RESPONSE OF FIBRE METAL LAMINATE UNDER LOW VELOCITY IMPACT

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Report

Projek Sarjana Muda I

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APPROVAL

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ABSTRACT

Fibre metal laminate (FML) composite is a widely used material as a structural application for automotive, aerospace, aircraft and ship due to its lightweight, low maintenance cost and outstanding strength to weight ratio. It is the new family of laminate composites which consists of thin metal layers that bonded together with the fibre-reinforce composite layer. In past decades FML had become an interest in modern industry. This is because hybridisation of both natural and synthetic fibre enhances the mechanical properties and environmental performance. Furthermore, FML has low production cost and are used in wide applications. Therefore, to implement the usability of FML an understanding of its mechanical properties should be investigated. Therefore a study had been carried out to find the properties of this FML with its hybridisation composite under a low velocity impact test where and experimental and numerical had been carried out it this study. The variable used in this study is the stacking sequence of the fibre composite in the FML where there will be four stacking sequence (GGG, GPG,PGP,PPP) for the experimental investigation. For the numerical analysis, the variable would be the metal thickness of how those the metal thickness play a role is changing the properties of the FMLs. From the study, it had found out that FML with the stacking configuration of GPG able to a suitable substitute for FML with the configuration of GGG due to its similarity it most of its properties analysis and for the metal thickness the optimal thickness that can used for the shell of the FML would be 1.0 mm where too thick of the metal will cause a higher chance of delamination to occur where else too thin of the metal would cause perforation to occur easily on the FML

ABSTRAK

Komposit laminasi logam adalah bahan yang banyak digunakan di dalam aplikasi automotif, aeroangkasa, pesawat dan kapal kerana keringanan, kos penyelenggaraan yang rendah dan nisbah kekuatan dan berat yang luar biasa. Ini adalah salah satu keluarga komposit lamina baru yang terdiri daripada lapisan logam nipis yang dicantumkan bersama dengan lapisan komposit penguat serat. Dalam beberapa dekad yang lalu komposit laminasi logam telah menjadikan minat dalam industri moden. Ini kerana hibridisasi gentian semula jadi dan sintetik meningkatkan sifat mekanikal dan prestasi persekitaran. Tambahan pula, FML mempunyai kos pengeluaran yang rendah dan digunakan dalam aplikasi yang luas. Oleh itu, untuk melaksanakan kebolehgunaan FML, pemahaman mengenai sifat mekaniknya harus diselidiki. Oleh itu, kajian telah dilakukan untuk mencari sifat FML ini dengan komposit hibridisasi di bawah ujian hentaman halaju rendah di mana dan eksperimen dan numerik analisi telah dilakukan dalam kajian ini. Ubahan yang digunakan dalam kajian ini adalah urutan susunan komposit serat di FML di mana akan ada empat urutan susunan iaitu (GGG, GPG, PGP, PPP) untuk penyelidikan eksperimen. Untuk analisis berangka ubahan yang dilakukan ialah ketebalan logam iaitu bagaimana ketebalan logam memainkan peranan mengubah sifat FML. Dari kajian tersebut, didapati bahawa FML dengan konfigurasi susun GPG dapat menjadi pengganti yang sesuai untuk FML dengan konfigurasi GGG kerana kesamaannya dengan kebanyakan analisis sifatnya dan untuk ketebalan logam optimum yang dapat digunakan untuk cengkerang FML akan menjadi 1.0 mm di mana tebal logam yang terlalu tebal akan menyebabkan pemisahan yang lebih tinggi di mana yang unuk terlalu tipis logam akan menyebabkan perforasi berlaku dengan mudah pada FML.

ACKNOWLEDGEMENT

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LIST OF ABBREVIATIONS

FML	Fiber Metal Laminate
LVI	Low Velocity Impact
GGG	Glass/Glass/Glass epoxy composite
GPG	Glass/Pineapple/Glass epoxy composite
PGP	Pineapple/Glass/Pineapple epoxy composite
PPP	Pienapple/Pineapple/Pineapple epoxy composite

LIST OF SYMBOL

E	Young's modulus
G	Shear modulus
ν	Poisson's ratio
X_t	Ultimate tensile stress
X_c	Ultimate compressive stress
S	Ultimate shear stress

CHAPTER 1

INTRODUCTION

1.1 Background

Fibre metal laminate (FML) composite is a widely used material as a structural application for automotive, aerospace, aircraft and ship due to its lightweight, low maintenance cost and outstanding strength to weight ratio. Fibre metal laminates (FML) was developed at Delft University of Technology in The Netherlands during the beginning of the 1980s. (Asaee, Shadlou and Taheri, 2015). It is the new family of laminate composites which consists of thin metal layers that bonded together with fibre-reinforce composite layer. (Salve, Kulkarni and Mache, 2016).

From its superior characteristic, it had lured many interests in researchers to carry out a study on FML which had led them in exploring hybrid composite. Hybrid composites are the combination of different type of fibres bonded together by its reinforcement. This hybridization commonly usually occurs between natural fibres and synthetic fibres(Akil *et al.*, 2011). Both fibres have their advantages and disadvantages. For an instant natural fibre are much cheaper and environmentally friendly than synthetic fibres where else synthetic fibre have a better mechanical property. By combining both fibres in the same matrix of the composite it will result in full advantage of the best properties of the constituents, and thereby an optimal, superior but economical composite can be obtained.

Therefore, throughout the years, several types of FML had been introduced base on the metal plies. Figure 1 shows the classification of the FML's.

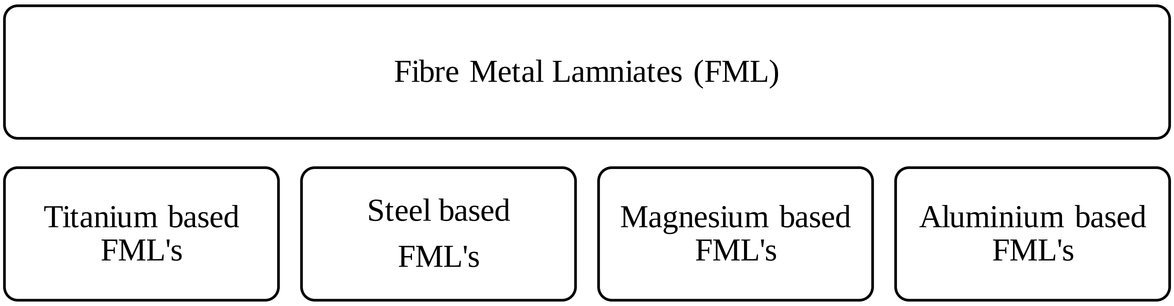


Figure 1. 1: Classes of FML’s

These days the widely used fibre metal laminate is glass-reinforced aluminium laminate (GLARE), based on high-strength glass fibres. This is due to its superior damage tolerance, better corrosion resistance, better fire resistance, and lower specific weight when compared to its metal (Wu and Yang, 2005). Therefore, a better understanding must be done on GLARE on its damage tolerance and strength to widen its usability based on complex applications.

1.2 Problem Statement

In past decades FML had become an interest in modern industry. This is because hybridisation of both natural and synthetic fibre enhances the mechanical properties and environmental performance. Furthermore, FML has low production cost and are used in wide applications. Therefore, to implement the usability of FML an understanding of its mechanical properties should be investigated.

1.3 Objectives

The objectives of this project are as follow:

1. To investigate the behaviour of FML with different woven lay-up of pineapple/glass fibre reinforcement composite which is subjected to low velocity impact.
2. To build a finite element model of FML for low velocity impact test.
3. To investigate the effect of metal thickness on FML that is subjected to low velocity impact.

1.4 Scope of Project

The FML test specimen for this project was prepared with different woven lay-up of pineapple/glass fibre reinforcement composite with the sample size of 150mm ×100mm. This sample is then tested under low velocity impact according to ASTM D7136. Then a finite element software ABAQUS/Explicitis was used for the simulation of low velocity impact on FML with a different metal thickness which consists of glass epoxy composite with the modal size of 150mm ×100mm. The results that had been obtained from both tests were be compared and analysed to find the optimal laminate composite layout.

CHAPTER 2

LITERATURE REVIEW

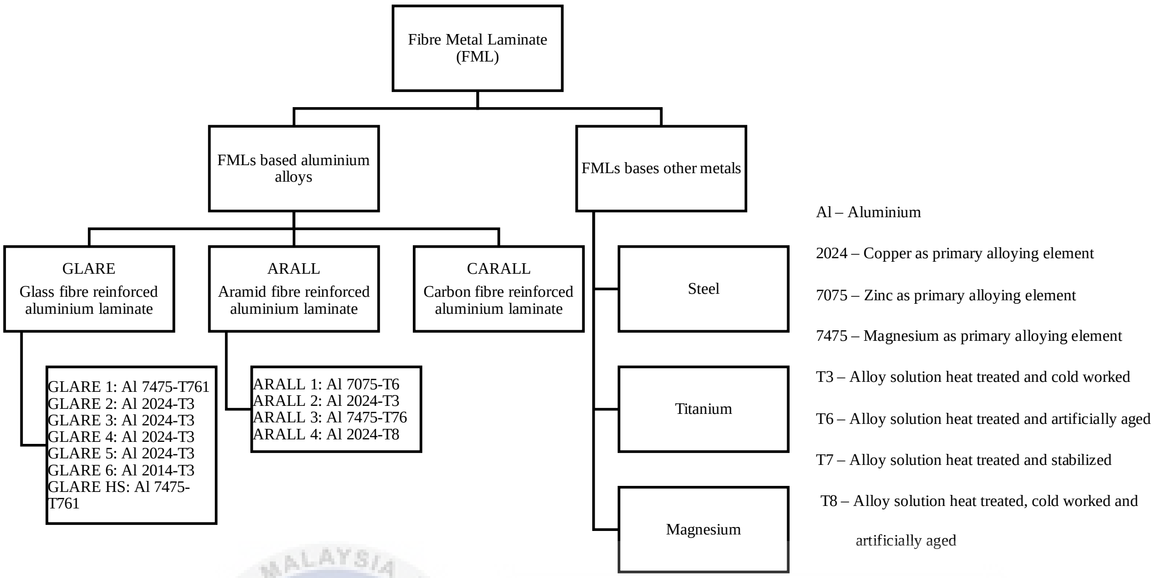
2.1 Introduction

This research literature review is the most crucial part that able to provide a proper understandings and guidelines base on the previous study that had been done regarding the research. The aim of this chapter is to widen the understandings and comparing the research of different authors on fibre metal laminate (FML) base on its constituents, mechanical properties, investigation on low-velocity impact test and compression strength after impact.

2.2 Fibre Metal Laminate

Fibre metal laminate or known as FML is a family of hybrid composite structure which having metal sheet bonded together with fibre reinforced polymer composite. The outside layer of a fibre metal laminate is a metal sheet shielding the fibre reinforcement polymer from moisture and scratches (Zhu and Chai, 2012). The polymer can be classified into two categories which are thermosets and thermoplastic. The most commonly used thermosets are phenolic, epoxy and polyester resins where else, on the other hand, the most commonly used thermoplastic is polypropylene (PP), polyethene (PE) and polyvinyl chloride (PVC).

Throughout the years' fibre metal laminate had grown major interest among the researches due to increasing demand for its superior lightweight, durable, and damage



tolerance material (Zhen, 2015). The common metals that are been used to fabricate fibre metal laminate are aluminium, magnesium, or titanium and the common composite reinforcement are glass fibre, carbon-fibre, or kevlar. Figure 2.1 shows the type of FML's that had been developed base on its metal and reinforcement.

Figure 2. 1: Type of FMLs where 'Al xxxx' defines the major aluminium alloying constituent and 'Txxx' demonstrates the type of heat treatment and tempering performed to the alloy solution (Das *et al.*, 2016).

Fibre metal laminate has optimal fatigue and fracture properties of fibre reinforced composite and superior durability characteristics of metal while at the same time eliminates their drawbacks (Zhen, 2015). Mechanical properties of the fibre metal laminate are influenced by certain factors such as the type of metal being used, matrix reinforcement, metal volume fraction and fibre volume fraction. Metal volume fraction (MVF) is defined as the ratio of the sum of the individual metal thickness to the thickness of the fibre metal laminate. The material properties base on metal volume fraction is determined by:

$$FML\ property\ = MVF + Metal\ Property + (1 - MVF) \times Fibre\ propert \qquad (1)$$

This equation can predict the tensile strength yield of the fibre metal laminate with a range of $0.45 < MVF < 0.85$ with the accuracy experiment results of 5% (Zhu and Chai, 2012). The fibre content in the composite also plays an important role in the mechanical properties where it enhances the impact resistance as the fibre percentage increase (Zhen, 2015). Fibre that aligned in loading direction is found to be having an improve considerably the modulus of elasticity, yield strength and ultimate tensile strength of the fibre metal laminate (Zhu and Chai, 2012). This shows that the orientation of the fibre is important in the fabrication of the fibre metal composite base on the applications. Figure 2.2 shows the composite reinforcement types.

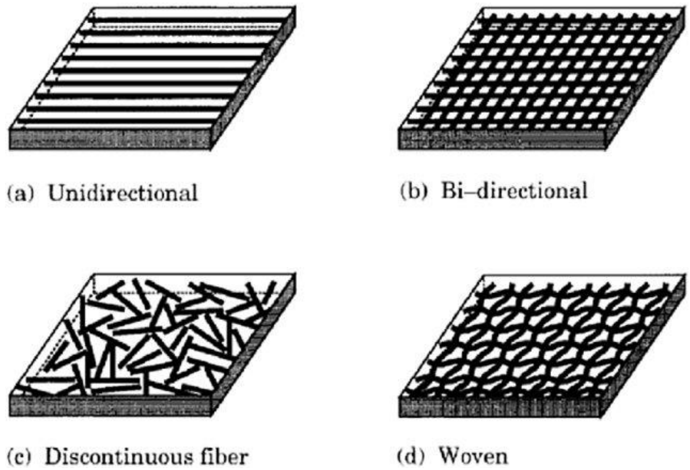
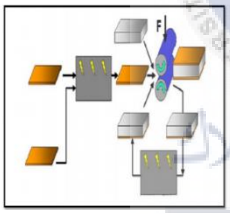
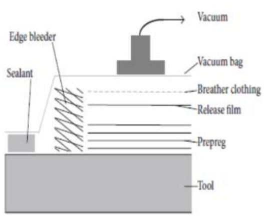


Figure 2. 2: Composites reinforcement types (Tawfik *et al.*, 2017).

There are several ways to fabricate fibre metal laminates. The fabrication process is depending on the type of reinforcement being used and the type of matrix used. Fabrication consists of four steps which are pre-treatment, preparation of prepreg, production of FML and post-treatment. Firstly, pre-treatment is required to obtain a proper bonding of the metal plate with the reinforcement. Secondly, is the manufacturing of the prepregs where the fibre is manufacture by a desirable dimension and is pre-impregnated with either thermoplastic or thermoset resin matrix with a certain ratio under a suitable designated curing condition. Then moving on with the fabrication of the fibre metal laminate where there are many methods of fabricating: hand layup, stamp forming, autoclave and Resin Transfer Moulding (RTM). Finally, is the post-treatment of the fibre metal laminate where the curing process of the resin that had been introduced into the reinforcement (Logesh *et al.*, 2017). Table 2.1 describes the

Fabrication method	Descriptions
Hand Layup 	i. The reinforcement is usually in the form of fabrics, fibres, or powders where it is been mixed with resin and being bonded with metal skin. ii. A moderated amount of pressure is applied to the skin in the form of pressing by hand or roller. iii. Enough time is allowed for proper bonding.
Stamp Forming 	i. Stamp forming is similar to hand layup technique except heavy force is applied for the bonding process. ii. The laminate and the prepreg are arranged as desired over the cavity of a blank and pressure is applied. iii. The design of the FML is based on the shape of the die used.
 Autoclave	i. The prepregs and the polythene sheets are stacks between one another between a pre-treated metal laminate. ii. Then it is placed into the autoclave and vacuumed. iii. Pressure and heat are then applied to enhance the bonding between the metal and the prepregs.

fabrication method of fibre metal laminate.

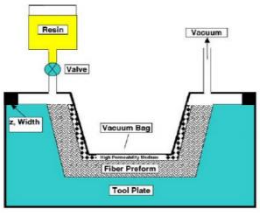
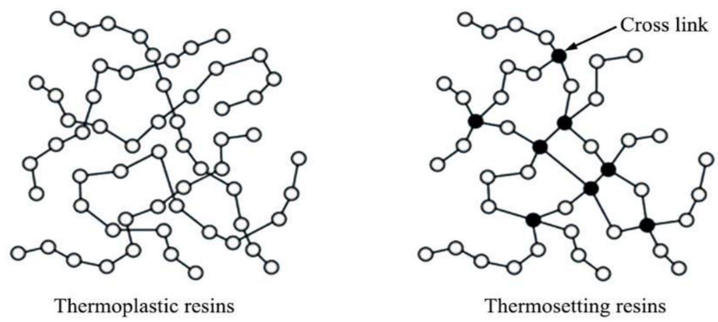
Resin Transfer  Moulding	i. The reinforcement and the metal skin are arranged and are placed into a mould. ii. The resin is then injected in to mould over the reinforcement with high pressure. iii. Then the FML is left for curing for retained its desirable properties.

Table 2. 1: Fabrication method of fibre metal laminate(Logesh *et al.*, 2017).

2.3 Matrix

Matrix is a medium that is used in making composite materials by embedding the reinforcement. The functions of the matrix are to transfer the load to the reinforcement of the composite and protect the reinforcement from mechanical and environmental damages. Three classifications of the matrix's being used which are a metal-ceramic matrix, metal matrix, and polymer matrix. In this review, polymer matrix would be the main interest due to certain advantages that gives the composite which is highly specific strength and high specific modulus.

The polymer matrix can be classified into two main groups which are thermoset (e.g., Polyester, Epoxy, Phenolic resins, etc.) and thermoplastics (e.g., Polypropylene, Polyethylene, Polyvinylchloride, etc.). It is known that the processing of thermoset composite



is much easier compared to thermoplastic due to the presence of the initial resin system in a liquid state where thermoplastic composite required an application of higher heat and pressure (Dogan and Arıkan, 2017). Besides, it is known that thermosets have a higher strength and stiffness compare to thermoplastic but has a lower ductility. The ductility of the thermoset can be explained by the molecular structure of the thermoset which is bonded together with crosslink and held by a strong covalent bond where else for thermoplastic do not have a permanent crosslink which benefits it by reheating and reshaping (Karuppiah and Engineering, 2016). Figure 2.3 shows the difference in the molecular structure of thermoplastic and thermoset.

Figure 2. 3: Molecular structure of thermoplastic and thermoset (Karuppiah and Engineering, 2016)

The distinguishing characteristic of thermosets compares to a thermoplastic that thermoset polymer cannot be remoulded or reform after the hardening process and this has given an advantage to thermoplastic. Therefore, it can be stated that thermosets are stiffer and strong compare to thermoplastics.

2.4 Reinforcement

Reinforcement composite gives a superior mechanical property to the composite. Most commonly phases of reinforcement will be fibre, particles, and flakes. The usually used reinforcement can be categorised into two classes which are synthetic fibre and natural fibre. Figure 2.4 shows the classification of natural and synthetic fibres.

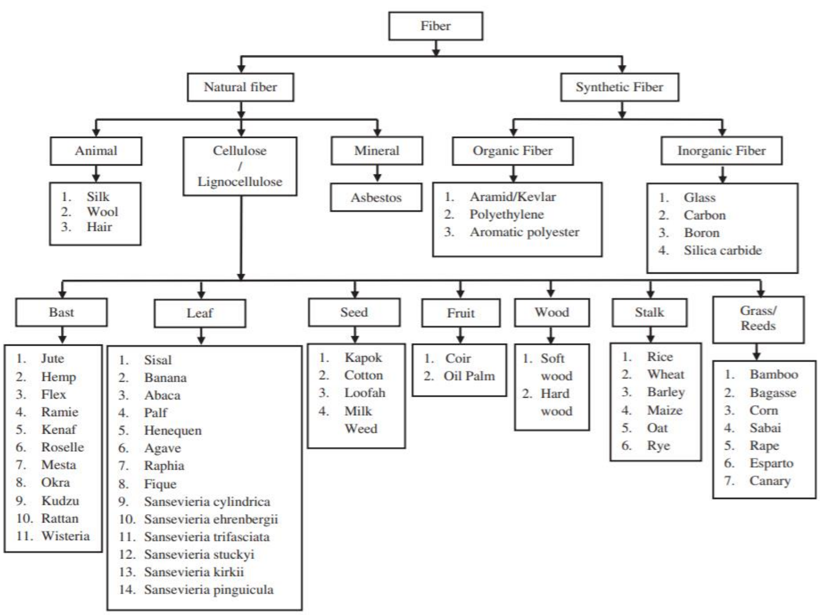


Figure 2. 4: Classification of natural and synthetic fibres (Jawaid and Abdul Khalil, 2011).

2.4.1 Synthetic Fibre

Synthetic fibre is known as a man-made fibre made from synthesized polymers or other small inorganic molecules). It was usually known that synthetic fibre has better mechanical properties compared to natural fibre. Synthetic fibre had been improved by scientists as a replacement option for metallic material. The main advantage of synthetic fibre is that it has high tensile modulus, ultimate strain, and low specific gravity but the downside of it is that they are not recyclable after the end of the lifespan. Figure 2.5 shows the classifications of synthetic fibres.

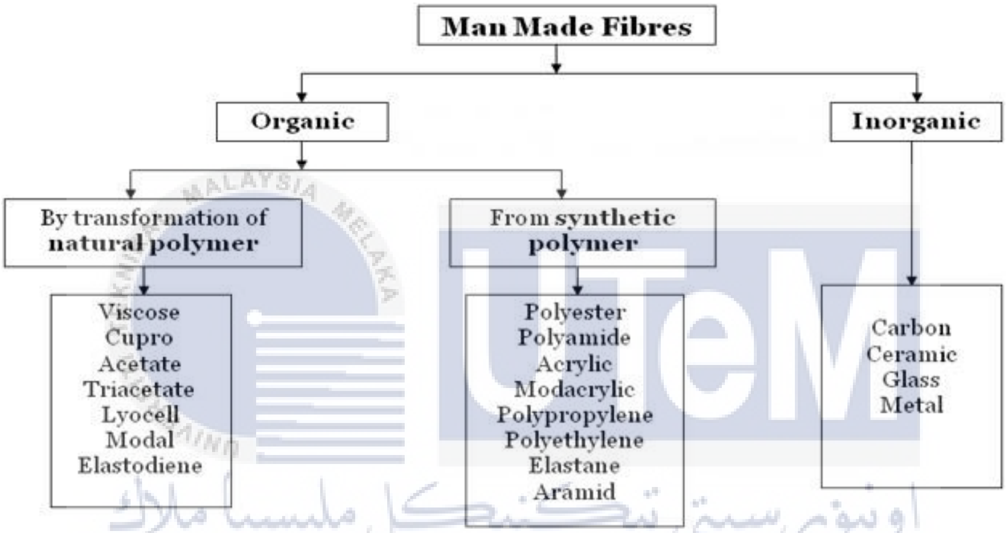


Figure 2. 5**:** Classifications of synthetic fibres (adapted from https://goo.gl/pUqixR).

2.4.1.1 Glass Fibre

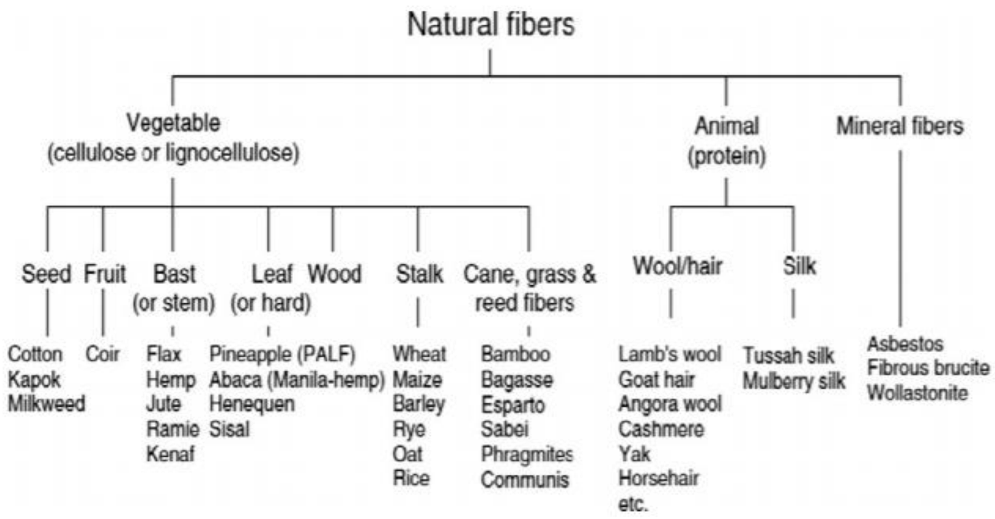
Glass fibre falls under the classification of synthetic fibre. Glass fibre is known to be one of the most famously used fibre among the others due to low-cost fabrication with comparable properties with other fibres. The fabrication process of fibre glass is that glass will be placed into the furnace and heated up to a very high temperature while the furnance temperature is kept control to attain a consistency glass flow. Once the molten glass is formed it will be extruded to fibre form (Arunabha Batabyal, Ramesh Kumar Nayak, 2018).

The most commonly used fibre glass is E-glass which is alumina-borosilicate glass that mainly uses for glass-reinforced plastics.Glass fibre has characteristics of lightweight, high strength and known to be a robust material (Chan.at.el.2018). The use of glass fibre is usually for thermal insulation, electrical insulation, sound insulation, corrosion-resistant fabrics, high strength fabrics, etc (Arunabha Batabyal, Ramesh Kumar Nayak, 2018)

Throughout the research that had been done, it is found out that glass fibre has a very good of energy absorption during impact and crash tests even though they exhibit diffuse damage during loading (Wu and Yang, 2005). From another researcher, it had been also found out that glass fibre able to improve the tensile strength and modulus with the ratio of 40:60 of glass fibre to jute fibre for jute-glass fibre reinforce hybrid laminate (Drahansky *et al.*, 2016). This shows that fibre glass would be suitable to be used as a constituent of a hybrid reinforcement laminate.

2.4.2 Natural Fibre

Natural fibre had become an interest in researches over the decades due to having a great capability of recyclability compare to conventional glass and carbon fibre. Besides, due to increasing pressure from environmental activities, preservation of natural resources, attended the stringency of laws had lured to the development of natural materials (Jawaid and



Abdul Khalil, 2011). Figure 2.6 shows the classification of natural fibre.

Figure 2. 6**:** Classification of natural fibre (Akil *et al.*, 2011).

Researches that work in the area of natural fibre and their composite had found the drawback that is having a poor wettability, incompatible with some polymeric matrices, and high moisture absorption by fibre (Wambua, Ivens and Verpoest, 2003). Consequently, natural fibre also has its own advantageous over which are low in cost, low in density, comparable specific tensile properties, non-abrasive to the equipment, non-irritation to the skin, reduced energy consumptions, and biodegradable (Ku *et al.*, 2011). Table 2.2 shows the comparison of natural fibre with synthetic fibre.

	Natural Fibre	**Synthetic Fibre**
Density	Low	Twice that of natural fibre
Cost	Low	Low, but higher than Natural fibre
Renewability	Yes	No
Recyclability	Yes	No
Energy Consumption	Low	High
Distribution	Wide	Wide
CO_2 neutral	Yes	No
Abrasion of machine	No	Yes
Health risk when inhaling	No	Yes
Disposal	Biodegradable	Non-Biodegradable

Table 2. 2**:** Comparison of natural fibre with synthetic fibre (Wambua, Ivens and Verpoest, 2003).

2.4.2.1 Pineapple Fibre

Pineapple fibre had been a recent focus to researchers and industry as a replacement for fibre glass fibre. This is because pineapple leaf fibre or known as PALF is being utilised effectively in the polymer matrix to develop composites with improved mechanical strength (Asim *et al.*, 2015).PALF is to be known to have higher inherent tensile properties compare to kenaf due to having a higher cellulose content, lower microfibrillar angle and ribbon-like orientation of its microfibrils, which provides it with spring-like extension in tension and compression(Aji *et al.*, 2013).

However, compare to kenaf fibre, PALF fibre, with its very high cellulose content is highly susceptible to degradation because of its gross water uptake which results in poor interfacial bonding which will affect the mechanical properties of the composite(Aji *et al.*, 2013).PALF is known to have high specific strength, rigidity, and flexural and torsional rigidity as much as jute fibres (Asim *et al.*, 2015). PALF has many chemical constituents like α-cellulose, pentosans, lignin, fat and wax, pectin, nitrogenous matter, ash content, degree of polymerization, the crystallinity of α-cellulose, and antioxidants. Table 2.3 shows the chemical composite of PALF and Table 2.4 Physical and mechanical strength of PALF.

Cellulose content (%)	Hemicellulose (wt.%)	Lignin content (%)	Pectin (wt.%)	Holocellulose	Moisture content (wt.%)	Extractives	Ash (%)	Fat & wax
85	—	12	—	—	—	—	—	—
70–82	—	5–12	—	—	11.8	—	—	
67.1–69.3	—	14.5–15.4	—	—	—	—	1.21	—
68.5	18.8	6.04	1.1	—	—	—	0.9	3.2
69.5	—	4.4	1.2	—	—	—	2.7	4.2
69.5	—	4.4	1.1	—	—	—	0.9	3.3
70–80	—	5.0–12.7	—	—	11.8	—	—	3.3
74.33	—	10.41	—	80.68	—	6.6 8	4.73	—

Table 2. 3: Physical and mechanical strength of PALF (Asim *et al.*, 2015)

Table 2. 4**:** Chemical composite of PALF (Asim *et al.*, 2015).

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The mechanical method and retting method were used in the extraction of pineapple fibre. Usually, fresh leaves yield about 2 to 3% of fibres and the fibrous cell of PALF consists of a vascular bundle system in the form of bunches which is obtained after mechanical removal of the entire upper layer after harvesting (Asim *et al.*, 2015). Figure 2.7 illustrates

Density (g/							Microfibril angle
1.52							—
1.526							—
1.44							—
1.526							—
1.07							—
	413–1627	34.5–82.5	—	—	1.6	20–80	14
1.526	170	6.260	—	—	3	—	—
1.52	170	6.21	—	—	3	—	—
1.07	126.60	4.405	—	—	2.2	—	—
1.526	413	6.5	—	—	1.6	30–60	—
1.526	170	62.10	—	—	3	—	—
1.44	413–1627	34.5–82.51	—	—	—	20–80	8–14
1.44	413–1627	34.5–82.51	—	—	1.6	20–80	—
1.44	170	6.26	—	—	1.6	5–30	12
1.526	413	4.2	—	—	3.0–4.0	50	14
1.440	—	—	—	—	—	1.56–4.5	8–15
—	293.08	18.934	—	—	1.41	150–300	—

the production of pineapple fibre.

Figure 2. 7**:** The production of pineapple fibre (Asim *et al.*, 2015).

2.5 Mechanical Properties

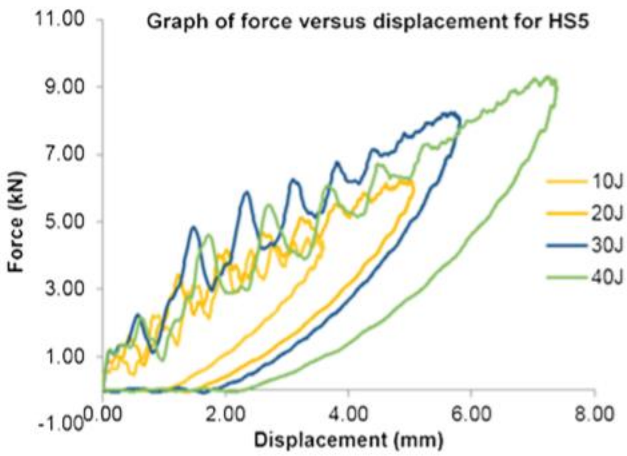
The aim of the research is to identify the mechanical properties of the fibre metal laminate through low velocity impact testing and the residual stress of the FML after the impact testing through compression testing. The performance of the FML can be caused by several factors which are a type of metal, composite, fibre, matrix, lay-up, metal volume fraction and fibre volume fraction (Zhen, 2015). It had been found that mechanical properties of the composite can be reduced significantly by low velocity impact and the residual stress after low velocity testing can reduce the compression strength up to 60% (De Moura *et al.*, 1997).

2.6 Low Velocity Impact

2.6.1 Composite

Based on (K. I. Ismail *et al.*, 2019) research had done by them to investigate the LVI and CAI of multi-walled carbon nanotube (MWCNTs) as nanofiller enhanced flax/carbon fibre composites (FLX-C) and flax/glass fibre composites (FLX-G) hybrid composites. In their finding under the investigation of displacement-time response, they had found out that there is a perforation that occurred at 15J impact energy on flax surfaces for FLX-C and FLX-G composite. Where else, for the impact on the carbon and glass surfaces the experience of perforation had occurred at the energy level of 20J impact energy which concludes that impact on a synthetic laminate is to be said more impact-resistant compared to a natural laminate in another words composite can withstand more impact energy on a synthetic laminate. Secondly, based on the velocity-time response they had found that for all the composite all graphs exhibited the same trend, where the velocity of the impactor decreases from the initial impact velocity to the residual penetration velocity. For force-time response hey had found an irregular behaviour (oscillation) that occurs from 10s onwards which indicates damage formation such as delamination. A smoother curve signifies less severe damage where the incident impact of 5J has a smoother curve than of incident impact of 15J which shows resultant damage from the incident impact of 5J is less severe. For the energy impact level of 20J, it shows a sudden drop at an energy impact level which proves specimen was penetrated by the impactor. For the energy impact level of 20J, it showed much oscillation which results in severe damage occurred on the specimen compared to a lower impact energy level. For the Force-displacement response for energy impact level of 5J and 10J for FLX-C and FLX-G composite and energy impact level of 10J and 15J for C-FLX and G-FLX composite, they had found out that has a closed-loop which means specimens did not experience any penetration, as the incident energy was fully transferred back to the specimen at the point of maximum and after the point of maximum the specimen had transferred the elastically stored impact energy back to the impactor. For the specimen that undergone full penetration displacement value did not return to zero. By this, it concludes that the maximum deflection of C-FLX is higher compared to that of FLX-C. In conclusion, it can be said that composite can withstand a higher impact on synthetic laminate and the value of absorbed energy for C-FLX was higher compared to that of G-FLX which means severe damage had occurred on C-FLX surface compared to that of G-FLX.

(M. F. Ismail *et al.*, 2019) had made a study to analyse the effect of hybridization of kenaf and glass fibre composite with varying weight ratios on low velocity impact response and the post-impact properties of the composites. They fabricated composite with different weight ratio is; (100% of glass fibre, 100% of kenaf fibre, 25% glass fibre +75% of kenaf



fibre, 30% glass fibre +70% of kenaf fibre, 50% glass fibre +50% of kenaf fibre, 70% glass fibre +30% of kenaf fibre, 75% glass fibre +25% of kenaf fibre). Before undergoing the low velocity impact testing on the specimens tensile testing was conducted on the composite and they had discovered that composite with the weight ratio of 75% glass fibre and 25% of kenaf fibre gives the best tensile properties and from there the specimen with this weight ratio had undergone low velocity impact testing. From this testing, they had discovered that the specimen can withstand up to 40J of impact with a peak impact load of and absorbed energy increased with the increase in incident impact energy. Figure 2.8 shows the force-displacement curve of the composite with the weight ratio of 75% glass fibre and 25% of kenaf fibre.

Figure 2. 8: Force displacement curve (M. F. Ismail *et al.*, 2019).

Base on (Ghelli and Minak, 2011) a study of Low velocity impact and compression after impact had been conducted on carbon/epoxy laminates with specimens of two different geometry (rectangular and circular).The impact energy that had been used for the low velocity impact is 6J, 12J and 18J. They had found that specimens with different dimensions and support fixture different impact response and damage. They had identified that more extended delamination had occurred on the smaller circular coupons than the larger rectangular even though they were subjected to the same impact energy. Besides, they had discovered stacking sequence had no effect on the behaviour of circular coupons where else on the rectangular plates differences on lay-up shows the difference in impact response and the failure modes. The stiffer configuration, which had external fibres parallel to the shorter side of the specimen, showed a similar delamination area but underwent more severe fibre damage, which was thought to be the reason for much larger energy absorption during impact. They also discovered the relation where the delamination area with absorbed energy and with maximum contact force measured during impact is to be independent of the test configuration and the stacking sequence.

2.6.2 Fibre Metal Laminate

(Oliver, 2013) had propose material and event-related parameters that influence the impact response of FMLs. Figure 2.8 Illustrates the parameter that influences the impact response of FMLs.

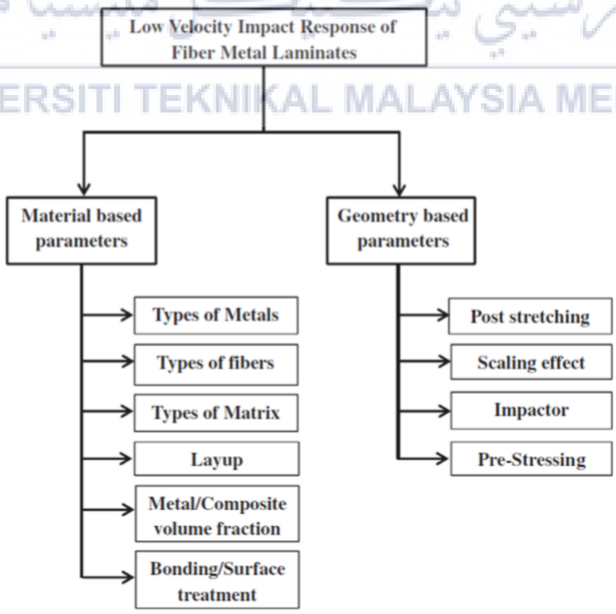


Figure 2. 9**:** Material and geometry event-related parameters that influence the impact response of FMLs (Oliver, 2013)

In his research, he had found that plasticity of the surface aluminium layers was dominant in energy-absorbing mechanism at low impact energies of 5 J and 8.2 J and when the energy had increased to 12.8 J to 19.5 J, the FML exhibited extensive metal plasticity in the form of front and rear crater damage, as well as aluminium cracking. Besides, he had found several modes of damage that had to occur on to the FML where the occurrence of matrix cracking, fibre failure, delamination and debonding. Figure 2.9 shows the Y-Z cross-section of damage mechanisms of FML.

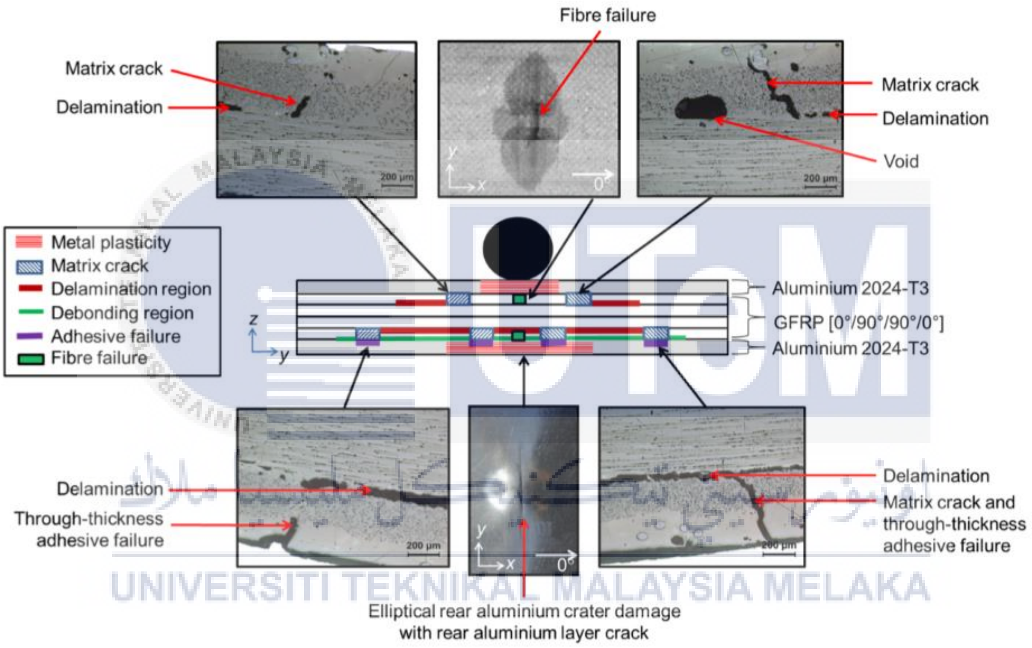


Figure 2. 10**:** Y-Z cross-section of damage mechanisms of FML under low-velocity impact (Oliver, 2013).

(Dogan and Arıkan, 2017) had an investigation on impact response of sandwich composite panels with thermoplastic and thermoset face-sheet where several low velocity impact tests were performed under various impact energies. In their finding, he had shown that bending stiffness of the thermoplastic samples is lower than that thermoset samples and this makes thermoset composite more rigid and stable, but load carrying and deformation capability of the thermoplastic face sheets are higher than thermoset. Besides they discovered that thermoset face sheets which subjected to impact loadings are needed more dense core materials, where else thermoplastic face sheets can be used with high deformation ability core materials. Thermoset face sheet with high-density core sandwich structure produces high contact force and low deformation values despite that thermoplastic face sheet with low-density core produces low contact force with high deformation.

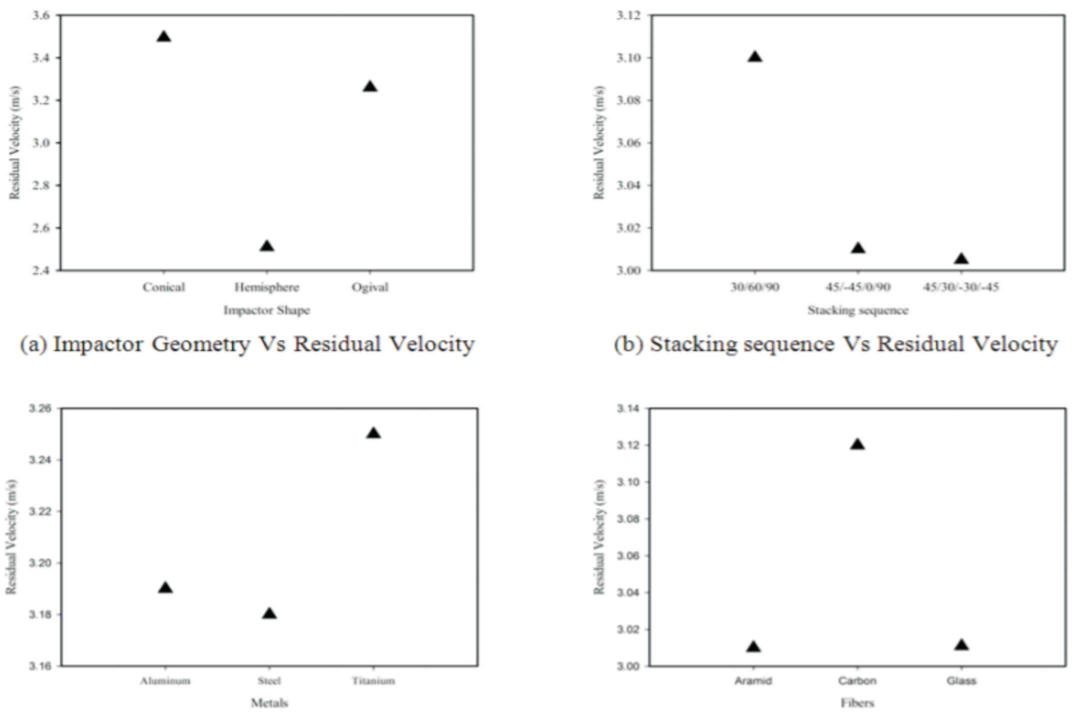
A numerical analysis of low velocity impact had been done on FML by (Balkumar *et al.*, 2016).Base on their study the Min focus of the researched is to identify the residual velocity of the impactor while the variable parameter is impactor geometry and the thickness of the FML plate with a different configuration of fibres. The aim of this study is to identify an optimal FML combination that provides a minimal residual velocity. To obtain the residual velocity, a few input parameters is been defined. Table 2.4 shows the input

Parameters	Level 1	Level 2	Level 3
FML Thickness (mm)	0.9	1.2	1.5
Stacking Sequence	0/30/60/90	45/-45/0/90	45/30/-30/-45
Type of Fibers	Glass/Epoxy	Aramid/Epoxy	Carbon/Epoxy
Type of Metals	Al -2024-T3	Ti-6Al-4V	AISI 4340
Impactor Geometry	Ogival	Conical	Hemispherical

parameter with their levels.

Table 2. 5:Process parameter and their levels. (Balkumar *et al.*, 2016)

Figure 2. 11: Residual velocity of glass epoxy based FML: a) impactor geometry, b) stacking



(a) Impactor Geometry Vs Residual Velocity

(b) Stacking sequence Vs Residual Velocity

(c) Metals Vs Residual Velocity

(d) Fibers Vs Residual Velocity

sequence, c) metals, d) fibres. (Balkumar *et al.*, 2016)

From computing this inputs and the results that had been generated from the aid of ABAQUS/Explicit, he found that from the perspective of the impactor geometry, conical chape impactor produces a higher residual velocity, following with ogival and hemispherical shaped impactor. From this what he had concluded based on the impactor geometry is that the FML provide maximum resistance to impactor only when the impactor has a blunt tip shape. Moving on, to the FML characteristic outputs, he found a finding that the fibre orientation plays a major role in compare to the fibre configuration when the FML is subjected to low impact velocity and from this finding he had justified that, ARALL, GLARE and steel based FML has a good impact resistance properties incomparable with other FMLs.

Following on to the research that had been done by (Asaee and Taheri, 2016) they had conducted a study on FML as well which is subjected to low velocity impact test through an experimental and numerical investigation through the aid of ABAQUS/Explicit software. The aim of their study is to investigate the influence of the stacking sequence of fibres and different thickness of FML from both the method. The focus of this investigation suggests and suitable FML stacking sequence and thickness of FML base on the strength, failure mode, stiffness and energy absorption. For their experimental work, the FML was fabricated with the metal plate of magnesium alloy and 3DFG fabric where the thickness varies for the 3DFG which are 4mm and 10mm where else for the numerical analysis the FML that had been modelled consist of Magnesium sheet, fibreglass plies and foam core. From their experimental investigation, they had found the FML with a thicker thickness provide a better energy absorption capacity as well the better stiffness and as for the numerical analysis it was found that for the FML that had a higher magnesium sheet ratio to glass fibre sheet ratio with the same FML thickness shows a higher contact stiffness and energy absorption capacity values.

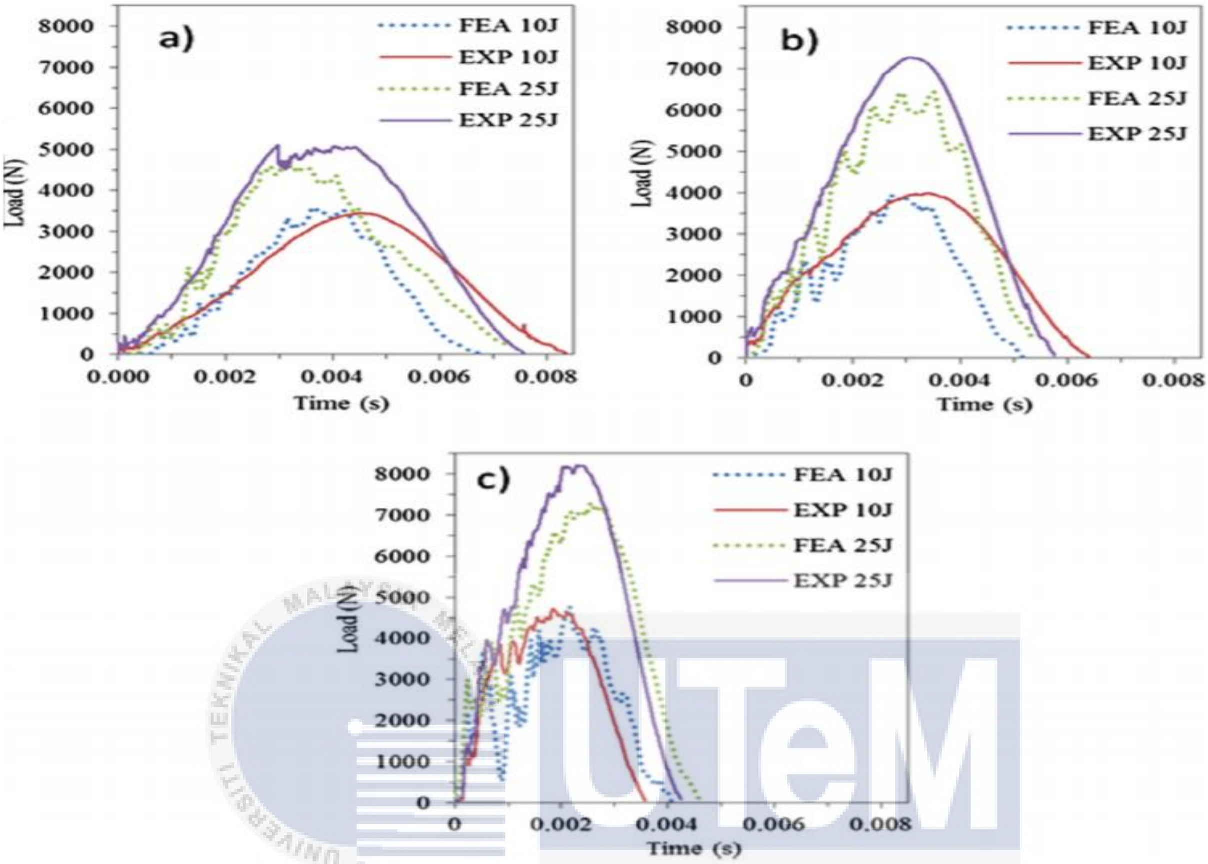
Based on (Fan, Guan and Cantwell, 2011) an investigation had been conducted by them by the aid of numerical modelling where and simulation is done on FMLs which were subjected to low velocity impact loading. The aim of this research is to focus on the FML failure mechanism and the perforation threshold with 2/1, 3/2, and 4/3 FMLs.In this research, the constituent of the FML consists of woven glass fibre composite and 2024-0 aluminium alloy. Table 2.6 shows the different configuration of glass fibre based FML that where conducted in their investigations.

Laminate	**Configuration**	**Nominal thickness (mm)**
2/1	2 Aluminium layers + 4 composite plies	1.4
2/1	2 Aluminium layers + 8 composite plies	1.8
3/2	3 Aluminium layers + 2×4 composite plies	2.3
3/2	3 Aluminium layers + 2×8 composite plies	3.1
4/3	4 Aluminium layers + 3×4 composite plies	3.2
4/3	4 Aluminium layers + 3×8 composite plies	4.4

Table 2. 6: Configuration of glass fibre based FML. (Fan, Guan and Cantwell, 2011)

From this different configuration of the FML modelling, they had said that the FML with a thicker nominal are more prone for delamination to occur even though it shows they have a better energy dissipation process. They found that as the thickness of the FML increases the perforation threshold of the FML increases which also goes as well for the increment of the composite layer. Another finding also found by them where the location of the impact doesn't really impact much on the impact response but increasing the plate size of the FML would significantly increase the perforation energy.

Based on, (Bienias, Jakubczak and Dadej, 2016) research, the had conducted an investigation of low velocity impact on aluminium glass laminate by experimental and numerical investigation. The purpose of their investigation is to investigate the reactions and the effected damage are of the FML under low velocity impact by the aid of numerical modelling with a comparison with an experimental result that done by them. This



investigation was carried out with a change of the FML layup of 2/1, 3/2, and 4,3 with its corresponding thickness of 1.5mm, 2.5mm, and 3.5mm at where the FML is made by using an alternative layer of AL 2024-T3 of 0.5mm with the composite layer of glass fibre/epoxy. Figure 2.12 shows their finding in comparison with the experimental and numerical analysis results with two energy level.

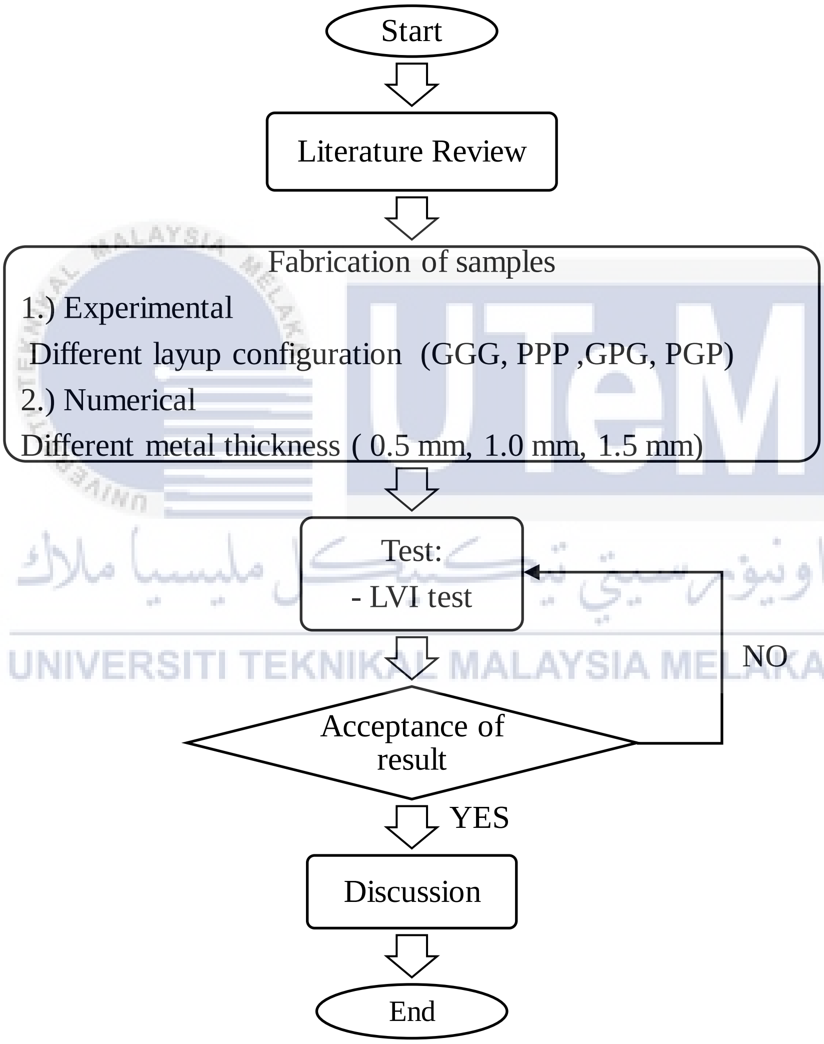
Figure 2. 12: Force-time graph of experimental and FEA of FML with a). 2/1, b). 3/2 and c). 4/3 lay-up. (Bienias, Jakubczak and Dadej, 2016)

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, the method and investigation of fibre metal laminated are being discussed by using two ways which are experimental and numerical method. This chapter consists of the fabrication method of the specimens physically and numerical modelling, and the way the experiment is conducted and the precaution that needs to be considered while conducting the experiment. The testing that had been conducted is being based on the specific standards from ASTM. Figure 3.1 shows a summary of the methodology in the form of a



flow chart.

Figure 3. 1: Flow chart of the methodology.

Experimental

3.2 FML

The specimen that is being fabricated in this investigation are hybrid and non-hybrid pineapple/glass fibre reinforcement composite. In the stacking sequence of the composite, the gram per meter square ratio of glass fibre to pineapple fibre is 1:2 due to the glass fibre having 600 g/m^2 and pineapple fibre of having 315 g/m^2 . Figure 3.2 illustrated the stacking sequence of fibres in the fibre metal laminate.

Aluminium sheet

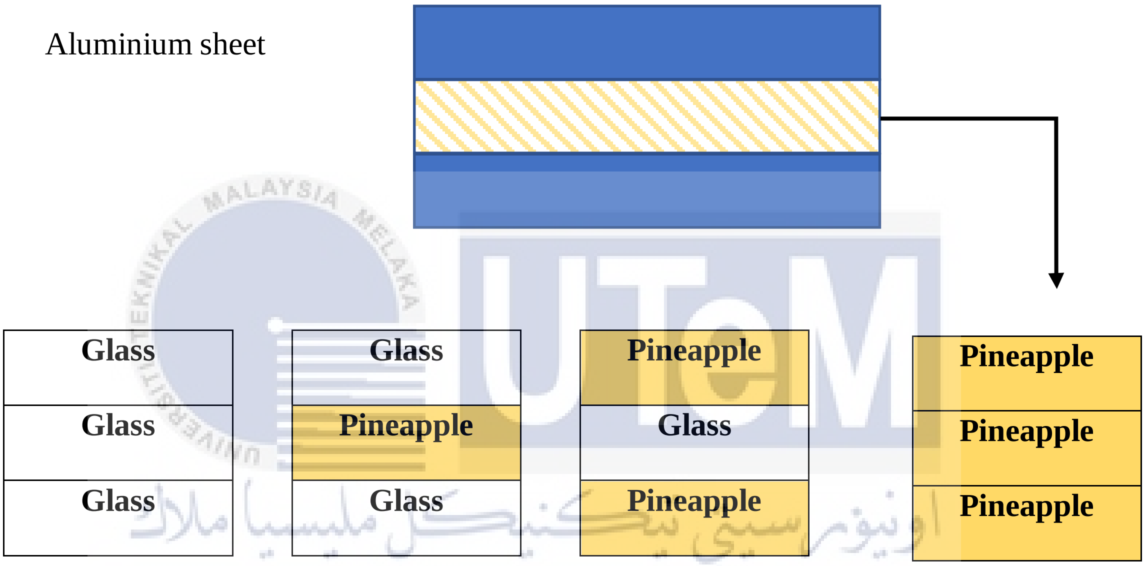


Figure 3. 2: Stacking sequence of fibre.

3.2.1 Epoxy

Hybrid/ Non-hybrid composite

Aluminium sheet

Epoxy is considered a classification of thermoset. The advantageous of using epoxy is

that it is easy to be handled due to the present phase of liquid. Besides, the fabrication process can be done under room temperature which would be unnecessary for any external heat. In the fabrication process, the type of epoxy that had been used is EpoxAmite 102 that were supplied by Multifillla (M) Sdn. Bhd which has to cure time of 10 to 15 hours under room temperature and also have a pot life of 20 minutes which would be a suitable timing for conducting the fabrication of the fibre metal laminate. The mixture volume ratio of the epoxy and the hardener is 1:3. Figure 3.3 shows the physical properties of the combination of EpoxAmite 100 and 102 Hardener.

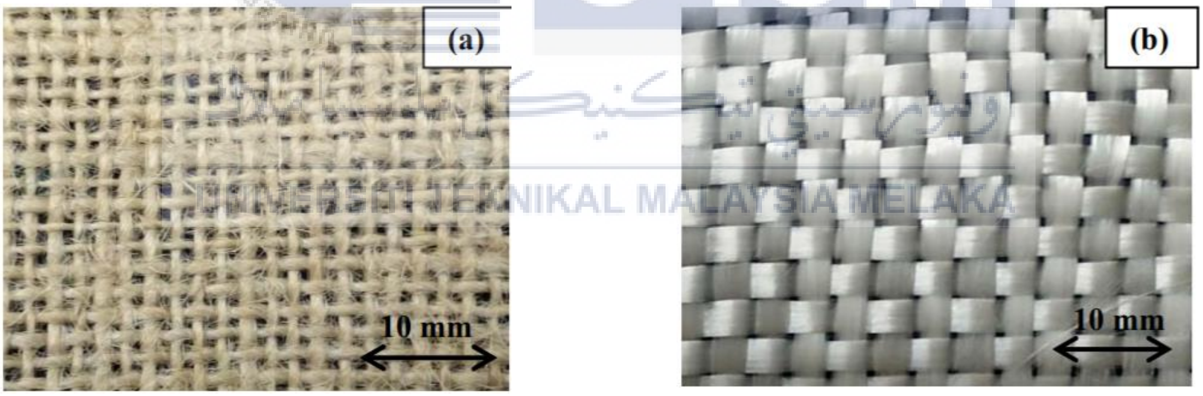
Figure 3. 3**:** Epoxy and hardener.

Physical Properties	**Psi**	**Pa**
Flexural strength (ASTM D790)	12,220	84.25×10^{6}
Flexural modulus (ASTM D790)	423,000	2.91×10^{9}
Ultimate tensile strength (ASTM D638)	8180	56.4×10^{6}
Tensile modulus (ASTM D638)	450,000	3.1×10^{9}

Table 3. 1**:** Physical properties of the combination of EpoxAmite 100 and 102 Hardener.

3.2.2 Fibres

In the fabrication process, the type of fibres that had been used is woven glass fibre (synthetic fibre) with an areal weight of 600 g/m^2 which was supplied by ZKK Sdn Bhd and woven pineapple fibre (natural fibre) with an areal weight of 315 g/m which was provided by Mecha Solve Engineering, Malaysia. For the pineapple fibre preparation, the fibre was first undergoing NaOH treatment to ensure that can have good interfacial adhesion between the fibres and the matrix. This process is done by soaking the fibre in a 0.5 mol/L NaOH solution for about 2 hours and were washed for several times with running water to remove the impurities from the fibre. Later on, the treated natural fibre is dried at room temperature for 24 hours before it is oven dried for 80°C till it is fully dried which is determined by weighing the weight of the fibre until the weight reading is constant. The both fibres are then cut into a dimension of 200 mm × 200 mm. Figure 3.5 illustrates woven glass and pineapple fabric



respectively.

Figure 3. 4: Woven pineapple fibre (a) and woven glass fibre pineapple fibre (b).

Properties	PALF	Glass fibre
Tensile strength (MPa)	170 – 1627	2000 – 3500
Tensile modulus (GPa)	60 – 82	70 – 76
Strain at break (%)	1 – 3	1.8 – 4.8

Density (g/cm3)	1.5	2.5

Table 3. 2**:** Properties of PALF and glass fibre (Gurunathan, Mohanty and Nayak, 2015).

3.3 Fabrication of Fibre Metal Laminate

The fabrication process of the fibre metal laminate is done through hand layup process. Prior to the layup procedure, aluminium 5052 that is being used will be sanded manually using 80 grit sandpaper and later on is being clean using ethanol to remove the impurities. There will be four stacking sequence which is (A/G/G/G/A, A/G/P/G/A, A/P/G/P/A, and A/P/P/P/A); where A is aluminium 5052, G is a glass fibre and P is pineapple fibre.

The FML panel is fabricated by firstly cutting the aluminium sheet and the woven fibres into a dimension of 200 × 200 mm and proceeded with layup process, where the layup is done within 30 minutes. Then, the FML is put into the hydraulic hot press with an applied force of 1MPa with a curing temperature of 80°C for about 2 hours and later on the FML is left to be cooled under room temperature. After the curing time is over the FML is kept up to 7 seven days to gain its ultimate strength and later on the FML will be cut into the required dimension based on the ASTM standards.

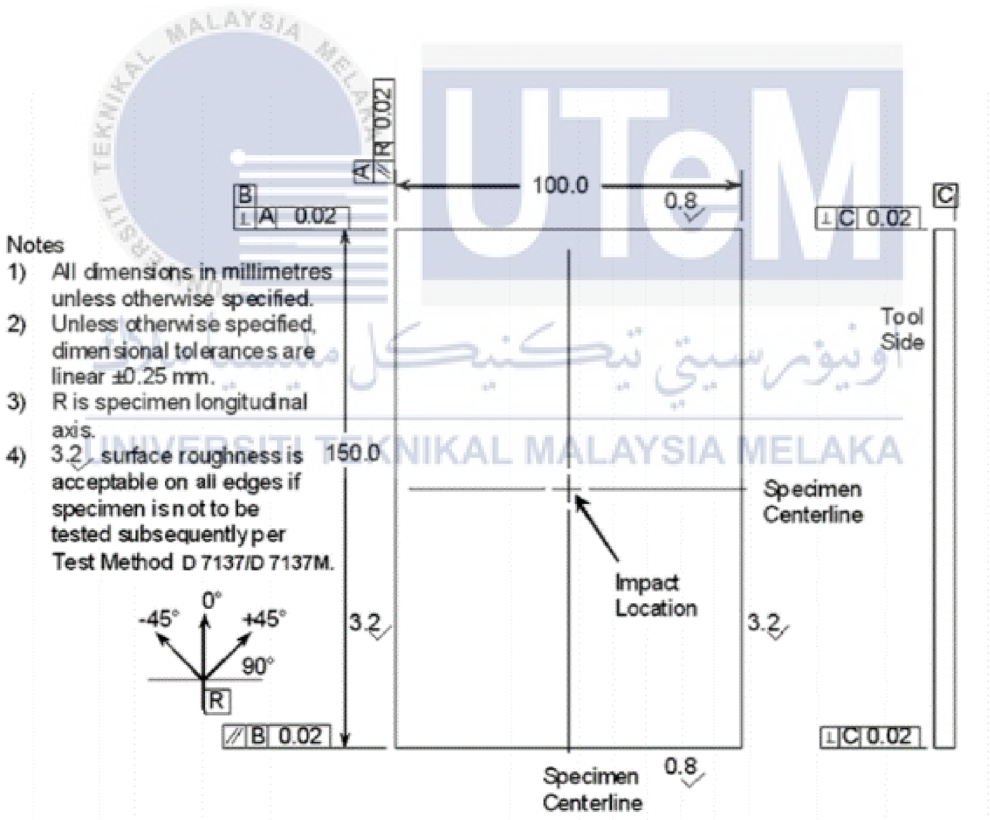
3.4 Specimen Preparation

The 200 mm × 200 mm fibre metal laminate from the layup process was being cut by using water jet into dimensions of 150mm × 100mm which is according to the ASTM standard for LVI testing.

Test	ASTM standard	Specimen Dimension (Length × Width)
Low Velocity Impact	ASTM D7136	150mm × 100mm

Table 3. 3**:** Specimen size base on the ASTM standard.

Figure 3. 5**:** Low Velocity Impact and Compression After Impact test specimen dimension (SI version) (Load *et al.*, 2013).



3.5 Low Velocity Impact Test

Low velocity impact test was been tested on the fibre metal laminate base on ASTM D7136 standard on the CEAST 9340 impact testing machine till the specimens are fully perforated. The impact force of the specimen was been measured by dropping a hemispherical impactor that having a diameter of 12.7 mm with a velocity of 3 ms^{-1} and a total mass of 4kg. After the impact had been done the computer that had been connected to the machine will analyse the captured the data. Figure 3.6 illustrates CEAST 9340 impact testing machine.

Figure 3. 6**:** CEAST 9340 impact testing machine.

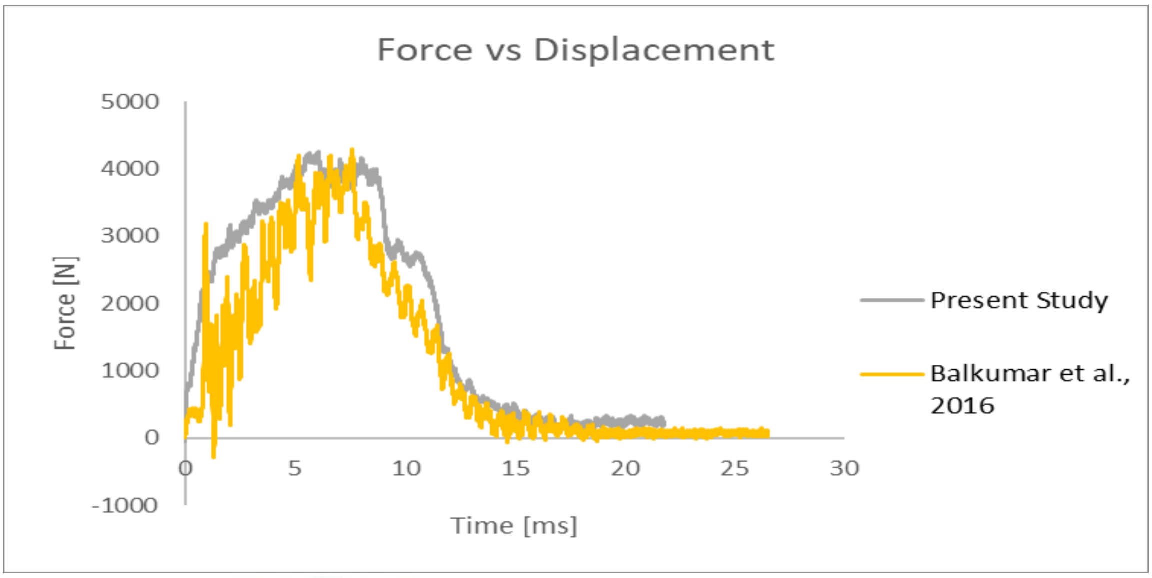
Finite Element Analysis

In this part of this study finite element simulations had been carried out by the aid of ABAQUS/Explicit software. Before the simulation was been carried out a validation had been done base on the results obtained in(Zhu and Chai, 2012). For the validation process, a diameter of 13.1 mm hemisphere impactor which has a mass of 2.735 kg is modelled. Besides in this validation process as from (Balkumar *et al.*, 2016) Johnson-Cook stress flow is modelled for aluminium alloy which is expressed as:

$$\sigma = (A + B\varepsilon n)\ (\ 1 + C \ln \dot{\varepsilon}\ \dot{\varepsilon} o\ )\ (1 - (\ T - TR\ Tm - TR\ )m)$$ (Balkumar *et al.*, 2016)

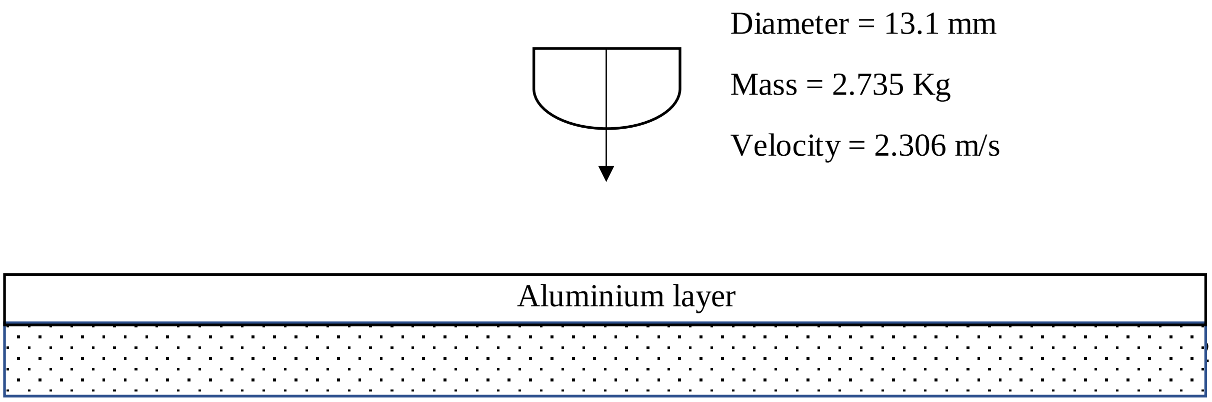
This model had been chosen to use due to its capabilities of the modal to produce an effective prediction on material behaviour in the form of dynamic mode which is suitable for these study purpose.

In this validation process, the nodes between the aluminium and the glass fibre/epoxy



were kept together while all the interactions properties in the simulations where referred and defined based on the interaction. After that properties had been defined the values of friction coefficient and the initial velocity between the impactor and the FML is defined to be 0.2 and 2.206ms^{-1} base on (Balkumar *et al.*, 2016) studies. Moving on with the modelling of the FML glass fibre/epoxy composite is been sandwich between the two aluminium plates with a definition of the deformable body with a mesh of C3D8R element while for the impactor its s defined as a rigid body. After defining all those properties, the simulations of the LVI is conducted where the impactor is placed above the canter of the FML and is submitted to strike the FML once. The studies of the mesh conversion are then taken and are compared with researches results of (Balkumar *et al.*, 2016) for the validation purposes.

Figure 3. 7:Damage progression for FML plate of the experimental and present study.



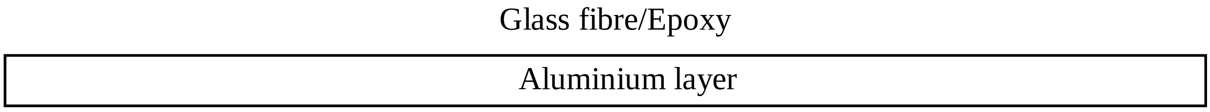


Figure 3. 8: Experimental Specimen.

3.7 Modelling

An LVI simulation had been done on FML with the model size of 150mm × 100mm with the variable of the metal thickness to be changed while keeping the glass fibre composite with the same thickness throughout the simulations. Besides, the impactor that had been model is declared to be a rigid body where no deformation would be occurring during the impact period with a dimension of 8 mm of diameter with a 2.735 Kg. In this modelling aluminium 2024-T3, alloy and woven glass fibre had been used and aluminium 2024-T3 was been declared base on Johnson-Cook stress flow where else for glass fibre/epoxy was declared to be an orthotropic elastic material. Table 3.4 shows the dimension FML layers and table 3.5 and 3.6 shows the properties of aluminium 2024-T3 alloy and glass fibre/epoxy composite.

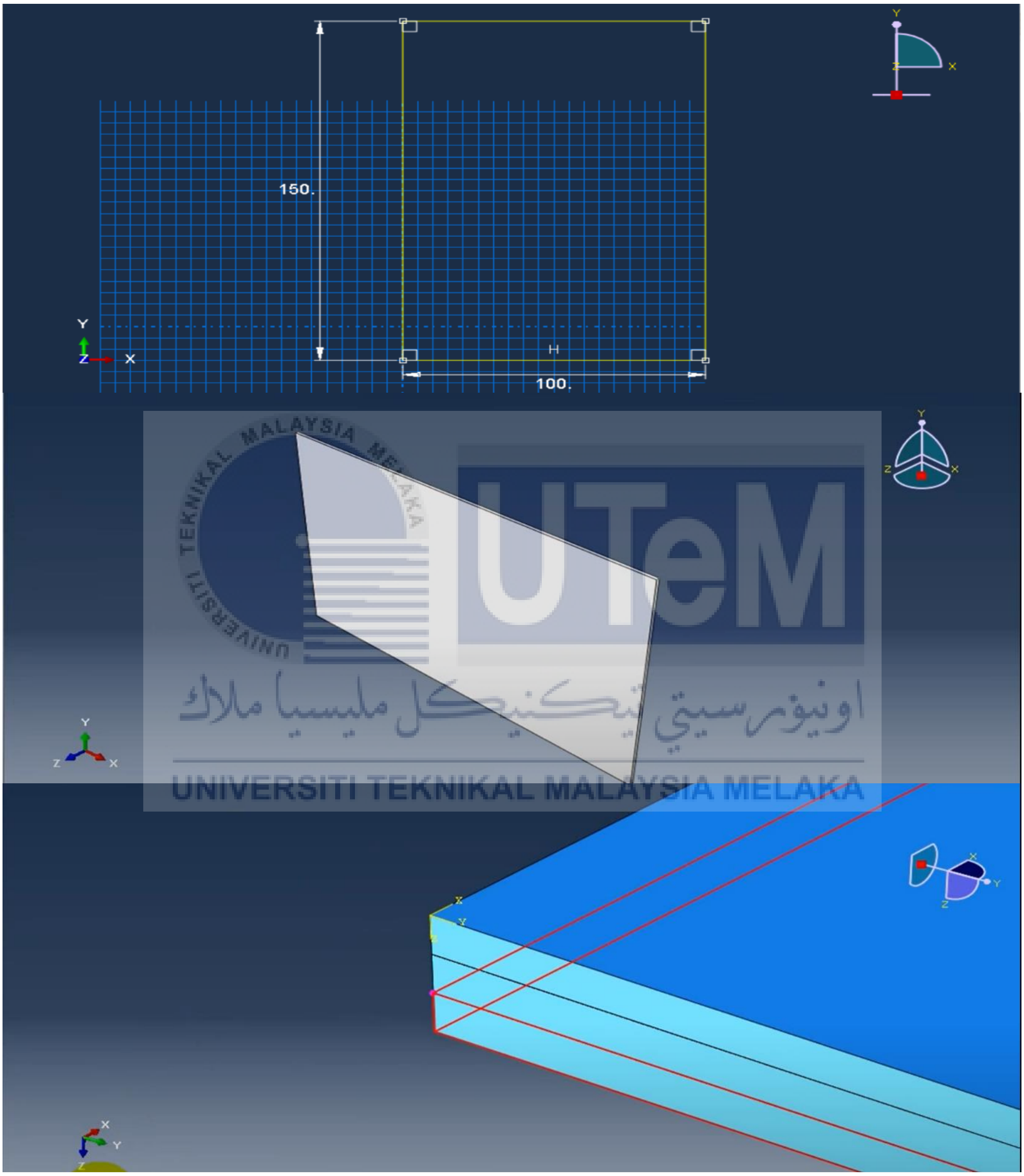


Figure 3. 9: Modelling of FML.

Diameter = 8 mm

Mass = 2.735 Kg

Velocity = 5 m/s

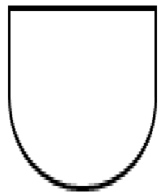


Figure 3. 10: Impactor modelling

Length (mm)	Width (mm)	Glass Fibre / Epoxy Thickness (mm)	Metal Layer Thickness (mm)	Total FML Thickness (mm)
150	100	1.0	0.5	2.0
150	100	1.0	1.0	3.0
150	100	1.0	1.5	4.0

Table 3. 4: Dimension of FML model.

Material	A (MPa)	B (MPa)	C	n	m	D1	D2	D3	D4	D5
Al 2024-T3	252	426	0.015	0.34	1	0.13	0.13	1.5	0.011	0

Table 3. 5: Johnson-Cook Material and damage constant of Al 2024-T3.

Properties	Glass/Epoxy
Density (Kg/m3)	1800
E1(GPa)	26
E2 (GPa)	26
E3 (GPa)	8
G_{12} (GPa)	3.8
G_{13} (GPa)	2.8
G_{23}(GPa)	2.8
ν_{12}	0.1
ν_{13}	0.25
ν_{23}	0.25
X_t (MPa)	414
X_c (MPa)	458
Y_t (MPa)	414
Y_c (MPa)	458
S_{12} (MPa)	105
S_{13} (MPa)	65
$G_{f\,t}$(KJ/m2)	10
$G_{f\,c}$ (KJ/m2)	1.562
G_{mt} (KJ/m2)	0.625
G_{mc}(KJ/m2)	0.14

Table 3. 6: Orthotropic material properties.

3.8 Meshing

Base on the previous study by (Nalla Mohamed, Ananthapadmanaban and Selvaraj, 2016) this model is generated by using 8 nodes solid element whereby for the face sheet was constituent to solid element (C3D8R) and the eight-node 3D cohesive element (COH3D8) were created for the composite interface. This meshing element was used in the study due to its accuracy results can be obtained from the previous study. Before the meshing was applied to the studied subject, the subject was first undergoing a partition separation for a more optimal simulation result base on the impact point location. These criteria need to be achieved before the meshing even begins to element unnecessary computation was the criteria able to eliminate element waste around the edges which are far from the impact point.

By this, more accurate computation results can be obtained while reducing the computing time.

Figure 3. 11: Structure meshing of the experimental modal.

3.9 Low Velocity Impact Computation

The LVI finite element modelling is executed on the three variances of the FMLs with different metal thickness. In the simulation, the impactor with a diameter of 8 mm and 2.735 Kg of mass is let to be strike at the centre of the FML panels at the speed of 5 ms^{-1}. Before the simulation was executed, the FML panel is set for its boundary condition where the panel is to be set to an impact support fixture based on ASTM 7136. After this boundary condition is defined, the boundary condition between the impactor surface and the FML panels surface is defined where the surface to surface contact will be declared to have a friction impact with the coefficient of 0.3 (Nalla Mohamed, Ananthapadmanaban and Selvaraj, 2016). After all the boundary condition is defined the computation of the study is submitted and the data of the study is generated.

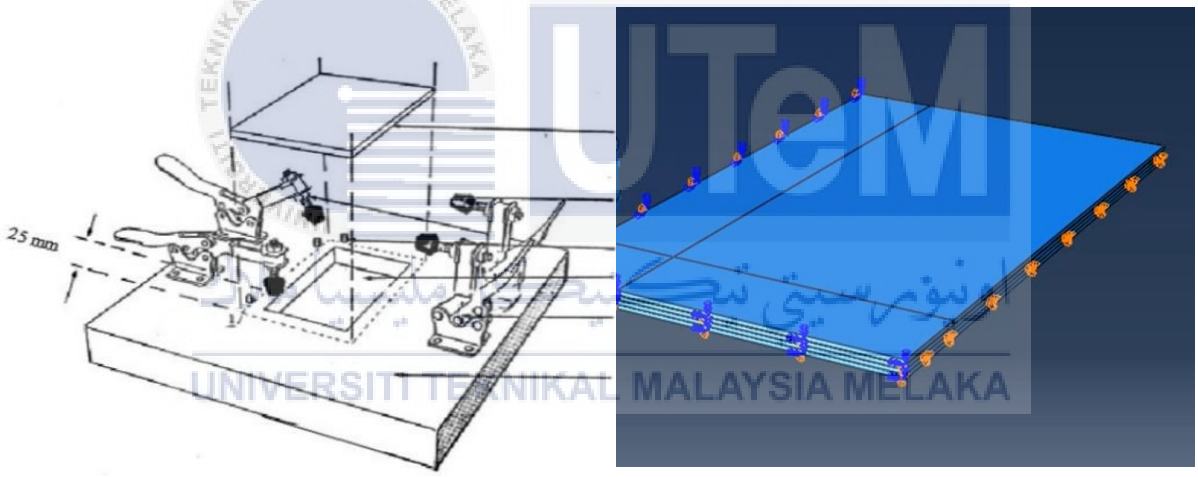


Figure 3. 12: Impact support fixture base on ASTM 7316. (SI unit Version). (Load *et al.*, 2013)

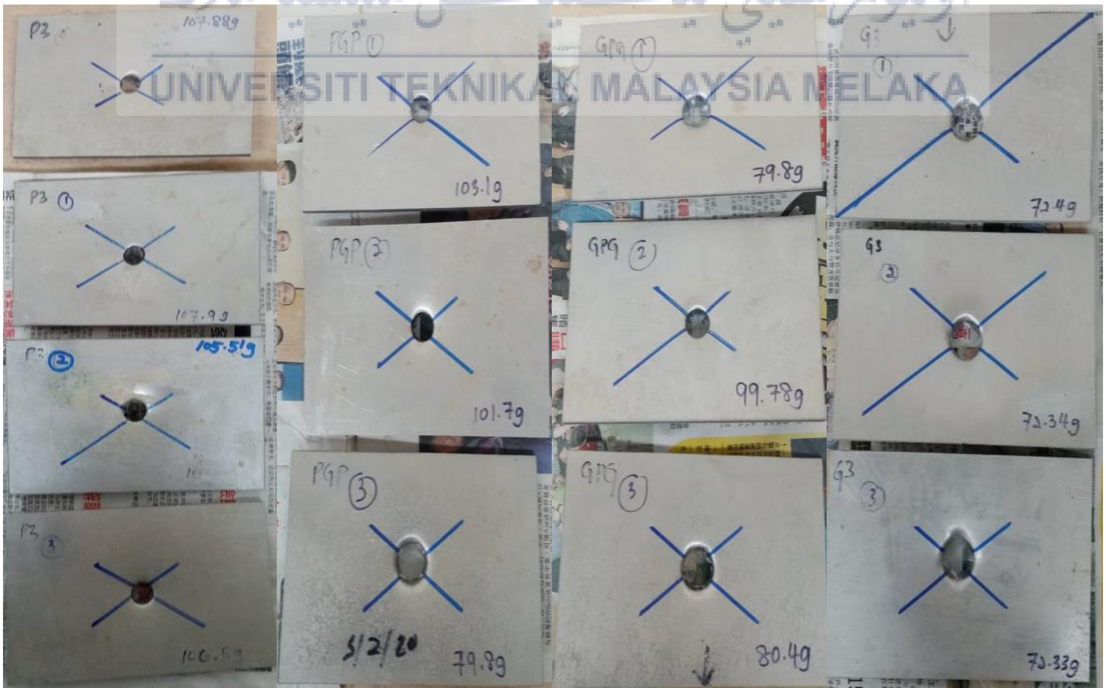
Figure 3. 13: Low-Velocity Impact Computation on FML.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Low-Velocity Impact (Experimental)

LVI test had been performed on the fabricated FML by using four stacking sequence which is (A/G/G/G/A, A/G/P/G/A, A/P/G/P/A, and A/P/P/P/A) with the same thickness of aluminium 5052. The test is conducted based on the methodology outlined on the previous chapter and the data that had been provided is then extracted and plotted into graphs (displacement-time response, velocity-time response, force-time response and displacement-time response) to analysis the properties, similarities and the practicalities of the panels. The LVI test is conducted three times for the same type of FMLs to acquire more reliable data to decide on. In this test all the specimens where fully perforated before the data was generated.

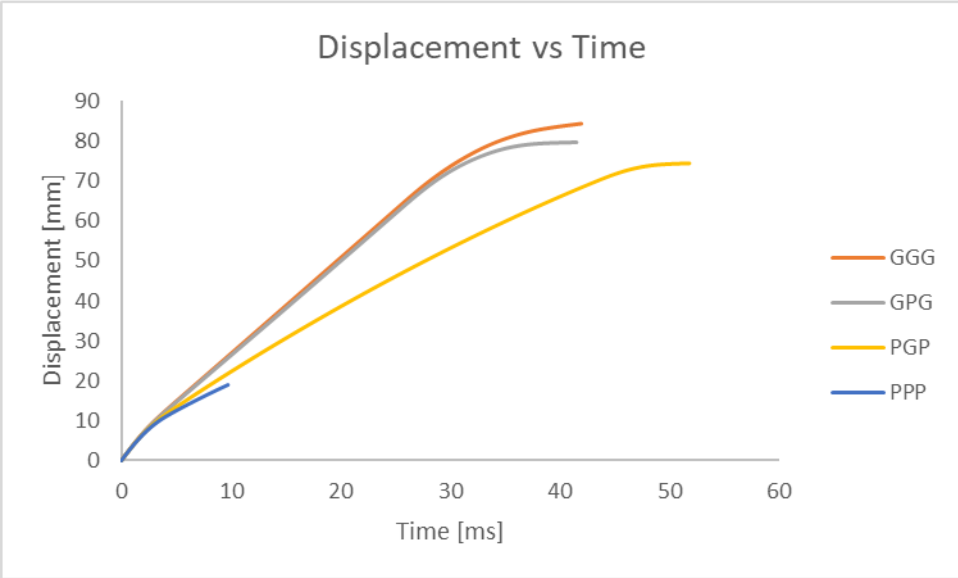


(a.) (b.) (c.) (d.)

Figure 4.1 shows the perforated FML,s for the four stacking sequence.

Figure 4. 1: FMLs that undergone full perforations (a.) PPP, (b.) PGP, (c.) GPG, and (d.) GGG.

4.1.1 Displacement-time response



Samples of FMLs	Maximum Displacement (mm)	Maximum Energy Absorbed (KJ)
GGG	84.34	55.20
GPG	79.67	55.27
PGP	74.42	55.16
PPP	18.97	45.18

Figure 4. 2: Displacement-time response graph.

Table 4. 1: The peak values of displacement and energy absorbed of every FMLs samples.

Figure 4.1 above shows the trend of displacement against time response of the four types of FMLs. From the observation that is conducted from the trend of the graph, FML that consist of GGG composite display a maximum displacement which is 84.34 mm where else for the FML that consist of pure PPP composite has the lowest maximum displacement which is 18.97 mm in a shorter time compared to other FMLs. From the trend of GPG composite FML, it almost shows a similar trend with GGG composite FML which have a maximum displacement of 79.67 mm which this composite configuration to be a substituted of the GGG composite FML. For the FML consist of PGP composite and the interesting trend can be seen from the graph. By adding a single layer of woven glass fibre, a significant improvement can be obtained in term of the impact resistivity of the FML panel in comparison the pure PPP composite FML and also its result in prolonging the impact by increasing the impact time which reduces the damage of the panel by dissipating the energy in a longer period. Based on figure 4.2, a trend it can be concluded that FML with the synthetic composites has a higher impact-resistance response in comparison to the natural FML. This show that FML is capable to withstand higher impact energy for the synthetic FMlL (K. I. Ismail *et al.*, 2019).

4.1.2 Velocity-time response

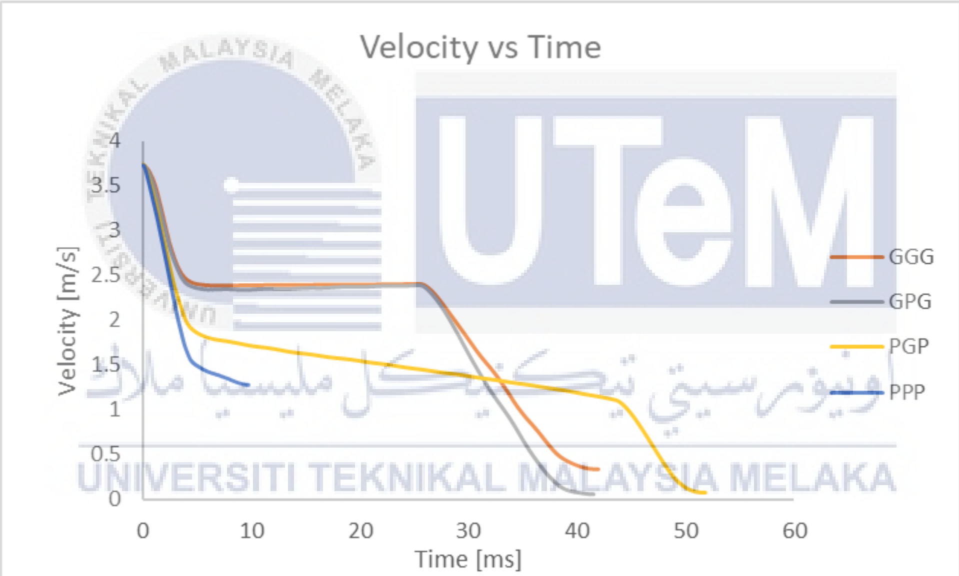


Figure 4. 3: Velocity-time response graph

Samples of FMLs	Perforation Threshold (m/s)	Penetration Duration (ms)
GGG	2.48	24.32
GPG	2.36	23.78
PGP	1.83	43.06
PPP	1.62	5.63

Table 4. 2: The perforation threshold and penetration duration of the FMLs.

Figure 4.3 shows the velocity-time response graph which indicated the penetration duration and also shows the perforation threshold of the FML panels. The use of this graph shows the representation of the impactors status as well (K. I. Ismail *et al.*, 2019). From this graph, two types of variables can be extracted from it that shows the impactors status during the impaction duration which is the free fall and the perforation (Belingardi and Vadori, 2002). From this graph, it can be observed all the FMLs give a similar trend as the time increases the velocity decreases. To comparison to the FML with the GGG composite and GPG composite, it almost shows a similar value of the impaction period where the perforation threshold and penetration duration are close to similarity which were 2.48 ms^{-1} and 24.32 ms for GGG composite and 2.36 ms^{-1} and 23.78 ms for GPG composite. As for PPP composite FML, it shows it has the lowest perforation threshold and the shortest penetration duration. Moving on for FML that consist of PGP composite sequence stacking it shows a unique trend where among the classes it has a longer perforation duration which shows that the combination of synthetic fibre and natural fibre able to exhibit combine properties from their domain characteristic. Therefore, from the values and trend of this velocity-time response graph, it can be concluded that FML with PGP composite has a better penetration duration but an average perforation threshold in compare to GGG and GPG composite FML. In the end, it all depends on the application condition base on the domain criteria.

4.1.3 Force-time response

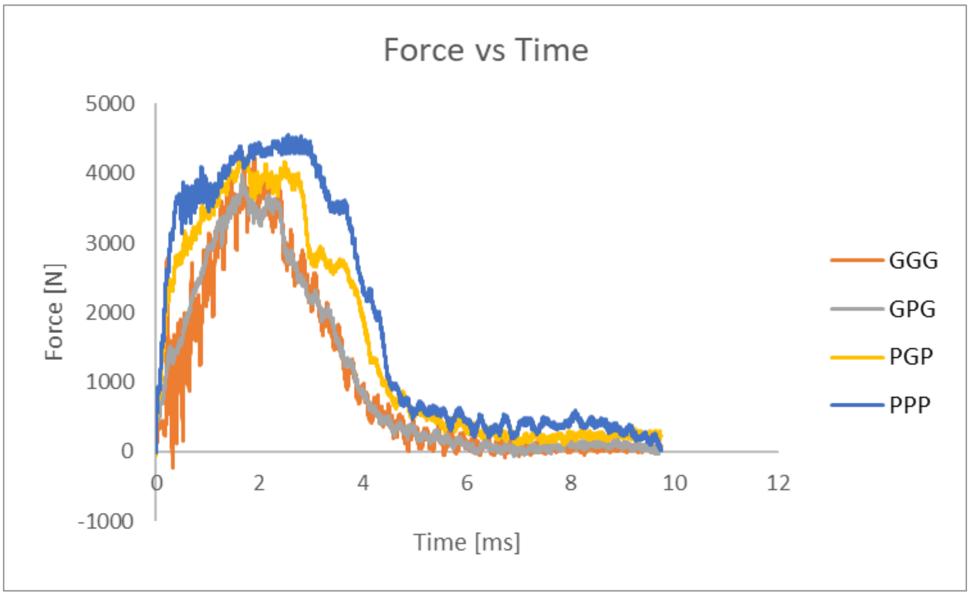


Figure 4. 4: Force-time response graph.

Samples of FMLs	Maximum Force (N)
GGG	4220.46
GPG	3978.37
PGP	4251.79
PPP	4552.13

Table 4. 3: Maximum force of the FMLs panels.

From this graph 4.4 which show the force-time response of the FMLs panels which purpose to show the reactions of the FMLs panels and the impactor during the impact throughout the period. As it can be seen that the trend of all the graph shows similarity but having a different magnitude in the maximum force. From this graph, we able to observe two types of threshold according to (K. I. Ismail *et al.*, 2019) were we able to analysis the sharp increase of curve and the oscillation of the graph throughout the period. As for the sharp increment, it shows the peak load that the FMLs undergoes during the strike which can be correlated to the steepness of the graph in the given period. For the oscillation, it provides information regarding the impactor loading and unloading on the surface of the FMLs. This loading and unloading amplitude indicate how much damage has been done to the fibre in the panel by the impactor. In another way, it can be said that the smoother the graph the lesser the internal damage is done to the fibres (Belingardi and Vadori, 2002). As can bee see from the graph GGG composite FML and GPG composite possess the same trend in the increment of the peak load but in terms of the oscillations of the curve, it shows that GGG composite FML has a bigger amplitude in the osculation compared to GPG composite which shows that there is more internal damage done in the GGG composite FML compare to GPG composite FML. By this show for GGG composite FML, it is possible to have a failure in the structure when the second impact is strike to it due to its losses in the structural integrity and in addition this oscillation also shows that the present the pineapple fibre provides a smoother transition that aid in dampening the loading and unloading effect of the impactor on the panel. Moving on to it can be observed that for the FML which consist of PPP composite have the largest maximum peak load of 4552.13 N and for the GPG composite have the smallest peak load of 3978.37 N among the other FMLs.In term of the smoothness of the graph, it can be seen that FML with PGP composite exhibit the smoothest transition follow by PGP, PPP and finally by GGG composite. As a conclusion from these graphs, it shows that the presence of pineapple fibre act as a dampening factor in the structure of the FML which minimise the residual stress of the FML panels.

4.1.4 Force-displacement response

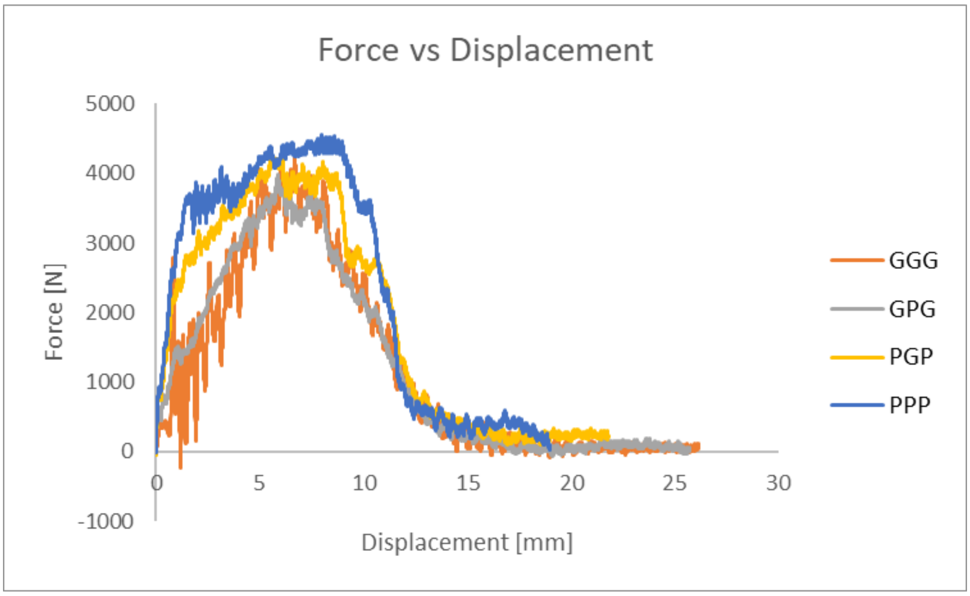
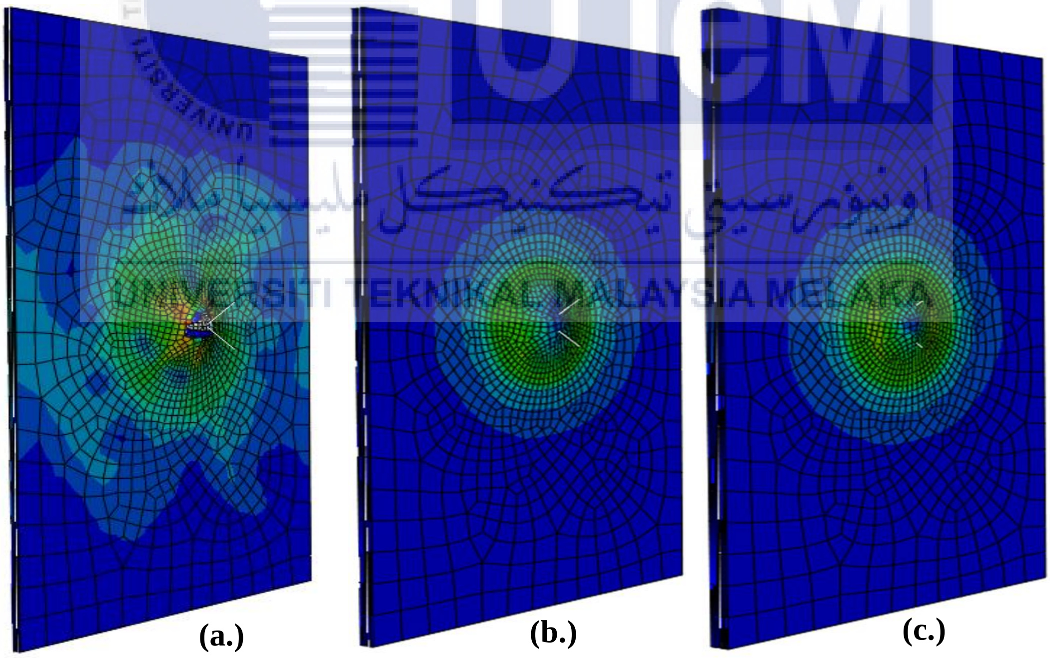


Figure 4. 5: Force-displacement response graph.

The graph 4.5 above illustrate force-displacement response which is very important to the study where it presents the impact behaviour of the FMLs panels. Base on the above graphs trend, all the graphs exhibit a close type of curve which shows the elasticity of the FMLs while subjected to impact loading. Base on (Payne, 2013) this graph can be divided into two stages where the increment section and the decrement section of the graph. Another factor that can be seen from this graph is that all the graph returns to zero values which indicate perforation had occurred the panels. This graph also correlated that the maximum displacement occurs when the force present is maximum for all the graphs. For the graph presented for PPP composite FML, it illustrates it had undergone a bigger deformation compare to others which can be correlated to force-time response graph and displacement-time response graph where bigger deformation result in lower energy absorb which lead to lower internal damage. For the GGG and GPG composite FML it shows a similar graph trend as usual and from this trend, the specimens have lower deformation compare to PPP and PGP composite FML. As a conclusion, it can be said in this investigation the synthetic fibre is more rigid compare to the natural fibre which by hybridising both the fibre able to acquire both of their superior properties.

4.2 Low Velocity Impact (Numerical Analysis)

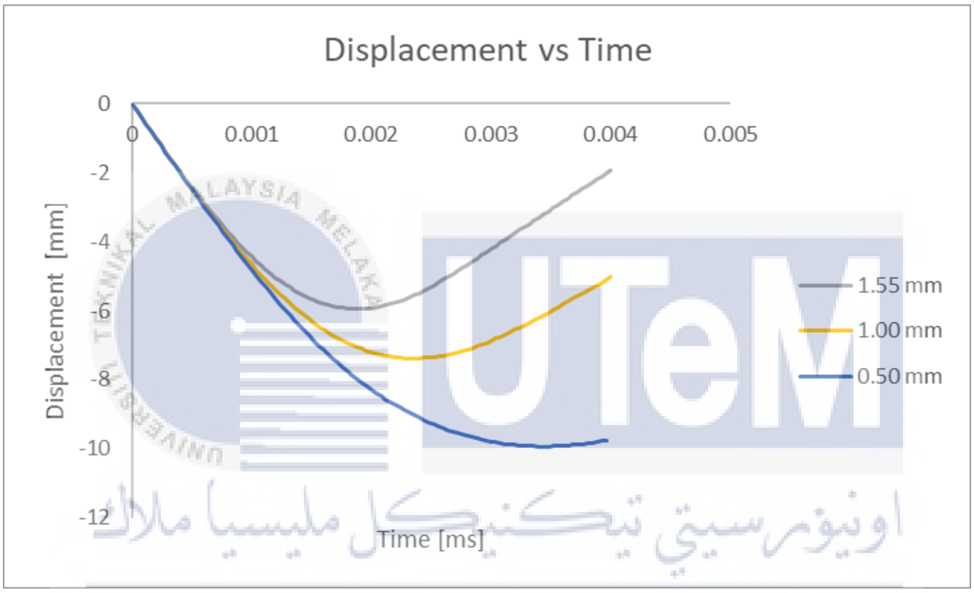
A numerical analysis had been carried out where a simulation of low velocity impact had been performed by the aid of ABAQUS/Explicit on fibre metal laminate which consists of a single layer of glass fibre/epoxy with the variable parameter of metal thickness where aluminium 2024-T3 is used in the study. The purpose of this simulation is to understand how the thickness does affect the material properties and also understand the behaviours of the FMLs. The simulation is conducted based on the outlined methodology stated in the previous chapter. From this simulation, some important data's where generated to plot some graphs (displacement-time response, velocity-time response, force-time response, and displacement-time response) where it aids to analyses the behaviour of the FMLs panel on its material properties. Figure 4.5 illustrates the area of energy heat map of FML when subjected to low



velocity impact.

Figure 4. 6: Illustration of energy heat map of FMLs with different metal thickness (a.) 0.5mm, (b.)1.0mm, (c.)1.5mm

4.2.1 Displacement-time response



Metal thickness (mm)	Maximum Displacement (mm)
0.5	-9.94
1.0	-7.38
1.5	-5.95

Figure 4. 7: Displacement-time response graph.

Table 4. 4: The maximum displacement corresponding to the metal thickness used.

As discussed in the previous section, the displacement-time response graph is to understand the behaviour of the FMLs in terms of the capability of the FMLs to impact resistivity. Base on the above graph trend it can be seen that for the three FMLs with different metal thickness exhibit the same trend. From the graphs, it can be observed that the deflection shows a negative trend due the displacement occurs in the direction of the gravity which results in a negative value is to be generated from the simulations. As from the observation of the graph, it can be seen that the metal thickness with the smallest thickness exhibit a higher deflection compares to the metal with bigger thickness due to poor rigidity of the metal plates. From the data and the graph trend, it is concluded that the FML that shell by a thicker metal plate show to have the capabilities to withstand higher impact energy.

4.2.2 Velocity-time response

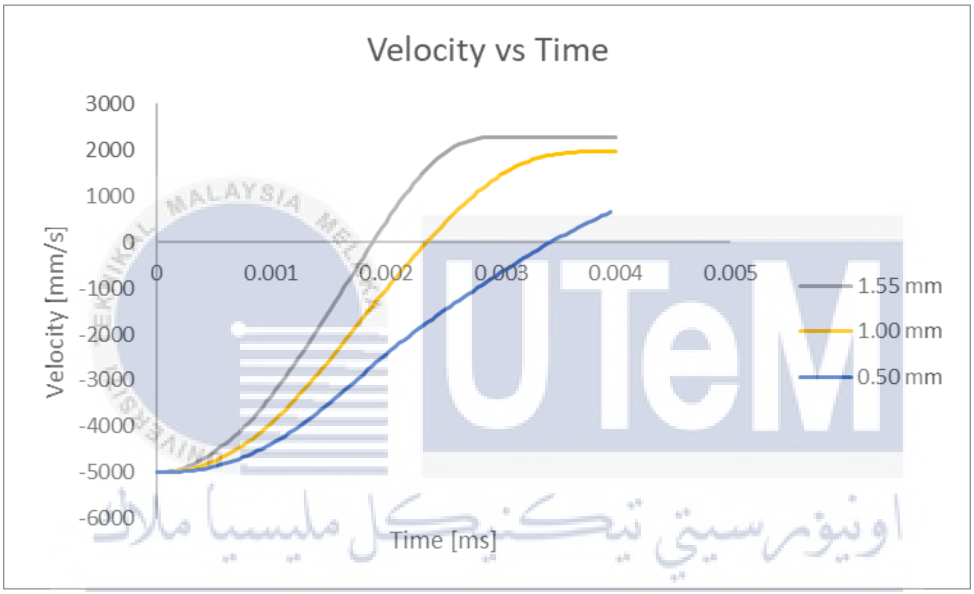


Figure 4. 8: Velocity-time response graph.

Metal thickness (mm)	Perforation Threshold (m/s)	Penetration Duration (ms)
0.5	-3.18	8.72
1.0	-4.35	21.33
1.5	-4.83	26.78

Table 4. 5:The perforation threshold and penetration duration of the FMLs.

From figure 4.8 which is velocity-time can extract the penetration duration and the perforation threshold of the FMLs. This data shows the interaction of the impactor and the panel surface was at which state those the perforation occurs and how long it takes for the impactor to penetrate through. From this numerical analysis data, it can be seen on table 4.5 that the higher metal thickness which is 1.5 m/s have a higher perforation threshold and longer penetration duration which is 26.78 ms follow by 1.0 mm metal thickness and finally 0.5 mm of metal thickness. As from the observation of the graph for the metal thickness of 1.0 mm has a closer gap in the graph trend to the metal thickness of 1.5mm compared to 0.5 mm of metal thickness even though the increment in term of the metal thickness is constant. Therefore, from the observation of this graph and the data's FML with the metal thickness of 1.0 mm have almost the same trend of for the metal thickness of 1.5 mm which may be a potential replacement by considering these criteria as discussed above.

4.2.3 Force-time response

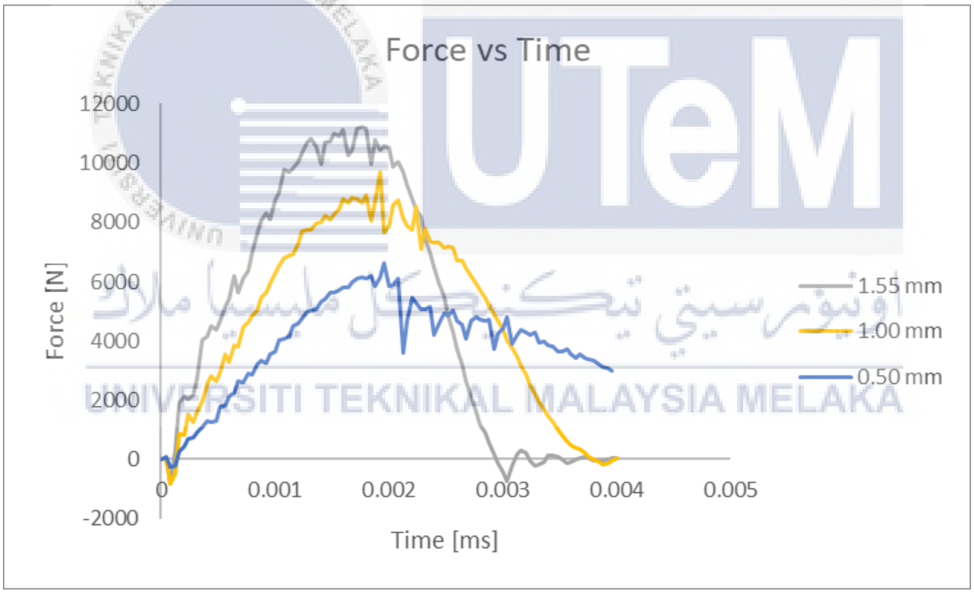
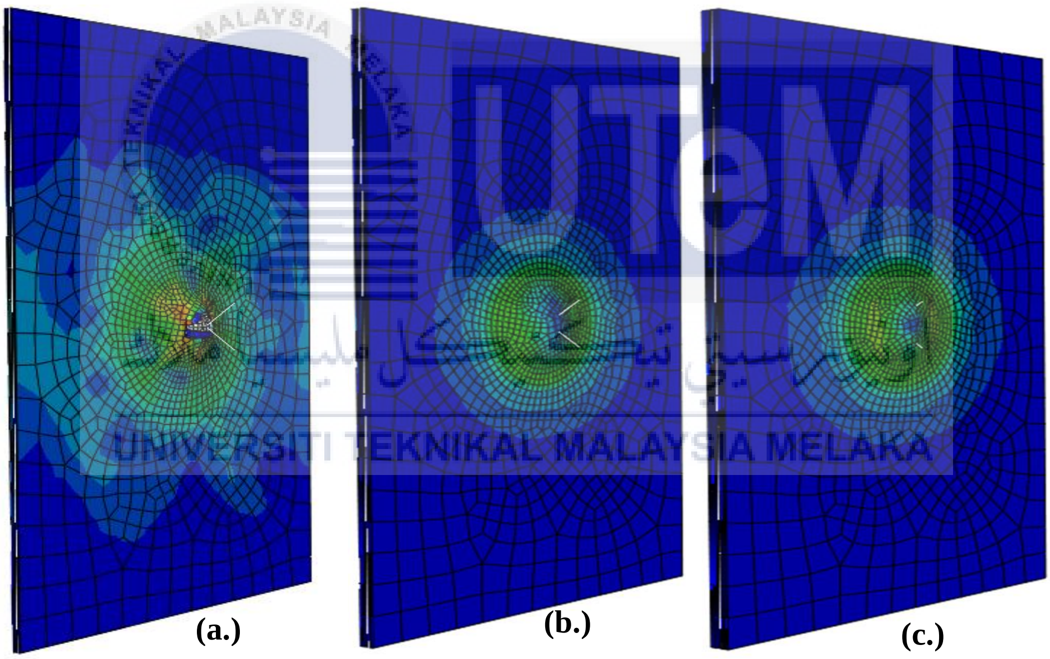


Figure 4. 9: Force-time response graph.

Figure 4. 10: Energy heat map of the FML with thickness of (a.) 0.5 mm, (b.) 1.0 mm, (c.) 1.5 mm.



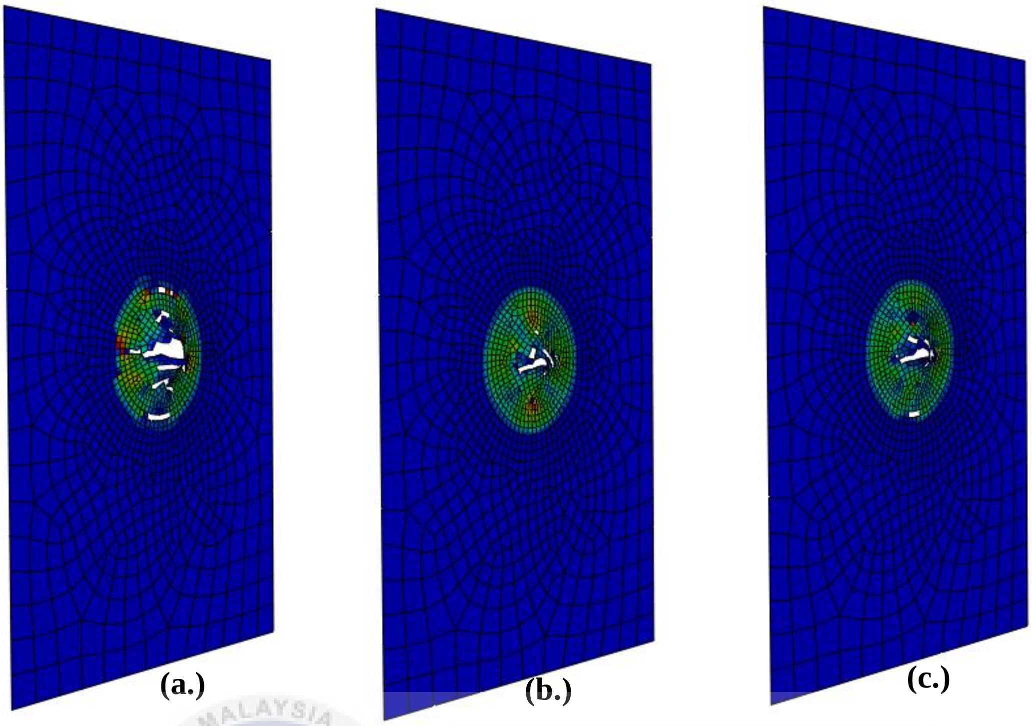


Figure 4. 11: Energy heat map of the fibre glass/epoxy. (a.) 0.5 mm, (b.) 1.0 mm, (c.) 1.5 mm.

Figure 4.9: Shows force-time response which purpose to identify peak force subjected to the FMLs and the loading and unloading of the impactor on the FMLs surface during the impact period. From the figure 4.10, the energy heat map had been generated during the peak force were subjected on to the FMLs and figure show the energy heat map of the fibre glass epoxy in the FMLs during the peak force as well. From the aid of this figures, it can be observed that there some internet damage had been to the glass fibre where even though for the case of the metal thickness of 1.0 mm and 1.5 mm is not fully perforated. These phenomena can be explained from the observation of the graph where all the graphs have oscillation within it were some internal damage had occurred. By looking on the oscillation of the graph trend, the metal thickness of 0.5 shows a higher in amplitude in the oscillations where else for the metal thickness of 1.5 shows there is a consistency of oscillation throughout the trend which for the and explanation can be observed from figure 4.11 where the area of the energy heat map of the glass fibre is larger for the 0.5 mm metal thickness followed by 1.5 mm metal

thickness and finally for the 1.0 mm metal thickness. This show for the cases above it can be said delamination's had occurred in the FMLs. The conclusion that can be made from the above observation is the metal thickness of 1.0 mm is the perfect candidate for contributing an optimal material property.

4.2.4 Force-displacement response

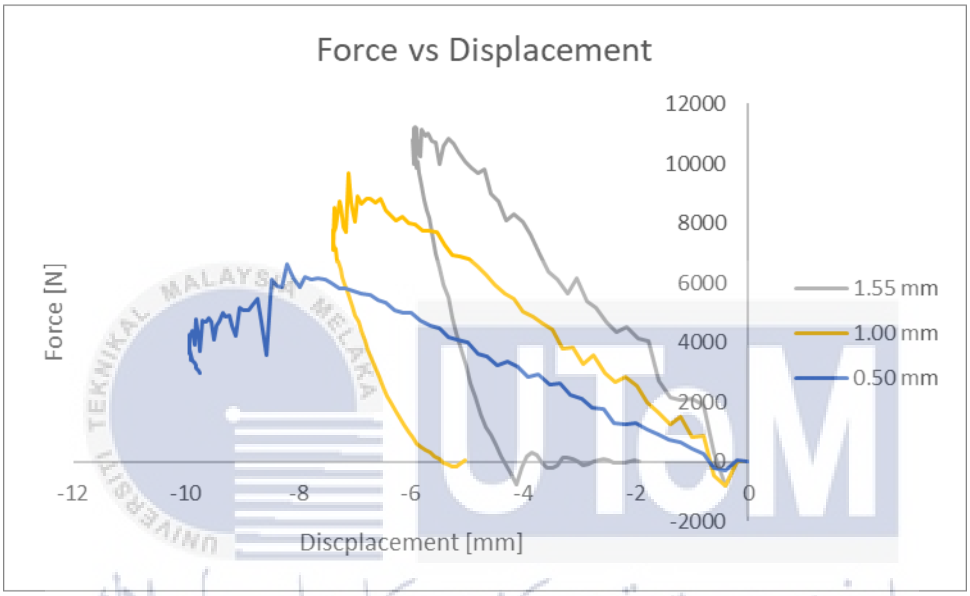


Figure 4. 12: Force-displacement response graph.

From figure 4.12 the graph exhibit two types of force displacement-curve which is the open type and the close type. As for the graph trend of 1.00 mm and 1.5 mm it shows and close type where it can be explained that the FMLs are not fully perforated and the energy is restored as based on the principle of energy conservation that states the total energy before and after the impact are equal. On the other hand, for the FML consist of metal thickness 0.5 shows and open type which explained full perforation had occurred on the panel. What can be observed from the trend is that the metal thickness of 1.55 mm thickness has a higher deformation followed by the metal thickness of 1.00 mm and finally is for 0.5 mm thickness. From this discussion above it can be said metal thickness of 1.55 mm is more elastic following by 1.00 mm metal thickness and finally is for 0.5 mm metal thickness.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this investigation, a study of FML is been done experimentally and by numerical analysis to conduct a low velocity impact test on the fabricated FML which the variable are the stacking sequence and the thickness of the metal plate used. An experimental low velocity test had been conducted for the variable of different stacking sequence of fibres which are (GGG/GPG/PGP/PPP) and for the numerical analysis simulation of low velocity impact test is conducted for the FML with the variable of different metal thickness while keeping the composite inside with a constant thickness.

Base on the experimental displacement-time response graph, FML with stacking sequence of GGG and GPG have a very similar trend and also both of this stacking sequence has the highest energy absorbed which are 55.20 Kj for GGG and 55.27 Kj for GPG sequence. Moving on to the velocity-time response graph GGG and GPG also exhibit a similar trend perforation threshold and penetration duration are 2.48 m/s and 24.32 ms for the GGG and 2.36 m/s and 23.78 ms for GPG. In the force-time response graph for the stacking sequence of PPP obtained the highest peak force where for GPG obtained the lowest peak force but in considering the reaction of the loading-unloading of the impactor, GPG has a smoother graph compared to GGG which have dampened the internal damaged criteria. Finally, as for the force-displacement response graph, GGG and GPG show a similar trend where they exhibit the smallest deformation compares to other stacking sequences where PPP have the highest deformation characteristics. As from the overall point of view, the substitution of the pineapple fibre with glass fibre provides a positive outcome where it is possible that the natural fibre can be a substitution in the hybridisation process of glass fibre while attaining its properties.

For the case of the numerical analysis of low velocity impact test simulation with the variable of the metal thickness in the fabrication of the FML, the metal thickness of 1.0 mm shows an obvious selection for the fabrication of FML were it the similarity properties with the metal thickness of 1.5 mm thick and better interaction with the fibre that avoid severe delamination to occurs beside it is more economically friendly.

Therefore, base on the study conducted it can be concluded that pineapple/glass fibre metal laminate reinforcement can be a potential candidate for the full glass fibre metal laminate in the engineering applications.

5.2 Recommendation

Selection of material is the most crucial part for the selection in an engineering application. There is an array of criteria that needed to be met such as the weight of the material, performance in term of the properties, the cost of the material and now the most important criteria need to be considered in this global era is the environmentally friendly product. As in this study, an experimental and a numerical analysis study had been carried for low velocity impact test. In the future more type of hybridization and study of the suitable metals needed to be conducted to obtain a wide array of material properties base on the engineering applications.

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