UNIVERSITI PUTRA MALAYSIA

POST OBLIQUE BALLISTIC IMPACT BEHAVIOUR OF HYBRID COMPOSITE PLATES REINFORCED WITH CARBON NANOTUBES

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By

ELIAS RANDJBARAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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DEDICATION

To all the scientists and researchers from the four corners of the world, no matter what the nationality, language, race, or skin colour are.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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Chairperson : Dayang Laila binti Abang Haji Abdul Majid, PhD
Faculty : Engineering

The present experimental investigation endeavoured to examine the tensile, compression, and 3-point bending strength of the laminates made of carbon/Kevlar hybrid reinforced textiles with carbon nanotubes (CNTs) fillers subjected to oblique ballistic impact loads. The advanced nano-fillers were chosen as reinforcement for the carbon/Kevlar hybrid textile composite because of their high Young's modulus. Although there are a number of experimental investigations on tensile properties of CNTs, the coupling effects of CNTs and oblique impacts on tensile, compression, and 3-point bending strengths have not been examined yet. Consequently, individual oblique impacts ranging from 0 to 40 degrees were conducted on the composite plates made-up of fabrics with diverse volumes of CNTs, which ranged from 0.1% to 1.5%. The plates were fabricated with eight layers of equal thickness arranged in different percentages of CNTs and neat epoxy resin. A conical steel projectile at dimensions of 15 mm length and 10 mm diametre was considered for a high velocity impact. While the projectile was placed very close to the plates, i.e. at their centres, they were impacted at sundry speeds. The modulus of elasticity and toughness were calculated for the stress-strain curves obtained from the mechanical tests. In the progress of the experiments, the variation of the kinetic energy, the increase in the internal energy of the laminates, and the decrease in the velocity of the projectile with disparate angles were examined. Results from the experimental tests indicated that the kinetic energy absorption of the projectile increased by 38% with the increase of the oblique angle of 40 degrees at 0.3% CNTs' desperation. The optimum dispersion of the CNTs fillers was 0.3% and by adding the CNTs, the kinetic energy absorption increased by about 35%. Additionally, the inclusion of the CNTs' fillers by 1.5% resulted in improving the compressive toughness of the specimens more than triple times. The increase of CNTs fillers by 1.5% caused the decrease of the tensile strength and toughness by 86%. Moreover, the incorporation of 1.5% of CNTs caused the increase of the flexural bending toughness of the specimens more than four times. Simultaneously, the flexural modulus of elasticity decreased by up to 38%. The incorporation of CNTs by 1.5% increased the flexural bending toughness more than four times; however, the flexural modulus of elasticity decreased by up to 38%.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

TINGKAH LAKU SELEPAS BALISTIK CONDONG KE ATAS PLAT KOMPOSIT HIBRID DIPERKUAT DENGAN NANOTUB KARBON

Oleh

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Januari 2022

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Penyelidikan eksperimen ini bertujuan untuk mengkaji kekuatan tegangan, mampatan dan lenturan lamina yang diperbuat daripada tekstil bertetulang hibrid karbon/Kevlar dengan pengisi tiub nano karbon (CNT) tertakluk kepada beban hentaman balistik serong. Pengisi nano termaju dipilih sebagai tetulang komposit tekstil hibrid karbon/Kevlar kerana modulus Young yang tinggi. Walaupun terdapat beberapa penyelidikan eksperimen berkenaan sifat tegangan CNT, namum kesan gandingan CNT serta hentaman serong terhadap sifat tegangan, mampatan, dan kekuatan lentur 3 titik masih belum disiasat. Oleh itu, hentaman serong individu dalam penjulatan 0 hingga 40 darjah telah dilakukan pada plat komposit yang dibuat daripada fabrik dengan pelbagai isipadu CNT yang terdiri daripada julat di antara 0.1% hingga 1.5%. Plat telah direka dengan lapan lapisan sama ketebalan yang disusun dalam peratusan CNT yang berbeza dan resin epoksi. Peluncur keluli kon dengan dimensi 15 mm panjang dan 10 mm diameter telah dipertimbangkan untuk hentaman halaju tinggi. Walaupun peluncur itu diletakkan di posisi berhampiran dengan plat, iaitu di bahagian tengah, namun plat tersebut terkena impak kelajuan yang pelbagai. Modulus keanjalan dan keliatan dikira daripada lengkungan tegasan-terikan yang diperoleh daripada ujian mekanikal. Susulan perkembangan eksperimen ini merangkumi penyiasatan dari segi variasi tenaga kinetik, peningkatan tenaga dalaman lamina, dan penurunan dalam halaju peluru dengan sudut yang berbeza. Keputusan ujian eksperimen ini menunjukkan bahawa penyerapan tenaga kinetik peluru meningkat sebanyak 38% dengan peningkatan sudut serong 40 darjah pada 0.3% CNT dalam keadaan yang extrem. Penyerakan optimum pengisi CNT ialah 0.3% dan dengan kehadiran CNT, penyerapan tenaga kinetik meningkat hampir 35%. Di samping itu, rangkuman pengisi CNT sebanyak 1.5% mengakibatkan peningkatan lebih tiga kali ganda dari segi keliatan mampatan spesimen. Manakala, peningkatan pengisi CNT sebanyak 1.5% menyebabkan penurunan keliatan kekuatan tegangan sebanyak 86%. Selain itu, penggabungan CNT sebanyak 1.5% menyebabkan peningkatan lebih daripada empat kali ganda dari segi keliatan lengkung lenturan spesimen. Dalam masa yang sama, modulus lentur keanjalan menurun sehingga 38%.

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

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

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LIST OF ABBREVIATIONS

AISI	American Iron and Steel Institute
ASTM	American Society for Testing and Materials
CAI	Compression After Impact
CMOS	Complementary Metal Oxide Semiconductor
CNT	Carbon Nanotubes
EDX	Energy Dispersive X-ray spectroscopy
FAA	Federal Aviation Administration
FPS	Frames Per-Second
GB	Giga Byte
GPa	Gigapascal
IEEE	Institute of Electrical and Electronics Engineers
J	Joule
$J.m^{-2}$	Joule Per Square Metre
$J.m^{-3}$	Joule Per Cubic Metre
kPa	Kilopascal
LOS	Line of Sight
$m.s^{-1}$	metre per second
$m.s^{-2}$	metre per square second
$m.s^{-3}$	metre per cubic second
MPa	megapascal
MWCNT	Multi-Walled Carbon Nanotube
NIJ	National Institute of Justice
RPM	Revolutions Per Minute
SEM	Scanning Electron Microscopy

STS	Space Shuttle Endeavour
SWCNT	Single-Walled Carbon Nanotube
UNS	Unified Numbering System
USB	Universal Serial Bus
V_{50}	ballistic limit velocity
VS.	Versus
XRD	X-ray Diffraction

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Carbon nanotubes (CNTs) as the filler material could be utilised for composite reinforcement. Due to the superlative mechanical properties of carbon nanotubes, it seems that using them in the James Webb Space Telescope is apt (Li et al, 2021). It has been realised that via the fabrication and experiment connecting the network of carbon with the other elements' networks may result in strengthening the backplane (NASA, 2017). Therefore, this property enables the engineers to design a reliable system resisting against the shifted temperatures in the atmosphere of Earth and space. As a subject in engineering studies, composite materials have undergone tremendous advancements during the past thirty years. Due to the frequent application of composite materials, their advantages over other materials have been well documented in the engineering studies during the last decades (Delfini et al, 2021; Ismail et al, 2021; Xia et al, 2021). In addition, the environmental resistance and strength-to-weight-ratio of composite materials have particularly made them pivotal in industries. For example, the United States Army is tending to use lightweight alternatives to substitute traditional steel or aluminium materials (Flora et al, 2021; Burdette-Taylor, 2018). Therefore, many research studies are motivated to investigate new composite systems (Oliveira et al, 2021; Hueber et al, 2019; Budhe et al, 2018). These desirable types of composite systems are regularly thick-section laminates that require significant damage tolerance to repeated impacts at the highest levels of energy (Wang et al, 2018; Zhu et al, 2018). Consequently, an examination of mechanical behaviour of the under impact plates in a laboratory setting is a requirement that may lead to practical results in the field of engineering of materials. Some impact experiments might be performed by a controllable and repeatable gas tunnel system that monitors the responses of the under impact plates and characterises the damage tolerance of them (Prabhakar et al, 2019).

The quest for advanced materials for tailor-made applications and new devices or for understanding the complexity of living matter has led to a tremendous research exploring the possibilities offered by various kinds of functional building blocks to design matters (Boparai et al, 2020; Murray & Örmeci, 2018; Keçili et al, 2018). Recent technological breakthroughs and the need for new functions generate an enormous demand for novel materials. Innumerable volume of the entrenched materials, such as plastics, metals, or ceramics cannot perform all technological needs for the various new applications. Recently, scholars realised that a mixture of materials can show superior properties compared with their pure corresponding items. One of the most lucrative examples is the group of composite materials, which are formed by the incorporation of a basic structural material into the matrix (Jia et al, 2018; Zhu et al, 2018).

There are two possibilities that the hybrids could be damaged; first, Bird-strikes during the flight. Second, dropping of tools during the maintenance service. Figure 1.1 illustrates an ongoing possible bird strike. The ballistic penetrated impact of bullets and bird-strike-taking place at the high speeds during the flight are appropriate examples of impact loads that may result to the very serious damages to the surface of the aircraft, especially the nose (Liu et al, 2021; Lu et al, 2021; Arachchige et al, 2020).

Figure 1.1: Bird Strike Is One of the Common Accidents Between Birds and Aeroplanes
(Source: Zhou et al, 2020)

Most of the bird-strike incidents are not as severe as illustrated in Figure 1.2. Only large and heavy birds can cause such a damage as depicted in Figure 1.2.a, which is resulted from a bird strike, a pelican involved (FAA Wildlife Strike Database, 2021), and can cause serious damage to aircraft. Figure 1.2 b, c and d. display United Airlines Boeing 737 striking a bird as it descended into the Denver International airport (Abbey, 2012). Figure 1.2. shows Iberia Airbus A340 with nose damage (Siegfried, 2021). However, a sizeable portion of an airline's (as well as military force) maintenance budget is for minor strikes. On every occasion, the flight crew becomes aware of or even suspicious of a bird strike, the aircraft must be inspected thoroughly for probable damages. Moreover, Federal Aviation Administration in 2019 reported bird-strike damages about $1.2 billion to commercial aircraft worldwide yearly in Figure 1.3. After engine damage, wing, body, and nose damages are the next (Metz et al, 2021; DiCaprio et al, 2020; Cai et al, 2019; Riccio et al, 2018).

Figure 1.2: Bird Strike Events
(Source: Metz et al, 2017)

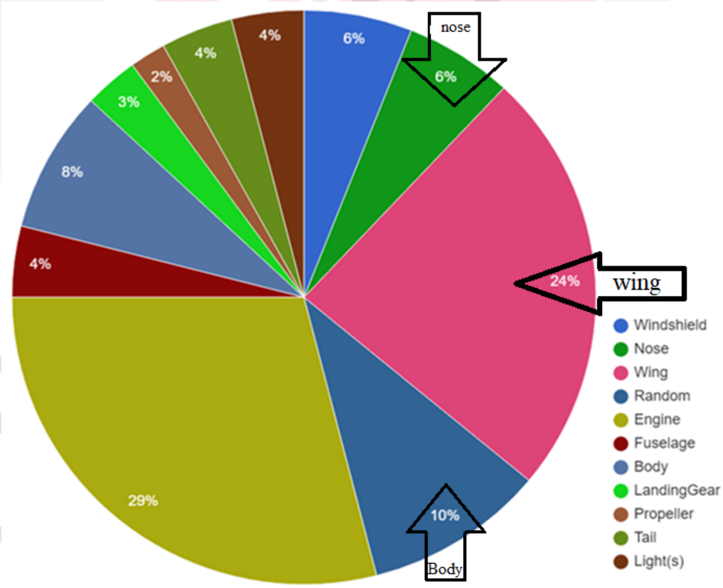

Figure 1.3: Statistics and Analyses for Bird Strikes
(Source: Novoselova et al, 2020)

Furthermore, the bird strikes put at risk the lives of aircraft crewmembers and their passengers. According to the report of the Associate Administrator of Airports in 2012, over 219 people have lost their lives worldwide due to wildlife strikes since 1988. The number of animal strikes reported annually went down from 1,793 in 1990 to 9,622 in

2010, with birds involved in 97.2% of the strikes. Seventy percent of those strikes occurred when the aircraft was at a height of less than 150 metres elevation (Sarkheil et al., 2020).

The events of the impact can be divided into four types of velocity ranges. They are low velocity, high velocity, hypervelocity and ballistic impact. Low velocity impact (less than 30 m/s) might be included in the situations like dropped tools whereas high velocity (50 m/s – 300 m/s) might include birds colliding with an aircraft. Situations such as the projectiles being fired from a gun at speeds exceeding 250 m/s classified under ballistic impact events (Yeter, 2019). Finally, orbital debris travelling in outer space at the velocity of 15,240 m/s as shown in Figure 1.4 is considered a hypervelocity impact event (Mahesh, 2021; Ye, 2018). Hence, Figure 1.4.a shows the computer-generated image of the distribution of the catalogued space debris around the Earth (Mahesh, 2021); Figure 1.4.b illustrates the entry-hole damage (5.5 mm diameter hole) to the endeavour's left side aft-most radiator panel observed during post-flight inspection. The endeavour suffered a major hit on the radiator during STS-118 (Mahesh et al, 2021).

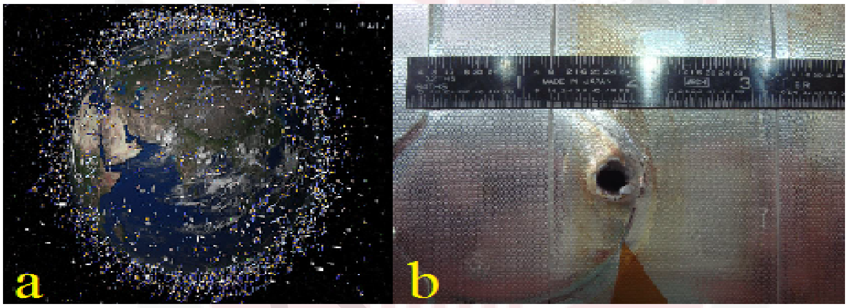

Figure 1.4: The Orbital Space Debris Impacts Observed for Modern Space Flight (Source: Mahesh et al, 2021)

Orbital debris, though small, could possess incredible amounts of energy. At typical impact speeds of 9,700 ms^{-1}, a one-gram object has the same kinetic energy as a bowling ball travelling at 114 ms^{-1}. That energy is more than sufficient to severely damage a satellite or spacecraft, demolish millions of dollars of hardware, or put people's lives in danger. In view of the fact that space is so large, the odds of event impacts are low although they are steadily rising with each launch. Concurrently several environmental problems, early prevention might be far economical than a later clean up (Radhamani et al, 2018).

Material or structural design must incorporate a consideration of damage. Therefore, the objects must be considered resistance, durability, and damage tolerance, as they are interrelated. Damage tolerance of composites is important in both ballistic and structural applications. For example, in ceramic-composite armour systems, high-energy impacts typically induce a global deflection of the panel and local crushing and fragmentation of the ceramic core at the impact spot. The effectiveness of the ceramic tile at each impact site is dependent on the retention of structural support (i.e. damage tolerance), but technically ceramic composites are heavy. Therefore, in the case of lightweight composite vehicle appliances, the composite materials must be able to withstand multiple low velocity impact such as tool drops and tree impacts over the vehicle lifetime without losing structural properties or excessive maintenance and repair - the composite materials for use in damage tolerance (Zhuang et al, 2018). They are susceptible to damage from out-of-plane impacts that ultimately reduce their overall mechanical properties through delamination and matrix and fibre cracking.

Compression after impact (CAI) has become an accepted standard for damage tolerance testing, which was developed flanking an impact method by the aerospace industry to test materials against simulated bird strikes or accidental tool impacts (Tuo et al, 2019; Liu et al, 2018; Sun et al., 2018; Abir et al., 2017) . On an actual structure, these events are typically considered isolated and the damaged component is promptly replaced or repaired. On the other hand, a thick-section composite structure is expected to be impacted consecutively at neighbouring locations before replacement. The number of impacts, dimension, and their proximity to each other is likely to have a unique effect on the residual properties of the material probably. According to the CAI testing, damage tolerant materials exhibit smaller damage sizes and higher residual strength after conducting the impact scenario (Sasikumar et al., 2021; Rubio-López et al, 2017).

1.2 Problem Statement

A recent material engineering studies mostly focused on simulation research to assess mechanical properties of materials (Mahesh et al, 2021). However, there are some other research inclined to do practical studies. On one hand, most researchers tended to do a singular mechanical test like impact, tensile, compression, and 3-point bending flexural (Panchagnula & Kuppan, 2019). Some other scholars like Cerquaglia et al (2017) conducted research to test materials under impact and compression, which were labelled as compression after impact tests (CAI). Therefore, a lot of published scientific articles discussed CAI in low velocity (Sasikumar et al., 2021; Tuo et al, 2019; Liu et al, 2018; Sun et al., 2018; Abir et al., 2017; Rubio-López et al, 2017). In contrast to this trend and to fill the literature gap, the current experimental study focused on the combination of all the mentioned mechanical tests under high velocity impacts in forms of normal and oblique impacts (0, 10, 20, 30, and 40 degrees)(Zhang et al, 2019). Thus, all the mechanical tests were performed after normal and oblique impacts that were not done in the attempts of other research.

Considering the use of the materials, MWCNT was found as the most conventional nano-filler embedding to the resin epoxy (Calado et al, 2018). Due to financially astute reasons, most researchers tried to reinforce the glass fibres epoxy with CNT (Pothnis et al, 2021; Su et al, 2021; Vertuccio et al, 2018). However, on account of possible hazardous effects of glass fibres (Nechifor et al, 2020; Hadley, & Crane, 2019; Loxham, & Nieuwenhuijsen, 2019; Du et al, 2018), the current study used the intra-ply hybrid carbon-Kevlar/epoxy composite laminates, with neat epoxy, and reinforced with CNTs (from 0.1% to 1.5%), which is the particular innovation of this experimental study. Moreover, most researchers used the single type of the fabrics and reinforced it with the nano-fillers. A very small number of research has since been sporadically reported on interply hybrid fabric (carbon and Kevlar) composites based on epoxy reinforced with nano-fillers (Gnanavel et al, 2021; Li et al, 2018; Ndiaye et al, 2018). However, no research to date has studied the mechanical testing on employing intra-ply hybrid carbon-Kevlar/epoxy composites reinforced with CNT.

In brief, an experimental investigation was conducted to explore the effects of applying CNTs into the composite system. The effects of mechanical tests after oblique impact scenarios were experimentally examined on reinforced hybrid composites.

1.3 Aims and Objectives of the Study

The present study endeavoured to assess the mechanical properties of fabrics under oblique ballistic impacts. To achieve this goal, eight layers' specimens of Carbon-Kevlar (reinforced with and without CNTs) were examined. Attempts were given to identify those important parameters that were the effects of inclusion of CNTs into laminated hybrid composite plates under bending, compression, and tensile after oblique ballistic impact scenarios. The most important physical and material parameters that affected oblique ballistic penetration were examined. In other words, the ballistic impact velocity as well as the rigidity and strength of the plates and CNTs volume of the plates were investigated. Therefore, the following objectives guided the study:

1. To investigate the mechanical behaviour of specimens which are made of intraply carbon and Kevlar hybrid fabric/Epoxy with and without CNTs under oblique ballistic impact scenarios.

2. To analyse the impact energy absorption of the specimens.

3. To calculate the ballistic limit velocity of the specimens under projectiles.

4. To compare the mechanical properties of the pre- and post-impact specimens in terms of tensile, compressive, and flexural strengths.

Some of the research conducted on CAI in hybrid laminated composites demonstrate the superiority of using these types of materials with respect to laminated composites made up of the single materials (Verma et al, 2021; Verma et al, 2019; Wang et al, 2019; Yeter et al, 2019; Zhang et al, 2019; Ye et al, 2018; Yang et al, 2017). Although there is a lack of literature review on CAI for hybrid laminated composite materials, the main hypothesis of the present research was that CAI of hybrid laminated composites are better than those laminated consisting of a single material. On the other hand, carbon and Kevlar hybrid fabric used in this study are among popular ones used in lightweight industries. Hybrid fibres are conventional materials readily available, easily found in the market, and they are available for purchase online as well. In addition, some notable advantages of Kevlar fibre can be its high compressive strength, high impact resistance, high tensile strength, and high fire resistance. Furthermore, some prominent advantages of carbon fibre can be high compressive strength and light. Moreover, the advantages of using this fabric provide a fabric, which possesses a high strength-to-weight ratio and dimensional stability as well as a remarkable ballistic impact, abrasion, and fatigue resistance. As a result, combining them can result in an appropriate plate for the applications, such as lightness, high strength, impact resist, and economic feasibility.

The various interesting properties of these fibres, which will be discussed in the following section, could not be achieved via only one of them. Therefore, achieving a suitable CNT volume is required to determine the effect of using hybrid materials to increase the impact resistance and mechanical testing considerably.

1.4 Scope of the Study

This study examined the mechanical strength of carbon/Kevlar hybrid laminate specimens, which were reinforced with carbon nanotubes (CNTs) subjected to oblique ballistic impact loads. CNTs were used with different volume fractions in reinforcing the epoxy matrix. Such an approach is proposed to cover:

1. The concept of using carbon/Kevlar hybrid laminate specimens is based on using the combination of dual properties of Kevlar and carbon fibres, which consolidated primarily from different broad views of argumentation into a specific perspective i.e. the structure modified to mass reduction in order to increase useful structural loads.

2. Experimental arguments such as inclusion of CNTs into epoxy resin with the variform volume fractions in reinforcing the epoxy matrix and the drawbacks of a relatively large amount of CNTs, which obtained the CNTs agglomerations to behave as crack initiation.

3. The inferences from the oblique ballistic impact testing method and post impacts have indicated that factors including speed, thickness, ballistic limit velocity, angles of the target, cutting of the specimens are practically significant in conducting of the impact scenario. Moreover, tensile, bending, compressive tests conducted to measure the mechanical properties of the specimens such as ultimate strength, breaking strength, maximum elongation, reduction in area, Young's modulus, yield strength, and more importantly the stress-strain curves of the specimens.

4. The inclusion of CNTs into epoxy has received great attention not only in the improvement of mechanical, chemical, and electrical properties, but also in other fields of investigation. However, this study focused on mechanical properties of the reinforced composite plates. Moreover, the results of the study were compared and contrasted with other significant studies on oblique impact, normal impact, tensile, three-point bending flexural, and compression tests.

5. The study additionally consolidated and focused on the other pertinent studies and the most identified variables (such as the CNTs' fractions and the angled targets) have been examined from other perspectives. This has rendered auxiliary support to the variables in conceptualising the new context.

6. Cross-sectional data have been collected from specimens with and without CNTs .

7. The proposed optimal amount of CNTs and the competing different mechanical examinations have been performed to verify the nanofiler effect and the angle targets in the ballistic impact tests and their relative post impact.

Concisely, the study specifically encompasses the mechanical properties of carbon/Kevlar fabrics, which were strengthened with CNTs subjected to angled impacts. CNTs were utilised with distinctive volume divisions in strengthening the epoxy network by using the NIJ Standard 0108.01 for the impact tests. The Dual Column tabletop Universal - 3360 Series from Instron testing machines for the tensile tests contingent on ASTM D3039 (2017), compressive tests according to ASTM D6641 (2021), and the Three-Point Bending Flexural test setup following the ASTM D0790 (2017) was performed. Finally, the recording of data for the mechanical tests was generated by using the Blue Hill Software for Static Test Systems.

1.5 Thesis Organisation

This thesis was organised in five chapters. Chapter one encompassed the background of the study, problem statement, aims and objectives of the study together with research questions, and scope of the study.

Chapter 2 provided detailed background information on the processing and testing methods used in this research. Therefore, a literature map including five concise tables were arranged to review related literature about compression of the ballistic impact, tensile compression impact and flexural testing and effects of CNTs on them. This review of literature not only resulted in an insight into the application of the used composite system in the present study, but also it clarified the gap in the literature and directed the study towards answering its research questions.

Chapter 3 introduced research design and methodology of the study. Besides, the characteristics of the used materials and test methods were presented. Testing procedures including tensile, compression, flexural bending, and importantly ballistic impacts at different angles were explained and clarified. Different specimens of Carbon-Kevlar fabrics reinforced with and without CNTs as the targets of impact scenarios introduced. How the specimens were divided into two groups of intact and impacted clarified and methods of targeting were discussed.

Chapter 4 introduced the results of the study including oblique ballistic impacts, ballistic limit velocities, calculating energy absorption after impact, chemical composition of applied materials, calculating strengths, toughness and modulus of tensile bending and compression, and microscopic inspections. All the achieved results were compared and contrasted with the related literature and the innovative result of this study denoted CNT inclusion is in reality is different from some published literature.

Finally, Chapter 5 discusses the results achieved during the experimental testing. Conclusions made of reinforced composite plates with and without CNT under tensile, compression, and bending after oblique ballistic impact. Approximating the residual mechanical properties according to damage size, ballistic energy absorption, and compression energy absorption (after and before conducting an impact test) are also discussed. Ultimately, the ability to modify these methods to accommodate full-scale panels will be discussed determine the relevance of the results to future studies.

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BIODATA OF STUDENT

The student, Elias Randjbaran, was born on 12th of December 1979. His educational journey started at Nursey School, which designed to support early development in preparation for participation in school and society. Programmes designed for children from age 3 to the start of primary education. Then he completed his primary education at Primary School, which typically designed to provide students with fundamental skills in reading, writing and mathematics and to establish a solid foundation for learning. He later furthered his secondary education at Grammar School that offers an academic course in preparation for university entrance and for the professions. Students usually begin attendance at age 12. In addition, he extended his study at High School, which providing learning experiences that build on secondary education and prepare for labour market entry and/or tertiary education. The content is broader than secondary but not as complex as tertiary education. These programmes may also provide a pathway to other tertiary programmes. The author graduated with Bachelor's Degree Programme in Materials Engineering. In 2008, he continued his journey to get a place at Universiti Putra Malaysia to do his Master's degree programme in the field of Materials Engineering. The topic of his master's thesis is Effect of Layer Stacking Sequence on Residual Compressive Strength for Hybrid Composite Plates under supervision of Prof. Dr. Rizal Zahari. After the dark days of COVID19, he successfully conducted his viva-voce on the 27th of January, in 2022. Both degree programmes were at the Department of Aerospace Engineering.

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