COMPRESSIVE PROPERTIES OF JUTE/KEVLAR UNDER STATIC AND IMPACT LOADING

FADLHLIN SAKINA BINTI ROSLI

UNIVERSITI SAINS MALAYSIA

2022

COMPRESSIVE PROPERTIES OF JUTE/KEVLAR UNDER STATIC AND IMPACT LOADING

By:

FADLHLIN SAKINA BINTI ROSLI

(Matrix no.: 142088)

Supervisor:

Dr. Sareh Aiman Hilmi bin Abu Seman

July 2022

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

School of Mechanical Engineering
Engineering Campus
Universiti Sains Malaysia

DECLARATION

I, Fadlhlin Sakina binti Rosli, hereby declare that the work displayed here is entirely original and was not published or submitted to another institution in order to fulfil a degree programme requirement. Any piece of literature or other work by another person that is referenced in this thesis has been properly acknowledged and listed in the reference section.

24/7/2022

………………………..	**………………………..**
Signature	Date

ACKNOWLEDGEMENT

All praises to Allah and His blessing for the completion of this thesis. I thank to God for all the chances, difficulties, and resources that have enabled me to complete the thesis.

First of all, I would like to express my sincere gratitude to my thesis advisor, Dr. Sareh Aiman Hilmi bin Abu Seman, for his guidance, support and understanding throughout this final year project work. He has given me a warm spirit and inspiration to accomplish my thesis. Having him as my supervisor has been a great pleasure and honour.

I am also sincerely grateful to Encik Hasfizan bin Hashim and Encik Mohd Shahar bin Che Had @ Mohd Noh, the assistant engineers at the composite lab of School of Aerospace Engineering for their guidance and cooperation while conducting the experimental work for this project. Special thanks also go to Encik Fakruruzi Fadzil and Encik Ashamudin Hashim, the assistant engineers of School of Mechanical Engineering for their sincere help during my final year project.

Besides, I would sincerely like to thank all to my beloved friends who were with me and support me through thick and thin. Lastly, I also want to extend my thanks to my family for their courage, love, and pray during the course of this project and support in all that I pursue.

This thesis would not have been possible without the collaboration and support of individuals who are generous with both their time and their willingness to put very personal aspects of themselves to carry out my project successfully.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRAK

Gentian sintetik dan semulajadi mendapat permintaan tinggi kerana kualiti unggulnya. Gentian asli mempunyai kualiti mekanikal yang baik dan lebih murah daripada gentian sintetik, memberikan mereka alternatif yang berpotensi kepada gentian sintetik. Disebabkan oleh masalah seperti kekuatan impak yang lebih rendah, penyelidik menumpukan perhatian pada penyepaduan kedua-dua gentian ini sebagai alternatif untuk mengatasi had gentian tunggal. Oleh itu, analisis ini memberi tumpuan kepada penghibridan gentian asli dan sintetik dengan kesan beban statik dan hentaman terhadap jujukan lapisan dan sifat mekanikal komposit hibrid berasaskan Jute-Kevlarepoxy. Sampel komposit jute dan Kevlar disediakan untuk mempunyai empat konfigurasi susun atur yang berbeza (iaitu, Jute-Jute-Jute [JF], Jute-Kevlar-Jute [H1], Kevlar-Jute-Kevlar [H2] dan Kevlar-Kevlar- Kevlar [KVF]). Sifat mekanikal komposit seperti kekuatan mampatan telah dinilai.

Daripada keputusan yang diperolehi, adalah diperhatikan bahawa kelakuan bahan atau sifat mekanikal komposit dipengaruhi dengan ketara oleh jujukan lapisan. Didapati antara empat jenis konfigurasi layup, gentian jute (JF) mempunyai kekuatan mampatan yang paling tinggi berbanding dengan Kevlar penuh (KVF), jut Hibrid (H1) dan Kevlar hibrid (H2) di bawah beban dinamik. Kevlar mempunyai kekuatan mampatan yang paling rendah, yang menunjukkan kekuatan mampatan rendah sepanjang gentian yang boleh membawa kepada pemisahan lapisan dalam lamina di bawah mampatan. Walau bagaimanapun, di bawah beban statik, jute hibrid (H1) menunjukkan kekuatan mampatan yang paling tinggi, manakala, Kevlar hibrid (H2) mempunyai kekuatan mampatan yang paling rendah. Mod kegagalan spesimen juga diperhatikan dalam eksperimen ini menggunakan Pengimbas Elektron Mikroskopik

(SEM). Di bawah beban statik, kerosakan utamanya adalah delaminasi, pecah gentian, penyahikatan antara muka dan gentian keluar, manakala keadaan kegagalan dalam kadar terikan yang tinggi terdiri terutamanya daripada jalur kink, pecah gentian, penyahikatan matriks gentian, kegagalan tepi dan penipisan.gentian.

ABSTRACT

Hybrid composite are in high demand due to their superior qualities. Natural fibres have good mechanical qualities and are less expensive than synthetic fibres, providing them a potential alternative to synthetic fibers. Due to problems such as their lower impact strength, researchers concentrated on integrating these two fibres as an alternative to overcome the single fibre's limitations. Thus, this analysis focused on the hybridisation of natural and synthetic fibres with the effect of static and impact loading towards the layer sequence and the mechanical properties of Jute–Kevlar- epoxy-based hybrid composite. The composite samples of jute and Kevlar are prepared to have four different layup configurations (i.e., Jute-Jute-Jute [JF], Jute-Kevlar-Jute [H1], Kevlar-Jute-Kevlar [H2], and Kevlar-Kevlar-Kevlar [KVF]). The mechanical properties of the composites like compressive strength have been evaluated.

According to the results obtained, the material behaviour or mechanical properties of composites are considerably affected by layer sequences. It is found that between the four types of layup configuration, jute fiber (JF) has the highest compressive strength compared to full Kevlar (KVF), Hybrid jute (H1) and hybrid Kevlar (H2) under dynamic loading. Kevlar has the lowest compressive strength, which indicate low compressive strength, which can lead to the separation of layers within a laminate under compression. However, under static loading, hybrid jute (H1) shows the highest compressive strength, while, hybrid Kevlar (H2) has the lowest compressive strength. The failures mode of the specimens is also observed in this experiment using Scanning Electron microscopic (SEM). Under static loading, the damages were primarily of delamination, fibre breakage, interfacial debonding, and fibre pull-out,

while the failure of the high strain rate condition consisted primarily of kink band, fibre breakage, fibre matrix debonding, edge failure, and fibre thinning.

CHAPTER 1

INTRODUCTION

1.1 Project background

In the field of fibre reinforced polymers, hybrid composites, which combine two or more distinct fibres in a single matrix, have become an interesting topic. Fibre reinforced polymer composites have been widely used in areas such as transportation, defense, aerospace and marine due to their strength and stiffness properties. jute, carbon, kenaf, basalt, hemp, glass, flax and Kevlar are some of the types of fibre composites available (Hisham et al., 2019). Weaved jute and Kevlar fibre were utilized to make hybrid composites in this investigation to study the materials' behavior under static and impact loading.

Jute is a potential material because it is relatively affordable, has greater strength and modulus and, most significantly, as its exclusive application in packaging is constantly threatened by synthetics, it would be highly desirable to find an additional field of application (Shah & Lakkad, 1981). Despite this rising interest, the impact behaviour of natural fiber-based composites at low and high speeds has received little attention.

Kevlar is a synthetic fabric that is commonly found in military equipment such as face masks, vests and helmets. Kevlar is a high-modulus, high-strength material with limited elongation, non-conductivity, low density and corrosion resistance that can absorb a lot of energy. DuPont's trademark for aramid fibres is Kevlar. Due to its high impedance to impact failure, kevlar fibre is frequently utilized in the field to reduce impact damage. Kevlar is obtainable as fabric materials (Salman et al., 2015).

Hybrid composites are utilised in a variety of applications. Currently, the majority of hybrid composites are created using simply synthetic fibres, such as Kevlar and carbon, Kevlar and fibreglass, carbon and fibreglass, etc. However, the global interest in hybrid composites combining synthetic and natural fibres has increased significantly in recent years.

According to the literature, fiber-reinforced polymer composites manufactured with synthetic fibre have several benefits, including high strength, high stiffness, extended fatigue life, flexibility to the structure's function, corrosion resistance, and environmental stability. This sort of material also has disadvantages, including high cost, high density, limited recycling capabilities, and nonbiodegradability. The choice of fibre is shifting away from synthetic fibre and toward natural plant fibre reinforced polymer composites for these reasons; materials with natural fibre have satisfactory specific strength and modulus, low weight, cheap cost, and biodegradability.

There are a variety of hybrid composites, including hybrids of synthetic synthetic fibres, synthetic-natural fibres, and natural-natural fibres. Kevlar, glass and carbon fibres are the synthetic fibres commonly utilised in hybrid composites. Synthetic fibres are typically produced through energy-intensive methods that generate toxic by products. Synthetic fiber-reinforced composites are both difficult to recycle and resistant to biodegradation.

In addition, increasing government pressure, as well as consumer and industrial awareness of the long-term effects of environmental pollution resulting from the lack of compostable polymeric products, has prompted numerous studies from throughout the world indicate an interest in building greener composites by excluding or minimising the use of nondegradable synthetic polymeric resin and fibres. Table 1.1 illustrates hybrid composites composed of synthetic-natural fibres, natural-natural fibres, and synthetic-synthetic fibres.

Table 1.1: Hybrid composites made from various fibers (Amir et al., 2018)

Synthetic-synthetic fiber	**Natural-natural fiber**	**Natural-synthetic fiber**
–	–	Coir – Kevlar
–	–	Kenaf – Kevlar
–	–	Kenaf – Prepreg Kevlar
–	–	Polylactide acid composite with empty fruit bunch – chopped glass strand
–	–	Palms – Kevlar
–	Sugar palm – Kenaf	–
–	Jute – Oil Palm	–
–	–	Jute – Glass
–	–	Kevlar – Rame polyester
–	Coir – Oil Palm	–

Hybrid composite materials are gaining increasing interest as they have numerous benefits in terms of impact resistance or strength-to-weight ratio, as well as elastic and non-conductive qualities. The complicated structure of the fiber/matrix interfaces and fiber/fiber in graphite-Kevlar hybrid and epoxy-based graphite-glass composites have revealed that these fiber/epoxy composites may have varying types and extents of hybrid effects. In general, the impact performance of epoxy composites is seen to improve with a high-ductility fiber. According to a recent study, several macroscopic failure mechanisms on energy absorption mechanisms and impact penetration resistance in hybrid-fiber composites can occur during impact loading (C. J. Wang et al.,).

Therefore, based on the above-mentioned finding, the purpose of this work is to report the effect of reinforcing jute fibre composites with woven Kevlar on the mechanical characteristics of jute fibres. Instrumented impact testing, such as the Universal Testing Machine (UTM), the Split Hopkinson Pressure Bar (SHPB), the Scanning Electron Microscopic (SEM), and a high-speed camera, were used to investigate the impact response of these hybrid matrix composites, including their microscopic and macroscopic failure modes.

1.2 Problem statements

Hybrid composites have recently become one of the most actively researched materials due to their promising features in research domains. Determining the compressive properties and the failure mechanism of hybrid composites such as the jute/kevlar composites is important for designing them, especially under static and impact loads. Currently, there are only few studies in this area, therefore, it will be great to develop the studies on the compressive properties of jute/kevlar and its failure morphology under static and impact loading. Under high impact point, numerous sorts of failure modes will arise in composite structures. Correlating this damage mechanism via impact ductility and toughness can help to understand the impact performance of these composites. A lack of understanding of differences in material strength in terms of static or impact rate would lead to inefficient and ineffective application of materials in designs. To enable the effective use of jute/kevlar composite materials in a variety of high-performance applications, it is required to differentiate and describe their behaviour under high rate and static loading.

1.3 Objectives of the project

The objectives of the project are:

1. To investigate the mechanical properties of jute/kevlar hybrid composites under static and impact loading.
2. To fabricate composite laminates with Jute fabric, Kevlar fabric, and epoxy resin using simple hand layup technique.
3. To study the failure morphology of jute/kevlar hybrid composites under static and impact loading.

1.4 Scope of the project

The scope of this project will be more focused on the experimentation of jute/kevlar hybrid composite under static and impact loading in order to understand and investigate the mechanical properties and its failure. The types of composites involved for this project which are jute and kevlar composites with the effect of difference strain rate. The proposed solution will be conducted by using a few equipment which include the SHPB, UTM, SEM and high-speed camera to evaluate the performances of the composites. This study also will discuss the related study regarding impact response of the jute/kevlar hybrid composites and its methodology. Under different impact and static loading conditions, different composites have different responses. The material elements of hybrid composites, as well as their behaviour under impact loading, are investigated. In addition, the various methods of mechanical characterization of composites are discussed in this paper. Lastly, it discusses jute/Kevlar hybrid composites' experimental methodologies and its probable failure modes.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The primary objective of this literature review is to obtain information regarding the project's journals, technical papers, and reference book. This chapter will discuss the information obtained from a variety of sources.

2.2 Composite material

If taken at face value, the phrase "composite" might refer to almost anything because, upon closer inspection, every material is made up of different subunits. However, the term is typically used in modern materials engineering to refer to a "matrix", a material that has fibre reinforcement. For illustration, the phrase "FRP "(for Fiber Reinforced Plastic) typically refers to a thermosetting polyester matrix incorporating glass fibres, and this specific composite controls the majority of the market in today's industrial sector.

Based on the type of matrix utilised, composite materials can be broadly categorised into three groups: metal matrix composites, ceramic matrix composites, and polymer matrix composites. In comparison to the other two, polymer matrix composites have a number of advantages, including a greater specific strength-to-weight ratio, a lower volume-to-weight ratio, the ability to be formed into a range of sizes and shapes, corrosion resistance, a simple manufacturing method, recyclability, and a reduced price. (H. Wang et al., 2019). The performance and cost of many composites utilised today are at the cutting edge of materials technology, being suitable for extremely demanding applications like spacecraft (Roylance, 2000).

When compared to homogeneous material compositions, composite materials frequently demonstrate significant stiffness and strength advantages. When these qualities are evaluated per unit weight, the benefit becomes quite clear. Additionally, composite materials have proven to be energy-efficient when viewed from a full life cycle perspective. The technology of composite materials has advanced quickly thanks to these motivating factors. (Christensen, 1983).

2.3 Jute fiber

Jute is the second most biodegradable and natural fiber. Jute is a bast fibre with a high production volume and low cost that is derived from the inner bast tissues of the plant stem (Corvhorus). The fibre bundles are kept cemented with non-fibrous tissues of jute bark by gummy components (pectinous substances) that bind the fibres together. To extract the fibre from the stem, these surrounding soft tissues must be softened, dissolved, and washed away. Retting is the process of steeping the stems in water to accomplish this. 808F is the ideal water temperature for retting. Depending on the temperature and the type of water used, microorganisms (mostly bacillus bacteria) destroy the gums and soften the tissues in 5 to 30 days. Higher concentrations of calcium and magnesium have been observed to seem to boost the toughness of fibre. (Gowda et al., 1999).

Jute fibres "as-received" will have a microcellular structure made up of microfibrils and very erratic transverse sections. The fibre cross-section is rather irregular. Additionally, the raw jute division of the IJIRA, Calcutta, has identified almost 1,000 types of jute (Gowda et al.,1999.). Jute fiber is an excellent alternative when thermal conductivity, cost, and strength are major concerns. Furthermore, jute fibres are also environmentally beneficial. Jute fiber-reinforced polymer composites are a significant field of research nowadays. Jute fibre is typically utilised for inexpensive and basic textile items. Both the cost and the environment would greatly benefit if the qualities of jute could be changed to benefit high-end and advanced textiles. Cellulose (47-71.5%) hemicelluloses (13.6-21%), and lignin (12-26%) make up the majority of jute. Lignin provides mechanical support because of the many aromatic rings it contains. Gum is any substance other than cellulose that reduces the fineness, pliability, and smoothness of jute (H. Wang et al., 2019).

Table 2.1 lists the chemical make-up of jute fibre. Strength and stiffness are influenced by the fiber's cellulose content, whereas moisture absorption, biodegradation and heat degradation, are influenced by the fiber's hemicellulose content. The thermal stability attribute of the fibre is influenced by its lignin content. Low density, high specific modulus and high specific strength are all characteristics of jute fibres. These fibres are commonly utilised in fiber-reinforced composites due to this reason. (Maharana et al., 2022).

Table 2.1: Chemical composition of jute fiber

	Cellulose (Wt. %)	Hemicellulose (Wt. %)	Lignin (Wt. %)	Others (Wt. %)
Jute	60–62	20–24	12–14	1–2

2.4 Kevlar

Kevlar is a type of aramid fiber. It is light weight and exceptionally strong, resistant to heat and corrosion, and is woven into textile materials. Numerous things, including boats, bulletproof vests, aerospace engineering (such as the body of an aeroplane), body armour, and vehicle brakes, utilise it. Typically, it has been used to create composites. Furthermore, Kevlar can be used with other fibres to produce hybrid composites. Kevlar and other synthetic fibre reinforced composites have high specific strengths, but due to their inherent properties, their application range is relatively constrained.

For example, jute/carbon hybrid composite, hemp composites, kenaf/glass hybrid composite, and jute/methacrylated soybean oil composite are just a few examples of the natural fibre composites that many researchers have created in the past. They came to the conclusion that natural fibre cannot tolerate increased impact loading on its own. As a result, adding alternative reinforcements or matrix, like a hybrid jute/kevlar composite, can enhance the tensile strength and impact capabilities of natural fibre composites (Bakar et al., 2015).

Particularly Kevlar fibres provide unmatched characteristics, such as stronger Young's modulus, better quality, better thermal conductivity, and more astounding electrical qualities than other fibres. Kevlar fibres are currently the most widely used fortress for composites as a result, because to their transparency and unflappable quality. Beginning late, more obvious emphasis has been produced in the improvement of fiber-filled composites exposed to common fibres with a view to exclusively or equally replace glass fibres for various purposes. The degree to which jute fibre is used in place of conventional glass fibres begins with the lower specific gravity and useful specific modulus of jute fibre that were demonstrated differently in comparison to those of glass fibre. Similar to how it connects with fibre to be used as a reinforcing material in the fiber-filled composite, it's cheaper cost and usefulness make it do so. (Bhanupratap R, 2019).

2.5 Mechanical Properties

Numerous factors, including fibre size length, composition, shape, orientation, and as well as volume percentage, affect the mechanical properties of composite materials. The matrix's mechanical characteristics, the manufacturing process, and the bond between the matrix and the fibres also play an important role. Since the 1930s, fibreglass has been utilised to reinforce polymer matrix composites. The primary natural fibres used as composite reinforcement are jute, kenaf, cane, sisal, bamboo, flax, wood flour, pulp, banana, cane, oil palm, coir and pineapple leaf. The drawbacks include a lack of durability when wet, susceptibility to microbial attack in humid regions, and yellowing in sunshine (Kumar & Srivastava, 2017).

2.5.1 Jute

Jute fibres typically have the following characteristics, according to Alves et al.: density of 1.5 g/cm3, tensile strength of 393–773 MPa, and elastic modulus of 10–30 GPa. Jute is one of the most popular fibres. It is affordable, has a decent amount of strength, and is rot-resistant. Typically, jute is used for packaging (sacks and bales) (Kumar & Srivastava, 2017). The jute fiber have some other promising properties like excellent tensile properties, low density, nonabrasive nature, long staple length and very easy to processing (Das et al., 2018).

2.5.2 Kevlar

Kevlar fibre is one of the most prominent fibres used in FRP composite products because of its exceptional qualities. Kevlar fibre composites (KFCs) are mostly used in high-tech industries like aerospace and defence. It has a substantially lower fibre elongation and a better tensile strength and modulus than other synthetic fibres. Additionally, it displays excellent high temperature characteristics for a polymeric material. Kevlar fibre has a glass transition temperature of about 360°C, therefore it does not melt like nylon (Singh & Samanta, 2015).

The longitudinal tensile characteristics of the Kevlar fibres are excellent. However, it was discovered that the composite's tensile strength varied from the values predicted by the law of mixture. It was because of the uneven distribution and dispersion of fibres. The primary mode of failure for Kevlar composites under tensile load is fibre splitting, which is frequently accompanied by substantial longitudinal matrix and interfacial shear fracture. The Kevlar fibre composites have a very high ratio of tensile to compression strength because of its anisotropic nature. Numerous researchers have examined the compressive strength of Kevlar composites (Singh & Samanta, 2015).

The compressive strength of Kevlar fibre is significantly lower than that of its competitors, such as glass and carbon, and as a result, its composites easily broke under compressive loads as a result of the failure of the fibres. The composite failed as a result of the Kevlar fibre primarily exhibiting kinking failure under the compressive load. Moreover, it was discovered that the poor compressive strength of the Kevlar composite is caused by both internal fibre failure and smooth surface debonding, and local failures occur within the fibre and at the interface (Singh & Samanta, 2015).

2.5.3 Mechanical properties under static and impact loading

2.5.3.1 Tensile properties

In contrast to hybrid composites and full kenaf fibre reinforced composites, the tensile strength of full hybrid Kevlar fibre reinforced composites was the highest (Figure 2.1). Full kenaf reinforced composites, on the other hand, exhibited the lowest tensile strength. The composite laminates' tensile strength was enhanced by the addition of Kevlar fibre layers. The increase in tensile strength is attributable to Kevlar fiber's inherent increased mechanical strength. Tensile strength was enhanced when Kevlar fibre replaced the middle layer of complete kenaf fibre. The tensile strength of hybrid composites with H2 fibre arrangement is greater than that of full KF composites. Nonetheless, it is intriguing to notice that H2 composite laminates exhibited tensile strength comparable to that of KVF composites. Since the outer layers influence the tensile strength of composite laminates, H2 composites have comparable tensile strength to KVF composites (Dhar Malingam et al.).

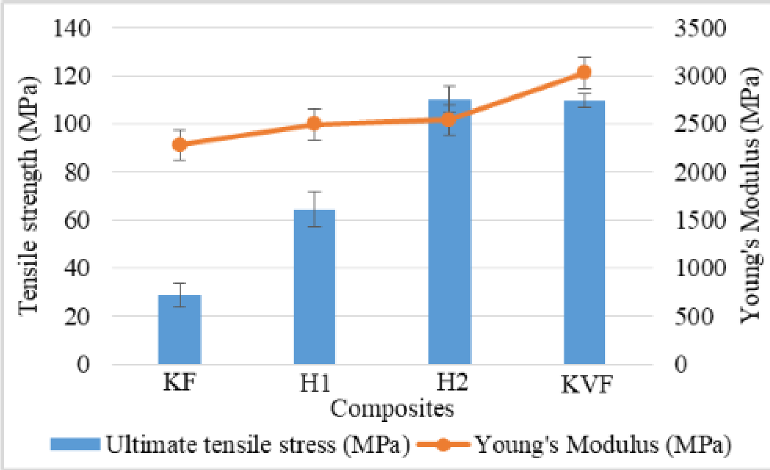

Figure 2.1: Tensile strength and tensile modulus of composite laminates (Dhar Malingam et al.).

2.5.3.2 Static Indentation Properties

To determine the penetration resistance of composite laminates with varied stacking sequences, static indentation tests were conducted. Full Kevlar fibre reinforced composites clearly demonstrated the highest peak load, followed by H2, H1, and full KF. Figure 2.2 depicts the maximum load and energy absorbed by composite laminates during quasi-static indentation testing. The trend indicates the positive hybrid effect, in which the energy absorption of composites including Kevlar fibres is superior to that of composites reinforced entirely with kenaf fibres. In reality, the perforation resistance of materials is determined by their bending stiffness. Therefore, the introduction of Kevlar fibres with high stiffness into composite laminates increases the perforation resistance. In addition, the incorporation of Kevlar fibres in the outermost layer of composites resulted in increased energy absorption and load resistance. Kevlar fibres require greater penetrating force and elongation to fracture than kenaf fibres. Therefore, the inclusion of high-strength Kevlar fibres in the composites' outermost layers increases peak load and energy absorption (Dhar Malingam et al.).

Salman et al. (2018) investigated the QSI behaviour of polyvinyl butyral hybrid composite laminates reinforced with kenaf and aramid fibres. In comparison to full kenaf reinforced composites, the hybrid composite laminates had a greater energy absorption capacity. Similar findings were obtained when high-strength glass fibre was placed on the surface of hybrid composites to increase penetration resistance (Dhar Malingam et al.).

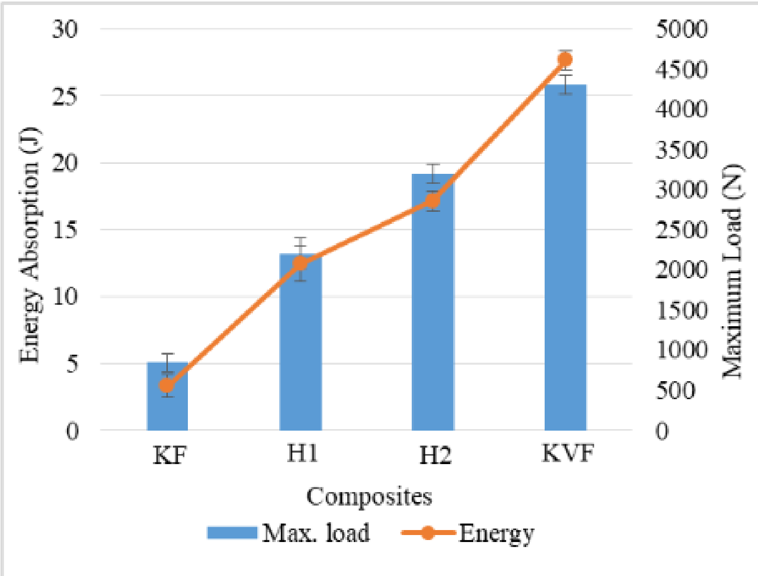

Figure 2.2: Maximum load and energy absorption of composite laminates under quasi-static indentation (Dhar Malingam et al.).

2.5.3.3 Impact test properties

The impact properties of kenaf-Kevlar hybrid composites are depicted in Figure 2.3. Numerous parameters, including matrix, interfacial bond strength and fibre, have a profound effect on the impact properties of fibre composites. A composite's impact failure is caused by factors including fibre or matrix fracture, fibre pull-out, and fibre/matrix debonding. As expected, sample H1 exhibited superior impact resistance than samples H4 and H5 due to its Kevlar and void content. The outcome suggests that the impact values for H4 and H5 are comparable. This may be a result of the sample's fibre content, high void content and thickness in tested samples. Impact toughness of samples H5, H4, and H1 is greater than that of Kevlar/epoxy composites, possibly because kenaf reacts as fillers to strengthen the epoxy matrix. (Yahaya et al., 2014).

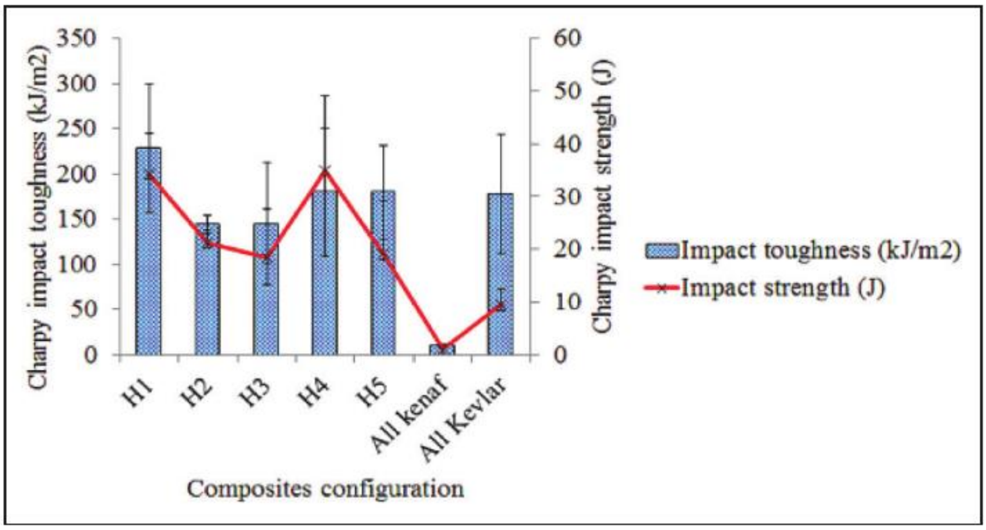

Figure 2.3: Impact properties (Yahaya et al., 2014)

2.6 Compression and Impact Test

Compression test and impact test are two tests that can be used to determine the mechanical properties under static or impact loading. The most typical combinations for impact testing use Charpy and Izod specimens. The notch is positioned facing the striker in the Izod impact test as opposed to the Charpy impact test. Thus, in the Charpy test, the specimen is held horizontally between two vertical bars, whereas in the Izod test, the specimen stands upright. (Saba et al., 2018).

In dynamic fracture tests, the Split Hopkinson Pressure Bar (SHPB) impact test is frequently employed as an instrumented loading device. It operates according to the one-dimensional wave propagation theory. This indicates that in a long elastic bar, a stress wave propagates non-dispersively at the velocity of an elastic bar (Sun, 2008), but composite compression testing methods offer a way to apply a compressive load to the material while keeping it from buckling. The behaviour of materials is determined through compression testing, and the compression and deformation at different loads are recorded to calculate compressive stress and strain (Saba et al., 2018). Low strain rate compressive tests or quasi-static tests are two types of compression tests that can both be performed using the Universal Testing Machine (UTM).

The findings of mechanical testing on a material's tensile, flexural, and impact qualities shed light on how well it can withstand an unexpected rupture or cleavage when given stress or pressure. Furthermore, the type of fibre, polymer, and fiber/matrix interfacial bonding has a significant impact on the mechanical characteristics of fiber-reinforced polymeric composites. In order to determine the right parameters for the failure criterion model incorporating failure prediction and ultimate strength of composite samples, researchers also conducted interlaminar strength test, compression and shear tests (Saba et al., 2018).

2.6.1 Split Hopkinson pressure bar (SHPB)

The split Hopkinson pressure bar (SHPB) has gained widespread recognition as a highly effective experimental tool for obtaining families of stress-strain curves for engineering materials at high strain rates between10^2 to $10^4 s^{-1}$. A conventional SHPB apparatus, consists of a gas gun (or a launching device), an incident bar, a striker, an energy absorption device, a transmission bar, and a data acquisition system which is schematically shown in Figure 2.4. The specimen is sandwiched between the incident bar and the transmission bar. Elastic waves are produced in the incident and striker bar when the striker, which is frequently released by compressed gas in the gas gun, impacts the end of the incident bar. Incident wave is the name for the elastic wave within the incident bar.

Due to the mechanical impedance mismatch between the incident bar material and the specimen, some of the incident wave travels through the specimen and is reflected back into the incident bar as a reflected wave. The remaining incident wave transmits through the specimen and compresses the specimen at a high rate into the transmission bar as a transmitted wave. The strain gauges on the incident bar sense the transmitted signals, while the strain gauges on the transmission bar sense the incident and reflected signals. Using either a digital oscilloscope or a computer, all three signals are captured.

During a SHPB experiment, the bars serve as sensors and must therefore adhere to stringent specifications such that the data interpretation has minimum uncertainties. To prevent wave overlapping, the pressure bars must, first, remain elastic and be suitably long in comparison to the incident wave's length. To reduce the effects of two-dimensional stress wave propagation in the bars, thin bars are suggested. Throughout the test, the ends of the bars in contact with the specimen must remain at and parallel. Additionally, the specimen's cross-sectional area must never be greater than that of the bars.

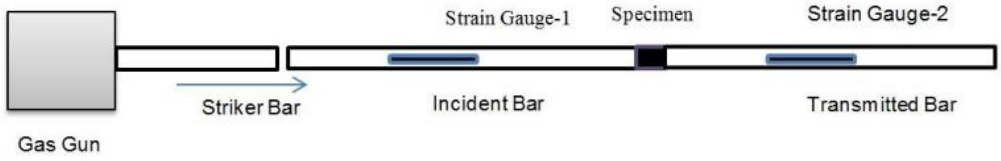

Figure 2.4: Schematic diagram of SHPB (Bilal Nutkani et al., 2020)

The strain rate, strain, and stress histories of the specimen are disclosed through a one-dimensional stress-wave analysis of the bars,

$$\dot{\varepsilon} = \frac{C_0}{L_s}\left[\varepsilon_i(t) - \varepsilon_r(t) - \varepsilon_t(t)\right] \quad (1)$$

$$\varepsilon = \frac{C_0}{L_s}\int_0^t \left[\varepsilon_i(t) - \varepsilon_r(t) - \varepsilon_t(t)\right] dt \quad (2)$$

$$\sigma = \frac{A_0}{2A_s}E_0\left[\varepsilon_i(t) + \varepsilon_r(t) + \varepsilon_t(t)\right] \quad (3)$$

Where respectively, $\varepsilon_i(t), \varepsilon_r(t), \varepsilon_t(t)$ represent incident, reflected, and transmitted strain histories sensed by strain gages; Ao is the cross-sectional area of the bars; E0 and C are Young's modulus and elastic bar wave speed in the bar material, respectively; A is the specimen's initial cross-sectional area and length. When the sample is under a constant stress,

$$\varepsilon_i(t) + \varepsilon_r(t) = \varepsilon_t(t) \quad (4)$$

Equation (1)-(3) can be simplified as

$$\dot{\varepsilon} = -2\frac{C_0}{L_s}\varepsilon_r(t) \quad (5)$$

$$\varepsilon = -2\frac{C_0}{L_s}\int_0^t \varepsilon_r(t)\, dt \quad (6)$$

$$\sigma = \frac{A_0}{A_s}E_0\varepsilon_t(t) \quad (7)$$

As a result, in a SHPB experiment, the recorded strain gauge signals can be used to extract the stress-strain data. According to equation (7), the transmitted signal ε_t is proportional to the tension in the specimen (Song & Chen, 2005).

2.6.2 Universal Testing Machine (UTM)

A tensile testing machine is a specialised testing tool made to carry out static tests and identify the mechanical characteristics of materials while they are subjected to axial tension, compression, and bending within the bounds of the machine's technical capabilities. The machine's structural components include a loading mechanism (either hydraulic or mechanical) and measurement elements that track changes in the force applied and the deformation of the tested sample.

2.7 The method of producing fiber jute/kevlar reinforced composite

The fabrication of the Kevlar and jute fibre reinforced hybrid composite laminates involves hand layup, and then applying pressure, using the vacuum bagging process. The natural and synthetic fibres are alternately layered throughout the entire specimen.

2.7.1 Hand lay-up process

The manufacturing process known as `hand layup' involves manually laying down individual layers or `plies' of a form of reinforcement known as `prepreg'. This is made up of many fibres that have been pre-impregnated with resin, bundled into tows, and either woven together or arranged in a single unidirectional ply. Each ply must be manually formed into the desired shape before being firmly adhered to the surface of the previous layer or mould, leaving no space between the plies. This can manufacture intricate features of high quality, has affordable startup costs, and is very adaptable to new components and design modifications. It is far from perfect, though, as there can be low production rates and occasionally high labour and material expenses. Human variation could lead to differences between pieces, much like with other manual processes. Despite these drawbacks, hand layup is still a vital component of the composites industry, serving as the primary manufacturing process for many manufacturing facilities due to its versatility and quality (Elkington et al., 2015).

The processing steps for hand layup are quite simple. The first step in constructing the clipboard is to cut out square (25cm x 25cm) of the reinforcement materials to be used. Fabric should be stacked with the weave facing outward. Once all of the material has been cut, start stacking it, starting with the top layer and working backward until reach the bottom layer, then set it aside. The material must be ready before the work area can be adequately prepared; it must be flat and smooth. Make the surface properly ready by:

a. Cleans it with alcohol to remove any foreign elements.
b. Put a thick coat of release wax (any vehicle wax would do) to the table surface, buff it out, and this will fill any minor scratches.

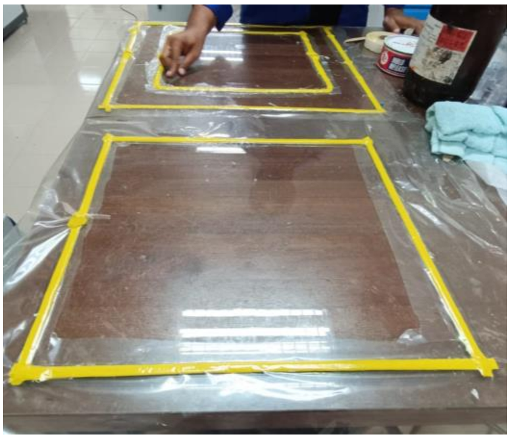

Figure 2.5:Clean it with alcohol to remove any foreign elements

Figure 2.6:Put a coat of release wax to the table surface

Prepare the epoxy matrices before the layup process begins (resin and hardener). Pouring epoxy resins into a cup and thoroughly mixing them with a stick or a resin mixing ratio. Start applying or pouring the epoxy right away. The pot life and working time will increase with the amount of combined material in the cup. A small amount of epoxy should be applied to the work surface, then it should be spread out to roughly the same size as the initial layer of material. When the epoxy is equally showing through over the surface, press the fibre into the epoxy. If the materials' surface becomes opaque, no extra epoxy is needed; if not, apply a little amount and spread it out over the surface before adding the next layer (materials) and pressing into place. Follow this procedure to finish the additional layers, with the final layer of materials being the layer that will form the bottom of the clipboard (Frank J.)

Figure 2.7: Hand layup process (Abdurohman et al., 2018)

2.7.2 Vacuum bagging process

Vacuum bagging (or vacuum bag laminating) is a form of clamping that utilizes air pressure to hold the adhesive or resin-coated components of a lamination in place while the adhesive cures. (When referring to composites, the term "resin" often refers to the resin system composed of cured resin and hardener.) By removing the need for much of the complex and expensive equipment used for laminating in the past, modern room-temperature-cure adhesives have contributed to making vacuum bag laminating techniques accessible to the average builder. Vacuum bagging's efficacy enables the lamination of a variety of materials, from conventional wood veneers to synthetic fibres and core materials. The vacuum bagging system includes an airtight clamping enclosure and a way to keep the envelope airless until the epoxy adhesive dries (Epoxy, 1990).

The vacuum bagging process can start after the work area has dried. The material for the vacuum bag should be trimmed so that it extends approximately two inches beyond the edge of the prepared work surface. After all layers have been thoroughly saturated with resin, the vacuum bagging procedure begins. Wrap sticky sealing tape over the boundaries of the work area. Apply continuous layers of wax and edge breather (a white, cotton-like material) all around the layup. This serves as a continuous vacuum path over the component and must stay away from the resin. Apply the bag material, then take off the backing paper. The bag should adhere to this. Remove creases from the bag, but do not pull too tight that the bag stretches. Work around the bag until it is sealed on all sides without excessive folds or wrinkles. Turn on the vacuum compressor once the bag has been completely assembled, the regulator, vacuum line, and gauge have been set, and the vacuum regulator has been installed. Take some time to smooth out any creases and look for leaks while the vacuum removes the air from the bag. To ensure a tight seal, compress the bag around the taped regions. Remove the component from the bagging material, check it, and make any necessary adjustments after it has fully cured (at least overnight). Use a belt sander, a random orbital sander, or a hand sander to remove extra material from the panel (Frank J.).

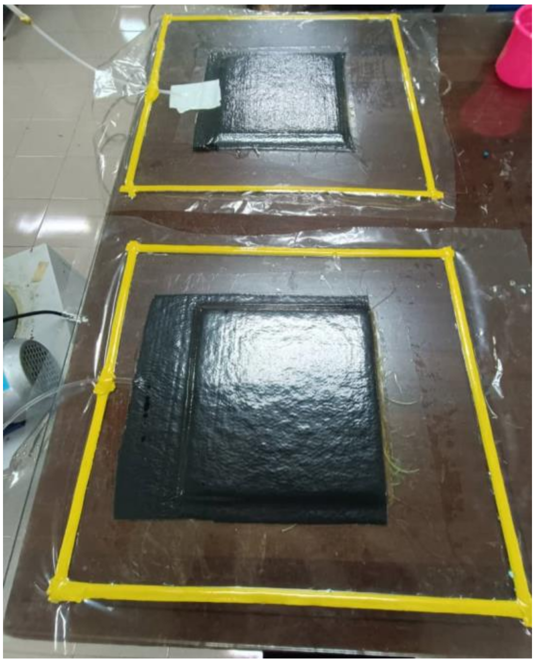

Figure 2.8: Vacuum Bagging Process