mechanical Engineering, Universiti Teknologi MARA (UiTM), Malaysia under the support of Fundamental Research Grant Scheme (FRGS) no: 600-RMI/FRGS 5/3 (145/2014) and Principal Investigator Support Initiative (PSI) no: 600-RMI/DANA 5/3/PSI (337/2013).

References

[1] Guru Raja, A. N. and Hari Rao, M. N. 2013. Hybridization Effect on Flexural Properties of Epoxy Based Woven Carbon/Glass And Kevlar/Glass Composites. *Int. J. Curr. Res.*

[2] Sapiai, N., Jumahat, A. and Hakim, R. N. 2014. Tensile and Compressive Properties of Hybrid Carbon Fiber/Kenaf Polymer Composite. *Adv. Environ. Biol.* 8(8): 2655-2661.

[3] Shaari, N., Jumahat, A., Yahya, K. H. and Sulaiman, M. F. 2014. Impact Resistance of Woven Fiber Reinforced Polymer Composites. *Adv. Environ. Biol.* 8(8): 2662-2668.

[4] Fu, Y. W., Shao-yun, Lauke, Bernd, Mader, Edith, Yue, Chee-Yoon, Hu, Xiao and Mai. 2001. Hybrid Effects on Tensile Properties of Hybrid Short-Glass-Fiber- and Short-Carbon-Fiber-Reinforced Polypropylene Composites. *J. Mater. Sci.* 36: 1243-1251.

[5] Peters, S. T. 1998. Ed. *Handbook of Composites*.

[6] Jumahat, A., Soutis, C., Abdullah, S. A. and Kasolang, S. 2012. Tensile Properties of Nanosilica/Epoxy Nanocomposites. *Procedia Eng.* 41: 1634-1640.

[7] Guru Raja, A. N., , Hari Rao, M. N. 2013. Effect of an Angle-Ply Orientation on Tensile Properties of Kevlar / glass Hybrid Composites. *Int. J. Theor. Appl. Res. Mech. Eng.* 3: 63-67.

[8] Haery, H. a., Zahari, R., Kuntjoro, W. and Taib, Y. M. 2012. Tensile Strength of Notched Woven Fabric Hybrid Glass, Carbon/Epoxy Composite Laminates. *J. Ind. Text.* 43(3): 383-395.

[9] Zhang, J., Chaisombat, K., He, S. and Wang, C. H. 2012. Hybrid Composite Laminates Reinforced with Glass/Carbon Woven Fabrics for Lightweight Load Bearing Structures. *Materials & Design*. 36: 75-80.

[10] Pandya, K. S., Veerraju, C. and Naik, N. K. 2011. Hybrid Composites Made of Carbon and Glass Woven Fabrics Under Quasi-Static Loading. *Mater. Des.* 32(7): 4094-4099.

[11] Tang, Y., Ye, L., Zhang, D. and Deng, S. 2011. Characterization of Transverse Tensile, Interlaminar Shear and Interlaminate Fracture in CF/EP Laminates with 10wt% and 20wt% Silica Nanoparticles in Matrix Resins. *Compos. Part A Appl. Sci. Manuf.* 42(12): 1943-1950.

[12] Jumahat, A., Soutis, C., Jones, F. R. and Hodzic, A. 2010. Improved Compressive Properties of a Unidirectional CFRP Laminate using Nanosilica Particles. *Advanced Composites Letters.* 19(6): 204-207.

[13] Talib, A. R. A., Ramadhan, A. A., Rafie, A. S. M. and Zahari, R. 2013. Influence of Cut-out Hole on Multi-Layer Kevlar-29 / Epoxy Composite Laminated Plates. *J. Mater.* 43: 89-98.

[14] Salleh, Z., Berhan, M. N., Hyie, K. M., Taib, Y. M., Kalam, A. and Roselina, N. R. N. 2013. Open Hole Tensile Properties of Kenaf Composite and Kenaf/Fibreglass Hybrid Composite Laminates. *Procedia Eng.* 68: 399-404.

[15] Zheng, Y., Cheng, X. and Yasir, B. 2012. Effect of Stitching on Plain and Open-hole Strength of CFRP Laminates. *Chinese J. Aeronaut.* 25(3): 473-484.