DEVELOPMENT AND ANALYSIS OF FLEXIBLE THERMOPLASTIC COMPOSITE LAMINATE FOR ANTI STABBING APLLICATIONS

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DEVELOPMENT AND ANALYSIS OF FLEXIBLE THERMOPLASTIC COMPOSITE AMINATE FOR ANTI STABBING APPLICATIONS

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Engineering Materials) (Hons.)

by

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DECLARATION

I hereby, declared this report entitled 'Development and Analysis of Flexible Thermoplastic Composite Laminate for Anti Stabbing Applications' is the results of my own research except as cited in references.

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Date : 25th JUNE 2015

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfilment of the requirements for the Degree of Manufacturing Engineering (Engineering Materials) (Hons.). The member of the supervisory committee is as follow:

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(Supervisor)

(MOHD YUHAZRI BIN YAAKOB)

ABSTRAK

Kajian ini memberi tumpuan kepada pembangunan dan analisis lamina komposit menggunakan HDPE dan LDPE sebagai bahan matriks. Matriks ini telah digabungkan dengan gentian kaca dan gentian aramid sebagai bahan penguatan melalui kaedah akhbar panas untuk mengenal pasti sifat-sifat lenturan dan prestasi anti-tikaman komposit yang dicadangkan. Terdapat tujuh sampel untuk kedua-dua matriks yang menjalani ujian lenturan dan kuasi ujian tikaman statik. Ujian lenturan dijalankan mengikut standard ASTM D790 dan kuasi ujian tikaman statik adalah berdasarkan standard NIJ 0.11500. Kajian ini menggunakan dua pisau saiz yang berbeza iaitu pisau yang saiz kecil, P1 dan pisau yang saiz besar, S1. Kesan tikaman kedua-dua pisau telah dibandingkan. Kesan kegagalan selepas kuasi ujian tikaman statik diperhatikan dengan menggunakan mikroskop imbasan elektron (SEM). Dapatan kajian menunjukkan LDPE komposit mempunyai kekuatan penembusan terendah untuk jumlah sesaran 20 mm dan 50 mm untuk kuasi ujian tikaman statik. Sebaliknya, HDPE mempunyai kuasa penembusan yang lebih tinggi dan daya lentur yang ttinggi pada anjakan 20 mm dan 50 mm. P1 menunjukkan keberkesanan yang lebih tinggi untuk menembusi komposit lamina untuk kedua-dua bahan matriks kerana P1 memerlukan tenaga yang kurang berbanding dengan S1. Tambahan pula, HDPE menunjukkan kecekapan yang lebih tinggi berbanding LDPE dalam menahan daya yang menikam. Walaupun dari segi fleksibiliti, LDPE mendapatkan tenaga yang kurang untuk menahan ubah bentuk di bawah beban, fleksibiliti LDPE adalah lebih tinggi bertanding dengan HDPE. Selain itu, kegagalan delamination berlaku pada sampel yang jumlah lapisan tertinggi. Ini adalah kerana ikatan pelekat yang lemah di antara matriks dan gentian tetulang. Gentian yang tertarik keluar dan serat kerosakan diperhatikan pada gentian selepas penembusan.

ABSTRACT

This research focuses on the development and analysis of laminate composite using HDPE and LDPE as matrix materials. This matrix was combined with glass fiber and aramid fiber as reinforcement materials through hot press method in order to identify the flexural properties and anti-stab performance of the proposed composite. There are seven samples for both matrix which undergoes flexural test and quasi static stab test. The flexural test was conducted according to ASTM D790 standard and quasi static stab test was based on NIJ 0115.00 standard. This research use two different sizes of knives which are a small size of knife, P1 and a big size of knife, S1. The stabbing effect of these two knives has been compared. The failure effect after quasi static stab test is observed by using scanning electron microscope (SEM). The finding shows LDPE composite has lowest penetration force for total displacement of 20 mm and 50 mm for quasi static stab test. In contrast, HDPE has higher penetration force and bending force at the displacement of 20 mm and 50 mm. P1 showed higher effectiveness to penetrate the laminate composite for both matrix materials because P1 required less energy as compare to S1. Furthermore, HDPE shown higher efficiency compared to LDPE in resist the stabbing force. While in term of flexibility, LDPE obtain less force to resist deformation under load, the flexibility of LDPE is higher competed with HDPE. Moreover, delamination failure occurred on the sample at highest number of layers. This is due to weak adhesive bonding in between the matrix and fiber reinforcement. The pull out fiber and fiber breakage were observed on the fiber after the penetration.

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DEDICATION

Dedicated to

my beloved father, Cm Hatta Bin Ibrahim

my appreciated mother, Rohani Binti Shafie

and my beloved friends

for giving me moral support, cooperation, encouragement and also understandings.

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LIST OF ABBREVIATIONS

ASTM	-	American society for testing and materials
EVA	-	Ethylene-vinyl acetate
GFRP	-	Glass fiber-reinforced polymer
GMT	-	Glass mat thermoplastic
H1	-	HDPE sample 3
H2	-	HDPE sample 4
H3	-	HDPE sample 5
H4	-	HDPE sample 6
H5	-	HDPE sample 7
HDPE	-	High Density Polyethylene
HG	-	HDPE with glass fiber (sample 2)
HK	-	HDPE with kevlar (sample 1)
L1	-	LDPE sample 3
L2	-	LDPE sample 4
L3	-	LDPE sample 5
L4	-	LDPE sample 6
L5	-	LDPE sample 7
LDPE	-	Lower Density Polyethylene
LG	-	LDPE with glass fiber (sample 2)
LK	-	LDPE with kevlar (sample 1)
NIJ	-	National Institute Justice
P1	-	Small knife
PE	-	Polyethylene
PET	-	Polyethylene terephthalate
PMC	-	Polymer matrix composite
PP	-	Polypropylene
PSM	-	Projek sarjana muda
RTM	-	Resin transfer molding

S1	-	Large knife
SEM	-	Scanning electron microscopy
SiO_2	-	Silicon oxide
TPU	-	Thermoplastic polyurethane
UHMWPE	-	Ultra high molecular weight polyethylene
UTM	-	Universal testing machine

LIST OF SYMBOLS

^{o}	-	degree
^{o}C	-	degree celcius
KPa	-	Kilo Pascal
kN	-	Kilo Newton
g/cm^3	-	gram per centimetre cubic
in.	-	inch
MPa	-	Mega Pascal
µm	-	micro metre
X	-	multiply
%	-	percent
:	-	ratio
mm	-	millimetre

CHAPTER 1
INTRODUCTION

1.1 Research Background

Composite materials are commonly used in engineering and military applications based on their characteristics in providing benefits in mechanical properties, especially towards the impact of performance characteristics to absorb the impact of energy (Evci and G"ulgecc, 2012). Since the first impact and damage failure in composite laminate product becomes an ultimate concern of engineers and manufacturers, Aktacs *et al.* (2009) stated that the real concern is on the behavior of the impact loading which can occur during the manufacture process, normal operation, and maintenance in industry. Based on Mayo *et al.* (2009), one of the challenging applications is for the product to have stab and puncture resistant, especially on the product like body armor which must be flexible and comfortable to protect law enforcement officers and security personnel against the stab attack. In European countries, stab assaults are higher compared to the firearm attack. In addition, the most common test for anti-stab behavior and performance is quasi static stab testing using universal testing machine and stab drop tower test as reported by Li *et al.* (2014a) and Stojanovica *et al.* (2013).

Since the flexible characteristic of composite laminate is being capable of bending easily on certain load without breakout, there are higher stiffness characteristic required to resist elongating when the external load is applied. Therefore, the composite required in this case should have a combination of strength and toughness, yet flexible. Due to the strength and stiffness different characteristics, since strength is the amount of the stress that materials can withstand before it breaks while stiffness is having the ability to resist elongating when the load is applied, Kim and

Nam (2012) commented that the flexibility and toughness of the reinforcing materials required for stab resistant performance and behavior should be looked from the manufacture process and the materials itself.

Adel (2012) found that thermoplastic have different properties compared to thermoset related to high ductility and toughness, facilities of processing and recycling potential. According to Kaw (1997), thermoplastic can also be formed at high temperature and pressure because of the weak bonding which is Van Der Waals bonding. Meanwhile, thermoplastic elastomers have become a significant part of the elastomers industry since they were first produced about 55 years ago (Kutz, 2011). Physical properties of thermoplastic elastomer are similar to rubber soft, flexible and resilience. Thus, between these three materials, thermoplastic is more focused because it can enhance mechanical properties compared to thermoset and elastomers. Besides, thermoplastic have more advantages than others.

As described by Tsai and Melo (2014), composite materials must emphasize those materials which contain matrix constituent that bind together and provides stronger and stiffness reinforcement constituent. The material used for composite materials as suggested by previous researchers are Kevlar/polyester (Li *et al.*, 2014b), Aramid/ LDPE (Kim and Nam, 2012) and Kevlar/PE (Hand *et al.,* 2011). This have proved aramid fiber is commonly used as reinforcement materials on industry application and human body protection against the ballistic and stabbing threats. According to Tien *et al*. (2011), the important parameter to do flexible and toughness composite is the types of resin and fiber used which is related to the stab resistant performance. In addition, the shape of the impact or used is also important to determine the depth penetration against the thickness and layer. However, there are only few researchers who focused on the flexibility and air permeability of the composite, especially thermoplastic materials.

Therefore, the aim of this research is to develop a new flexible thermoplastic composite laminate using glass fiber and aramid fiber as a reinforcement materials. Meanwhile, for a matrix material, the thermoplastic chosen is high density

polypropylene (HDPE) and lower density polypropylene (LDPE) based on the properties performance and the lower prices of the materials.

1.2 Problem Statement

Yong (2014) conducted a research to produce flexible laminated composites based on rubber compound and rubber wood fibers addition with adhesive system using carboxylated nitrile latex. All the laminated composites give good reinforcing behavior and strong elastomeric features. This type of laminated composite has potential to be used for anti-stab body amour applications based on National Institute Justice (NIJ) 0115.00 standard. In contrast with this research, the materials chosen come from thermoplastic family which is to be Polymer Matrix Composite (PMC). There many types of thermoplastic and their advantages were discussed in previous researches Li *et al.* (2014a), Kim and Nam (2012) and Tien *et al*. (2011). The main findings of these researches are how to choose the suitable processes on thermoplastic method which can generate a new flexible composite laminates that have the same properties of good mechanical behavior and anti-stab performance. Thus, the selection of thermoplastic as matrix materials must be matched with suitable reinforcement materials, in which aramid is having good mechanical properties such as flexibility and strength.

The reason for using thermoplastic, according to Carillo *et al.* (2012) is because thermoplastic polymers have more advantages compared to thermosetting matrices. The former have high stiffness and low deformation when added thermoplastic resin into the fabric because it can improve the impact of resistance. In addition, this is also due to thermoplastic matrix are able to maintain the orientation and position of the fiber during the impact occurred since it distribute the entire load which is caused by the impact among all the fibers. This proves that thermoplastic is the best matrix materials. Therefore, the selection of the thermoplastic must be precise with the properties which will bring effect to produce flexible composite laminate and the materials cost must be at lower rate.

Based on the strength and flexibility of the laminated composite, specifically for personel body protection, there are requirements related to the protection performance against the kinetic impact such as involves in bullet of firearm and the intrusion of a sharp edge such as sword or knife. There were scholars have conducted the experiment in sharp edge which is known as anti-stab testing using composite laminate such as Yong (2014), Stojanovica *et al.* (2013), Tien *et al.* (2011) and Decker *et al.* (2007). In this testing, all of the researchers only focused on stab behavior and performance, but less on making with the low costs materials. In addition, there are no fully consideration of the effective layer numbers. The minimum and maximum numbers of plies used are between three and ten layer Li *et al.* (2014a), Kim and Nam (2012) and Hand *et al.* (2011).

Therefore, this research is conducted to investigate the main factor needed when fabricate a flexible composite laminate based on the orientation and numbers of plies to handle force applied towards bending and damage on the surface of the composite laminate through the destructive testing. The parameters considered in this study refer to NIJ 0115.00 standard. Hence, this research also need to find the right selection and decision on the materials, orientation, number of ply, and others importance criteria for a new flexible thermoplastic composite laminate. Particularly, the flexible composite laminate which can withstand stab impact by using low cost materials.

1.3 Objectives

The objectives of this research are:

(a) To develop flexible polymer matrix composite using glass fiber and aramid fiber as reinforcement materials that binds by two types of matrix material namely high density polypropylene (HDPE) and lower density polypropylene (LDPE) via hot press fabrication.

(b) To study the flexural property and anti-stab performance of the proposed composite.

(c) To analyze the failure mechanism after the test and to proposed the optimum performance of the hybrid composite.

1.4 Scope of Research

To ensure this research can be completed and achieve all the objectives, the scope of the research covers the following:

(a) Study the characteristics of the glass fiber and aramid fiber to find the most suitable types of thermoplastic that bind together which can give properties of flexible and high strength.

(b) Determine the suitable reinforcement and matrix material based on types of thermoplastic that has been chosen.

(c) Design a composite laminate based on the orientation, number of layer, and thickness, suitable to be tested on anti-stab testing.

(d) Discuss the velocity, energy, height of stab tower and the types of impactor used in the anti-stab testing.

(e) Analyze the flexibility of the thermoplastic using three point flexural test based on different number of plies in laminated composite.

(f) Research on the damage and penetration depth that occur on the surface of the laminated composite.

(g) Evaluate and propose the best types of thermoplastic that can be used as matrix materials which can give the potential of stab performance after stabbing test.

1.5 Rational of Research

(a) Generate new idea in making flexible composite laminate for the anti-stabbing purpose using thermoplastic materials which have high stiffness and low deformation compare to thermoset.

(b) To create understanding on the response of laminated composite under anti-stabbing by using knife blade.

(c) To gain information on the flexibility of laminated composite based on the number of plies.

(d) Create new scientific data by comparing anti-stabbing and quasi static stab test on the laminated composite.

(e) Provide lower costs of materials by using laminated composite compare to other materials such as metal in defense applications.

1.6 Research Methodology

The sequence to conduct this research starts from choosing the suitable thermoplastic materials that can give more flexibility in the composite laminate. Moreover, the choosing of materials must be correct to achieve the objectives and getting appropriate results. The flowchart of methodology is represented in Figure 1.1.

The second step is fabricating the composite laminate using hot press technique with the fiber and matrix materials. The designing of the laminate must fulfill the

requirement of being flexible but higher in strength and toughness. It is important to determine the standard orientation of the plies and number of layer with the suitable thickness to give good mechanical properties. After designing the composite laminate, the laminate must be tested under drop tower system. This test is to determine the flexibility of the composite laminate and penetration depth based on the thickness and layer. The testing uses stab testing frame, conventional drop tower based on National Institute of Justice 0115.00 standard. In addition, quasi static stab testing also is conducted to compare the data with stab drop tower test. Furthermore, three point flexural tests is conducted to analyze the bending based on different number of plies in composite laminate. The value of flexural is important to know the significant of force required to bend the composite and to identify the strength of the composite based on the thickness. After conducting the test, all the data and result will be recorded and discussed. Conclusion will be made by analyzing the current data and analysis done in previous research such as performance of anti-stabbing behavior.

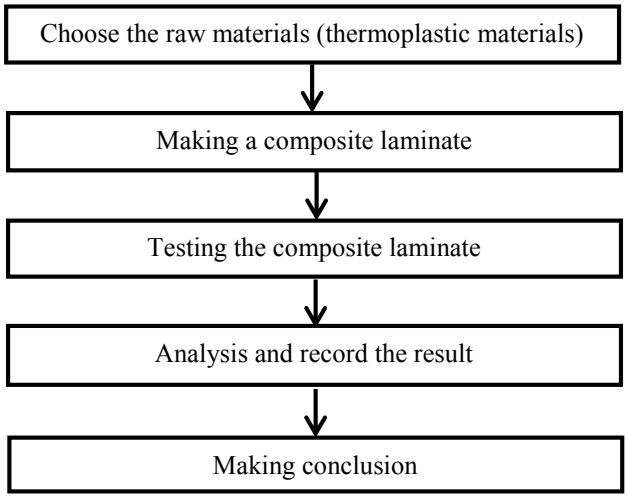

Figure 1.1: Flowchart of methodology.