UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF COMPOSITE HYBRIDIZATION OF KENAF FIBRE AND X-RAY FILM FOR AEROSPACE BALLISTIC IMPACT APPLICATIONS

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DEVELOPMENT OF COMPOSITE HYBRIDIZATION OF KENAF FIBRE AND X-RAY FILM FOR AEROSPACE BALLISTIC IMPACT APPLICATIONS

By

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During flight, aerospace structures are often exposed to high velocity impacts with both hard and soft or deformable objects. These objects include metal pieces or fragments, stone debris, birds, hailstones, and tyre rubber. Therefore, in the design of aerospace structures, engineers are required to implement composite structures that are able to withstand this type of impact. This thesis aims at developing a novel hybrid composite material based on kenaf fibre and x-ray films and at analysing the obtained materials with regard to their mechanical properties, as well as high velocity impact and compression after impact behaviour, with a view to determining their potential to compete with existing high velocity impact resistant materials, which are presently used to fabricate the insert plates of bulletproof vests. The kenaf fibre used to reinforce the composites was treated with NaOH solution, and, for comparison purposes, composites were prepared with both treated and untreated kenaf fibre. Similarly, the x-ray films were punctured to improve adhesion between the layers and composites were fabricated with both punctured and unpunctured x-ray films. The materials were fabricated using the conventional hand lay-up method, with 7 layers arranged according to different configurations. The optimum configuration was then chosen – judging by the mechanical characteristics obtained – and improved. The new configuration was then used to fabricate a series of samples to be tested with regard to their behaviour to high velocity impact. A single stage gas gun was used for the tests, and the analysed variables were the pressure of the gas gun – which influences the velocity of the bullets – and the type of the bullets. The bullet types used were: blunt or flat bullets, hemispherical bullets and conical or chisel-pointed bullets. The pressure for the gas gun was varied as follows: 20 bar, 30 bar, 40 bar and 50 bar. The tests revealed that the hemispherical bullets penetrated the specimens the most easily, followed by the conical ones and lastly by the blunt bullets. The experiments demonstrated that the developed composite was impact resistant and managed to absorb more than 130 J of energy at a bullet speed of up to 230 m/s.

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

REKABENTUK PENGGABUNGAN KOMPOSIT ANTARA FIBER KENAF DAN FILEM X-RAY BAGI TUJUAN APLIKASI DALAM IMPAK BALLISTIK AEROANGKASA

Oleh

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Dalam penerbangan, struktur aeroangkasa sentiasa berpeluang menerima impak berhalaju tinggi daripada objek yang keras mahupun objek lembut atau berubah bentuk. Contoh objek-objek ini adalah cebisan atau pecahan besi, batu, burung, hujan batu dan getah tayar. Oleh itu, para jurutera perlu menggunakan struktur komposit yang mampu menahan impak sebegini dalam rekabentuk struktur-struktur aeroangkasa. Tesis ini membincangkan pencirian mekanikal, ujian impak berhalaju tinggi serta mampatan selepas ujian impak pada bahan komposit baru yang ingin dibandingkan dengan bahan mampu tahan impak berhalaju tinggi yang sedia ada iaitu plat imbuhan untuk baju kalis peluru yang sedia ada. Bahan yang dipilih untuk kajian ini adalah fiber kenaf – yang tidak dirawat dan yang dirawat dengan solusi NaOH – serta filem x-ray – yang tidak dirawat dan yang dirawat permukaannya dengan lubang konsisten. Bahannya difabrikasi menggunakan kaedah susunan tangan yang tradisional kepada 7 lapisan yang berbeza ususan. Susunan yang terbaik dipilih – melalui ciri mekanikal yang diperoleh – dan diperbaiki. Susunan baru ini kemudian difabrikasi dengan banyak dan diuji dengan ujian impak berhalaju tinggi. Spesimen tersebut diuji menggunakan pistol gas, dengan tetapan tekanan yang berlainan – yang mana memberi halaju peluru yang berlainan – dan tiga jenis peluru yang berbeza. Peluru yang digunakan adalah peluru tumpul atau leper, peluru semi-sfera dan peluru kon. Tetapan tekanan bagi pistol gas tersebut adalah 20 bar, 30 bar, 40 bar dan 50 bar. Peluru semi-sfera menembusi specimen paling mudah, diikuti dengan peluru kon dan akhirnya peluru leper. Daripada experimen ini, specimen tersebut didapati Berjaya menahan peluru serta mampu menyerap lebih daripada 130 J tenaga dan peluru berhalaju hingga 230 m/s.

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I certify that a Thesis Examination Committee has met on 12 October 2018 to conduct the final examination of Ahmad Mustafa bin Rayney Azmi on his thesis entitled "Development of Composite Hybridization of Kenaf Fibre and X-ray Film for Aerospace Ballistic Impact Applications" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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LIST OF ABBREVIATIONS

AP	Armour-Piercing
ASTM	American Society for Testing and Materials
BMCI	Block Manometric Cannon Interchangeable
CAI	Compression After Impact
CFRP	Carbon-Fibre-Reinforced Polymer
cm	Centimetre
FMJ	Full Metal Jacketed
FRP	Fibre-Reinforced Polymers
FSP	Fragment Simulation Projectile
g	Gram
G	Giga
GRP	Glass-Reinforced Polymer
ICI	Imperial Chemical Industries
J	Joules
kg	Kilogram
m	Metre
M	Mega
m/s	Metre per Second
MAS	Multi-Layered Armour System
mm	Millimetre
N	Newtons
NATO	North Atlantic Treaty Organization
NIJ	National Institute of Justice

Pa	Pascal
STF	Shear Thickening Fluid
UHMWPE	Ultra-High-Molecular-Weight Polyethylene

CHAPTER 1

INTRODUCTION

1.1 Introduction

Aerospace structures are subjected to a lot of impacts during flight. These impacts fall into the category of high velocity or ballistic impacts, considering the high speed that the aircraft travels at. In order to protect the aircraft and spacecraft from damages caused by such impacts, they need to be covered with ballistic-resistant materials, which are very similar to those used for protective gear, such as body armours, helmets and shields. The purpose of these ballistic-resistant materials is not simply to stop the high-velocity bullets, but also to safeguard the individual from fragmenting devices, such as grenades, mortars, and artillery shells. Since such materials are accessible and have already been tested, the present study will start with a discussion of their properties and related equipment.

Ballistic-resistant materials, including conventional body armours and helmets, are known to comprise high strength fibres. Commonly used fibres include aramid fibres, such as poly (phenylenediamine terephthalamide), graphite fibres, nylon fibres, glass fibres and the like.

One of the components used to prepare a composite material is termed as the matrix or binder. It binds together the other component, i.e. the fibre, which is termed as the reinforcement. The most commonly used composites are fibre-reinforced polymers or FRPs. Two types of FRPs that have wide application in various industries are the glass-reinforced polymer or GRP, and the carbon-fibre-reinforced polymer or CFRP [1].

FRPs can also be grouped into thermoplastic and thermoset based materials. The main difference between thermoplastic and thermoset polymers is that a thermoset would retain its shape permanently after curing, whereas thermoplastics can be turned back into liquid form through melting. Compared to thermoplastics, thermoset plastics can withstand a higher temperature and are generally cheaper. Epoxy resin, a type of thermoset, has very good flexural strength. Thermosets are also stronger than other resins, and not as brittle as polyester.

In terms of reinforcement, FRPs can be classified into synthetic composites, natural fibre composites and hybrid composites. Hybrid composites can be further classified into natural-natural hybrid composites, natural-synthetic hybrid composites, and synthetic-synthetic hybrid composites. Natural-synthetic hybrid composites are desirable due to their combined advantages of environmental friendliness provided by the natural fibre and the high strength imparted by the synthetic fibre.

Radiographic films or x-ray films are commonly used for medical purposes to capture radiographic images of the inside of the body, i.e. the organs and/or internal structures. However, they can also be used to view the internal form of an inanimate object. These films consist of a transparent polymeric base, coated with emulsion-gelatine containing radiation sensitive silver halide crystals. The base makes the films very flexible and the coating makes the surface very smooth.

Kenaf fibre is extracted from the stems of *Hibiscus cannabinus*, a plant in the genus *Hibiscus*, and the family of Malvaceae. Kenaf plants require a small amount of water to grow, they have a growing cycle of 150 to 180 days, and an average yield of 1700kg/ha [2].

Studies [3,4] have revealed that kenaf plant breathes in carbon dioxide roughly one and a half times its weight. It signifies the highest level of carbon dioxide absorption among the different plants included in the study. Zaveri [5] found that kenaf plants can grow to a height of almost 3.5 to 4.5 meters in a period of four to five months, yielding six to ten tonnes of dry fibre per acre annually. This is about the quadruple of the fibre yield of southern pine trees.

1.2 Problem Statement

Aerospace ballistic impact happens when the body of an aircraft or spacecraft is subjected to impact with debris in flight. The debris could be rocks and stones stuck in the tyres of the aircraft, pieces of metal like screws and nuts that came off the aircraft, birds in flight, hailstones, or even debris in space like old satellites and spent rocket stages, including fragments from their disintegration, erosion and collisions. Thus, if not manufactured from materials suitable for protection, the structures would be damaged or, even worse, would be penetrated upon such impact. Therefore, these structures are often made using composite materials, which are known to have high resistance to impacts.

Commonly used composite materials for such purposes comprise synthetic fibres, which are quite expensive and are derived from limited fossil resources. Moreover, synthetic fibres raise further environmental concerns because of their non-biodegradability. To resolve these issues, hybrid composite materials fabricated using natural fibres and synthetic fibres are being investigated.
Natural fibres, which are environmentally friendly, easily available and a lot less expensive, while yielding good properties in composites, seem to be the best choice for partially replacing synthetic fibres in currently used materials.

X-ray films are mostly based on synthetic polymers. Because of this, they are non-biodegradable and thus they need to be disposed of properly. Even more so, they contain silver halide crystals, which are harmful to the environment when they are not dealt with in the right way. Besides that, these x-ray films also contain private health information, which should not be disclosed. Hence, their disposal should be made with care. On the other hand, hospitals and imaging clinics amassed these used x-ray films due to the difficulty of disposal. From another point of view, a lot of hospitals and imaging clinics are switching to digital x-ray imaging. Hence, they have a lot of unused x-ray films in stock which now serves no purpose. This research work proposes a novel way of making use of these x-ray films by recycling them to fabricate composites.

1.3 Objectives

A comprehensive literature review has been conducted, revealing that the use of x-ray films in composites has not been reported as yet. Therefore, the present thesis focuses on the development of hybrid composites based on x-ray films and kenaf fibre. Also, from the literature review conducted, it has been found that the impact behaviour of hybrid composites has been insufficiently investigated and it is thus a major research gap that needs to be addressed. In order to develop a novel hybrid composite using x-ray films and kenaf fibre, as well as evaluate its impact behaviour, several objectives have been summarized as follows:

(i) To investigate the mechanical properties, namely tensile and flexural properties, of the kenaf fibre/x-ray film hybrid composite.

(ii) To determine the impact properties, such as the energy absorbed, force and penetration behaviour, of the kenaf/x-ray film hybrid composite.

(iii) To estimate the damage area of the impacted kenaf/x-ray film hybrid composite through the dye penetration test.

(iv) To investigate the residual strength of the kenaf/x-ray film hybrid composite through compression after impact (CAI) testing.

1.4 Scope of Thesis

(i) In this research, composites with eleven different configurations consisting of layers of kenaf fibre and x-ray films embedded in an epoxy matrix were fabricated and subjected to tensile and flexural tests.

(ii) The configuration that gave the best results in terms of tensile and flexural strength was then used to fabricate multiple samples, which were subjected to high-velocity impact tests.

(iii) For the high-velocity impact tests, the specimens were shot by a single stage gas gun using different types of bullets.

(iv) Different pressure levels were used, which resulted in a variation of bullet velocities.

(v) The penetration was observed and recorded, and the energy absorbed was discussed.

(vi) Damage area and depth were observed and approximated by dye penetrant examination.

(vii) Residual strength of the specimens was investigated by compression after impact tests.

1.5 Thesis Outline

This thesis is divided into five chapters and is organized as follows:

(i) Chapter 1, Introduction: This part offers an overview of composites, x-ray films and kenaf fibre.

(ii) Chapter 2, Literature Review: This chapter synthesizes previous research on ballistic-resistant materials, including ballistic studies and testing, as well as the applications of existing composite materials in anti-ballistic designs.

(iii) Chapter 3, Methodology: This part clarifies specifics related to material selection and fabrication, curing and post-curing treatments of the test specimens, as well as testing.

(iv) Chapter 4, Results and Discussion: This chapter presents the results of mechanical characterization and high velocity impact tests, as well as analyzes the findings.

(v) Chapter 5, Conclusion and Recommendation: This chapter summarizes the findings of the study and outlines directions for further research.

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He took his primary education at Sri Al-Abqari, where he was a consistent honour student and was appointed as the head of prefect. His secondary education was at SAM Rawang and SMT Gombak, where he was awarded the Excellence in Mathematics and Best Student for English award. He then went to Johor Technical Matriculation College, where he was awarded as best student when graduated with a perfect CGPA. In 2012, he was admitted at Universiti Putra Malaysia under the Bachelor of Aerospace Engineering program. Now, since 2016 he's been under the Master of Science program, specializing in Materials Engineering also in Universiti Putra Malaysia.

Aside from academics, he also engaged in a lot of extra-curricular activities. He was appointed as the President for Mentor Mentee Committee as well as the Vice-President for English Club in Matriculation. He was also a member of the Student Representative Council in his second year of Bachelor Degree. Now, he also does tutoring for refugees, facilitating school camps and corporate team buildings, as well as volunteering for events outside the University.

LIST OF PUBLICATIONS

Journals

Azmi, A.M.R., Sultan, M.T.H., Jawaid, M., Talib, A.R.A. & Nor, A.F.M., (2018). Tensile and Flexural Properties of a Newly Developed Bulletproof Vest Using a Kenaf/X-ray Film Hybrid Composite. Bioresources, 13(2), 4416-4427. – Published

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Book chapters

Azmi, A.M.R., Sultan, M.T.H., Jawaid, M., Nor, A.F.M., (2018). A Newly Developed Bulletproof Vest Using Kenaf–X-Ray Film Hybrid Composites. Mechanical and Physical Testing of Biocomposites, Fibre-Reinforced Composites and Hybrid Composites – Accepted

Ain U, M.S., **Azmi, A.M.R.**, Safri, S.N.A., Ismail, K.I., Nor, A.F.M., Razali, N., Sultan, M.T.H., (2017). Numerical and Experimental Analysis of Delamination in Fibre Reinforced Polymer Composites. Failure Analysis in Biocomposites,Fibre Reinforced Composites and Hybrid Composites – Accepted

Conferences

Azmi, A.M.R., Sultan, M. T. H., Francisco, C., & Jawaid, M. (2016). Design and Development of a Bullet Proof Vest Embedded with Kenaf Fibre and X-Ray Films – An Approach from Waste to Wealth. The 4th Symposium on Applied Engineering and Sciences

Azmi, A.M.R., Sultan, M. T. H., Francisco, C., & Jawaid, M. (2017). Design and Development of a Bullet Proof Vest Embedded with Kenaf Fibre and X-Ray Films – An Approach from Waste to Wealth. Mechanical Engineering Research Day

Workshops and Seminars

1. Global Aerospace Industry Outlook and Insight into Malaysia's Aerospace Initiatives Talk, Aerospace Manufacturing Research Centre, UPM, 2 March 2017 – Participant

2. Introduction to TRIZ Talk, Aerospace Manufacturing Research Centre, UPM, 8 March 2017 – Participant

3. Composite Technology - Current and Future Trends Talk, Aerospace Manufacturing Research Centre, UPM, 16 March 2017 – Participant

4. FEA ABAQUS Workshop, Aerospace Manufacturing Research Centre, UPM, 3 April 2017 – Participant

5. International Workshop on Advanced Composites And Its Manufacturing, Aerospace Manufacturing Research Centre, UPM, 10 April 2017 – Participant

6. Introduction to Taguchi Method Talk, Aerospace Manufacturing Research Centre, UPM, 26 April 2017 – Participant

7. Sharing Session on Student - Supervisor Relationship, Aerospace Manufacturing Research Centre, UPM, 2 May 2017 – Participant

8. Taguchi Method Workshop, Aerospace Manufacturing Research Centre, UPM, 3 May 2017 – Participant

9. Predictive Engineering Analytical for Sustainability and Recent Trends, Aerospace Manufacturing Research Centre, UPM, 20 July 2017 – Participant

10. LabVIEW – Hands On Training Workshop, Aerospace Manufacturing Research Centre, UPM, 7 September 2017 – Participant

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