HIGH STRAIN RATE AND QUASI-STATIC COMPRESSIVE FAILURE OF UNIDIRECTIONAL HYBRID KENAF/GLASS FIBRE-REINFORCED COMPOSITES

MEGAT NAIMAN BIN MEGAT ANORHISAM

UNIVERSITI SAINS MALAYSIA

2021

HIGH STRAIN RATE AND QUASI-STATIC COMPRESSIVE FAILURE OF UNIDIRECTIONAL HYBRID KENAF/GLASS FIBRE-REINFORCED COMPOSITES

By:

MEGAT NAIMAN BIN MEGAT ANORHISAM

(Matrix no. 137825)

Supervisor:

DR. SAREH AIMAN HILMI BIN ABU SEMAN

June 2021

This dissertation is submitted to
Universiti Sains Malaysia
As partial fulfilment of the requirement to graduate with honors degree in
BACHELOR OF ENGINEERING (MECHANICAL ENGINEERING)

School of Mechanical Engineering
Engineering Campus
Universiti Sains Malaysia

DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Signed…………………………………….(Megat Naiman Megat Anorhisam)

Date…………………………………………………………….(3/8/2021)

STATEMENT 1

This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by giving explicit references. Bibliography/references are appended.

Signed……………………………………(Megat Naiman Megat Anorhisam)

Date………………………………………………………...(3/8/2021)

STATEMENT 2

I hereby give consent for my thesis, if accepted, to be available for photocopying and for interlibrary loan, and for the title and summary to be made available outside organizations.

Signed………………………………………(Megat Naiman Megat Anorhisam)

Date…………………………………………………………..(3/8/2021)

ACKNOWLEDGEMENT

First and foremost, I would like to express my utmost gratitude to the School of Mechanical Engineering, Universiti Sains Malaysia, to provide the required equipment and the necessary materials to complete my Final Year Project (FYP). The golden opportunity given to me to complete this four-year course in Mechanical Engineering is sincerely appreciated. I believe all the knowledge and technical skills acquired will definitely be valuable for my future career as an engineer. Besides, I would like to express my gratitude to my supervisor, Dr Sareh Aiman Hilmi Bin Abu Seman, who supervised and supported my research. The guidance and encouragement from my supervisor have always motivated and assisted me in overcoming the challenges encountered.

Furthermore, I would also like to acknowledge with much appreciation the crucial role of the staff of the School of Mechanical Engineering, Universiti Sains Malaysia (USM), Mr Fakruruzi, Mr Ashamuddin, Mr Norijas and Mr Hasfizan. They have provided insight and expertise that greatly assisted the research. Besides that, many thanks go to the coordinator of this course, Dr Fauzinizam, who has invested his total effort in conducting seminar talks to help us achieve our goal. Last but not least, I have to appreciate the guidance and advice given by other supervisors as well as the panels, especially in the project presentation.

TABLE OF CONTENTS

DECLARATION .... **iii**

ACKNOWLEDGEMENT .... **iv**

TABLE OF CONTENTS .... **v**

LIST OF FIGURES .... **viii**

LIST OF TABLES .... **x**

LIST OF ABBREVIATIONS .... **xi**

LIST OF APPENDICES .... **xii**

ABSTRAK .... **xiii**

ABSTRACT .... **xiv**

CHAPTER 1 INTRODUCTION **1**

1.1 Overview of the project 1

1.2 Project Background 3

1.3 Problem Statement 3

1.4 Scopes of Project 3

1.5 Objectives 4

CHAPTER 2 LITERATURE REVIEW **5**

2.1 General knowledge of hybrid composites 5

  2.1.1 Fibre phase 5

    2.1.1(a) Natural Fibers 5

    2.1.1(b) Glass Fibers 6

  2.1.2 Matrix Phase 7

2.2 Application of Hybrid Composites 8

  2.2.1 Automation 8

  2.2.2 Machine Structures 8

  2.2.3 Aerospace 9

2.3 Performance of Kenaf, Glass, and Kenaf/Glass Hybrid Composites.............. 9

2.3.1 Performance of Kenaf composite under Dynamic Loading............ 9

2.3.2 Performance of Kenaf composite under Static Loading 10

2.3.3 Performance of Glass composite under Dynamic Loading........... 10

2.3.4 Performance of Glass composite under Static Loading 10

2.3.5 Performance of Kenaf/Glass Hybrid Composites under Dynamic Loading... 11

2.3.6 Performance of Kenaf/Glass Hybrid Composites under Static Loading.. 11

2.4 Failure of Kenaf, Glass, and Kenaf/Glass Hybrid Composites...................... 11

2.4.1 Types of failure in composite... 11

2.4.2 Failure of Kenaf composite under Dynamic Loading................... 13

2.4.3 Failure of kenaf composite under Static Loading 14

2.4.4 Failure of Glass composite under Dynamic Loading.................... 14

2.4.5 Failure of Glass composite under Static Loading 14

2.4.6 Failure of Kenaf/Glass Hybrid Composites under Dynamic Loading.. 15

2.4.7 Failure of Kenaf/Glass Hybrid Composites under Static Loading.. 15

2.5 Summary 16

CHAPTER 3 METHODOLOGY.. 17

3.1 Materials.. 17

3.1.1 Kenaf fibre composites... 17

3.1.2 Kenaf/glass hybrid composites.. 18

3.2 Experimental procedure 19

3.2.1 Mechanical Tests.. 19

3.2.1(a) Static test... 20

3.2.1(b) Dynamic test 20

3.2.2 Morphology observation 20

3.2.3 High-speed camera 21

CHAPTER 4 RESULTS.. 22

4.1 Quasi-static loading 22

4.1.1 Stress-strain behaviour 23

4.1.2 Failure mechanism 24

4.2 High strain rate loading 25

4.2.1 Stress-strain behaviour 26

4.2.2 Failure mechanism 27

4.2.3 High-speed camera analysis 28

4.3 Comparison of kenaf and kenaf/glass hybrid composite under static and dynamic loading 29

CHAPTER 5 CONCLUSION AND FUTURE RECOMMENDATIONS...... 31

5.1 Conclusion 31

5.2 Recommendations for Future Research 32

REFERENCES.. 33

APPENDICES

LIST OF FIGURES

Page

Figure 1.1 (a)Kenaf plant[8] and (b)Kenaf fibre before treatment[9] 2

Figure 1.2 Glass fibres[11]. 3

Figure 2.1 The three main type of hybrid configuration: (a) interlayer hybrid or layer by layer, (b) intralayer hybrid or yarn by yarn, and (c) intrayarn hybrid or fiber by fiber[14]. 5

Figure 2.2 Classification of natural fibers[17]. 6

Figure 2.3 The matrix phase with the filler inserted[19]. 7

Figure 2.4 Carpeting for the inside of a vehicle's door constructed from a bio-composite of hemp fibres and polyethylene[22]. 8

Figure 2.5 Application of composites on aircraft[27]. 9

Figure 2.6 Fibre-matrix debonding[35]. 12

Figure 2.7 Fibre splitting illustration[37]. 12

Figure 2.8 Matrix cracking on specimen surface[38]. 13

Figure 2.9 Brittle failure of glass fibre[41]. 13

Figure 3.1 Flow chart of project methodology. 17

Figure 3.2 Kenaf composite unidirectional fiber arrangement. 18

Figure 3.3 Kenaf/glass reinforced polyester composites fibers arrangements. ... 19

Figure 3.4 Split Hopkinson pressure bar. 20

Figure 3.5 Scanning Electron Microscope (SEM) 21

Figure 3.6 Olympus i-Speed 2 camera 21

Figure 4.1 Stress-strain curves of kenaf/glass hybrid composites under dynamic loading. 22

Figure 4.2 Stress-strain curves of kenaf composites under static loading. 23

Figure 4.3 Failure of a)kenaf and b) kenaf/glass hybrid composites under ststic loading. 24

Figure 4.4 SEM images of specimens surfaces a) kenaf and b) kenaf/glass hybrid composites under static loading. 24

Figure 4.5 Stress-strain curves of kenaf/glass hybrid composite under dynamic loading. 25

Figure 4.6 Stress-strain curves of kenaf composite under dynamic loading. 25

Figure 4.7 The different degrees of arrangement are depicted graphically (a) two layers, (b) alternating layers, (c) bundle by bundle dispersion, and (d) completely random dispersion[14]. 26

Figure 4.8 Failure of a) kenaf and b) kenaf/glass hybrid composites under dynamic loading. 27

Figure 4.9 SEM images of specimens surfaces of a) kenaf and b) kenaf/glass hybrid composites. 27

Figure 4.10 Failure sequence of kenaf composite under dynamic loading using high-speed camera. 28

Figure 4.11 Failure sequence of kenaf/glass hybrid composite under dynamic loading using high-speed camera. 28

Figure 4.12 Stress-strain curves of kenaf and kenaf/glass composite under a)static loading and b) dynamic loading. 30

LIST OF TABLES

Page

Table 3.1 Polymer resin compound formulation[52] 18

Table 3.2 Fabrication of pultruded profile parameters[52]. 19

Table 4.1 Effect of strain rate on composites’ mechanical properties and failure behaviour. 29

LIST OF ABBREVIATIONS

ASTM	American Society Testing Materials
BMW	Bayerische Motoren Werke
BPO	Benzyl Peroxide
FE	Finite Element
GC	Glass Composite
KC	Kenaf Composite
K/G	Kenaf/Glass Hybrid Composites
SEM	Scanning Electron Microscope
SHPB	Split Hopkinson Pressure Bar
UPE	Unsaturated Polyester
USM	Universiti Sains Malaysia
UTM	Universal Testing Machine

LIST OF APPENDICES

Appendix A	SETUP OF THE EXPERIMENT
Appendix B	RAW DATA FROM EXPERIMENT

ABSTRAK

Baru-baru ini, penggunaan komposit hibrid sangat penting dalam operasi pembuatan. Komposit hibrid digunakan dalam pelbagai aplikasi kerana sifat mekaniknya yang bertambah baik. Kajian ini menilai sifat mekanik dan tingkah laku kerosakan komposit kacukan kenaf dan kaca. Komposit Kenaf dan Kenaf / kaca hibrid adalah dua jenis spesimen yang digunakan dalam projek ini. Sampel akan dikenakan dua jenis pemuatan mampatan: kuasi statik dan pemuatan tegangan tinggi. Kamera berkelajuan tinggi akan digunakan untuk merakam momen kegagalan dalam komposit semasa analisis kegagalan. Penyebab kegagalan kemudian disiasat lebih jauh menggunakan mikroskop elektron pengimbasan untuk menentukan morfologi patah tulang dan jenis kerosakan yang berlaku. Kajian ini memberikan pemeriksaan menyeluruh mengenai proses kegagalan serta penyebaran kerosakan. Penemuan utama dari literatur dan ujian mampatan mengenai ciri komposit gentian Kenaf dan Kenaf / Glass dibandingkan dan dibincangkan.

ABSTRACT

Recently, hybrid composites have been critical in the manufacturing operations. Hybrid composites are being used in various applications due to their improved mechanical properties. This study assesses the mechanical properties and damage behaviours of kenaf and glass hybrid composites. Kenaf fibre and Kenaf/glass hybrid composites are the two types of specimens used in this project. The samples were subjected to two different types of compressive loading: quasi-static and high strain rate loading. A high-speed camera was used to capture the moment of failure within the fibre reinforced polymer during the failure analysis. The failures causes are then investigated further using a scanning electron microscope to determine the fracture morphology and type of damage that occurred. This study provides a thorough examination of the failure process as well as damage propagation. The main findings from the literature and compressive testing on the characteristics of the Kenaf fibre and Kenaf/Glass hybrid composites are compared and discussed.

CHAPTER 1

INTRODUCTION

1.1 Overview of the project

Because monolithic materials frequently have constraints in meeting rising performance requirements in varied applications, research emphasis has shifted to fibre-reinforced polymeric materials in the last 20 years. The aerospace, automotive, construction, and athletic sectors are currently dominated by these novel composite materials (notably Glass, aramid, and carbon fibre-reinforced plastics). While synthetic materials have aided civilization by providing benefits and conveniences to human existence, they also place a range of environmental costs on the environment at every manufacturing stage [1]. Hybrid composites have been widely employed in sophisticated technical applications such as the automotive and aviation sectors because of their high strength, low mass, and exceptional fatigue resistance. Their behaviour under impact loads has also been a source of concern in engineering. To date, there are only several studies on the impact response of composite materials and structures in the literature[2].

Composites are made up of various built-in components that have entirely different properties when treated, resulting in a material with characteristics that are modified from the separate elements. Hybrid Composites are multipurpose structural materials that can be utilized to create resourceful materials with specific qualities[3]. A hybrid composite is made up of many discontinuous phases embedded in a continuous phase. The discontinuous phase, which is generally more rigid and stronger than the continuous phase, is referred to as the hybrid reinforcement. In contrast, the continuous phase is referred to as the matrix. Metallic, polymeric, and ceramic matrix materials are the three types of the matrix material. However, polymer matrix composites have recently become popular in a variety of applications, including automobile parts, aircraft interior components, home appliances, and building materials[4].

The reinforcing phase might be fibrous or non-fibrous (particulates) in nature, and natural fibres are those that are generated from plants or other living creatures[4]. Depending on the source of extraction, natural fibres are classed as plant, animal, or mineral fibres. These natural fibres are employed as reinforcement in bio-based composites and polymer composites based on their use in polymer matrices. Natural fibres have piqued researchers' interest due to their unique characteristics, such as low density, cheap cost, easy availability, biodegradability, and ease of processing[5]. It also has excellent mechanical, thermal, and acoustic qualities, as well as high fracture resistance[6]. According to research, natural fibres have been used in polymer composites with exceptional acoustic characteristics and excellent fracture resistance. According to Vinod, Sanjay, Suchart & Jyotishkumar, 2020[7], natural fibres have been used to substitute for synthetic materials in polymer composites and bio-based composites.


(a) (b)

Figure 1.1 (a)Kenaf plant[8] and (b)Kenaf fibre before treatment[9]

Glass fibre is another reinforcing fibre. Other fibres, such as polymers and carbon fibre, have mechanical qualities that are generally equivalent to glass fibre. Although not as stiff as carbon fibre, it is far less expensive and brittle when used in composites. Another form of reinforcing fibre is glass fibre. Other fibres, such as polymers and carbon fibre, have mechanical properties that are similar to glass fibre. Although not as rigid as carbon fibre, it is significantly less costly and brittle when used in composites[10]. This substance is denser and a more inadequate thermal insulator than glass wool since it contains little or no air or gas. Glass fibres were chosen because they have high mechanical strength and are less expensive than other synthetic fibres. The creation of hybrid jute/glass(natural/artificial) fibre composites shown that these two fibres have distinct properties that contribute to the composite's overall performance[11].

Figure 1.2 Glass fibres[11].

1.2 Project Background

The project was designed to investigate the characteristics of unidirectional kenaf/glass hybrid composite. The project needs to be done because there is lack information on kenaf/glass hybrid composite mechanical behaviour under compressive loading. This information is important in determining the usefulness of kenaf/glass hybrid composite to be used as a primary structure in various applications. First of all, the specimen will undergo two types of loading tests: quasi-static and dynamic loading.

1.3 Problem Statement

Fibre-reinforced composites are increasingly being used in a variety of technical fields. This is due to their lightweight and high-strength characteristics, which is suitable for specific applications[12]. Under two distinct loading circumstances, this work intends to offer thorough fractographic observations on how compression damage processes occurred and the influence of fibre hybridization on these processes the lack of data on dynamic properties of hybrid kenaf/glass composite making it unsuitable to be used as a primary structure in manufacturing. Because there is minimal information on this issue, this study is done to determine the mechanical characteristics of kenaf/glass hybrid composites as well as the failure process of the hybrid composites under static and dynamic loading.

1.4 Scopes of Project

Several scopes of work have been identified to achieve project objectives. This work will be performed under static and impact loading. First of all, the specimen will undergo two types of loading tests: quasi-static and dynamic loading. Typical differences between quasi-static and dynamic loading seen in axial crushing include the machine used and type of tests. Furthermore, the test will be done to see the difference between response of the profiles subjected to quasi-static and dynamic loading[12].

The compression test will be conducted using Universal Testing Machine (UTM) and Split Hopkinson Pressure Bar (SHPB). UTM will be used to conduct quasi-static loading, while the SHPB will be used to perform dynamic loading. The tensile and compressive strength of materials is usually tested using a universal testing machine (UTM), also known as a universal tester[1]. The Split Hopkinson Pressure Bar (SHPB) is frequently employed as an instrumented loading device in dynamic fracture investigations. It is based on the one-dimensional wave propagation idea. This means that with a long elastic bar moving at adjustable bar velocity, a stress wave propagates non-dispersively[13]. Next, to identify the microscopic failure, the scanning electron microscope will be applied. Finally, to determine the failure mechanism under dynamic loading, a high-speed camera will be used. The results will then be calculated to compare the mechanical properties of the kenaf fibre and kenaf/glass hybrid composites under different loadings.

1.5 Objectives

Based on the research gap stated in the literature review, several objectives need to be achieved, which are:

1. To investigate mechanical properties of kenaf and kenaf/glass hybrid composites under static and impact loading.
2. To identify the failure mechanism of kenaf and kenaf/glass hybrid composites under static and dynamic loading.
3. To determine the type of failure of kenaf and kenaf/glass hybrid composites under static and dynamic loading.

CHAPTER 2

LITERATURE REVIEW

2.1 General knowledge of hybrid composites

The hybrid is a relatively recent fibre-reinforced composite made by combining two or more different types of fibres in a single matrix. In comparison to composites comprising only a single fibre, hybrids have a more excellent overall combination of qualities. There are a variety of ways to combine the two fibres, each of which will have an impact on the overall characteristics. For example, the fibres may all be aligned and tightly intermingled, or laminations might be made up of layers, each of which is made up of a single fibre type that alternates with the next. Anisotropic characteristics exist in almost all hybrid composites. As shown in Figure 2.1, there are three main types of hybrid configuration which is layer by layer, yarn by yarn and fibre by fibre[14].

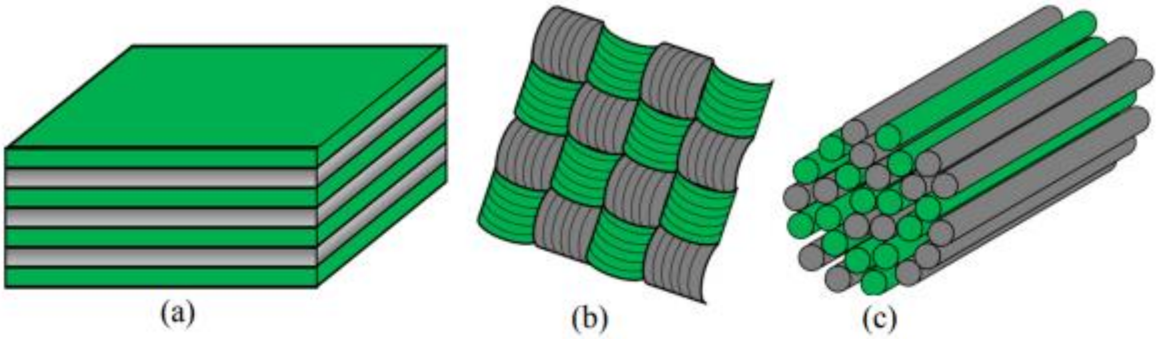

Figure 2.1 The three main type of hybrid configuration: (a) interlayer hybrid or layer by layer, (b) intralayer hybrid or yarn by yarn, and (c) intrayarn hybrid or fiber by fiber[14].

2.1.1 Fibre phase

2.1.1(a) Natural Fibers

Natural fibres are a widely available and easy-to-find substance in nature. Natural fibres are favoured because of their low density, high stiffness-to-weight ratio, low cost, high strength-to-weight ratio, and environmental friendliness. Researchers have recently begun evaluating prospective plant fibres for medium- and low-load applications in order to find possible plant fibres. Natural fibres, on the other hand, have hydrophilicity and moisture absorption restrictions. In general, human cells, tissues, and other biological fluids come into touch with the outer surface of the bone plate. This contact enhances wettability and has an impact on the material's surface characteristics[15].

Cost reduction compared to fibres such as glass and carbon fibre, weight reduction for final products, and the potential market for renewable and recycled materials are all well-known driving drivers for performing research on natural fibres reinforcing in Malaysia. Kenaf, also known as a short-term plant, generates at least 15 to 20 tonnes of bast fibre per hectare in Malaysia. The government of Malaysia's endeavour in the 9th Malaysia Plan[16] to replace the tobacco plant with kenaf inspired the idea of producing a composites structure that uses kenaf fibre as the reinforcing phase. Natural fibres such as kenaf, flax, jute, and hemp have recently become the most popular reinforcement for bio-composites. Natural fibres (Figure 2.2) combined with inorganic or organic polymers and nanoparticles have a lot of promise for increasing mechanical properties and hence increasing application areas[17].

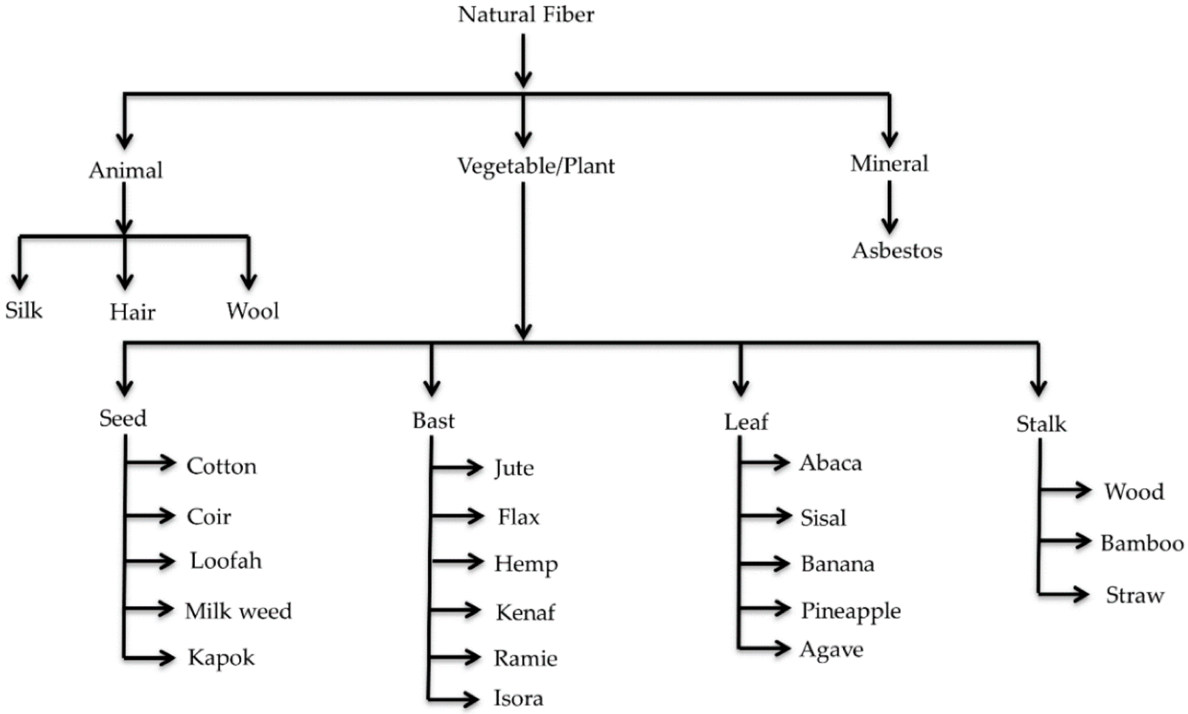

Figure 2.2 Classification of natural fibers[17].

2.1.1(b) Glass Fibers

Fibreglass is essentially a composite made up of continuous or discontinuous glass fibres encased in a polymer matrix. This sort of composite is made in the most significant numbers. The Glass's composition is most typically drawn into filaments. Fibre diameters typically range from 3 to 20 µm. For numerous reasons, Glass is widely used as a fibre reinforcing material such as it can be readily pulled into high strength fibres while still molten. Other than that, it is widely accessible and may be produced into a glass-reinforced plastic utilizing a number of composite manufacturing processes at a low cost. Glass also is a reasonably strong fibre that generates a composite with a very high specific strength when implanted in a plastic matrix[18].

2.1.2 Matrix Phase

The matrix phase has numerous functions in fibre-reinforced composites. First, the matrix phase links the fibres together and acts as the medium via which an externally applied stress is transmitted and distributed to the fibres; however, the matrix phase can only bear a limited percentage of the imposed load. In addition, the matrix material must be ductile. Furthermore, the fibre's elastic modulus should be substantially higher than the matrix's. The matrix's second purpose is to shield individual fibres from surface damage caused by mechanical abrasion or chemical reactions with the surrounding environment; the dispersed phase refers to the substance that is scattered throughout the matrix, as shown in Figure 2.3 [19].

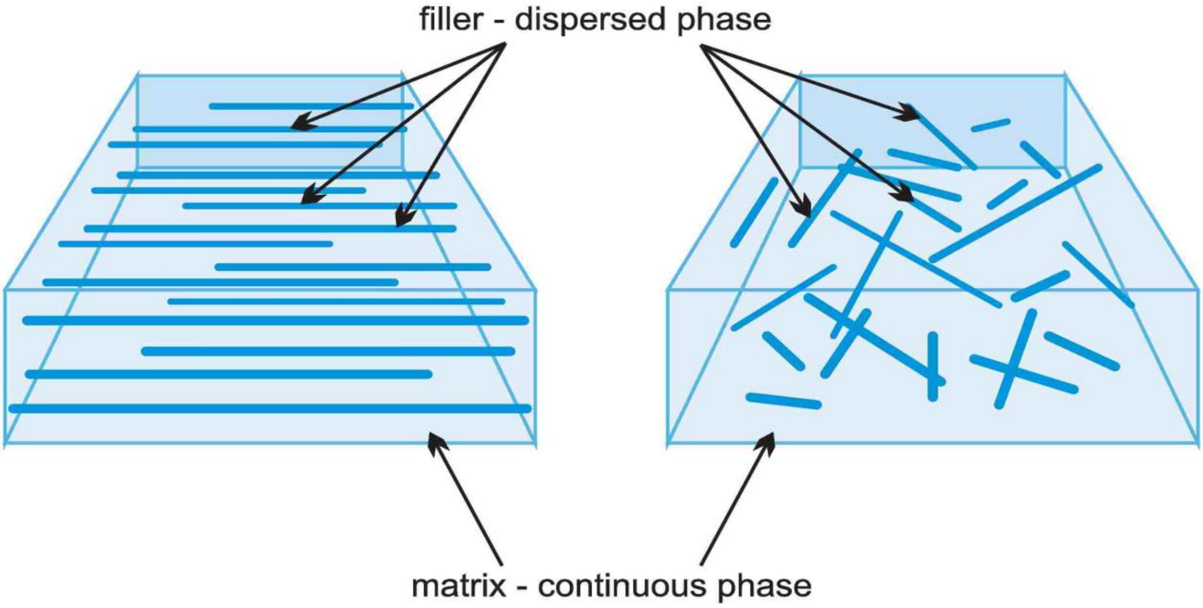

Figure 2.3 The matrix phase with the filler inserted[19].

2.2 Application of Hybrid Composites

2.2.1 Automation

Automobile manufacturers such as Mercedes-Benz, Audi, BMW, and Volkswagen have already begun to utilize these composites in the interior and external sections of their vehicles[20]. In addition, hybrids are gaining popularity in areas other than automotive since they provide customers with the choice of experiencing new features. We are frequently told that we cannot have it all, but composites make it possible. Combining two materials to produce a hybrid composite not only allows us to experience the benefits of each material but also allows us to experience a new set of attributes that cannot be accomplished with just one type of fibre or one specific material[21][22].

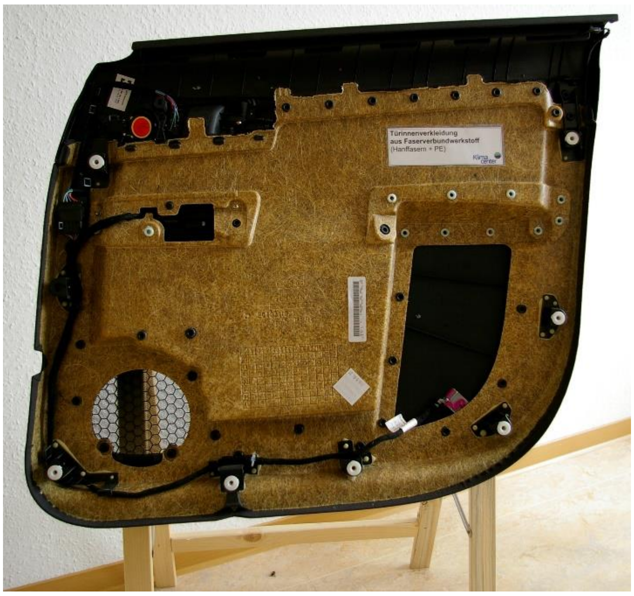

Figure 2.4 Carpeting for the inside of a vehicle's door constructed from a bio-composite of hemp fibres and polyethylene[22].

2.2.2 Machine Structures

Of course, one of the primary goals of employing composite materials in industrial machinery is to reduce the weight and inertia of moving machine components. Pick-and-place robot systems are an excellent example of this, such as the KUKA robot arm[23]. Other than that, the use of composites in spindles and cutting tools of machining centre has been researched in order to minimize the moment of inertia of spindle rotors and tool bodies, limit their heat development, and improve dynamic behaviour[24].

2.2.3 Aerospace

Materials with certain features, such as strong mechanical and thermal properties while being light and inexpensive, are required for the aircraft sector. Composite materials have found a lot of use in the aircraft industry as a different class of technical materials[25]. The usage of composite materials for numerous aerospace components in current programmes worldwide has resulted in significant weight savings of up to 30%. The technology developed and the trust acquired have prepared the door for composites to be used in increasingly complex aerospace components, such as aeroplane fuselages, to save even more weight[26][27].

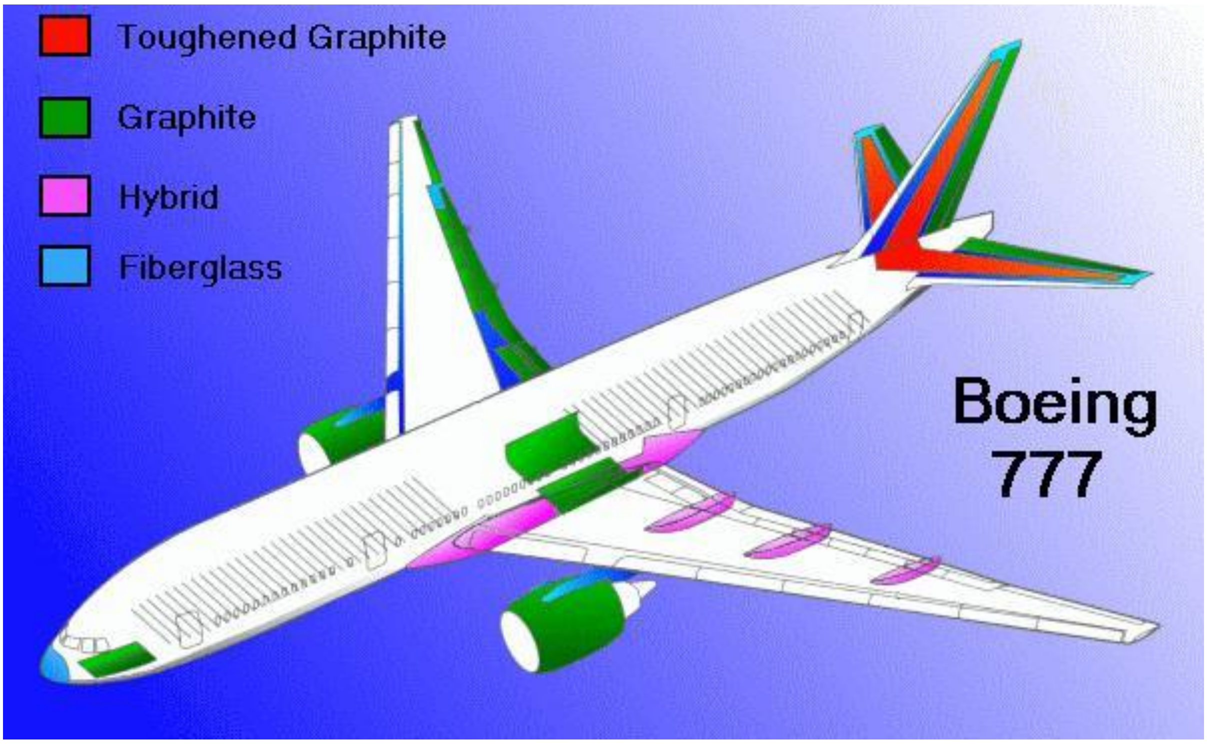

Figure 2.5 Application of composites on aircraft[27].

2.3 Performance of Kenaf, Glass, and Kenaf/Glass Hybrid Composites.

2.3.1 Performance of Kenaf composite under Dynamic Loading

A drop weight impact test was done by Majid et al., 2018 [28] according to ASTM D7136 using IMATEK IM10T-15HV instrument shows that kenaf's resistance to impact loading was low. The test was done on a specimen with a layer-by-layer arrangement by using chopped strands of fibres. As a result, combining it with glass fibre improved its load-carrying capability when subjected to impact loading.

2.3.2 Performance of Kenaf composite under Static Loading

In comparison to hybrid and glass fibre composite tubes, Kenaf fibre composite has absorbed the most energy[29]. Fibre orientations played a crucial impact in force-displacement curves for both types of composites (2 and 3 layers), and the influence is more noticeable when thicker tubes are employed. Furthermore, when the fibres are aligned using unidirectional orientation, higher specific energy absorptions are obtained compared to other types of composites[30].

2.3.3 Performance of Glass composite under Dynamic Loading

A high strain rate test using a Split Hopkinson Pressure Bar by Tarfaoui et al., 2009 [31] was done using strain rates ranging from $200s^{-1}$ to $2000s^{-}1$. For in-plane tests, the initial finding is that materials have a strong dependence on fibre orientation and impact pressure. Only specific impact pressures cause damage. There was no visible damage in this lower range of impact pressure, although microscopic damage is still a possibility. It is also worth noting that the nature of the damage is highly influenced by the laminates' orientation, which is an essential factor in enhancing dynamic compressive strength[31].

2.3.4 Performance of Glass composite under Static Loading

A quasi-static test using UTM was done on a specimen with specimens that were prepared by the automated filament winding technique. The test was done to study the energy absorption response of density for three different composites, which is kenaf/glass fibre, kenaf fibre and glass fibre. Glass fibre has the maximum density, followed by hybrid fibre composite and kenaf fibre composite, according to the density value of composite fibre. From the results, the higher the density means that less energy absorption by the materials; thus, we can conclude that the material exhibit brittle properties. It was also found that hybrid reinforcements containing kenaf/glass fibres showed better results in terms of density and collapsed behaviour[29].

2.3.5 Performance of Kenaf/Glass Hybrid Composites under Dynamic Loading

The impact strength qualities of hybrid composites are influenced by a number of factors, including volume fraction, fibre matrix adhesion, fibre orientation, fibre length, stress transmission, and composite thickness. The hybrid composite's improved impact strength has led to speculation that it may be utilized in structural applications[32]. Because they interact with matrix fracture development and operate as a stress transmission medium, both kenaf and glass fibres play an essential role in the composite's impact resistance. As a result, it can be seen that adding kenaf fibre to an unsaturated polyester-based composite improves its impact resistance. On the other hand, the impact resistance of the composite is increased when glass fibre is added to the outer layers because glass fibre higher strength than kenaf fibre[33].

2.3.6 Performance of Kenaf/Glass Hybrid Composites under Static Loading

A quasi-static test using UTM was done on a specimen with specimens that were prepared by the automated filament winding technique. The test was done to study the energy absorption response of density for three different composites: kenaf/glass fibre, kenaf fibre, and glass fibre. As glass fibre tubes are hybridized with kenaf fibre, mechanical qualities in the density function of hybrid composite tubes diminish. On the other hand, hybrid tubes can be used in situations when two or more qualities must be interchanged. For example, in using in large quantities, the cost of kenaf fibres is significantly lower; thus, by hybridizing it with Glass to increase its mechanical properties, the overall cost would be significantly lower. From the result, kenaf/glass hybrid tubes perform better while being more cost-effective than kenaf fibre[29].

2.4 Failure of Kenaf, Glass, and Kenaf/Glass Hybrid Composites

2.4.1 Types of failure in composite

There are various types of failure that can occur in fibre reinforced composites. The various types of failures are fibre-matrix debonding, fibre splitting, matrix cracking and brittle failure. Fibre-matrix debonding refer to the separation of the interface between the fibre and the matrix such as in Figure 2.6[34]. Fibre-matrix debonding can easily be seen when there are two fibres in the composite and the separation between the fibres is considered to be the fibre matrix debonding.

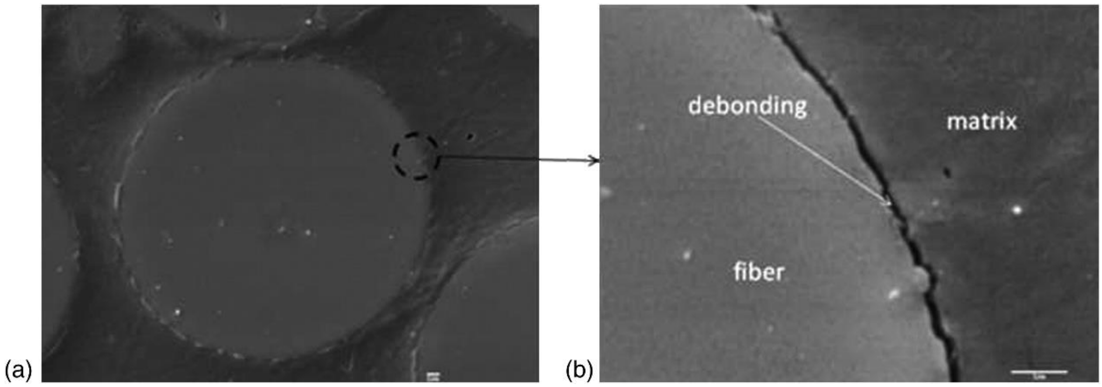

Figure 2.6 Fibre-matrix debonding[35].

The splitting failure is predicted to happen when a pre-existing flaw inside the specimen starts to grow when the specimen is under compression load. The splitting failure is believed to be caused by small, inevitable defects in the composite[36]. Splitting failure can be seen form a single fibre composites when the fibers having large void or separated in between each other. Figure 2.7 shows the illustrations on fiber splitting that happens in a single fibre.

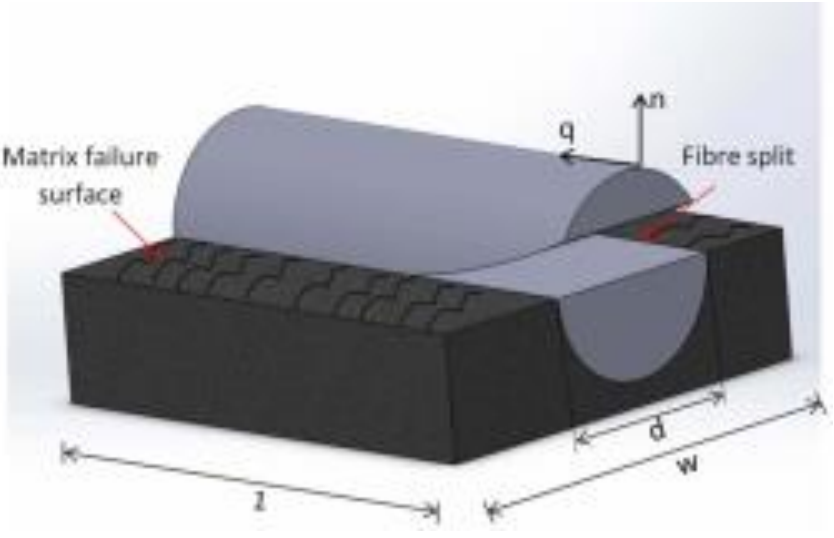

Figure 2.7 Fibre splitting illustration[37].

Matrix or resin cracking is the term to denotes the failure when matrix reaches the ultimate strain[34]. Matric cracking can be seen at the surface of the specimens which usually the surfaces appear to have cracks on it such as in Figure 2.8.

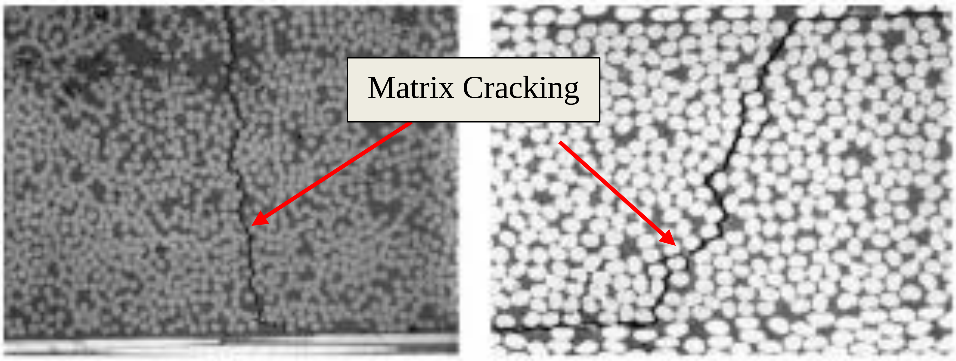

Figure 2.8 Matrix cracking on specimen surface[38].

Brittle fracture occurs without any significant deformation and the crack propagation is fast. The direction of crack motion is almost perpendicular to the direction of applied tensile stress, resulting in a fracture surface that is relatively flat[39]. In compression, however, the shape of the branching crack originating from an inclined elliptical defect poses mathematical challenges that have yet to be overcome. Many straight load-parallel tensile fractures can be seen on microscopic examination of rock specimens that failed in compression[40]. This indicate that in compression tensile stress still acting on the specimen which causes the brittle failure.

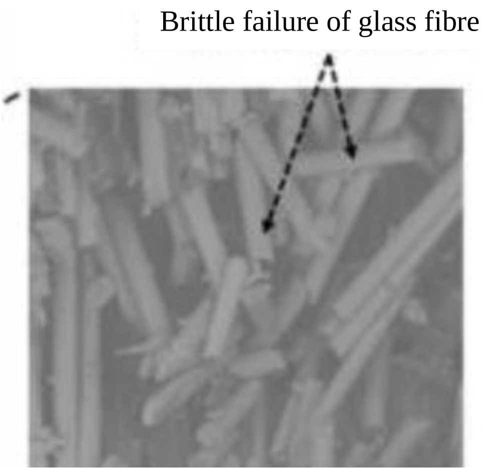

Figure 2.9 Brittle failure of glass fibre[41].

2.4.2 Failure of Kenaf composite under Dynamic Loading

During an impact event, reactions such as bouncing, penetration, and perforation will occur[42]. Matrix cracking, delamination, and fibre failure are examples of failures that could occur during a dynamic loading event. The first stage of damage caused by dynamic loading is matrix cracking[43]. When a more significant load is applied, the number of cracks will rise, leading to another failure called delamination. Delamination is induced by matrix cracking, which occurs when strong transverse shear stresses at the adjacent matrix surface strike the matrix surface, resulting in a weak interfacial link, which leads to fibre fracture and fibre pull-out[44], [45].

2.4.3 Failure of kenaf composite under Static Loading

A flexural testing done by Shalwan et al. [46] to study the mechanical properties of kenaf/epoxy under static loading. The test using ASTM D790-07 flexural testing standard with crosshead speed of 2mm/min. It was found that the untreated kenaf has more failure mechanism compared to the treated kenaf. The failure mechanism includes fibre debonding, tearing, detachment and pull out meanwhile the treated kenaf just having a breakage at the end of the fibres.

2.4.4 Failure of Glass composite under Dynamic Loading

Tarfaoui et al. [31] conducted a dynamic compression loading on Tex E-glass fibres impregnated with epoxy matrix. The tests were done with strain rates ranging from $200s^{-1}$ to $2000s^{-1}$. More damage mechanisms are engaged as the strain rate increases, ranging from matrix cracks to delamination with various routes to final fracture. The fibre orientations of the specimen greatly influence the damage kinetics for in-plane loading. At various strain rates, the initiation and propagation of failure mechanisms were investigated. At low strain rates, specimens fail due to fibre kinking, while high strain rate failures are dominated by delamination and interfacial separation.

2.4.5 Failure of Glass composite under Static Loading

A tensile quasi-static test was done by Miskdjian et al.[47] on glass/epoxy specimen with the rate of 2mm/min until failure. The macro-scale analysis of the laminate's top surface reveals the commencement of matrix cracks, which started at the specimen's edge and progressed through the breadth due to the free-edge effect. Due to the characteristics of glass being brittle, the crack propagation spreaded quickly in the thickness direction, and as the stress level rose, more cracks appeared.

2.4.6 Failure of Kenaf/Glass Hybrid Composites under Dynamic Loading

A Charpy impact test has been done by Ramesh & Nijanthan, 2016[48] to study the response of the hybrid kenaf/glass composites on a suddenly applied load. The specimens were prepared following the ASTM D6110 standards for the Charpy impact test. Morphology studies were conducted after the test, and SEM was used to look at the detail of the failure that occurs. From the SEM images, the creation of voids within the material resulting from low resin flow and shattered fibre particles resulting from the impact load can be seen. The photos also reveal the shattered specimen's fibre orientation, matrix cracking, and fibre debonding from the matrix. The interfacial properties and the internal surface of the shattered specimens are evident due to the application of the impact stress. It is also found that hybrid composites with 90° fibre orientation performed better under impact than unidirectional fibre orientation[48].

2.4.7 Failure of Kenaf/Glass Hybrid Composites under Static Loading

Crushing tests were carried out by Kumar and Sundaram, 2018 [49] on produced composite wrapped capped cylindrical tube specimens utilizing a computerized Universal Testing Machine(UTM) at a speed of 5 mm/min under static loading conditions. Matrix cracking, delamination, progressive crushing, fabric micro-buckling, and fracture are the most critical energy absorbing mechanisms discovered in this study[49]. Another axial quasi-static axial crushing test with a constant rate of 5 mm/min and a loading capacity of 100 kN, were conducted that adhered to the ASTM D7336M-12 standard code. All specimens are set to a height of 10 mm and will crush at a rate of 80% to 100% tube crushing displacement. The gradual crushing of hybrid kenaf/glass composite material began with matrix fracture and the undulation fibre, followed by growth creation of fracture along the fibre line, and finally broke the tube into two pieces with huge piece wedges. During the crushing operation, the breaking wall wedges extend outwards, tangling and slitting portions of the fibre from the outer layer wall. The hybrid density function effect in quasi-static compression analysis has revealed that the hybrid composite energy absorption tube has adopted the combined failure mechanism of the kenaf composite tube and glass fibre composite tube, which appears to have stable collapse deformation[50].

2.5 Summary

The literature review highlights the mechanical properties of kenaf, glass and kenaf/glass hybrid composites. However, based on the findings, we have found that there are limited number of studies exists on these hybrid composites properties on compressive loading. Thus, this study is to elaborate more on this hybrid composite's mechanical properties, failure mechanism and also to determine the hybrid composite types of failure under static and dynamic loading.

CHAPTER 3
METHODOLOGY

3.1 Materials

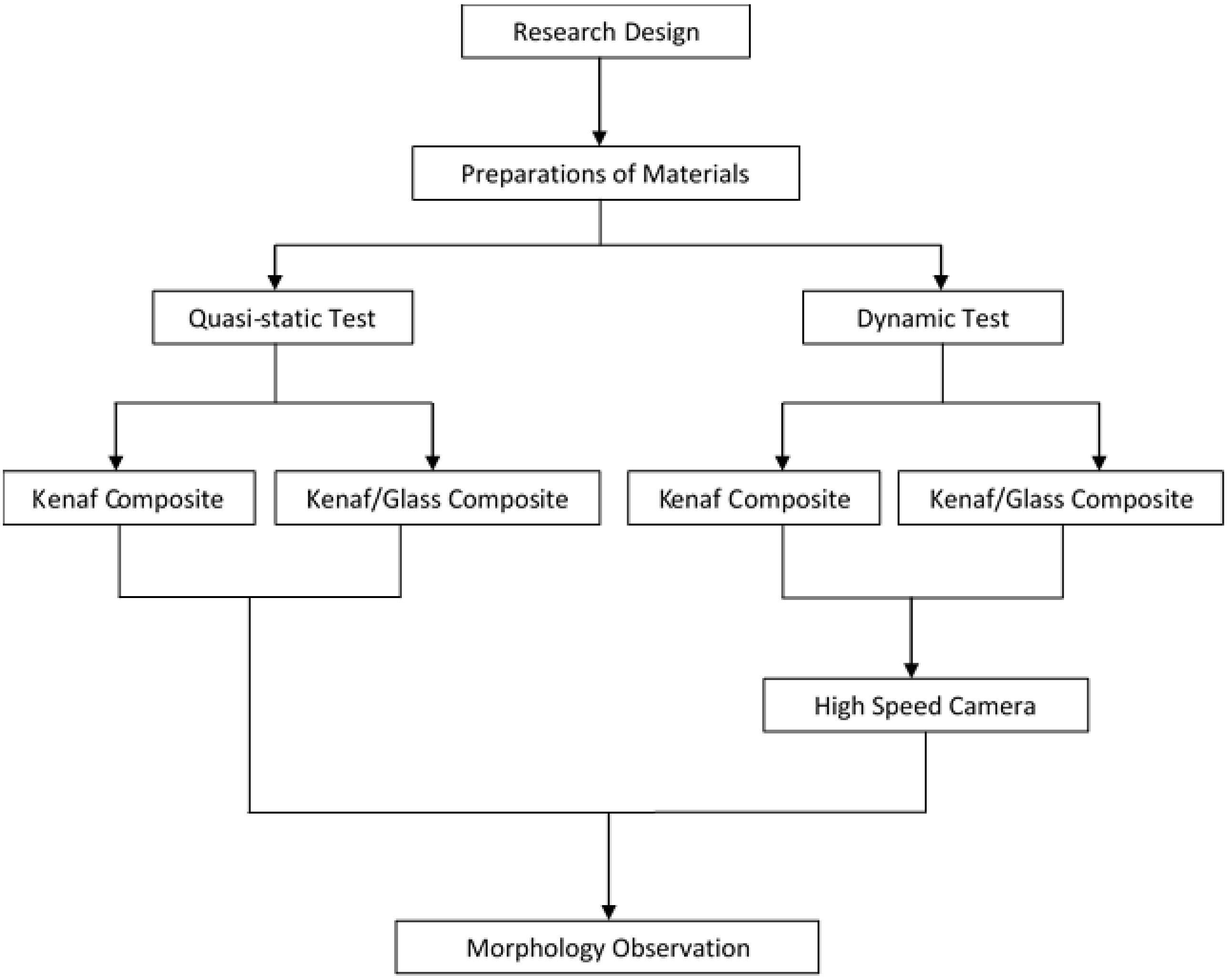

Figure 3.1 Flow chart of project methodology.

3.1.1 Kenaf fibre composites

Pultruded kenaf fibre reinforced composites were prepared using a thermoset pultrusion machine at USM School of Materials and Mineral Resources Engineering. During the production of these composites, roving’s of kenaf fibre yarn was put on bookcase-style shelves with a roving guide to direct the strands into the resin bath. A curing die, a precise machine used to impart the final form, was utilized for curing. Kenaf fibre was cured at a temperature of 120°C. All composite rods had a diameter of 12.7mm on average[51].

Figure 3.2 Kenaf composite unidirectional fiber arrangement.

3.1.2 Kenaf/glass hybrid composites

Pultruded kenaf reinforced polyester composites were made in this work using pultrusion techniques developed at Universiti Sains Malaysia's Engineering Campus' School of Materials and Mineral Resources Engineering. Unidirectional kenaf fibres and glass fibres were used to reinforce these composites, which were made with an unsaturated polyester (UPE) resin as the matrix. The ratio of kenaf to glass fibre mat in hybrid composite specimens is roughly 1:1. The filler was calcium carbonate (CaCO3) powder. At temperatures ranging from 90°C to 125°C, the catalyst Benzoyl Peroxide (BPO) was utilized to cure the polymer resin. Next, an internal mould release agent was applied to achieve a smoother release of the pultruded profile from the mould. Table 3.1 shows the constituent ratios that must be added to the UPE resin due to the computation. This mixture was then homogeneously mixed and stirred at room temperature before being transferred to the resin bath for the following step.

Table 3.1 Polymer resin compound formulation[52]

Ingredient	Type	Weight (g)	Ratio
Resin	Unsaturated polyester (Reversol P9565)	1000	1:1
Filler	Calcium carbonate (CaCO3)	200	1:0.2
Catalyst	Benzoyl peroxide (BPO)	17.5	1:0.0175

Release agent	Internal mold release powder	30	1:0.03

During the production of these composites, roving's of kenaf fibre yarn was put on bookcase-style shelves with a roving guide to direct the strands into the resin bath. A curing die, a precise machine used to impart the final form, was utilized for curing. Hybrid kenaf/glass was cured at a temperature of 120°C. All composite rods had a diameter of 12.7mm on average[52].

Figure 3.3 Kenaf/glass reinforced polyester composites fibers arrangements.

Table 3.2 Fabrication of pultruded profile parameters[52].

Parameter	Unit	Value
Pulling Speed	mm/min	180-190
Die Temperature	Zone 1 (°C)	120-130
	Zone 2 (°C)	170-180
	Zone 3 (°C)	170-180

3.2 Experimental procedure

3.2.1 Mechanical Tests

Two types of specimens were used for mechanical testing: Kenaf fibre and kenaf/glass hybrid composites. Each specimen is subjected to both quasi-static and high strain rate compression testing. The dimension of the specimens was 12.7mm diameter with 40mm length. The specimens were then cut into samples according to

ASTM standard for testing with quasi-static samples having a slenderness ratio of 1.5. In contrast, split Hopkinson pressure bar samples have optimal slenderness of 0.5, according to Davies and Hunter[53], [54]. Slenderness can be defined as the ratio between the height and width of a specimen.

3.2.1(a) Static test

The quasi-static samples were prepared and tested according to ASTM E9-89, using an INSTRON universal testing machine with crosshead speeds of 1mm/min, 2mm/min, and 3mm/min.

3.2.1(b) Dynamic test

High strain rate testing was done using a split Hopkinson pressure bar with pressures of 0.8bar, 0.9bar, and 1bar. The average was obtained after three repetitions of each loading.

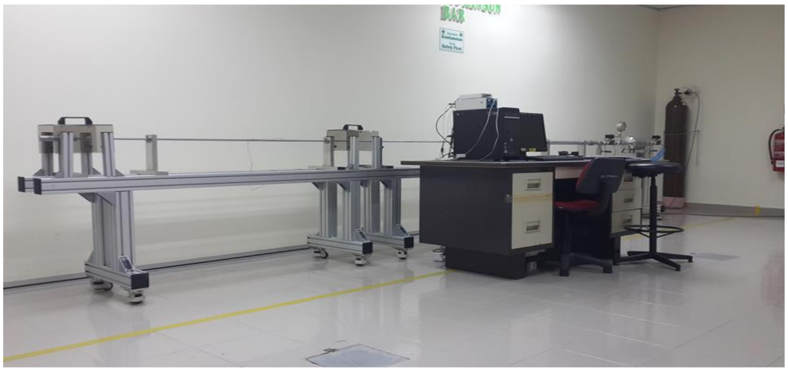

Figure 3.4 Split Hopkinson pressure bar.

3.2.2 Morphology observation

Micro images were taken with a Scanning Electron Microscope (SEM) model (Hitachi S-3700N VP-SEM) at the School of Mechanical Engineering of Universiti Sains Malaysia. The test aims to obtain a closer look at the bonding between glass and kenaf and the other type of failure[55]. Furthermore, by having SEM images, a detailed fractographic failure mechanism can be observed on the surface of the samples.

Figure 3.5 Scanning Electron Microscope (SEM)

3.2.3 High-speed camera

A high-speed camera was used to capture the moment of impact of the samples to identify the failure mechanism under a high strain rate loading. The model used was the Olympus i-speed 2 series. The frame rate used was 20,000 fps and ambient lighting colour.

Figure 3.6 Olympus i-Speed 2 camera

CHAPTER 4
RESULTS

4.1 Quasi-static loading

Static tests were done on three different rates on hybrid kenaf/glass, as well as kenaf composite. Figure 4.1 and Figure 4.2 illustrate the compressive strength of both composites. The stress-strain curve for the hybrid composites is quite rocky due to the difference in the time of failure of the fibre in the composites. Meanwhile, kenaf composite has a smooth stress-strain curve due to having only one breaking point throughout the specimen. The findings indicate that kenaf composite may withstand a more significant amount of stress before failure compared to hybrid kenaf/glass. The maximum compression stress achieved by kenaf composite is at 91MPa, which occur at a strain rate of 0.001852s^{-1}, while the maximum compression stress for hybrid kenaf/glass is at 78MPa, which occur at strain rate 0.002778s^{-1}. In terms of compressive strain, the trend suggests that kenaf composite also has a greater compressive strain 0.075 than hybrid kenaf/glass, which is at 0.025; this is attributed to the elasticity of kenaf fibres in comparison to glass fibres; this finding is also validated by Rao et al. and Sharba et al. [55], [56].

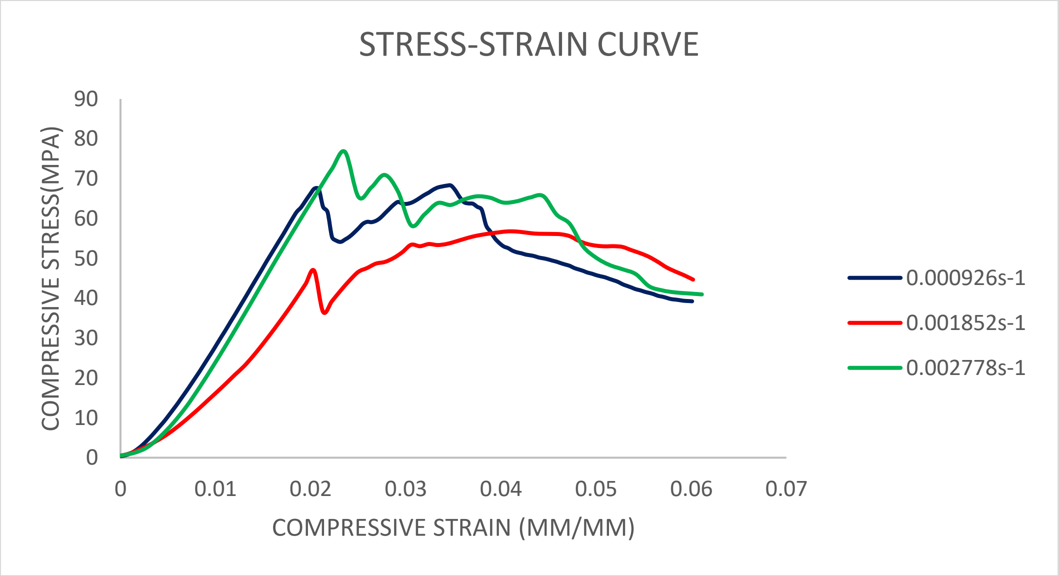

Figure 4.1 Stress-strain curves of kenaf/glass hybrid composites under dynamic loading.

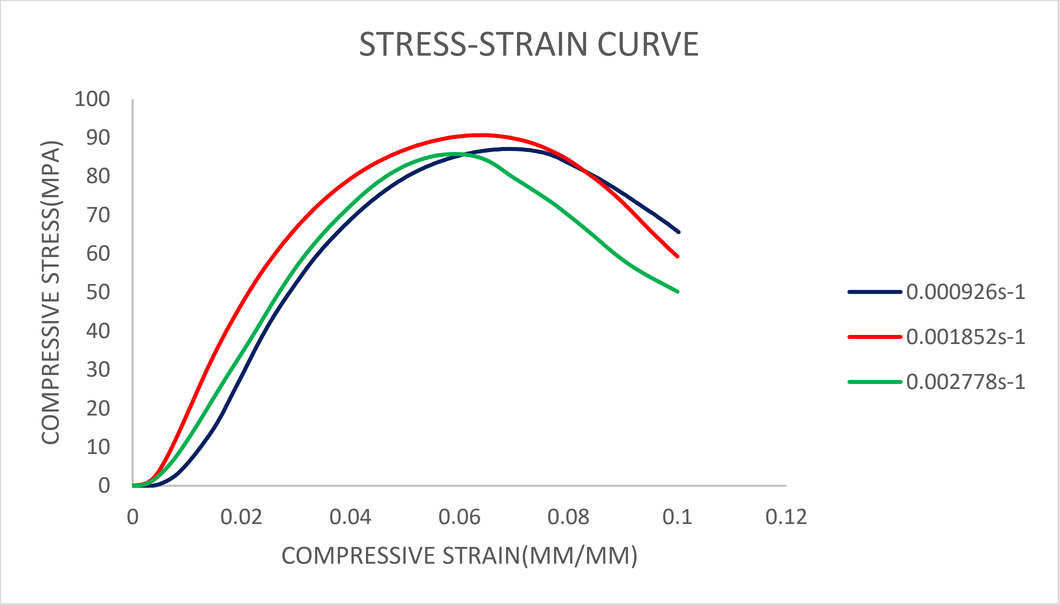

Figure 4.2 Stress-strain curves of kenaf composites under static loading.

4.1.1 Stress-strain behaviour

The stress-strain relationships of the hybrid kenaf/glass began linearly and then underwent a rapid reduction in stress before reaching the maximum point of stress. After then, the tension climbed to the maximal compressive strength, and the load dropped statically. The initial failure during compression testing was ascribed to the breaking strength differential between glass and kenaf, as well as load transmission from lower compressive strength fibre to the higher ones. In this case, the kenaf fibre in the hybrid kenaf/glass composite was having strain first while the glass fibre is trying to retain its position, thus causing two breaking points in the experiment as can be seen from Figure 4.1, which started by the breaking of the glass followed by the kenaf fibre. Unlike hybrid kenaf/glass, kenaf composite shows a smooth stress-strain curve until it reaches the peak stress, which then the failure occurs. This condition is due to the fact that kenaf composite contains only one unidirectional fibre in the composite.

As mentioned above, the compressive strain of kenaf composite is better than hybrid kenaf/glass due to the ductile properties of the kenaf fibre as compared to the glass fibre [56], thus allowing kenaf fibre to have a larger displacement before the failure occurs to the sample as compared to hybrid kenaf/glass. The failure propagation for the kenaf fibre starts at the middle of the specimen, where shear at about 60° occurs.

Meanwhile, the failure for hybrid kenaf/glass starts from brooming at the top part of the specimen, causing the debonding between the surface of glass and kenaf. The failure then propagated through the specimen longitudinally, causing several longitudinal cracks to happen to the specimen.

4.1.2 Failure mechanism

Figure 4.3 shows the macro failure that can be seen on the specimen after being subjected to quasi-static loading. The figure shows that the kenaf composite failed with shear banding failure at 60° while the kenaf/glass composite failed with longitudinal splitting along the fibre’s direction. The SEM images in Figure 4.4 shows that the matrix cracking was dominant for kenaf composite while fiber-matrix debonding was observed for kenaf/glass composite when loaded statically. Thus, the low bonding strength between kenaf and glass fibres would be the main cause of the low failure strength of the hybrid composite.

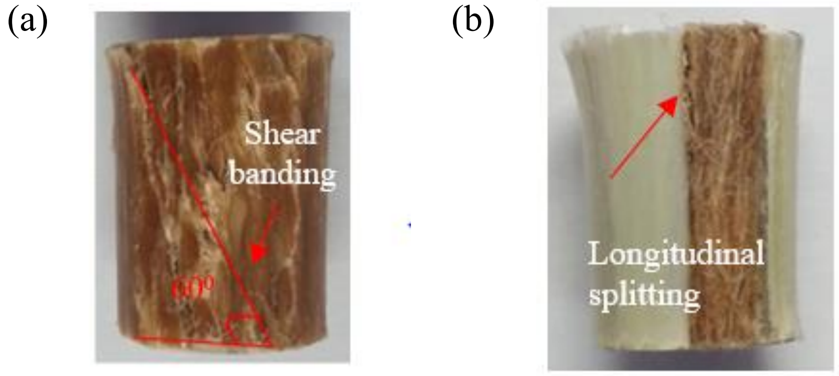

Figure 4.3 Failure of a)kenaf and b) kenaf/glass hybrid composites under ststic loading.

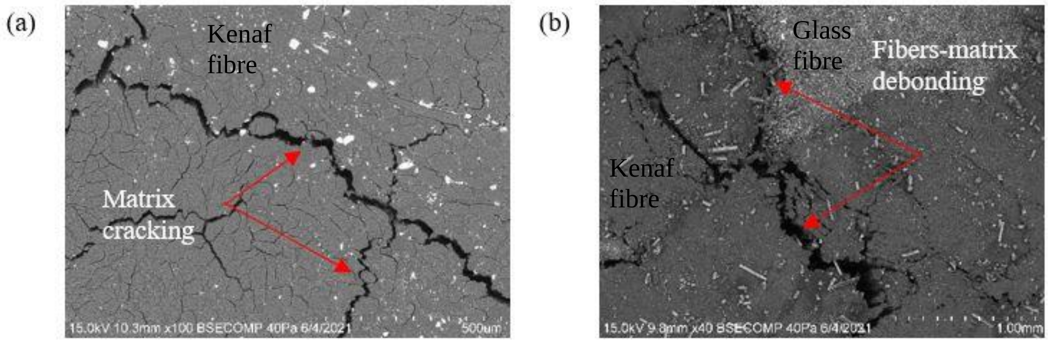

Figure 4.4 SEM images of specimens surfaces a) kenaf and b) kenaf/glass hybrid composites under static loading.