Advances in Environmental Biology, 8(8) 2014, Pages: 2662-2668

AENSI Journals

Advances in Environmental Biology

Journal home page: http://www.aensiweb.com/AEB/

Impact Resistance of Woven Fiber Reinforced Polymer Composites

[1,2]Norazean Shaari, [1]Aidah Jumahat, [1]Khaleel H. Yahya, [1]M. Faizal Sulaiman

[1]*Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, MALAYSIA*
[2]*Faculty of Engineering, Universiti Selangor, Bestari Jaya Campus, Jalan Timur Tambahan, 45600 Bestari Jaya, Selangor, MALAYSIA*

A R T I C L E I N F O

Article history:
Received 28 February 2014
Received in revised form 25 May 2014
Accepted 6 June 2014
Available online 20 June 2014

Keywords:
Polymer composite
Kevlar reinforced polymer
Glass fiber reinforced polymer
Impact Resistance
Alumina powder

A B S T R A C T

Background: The performance of fiber reinforced polymer (FRP) composite materials is usually characterized by damage resistance of the laminates. Damage resistance of a composite material is commonly defined as a resistance to impact damage. Impact by foreign objects is expected to occur during manufacturing, service and maintenance operation. In composite structures, impact loads create internal damage that often difficult to be detected by visual inspection. This internal damage can cause severe reductions in strength and can grow under continuous loading. In this study, the impact resistance behavior of Kevlar fiber reinforced polymer (KFRP) and glass fibers reinforced polymer (GFRP) were studied experimentally using drop weight impact test according to ASTM D7136. Impact resistance behavior was studied at nominal impact energy level of 47 J. The influence of alumina powder Al_2O_3 (size 63µm) on impact properties of GFRP and KFRP was also investigated. **Objectives:** The purposes of this study are to evaluate the impact resistance behavior of KFRP and GFRP as well as to investigate the effect of micron size alumina filler on the impact properties of both composite laminates. **Results:** The unmodified specimens of KFRP and GFRP were fabricated using two techniques namely hand lay-up and vacuum bagging. In addition, specimens of 3 wt% alumina filled KFRP and GFRP composites were fabricated by using vacuum bagging method. In order to investigate the effect of fabrication method and influence of alumina filler on impact properties, drop weight tests were performed to measure the impact resistance of the specimens. From the results, it was observed that the impact resistance of specimen fabricated using vacuum bagging method was better when compared to that of specimens fabricated using hand lay-up method. Additionally, the presence of alumina fillers enhanced the impact energy absorption of FRP composite. **Conclusion:** Fabrication method plays important role in enhancing the properties of FRP. Based on the results, the incorporation of micron size alumina filler enhanced the energy absorbed during crushing, increased stiffness and strength of composites hence improved the impact resistance.

To Cite This Article: Norazean Shaari, Aidah Jumahat, Khaleel H. Yahya, M. Faizal Sulaiman, Impact Resistance of Woven Fiber Reinforced Polymer Composites Names of authors., Paper title. ***Adv. Environ. Biol., 8(8), 2662****-2668, 2014*

INTRODUCTION

Fiber-reinforced polymer (FRP) composites are made by combining a plastic polymer resin with strong reinforcing fibers. The components retain their original form and contribute their own unique properties that result in a new composite material with enhanced overall performance. Reinforcing polymer material with fibers improves their strength and stiffness. Public's interests towards the usage of FRP composite are increasing during the last four decades in high technology as well as conventional applications. FRP composite has been extensively used in aerospace, automotive, marine, transportation, infrastructure, military and sports industries [9,4,16]. The remarkable properties of FRP composite such as high specific stiffness and strength to weight ratio, enhanced dimensional stability, energy absorption, improved corrosion and environmental resistance, design flexibility, improved fatigue life, as well as reduced processing cost have made them superior and widespread than other materials [3,13,15]. FRP composites are expected to absorb low velocity impacts either during manufacturing or in use. Impacts may arise from dropped tools, foreign objects such as rocks and debris and from hail and ice [7].

Recently, numerous researchers have been studying the effect of impact load on composite laminates. Low velocity impact of FRP has been the subject of many experimental and analytical investigations. Investigated and characterized the impact damage of woven GFRP (E-glass) composite under drop weight impact with several drop height. Results showed that the absorbed impact energy increases with increasing of drop height.

Corresponding Author: Aidah Jumahat, Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, MALAYSIA.
Tel: +60 3 55435135 E-mail: aidahjumahat@salam.uitm.edu.my

The micrographic observation found that the specimens formed cross shape cracking on the front surface due to the effect of fiber orientation and delamination. Shyr and Pan [17] studied the impact behavior and damage characteristics of several fabric structures with various thicknesses of laminates, under low velocity impact. The results showed that the number of layer is one of the most important parameters that determines the energy dissipation mechanism in composite laminates. Evci and Gülgeç [5] investigated the impact damage growth and determined the Hertzian failure and maximum force thresholds in three different types of composites namely unidirectional E-Glass, woven E-Glass and woven Aramid composite. According to the test results, woven composites have superior protection limit and low damage growth under low velocity impact when compared to unidirectional composites. A study on the response of GFRPs under low-velocity impact by experimental and simulation was also performed by Hassan [7]. Three (3) different specimen thicknesses were prepared. The influence of velocity and initial energy on deflection and damage of the test was investigated. The simulation and experimental results showed a good agreement regarding maximum contact force and contact time with insignificant amount of damage.

Hosur [8] studied the low velocity impact response of twill weave carbon fabric and plain weave S2-glass fabric hybrid composites. Results of the study indicates that there is considerable improvement in the load carrying capability of hybrid composites (glass/carbon/epoxy) as compared to carbon/epoxy laminates with slight reduction in stiffness. Gustin [6] also studied the impact, compression after impact, and tensile stiffness properties of hybrid carbon fiber and Kevlar sandwich composites. From the study, it was concluded that the addition of Kevlar into the carbon face sheet improved the maximum absorbed energy and average maximum impact force compared to the pure carbon fiber specimens. The addition of Kevlar into the carbon laminates also slightly reduced the compression after impact strength and elastic moduli. The effect of operation temperature on hybrid (carbon-glass fiber/epoxy) composite laminates under impact loading was investigated by Sayer [17].

A temperature range of -20 to 60ºC with increasing impact energy were used in the study. Test results showed that temperature variations affect the impact characteristics of hybrid composites. In addition, at lower impact energy, damage concentrates at the impact contact point. At higher energy level, the main failure mechanisms are fiber breakage through the sample thickness, interlamina and intralamina delamination between adjacent layers.

Other researchers have focused their studies on effect of adding fillers into composite laminates. Jumahat [12] and Jumahat [11] stated that modification of epoxy resin with various types of filler can improve the impact or damage resistance of the composite. Taraghi [18] investigated the influence of adding different weight percentages of multi-walled carbon nanotubes (MWCNTs) into woven Kevlar/epoxy laminated composites. Results showed that the MWCNTs was improved the impact response and was restricted the damage size in the woven Kevlar fiber composites. Kostopoulos [12] also studied the influence of multi-wall carbon nanotubes (MWCNTs) on the impact and after impact behavior of carbon fiber reinforced polymer (CFRP) laminates. Results showed that at higher energy levels, the CFRP impact performance was enhanced. According to compression after impact test, compression modulus and compression strength was improved. Compression–compression fatigue after impact performance was also improved, by extending the fatigue life. The effect of cork powder and nanoclays Cloisite 30B in Kevlar/epoxy matrix composite laminates were studied by Reis [14]. The impact behavior and damage tolerance of Kevlar/filled epoxy matrix were investigated. Results showed that the addition of fillers increase the maximum impact load and maximum residual tensile strength, lower displacements, and obtained the best performance in terms of elastic recuperation. Saharudin et al. (2013) studied the influence of alumina Al_2O_3 on impact properties of short glass fiber reinforced polymer. According to the results, the incorporation of micron size alumina filler enhanced the energy absorbed, reduced the depth of penetration of impactor, prolonged the total impact time thus improved the impact properties of the composites. The nanoclay influence on impact response of GFRP laminated plates were investigated by Avila [2]. The results have shown delamination phenomenon is reduced and damping is increased during the rebounds.

The main goal of this work is to investigate the impact resistance properties of KFRP and GFRP composite laminates with different fabrication methods. Modified and unmodified specimens of KFRP and GFRP were prepared to study the influence of filler in composite laminates. Micron size alumina (Al_2O_3) powder was used as the filler in this study. Impact damage was observed using a destructive method namely drop weight impact test to identify the damage characteristics.

Materials and Methodology:

Materials:

The composite specimens were fabricated using Morcrete BJC 39 resin system supplied by Morstrong Industry Sdn. Bhd., 2443 twill weave Kevlar produced by Fibre Glast Developments Corp. and CWR200 plain weave fiberglass as the reinforcement material. 63μm alumina (Al_2O_3) powder was used as filler in this study. Table 1 and 2 below show the fabric and epoxy properties used in the study.

Table 1: Fabric properties.

	Fiberglass	Kevlar 49
Weave pattern	Plain	2x2 Twill
Area density (g/m^2)	200	125.63
Thickness (mm)	0.2	0.2794
Count (rows/tows per in.)	15x15	17x17

Table 2: Properties of Morcrete BJC 39 epoxy.

Density	1150 kg/m^3
Mixing ratio (epoxy:hardener)	3.7:1.3
Compressive strength (ASTM C579)	75.8 MPa
Tensile strength (ASTM 190-85)	13.1 MPa
Pot life (25ºC)	25-30 minutes
Cure time	8 hours
Cure temperature	Room temperature

Specimen pPreparation:

An average of 4 mm specimen's thickness of the unmodified Kevlar fiber reinforced polymer (KFRP) and unmodified glass fiber reinforced polymer (GFRP) composites were fabricated using two different methods namely hand lay-up (HLU) and vacuum bagging (VB0) while the 3 wt% alumina modified KFRP and GFRP (VB3) composite samples were prepared using vacuum bagging method only. For hand lay-up method, an aluminum mold frame with the outer and inner dimension of 340mm x 240mm and 320 mm x 220 mm was fabricated as in Fig. 1. Aluminum plate was prepared as the base plate and transparent plastic was put on the plate. Frekote 700-NC releasing agent was applied on the plastic before a mold frame was placed on top of the plastic. Then, mixture of epoxy and hardener was poured into the frame and spread evenly. A layer of woven fiber (fiberglass or Kevlar) which has the same size as the inner of mold frame was then laid onto the resin system. Both steps were repeated until the required thickness was achieved. Finally, transparent plastic was put on top of the fiber followed by another aluminum plate on it to give weight to the laminate. Specimen was cured for approximately 72 hours.

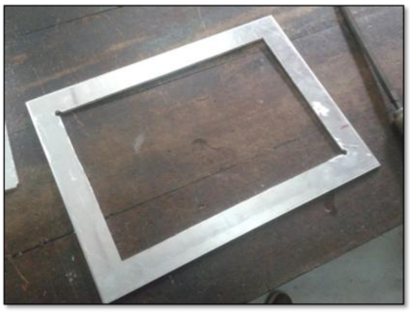


Fig. 1: Aluminum mold frame.

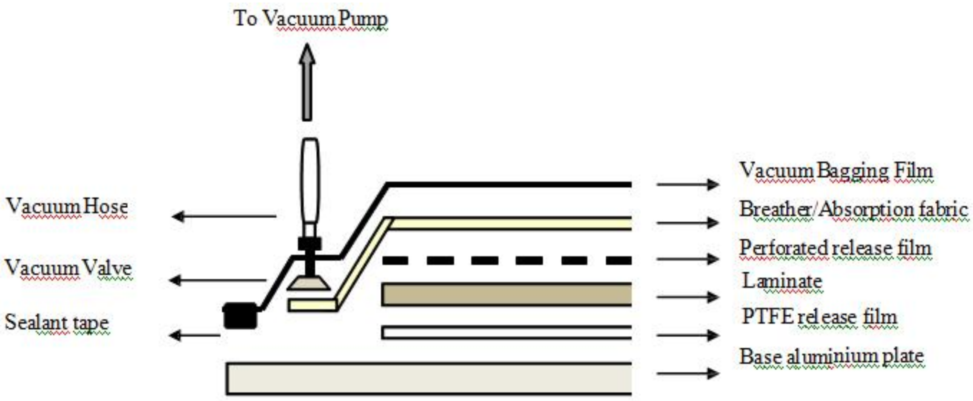


Fig. 2: Cross sectional view of vacuum bagging system.

For vacuum bagging method, the similar steps as hand lay-up method were repeated; however mold frame was not used in this method. Once the required thickness of fiber reinforced polymer was achieved, perforated release film was put on top of laminate followed by absorption fabric. Finally, vacuum bagging film was placed on the laminate and pressed firmly against the sealant tape to provide a vacuum tight system. Fig. 2 shows the cross sectional view of the vacuum bagging system. Specimen was vacuum for one hour and left to cure for 24 hours. All specimens were cut using composite cutting machine with a dimension of 100 mm x 100 mm.

Drop Weight Impact Test:

Instron Dynatup 8250 Drop Weight Impact Tester was used to determine the energy absorbed during impact test for both modified and unmodified specimens. The test was conducted according to ASTM D7136. In this test, an impactor of 6 kg was released and slide on guide bars at constant height of 0.8 m, resulting in a kinetic energy of 47 J for each impact. The impact velocity was held at approximately 3.9 m/s. The experimental test was calculated based on the potential energy of the impactor due to its vertical positioning. Once the impactor was released, the potential energy was converted into kinetic energy before hitting the specimen.

Micrograph Observation:

The impact damage of the specimen was analyzed via Stereo-zoom Microscope. The IMAP software was used to enlarge image of the specimen in order to investigate the fiber dispersion and fiber-matrix characteristic on the fracture surface.

RESULTS AND DISCUSSION

Drop Weight Impact Test:

Impact test was performed to measure the response of a material to dynamic loading. The results of drop weight impact test on both modified and unmodified KFRP and GFRP are presented below. From the result shown in Fig. 3, vacuum bagging fabrication method helps to increase the energy absorbed of both composites by 84% for KFRP and 26% for GFRP compared to hand lay-up method. Kevlar is known as high impact resistance material thus, KFRP was found to have high energy absorbed compared to GFRP. This was agreed with previous study by Abu Talib et al. (2012) when the higher amount of Kevlar was employed, higher strength of the composite was obtained. Addition of alumina filler to composite laminate also helps to increase energy absorbed by 27 – 44% of both composite laminate. Saharudin [15] also agreed that the addition of alumina filler had improved the energy absorbed of composites.

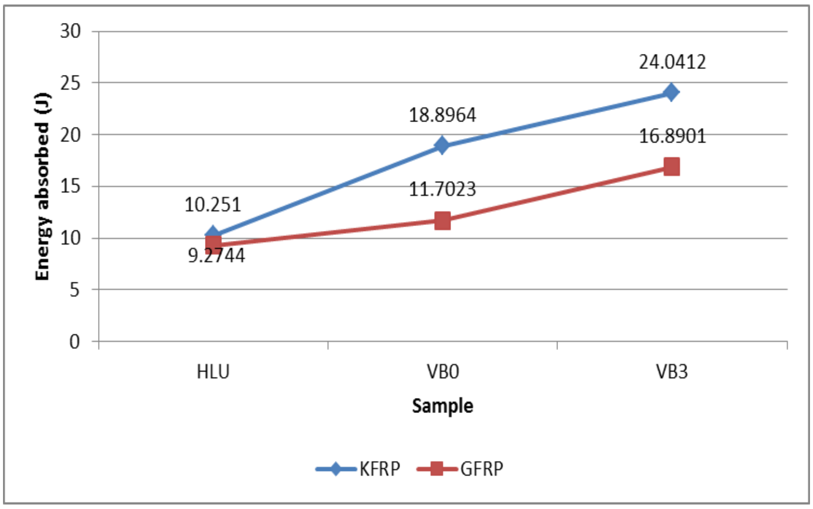


Fig. 3: The effect of fabrication methods and alumina filler on energy absorbed of GFRP and KFRP composite laminate

Fig. 4 shows the effect of fabrication methods and alumina filler on deflection of KFRP and GFRP composite laminates. According to the figure, KFRP showed higher deflection compared to GFRP. This is because Kevlar is already known to has higher Young's modulus than fiberglass. Young's modulus is a measure of the stiffness of an elastic material. Higher elastic modulus means the material is stiffer. The deflection of the specimen increased with addition of alumina filler in the system. Without alumina filler, the laminate is rigid, therefore it has small deflection. With addition of filler, the laminate become less stiff, hence bending and deflection increase. Fabrication methods also affected the deflection value. Composite laminate fabricated using vacuum bagging system showed higher deflection value compared to laminate prepared using hand lay-up methods.

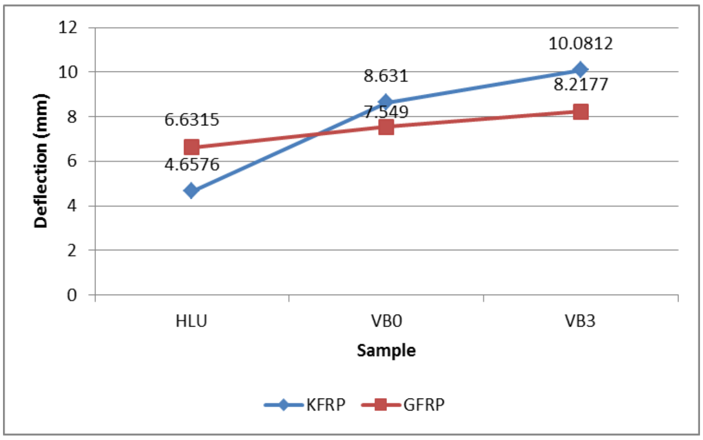


Fig. 4: The effect of fabrication methods and alumina filler on deflection of GFRP and KFRP composite laminate

The vacuum bagging fabrication method had increased the maximum load of KFRP and GFRP by 17% and 15% as in Fig. 5. Whereas, the addition of alumina filler had slightly increased the maximum load of both composite by 4-5%. Similar result was observed by Reis [14] in which the addition of filler increased the maximum impact load. This results indicate that fabrication methods and filler help to improve the mechanical properties of composite laminates. Increase in maximum load makes the laminates becomes high strength, stiffer and resist the impact in a ductile manner.

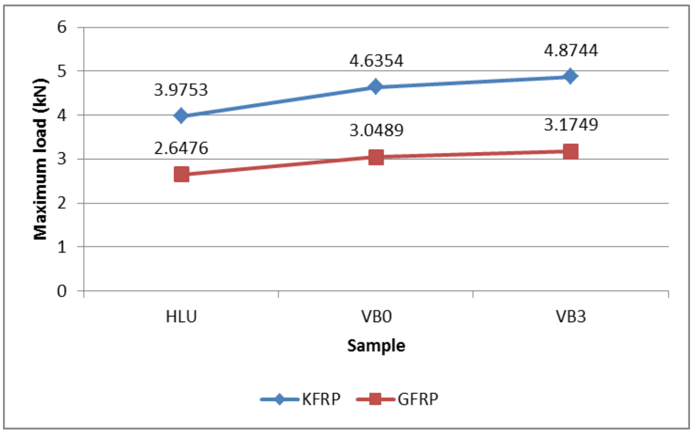


Fig. 5: The effect of fabrication methods and alumina filler on maximum load of GFRP and KFRP composite laminate

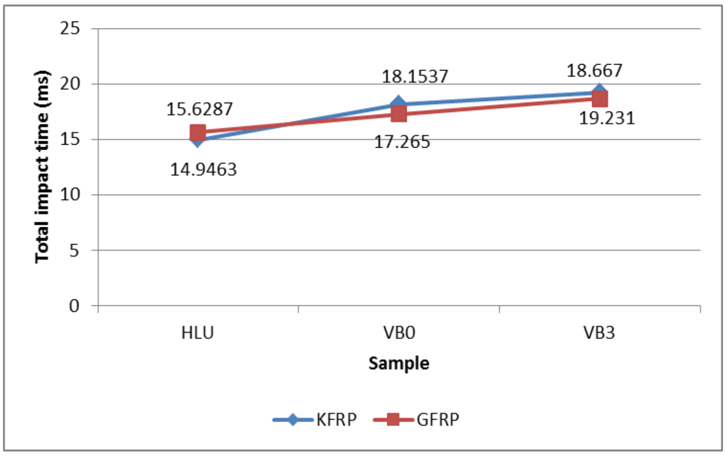


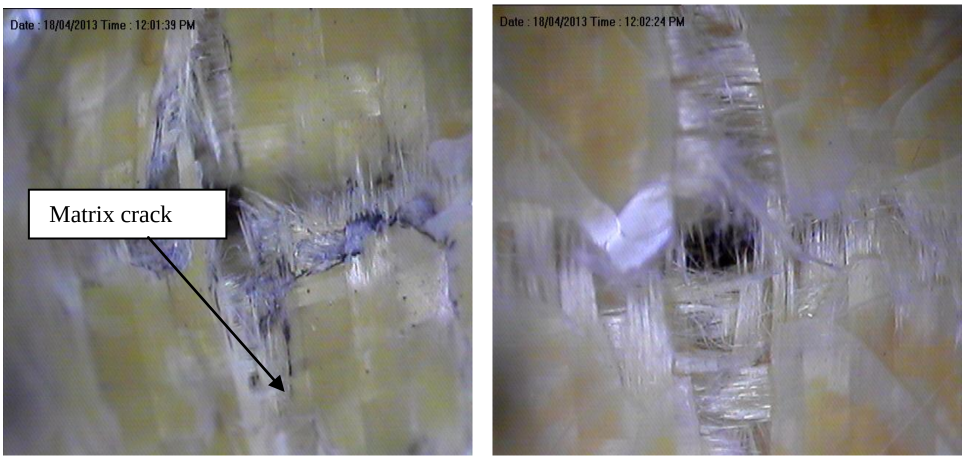
Fig. 6: The effect of fabrication methods and alumina filler on total impact time of GFRP and KFRP composite laminate

Advances in Environmental Biology, 8(8) 2014, Pages: 2662-2668

From the result in Fig. 6, the vacuum bagging fabrication method and addition of filler in the composites had prolonged the impact time of the composites. The total time of impact for KFRP and GFRP fabricated by hand lay-up were recorded at 14.9463 ms and 15.6287 ms. Fabricating both composites using vacuum bagging method had increased the total time by 11-22%. Besides, addition of alumina filler also resulting in longer impact time as recorded at 18.667 ms (KFRP) and 19.231 ms (GFRP). Saharudin [15] also found that alumina filler influence the increment of total impact time. Thus, it can be concluded that vacuum bagging method and alumina filler help prolonged the impact time.

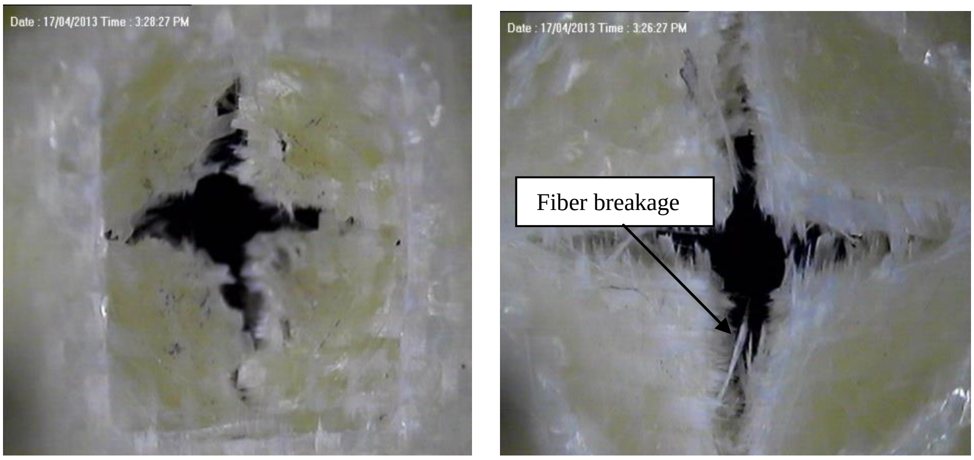
Micrograph Observation:

The impact damage was observed for all modified and unmodified composite laminates. Fig. 7 and 8 present the principal damages observed in both composite laminates. Damaged can only found around striker area. It is concluded that the damage was in the form of fiber breakage and matrix crack promoted by the impact load. The delamination pattern for both composite laminates was cross shaped on the front face and back face. The visual observation of impacted KFRP and GFRP specimens revealed that delamination area was reduced with addition of alumina filler.



(a) (b)

Fig. 7: Damage patterns of KFRP composite laminate (a) front face (b) back face.



(a) (b)

Fig. 8: Damage patterns of GFRP composite laminate (a) front face (b) back face.

Conclusion:

The unmodified KFRP and GFRP composite laminates were successfully fabricated using two fabrication methods namely hand lay-up and vacuum bagging. The alumina modified KFRP and GFRP were successfully fabricated using vacuum bagging method. The behavior of both modified and unmodified composite laminates subjected to drop weight impact was studied and examined. The results proved that fabrication method plays important roles in enhancing the impact properties of composites. It was observed that both KFRP and GFRP fabricated using vacuum bagging method recorded higher value of energy absorbed, deflection, maximum load and impact time. Other than that, the addition of alumina filler also helps to increase the value of impact properties.

ACKNOWLEDGEMENT

The authors would like to thank Research Management Institute (RMI) UiTM and Ministry of Higher Education Malaysia for the financial supports. This research work is conducted at the Faculty of Mechanical Engineering, Universiti Teknologi MARA (UiTM), Malaysia under the support of Principal Investigator Support Initiative (PSI) no: 600-RMI/DANA 5/3/PSI (119/2013).

REFERENCES

[1] Abu Talib, A.R., L.H. Abbud, A. Ali and F. Mustapha, 2012. "Ballistic Impact Performance of Kevlar-29 and Al2O3 Powder/epoxy Targets under High Velocity Impact." *Materials & Design,* 35: 12–19.
[2] Avila, Antonio, 2006. "The Nanoclay Influence on Impact Response of Laminated Plates." *Latin American Journal of Solid and Structures,* 3: 3–20.
[3] Baucom, J.N. and M.A. Zikry, 2005. "Low-Velocity Impact Damage Progression in Woven E-Glass Composite Systems." *Composites Part A: Applied Science and Manufacturing,* 36: 658–64.
[4] Dale, Michael, Betiana, A. Acha and Leif, A. Carlsson, 2012. "Low Velocity Impact and Compression after Impact Characterization of Woven Carbon/vinylester at Dry and Water Saturated Conditions." *Composite Structures,* 94(5): 1582–89,3
[5] Evci, Celal and Müfit Gülgeç, 2012. "An Experimental Investigation on the Impact Response of Composite Materials." *International Journal of Impact Engineering,* 43: 40–51,3
[6] Gustin, Jeremy, Aaran Joneson, Mohammad Mahinfalah and James Stone, 2005. "Low Velocity Impact of Combination Kevlar/carbon Fiber Sandwich Composites." *Composite Structures,* 69(4): 396–406,3
[7] Hassan, M.A., S. Naderi and A.R. Bushroa, 2014. "Low-Velocity Impact Damage of Woven Fabric Composites: Finite Element Simulation and Experimental Verification." *Materials & Design,* 53: 706–18,3
[8] Hosur, M.V., M. Adbullah and S. Jeelani, 2005. "Studies on the Low-Velocity Impact Response of Woven Hybrid Composites." *Composite Structures,* 67: 253–62.
[9] Jiang, Zhenyu, Hui Zhang, Zhong Zhang, Hideki Murayama and Keiji Okamoto, 2008. "Improved Bonding between PAN-Based Carbon Fibers and Fullerene-Modified Epoxy Matrix." *Composites Part A: Applied Science and Manufacturing,* 39(11): 1762–67,3
[10] Jumahat, A, C. Soutis, F.R. Jones and A. Hodzic, 2010. "Improved Compressive Properties Of A Unidirectional Cfrp Laminate Using Nanosilica Particles. " *Advanced Composites Letters,* 19(6): 218-221
[11] Jumahat, Aidah, Costas Soutis, Jamaluddin Mahmud and Nurulnatisya Ahmad, 2012. "Compressive Properties of Nanoclay/Epoxy Nanocomposites." *Procedia Engineering* 41(IRIS): 1607–13.
[12] Kostopoulos, V., A. Baltopoulos, P. Karapappas, A. Vavouliotis and A. Paipetis, 2010. "Impact and after-Impact Properties of Carbon Fibre Reinforced Composites Enhanced with Multi-Wall Carbon Nanotubes." *Composites Science and Technology,* 70(4): 553–63.
[13] Pandya, Kedar S.Ch. Veerraju and N.K. Naik, 2011. "Hybrid Composites Made of Carbon and Glass Woven Fabrics under Quasi-Static Loading." *Materials and Design,* 32(7): 4094–99.
[14] Reis, P.N.B., J.A.M. Ferreira, P. Santos, M.O.W. Richardson and J.B. Santos, 2012. "Impact Response of Kevlar Composites with Filled Epoxy Matrix." *Composite Structures,* 94(12): 3520–28.
[15] Saharudin, Mohd Shahneel, Aidah Jumahat, Amir Z.A. Kahar and Shaharudin Ahmad, 2013. "The Influence of Alumina Filler on Impact Properties of Short Glass Fiber Reinforced Epoxy." *Applied Mechanics and Materials,* 393: 88–93.
[16] Sayer, Metin, Numan B. Bektaş, Ersin Demir and Hasan Çallioğlu, 2012. "The Effect of Temperatures on Hybrid Composite Laminates under Impact Loading." *Composites Part B: Engineering,* 43(5): 2152–60.
[17] Shyr, Tien-Wei and Yu-Hao Pan, 2003. "Impact Resistance and Damage Characteristics of Composite Laminates." *Composite Structures,* 62(2): 193–203.
[18] Taraghi, Iman, Abdolhossein Fereidoon and Fathollah Taheri-Behrooz. 2014. "Low-Velocity Impact Response of Woven Kevlar/epoxy Laminated Composites Reinforced with Multi-Walled Carbon Nanotubes at Ambient and Low Temperatures." *Materials & Design,* 53: 152–58.