Effect of Fibre Architecture on Impact Response of Glass-Aluminium Fibres Metal Laminates (FML)

Masaki Hozumi, Aidah Jumahat, Napisah Sapiai and Zuraidah Salleh

Abstract*: This paper investigates the drop weight impact behavior of glass fibre-aluminum (GFRP-AL FML) composites. The purpose of the research is to study the effect of different type of glass fibres architecture, i.e woven and unidirectional, with existence Al sheet in the middle of the glass fibre reinforced polymer composites (GFRP). The impact behaviour of these GFRP and GFRP-AL FMLs was investigated using a drop-weight impact tower at three different energy level, which are 10J, 20J and 30J. The Load - deflection curves were used to measure the absorbed energy. The results showed that the woven type of GFRP exhibited the highest peak load but lowest deflection thus reducing the total energy absorbed. In contrast, the unidirectional types of GFRP possessed the lowest peak load and highest deflection, which results in the highest energy absorbed. For the GFRP-AL FML composites, the energy absorbed obtained almost similar for both woven and unidirectional types. This is may be due to poor adhesion between the GFRP and Al sheet, thus make both materials separated and delaminated when subjected to impact load. The optical analysis proved that the GFRP-AL debonding, fibres breakage, fibres delamination and matrix cracking occurred during the impact loading. These are the main impact energy –absorption mechanisms involved during the test.

***Keywords* : Glass fibre, Aluminium, Fibre Metal Laminates (FML), Impact Response.**

I. INTRODUCTION

Fibre metal laminates (FML) are relatively new hybrid materials that have been used in a wide variety of applications such as aerospace, automotive and biomedical applications. FML are hybrid materials consisting of arranged metal layers bonded with layers of fibres reinforced polymer composites. The combination of metals and fibres allows the FML to have simple metallic structure with specific advantages such as a high impact resistance, fatigue properties, superior corrosion resistance, improved fire resistance, and weight-savings [1]–[4] The GLARE (Glass Aluminium Reinforced Laminates) applied in aircraft industry are the most prevalent and most investigated type of FML laminates [1], [5], [6] GLARE exhibits outstanding damage tolerance capabilities in combination of excellent impact resistance when compared to fibre reinforced polymer (FRP) composites and monolithic metals [7].

In high performance application such as automotive and aerospace applications, it is important to consider impact damage and impact properties in the design process for safety reasons. The impact properties of the FML depend on several factors such as fibre orientation, fibre architecture, fibre volume, fibre type, thickness of metal sheet, type of metal, arrangement of the metal-fibre (stacking sequence) and matrix type [8]–[13] For example, Yaghoubi et.al in their study of effect stacking sequence and geometrical [12] and lay up orientation [11] on the low velocity impact and ballistic impact of GLARE 5 concluded that GLARE 5 fabricated from unidirectional fibers attained the worst impact resistance, followed by cross-ply and angle-ply configurations, while the quasi- isotropic lay-up showed the best resistance to impact. Sharma and Khan [14] in their study of the effect of the distribution aluminum layer through the thickness of FMLs on impact response stated that the thinner aluminum sheet resulted in highest deflection and the permanent deformation. Ortiz de Mendibil et al. [15] studied the effect of holes on the impact behaviour of GFRP/AL FML and resolved that the presence of the holes has no effect on the performance of the plate. However, when the holes are inside the impact contact zone the damage propagation mitigated by fibre bridging mechanism. While, there have no effect in the damage mechanisms when holes far from impact contact zone. In addition, Abdullah et al. [1] claimed that the adhesion is the key factor in determining the mechanical performance for the FML systems.

Even though there are several studies discussed on the FML system, the sequence of the FML are varied and the arrangement of metal sheets in between fibre plies, FRP/Metal/FRP, are rarely being developed and evaluated. Therefore, more extensive research is required to establish the data base for wide-spread application of the FML. This paper focuses on the impact behavior of two types of glass fibre i.e woven and unidirectional with additional of Al sheet in the middle of the glass fibre reinforced polymer composites systems.

Revised Manuscript Received on October 30, 2019.

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II. METHODOLOGY

A. Materials and Specimen Preparation

The glass-Aluminium fibres metal laminates were fabricated using woven and unidirectional types of glass fibres, aluminium plate and epoxy resin. The woven and unidirectional glass fibres were supply by Innovative Pultrusion Sdn. Bhd. The 2 mm thickness of aluminium plate was purchased from Ye Ann Hardware Trading Sdn. Bhd. The Miracast 1517 epoxy resin with ratio of 100:30 (epoxy: hardener) was supplied by Miracon Sdn. Bhd.

The woven glass fibres reinforced polymer (WVGFRP), unidirectional glass fibres reinforced polymer composites (UDGFRP), woven glass-aluminium fibre metal laminates (WVGFRP/AL-FML) and unidirecional glass-aluminium fibre metal laminates (UDGFRP/AL-FML) were prepared using a combination of vacuum bagging system and cold press machine. The FML specimens were arranged according to stacking sequence as describe in Table-I. The GFRP and FML specimen plates were cured at room temperature for 24 hours before it was cut into specimens of dimension of 50 x 50 mm.

Table-I: Specimen Designation

Specimens	Thickness (mm)	Description
WVGFRP	5.2±0.25	20 plies woven glass fibres
UDGFRP	4.9±0.15	12 plies unidirectional glass fibre
WVGFRP/AL-FML	5.1±0.15	7 plies woven glass fibres/2mm Aluminium/7 plies woven glass fibres
UDGFRP/AL-FML	4.8±0.25	4 plies unidirectional glass fibres/2mm Aluminium/4 plies unidirectional glass fibres

Physical and Mechanical Tests

Density Test

A density of the GFRP and FML specimens were performed using GR-200 AND analytical balance machine according to ASTM D792. At least 5 specimens were measured for each system. The calculation of the density was obtained by using the following equation (1).

$$\rho = \frac{A}{A-B} \times (p_0 - d) + d \quad (1)$$

Where;

ρ is a density of specimen, A is a weight of specimen on air, B is a weight of specimen in liquid, ρ_o is a density of liquid, 0.99730 g/cm^3 and *d* is a density of air, 0.001g/cm^3.

Hardness Test

Hardness of specimens were performed using Instron Rockwell Series 600 Tester according to ASTM 785. The average of five indentations were evaluated for each system.

Drop Weight Impact Test

The impact tests were performed using Instron Dynatup 8250 Drop Weight Impact Tester in accordance with ASTM D7136. The 50 mm length x 50 mm width of specimens were tested under impact energy of 10, 20 and 30 J using 13 mm diameter of hemispherical tip impactor. The load carrying capabilities, energy absorbed, deflection, damage and impact strength of composite laminates were determined from this test. At least five specimens for each system were tested to get an average of impact properties. The impacted specimens were then observed under digital camera in order to study the damage behavior of the composite systems

III. RESULT AND DISCUSSION

A. Density and Hardness properties

Table-II shows the density and hardness value of the GFRP and FML composites for both type of woven and unidirectional. The woven type of GFRP and FML (WVGFRP and WVGFRP/AL-FML) had lower density and higher hardness value as compared to unidirectional type of GFRP and FML (UDGFRP and UDGFRP/AL-FML). The density of GFRP/AL FML was increased as compared GFRP system due to the existence of AL sheet, which had ~ 2.7g/cm^3 of density. In addition, the hardness value of AL is ~ 3 0 HRR which resulted in reducing hardness value when combined GFRP.

Table-II: Density and hardness properties of WVGFRP, UD GFRP, WVGFRP/AL-FML and UD GFRP/AL-FML composites.

Composite systems	Density (g/cm^3)	Hardness (HRR)
WVGFRP	1.6328±0.1474	110.17±0.37
UD GFRP	1.8115±0.1017	106.50±1.63
WVGFRP/AL-FML	1.9695±0.0934	103.40±2.54
UD GFRP/AL-FML	2.0111±0.0519	101.1±0.88

B. Impact response of GFRP and GFRP/AL-FML composite

Fig. 1 shows the load versus deflection curves for the WVGFRP, UDGFRP, and WVGFRP/AL-FML and UD GFRP/AL-FML composites at 10J, 20J and 30J energy level. Each curve represents the increasing load with several fluctuations until it reaches a maximum load. The fluctuation in loads is due to the delamination propagation of composite plies, whereas the maximum damage in the composite plies was induced around peak load until composite completely fail at maximum load. From the figure, it can be seen the behavior of the GFRP and GFRP-AL FML systems, which the deflection increases by increasing the impact energy for all types of GFRP and GFRP/AL-FML composites. The woven type of GFRP exhibits the highest peak load, but indicated the lowest energy absorbed followed by woven type of GFRP/AL-FML at all different level of impact energy. The unidirectional type of GFRP (UDGFRP) presented the lowest peak load but highest energy absorbed at all impact energy level.

The impact strength of the FML can be defined as capability of the materials to absorb energy when subjected to impact loading until failure. As illustrated in Table-III, the absorbed energy was recorded 9.34J (10J), 16.63J (20J) and 23.69J (30J) for WVGFRP, 10.46J (10J), 20.19J (20J) and 29.63J (30J) for UD GFRP, 10.46J (10J), 19.53J (20J), 28.32J (30J) for WVGFRP/AL-FML and 10.45J (10J), 19.41J (20J), 29.11J (30J) for UD GFRP/AL-FML composites. It can be concluded that as the impact energy increases, the energy absorbed is also increases. However, the energy absorbed was recorded almost similar for WVGFRP/AL-FML and UD GFRP/AL-FML composites

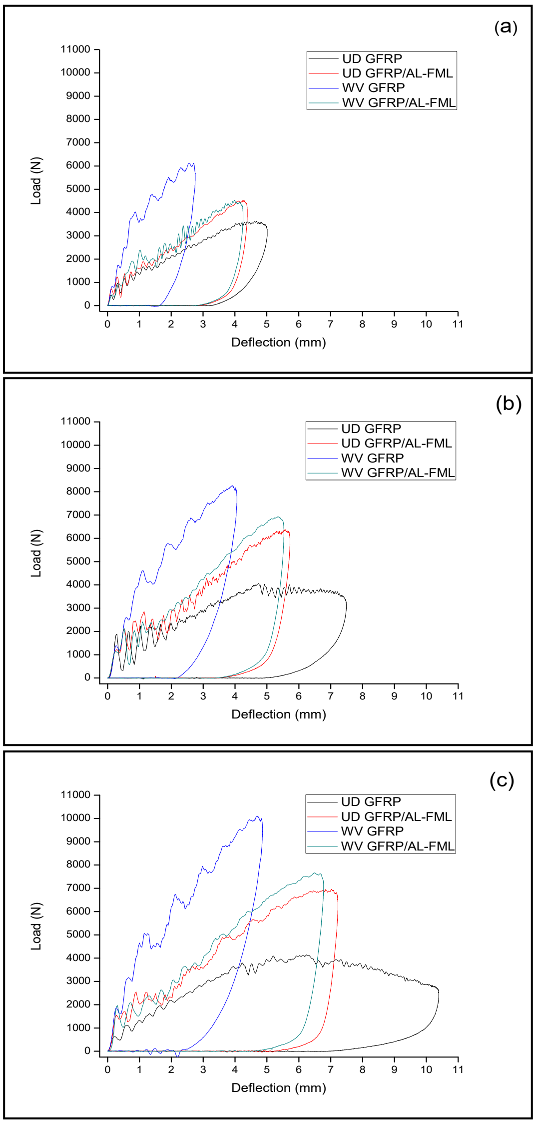


Fig. 1. Load versus deflection response of WVGFRP, UD GFRP, WVGFRP/AL-FML and UD GFRP/AL-FML composites at different impact energy (a) 10J (b) 20J and (c) 30J

From the observation, the placement of the glass fibre at the outer layers of the FML systems does not improve the impact resistances due the fibre-matrix and glass fibre-Al debonding occurred during impact test as proven in Figures 2 and 3. The lateral view show that the Al was separated from GFRP-AL FML systems for both woven and glass types. In this case, the bridging mechanism between glass fibre-aluminum is less efficient, which resulted in similar energy absorbed as compared to UDGFRP. This finding was also supported by the results obtained by Trzepiecinski et al. [16], in which they concluded that the mechanical strength of the FMLs is governed by the adhesion between fibre and matrix. The strong adhesion bonding between fibres and metal sheets will increase the flexibility of the joint and elasticity thus will contribute to the improvement of the strength and durability of the composite.

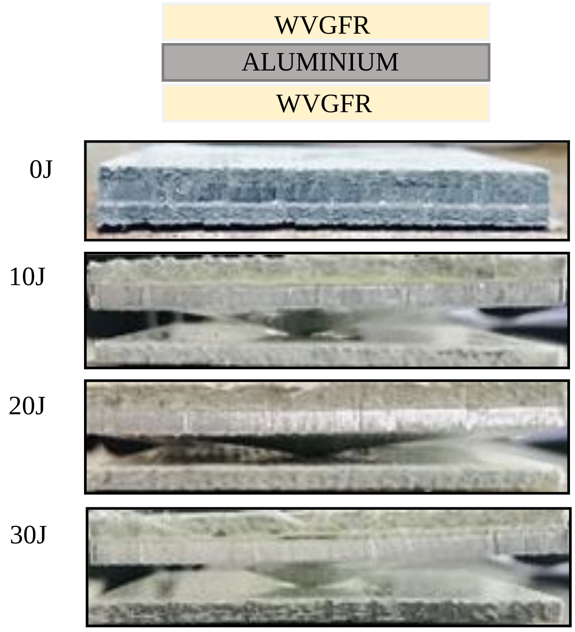


Fig. 2. Lateral view of WVGFRP/AL-FML composite following the different impact energies

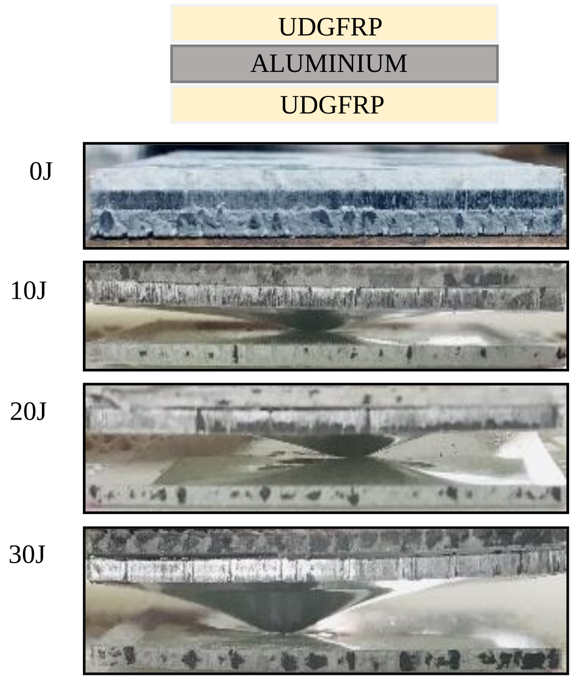


Fig. 3. Lateral view of UDGFRP/AL-FML composite following the different impact energies

Table-III: Parameters obtained from impact test for WVGFRP, UD GFRP, WVGFRP/AL-FML and UD GFRP/AL-FML composites at different impact energy.

IMPACT ENERGY (J)	COMPOSITE SYSTEMS	PEAK LOAD (N)	DEFLECTION AT PEAK LOAD (MM)	ENERGY AT PEAK LOAD (J)	ABSORBED ENERGY (J)	DAMAGE DEGREE
10	WVGFRP	6093.35± 110.22	2.59± 0.03	10.06± 0.05	9.34± 0.08	1.00
	UD GFRP	3534.71± 221.88	4.43± 0.20	9.44± 1.19	10.46± 0.22	1.10
	WVGFRP/AL-FML	4587.71± 109.12	3.95± 0.0320	10.34± 0.06	10.46± 0.06	1.11
	UD GFRP/AL-FML	4536.77± 93.15	4.22± 0.03	10.90± 0.09	10.45± 0.07	1.11
20	WVGFRP	8344.07± 329.39	3.82± 0.13	20.01± 0.61	16.63± 0.73	0.86
	UD GFRP	4068.38± 376.86	5.95± 1.2397	15.61± 3.72	20.19± 0.68	1.04
	WVGFRP/AL-FML	6834.70± 174.17	5.38± 0.08	20.39± 0.19	19.53± 0.21	1.01
	UD GFRP/AL-FML	6384.05± 81.48	5.52± 0.0893	20.14± 0.12	19.41± 0.29	1.01
30	WVGFRP	10141.29± 123.82	4.67± 0.03	28.86± 0.08	23.69± 0.61	0.83
	UD GFRP	4200.23± 230.15	5.83± 0.82	15.42± 2.08	29.63± 0.35	1.04
	WVGFRP-FML	7820.33± 152.89	6.35± 0.18	28.13± 1.25	28.32± 0.09	1.00
	UD GFRP-FML	7040.25± 138.66	6.67± 0.46	27.71± 2.71	29.11± 0.45	1.02

C. Damage Pattern of the of GFRP and GFRP/AL-FML composites

Table IV, V, VI and VII show graphical observation of the front and back view for WVGFRP, UD GFRP, WVGFRP/AL-FML and UD GFRP/AL-FML, respectively. There are two different damage patterns that were observed. The damage pattern differs due to the two types of the glass fibres used. The woven type glass fibre composites (WVGFRP and WVGFRP/AL-FML systems) was attained spherical damage pattern around the impacted surface. This is because the delamination started in the middle impacted area and propagated along warp and weft direction. For the unidirectional type glass fibres composites (UD GFRP and UD GFRP/AL-FML), the damage also started in the middle of the impacted area and propagated along with fibres direction. As the impact energy increased, the larger damage area was found in both type of GFRP and GFRP/AL-FML composites. According to Norazean et al. [17], the damage pattern is an indicator to estimate the energy absorption mechanism via fibres breakage and delamination in fibre reinforced polymer composites (FRP) systems. The smaller impact energy, the smaller damage area was observed, indicated that less energy absorbed for all type GFRP and GFRP-FML system.

The bright tonalities around the impacted surface was the epoxy matrix cracking which had brittle failure after subjected to impact load. As illustrates in Tables VI and VII, the back view of the damage area was reduced, which concluded that the existent of the AL sheet could absorbed more energy as compared to WVGFRP. However, the poor adhesion bonding between GFRP and Al caused the energy absorbed similar to UDGFRP. As depicted in Figure 3 and 4, the lateral view of GFRP-AL FML show the AL sheet deformed plastically and detached with GFRP systems. As reported by Yaghoubi and Liaw [11], the FML had unique criteria as compared to the traditional composite materials because they contain additional metal layers. So, instead of the damage created in the FRP layers, there are two extra failure mechanisms were found in FML which are damage in the aluminum layers and interfacial fracture between the aluminum and prepreg layer. They also suggested that the aluminum layers failed through bulging, petalling and plugging (caused mainly by shear).

Table-IV: Photos of front and back view of damaged area for WVGFRP composite

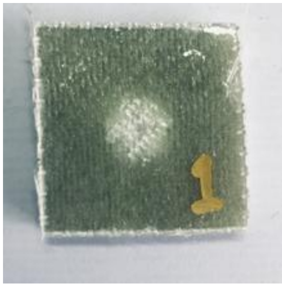
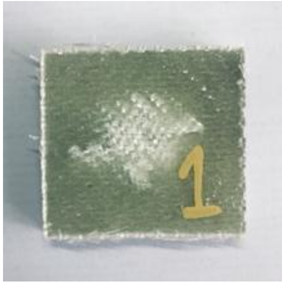
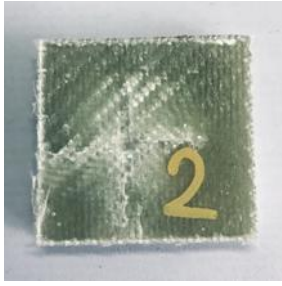
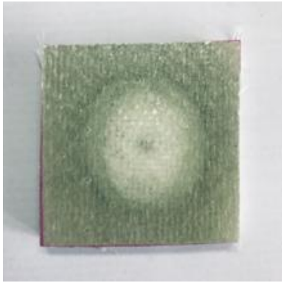
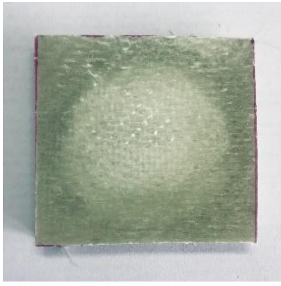
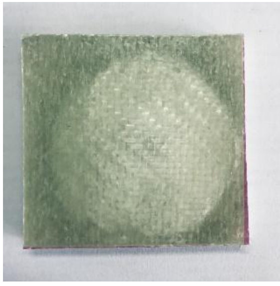
WVGFRP	IMPACT ENERGY		
	10J	20J	30J
FRONT VIEW			
BACK VIEW			

Table-V: Photos of front and back view of damaged area for UD GFRP composite

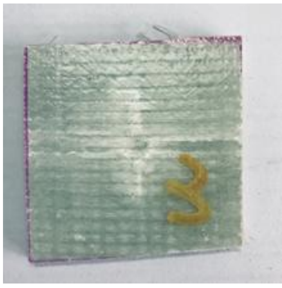
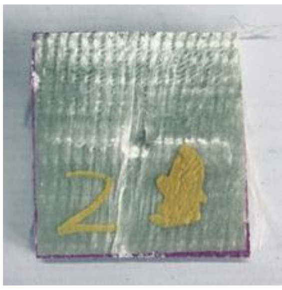
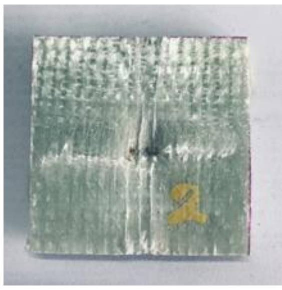
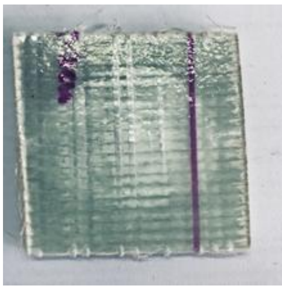
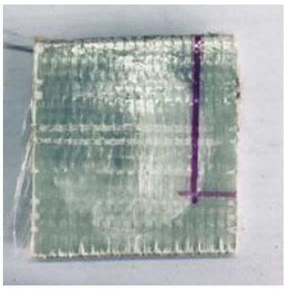
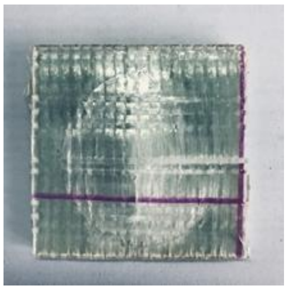
UDGFRP	IMPACT ENERGY		
	10J	20J	30J
FRONT VIEW			
BACK VIEW			

Table-VI: Photos of front and back view of damaged area for WVGFRP/AL-FML composite

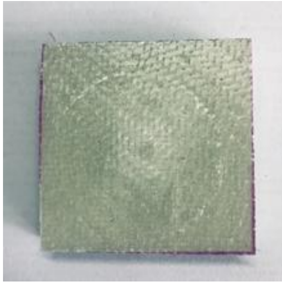
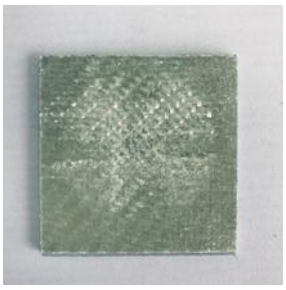
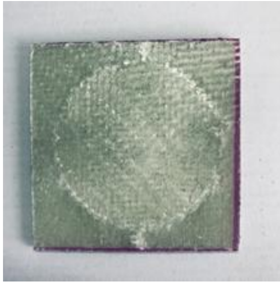
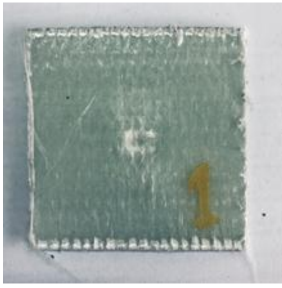
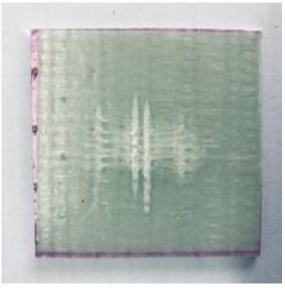
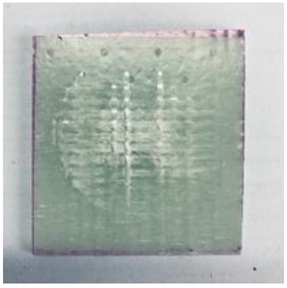
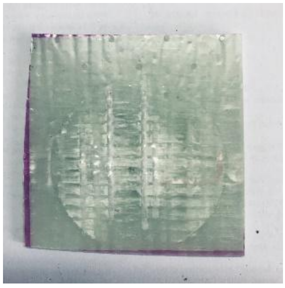
WVGFRP/AL-FML	IMPACT ENERGY		
	10J	20J	30J
FRONT VIEW			
BACK VIEW			

Table-VII: Photos of front and back view of damaged area for UD GFRP/AL-FML composite

UDGFRP/AL-FML	IMPACT ENERGY		
	10J	20J	30J
FRONT VIEW			
BACK VIEW			

Retrieval Number: A3039109119/2019©BEIESP
DOI: 10.35940/ijeat.A3039.109119

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IV. CONCLUSION

The drop weight impact behavior of woven and unidirectional GFRP and GFRP-AL FML was successfully characterized. The woven types of GFRP (WVGFRP) exhibited the highest peak load but the lowest energy absorbed as compare to unidirectional GFRP (UDGFRP). In FML systems, both of the WVGFRP and UDGFRP possess similar impact behavior, which attained almost equal energy absorbed. This is due to the poor addition bonding between GFRP and Al thus reduce the ability of the GFRP-AL FML to absorb more energy. The energy absorbed was increased with increasing of the impact energy for all types of GFRP and GFRP-AL FML composites. The analysis of the damage pattern showed that the damage area increased with increasing of the impact energy with fibres breakage and delamination propagated along the fibres direction for all type of GFRP and GFRP-AL FML composites.

ACKNOWLEDGMENT

The authors would like to express their gratitude to the Universiti Teknologi MARA (UiTM), Ministry of Education Malaysia and Institute of Graduate Studies (IPSIS) for the financial supports. The research is performed at the Faculty of Mechanical Engineering, UiTM, Malaysia under the support of Fundamental Research Grant Scheme (FRGS) no: 600-IRMI/FRGS 5/3 (163/2019).

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