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LOW VELOCITY IMPACT ANALYSIS OF GLASS/KENAF HYBRID COMPOSITES FOR AEROSPACE STRUCTURAL APPLICATIONS

MUHAMMAD FAIZZUDDIN BIN ISMAIL

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By

MUHAMMAD FAIZZUDDIN BIN ISMAIL

Thesis Submitted to the School of Graduates Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Master of Science

October 2018

DEDICATION

To my parents, Ismail Awg Hamat and Faridah Mat Zin, for their unconditional love, understanding and moral support.

To my beloved wife Zuhairah Hayati Hared and our children for their motivation.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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Chair : Mohamed Thariq Hameed Sultan, *PhD, PEng, CEng, PTech*
Faculty : Faculty of Engineering

The usage of natural fibres as a reinforcement in material composites has increased over time. This utilization had been applied widely in several regions of the world and has already reached maturity in terms of technology, infrastructure and cost competitiveness. Aerospace industries were looking forwards on fully utilized their structural components by using composites material towards environmentally friendly solutions. The application of hybrid composites can be utilized by reducing the usage of synthetic fibre and replacing them with natural fibre. Nonetheless, the applications of composites in aircraft's structure is tends to develop, especially the use of hybrid composites for fuselage which has many conflicting requirements. Several issues are highlighted in this research such as the selection of natural fibre that suits the usage in aerospace structural applications and the most suitable weight percentage combinations of individual fibre in hybrid composites that approaching the original constituents. Hence, the objectives of this research can be summarised as follows: the mechanical properties of a hybrid composite of glass/ kenaf fibre were investigated, especially with regards to tensile strength and low velocity impact (LVIT) resistance. A non-destructive test (NDT) was conducted by using dye penetrant to inspect the damages after impact where those areas were measured and analysed. The compression after impact (CAI) test was also performed on the impacted hybrid composite samples to analyse further the damage progression of the sample from the compressive aspect. It was found that, through mechanical analysis, the hybrid composite with the combination of 75% weight percentage of glass fibre and 25% weight percentage of kenaf fibre had the best tensile properties that approaching the tensile strength of 100% glass fibre. Furthermore, the best selected sample may experience LVIT impact forces up to 40 Joule. The higher impact force had led to larger damage and dents areas. CAI tests were carried out resulting in the decreases of the compression force exerted to the impacted damaged of the 40 Joule's sample.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
Sebagai memenuhi keperluan untuk ijazah Master Sains

ANALISIS IMPAK HALAJU BERKADAR RENDAH TERHADAP KOMPOSIT HIBRID FIBER GENTIAN KACA/KENAF DAN APLIKASINYA DALAM STRUKTUR AEROANGKASA

Oleh

MUHAMMAD FAIZZUDDIN BIN ISMAIL

Oktober 2018

Pengerusi : Mohamed Thariq Hameed Sultan, *PhD, Peng, CEng, PTech*
Fakulti : Fakulti Kejuruteraan

Pengunaan fiber semulajadi sebagai pengukuh dalam industri komposit semakin berkembang pesat. Ia telah mencapai tempoh kematangan tersendiri daripada aspek teknologi, infrastruktur dan penjimatan kos seiring perkembangan secara meluas di serata dunia. Industri aeroangkasa mengambil langkah kehadapan dengan menggunakan sepenuhnya bahan komposit dalam struktur komponen menjurus kepada penyelesaian yang bersifat mesra alam semulajadi. Penggunaan komposit hibrid berjaya mengurangkan penggunaan fiber sintetik dengan menggantikannya kepada fiber semulajadi. Tambahan pula, pembuatan daripada bahan komposit telah merangkumi hampir keseluruhan struktur kapal terbang termasuklah badan kapal terbang (fuselaj) itu sendiri walaupun menghadapi pelbagai cabaran dalam merealisasikannya. Antara perkara yang dapat diketengahkan dalam kajian ini adalah pemilihan sesuatu fiber semulajadi dan kombinasi campuran berat fiber semulajadi dan sintetik yang sesuai digunakan dalam industri aeroangkasa yang menghampiri ciri-ciri fiber komposit sedia ada. Oleh yang demikian, objektif kajian dapat disimpulkan seperti berikut: kajian berkenaan sifat mekanikal komposit hibrid campuran fiber kaca dan fiber kenaf yang merangkumi kemampuan tensil dan kemampuan untuk menghadapi impak halaju rendah (LVIT). Ujian tanpa musnah (NDT) menggunakan cecair telah dijalankan bagi menganalisa dan mengukur kadar kerosakan. Seterusnya, ujian mampatan selepas impak (CAI) dijalankan untuk analisis lebih lanjut tentang kadar ketahanan yang masih berbaki. Melalui kajian yang dijalankan, dapatlah dibuktikan bahawa, komposit hibrid dengan peratusan berat 75% fiber kaca dan 25% fiber kenaf mempunyai kemampuan tensil terbaik yang menghampiri kemampuan tensil peratusan berat 100% fiber kaca selain mampu menghadapi daya impak LVIT sehingga 40 Joule. Semakin tinggi daya impak, semakin besar kerosakan yang terhasil. Ujian CAI yang dijalankan membuktikan penurunan daya mampatan yang dikenakan kepada sampel 40 Joule yang sudah menjalani ujian impak.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Name of Member of Supervisory Committee:	Assoc. Prof. Ir. Ts. Dr. Abd Rahim Bin Abu Talib

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LIST OF ABBREVIATIONS

3 D	Three dimensional
ABS	Acrylonitrile butadiene styrene
ASTM	American Society for Testing and Materials
BVID	Barely Visible Impact Damage
CAI	Compression After Impact
CMC	Ceramic Matrix Composites
FEA	Finite Element Analysis
FOD	Foreign Object Damage
FRP	Fibre-Reinforced Plastics
g	Grams
GS	Glass Fibre sample
HMC	Hybrid matric composites
HS	Hybrid sample
J	Joule
kN	Kilo Newton
KS	Kenaf Fibre sample
lbs	Pounds
LVIT	Low Velocity Impact Test
m/s	Metre per second
mm	millimetre
MMC	Metal Matrix Composites
MPa	Mega Pascal
MRO	Maintenance, Repair and Overhaul
NaOH	Sodium Hydroxide
PMC	Polymer Matrix Composites
UPM	Universiti Putra Malaysia

CHAPTER 1

INTRODUCTION

1.1 Background

In recent years, plant fibres have been considered environmentally friendly. These natural fibres have been cultivated for thousand years, and yet have become raw materials of many industries which include aerospace, automotive, marine and other military applications, including the defence industry. Findings have shown that natural fibres have been utilized for more than 3000 years ago as reinforcement for materials (Taj et al., 2007, Nadlene et al., 2016). Thus, they have played an important role in developing industry towards a green concept which is environmentally friendly and economically efficiency. The renewable resources of natural fibres are obtained annually and provide positive environmental benefits in the utilization of raw material.

A material with a combination of two or more fabrics or fibre materials is called a composite. It may have reinforcing fibres embedded in a weaker matrix to strengthen its properties. The reinforcement by the natural fibre itself may possible to replace up to 50% weight percentage for better load capacity of the composite materials (Monteiro et al., 2008). Thus, composites with higher fibre strength will increase the strength of the composite materials itself. High stiffness in plane and higher strength may be achieved. Furthermore, replacing metal with a composite may decrease the structural weight of a material. The mechanical properties of the composites will have increased with the existing of fibres as a reinforcement. Tremendous achievements have been reached with the usage of fibre reinforced composite materials in the aerospace, automotive, structural and construction industries. In composite industries, the findings may be significant if we can increase the stiffness and energy dissipating properties of the materials structure (Rajesh and Pitchaimani, 2017).

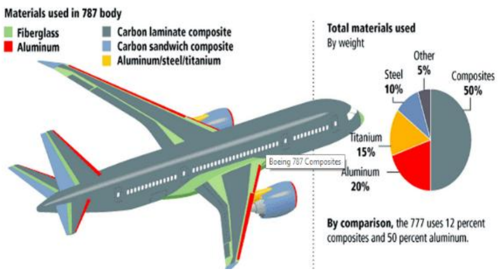

Figure 1.1: Composites Used In Commercial Aircraft Boeing 787 (Aviation SE, 2017).

In the aerospace industry, composites are usually applied in the aerospace structure to reduce the structural weight of the aircrafts and enhancing the efficiency of fuel consumptions (Buckley et al., 2017). Composite structures are utilised for a wide range of jets and aeroplanes, from the smallest scale such as private aircraft, business and regional jets up to the bigger scale of transport aircraft (Fig. 1.1) for commercial usage and combat aircraft (Fig 1.2) for military and defence purposes (Deo et al., 2001).

Figure 1.2: Composites Used In Military Aircraft Rafale (Indian Defence, 2012, Aviation SE, 2016)

Most researchers nowadays emphasize the development of new natural fibre composites and are focusing their work on green materials (Chauhan and Chaudan, 2013, Nadlene et al., 2016). The research involves on their mechanical properties involving tensile, flexural, and impact factors (Dhawan et al., 2013, Vimalanathan et al., 2016). Most of these natural fibres are used as reinforcement to synthetic fibres in hybridize composites (Lee and Wang, 2006, Bodros et al., 2007). Natural fibres in woven form may overcome the poor properties of its origin constituent in state of raw materials. Natural fibre composites are emerging as acceptable alternatives to replace or reinforced synthetic fibre composites such as glass-reinforced composites in many applications. The trends for such development are likely due to the attractive property of the natural fibre composites itself, as mentioned previously.

Impact can be classified into three types of testing that are drop test, pendulum test and ballistic test. Generally, the drop test and pendulum test can be categorized as low velocity impact, while the ballistic test is high velocity impact. Other categories of impact are intermediate velocity impact and hyper velocity impact. Low velocity impact involving tool drops (Fig. 1.3) may occur at a velocity below 10 m/s.

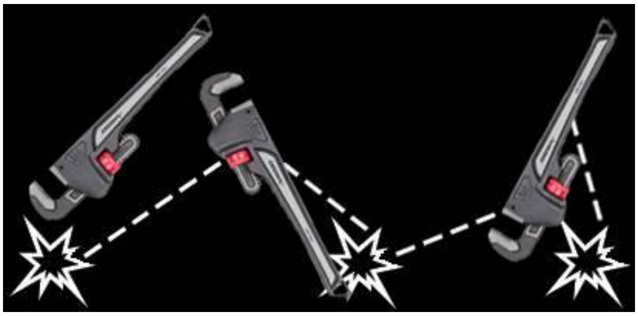

Figure 1.3: Tools Drops From A Height (Roman, 2017)

This direct impact may cause dents and visible damage on surface due to delamination, matrix cracking and fibre breaking of the material after impact response (Razali et al., 2014). Intermediate impact because of collision with a debris on roads, railways and runways may occur at velocity range from 10 m/s and 50 m/s velocity. High velocity impact may range between 50 m/s to 1000 m/s while hyper velocity impact has a range of 2 km/s to 5 km/s (Abrate, 1998). Figure 1.4 shows impact by aircraft crash.

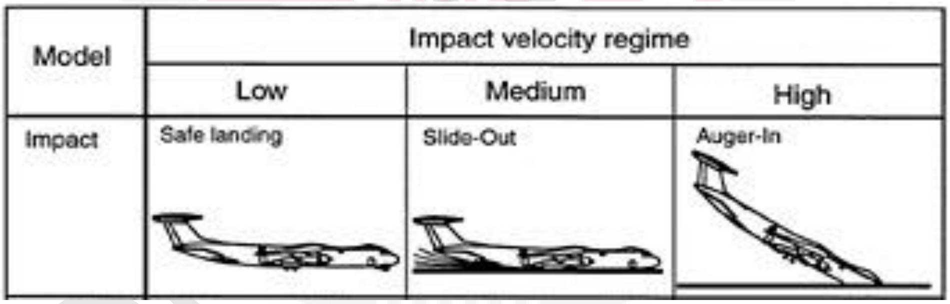

Figure 1.4: Classification Of Crashes By Impact Velocity (Faeth 1997)

The impact threat can cause damage to the composites in aerospace structure. Impact response can be elastic, plastic and fluid or any combination of it (Borvik, 2003, Razali et al., 2014). This is the fundamental basis of impact dynamics of fracture and fragmentation (Borvik, 2003). Aerospace structural damage during maintenance, repair and overhaul (MRO) or even assembly is caused by variety type of impacts. Low velocity impact is considered the most dangerous (Sanchez et al., 2005). Those impact may be due to a bird strike (Fig. 1.5) or bullet strike during operations (Fig. 1.6). While during non-operations, a contact with the ground equipment such as cargo vehicles, tools drop (Fig. 1.3) or foreign object damage (FOD) (Fig. 1.7) may also result in impact.

Figure 1.5: Impact Due To Bird Strike (Simon, 2012)

Figure 1.6: Impact Due To Bullets During Dogfight In World War II (Pinterest UK, 2017a)

Figure 1.7: FOD At Tarmac (RAF Lakenheath, 2015)

On the other hand, induced damage in automotive industries is called barely visible impact damage (BVID) and is categorized as a source of mechanical weakness in the chassis and other body parts structures. Those damaged will contribute to reducing of aerodynamic efficiency to the vehicles body parts (Nikfar and Njuguna, 2014). The most critical damage caused by impact includes holes and cracks, which may reduce the material strength (Horton and McCarty 1993). The damages that are not visible can become larger and wider. This may cause total loss to the material structure itself.

1.2 Problem statement

Composites from the natural fibre that had been hybridized with synthetic fibre were not just used in aerospace industry only, but also used in other developed industries such as automotive, marine, military, defence and construction. The components of aircrafts made of composites is developing from time to time and covered almost all of its structures. The increased in environmental awareness had attracted the researchers to contribute on the development of renewable resources in real time. Even though there are substantial demands for a composite in producing a stronger, stiffer and lightweight material, there are several issues that can be highlighted which result in a more cost-effective and environmentally friendly solution.

Firstly, the utilisation of natural fibre in manufacturing the aircraft's structure that reduce the usage of synthetic fibre. There is an advantage if the natural fibre can replace completely the role of the synthetic fibre. In addition, the selection of natural fibre that are suitable for aerospace usage should be conducted seriously. Kenaf fibre was selected in this research as it is one of the natural fibre that are convenient and having a continuous supply with low production costs. Thus, mechanical properties and congeniality of kenaf fibre need to be justify further. In addition. by weaving the fibre will increase the strength of the kenaf itself. Secondly, there is the issues of the most important factors that contribute to the efficiency of the aircraft. Those factors are aerodynamic, engine performance and weight. By reducing the weight of the aircraft, less fuel's burn will be consumed by the engines that results in fewer carbon dioxide emissions. Thus, more operational cost saving competitiveness could be achieved. However, the selection of aircraft's parts to be manufactured should be investigated further. Fuselage was selected for the aircrafts part even though it has many conflicting requirements. This is because, fuselage is the centre of gravity where most of the weight during operational and non-operational were focused on here.Furthermore, is by using hybrid composite with the existing of natural fibre will helps in reducing the weight or vice versa? The state of the problem can be illustrated as follows:

1) Can hybrid composite parts play the role as original part of aircraft's structure when bonded or embedded to the aircraft during operations?

2) Does hybrid composite perform better in terms of its mechanical properties compared to the existing findings?

3) May hybrid composite assists in weight reduction by the existing of natural fibre rather than using synthetic fibre as a whole?

All of the issues are being investigated in this thesis. Several experimental methodologies are conducted further to achieve the research objective. The aim of this research is to increase natural fibre content by decreasing the percentage of synthetic fibres while maintaining the nature of mechanical and physical behaviours of the materials. Tensile test, low velocity impact test and compression after impact test are utilised to determine its mechanical properties. The non-destructive testing was performed to measure and analyse the effect of impact under low velocity with the progression of those damages. In a nutshell, this research will fill in the gap between renewable and non-renewable sources so that both sources can react simultaneously to ensure eco-friendly environmentally friendly for future development.

1.3 Research objectives

From the literature review of the current research, it was found that the main gap still lacking in terms of research is in the field of impact on natural fibres. Therefore, the main objectives of this current work will be centred on impact analysis. The specific objectives of this current works are as follows:

1) To determine the tensile properties of glass/kenaf hybrid composites with varying weight percentage ratios.
2) To identify the low velocity impact properties of glass/kenaf hybrid composites corresponding to varying impact energy levels.
3) To estimate the damage area of the impacted specimens using the dye penetrant method.
4) To evaluate the damage progression from the properties of compression after impact (CAI) on the impacted specimens of glass/kenaf hybrid composites.

The best performance sample in the tensile test of different weight compositions among the hybrid samples from the first objective will be selected to undergo a low velocity impact test to achieve the second objective. Meanwhile, the third objective of estimating the damage area is based on the result of the second objective. Finally, the fourth objective will be accomplished when the same hybrid sample from the low velocity impact test later undergoes compression after impact test.

1.4 Scope of the Study

The scope of this study concerns on the applications of glass/ kenaf fibre hybrid composite for the manufacturing of aircraft's fuselage. The utilisation of hybrid composite is expecting to reduce the costs while preserving natural resources from the combination of kenaf fibre and glass fibre as well as by decreasing the weight of the fuselage for a better performance. The factors involved that affecting the aircraft's performance is investigated in this research. The mechanical properties of natural fibre and synthetic fibre and also the combination of them are being determined. The tensile test is conducted to compare the mechanical properties of those combination with respect to the different weight percentage of individual sample. Mechanical properties testing was conducted to experimentally select the best sample from the hybrid composite combination and to find those that exhibit similar mechanical and physical properties to their sources. In addition, the LVIT analysis was conducted to the best sample selected from the tensile test to measure the maximum impacting energy that the sample can withstand.

Furthermore, further analysis from the impacted sample is also conducted by using NDT penetrant to investigate the damage progression and to optimise the parameters by evaluating and measuring the damage from the impact. While CAI test is set up later to measure how much extent the sample can withstand longer after experiencing earlier impact. These analyses are utilised to synthesise the correlation amongst those mechanical properties. Even though the main research is focused on the utilisation of natural fibre to replace existing usage of synthetic fibre, the fundamental assessment of the factors that contributes to the weight reduction of the aircraft's fuselage is also taken in accounts to compliments the research for future benefit and reference. No extensive research to optimise the fuselage design. Hence, the fabrication process to provide new shape of entire structure of fuselage is reported as engineering growth to the author and is beyond the research scope. This study serves industry by providing an insight into the low velocity impact behaviour of synthetic fibre (glass fibre) and natural fibre (kenaf fibre) hybrid composites. The implications of this research will help industrial designers to understand the impact behaviour of glass/kenaf hybrid composites laminates. The use of natural fibres as renewable materials will reduce the usage of synthetic fibres, thus preserving natural resources.

1.5 Organisation of the thesis

This thesis, consisting of five chapters, is traditionally organised to provide the background, literature review, methodology research, discussion and conclusion. The subsequent chapters are as follows:

Chapter 1 introduces the background and motivation for the study as well as outlining the scope and objectives of the research.

Chapter 2 summarises the literature review with previous research studies on natural fibre and synthetic fibre, a review of composites, current technology and related industry. This chapter will also describe the potential of glass/kenaf hybrid laminates in composites industries.

Chapter 3 describes the materials and research methodology includes the material selection and fabrication of test specimens, tensile testing procedures, low velocity impact testing procedures, dye penetrant inspection method and compression after impact testing method.

Chapter 4 presents results and discussion from the analyses of tensile testing, low velocity impact testing, in terms of impact load and absorbed energy, corresponding to incident impact energy, followed by damage progression and compression after impact. Comparisons between the results of tensile test, low velocity impact and compression after impact are also made.

Chapter 5 concludes the research work and summarises all the findings on this subject. Recommendations for future research works are also included.

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LIST OF PUBLICATIONS

Journal papers

Ismail, M. F., Sultan, M. T. H., Hamdan, A., and Shah, A. U. M. (2018). A Study on the Low Velocity Impact Response of Hybrid Kenaf-Kevlar Composite Laminates Through Drop Test Rig Technique (2018). Bioresources Volume 13, Issues 2, Page 3045-3060. DOI:10.15376/bbiores.13.2.3045-3060. Articles submitted: September 29, 2017; Published on March 6, 2018.

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Workshop and Seminars

Workshop on Thermal Mechanical Analyzer (TMA), organized by *Laboratory of Technology Biocomposite at Institute of Tropical Forestry and Forests Products* (INTROP), Universiti Putra Malaysia on 1st June 2016. – Participant.

Workshop on How to Structure Post-Graduate Research: Introduction to K-Chart, organized by *Research Centre of Excellence for Wireless and Photonic Network* (WiPNET), Department of Computer System and Commounication Engineering, Faculty of Engineering Universiti Putra Malaysia on 20th August 2016 – Committee and Participant.

Seminar on Structured Approach for Writing and Publishing Scientific Papers: S.P.A.M Approached, organized by *EduExplore Sdn. Bhd*., at Significant Technology (SIGTech) Balakong HQ, on 14th February 2017 – Participant

1st International Conference on Safe Biodegradable Packaging Technology (SafeBioPack 2018), organized by *Institut Perhutanan Tropika dan Produk Hutan* (INTROP), Universiti Putra Malaysia, at Malaysian Industry-Government Group for High Technology (MiGHT), Cyberjaya, on 24-26th July 2018 – Participant with Third Prize in Poster Presentation.

Book chapters

Ismail, M. F., Sultan, M. T. H., Hamdan, A., and Shah, A. U. M. (2018). Tensile properties of glass/kenaf hybrid composites with varying weight percentage. Status submission: Published.

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