Failure Behaviour of Aluminium/CFRP Laminates with Varying Fibre Orientation in Quasi-static Indentation Test

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Abstract. The response of the aluminium/carbon laminate was examined by an experimental work. The investigation on fibre metal laminate behaviour was done through an indentation test in a quasi-static loading. The hybrid laminate was fabricated by a compression moulding technique and used two types of carbon fibre orientations; plain weave and unidirectional. The plain weave orientation is dry fibre, and unidirectional orientation is prepreg type fibre. The plain weave carbon fibre and aluminium alloy 2024-0 was laminated by using thermoset epoxy while the unidirectional carbon fibre was pressed by using a hot press machine and cured under a specific temperature and pressure. A compression moulding technique was used for the FML fabrication. The aluminium sheet metal has been roughening by a metal sanding method which to improve the bonding between the fibre and metal layer. The main objective of this paper is to determine the failure response of the laminate under five variation of the crosshead speeds in the quasi-static loading. Based on the experimental data of the test, the result of 1 mm/min in the plain weave CFRP has lower loading than unidirectional fibre which the value of both was 4.11 kN and 4.69 kN, respectively.

1. Introduction
A fibre metal laminate (FML) or also known as a hybrid laminate contains metal layers and composite materials [1]. The fibre metal laminate can be applied to many applications because of the fibre metal laminate can withstand the impacts, loadings and harsh environments for a long period. The combination of the metal layers and composite fibres produce superior characteristics such as fatigue and fracture. [2]. The fibre metal laminate started and applied in military application after the Second World War [3]. From the positive feedbacks of the application, the fibre metal laminate began the application widely in aircraft structures such as fuselage and wings [4]. The example of the application is in the Airbus A380 due to the improvement in fatigue, resistance to corrosion and impact and weight reduced nearly 794 kg [5, 6]. The other organisations such as NASA, Bombardier and EMBRAER interested in the substitution of the aluminium in a fibre metal laminate. The high strength and stiffness are a good combination and resulted in a great performance in space applications [7].
The debonding process between a sheet metal layer and composite fibre layer, delamination of the composite layers, fracture due to a plasticity behaviour of a metal commonly happen to a fibre metal laminate structure which because of the impact of a load and depended on the layup configurations [8, 9]. The process of curing by using an autoclave will take long hours of processing and required intensive of labour cost for the whole production [2].

The purpose of this paper is to compare the strength of two types of carbon fibre orientations under quasi-static indentation test.

2. Experimental work

The behaviour of a fibre metal laminate was studied based on the aluminium alloy 2024-0 sheets and unidirectional carbon fibre prepreg. The prepreg fibre was bonded to the two sheet metal layers. The surface of the aluminium alloy was treated with a metal sanding. The grit size of sandpaper is 80. The purpose of the metal sanding is for surface roughness. The surface roughness will increase the bonding strength of the sheet metal and glass fibre. The layup configuration of the FML is 2/1. The size and thickness of the FML are 150 mm x 150 mm and 2.00 mm. The FML was fabricated by a compression moulding technique. The glass fibre and aluminium alloy sheet metal alloy laminated by using the thermoset epoxy. A pressure was applied by placing a moderated load on it and cured in at room temperature for 24 hours. The experiment was setup as in Figure 1. The shape and size of the indenter are hemispheres and 12.7 mm as in Figure 2.

![Figure 1. The setup for quasi-static test.](image1)

![Figure 2. Hemispherical indenter.](image2)

3. Results and discussion

The damage area of the laminate depended on a cross speed of the quasi-static loading. The crosshead speed and the constituent materials, the 2024-0 aluminium alloy and carbon fibre reinforced polymer was in the present case. From the graph in Figure 3, it showed that the trending of failure on the fibre metal laminate became decreased when the cross speed was increased from 1 mm/min to 100 mm/min.
Figure 3. Graph of load against displacement of Aluminium/CFRP FML.

The failure process of the quasi-static indentation on the FML was investigated by examining the front surface and rear-surface of the impact damaged samples. The initial fracture onto the 2/1 FML by 1 mm/min cross speed. The experiment was handle by using Instron 3369 Universal Testing Machine. The 1 mm/min impact shown in a Figure 4a. The damaged area has been taken through an indentation stage by the indenter at a top surface of the aluminium alloy. At the second stage, there was a localize crack on the matrix. The failure of the matrix because of the preparation of layup process. The laminate start to bend because of the maximum load that acted on it and the laminate has a maximum bending. After that, there was a fibre breakage because of the maximum bending of the loading and the stiffness of the fibre. Then, there was an indentation on the bottom ply, aluminium alloy. The perforation of the laminate happened at the third stage of failure. The passage of the indenter through the target and produce a clean hole with a diameter that similar to the indenter. From the graph, the perforation involved a local ductility.

The higher cross speed resulted in a decrease of composite structure degradation. Besides that, there was a number of transverse cracks which increases the delamination of the laminate especially at the middle area of the specimen. The matrix crack also caused delamination of the laminate. When the testing was carried out with the highest cross speed of quasi-static loading it resulted in an extensive delamination at the middle part and bottom ply. When the cross speed increased, the deformation of the fibre metal laminate happened at the same time. The matrix of the laminate damaged caused by impact and the connection between matrix-fibre became degradation. The epoxy resin is brittle and has low resistance to the crack propagation. The crack happened at a high transverse shearing stress which connected with the contact force. The bending crack occurred easily if the volume of the matrix is higher than the volume of the fibre.
Figure 4. The visual result FML penetration based on different cross speeds.

In the Figure 4 showed a surface area of damages in the aluminium/carbon fibre laminate which based on different crosshead speeds of the indentation. The evaluation of a composite structure based on the damaged area. A delamination between a sheet metal and fibre layer normally found after cracking of the matrix and fibres. The damaged area on the FMLs was analysed and followed by increasing the crosshead speed of the indentation. The values of the damaged area were determined through an experimental. The values were compared based on the crosshead speed and a thickness of the laminate. The shape of damage for all specimens is same which called as petal pattern.

Figure 5. Graph of load against displacement in Aluminium/UD CFRP.

The failure process during the quasi-static indentation was recorded. The damaged samples were investigated by measuring the length of deflection and examined through a load-displacement curve. There was an initial fracture of the 2/1 FML by 1 mm/min crosshead speed. The testing was done by using a compression machine which the compression plate was replaced with an indenter. The damaged area has been taken through an indentation stage by the impactor at a first ply of the aluminium alloy. Based on the graph above, specimen 1 and 5 mm/min almost have same graph pattern. At the first stage, a load was acted on the FML until reached the maximum load. The load was caused the matrix started to appear and the sound of cracking could listen. When the continued load reached the second stage, the fibre started to delaminate. From the continued load, it was caused a sheet metal of first ply started to crack. The indenter started to perforate the metal alloy at first ply and the maximum bending happened. The maximum bending caused the fibre tend to break. This happened at the third stage. After the load reached to ultimate value, the indenter started to penetrate the FML and happened at the fourth stage. At this stage, the penetration of a sheet metal also depended on its ductility.
According to Figure 5, the higher crosshead speed resulted in an increase of composite structure degradation. Besides that, there was a number of transverse cracks which increases the delamination of the laminate especially at the middle area of the specimen. The matrix crack also caused delamination of the laminate. When the testing was carried out with the highest crosshead speed of quasi-static loading it resulted in an extensive delamination at the middle part and bottom ply. When the crosshead speed increased, the deformation of the fibre metal laminate happened at the same time. The matrix of the laminate damaged caused by impact and the connection between matrix-fibre became degradation. The epoxy resin is brittle and has low resistance to the crack propagation. The crack happened at a high transverse shearing stress which connected with the contact force. The bending crack occurred easily if the volume of the matrix is higher than the volume of the fibre.

![Figure 6](image)

**Figure 6.** The visual results of FML penetration based on the different crosshead speeds

Based on the Figure 6 showed the damaged surface area of aluminium/unidirectional carbon fibre laminate by various crosshead speed of the indentation loading. The evaluation of the damage FML depended on the surface area. The delamination between a sheet metal layer and a fibre layer was found after a cracking process in the matrix. These FMLs were tested by increasing the crosshead speeds. The measurement of the damaged area has been taken and recorded. The results were compared and analysed the reasons for failure. The pattern of failure looked like a petal. The maximum force values were evaluated by the experimental work under the quasi-static load. Through experimental records that have been made, the records were accompanied by the increasing of quasi-static crosshead speed and laminate thickness. The specimens of aluminium/unidirectional carbon fibre have the same thickness. The internal damage of the FML has been studied and concluded by this author, [10] the penetration and perforation energy was depending on the laminate thickness and cross-section size. Area of damage is a necessity to evaluate the composite laminate. The cracks formation and fibre breakage were recognised as a form of failure to the FML [11].

The cross-section of the laminates has been compared between of them. Based on the observation that has been made, damage contour in the sheet metal and composite fibre layers were mainly followed by a lower layer in a particularised composite interface. The diverse of fibre orientation could cause bending stiffness happened in different phases. The differences in bending stiffness referred to the anisotropy of mechanical properties in composite laminates. These have been related to Young’s modulus in the longitudinal and perpendicular direction of the fibre arrangement.
Greenhalgh has made a conclusion that the delamination would happen in the area with higher bending stiffness [12].

4. Conclusion
The current study describes the comparison of a 2/1 fibre metal laminate between plain weave CFRP and unidirectional carbon fibre. Both laminates have been fabricated in a different way. The aluminium/CFRP laminate was manufactured by using epoxy and hardener. Then it was cured at a room temperature for 24 hours. While the aluminium/unidirectional laminate was fabricated by using a hot press machine and it was cured at the specific condition. The technique of manufacturing for both laminates was same, compression moulding. These laminates have been tested under a quasi-static loading with difference crosshead speeds.

On the basis results that have been obtained through the experimental work, the behaviours of the laminates were investigated through a load-displacement curve. The high value of maximum load stipulated to the high resistance of the fibre metal laminates to the quasi-static indentation. The relationship between indentation crosshead speeds and the thickness of the laminate have been confirmed by the experimental research.

The evaluation of the damaged fibre metal laminate it is possible to compare the damaged surface areas by an experimental research. It has been found that increasing of crosshead speed would increase the damaged surface area. A detail observation on the cross-section of the fibre metal laminates was revealed by the presence of matrix cracking and delamination between composite layers as well as delamination at the metal-composite interface.

The laminate thickness was lead to degradation degree. The lower thickness of laminates would have greater deformation and lower metal layer cracking. A laminate increased with thickness was accompanied by decreasing the degree of laminate deformation and occurring delamination between the individual composite layers and delamination on the metal-composite interface.

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