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Woven and Unidirectional Glass-Aluminium Fibre Metal Laminates (FML): Quasi-Static Indentation Properties

Aidah Jumahat, Muhammad Naim Najib, Napisah Sapiai

Abstract: In this study, the effect of fibre arrangement and aluminium thin sheet on quasi-static indentation properties of fibre metal laminates (FML) based on glass fibre reinforced polymer composite (GFRP) and Aluminium (Al) was investigated. The woven and unidirectional types of glass fibre prepreg and 0.5mm, 1mm and 2 mm of Al sheet thickness were used in the fabrication of Glass fibre-Al FML systems. The GFRP and FML samples were fabricated using a combination of hand lay–up and hot press methods. Quasi-static indentation test was performed according to ASTM D6264. The results showed that the woven type of GFRP and FMLs exhibited the highest energy absorption as compared to those of unidirectional of GFRP and FMLs. It was observed that for the woven type specimens of GFRP and FMLs, the matrix cracking and fibre breakage/delamination triggered in weft and wrap direction, which showed diamond-shaped damage. While the damage surface of unidirectional GFRP and FMLs showed single axis orientation damage type that lateral with the direction of the fibre namely fibre splitting mechanism. The FML2 systems for both woven and unidirectional, that used 2mm thickness of Al, demonstrated the highest energy absorption when compared to the other FML systems. This shows that FMLs absorbed more energy when thicker Al sheet was used.

Keywords: fibre metal laminates (FML). Fibre reinforced polymer (FRP), quasi-static indentation (QSI), Glass fibre, Aluminium, Delamination

I. INTRODUCTION

Fibre Metal Laminates (FML) are a new structure of hybrid material that are formed from the combination of metal layers sandwiched with fibre reinforced polymer layers [1]–[8]. The fibre/metal composite technology combines the advantages of metallic materials and fibre reinforced matrix systems. Metals are isotropic materials which have a high bearing strength and impact resistance in all direction, while, fibre composites have excellent corrosion resistance characteristics and high specific strength and stiffness. The low fatigue and corrosion resistance of metals and the low bearing strength and impact resistance of composites are overcome by combining the metal and fibres [7].

GLARE is the most common FML that consists of alternating aluminium alloy as metallic sheets and glass/epoxy as composite layers. The combination of both constituents demonstrated outstanding damage tolerance capability with excellent impact resistance when compared to GFRP and monolithic Al alone. With outstanding properties, GLARE gained a lot of interest in aircraft application and was applied in cargo floors, engine cowlings, patch repair, stringers and cargo containers.

In aircraft structures, the impact damage is an important type of failure that needs to be concerned. Impact damage usually caused by runway debris, hail, dropped tool, collisions between service cars or cargo, bird strike, engine debris, tire shrapnel from tread separation [2]. There a lot of studies on the GLARE to enhance the impact properties especially in different arrangement of fibre/metal, fibre/metal thickness, fibre/metal types and the method approached. According to Vlot and Krul [9], GLARE had approximately equal or 15 % better specific minimum cracking energy at low velocity impact compared to monolithic aluminium. Besides, GLARE has higher minimum cracking energy and smaller damage if the GFRP content is increased. Ardakani et al. [10] investigated on the impact resistance of different types of GLARE laminates varies in their thickness and sequence of fibre-aluminium composites. It was found that the damage behaviour of GLARE was influenced by their thickness, which the damaged area in thin GLARE was 3 to 5 times larger than thick GLARE [10]. Ankush et al. [11] studied on the effect of different thickness of the fibre metal laminates on the impact properties using high speed 3D digital image correlation technique (DIC). They found that the damage of the fibre ML was reduced by applying thicker aluminium within the composites laminates [11]. Ahmadi et al.[12] investigated on the effect of difference aluminium layers thicknesses and found that the thin aluminium layer lay up at the rear side of the laminates resulted in higher energy absorption. Although many articles have been published regarding to impact properties of the GLARE, the information on quasi static indentation is still lacking.

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The effect of metal thin sheet on the quasi static indentation properties of fibre composites need to be further studied. Therefore, the purpose of this paper is to study the impact properties of FMLs through quasi static indentation, which also considered as an important parameter in impact properties.

II. METHODOLOGY

Fabrication of Composites

The FML systems were fabricated using woven (WV) and unidirectional (UD) prepreg glass/epoxy and 6061 aluminium sheet with thickness of 0.5, 1 and 2 mm according to arrangement and configuration as listed and demonstrated in Table-I and Fig. 1. The prepreg glass/epoxy and aluminium sheet were cut into 250 mm x 250 mm dimensions. The FML and GFRP, in total of 8 systems, were then fabricated using hand lay-up process with specific arrangement system design based on the plies of fibres and thickness of Aluminium sheet as shown in Table I and Fig 1. These laminates were then pressed using hot pressing machine with temperature of 154°C for an hour before left for post-curing. The FML and GFRP laminates were cut in the size of 50 mm x 50 mm for Quasi Indentation Test (QSI).

Table-I: Designation and stacking sequence of specimen

System	Lay-up sequence	Average thickness
UD GFRP	32 layers unidirectional GFRP	5.0
WV GFRP	24 layers woven GFRP	4.8
UD FML2	11GF/2mmAL/11GF	4.9
UD FML1	8GF/1mmAL/6GF/1mmAL/8GF	4.8
UD FML0.5	5GF/0.5mmAL/5GF/0.5mmAL/3GF/0.5mmAL/5GF/0.5mmAL/5GF	4.9
WV FML2	7 GF/2mmAL/7 GF	4.7
WV FML1	5GF/1mmAL/4GF/1mmAL/5GF	4.9
WV FML0.5	3GF/0.5mmAL/3GF/0.5mmAL/3GF/0.5mmAL/3GF/0.5mmAL/3GF	5.1

Quasi-Static Indentation Test (QSI)

The quasi-static indentation (QSI) test follows the standard test method for measuring the damage resistance of the fibre metal laminates to a concentrated quasi-static indentation force compliant with ASTM D6264. The damage is caused by a concentrated force which perpendicular to the plane of the laminated plates applied through slowly pressing a displacement-controlled hemispherical indenter onto the surface of the specimen as shown in Fig. 2. The dimensions of the specimens used in the test were 50 mm x 50 mm, as stated in the standard. The QSI test was conducted using Instron Universal testing machine with speed rate of indenter was set to 1 mm/min. Five specimens for each system were tested, and the average values of load, deflection and energy absorb were recorded. The deflection of the damage was identified by the displacement until fully penetrated into the specimen and then the damaged surface was observed using digital camera.

Fig. 3 shows a schematic load-displacement curve for typical quasi-static indentation test on quasi-isotropic composites plates. It illustrates the indentation process [13] in which load increases initially resulting in matrix cracking and initiation of delamination with local indentation (see Fig. 3, Section 1). Then, it follows with the severe delamination penetration and fiber ruptures that lead to decrease load carrying capacity (see Fig. 3, Section 2). Finally, samples were subjected to a perforation leading to friction between sample and indenter (see Fig. 3, Section 3).

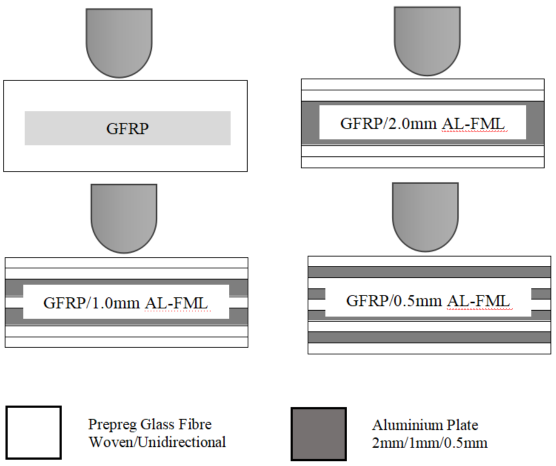

Fig. 1. The configuration of GFRP and FML composites

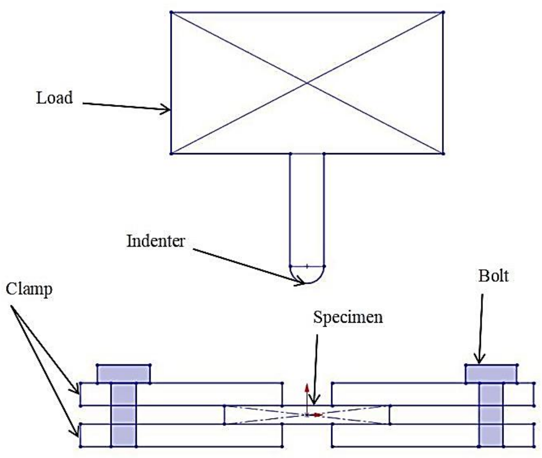

Fig. 2. Schematic drawing of indentation test.

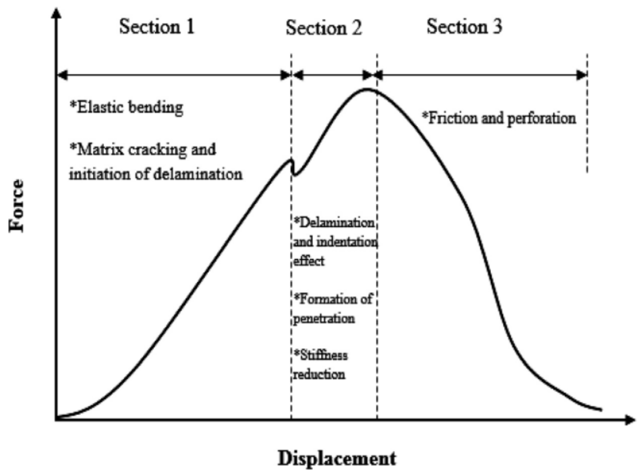

Fig. 3. Schematic load-displacement curve for typical quasi-static indentation test on quasi-isotropic composites plates [13].

III. RESULTS AND DISCUSSION

Fig. 4 shows the typical load-deflection curves for WVGFRP and WVFMLs. The pattern of the curves is similar to each other where the WVFML2 showed the highest indentation load among all by 7.769kN with the deflection of 7.876 mm. Then, followed by WVFML1, WVFML0.5, and WVGFRP with the peak loads of 5.300kN, 5.521kN, and 3.374kN respectively. The similar load-deflection curves pattern was found for UD GFRP and UD FMLs as shown in Fig. 5. The curves of both WV and UD type of GFRP and FMLs show almost similar pattern where they started linearly until it reaches the knee point. The knee point describes the behaviour of the specimen under quasi static loading at a point where it reaches the first delamination layer resulted from matrix cracking. The knee points for all systems occurred at different load. In general, it can be said that when the thickness of the thin metal ply reduced within the laminates, so does the knee point loads. Basically, Figures 4 and 5 show load-deflection curves pattern of two different types of fibre, woven and unidirectional, respectively. All four (4) curves of woven ply metal laminates and four (4) curves of unidirectional metal laminate show three distinctive regions, i.e. Elastic bending, Penetration and Perforation. These three behaviour have been described by Bulut and Erkliğ [13]. All curves show that the quasi indentation behaviour could be divided into three sections, which first section is the parts that GFRP and FML experience elastic bending before matrix cracking and fibre delamination. In second section, the delamination of the fibres was continued until maximum load and the indenter start to penetrate. Last section shows the penetration of indenter with the fibres and matrix continue to breakage until indenter completely perforated. In this study, the UD FML2 exhibits the highest value for both knee point load and peak load of 4.24kN and 7.91kN respectively, followed by UD FML1 and UD FML0.5 and UDGFRP. Table-II and Table-III show the Indentation results for woven and unidirectional GFRP and FML, respectively.

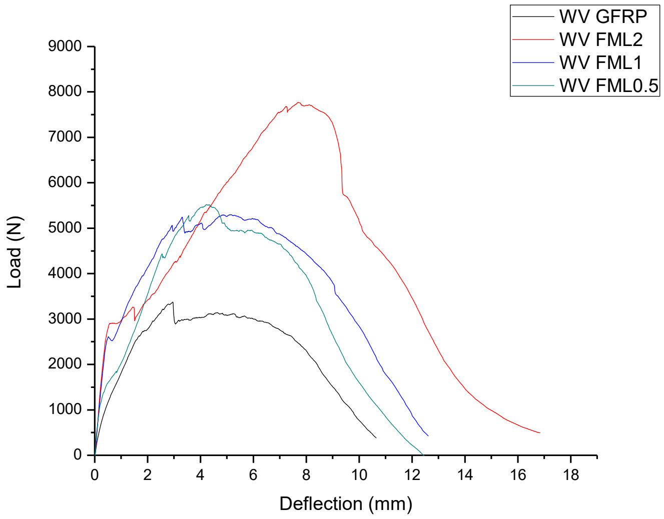

Fig. 4. Typical load-deflection curves for woven GFRP and woven-FML.

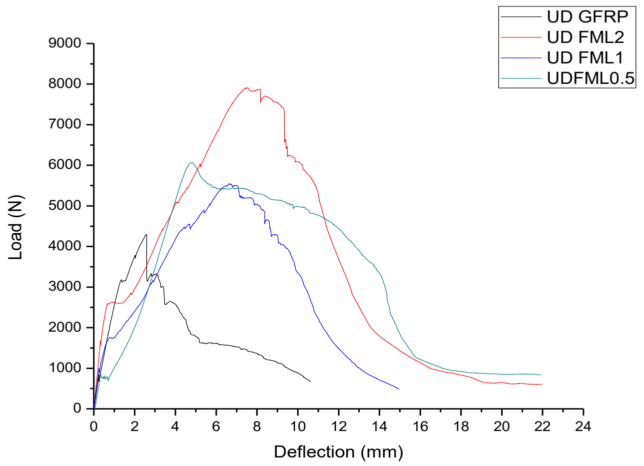

Fig. 5 Typical load-deflection curves for UD GFRP and FML.

Table-II: Indentation results for woven GFRP and FML.

System	Load (kN)	Energy absorbs (J)	Deflection (mm)
WVGFRP	3.374 ± 0.171	8.412 ± 5.753	3.402 ± 1.727
WVFML2	7.769 ± 0.554	37.832 ± 3.084	7.876 ± 0.541
WVFML1	5.691 ± 0.448	21.517 ± 0.194	4.956 ± 0.301
WVFML0.5	5.450 ± 0.813	16.957 ± 2.616	4.274 ± 0.057

Table-III: Indentation results for unidirectional GFRP and FML.

System	Load(kN)	Energy absorbs (J)	Deflection (mm)
UDGFRP	4.296 ± 0.971	6.518 ± 1.133	2.624 ± 0.054
UDFML2	7.910 ± 0.603	35.154 ± 1.811	7.939 ± 0.385
UDFML1	5.547 ± 0.723	18.889 ± 3.554	6.547 ± 0.189
UDFML0.5	6.063 ± 0.889	14.580 ± 4.733	5.129 ± 0.689

Fig. 6 shows the energy absorption of quasi static load by both unidirectional and woven glass fibre metal laminates. Clearly, it can be seen that woven type GFRP exhibited the highest energy absorbed as compared to unidirectional type GFRP. This is due to the fibre architecture which woven fibre was constructed by dual axis fibre orientation (weft and wrap) which subsequently would have resulted in more rigid structure that could handle more energy impacted on the specimens. So when the load was impacted thru the z-axis, the fibre fracture would react in both direction, hence created the diamond-shaped indentation on the surface as shown in Table-IV. While unidirectional was constructed only from single axis orientation which was 0^{o} degree hence resulted in less strength on surface impact. Hence, the surface damaged would clearly lateral with the direction of the fibre. This failure mechanism is called fibre splitting and matrix cracking along the fibre length. Chen et al. [8] also found the same damage behaviour where the indentations of woven fibre are resulted in diamond shaped cracks on the laminate represented by a ‘‘+” shape, while unidirectional fibre are resulted in ellipse shaped cracks on the laminate look like a fallen ‘‘I”. These failure mechanisms contribute to the amount of energy absorbed by the FML system, in which it is clearly can be seen that the woven fibre absorb more energy compared to unidirectional fibre during static indentation loading. Ahmed et al. [14] also reported that the woven type of fibre resulted in minimum deformation and maximum force and energy. He concluded that woven type composites have good ability to absorb large energy, while unidirectional type of fibre showed low energy absorption [14].

In comparing between FRP and FML systems, FML2 exhibits the highest energy absorption for both unidirectional and woven with 35.15J and 37.83J respectively. The inference would be due to the thickness of the 2mm metal within the laminates which resulted in better quasi static indentation properties of the specimens. In woven FMLs, the energy absorbed was increased by 349.73%, 155.79%, and 101.50% for WVFML2, WVFML1 and WVFML0.5, respectively as compared to WVGFRP. As for unidirectional, UDFMLs, the energy absorbed was improved by 439.34%, 189.78%, and 123.69% for UDFML2, UDFML1 and UDFML0.5, respectively as compared to UDGFRP. It can be concluded that the energy absorbed increased with increasing of Al sheet thickness that was used in FML fabrication. The 2mm thickness of Al sheet in FML system absorbed more energy as compared to 1mm and 0.5mm thickness of Al sheet in FML systems.

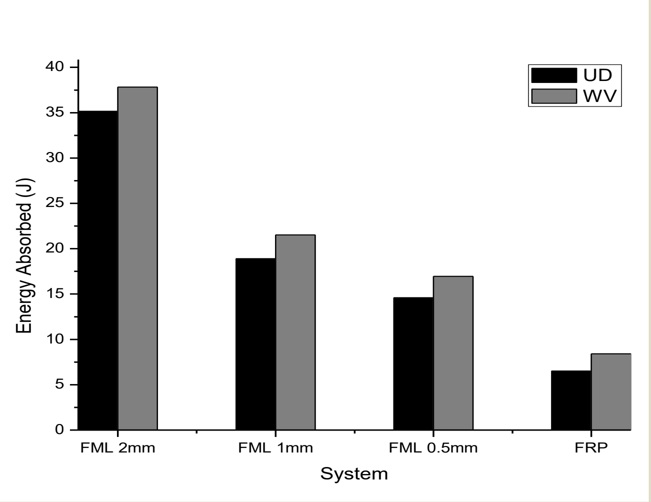

Fig. 6 Energy absorbed of FML under quasi static loading.

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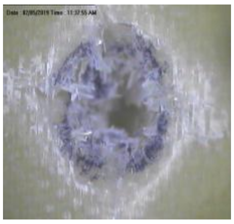
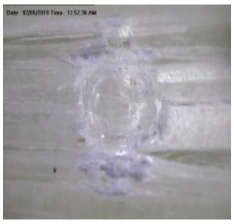
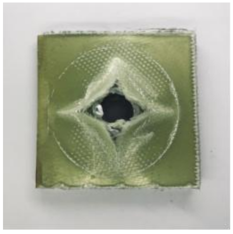
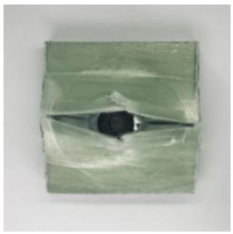
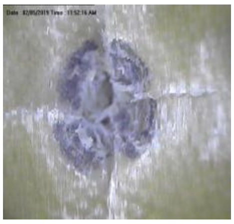
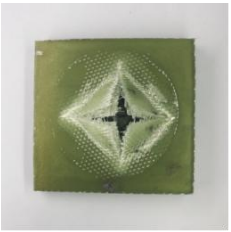
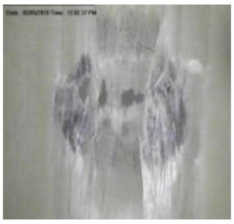
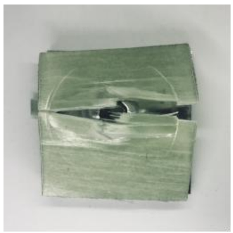
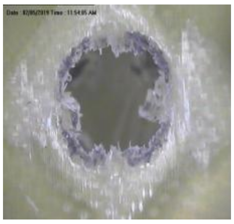
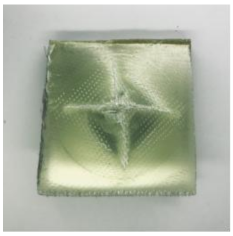
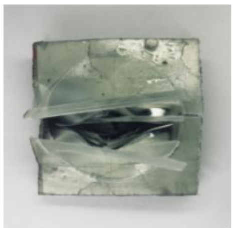
Table-IV Observation of damage surface after quasi-static loading for 8 different types of FRP and FML. (a) Woven and (b) Unidirectional types of GFRP and FML composites

(a) Woven type of GFRP			(b) Unidirectional type of GFRP		
Specimen	Front View	Back View	Specimen	Front View	Back View
WVGFRP	 d=0.9cm		UDGFRP	 d=0.5cm	
WVFML2	 d=1.0cm		UDFML2	 d=1.0cm	
WVFML1	 d=0.9cm		UDFML1	 d=1.0cm	
WVFML 0.5	 d=0.9cm		UDFML 0.5	 d=1.0cm	

IV. CONCLUSION

Throughout this research, all eight systems include GFRP and FMLs of both woven and unidirectional fibre glass have been tested in accordance to the quasi-static indentation standard. WVFML2 recorded the highest mechanical properties under quasi static loading compared to other FMLs and GFRPs. For woven FMLs, there were increments in energy absorption of 349.73%, 155.79%, and 101.50% for WVFML2, WVFML1 and WVFML0.5, respectively as compared to WVGFRP. As for unidirectional, UDFMLs recorded increment in energy absorption of 439.34%, 189.78%, and 123.69% for UDFML2, UDFML1 and UDFML0.5, respectively as compared to UDGFRP. This is because of the thickness of aluminium sheet plays important role in absorbing the indentation energy, in which it was found that aluminium sheet of 2mm thickness used within the laminates tends to absorb more energy compared to 1mm and 0.5mm aluminium sheets.

By comparing the fibre architecture, woven glass fibre of GFRP and FMLs had better quasi static indentation properties as compared to the unidirectional glass fibre due woven fibre was constructed by dual axis fibre orientation (weft and wrap) which subsequently could handle more indentation energy.

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REFERENCES

1. S. Zhu and G. B. Chai, "Impact of aluminum, CFRP laminates, fibre-metal laminates and sandwich panels," in Conference Proceedings of the Society for Experimental Mechanics Series, 199-205, 2013.
2. M. Sadighi, R. C. Alderliesten, and R. Benedictus, "Impact resistance of fiber-metal laminates: A review," International Journal of Impact Engineering, vol. 49, pp. 77–90, 2012.
3. A. Seyed Yaghoubi and B. Liaw, "Thickness influence on ballistic impact behaviors of GLARE 5 fiber-metal laminated beams: Experimental and numerical studies," Composite Structures, vol. 94, no. 8, pp. 2585–2598, 2012.
4. T. Trzepiecinski, A. Kubit, R. Kudelski, P. Kwolek, and A. Obłój, "Strength properties of aluminium/glass-fiber-reinforced laminate with additional epoxy adhesive film interlayer," International Journal of Adhesion and Adhesives, vol. 85, no. May, pp. 29–36, 2018
5. N. A. Patil, S. S. Mulik, K. S. Wangikar, and A. P. Kulkarni, "Characterization of Glass Laminate Aluminium Reinforced Epoxy- A Review," Procedia Manufacturing, vol. 20, pp. 554–562, 2018.
6. C. Poon and P. V Straznicky, "Low Velocity Impact Damage In Glare"Conferences Proceding: The Thirteenth International Conference on Civil, Structural and Environmental Engineering Computing January 2011.
7. T. Sinmazçelik, E. Avcu, M. Ö. Bora, and O. Çoban, "A review: Fibre metal laminates, background, bonding types and applied test methods," Materials & Design, vol. 32, no. 7, pp. 3671–3685, 2011.
8. Q. Chen, Z. Guan, Z. Li, Z. Ji, and Y. Zhuo, "Experimental investigation on impact performances of GLARE laminates," Chinese Journal of Aeronautics, vol. 28, no. 6, pp. 1784–1792, 2015.
9. A. Vlot and M. Krull, "Impact Damage Resistance of Various Fibre Metal Laminates," Journal de Physique IV, 1997.
10. M. Ardakani, A. Khatibi, and H. Parsaiyan, "An experimental study on the impact resistance of glass-fiber-reinforced aluminum (Glare) laminates," 17^{th} International Conference on Composite Materials, Edinburgh, UK, 2009.
11. A. P. Sharma and S. H. Khan, "Influence of metal layer distribution on the projectiles impact response of glass fiber reinforced aluminum laminates," Polymer Testing, vol. 70, no. May, pp. 320–347, 2018.
12. H. Ahmadi, H. Sabouri, G. Liaghat, H. Hadavinia, and A. Abotorabi, "Quasi-Static Perforation of GLARE Fiber Metal Laminates," ICMIE2013, pp. 71–73, 2013.
13. M. Bulut and A. Erkliğ, "The investigation of quasi-static indentation effect on laminated hybrid composite plates," Mechanics of Materials, vol. 117, no. July 2017, pp. 225–234, 2018.
14. P. S. Ahmed, B. M. Fadhil, A. Ali, and K. Mohamed, "Effect of Impactor Design on Unidirectional and Woven fiber Reinforced Composites," Sulaimani Journal for Engineering Sciences, vol. 3, no. 3, pp. 21-29, 2016.

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Dr. Aidah Jumahat has a PhD degree in Mechanical Engineering from the University of Sheffield United Kingdom, a MSc (Mechanical Engineering) degree and a B.Eng. (Hons.) Mechanical and Materials Engineering degree from the Universiti Kebangsaan Malaysia. She joined the Faculty of Mechanical Engineering UiTM as a lecturer in 2001. Currently, she is an Associate Professor at the Faculty of Mechanical Engineering and the Director at Community of Research Frontier Materials and Industrial Application (CoRe FMIA) Institute of Research Management and Innovation (IRMI) Universiti Teknologi MARA Shah Alam Selangor Malaysia. Dr. A Jumahat has been lecturing on Composite Materials, Finite Element Method, Mechanics of Materials, Manufacturing Processes, Product Design and Advanced Materials, which happens to be her areas of research interest. She has published more than 100 technical papers in journals and conference proceedings locally and internationally in these research areas. She is an esteemed member of the panel of judges for the International Invention, Innovation & Technology Exhibition (ITEX) since 2012 and an executive member of several professional bodies.

Muhammad Naim bin Mohd Najib completed his Bachelor Degree (Hons) in Mechanical Engineering from Universiti Teknologi MARA (UiTM) in 2019. His main research of interest is in fibres metal laminates. His final year project involved investigation on impact resistance and quasi-static indentation properties of woven and unidirectional glass-aluminium fibre metal laminates.

Napisah binti Sapiai obtained Bachelor of Material Engineering (2005) and Master of Science in Materials Engineering (2011) from School of Materials and Mineral Resources Engineering, Universiti Sains Malaysia, Pulau Pinang. She completed her PhD degree in Mechanical Engineering (2017) from Universiti Teknologi MARA, Shah Alam, Selangor. Her PhD involved investigation on mechanical and wear behaviour of CNT-modified kenaf and CNT-modified hybrid glass/kenaf composites. Her study had also been focused on the nanofillers, carbon nanotubes, surface modification via concentrated acid and three-aminopropyl Triethoxysilane, natural fibres and synthetic fibres. She had managed to publish 14 journals related to her field.