Jurnal Teknologi

Full Paper

Impact Resistance Properties of Kevlar/Glass Fiber Hybrid Composite Laminates

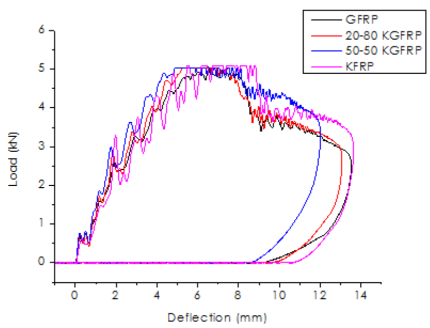
Article history
Received
15 february 2015
Received in revised form
30 April 2015
Accepted
31 May 2015

Norazean Shaari[a,b], Aidah Jumahat[a*], M. Khafiz M. Razif[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

In this paper, the impact behavior of Kevlar/glass fiber hybrid composite laminates was investigated by performing the drop weight impact test (ASTM D7136). Composite laminates were fabricated using vacuum bagging process with an epoxy matrix reinforced with twill Kevlar woven fiber and plain glass woven fiber. Four different types of composite laminates with different ratios of Kevlar to glass fiber (0:100, 20:80, 50:50 and 100:0) were manufactured. The effect of Kevlar/glass fiber content on the impact damage behavior was studied at 43J nominal impact energy. Results indicated that hybridization of Kevlar fiber to glass fiber improved the load carrying capability, energy absorbed and damage degree of composite laminates with a slight reduction in deflection. These results were further supported through the damage pattern analysis, depth of penetration and X-ray evaluation tests. Based on literature work, studies that have been done to investigate the impact behaviour of woven Kevlar/glass fiber hybrid composite laminates are very limited. Therefore, this research concentrates on the effect of Kevlar on the impact resistance properties of woven glass fibre reinforced polymer composites.

Keywords: Kevlar fiber reinforced polymer (KFRP), glass fiber reinforced polymer (GFRP), hybrid composites, impact test, polymer composite

1.0 INTRODUCTION

Many studies were conducted to investigate the impact behaviour of fiber reinforced composites due to the increasing demand of these materials in the automotive, maritime, aviation, infrastructure, military, petroleum and sport sectors [1][2]. Most of the studies were focused on reinforcing single synthetic or natural fiber such as carbon fiber, glass fiber, Kevlar fiber, Kenaf, jute, hemp, abaca, sisal and many more to the polymer matrix.

However, in order to obtain new properties, several researchers studied on hybridizing fibers into polymer matrix. Fibers can be hybridized between synthetic fibers such as glass/graphite fibers [3], Kevlar/glass fibers [2][4][5][6] or carbon/glass fibers [7][8], or between natural fibers such as banana/sisal fibers [9], empty fruit bunch/jute fibers [10] and many more. Study also conducted on hybridizing synthetic fiber with natural fiber such as short banana/glass fibers [11], basalt/carbon fibers [12] or coconut/glass/Kevlar fibers [13]. In this study, two synthetic fibers that are Kevlar and glass fibers were hybridized as reinforced materials. Kevlar/glass fiber reinforced hybrid composites are frequently used as lightweight materials in marine applications, sporting equipment and military structures [14].

Gustin et al. [15] studied the effect of hybridizing Kevlar fiber to carbon fiber on the impact behaviour of the sandwich composites. The results concluded that adding Kevlar into carbon fiber has improved the impact properties of carbon and maintaining the high stiffness. Low velocity impact response of carbon fiber and S2-glass fiber was studied by Hosur et al. [8]. Results indicated that hybridization of S2-glass to carbon fiber improved the load carrying capability of hybrid composites as compared to carbon fiber reinforced polymer with slight reduction in stiffness. Park and Jang [5] investigated the impact behaviour of four-layer composites of Kevlar-29/S2-glass fiber hybrid composite through the analysis of delamination area. The research revealed that position and surface treatment of Kevlar layer influenced the impact energy and delamination area of hybrid composites. Higher impact energy and delamination area was observed when Kevlar layer was at the back surface while in surface-treated composites, position of Kevlar layer had a slight effect on the impact energy of hybrid composites.

In addition, Evci and Gulgec [6] compared the impact properties of three different types of composites, that are unidirectional E-glass, woven E-glass and woven aramid. Results showed that woven fiber has better impact resistance as compared to unidirectional fiber. This is because damage development in the woven composites was hindered within the fabric cells formed by the weft and warp yarns. Therefore further development outside the cell zone could not be obtained. Aramid fiber was also known to has better resistance to impact damage compared to glass fiber.

Recent study on mechanical behaviour of Kevlar plain fabric and glass/Kevlar hybrid fabric reinforced epoxy polymer were performed by Valenca et al. [2]. The study concluded that Kevlar/glass hybrid composites showed better results on specific mechanical strength, as well as bending and impact energy.

In this study, the performance of interlaminated twill weave Kevlar-49/plain weave C-glass fiber hybrid composites, in terms of the impact behaviour, was investigated via drop weight impact test. Further evaluation on damage pattern and depth of penetration were also performed to support the impact test results.

2.0 EXPERIMENTAL

2.1 Materials And Specimen Preparation

Composite laminate was fabricated from 2443 twill weave Kevlar-49 produced by Fibre Glast Developments Corp. and CWR200 plain weave C-glass fiber as the reinforcement materials and Mocrete BJC 39 resin system supplied by Morstrong Industry Sdn. Bhd as the matrix material. The properties of fibers and resin used can be referred in [1].

An average of 5±0.2 mm specimen thickness of four different types of composite laminates with different ratios of Kevlar to glass fiber (0:100, 20:80, 50:50 and 100:0) were fabricated using vacuum bagging method. Hybrid specimens were arranged according to the following stacking sequences: Kevlar fiber in the interior while glass fiber in the exterior. All specimens were cured at room temperature for 24 hours. Then, specimens were cut into a dimension of 100 mm x 100 mm for drop weight impact test. Table 1 presents the basic properties and specification of each composite specimens.

2.2 Physical And Mechanical Tests

All tests were performed in the Faculty of Mechanical Engineering, Universiti Teknologi MARA, Malaysia. Drop weight impact test was performed using Instron Dynatup 8250 Drop Weight Impact Tester according to ASTM D7136. The drop tower is equipped with 16 mm in diameter of hemispherical tip impactor weight 5.5 kgs and the drop height measure 0.85 m resulting in a kinetic energy of 45.9 J. Constant gravitational speed was approximately 3.9 m/s. Five specimens were tested for each specimen type.

After the impact test, depth of penetration test and x-ray tests were also carried out in order to support the drop weight impact test results. Depth of penetration test was carried out using Coordinate Measuring Machine (CMM) model Beyond 707. CMM is a fully robotic computerized system which is supported by pneumatic system. It can be controlled by using the coordinate in three axes which are X, Y and Z.

Specimen was placed under the tip of the machine measured 1 mm in diameter on two plates by not disturbing the penetrated area. The image of the penetrated parts was taken using a digital camera. X-ray test was also performed to view the internal damage propagation and area of the specimen. Phoenix x-ray model NDT/analyser M225 was used to perform the test with scale of 2000µm.

Table 1 Basic properties and specification of composite specimens

Composite specimen	Average thickness (mm)	Average weight (g)	Average density (g/cm³)	Average hardness (HRR)	Layup
GFRP	4.8	70.4	1.586	114.68	20 GF
20-80 KGFRP	4.8	63.4	1.331	95.68	8GF/4KF/8GF
50-50 KGFRP	5.1	66.3	1.289	89.38	5GF/10KF/5GF
KFRP	4.8	53.7	1.109	75.95	16 KF

Note: Density and hardness data were taken from hardness and density tests conducted based on ASTM785 and ASTM792.
GF denotes glass fiber while KF denotes Kevlar fiber.

3.0 RESULTS AND DISCUSSION

3.1 Drop Weight Impact Test

Low-velocity impact response of all composite laminates was evaluated using an instrumented impact testing machine at constant nominal impact energy, E_i = 45.9 J. Transient response of each laminates was recorded in terms of load, energy and deflection. Load and energy versus time response and load–deflection responses were plotted from representative specimen of each laminates. Figure 1 shows load and energy versus time responses for each laminate system while load-deflection plots are shown in Figure 2. Incipient damage load, P_I, is the first failure or damage point that can be identified by the first sudden load drop cause by interface failure or matrix cracking near the back face of the composite laminate. Peak load, P_L, represents the maximum load value that a composite laminate can withstand, under a particular impact level before undergoing major damage [16].

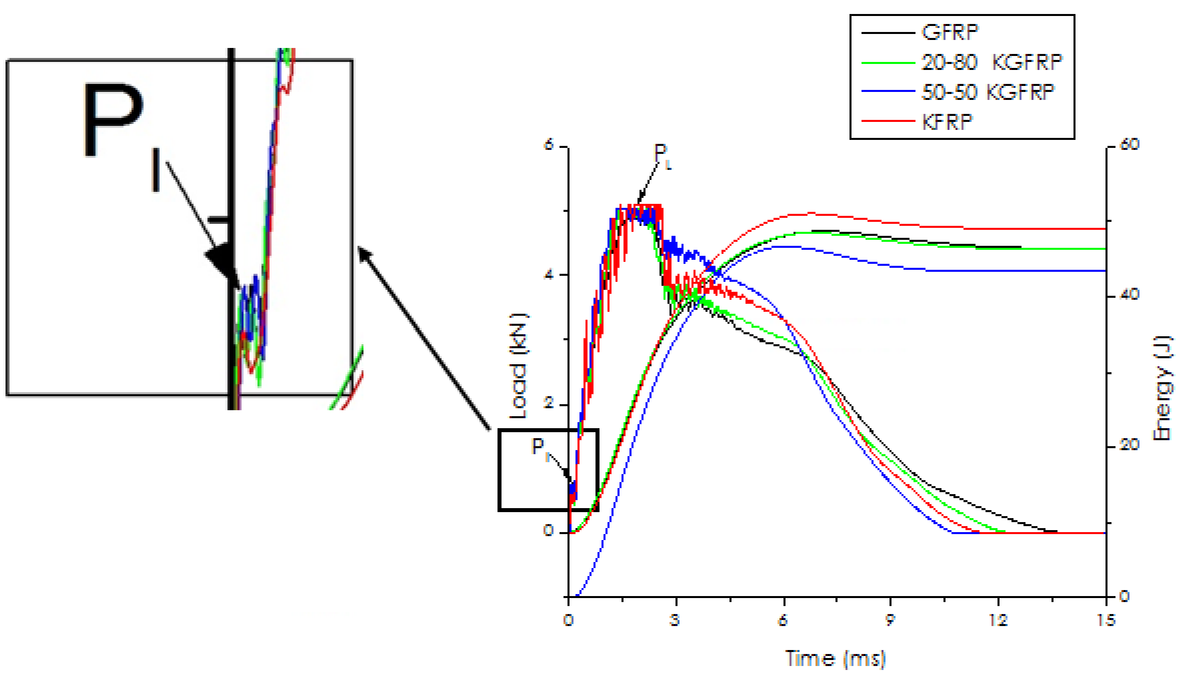


Figure 1 Load and energy versus time response for four types of composite laminates

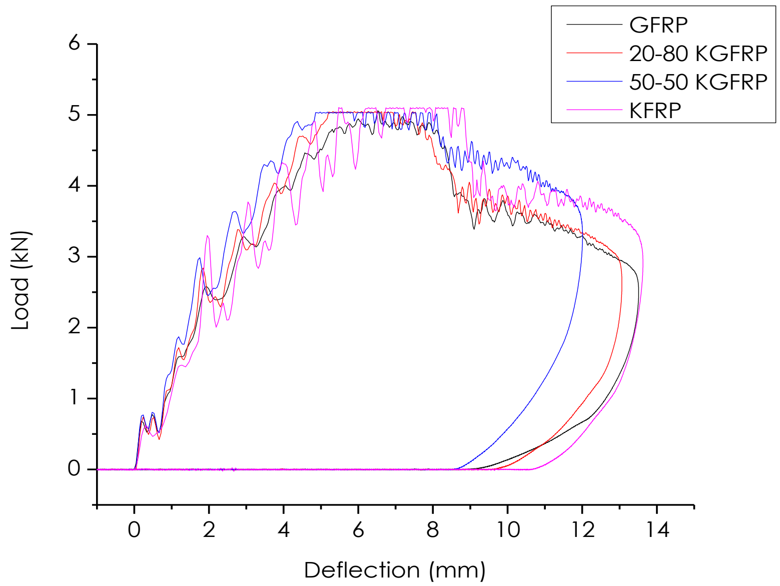


Figure 2 Load versus deflection response for four types of composite laminates

Peak load, deflection at peak load, energy to peak load, impact energy, absorbed energy and damage degree were presented in Table 2. The absorbed energy, E_a is the energy absorbed by the specimen due to the formation of damage and the friction between impactor and specimens. It is determined from the difference between total energy and energy at peak load [8][17]. From the table, it is noticed that the addition of Kevlar fiber to glass fiber has increased the peak load insignificantly and decreased deflection at peak load. These results indicate that addition of Kevlar fiber will increase the load carrying capability and resistance to deformation with slight reduction in stiffness. These observations match to the results obtained by Naik et. al [18] in the study of glass/carbon/epoxy hybrid composite.

Table 2 Parameters obtained from impact test for GFRP, KFRP and KGFRP hybrid composites.

Composite specimen	Peak load (kN)	Deflection at peak load (mm)	Energy to peak load (J)	Impact Energy, E_i (J)	Absorbed energy, E_a (J)	Damage Degree
GFRP	5.023	6.964	22.668	45.752	21.358	0.467
20-80 KGFRP	5.047	6.056	18.324	45.820	26.512	0.579
50-50 KGFRP	5.042	5.572	16.605	45.711	27.507	0.602
KFRP	5.103	5.434	14.664	45.932	32.542	0.708

In this research work, glass fiber with high inplane properties and Kevlar fiber which provide higher impact resistance were incorporated in the same laminate of hybrid composites. Kevlar fibers also known to have higher strain to failure in tension when compared to glass fibers. Therefore, from the results, it was observed that the absorbed energy for KFRP laminates was the highest as compared to GFRP with above 50% of increment, indicating that KFRP was able to absorb more energy upon impact. Since Kevlar fiber was well known as the good impact resistance material, thus hybridising glass fiber with Kevlar fiber has increased the impact resistance of the hybrid composite. Similar finding was reported by Winkel and Adams in their study [19]. Damage degree is define as the ratio of absorbed energy to impact energy, E_a/E_i. Damage degree is use to assess the damage accumulated by the materials [12].

From Table 2, damage degree increases with the addition of Kevlar fiber into the composite system, thus disclosed the positive influence of hybridizing Kevlar fiber to glass fiber, which improves the impact energy absorption. Sarasini et al [12] discussed the similar finding their paper of hybridizing basalt fiber to carbon fiber.

During impact event, energy is absorbed in the form of elastic deformation, plastic deformation and/or through formation of new surfaces during failure. However, in composite materials, there is very little or no plastic deformation occur [8][16]. Therefore, impact energy is absorbed through both elastic deformation and creation of new surface of damage. Various failure modes such as matrix cracks and delamination may occur during the creation of new surfaces. Usually, impact failure is initiated as matrix crack, propagate towards the interface of the laminates and growths as delamination.

3.2 Damage Pattern

Figure 3 shows visual observation of the front and back face of the damage laminates for all four different types of composite specimen. From the observation, all specimens show almost similar damage pattern at the back face with delamination clearly seen in GFRP and hybrid specimens. However for front face, different damage patterns were observed. Large damage area around the impacted surface was observed in GFRP specimen and the damage area was observed to decrease with the increasing of Kevlar fiber, suggesting that Kevlar fiber tends to absorb more energy. KFRP composite laminate shows small damage area at impacted surface; however the brittle aspect of the epoxy matrix looks visible by the bright tonalities (cross-shaped cracks) as seen in Figure 3 (front face-KFRP). This confirmed that the damage or failure mode is different for different fibers, therefore, explain the better effect of Kevlar fiber to the impact strength of the hybrid composite laminate.

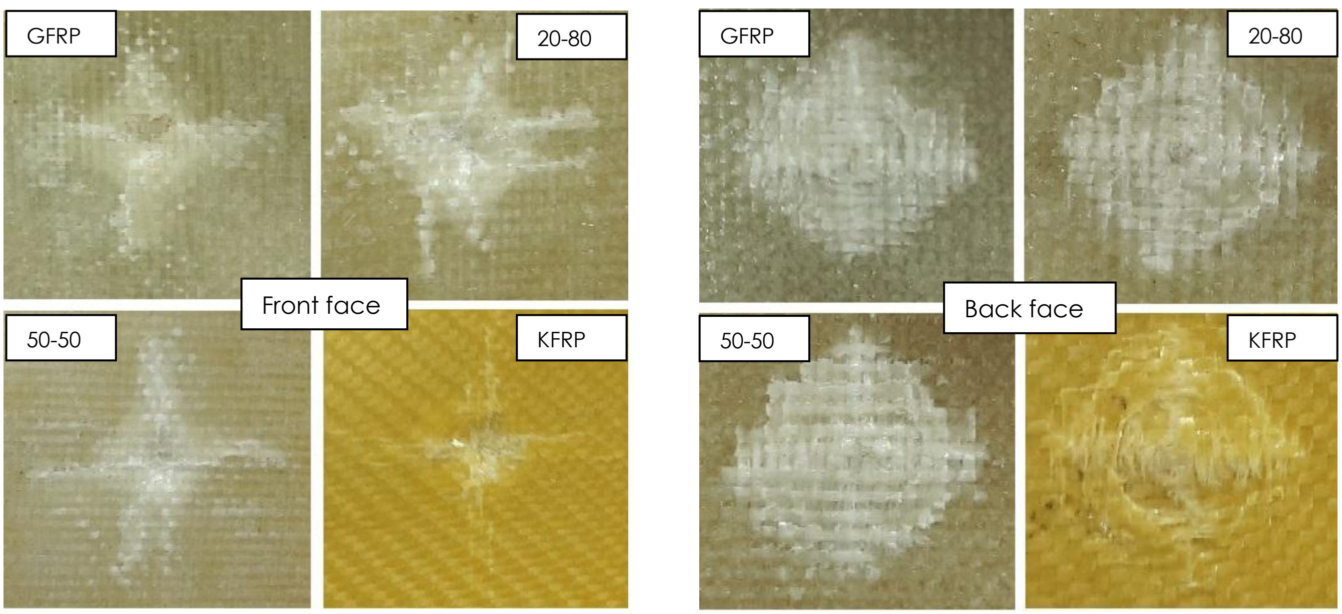


Figure 3 Visual observation of front face and back face of damage specimens of four different composite specimens by visual observation

These damage patterns were also confirmed through X-ray test as in Figure 4. Bright tonalities were become clearer as the amount of Kevlar fiber increase in the composite laminate. According to Aktas et al.[20], fiber breakage and delamination is the main energy absorption mechanism in GFRP and KFRP, respectively. In woven laminate, delamination was started in the middle of impacted area and propagated along the directions of warp and weft fibers. Evci and Gulgec [6] also proved that impact performance of woven Kevlar composite is the best compared to woven E-glass and unidirectional E-glass composite.

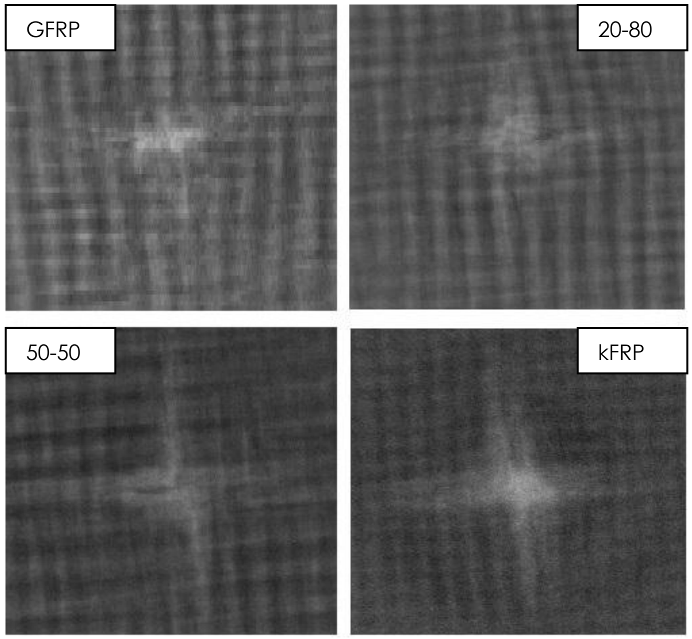


Figure 4 Damage pattern of front face specimen viewed under x-ray analyser

3.3 Depth Of Penetration

The damage specimens were further investigated through the depth of penetration. According to depth of penetration results as in Figure 5, GFRP shows the lowest depth of penetration with only 1.417mm depth followed by 20-80 KGFRP, 50-50 KGFRP and KFRP. This result indicates that although KFRP displayed the smallest damage area but it demonstrated the highest depth of penetration. This result also tally with hardness data as in Table 1. According to hardness data, GFRP has the highest hardness value (HRR 114.68) compared to KFRP (HRR 75.95). Therefore, it can be concluded that GFRP has more resistance towards indentation or penetration as compared to KFRP. For all results and data tabulated, hybrid specimens exhibit values that are between those exhibited by GFRP and KFRP.

All presented results are valuable since this experimental data contributes to an additional knowledge on the properties of glass fibre reinforced polymer composites when combined with previous researches that have been conducted [21-23].

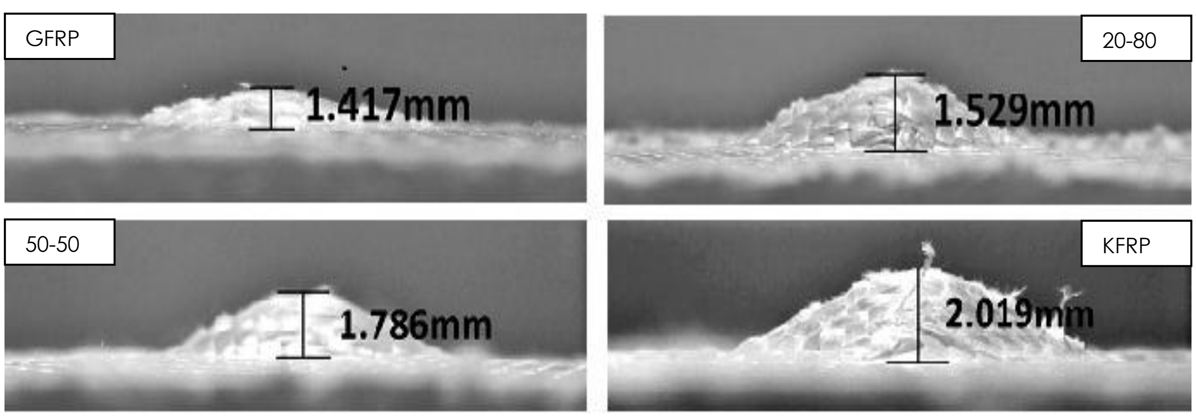


Figure 5 Depth of penetration results (top view)

4.0 CONCLUSION

Drop weight impact test was successfully performed on four different composite laminates with different ratio of Kevlar to glass fiber according to ASTM 7136. As the conclusion, addition of Kevlar fiber to glass fiber has improved the load carrying capability, energy absorbed and damage degree of the specimen. These results proved that Kevlar showed better resistance towards impact loading. However, deflection at peak load of KFRP was reduced, as a result of the reduction in depth of penetration.

Analysis of the damage pattern showed that GFRP had the largest damage area as compared to KFRP. Therefore, hybridizing Kevlar fiber to glass fiber laminate tends to reduce the damage area of the hybrid specimens as Kevlar fiber could absorb more energy.

Acknowledgement

The authors would like to thank Research Management Institute (RMI) Universiti Teknologi Mara (UiTM), Ministry of Education Malaysia and Institute of Graduate Studies (IPSIS) UiTM for the financial supports. This research works is performed at the Faculty of Mechanical Engineering, UiTM Malaysia under the support of Research Acculturation Collaborative Effort (RACE) no: 600-RMI/RACE 16/6/2(7/2013) and Principal Investigator Support Initiative (PSI) no: 600-RMI/DANA 5/3/PSI (361/2013).

References

[1] 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.

[2] Valença, S. L., Oliveira, V. G. G, Sussuchi, E. M. and de Cunha, F. G. C. 2015. Evaluation of the mechanical behavior of epoxy composite reinforced with Kevlar plain fabric and glass/Kevlar hybrid fabricriza, Sandro de. *Compos. Part B Eng.* 70: 1–8.

[3] Sevkat, E., Liaw, B. and Delale, F. 2013. Drop-weight impact response of hybrid composites impacted by impactor of various geometries. *J. Mater.* 52: 67–77.

[4] Fidan, S., Sınmazcelik, T., Avcu, E., Bora, M. O.and Coban, O. Jan 2012. Detecting Impact Damages in an Aramid/Glass Fiber Reinforced Hybrid Composite with Micro Tomography. *Adv. Mater. Res.* 445: 9–14.

[5] Park, R. and Jang, J. S. 2001. Impact behavior of aramid fiber glass fiber hybrid composite: Evaluation of four-layer hybrid composites. *J. Mater. Sci.* 36: 2359–2367.

[6] Evci, C. and Gülgeç, M. May 2012. An experimental investigation on the impact response of composite materials. *Int. J. Impact Eng.* 43: 40–51.

[7] Sayer, M., Bektaş, N. B., Demir, E. and Çallioğlu, H. Jul 2012. The effect of temperatures on hybrid composite laminates under impact loading. *Compos. Part B Eng.* 43(5): 2152–2160.

[8] Hosur, M. V., Adbullah, M. and Jeelani, S. 2005. Studies on the low-velocity impact response of woven hybrid composites. *Composite Structures*. 67: 253–262.

[9] Venkateshwaran, N., Elayaperumal, a. and Sathiya, G. K. 2012. Prediction of tensile properties of hybrid-natural fiber composites. *Compos. Part B Eng.* 43(2): 793–796.

[10] Jawaid, M., Khalil, H. P. S. A., Bhat, A. H.and Baker, A. A. 2011. *Impact Properties Of Natural Fiber Hybrid Reinforced Epoxy Composites*. 265: 688–693.

[11] Haneefa, a., Bindu, P., Aravind, I. and Thomas, S. 2008. Studies on Tensile and Flexural Properties of Short Banana/Glass Hybrid Fiber Reinforced Polystyrene Composites. *J. Compos. Mater.* 42(15): 1471–1489.

[12] Sarasini, F., Tirillò, J., Ferrante, L., Valente, M., Valente, T., Lampani, L., Gaudenzi, P., Cioffi, S., Iannace, S. and Sorrentino, L. Mar 2014. Drop-weight impact behaviour of woven hybrid basalt–carbon/epoxy composites. *Compos. Part B Eng.* 59: 204–220.

[13] Yuhazri, M. and Dan, M. M. 2008. High Impact Hybrid Composite Material for Ballistic Armor. *J. Adv. Manuf. Technol.* 2(1): 1–10.

[14] Fidan, S., Sınmazcelik, T., Avcu, E. and Coban, O. 2012. *Detecting Impact Damages In An Aramid / Glass Fiber Reinforced Hybrid Composite With Micro Tomography*. 445: 9–14.

[15] Gustin, J., Joneson, A., Mahinfalah, M. and Stone, J. Aug 2005. Low velocity impact of combination Kevlar/carbon fiber sandwich composites. *Compos. Struct.* 69(4): 396–406.

[16] qbal, K., Khan, S. U., Munir, A. and Kim, J. K. Sep 2009. Impact damage resistance of CFRP with nanoclay-filled epoxy matrix. *Compos. Sci. Technol.* 69(11–12): 1949–1957.

[17] Taraghi, I., Fereidoon, A. and Taheri-Behrooz, F. Jan 2014. Low-velocity impact response of woven Kevlar/epoxy laminated composites reinforced with multi-walled carbon nanotubes at ambient and low temperatures. *Mater. Des.* 53: 152–158.

[18] Naik, N., Ramasimha, R., Arya, H., Prabhu, S. and ShamaRao, N. Oct 2001. Impact response and damage tolerance characteristics of glass–carbon/epoxy hybrid composite plates. *Compos. Part B Eng.* 32(7): 565–574.

[19] Winkel, J. D. and Adams, D. F. 1985. Instrumented drop weight impact testing of cross-ply and fabric composites. *Composites.* 16(4): 268–278.

[20] Aktaş, M., Atas, C., İçten, B. M. and Karakuzu, R. Feb 2009. An experimental investigation of the impact response of composite laminates. *Compos. Struct.* 87(4): 307–313.

[21] Ismail, M.F., Jumahat, A., Ahmad, N and Ismail, M.H. 2015. Low Velocity Impact Of Aluminium Foam – Glass Fibre Reinforced Plastic Sandwich Panels. *Advanced Materials Research*, 1113: 74-79.

[22] Hashim, U.R., Nordin, A.H., Jumahat, A. and Ismail M.H. 2014. Compressive properties of glass fibre reinforced polymer (GFRP) rod with aluminium foam core. *Advances in Environmental Biology*. 8(8): 2780 - 2785.

[23] Bakar, N.H., Hyie, K.M., Ramlan, A.S,, Hassan, M.K, and Jumahat, A. 2014. Mechanical Properties of Kevlar Reinforcement in Kenaf Composites. *Applied Mechanics and Materials. 465-466: 847-851.*