EFFECT OF WATER ABSORPTION TOWARDS MECHANICAL AND PHYSICAL PROPERTIES OF HYBRID FLAX/GLASS FIBER LAMINATED COMPOSITES

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DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled ‘**Effect of Water Absorption Towards Mechanical and Physical Properties of Hybrid Flax/Glass Fiber Laminated Composites**. I also declare that it has not been previously submitted for the award of any degree and diploma or other similar title of this for any other examining body or University.

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Date:

Witness by

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Date:

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LIST OF SYMBOLS

%wt	Weight percentage
b	breadth
cm	Centimeter
h	height
L	length
g/cm^3	Gram per centimeter cube
mm	Millimeter
J	Joule
g	Gram
MPa	Mega Pascal
GPa	Giga Pascal
gsm	Gram per square meter
pH	Potential of hydrogen

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
FF/GF	Flax Fiber / Glass Fiber
GF/FF	Glass Fiber / Flax Fiber
ISO	International Organization for Standardization
NaOH	Sodium Hydroxide
RH	Relative Humidity
SEM	Scanning Electron Microscope
UTM	Universal Testing Machine
UV	Ultraviolet
VARTM	Vacuum Assisted Resin Transfer Molding

KESAN PENYERAPAN AIR TERHADAP SIFAT-SIFAT MEKANIKAL DAN FIZIKAL KOMPOSIT HIBRID BERLAMINASI GENTIAN FLAX/KACA

ABSTRAK

Kesan penyerapan air terhadap komposit berlamina hibrid gentian flax/kaca terhadap fungsi masa selepas diletakkan di dalam pelbagai jenis larutan dikaji. Gentian sintetik dan gentian asli digabungkan dengan menggunakan konsep hibrid. Dua jenis komposit dengan jumlah sembilan lapisan gentian hibrid difabrikasi menggunakan teknik manual dan beg vakum. Komposit direndam ke dalam tiga jenis larutan yang berbeza paras pH selama 21 hari. Pencirian yang melibatkan ujian mekanikal ujian tegangan, ujian lenturan dan ujian hentaman serta analisis morfologi menggunakan mikroskop elektron imbasan (SEM). Tahap degradasi selepas process penyerapan air dijangka akan berlaku kerana molekul air telah mengubah struktur di dalam komposit hibrid. Didapati bahawa komposit yang direndam dalam larutan beralkali merosot lebih cepat berbanding komposit di dalam air suling dan larutan berasid. Hasil ujian mekanikal menghasilkan trend yang hampir serupa di mana sifat mekanikal sampel yang direndam berkurang dengan peningkatan masa rendaman menunjukkan bahawa berlakunya proses degradasi. Analisis morfologi yang diperolehi daripada permukaan patah ujian tegangan dan hentaman dan menunjukkan bahawa semua sampel mempunyai kecacatan terutamanya rongga dan daya lekatan antara muka yang lemah disebabkan oleh komposit telah disediakan adalah tidak konsisten. Juga didapati bahawa komposit hibrid dengan lapisan gentian kaca yang lebih banyak mempunyai sifat yang lebih baik berbanding dengan komposit jenis FF/GF.

EFFECT OF WATER ABSORPTION TOWARDS MECHANICAL AND PHYSICAL PROPERTIES OF HYBRID FLAX/GLASS FIBER LAMINATED COMPOSITES

ABSTRACT

The moisture uptake of flax/glass hybrid laminated composite in the function of time after immersion in various solutions was studied. Synthetic fiber and natural fiber were combined by using hybrid concept. Two type nine layers of hybrid composites with different stacking sequences were fabricated using both hand lay-up and vacuum bagging technique. The laminates were subjected to water absorption which were immersed into various solutions of different pH level for 21 days. The characterization involving mechanical testing of tensile test, flexural test and impact test and morphological analysis by using scanning electron microscope (SEM). Degradation was expected after ageing in the different solutions in which the water molecules break down the structure in the composites. It was found that composite immersed in basic solution can deteriorate faster than in distilled water and acidic solution. The outcome of mechanical testing results in almost similar trend which the mechanical properties of immersed samples decreased with increasing immersion time indicating fiber degradation. The morphological analysis obtained from fracture surface of tensile and impact test and showed that all samples have defect especially voids and poor interfacial adhesion due to the composites were prepared were inconsistent. It was also found that hybrid composites with more glass fiber layers have higher mechanical properties compared to FF/GF composite.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Natural fibers and synthetic fibers have been used as reinforcing materials in composite fabrication as they exhibit their advantages along with the application (da Silva *et al.*, 2021). Synthetic fibers are manufactured fibers that were synthesized chemically, where the fibers were fabricated through extruding polymer solution into fibers. Some of the examples of commonly used synthetic fibers are glass, carbon and nylon (de Albuquerque *et al.*, 2000). Glass fiber used in this study consists of a very fine strand of fibers made of glass which can give an outstanding mechanical property includes high strength and flexibility but to produce these materials require high cost and they are also non-renewable (de Albuquerque *et al.*, 2000).

On the other hand, natural fibers has become a valuable reinforcing material in polymer composite due to its properties. Natural fibers are generally having good modulus, toughness, strength, low density, renewable and environmentally friendly as can bring no risk with safety and human health during handling the fibers (Stamboulis et al., 2001; Nosbi et al., 2011; de Albuquerque et al., 2000). Natural fibers such as kenaf, jute and hemp are the most common reinforcement used to produce composites component recently. All natural fibers are categorized based on Figure. 1.1. Lignocellulosic natural fibers or cellulose-based has also become a substitute material to the synthetic fibers over the recent years because as it is an naturally occurring and it can offers low cost with good performance ratio. In addition, they may be burned for energy recovery as these fibers are nonabrasive and have a high calorific value (de Albuquerque *et al.*, 2000; Awais *et al.*, 2020).

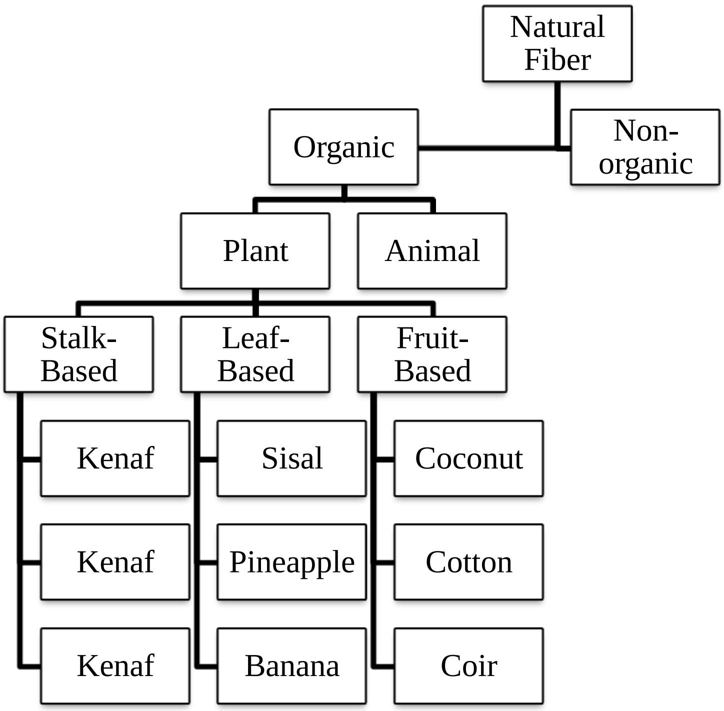


Figure 1.1 Type of natural fiber (Campbell, 2010)

As compared to glass or aramid, flax and hemp has better mechanical properties such as high specific stiffness and low density due to the fibers consists of several elementary fibers that is glued along by middle lamella origin from pectin making them able to be as reinforcement material to polymer composites (Papa et al., 2020). Composites made of flax fibers would have high moisture absorption competency hence this could decrease the material's stable lifespan. In the area of composites, hybrid composites with synthetic and natural fibers are a desirable choice because they combine the mechanical performance of synthetic materials with the benefits of natural fiber (Huner, 2015). In industrial level, natural fibers in product application with monolithic materials are utilized by researchers and engineers to study about the material behavior when in service or exposed to various environment conditions (Nosbi et al., 2011). Based on the limited studies of natural fibers and synthetic fibers hybrid composite, the investigation of effect of water absorption towards mechanical and physical properties of the flax/glass fibers hybrid composites is carried out.

1.2 Problem Statement

Synthetic fibers such as glass fibers typically are readily available in market as they are used in a wide range of applications such as structural composites, automotives, pipes and boats. Even though synthetic fibers possess outstanding bulk properties for many applications, however they does not satisfy the environmental issue which it should be more sustainable, can be recycled, renew and biodegradable (Nosbi *et al.*, 2010; da Silva *et al.*, 2021). Therefore, due to the sustainability and price concern has resulted in making natural fibers as an alternative in producing polymer composites. Natural fibers exhibits some advantages compared to synthetic fiber especially in term of cost and their sustainability behavior for instance low energy consumption, has no residues when incinerated and has renewable resource (Stamboulis et al., 2001; Awais et al., 2020). However, to contrast the mechanical properties between the synthetic and natural fibers are the strength is higher for the former and lower strength for the latter. Natural fiber also has high moisture absorption hence the performance of the composite composed of natural fiber as reinforcement material would be reduced for them to function well in in challenging conditions.

Recently, researchers have proposed the concept of embedding natural and synthetic fibers together to form an improved version of hybrid composite (Islam and Begum, 2013). The benefits of each type of fibers generate composites product samples with very good and balanced properties. Fiber bundles were used instead of individual fiber because when fiber was in bulk, the fiber cell are bonded by pectin hence the strength of fiber improved. However, this material has shortcoming to withstand swelling as they have high water absorption. For instance, the composite can degrade faster than expected lifetime service due to moisture and temperature exposure making them not suitable for outdoor application. Fiber swelling can cause microcracking in the composite and a loss of mechanical behavior (Stamboulis et al., 2001; Huner, 2015; Rahman and Syed Putra, 2019). Besides that, the composite matrix such as epoxy that were commonly used also reported can absorb water easily therefore this matter can add up the degradation issue on the material composite (Huner, 2015).

In order to get the best performance of composites, it is critical to investigate the water absorption behaviour to assess the potential implications of the water ingested and also the way to reduce the water intake of natural fibers. Natural fiber is becoming less preferred and unsuitable for outdoor applications due to its sensitivity to environmental deterioration after prolonged exposure. According to these investigations, combining natural and synthetic fibres may be the way to solve the issue however, as the name suggest; hybrid composite compose of different type of fibers. The arrangement of the fibers requires greater consideration since it might impact the characteristics of hybrid composites depending on where the fibers are placed inside the composites.

Polymeric composites not only will degrade upon mechanical force but can also be subjected to various environmental factors in real-life applications, including water, seawater or various liquids chemicals (Yousif et al., 2012). In humid environments or when immersed in water, all polymer composites absorb moisture to some degree due to the influence of humidity on their mechanical characteristics. This impact is influenced by a number of variables, including fiber type and matrix used, the fiber percentage, orientation, stacking order, and the size of the exposed surface. The mechanical and physical properties of composites are affected by environmental factors, according to all of the published studies, and the impact of water absorption is the major focus of these studies (Yousif et al., 2012; Lu et al., 2022; Moudood et al., 2017).

There are several works that has been reported regarding the water absorption behavior of natural fiber rather than hybrid laminated composites (Yousif et al., 2012;

Davies and Bruce, 1998; Huner, 2015). Thus, the present work provides results on the effect of water absorption towards the composite after immersion in different solutions. The nature of the real environments was expected to vary depending on the exposure circumstances. Microstructural details relating to the physical impact of the surroundings on the hybrid laminated composites were provided by SEM. Abd El-baky and Attia (2018) study found that the poor interfacial adhesion between fiber and the matrix brought on by water absorption would drastically affect the mechanical parameters such as tensile and flexural strength. Due to that, study of hybrid laminated composites in different pH medium is conducted to illustrate the behavior of hybrid flax/glass fiber laminated composites in different conditions. The purpose of this study is to observe the behaviour of hybrid composites when exposed to different solutions for 21 days. To compare the effect of water absorption, two different stacking of the same plies of fibers were fabricated.

1.3 Research Objectives

The study is aimed to achieve the objectives as follows:-

1) To study the moisture uptake of the hybrid laminated composite with the function of time after immersion in various solutions
2) To compare mechanical and physical properties of 9-ply GF and FF with different stacking sequences

1.4 Thesis Outline

This thesis is presented in 5 main chapters. In Chapter 1 presents about the introduction of composites and hybrid laminated composites in general. Some of the research background of the project also presented. Besides that, problem statements and objectives of the research are defined at the end of the chapter.

Chapter 2 consists of literature review related to the composites, laminated composites, natural and synthetic fiber, water absorption and their application. Method to produce hybrid laminated composite also considered. Literature review relates the investigation and finding of this project to the previous study which helps to understand and critically analyze the background research.

Chapter 3 is the methodology of the research project. This chapter covers the experimental process involves while completing the project. All procedures were recorded from obtaining the material until testing and characterization. Flow chart, pictures and illustration are provided for better understanding on the work process on the hybrid laminated composites. There are also equations used for data collection for the result analysis.

Chapter 4 covers all the result and findings after carrying out the experimental project. The result and data are discussed according to the problem statement and research objectives mentioned in Chapter 1. In this chapter, there are result to the testing performed to the hybrid laminated composite such as tensile test which provides stress-strain curve and Young’s modulus. Physical observations by using SEM also been conducted and analyzed in this chapter.

Chapter 5 is the last chapter which provides the conclusion of the project study and describes some idea and suggestions or improvement for future works in this field of work.

CHAPTER 2

LITERATURE REVIEW

2.1 Composite Materials

Composite consists of multiphase material, combination of two or more materials that exhibits a significant proportion of the properties of both constituent phases for a better combination of properties (Callister and Rethwisch, 2007). Usually, composite materials composed of a reinforced phase distributed in the matrix phase which is discrete or unconnected for the former and continuous phase for the latter. Though the concept of composites differs based on each author after the factors and considerations, composite allows to develop an infinite number of new material systems with unique features that are unlikely to be achieved with only single monolithic material (Zweben, 2015). In other definition from other author, composite must be meet these certain requirements includes must be made by man and have a suitable combination of diverse phases whether physical and/or chemical (Smith and Yeomans, 2011; Chawla, 2012; Otani *et al.*, 2014). Figure 2.1 shows the classification of composite materials where there are three categories of composite in general.

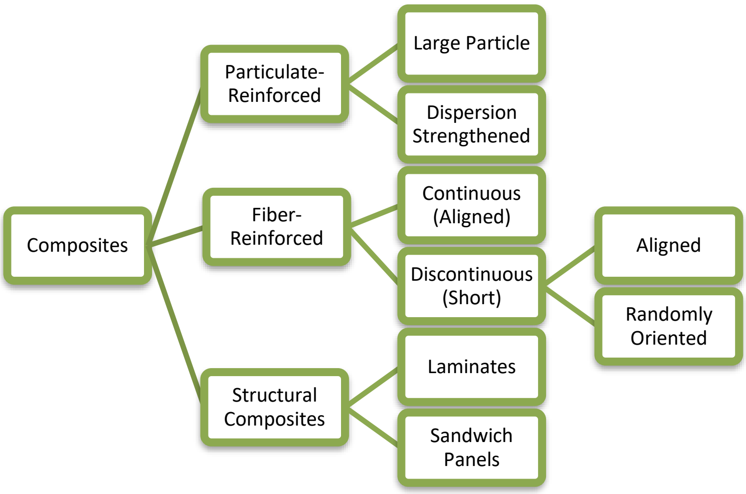


Figure 2.1 Classification of Composite Materials (Otani *et al.*, 2014)

To simply describe each of the categories, particulate-reinforcement composites, refers to a material that made up of particles embedded in a matrix. Particles can come in variety shapes, sizes and arrangement. The shapes are mainly come in spherical, irregular or ellipsoidal shape. Particles reinforced composite usually used in ceramic matrix composite (CMC) due to the particulates are utilised to improve the strength or other attributes of low-cost materials by combining them with other materials (Staab, 1999; Smith and Yeomans, 2011).

Fiber reinforcement were reported to have most significant changes in mechanical properties of the matrix material. Uni-axial, bi-directional in plane, multidirectional in plane, random planar, and three-dimensional continuous fiber reinforcement are the types of fiber reinforcement orientation. The length of fibers is substantially longer than its diameter. The aspect ratio refers to the length-to-diameter ratio, which can differ substantially. Long aspect ratios are seen in continuous fibres, while small aspect ratios are found in discontinuous fibres (Campbell, 2010). When stress is applied parallel to the fibre orientation, continuous fibre reinforcements would exhibit the greatest mechanical qualities of all the reinforcing kinds. Continuous fiber systems have a lot of anisotropy, which means that the characteristics along the fiber direction vary from the properties that were perpendicular to the fiber direction. This anisotropy can be highly useful in some applications and laminates composite consists of several layers of fibers at various angles can be introduced to obtain different isotropic behavior. When compared to non-woven equivalents, composites with plain weave reinforcement provide more processing flexibility particularly in terms of drape while sustaining appropriate mechanical properties. (Smith and Yeomans, 2011).

Structural composite can be represented in laminates or sandwich panels. A laminate is a one ply or lay-up where all of the layers or plies are placed in the same arrangement. The primary objective of laminate structure is to absorb low velocity impacts when load is exerted (Shyr and Pan, 2003). Sandwich panels as the name suggests, generally consists of outer skins and core layer whereby the outer layer are thin and the core has thick structure. The rigidity of such composites can be attributed to the core structure. Sandwich composites are lightweight and have a high strength and stiffness regardless the thickness of the core. The spatial structure of these composites has an impact on their thermal insulator characteristics (Krzyżak *et al.*, 2016).

2.2 Fundamental of Hybrid Composites

A hybrid composite is a polymer composite where the reinforcing material is integrated in a combination of several matrix' mixture, two or even more reinforcement and filler elements are present in a matrix, or both techniques are utilized. Usually, hybrid system is used in order to gives the composite better properties especially for increased strength and durability. The hybrid approach aims to acquire a favourable feature for a certain part, enhancing performance while reducing the structure's flaws. In addition, hybrid composites also help to lower the material and fabrication cost while maintaining the high strength and other mechanical performance comparable to the material with higher cost such as composites with synthetic material as their reinforcement. These composites provide a variety of qualities that are not possible to attain with just one type of reinforcement. Researchers have recently been explored by the utilization of various reinforcing fibres in composites to modify their mechanical characteristics. Table 2.1 and Table 2.2 show the comparison of mechanical properties of several natural fibers and synthetic fibers respectively.

Table 2.1 Comparison of mechanical properties of natural fibers (Spārniņš, 2009)

Fiber	**Density (g/cm^3)**	**Young's Modulus (GPa)**	**Strength (MPa)**	**Specific Modulus**	**Specific Strength**
Flax	1.4-1.5	50-70	500-900	~41	~480
Hemp	1.48	30-60	300-800	~30	~370
Jute	1.3-1.5	20-55	200-500	~27	~250

Table 2.2 Comparison of mechanical properties of synthetic fiber (Li et al., 2007)

Fiber	**Density (g/cm^3)**	**Elongation (%)**	**Tensile strength (MPa)**	**Young's modulus (GPa)**
E-glass	2.5	2.5–3.0	2,000–3,500	70
S-glass	2.5	2.8	4,570	86
Aramide	1.4	3.0–3.7	3,000–3,150	63–67
Carbon	1.4	1.4–1.8	4,000	230–240

To highlight the comparison between natural and glass fibers are natural fiber reinforced polymer has better advantages at technological field as it has good processing and machining properties compared to glass fibers. Most of natural fibers has low density as shown in Table 2.1 where the density ranging 1.3 to 1.5 g/cm^3 and they are much lighter than glass fibers. In addition, natural fibres have benefits over glass fibers in terms of ecological assessment and eco-balance. Since natural fiber is plant-based fiber, therefore the energy needed to produce a natural fiber mat include cultivation, harversting and fiber digestion process is much lower than energy consumed during producing glass fiber mat. In all, both of the fibers are used to identify the mechanical properties of flax and glass fibers.

There are several combinations of orientation of reinforcement material in composites:

i. Unidirectional
ii. 0°/90° orientation (woven, stitched or hybrid)
iii. Random orientation

The laminates analysis will be considered first, which consider for a unidirectional ply and next for plies placed at angle to the loading axis. Following the identification of laminates properties, classical lamination theory may be utilized to determine laminates behavior to the external loads and moments. The focus will be on in-plane loading due to laminate composites are generally thin in comparison to their length and width when there are put in plane stress conditions.

In a hybrid laminated composite for instance combination of flax fibers (natural fibers) and glass fibers (synthetic fibers) would have a possible orientation at angle of [0°f, ±45°g, $\overline{90}$ °f]s where f stands for flax and g indicates glass fibers. The bar above the 90° ply denotes that the symmetry centerline runs halfway through the layer. This laminate might be described as [0°f, 45°g, -45°g, 90°f, -45°g, 45°g, 0°f] in extended form.

Other than that, some notations also be used such as 0_3°, which showing that the balanced and symmetric laminate of [0_3°, ±45°, 90°]s. This also means that there are three at angle of 0° plies that were lumped together. For example, [0°, 0°, 0°, 45°, –45°, 90°, 90°, –45°, 45°, 0°, 0°, 0°]. Meanwhile, designation of [±45°]$_{2s}$ means that the 45° grouping is repeated twice on either side of the symmetry centre, hence [45°, –45°, 45°,

–45°, –45°, 45°, –45°, 45°]. The failure in laminated composite are shown when load is applied to their breaking point. Though during failure, the plies are not damaged simultaneously. Figure 2.2 shows the progressive plies failure in [0°/45°/90°/–45°]s laminates. From the graph, the laminates will fail according to the amount of strength it can sustain in the loading direction. The transverse direction plies will experience breaking prior to the unidirectional plies due to the transverse strength of the longitudinal direction laminates are higher than the unidirectional laminates. Failure of the 90 ° plies is usually followed by failure of other off-angle plies, such as 45°, and lastly failure of the far more powerful zero-degree plies. Although a conservative design specifications, the causes of first ply failure is frequently utilized in the aerospace industry to detect laminate failure.

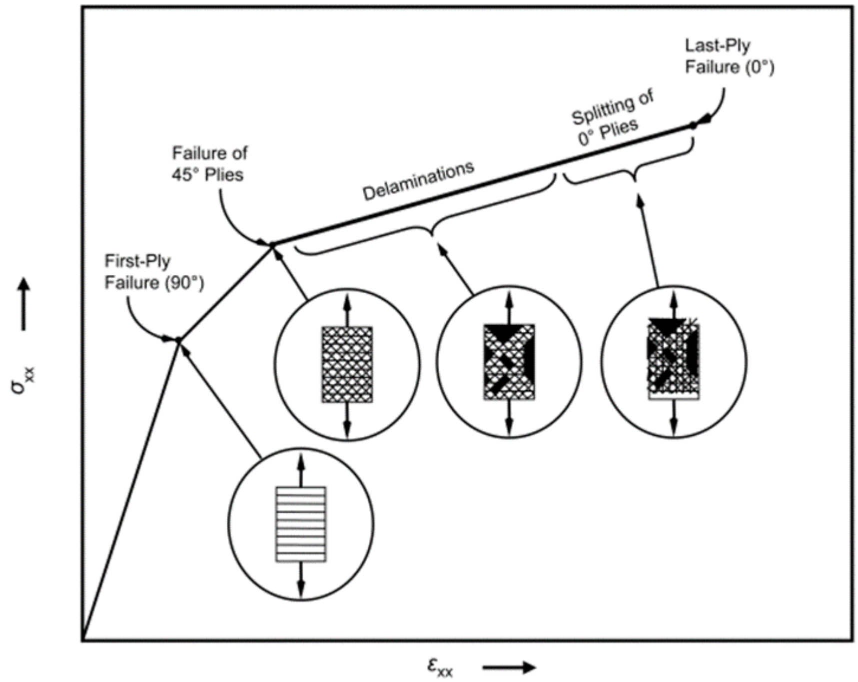
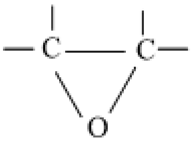


Figure 2.2 Stages ply failure for a [0°/45°/90°/-45°]s laminated composite (Campbell, 2010)

2.3 Material Overview

2.3.1 Epoxy Resin

Epoxy resin is the most utilized thermosetting polymer in a wide range of applications. For instance, epoxy resin is utilized as a matrix phase in carbon-fiber composites for aircraft constructions, as well as an adhesives in aircraft structural connections and maintenance. They exhibit a great mix of strength, adhesion, minimal shrinkage, and processing flexibility. Epoxy resin is chemical product with two or more epoxide groups per monomer and tightly packed oxirane ring structure which is the site of crosslinking (Campbell, 2010). The hardener opens the C—O—C rings during polymerisation, rearranging the links to unite the monomers into a three-dimensional network of crosslinked chain-like molecules.



Typically most commercial epoxy matrix and adhesives have two main epoxy, one to three minor epoxies, and one or two curing agents (Campbell, 2010). These epoxies has their own function such as the minor epoxies used to increase toughness, allow the control of epoxy's viscosity, to lower the likelihood of moisture absorption and impart higher elevated temperature properties. The main major epoxies known as diglycidyl ether of Bisphenol A (DGEBA) and tetraglycidyl methylene dianiline (TGMDA) also can be named as tetraglycidyl-4-40-diaminodiphenylmethane (TGGDM) which generally used for adhesives, pultrusion and filament winding applications for the former and used as commercial composite matrix for the latter. Figure 2.3 and 2.4 below show the typical chemical structure of the main major epoxies.

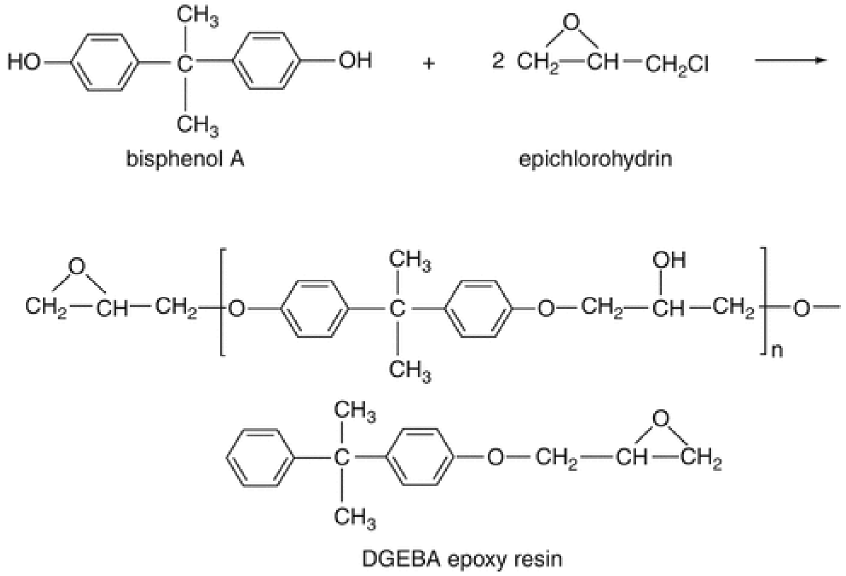


Figure 2.3 Structure of diglycidyl ether of Bisphenol A (DGEBA) (Nixon et al., 2012)

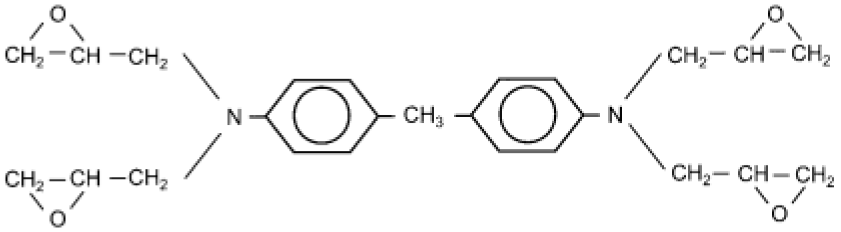


Figure 2.4 Structure of tetraglycidyl methylene dianiline (TGMDA) (Campbell, 2010)

The breakdown of the oxirane ring and crosslinking with the curing agent are used to cure epoxy resins. Therefore, due to the epoxide group has an unfavourable bond angle, it is chemically react with a wide range of chemicals that may easily open the ring and generate a strongly crosslinked structure (Hodd, 1989). The efficiency with which the curing response may be tailored to the fabrication process. Thus, the exothermic curing reaction can be generated at ambient or increased temperatures, or it can be triggered by UV radiation in the presence of suitable catalysts. The correct mixture of resin, curing agent, and/or hardener determines the particular curing technique necessary to create a cured resin with improved performance characteristics (Hodd, 1989).

According to Abdellaoui et al., (2019), epoxy resin can possess a good matrix and adhesion on various type of materials. In overall of the mechanical characteristic such as tensile strength, compression strength and flexural strength of epoxies are much better than polyester resin. Apart from the good mechanical properties, epoxy also appear to have good physical properties and have outstanding chemical resistance. Epoxy resin has lower shrinkage at 1% compared to polyester with 6% of shrinkage which making epoxy to maintain their mechanical properties better. However, epoxy resin also has their shortcomings as the resin is costly due to the fact that the raw ingredients necessary for manufacture are much more expensive than other low-end resins and the manufacturing process is complex with a limited tolerance for mistakes. When epoxy was used as a product, it is susceptible to cracking because it becomes brittle upon curing. Another downside of epoxy resin is it has strict condition of use because temperature and moisture can highly affect the matrix (Zweben, 2015). Table 2.3 below shows the general mechanical properties of epoxy resin.

Table 2.3 Mechanical properties of epoxy resin (Abdellaoui et al., 2019)

Properties	**Value**
Density	1100 – 1500 kg/m^3
Modulus of elasticity in adhesion	30 – 50 GPa
Bending failure stress	100 - 150 MPa
Elongation at break	2 – 5%
Shear strength	30 – 50 MPa
Breaking stress	60 – 80 MPa

2.3.2 Glass Fiber

Glass fibers come in a variety of types, but the three most frequent in composites are E-glass, S2 glass, and quartz. The most popular and least costly is E-glass, which offers a nice combination of tensile strength of 3.5 GPa and modulus of 70 GPa (Campbell, 2010; Singh *et al.*, 2016). Because the letter "E" stands for electrical, E-glass is typically employed in electrical insulation applications. Glass fibre may be recycled and reused in the future to lower product cost and improve the quality of specific goods. On the other hand, S-glass, with a tensile strength of 4.5 GPa and a modulus of 86 GPa, is more costly than E-glass, but it is 40% stronger and keeps a higher proportion of its strength at higher temperatures (Campbell, 2010). Glass fibers generally has good durability in extreme conditions and are commonly utilised as reinforcing in laminates to increase their impact resistance. (Shyr and Pan, 2003; da Silva *et al.*, 2021). The mechanical and chemical stability of the matrix–reinforcement interaction has been studied intensively. The kind of glass fiber, reinforcement, and bonding agent all have an influence on the interfacial stability of composite. E-glass fiber has a high density and elongation, giving it outstanding elastic strength and the low Young's modulus ensures resistance to failure (Singh *et al.*, 2016). Due of its low cost, chemical resistance, non-flammability, and high manufacturing rate, commercial E-glass is becomes one of top choice to be used in wide range of applications.

2.3.3 Flax Fiber

Polymers such as cellulose, hemicelluloses, lignin, and pectin are the primary elements in the composition of plant fibres. Plants such as flax (see Figure 2.5) and hemp provide the strongest and stiffest natural fibers; they also have some elementary fibres which bonded along by central lamella, primarily made of pectin. The elementary fibers can have the length in range of 2 cm to 5 cm and their diameter is in between 10 to 25 cm (Papa *et al.*, 2020).

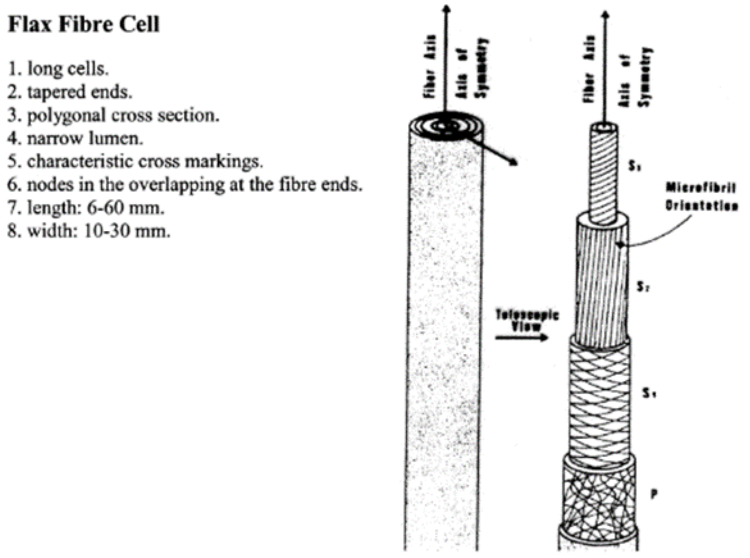


Figure 2.5 Structure of Flax fiber cell (Stamboulis et al., 2001)

The elementary fiber that are made if pectin primarily consists of crystalline cellulose fibrils that are oriented at angle ±10° with the axis of fiber and amorphous hemicellulose. This orientation will contribute to its tensile strength. When flax is compared to synthetic fibers such as glass or aramid, they would have a lower density and high specific stiffness, and they have the ability to reinforce polymers (Spārniņš, 2009; Moudood *et al.*, 2019). Recent research has revealed a growing demand for flax composites in a range of industries. Sandwich panels to replace hardwood fittings and furniture, and to reduce component bulk and boost sound absorption capabilities in automotive parts, rather than tubing encased concrete as bridge pier, are only a few of the most common current uses (Stamboulis et al., 2001; Spārniņš, 2009; Papa et al., 2020).

According to several research, elementary flax fibers are significantly stronger than technical fibers (Hornsby et al., 1997). Natural fibers such as flax and nettle has been tested at single gauge length and the Weibull distribution is shown to be appropriate to the approximate strength distribution of natural fibres (Baley, 2002; Bos et al., 2002; Joffe et al., 2003; Davies and Bruce, 2016). The stress-strain response is reported to be nonlinear (Hornsby et al., 1997; Baley, 2002). Rearrangement of the cellulose fibrils in the direction of the fiber (loading) axis shows a high level in Young's modulus with strain. It has been demonstrated through fatigue experiments that this impact is irreversible (Baley, 2002). To summarize, research shows that flax fibres have the greatest potential to have good performance for polymer composites applications.

2.4 Composite Preparation

Fabricating hybrid laminated composite materials were done using some approaches. The following are some of the most typical processing techniques for thermosetting-based polymer composites.

2.4.1 Hand Lay-up

Hand lay-up method is the traditional approach of composite manufacturing which also made most common method form composites (Raji *et al.,* 2019). Since the process method is simple, has a minimal production start-up time and inexpensive equipment costs, and is very suitable for producing large product. After pouring a resin, reinforcing materials such as woven glass fiber, polymeric, or natural fibers are manually placed into the open molds. Prior to that, to prevent polymer from adhering to the surface, the surface is coated with a release anti adhesive agent (Kornmann *et al.*, 2005). The resin is mixed with harder or catalyst at the right ratio. After that, a thin plastic layer is put to the top and bottom of the mold plate to get a smooth finish. The woven reinforcing layers are cut to the desired shapes and size then put on the mold's surface. As previously stated, the resin was combined with other materials and infused onto the surface of the fiber that had already been placed in the mold, using an assist brush or roller to spread it evenly. The fiber was placed one by one along with sufficient amount of epoxy. To remove any trapped air and excessive resin, the material is squeezed with a hand roller (Alam et al., 2014; Raji *et al.*, 2019). Theoretically, after making sure the laminates were properly compressed, the mold is closed and let it cures at room temperature before removing them (Raji *et al.*, 2019).

On the other hand, this traditional approach has several limits in terms of product quality and structure. To achieve a good performance of laminated composite, the amount of void must be minimum. Therefore, it is critical to ensure the resin were properly mixed, the properties of resin such as the gel time and the resin were distributed uniformly on the reinforcement fiber. The good laminate is typically manufactured by including a low number of voids (Jamir et al., 2018). Since hand lay-up resins contain smaller molecular weights, they have the potential to be more damaging than larger molecular weight compounds. The resins decreased viscosity also means that they have a higher tendency for penetrating fibres mat. To be manageable by hand, resins for hand lay-up method must have a low viscosity (Campbell, 2010). Furthermore, the processing method has a significant impact on the amount of fibre loading. This is also impacted by the fibres' physical properties, which include intra-fiber spaces known as lumens (Jamir et al., 2018).

2.4.2 Vacuum Bagging

Vacuum bagging always come together after hand lay-up technique for creating laminated composite product. Vacuum bagging has limited application especially in automotive sector due to it is a labor intensive procedure with a long cycle durations. It has mostly been used to make prototype automotive composite parts, but it might also be utilised to make major components like roof panels and floor pans in the future, especially if a laminated structure is employed and the production volume is low (Mallick, 2021). Vacuum bagging makes hand lay-up easier while also providing a component with improved characteristics due to its compaction. When a laminate is vacuum bagged, air gaps are removed. Overall, it's an excellent method for enhancing the composite laminate. According to Campbell (2010), after the composite has already anti-adhesive flexible sheet is added to the composite after it has been formed into its mold, and then a mild vacuum is created at suitable pressure. Figure 2.6 shows the basic set up of vacuum bagging process.

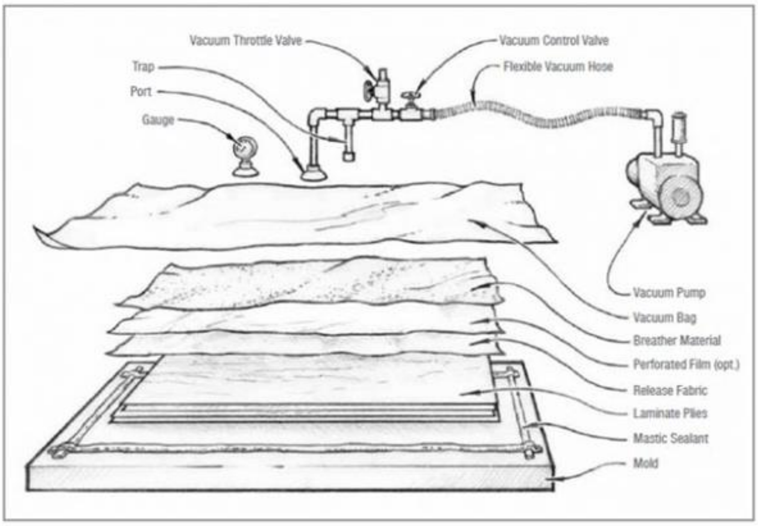


Figure 2.6 Schematic diagram of vacuum bagging setup (Geerts, 2019)

Vacuum bagging process also possess of few advantages and disadvantages. After the composite has been manufactured, the possibility for the composite to have a good and fine surface are high due to the ease to remove air bubbles and porosity by vacuuming the air out. In addition, the curing process also indirectly can be accelerated by heated oven after vacuum bagging. However, the downside of this process are they are complex process as it require extra cost to invest on vacuum machine. Other than that, the set up material of vacuum bagging such as vacuum bag, breather and size of mold need to be customized according to each product (Geerts, 2019).

2.5 Potential Applications

Polymer matrix composites has a wide range of applications including transportation, structural, aerospace, marine and sports goods. Typically, high-performance but more expensive continuous carbon fiber composites are utilized in demanding applications that need high mechanical strength as well as low weight, whereas far less expensive fiber glass composites are employed in less demanding applications where weight is not as important consideration. The differential in coefficient of expansion between the fiber and the matrix makes composite materials sensitive to weathering and residual stress. Thermoset polymeric matrix composites may effectively replace steel and concrete in structural construction projects, with they possess having higher oxidation resistance and having better freeze thaw resistance. This characteristic might lead to structural components that are more resistant to degradation.

Natural fibre composites have traditionally been used only for non-structural or non-critical products. As for natural fiber composite applications are rather focused on the automotive market rather than the aviation sector. In general, no study has been done on the use of natural fibres as one of the principal reinforcements for aviation components. Limited impact resistance and moisture deterioration of natural fibers during composites production or end of product service use are the primary reasons for the low market response for natural fibres in aircraft industries Natural fibers becomes unfavourable for fabrication of aircraft components due to they have lower heat resistance and their sensitivity towards exposure to the moisture. This behaviour could lead to lower strength specifically in impact strength. There also not enough research on the usage of natural fiber in aviation applications.

In polymer composite field, natural fiber composited are typically compared with glass fiber reinforced composites from the same type in term of fabrication method, type of fibers, matrix and orientation. Density of the fiber reinforcement must be taken into consideration as it contributes to the behavior of the fiber composites. Natural fiber is proven to have a relatively high specific stiffness and fair tensile strength (Oksman, 2000; Wambua et al., 2003). Nevertheless, the impact strength for natural fiber composite seems to be at disadvantage (den Oever et al., 2000; Oksman, 2000). To overcome that, the impact strength can be improved through adhesion Gassan & Bledzki, 2000). Natural fiber composite also has a smaller flexural strength than glass fiber reinforced polymer (den Oever et al., 2000). Among all the common used natural fiber, flax fiber has the best properties and it can match alongside E-glass reinforced polymer composite in high stiffness structure, though these materials need to be developed further for strength and impact specialized applications. As mentioned above, flax and banana fibers has been used in automotive industry such as disk brakes instead of using asbestos fibers shows that there is a chance for natural fibers to be used in wide range of application. (de Bruijn, 2000; Spārniņš, 2009).

2.5.1 Issues on Laminated Composite in Applications

Delaminations (ply separations) in composites can occur during manufacture, assembling, and service. Foreign elements, such as prepreg backing paper, contaminates like dust might be accidentally left in the lay-up during production. Delaminations can occur during production due to poor part handling or wrongly fitted fasteners. Low-velocity impact damage from fallen tools or forklifts colliding with aircraft can cause damage while in service. Although the damage may look as a minor indentation on the surface, it can spread into the laminates, resulting in a complicated network of delaminations and matrix cracks. The static and fatigue strength, as well as the compression buckling strength, might be reduced depending on the size of the delamination. It can develop under fatigue loading if it is large enough. The use of a hardened resin can help to enhance impact resistance notably (Spārniņš, 2009).

2.6 Water Absorption of Polymer Composites

Depending on the particular material system and the particular environment, composites may or may not degrade when exposed to different environmental conditions. When environmental deterioration does happen, the matrix is often but not always the objective. Composites that exposed to different conditions may result in varied degrees of performance degradation. Moisture absorption in polymeric matrix composites is a major problem since water is always in presence (Campbell, 2010).

The composites deterioration may be induced by the environmental conditions according to their material system and the surrounding. The matrix of the composites is frequently impacted by the environmental deterioration. Fluids, temperature, UV radiation, heat damage are among probable degradation conditions that can lower the performance of composites but in this study, moisture uptake of the polymer composite is the main concern. Moisture absorption in polymer composites has becomes a major issue since water in surrounding would always exists. As we all know, there are presence of air and moisture around us at all time and most conditions. When immersed in water or exposed to a humid atmosphere, all forms of polymer composites will absorb moisture to some level. Polymeric composites will have different degradation mechanism when subjected to a various type of environmental factors in real-world applications, such as immersion in water, salt water, and/or other chemical liquids (Yousif et al., 2012).

In the composite system, the polymer matrix and the reinforcement, particularly natural fibers has the ability to absorb water. This is specifically because natural fibres are more hydrophilic than synthetic fibres, making them more vulnerable to water absorption and producing volatility in the characteristics of composites. There are three main potential ways for moisture to get into composite materials, including the migration of water molecules into the microscopic spaces between polymer strands. In addition, the capillary movement liquid water into the cracks and crevices at the fiber-polymer contacts as a result of insufficient wettability and impregnation. Lastly, diffusion via matrix microcracks created during compounding (Nosbi et al., 2010). The properties of matrix in composite materials will change in some ways when it were exposed to the moisture. The composites will absorbs moisture through method as follows (Figure 2.7):

i. As water damages the matrix, the properties of the matrix that are affected by high temperatures (the hot-wet state) are the ones that are most directly impacted. Almost all laminates are degraded to some degree since actual laminates used in constructions often feature 40 to 50 percent off-axis plies.

ii. Water expands when it solidifies, therefore if water vapour or liquid is caught in microcracks or delaminations, it can grow and produce bigger macrocracks or delaminations when the composite is in frozen and thawed cycles.

iii. Due to water or humidity absorption, it can cause the composite to expand, causing stresses in the thickness direction and causing warpage.

iv. The plasticizing influence of moisture in adhesives, particularly untoughened adhesives, can certainly be useful since the bonding becomes more flexible and tolerant.

v. When doing high-temperature repairs, absorbed moisture might be a problem. Moisture can impede the repair patch or adhesive from curing properly, or, if present in large enough quantities during high-temperature cures, it can cause steam pressure delamination. As a result, items that will be repaired using high-temperature bonding should always be properly dried before being heated.