

2 DIMENSION WOVEN KENAF UNSATURATED POLYESTER COMPOSITE

MOHD PAHMI BIN SAIMAN

A thesis submitted in
fulfilment of the requirement for the award of the
Doctor of Philosophy

Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia

AUGUST 2014

ABSTRACT

In recent years, natural fiber from vegetables such as hemp, sisal, ramie, jute and kenaf has been recognized and studied by many researchers due to its potential as an alternative material for synthetic fibers in composite application. Kenaf fiber is a potential reinforced material for composite due to its acceptable properties and supported by the development in Malaysian Kenaf cultivation. Previous studies have demonstrated that Kenaf fibers were recognized in several applications such as automotive component, panel board, packaging, filter material and industrial paper. However, the reinforcement of the fibers is in random, unidirectional and particle form. Therefore, this research is focusing on the composites woven structural preform from the kenaf fiber assisted with the use of internal geometry modeling for optimization. The effect of primary parameters, which are the yarns properties, the fabric count and the weave designs were evaluated on its physical and mechanical properties. Different woven design preform (plain, twill 4/4, satin 8/3 and basket 4/4) were fabricated using floor loom and infused with unsaturated polyester resin using vacuum infusion process. The mechanical properties of the composites were measured and showed that satin 8/3 has highest tensile strength of 39MPa and Plain has highest tensile modulus of 2.63GPa, with flexural strength and impact strength of 48MPa and 29kJ/m² respectively. The use of VIP and UPE show a good infusion of resin between intra yarns but need much lower viscosity on the UPE for inter yarns. The use of 5% sodium hydroxide solution with the application of tension during the treatment enhanced the composite strength of 12%. The stacking sequence and orientation of 0°,45°,0° of the laminate composite had increased the flexural strength and impact strength of 73MPa and of 82MPa respectively. It is recommended to use a plain and satin structure for better infusion in vacuum infusion process.

ABSTRAK

Beberapa tahun kebelakangan ini, serat semulajadi dari tumbuhan seperti hemp, sisal, rami, jut dan kenaf telah diiktiraf dan menjadi bahan kajian oleh ramai penyelidik kerana kemampuannya sebagai bahan alternatif serat sintetik dalam aplikasi komposit. Serat kenaf merupakan bahan berpotensi untuk digunakan sebagai pengukuh komposit kerana sifatnya yang boleh diterima dan disokong oleh pembangunan penanaman Kenaf di Malaysia. Kajian terdahulu menunjukkan serat kenaf dikenali dalam beberapa aplikasi seperti komponen automotif, papan panel, pembungkusan, bahan penapis dan kertas industri. Namun begitu, serat pengukuh berbentuk rawak, satu arah, dan partikal. Oleh itu, kajian ini memberi tumpuan kepada prabentuk struktur tenunan kering daripada serat kenaf dibantu dengan penggunaan pemodelan geometri dalaman sebagai pengoptimuman. Kesan parameter utama iaitu sifat yan, ketumpatan fabrik dan rekaan tenun dinilai pada sifat fizikal dan mekanikal. Rekaan tenunan berbeza (plain, twill4/4, satin8/3 dan basket4/4) dihasilkan menggunakan mesin tenun lantai dan melalui pengisian resin poliester tak tepu menggunakan proses infusi vakum. Sifat mekanikal komposit dinilai dan didapati satin 8/3 mempunyai kekuatan tegangan pada 39MPa dan Plain mempunyai modulus tegangan 2.63GPa, kekuatan lenturan pada 48MPa dan kekuatan impak pada 29kJ/m². Penggunaan proses infusi vakum menunjukkan infusi yang baik diantara yan tetapi memerlukan poliester tak tepu yang lebih rendah kelikatannya untuk antara serat. Penggunaan larutan 5% sodium hidroksida dengan aplikasi tegangan semasa rawatan meningkatkan kekuatan komposit sebanyak 12%. Urutan susunan dan orientasi 0°,45°,0° komposit lamina dapat meningkatkan kekuatan lenturan dan kekuatan impak masing-masing pada 73MPa dan 82MPa. Adalah dicadangkan untuk menggunakan struktur plain dan satin untuk infusi yang lebih baik menggunakan kaedah proses infusi vakum.

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LIST OF SYMBOLS AND ABBREVIATIONS

| | | |
|-----------|---|------------------------------------|
| 2D | - | 2 dimension |
| d | - | Diameter |
| V_f | - | Fibre volume fraction |
| N_f | - | Numbers of fibers |
| W_{t_f} | - | Weight fibre fraction |
| f_{wa} | - | The number of warp intersections |
| f_{we} | - | The number of weft intersections |
| L, l | - | Length |
| P | - | Actual length of the yarn |
| n | - | Fabric ply number in the composite |
| m | - | Areal density |
| ρ | - | Density |
| h | - | Thickness |
| P | - | Tension curve |
| F_x | - | Force acting in warp direction |
| F_y | - | Force acting in weft direction |
| γ | - | Shear angle |
| N_e | - | English cotton count |
| NaOH | - | Sodium hydroxide |
| MEKP | - | Methyl ethyl ketone peroxide |
| FRP | - | Fibre reinforced polymer |
| LCM | - | Liquid composite moulding |
| UPE | - | Unsaturated polyester |
| VIP | - | Vacuum Infusion Process |
| VOC | - | Volatile organic compounds |

| | | |
|------|---|--|
| RTM | - | Resin transfer moulding |
| SEM | - | Scanning Electron Microscope |
| ASTM | - | American Society for Testing and Materials |
| CSM | - | Chopped strand mat |

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Currently, the use of natural based composite has significant potential for positive environment outcome. Conventional synthetic materials are excellent for their physical and mechanical properties but these fibres have serious drawbacks such as not being non-renewable, non-recyclable, high energy consumption during the manufacturing process, health risk and non-biodegradable [1]. Due to these issues, the composite industry consisting of natural based composites began to show concern when green advantages (renewability and biodegradability) of natural based composites became an important criteria and top-end mechanical properties were not the primary motivation [2]. Although natural fibres can be used as a green substitute, properties like low density are known for its suitability for use in lightweight structures. In most cases, natural fibres are cheaper compared to synthetic fibres and pose less health problems. Therefore, the interest in the use of natural fibres as reinforcement for polymeric matrix composite has attracted attention from the engineering, automotive and consumer sectors.

Generally, there is a broad range of natural fibres that mainly originate from vegetable, animal and mineral fibres. Most fibres that are considered natural fibre composites are vegetables bast fibres that have inherit good mechanical properties due to its cells or groups of cells that are designed for strength and stiffness [3]. This includes the Kenaf bast fibre, which is an annual crop that is native to Africa. It has been identified as a potential alternative crop to be grown in Malaysia due to its

industrial value and this would have an economic impact on farmers. Traditionally, Kenaf fibers were used in products, such as ropes, twine and burlap but studies have shown that it is capable of being an industrial material. At present, most of the Kenaf fibres produced are reinforced material for composites that are in form of random short fibres. It is well known as a raw material in fibre reinforced polymer composites and is already adopted as automobile parts due to its lightweight and mechanical properties [4]. However, there is no indication that the emphasis on structural reinforced material has been highlighted.

A structural reinforced material in composite can be classified as a 2Dimensional (2D) and 3Dimensional (3D) textile preform. It can be defined through the in-plane thickness where 2D preform is a single layer thickness while 3D is discrete layers stacked at a desired thickness with interlock system. However, at the moment 2D is more demanding due to its low cost production. A 2D woven Kenaf as a structural reinforced material for natural based composites in its area of study has yet to be explored although some work on natural fibres such as flax [5], hemp [6-8] and jute [5-9] have already been published. The application of 2D woven is a structural reinforcement with bidirectional orientation to provide greater strength and stiffness depending on the fabric architecture [10]. Traditionally, the woven structural composites were used in high-end applications such as aerospace, automotive, energy and civil constructions. These structural woven composites have potential demand due to the material's greater stiffness and strength yet being lighter in the field. The construction of the woven structure has gained attention as it offers flexible designs with greater advantage during fabrication and performances. The fabrication with polymers using different processing techniques generates different properties for the suitability of application. Reports indicate that some of the properties have shown to be comparable or even better than glass fibres such as; specific modulus [11], energy production [6, 12], low cost [13] and processing flexibility [14].

The development of 2D woven Kenaf composite can be seen as an attempt to decrease the dependence on synthetic fibres in composites and increase the usability of kenaf-based products. This leads to the need for investigations on the structural architecture of the dry preform and fabrication technique to optimize the performance of the composite.

1.2 Problem statement

In order to prepare natural fibres as engineering materials for composites, many researchers have attempted different kinds of techniques. Natural fibres can be produced as reinforced material in different ways such as particle, randomly oriented fibres, structural, laminate, etc. There have been previous studies on Kenaf fibres, particularly in form of random fibres and unidirectional [4, 15-18]. Composites made from random fibres have strengths in all possible directions but not as strong or as stiff as unidirectional or bidirectional woven reinforced composites [19]. When in the form of unidirectional structure, the strength is characterised in one direction but weak in the transverse direction. In order to gain balanced mechanical properties, the structural woven composite is found to have advantages in terms of mechanical properties in biaxial way.

However, to produce a woven fabric made from natural fibre to be used as reinforcement materials and matching it with polymer matrix involves the consideration of several basic concepts. Many studies on the structurally natural based woven composites have neglected the basic formation of the reinforced structure that would affect the mechanical and physical properties of the composites. The studies had focused on the fibres while ignoring the basis of the structure such as the fabric count, yarn linear density and weave design. This is important as the structure of the woven itself has its own weakness such as the waviness of yarn crimps or the degree of bending occurring due to the interlacement between yarns. Hence, higher crimp produces stiffer fabrics with poor drapeability and reduces the fibre's load bearing capability [20].

Therefore, the emphasis on the structural formation of the dry fabric or dry preform will determine the ability towards the processing methods, the effectiveness of the matrix and the composite itself. The processing method such as hand lay-up, compression and closed mould have been used in the fabrication of natural based composite. However, the condition of the twisted continuous strand in a biaxial weave preform require well-suited matrix material and processing methods to produce a good composite This is important as it involves in the wetting process, impregnation and penetration between inter and intra yarn. Information on it was not well established in previous studies.

In addition, Kenaf fibres or *lignocellulosics* are agro-based materials that contain cellulose, hemicelluloses and lignin and it needs adaptation to make it compatible with the process of making composites. Therefore, due to its native properties, the typical problems are the lack of good interfacial adhesion, low degradation temperature and poor resistance towards moisture that makes it less attractive than synthetic fibre, which has been up until now the only choice for reinforcing polymeric composites due to their superior mechanical properties [6]. Previous studies have shown significant improvement in the mechanical properties as shown in the treatment of random fibres. This could indicate that there are several techniques that can be used to improve the properties of a Kenaf woven composite.

Several investigators have used different kinds of technique in structural composite to enhance the mechanical properties of the composites and one of it is laminate technique. It is a popular technique due to their low cost, high strength and stiffness to density ratio [21]. Applying it in structural composite depends on several factors such as fibers, matrix and the interface [22]. Others factors may influence on the properties are the stacking sequence and the angles which might increase or decrease the mechanical properties of the composites. However, the suitability to apply it in kenaf structural reinforced material needs to be studied.

Therefore, from the best of the author's knowledge, no study has reported on 2D woven Kenaf composites in terms of structure and the processing technique. Therefore, this study is focusing on the parameters of the 2D woven kenaf structure formation with different design processing techniques to enhance the mechanical properties of the composite.

1.3 Objectives

The aim of the research is to develop a composite made from 2D woven kenaf fibres impregnated with unsaturated polyester using the Vacuum Infusion Process (VIP). This will be completed with the following objectives:

1. To investigate the dry woven Kenaf preform primary parameters (yarn linear densities, fabric count and weave design) using internal geometrical modelling.
2. To investigate the fabrication method using unsaturated polyester impregnated with Vacuum Infusion Process (VIP).
3. To analyse and evaluate the effect of woven design parameters using sodium hydroxide treatment and stacking sequence on the mechanical properties of composites using the experimental method.

1.4 Scope and limitations

The scope of the study is to develop a natural-based composite in the form of a structurally reinforced woven polymer matrix. The study will include the use of internal geometric modelling software to predict and analyse the dry fabric and the composite. The experiment will focus on the processing method in the fabrication of naturally based woven fabrics with polymer matrix to gain the results in terms of mechanical properties. The study involves kenaf fibres with unsaturated polyester resin and infused into a composite using vacuum infusion. The experiment will look at the woven fabric structure, treatment and laminating composites in identifying the mechanical properties.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter introduces and elaborates the background of composites, especially focusing on reinforced fibres, polymer matrix and the use natural fibres as reinforced material. The emphasis was given towards kenaf fibres, focusing on the properties and the development in the area of natural based composites. Certain techniques were introduced in this chapter related to the enhancement of mechanical properties against the dry preform and composite. The selection of the polymer resin and the appropriate processing method has been described based on the relevance of the composite fabrication.

2.2 Polymer matrix composites

Polymer matrix composite (PMC) is a composite consisting of a polymer thermoplastic or thermosetting reinforced by fibres [23]. The reinforced material provides the mechanical and physical properties as a load barrier. The matrix plays the role of protecting the fibres against environmental degradation and mechanical damage, but the main purpose is to hold the fibres together and transfer the loads on it.

PMC can be classified according to the geometry of the reinforcement or by the use of matrix materials as illustrated in Figure 2.1. The form of reinforcement and the arrangement usually shows anisotropy properties (directionally dependent)

because of the distinctive properties of the constituents and the non-homogeneous or textured distribution of the reinforcement. However, it can be isotropic when the reinforcement becomes smaller in size and randomly oriented [20]. PMC can further sub-divide according to the matrix, which is thermoplastic and thermosetting. Commonly, the main difference between thermoplastic and thermosetting is that thermoplastic can be re-melted and recycled. Thermosetting polymer is typically cured and moulded into shaped which is difficult to be recycled.

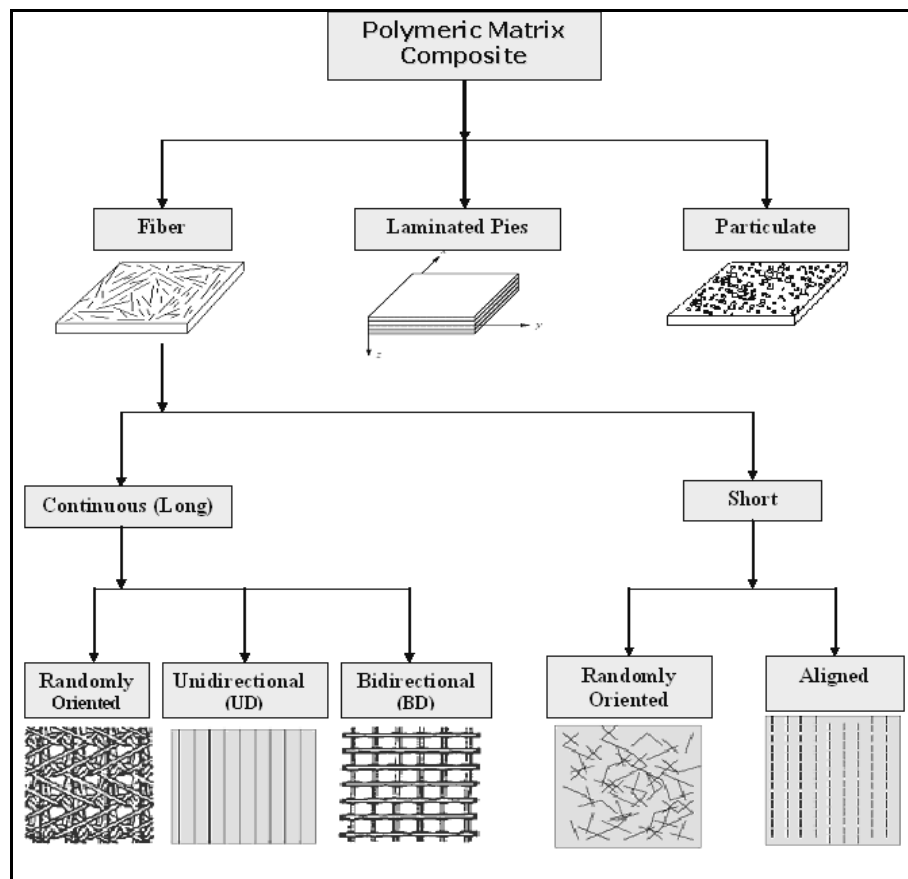


Figure 2.1: Classification of PMC composites [24].

The properties of fibre reinforced polymer (FRP) composite are usually compared based on the mechanical properties of strength and stiffness. The high strength and stiffness of the reinforced fibres make them desirable materials for use in many applications [25]. Apart from the transfer matrix to reinforcement, the strength and stiffness has also been determined along fibre direction and transverses the fibre direction [20]. Nevertheless, the matrix properties can also be considered as

it determines the resistance of the composites that may cause the failure of the structure. Table 2.1 shows the general characteristics of the polymer matrix. However, failure or fracture during servicing might occur, which is affected by the following variables: (a) type of fibre and fibre assembly construction; (b) type of matrix; (c) fibre-matrix interfacial bond strength and toughness; (d) fibre orientation and ply stacking sequence; (e) presence of flaws or discontinuities; (f) mode and rate of loading, and (g) environment (heat, moisture, chemicals) [26].

Table 2.1: Comparison between Thermosetting and Thermoplastic matrix [27].

| Resin Type | Process temperature | Process time | Use temperature | Solvent resistance | Toughness |
|---|---------------------|------------------|------------------|--------------------|------------------|
| Thermoset Toughened Thermoset Lightly cross linked Thermoplastic Thermoplastic | Low ↑ High | High ↓ Low | High ↑ Low | High ↓ Low | Low ↑ High |

The typical applications of FRP are desired due to the specific strength (strength to weight ratio) and specific stiffness (stiffness to weight ratio) of the composites. It is proven to be adaptable as engineering materials for application in sectors such as automotive, civil, electrical and electronic, marine, transportation, consumer products, etc. The most widely used FRP is glass fibre reinforced polymer (GFRP), while the less common types are carbon and aramid fibres, which are subjected to the cost range between fibres. The major resin polymer matrix is unsaturated polyester, which has good mechanical properties with acceptable cost and when more mechanical properties are needed, epoxy is preferable with a higher cost [28]. The fabrication techniques employed by the FRP industry are illustrated in Figure 2.2 and shows two different types of factor. First, is the type of polymer matrix, which is both a thermosetting or thermoplastic polymer and the second factor is the type of reinforced fibre, either a short or long fibre. The process will determine the performance of the composite, even though the focus is on the reinforcing materials. For example, study on the processing method between compression moulding and twin screw extrusion process on glass fibres reinforced with wood/PVC composites shows compression moulding has better mechanical

properties because of lower shearing stress [29]. A comparison between wet lay-up with autoclave consolidation and resin transfer moulding (RTM) by vacuum impregnation to fabricate glass fibre epoxy composites shows different fibre fractions where autoclave is much higher due to higher compaction resulting in better mechanical properties [30].

Undoubtedly, synthetic fibres are dominant in FRP composites, especially GFRP but over the last few years, a good deal of work has been dedicated to natural fibres with the hope of replacing synthetic fibres. This is truly important as a step towards finding a solution for environmental sustainability. Since some technical issues of natural fibres seem to be barriers towards becoming replacement fibres, the art of improvement embraces the architecture and the processing method is indispensable.

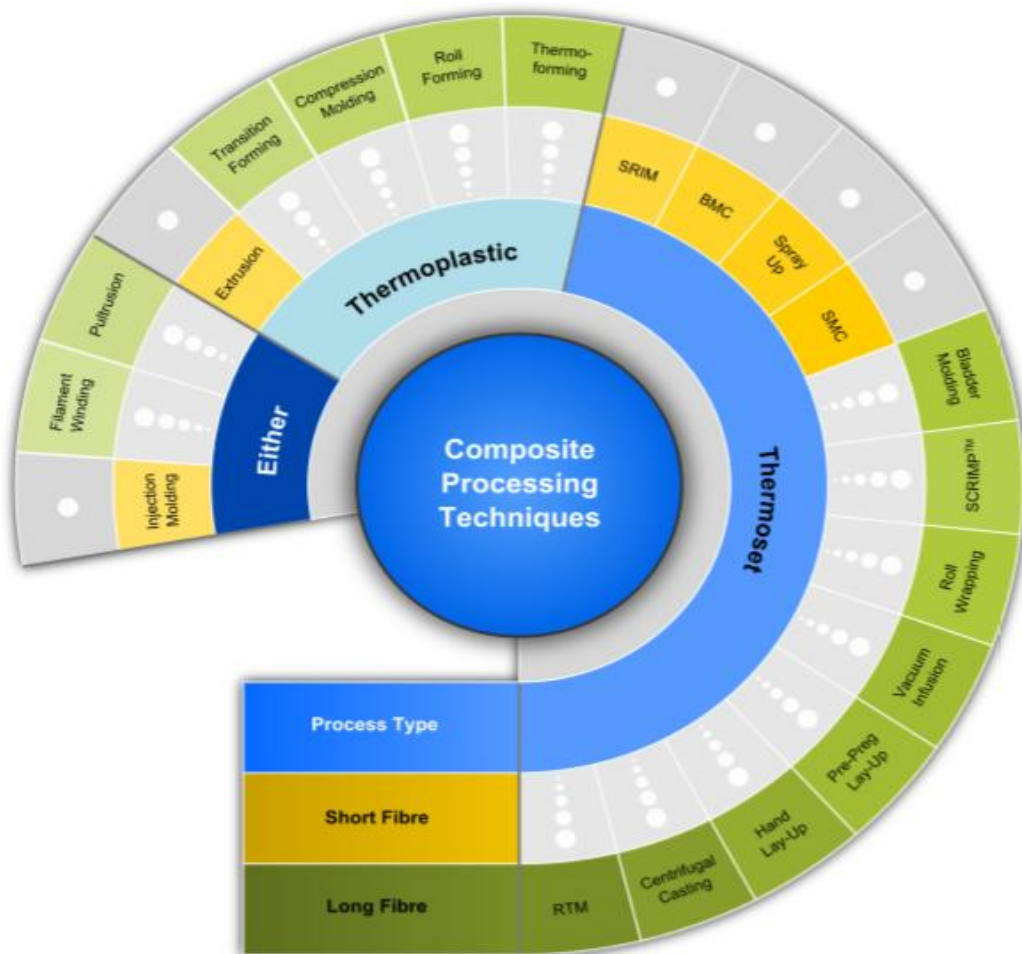


Figure 2.2: Common processes in Composite Fabrication [31].

2.3 Natural fibres

In recent years, owing to the increased environmental awareness, the use of natural fibres as a potential replacement for synthetic fibres such as carbon, aramid and glass fibres in composite materials has gained interest among researchers [32]. Enhanced with the issues of over rising costs, unstable supply and negative environmental impact of fossil fuels, the use of natural fibres is being vigorously promoted.

Natural fibres are classified (Figure 2.3) according to their source, which are animal, vegetable or mineral. There are many types of natural fibres being investigated but most of them come from vegetables due to its properties. Vegetable fibres from seeds, bast, leaf and fruits are common forms of fibres and are expected to replace the traditional synthetic fibres. The most common fibres used are flax, hemp, jute, wood, rice husk, wheat, barley, cane (sugar and bamboo), grass, kenaf, ramie, sisal, coir, kapok, banana fibres and pineapple leaf fibres. These fibres are usually used as the reinforcement in the development of natural based composites.

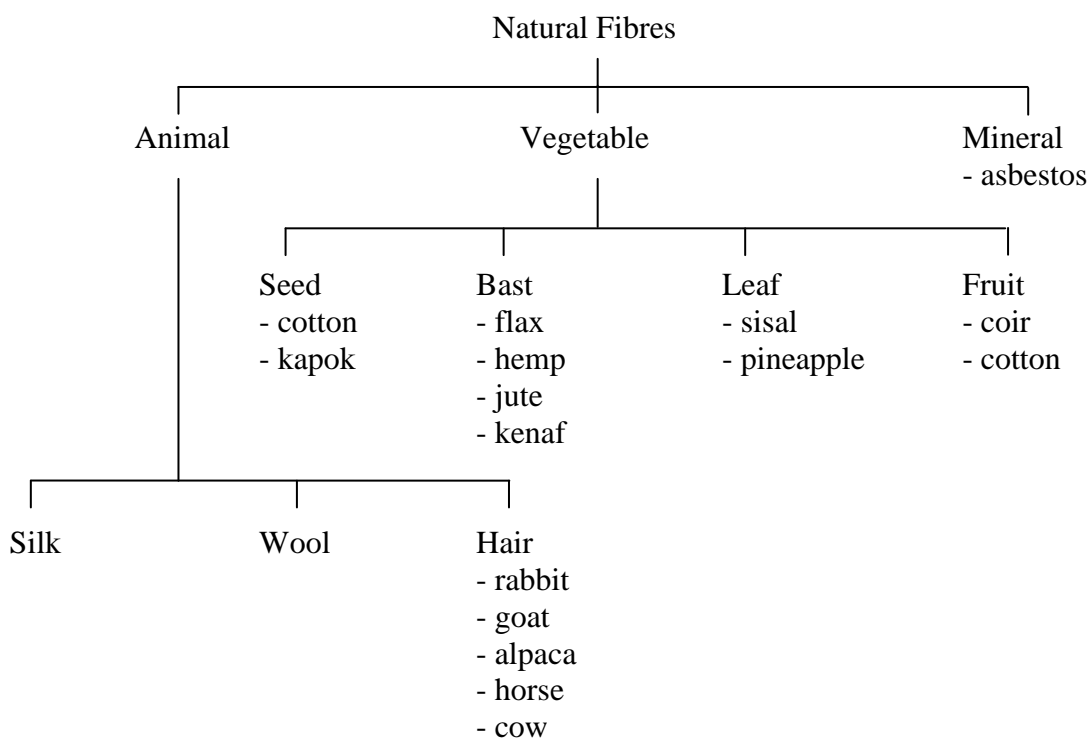


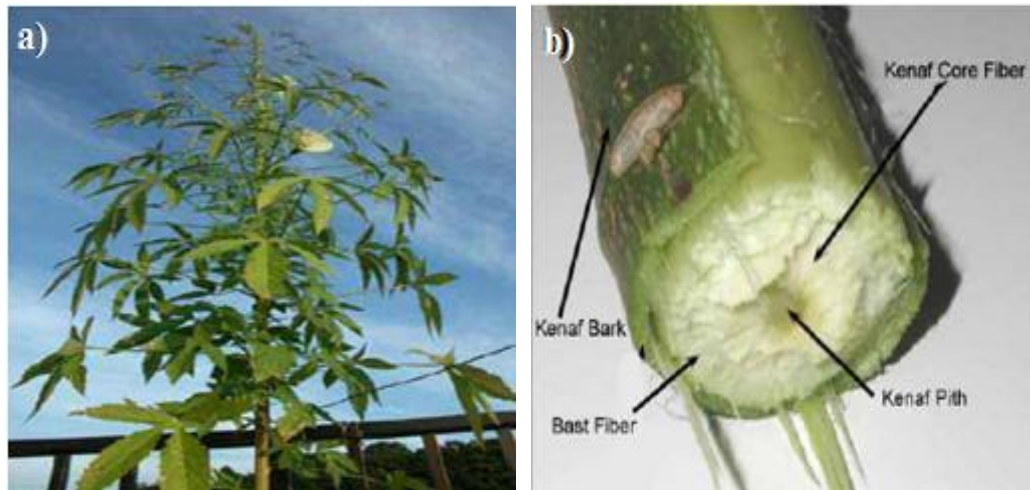
Figure 2.3: Classification of natural fibres.

The advantage of natural fibres over other established materials are that it is environmentally friendly, fully biodegradable, abundantly available, renewable and cheap and has a low density [33-35]. Furthermore, properties such as being lightweight, of reasonable strength and stiffness make it a material of choice when replacing synthetic fibres [36]. Even though, natural fibres look like promising materials, there are a few drawbacks to be considered. According to Mallick [37], among the disadvantages of natural fibres are its low tensile strength compared to traditional fibres such as E-glass and carbon fibres. It also has a low decomposition temperature and a tendency to absorb moisture. At temperatures higher than 200°C, most natural fibres start to degrade, which leads to odour, discoloration, release of volatiles, and deterioration of mechanical properties. Besides, it also has poor adhesion between natural fibres and the polymer matrix due to the hydrophilic nature of plant fibres and the hydrophobic of the matrix.

However, the disadvantage of low tensile strength of plant fibre is balanced by its low density, making it high in strength per weight ratio. Low decomposition temperature of plant fibre occurs during processing and most of the processes are below 200°C, which makes it acceptable. The tendency of poor adhesion between fibres and matrix has led towards various studies. This has led to several varieties of treatment to increase the compatibility between the fibre and matrix such as the use of coupling agents and alkali treatment. Nevertheless, there is more to be explored before it is steadily being used as a preferred reinforcing material.

2.3.1 Kenaf bast fibers

Kenaf fibre as shown in Figure 2.4 is an agricultural crop extracted from the Kenaf's bast (*Hibiscus Cannabinus*, L; family *Malvaceae*) as a potential fibre for industrial applications. Kenaf originates from Africa and is mainly grown in South-east Asia. It grows so fast that as many as three harvests a year are possible and it is an environmental friendly crop as 1 ha of kenaf cultivated area can absorb about 30-40 tons of CO₂, during one cultivation cycle [38].



Kenaf plant

Kenaf stem



Kenaf long fibers

Figure 2.4: The condition of Kenaf beginning from plant, stem and fibers.

In the Malaysian scenario, the development of Kenaf started during early 2000, beginning with research and development (R&D) by the Malaysian Agricultural Research and Development Institute (MARDI) and other academic sectors and government agencies. Since then, the Malaysian government has spent more than RM48 million for research in Kenaf cultivation and utilization [39]. This has been accelerated with the government's agenda on the development of Kenaf cultivation as an alternative crop for tobacco. Furthermore, the National Tobacco Board (LTN) was restructured and named the National Kenaf and Tobacco Board (LKTN). There are indications that Kenaf can grow in several areas in Malaysia and

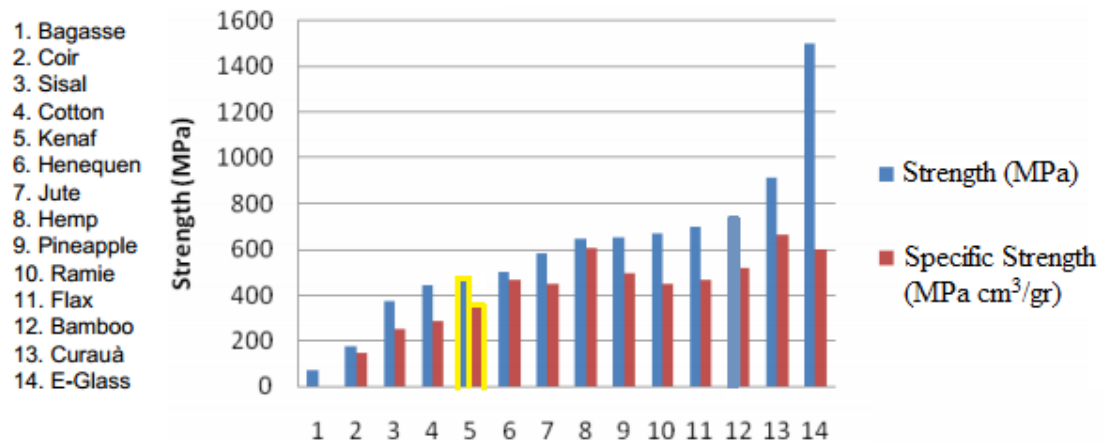
in 2004 and 2005 the area cultivated by Kenaf was 42.2 hectares and in 2007 it grew to 700 hectares [40]. With the development of Kenaf cultivation, it is necessary to diversify the use of Kenaf, especially in industrial applications.

2.3.2 The Properties of Kenaf fibres

Kenaf has a high fibre yield, consisting of an inner core fibre (75–60%) and an outer bast fibre (25–40%) [41]. The long bast fibres are usually used in the production of high grade pulp in the pulp and paper industry, protective packaging for fruits and vegetables, filters, composite boards and textiles [42]. Kenaf comprises three principle chemical constituents, which are cellulose, hemicelluloses and lignin. The content of cellulose is 60-80%, lignin is 5-20% and moisture is 20% [43]. The strength and stiffness of the fibres are provided by cellulose components via hydrogen bonds and other linkages. The cellulose is highly crystalline, thus making it resistant to chemical attacks and degradation. Hemicellulose is physically a white solid material with rare crystalline or fibrous matter, which is in a form of flesh that fills out the fibre. It is responsible for biodegradation, moisture absorption, and thermal degradation of the fibre. On the other hand, lignin (pectin) is thermally stable, but responsible for the UV degradation of the fibres. The structure of lignin is intended as a binder to hold the fibre together and as a stiffening agent within the fibres [42, 44].

Traditionally, Kenaf fibres were used as a cordage crop to produce twine, rope, gunny-sacks and sackcloth [36]. The Kenaf's bast fibre was expanded into a new market of mouldable, nonwoven fabric and reinforced composite materials in automotive, aerospace, packaging and other industrial applications. The interesting part of Kenaf fibre is in its properties such as low cost, lightweight, renewable, biodegradable and highly specific mechanical properties. It has superior flexural strength and excellent tensile strength that makes kenaf a good candidate for many applications [15]. However, kenaf is at the middle range compared to other natural fibres in terms of strength, specific strength, stiffness and specific stiffness as shown in Figure 2.5. It also has its advantages and disadvantages which is comprised of natural fibres as being mentioned in Table 2.2.

a) Strength and specific strength



b) Stiffness and specific stiffness

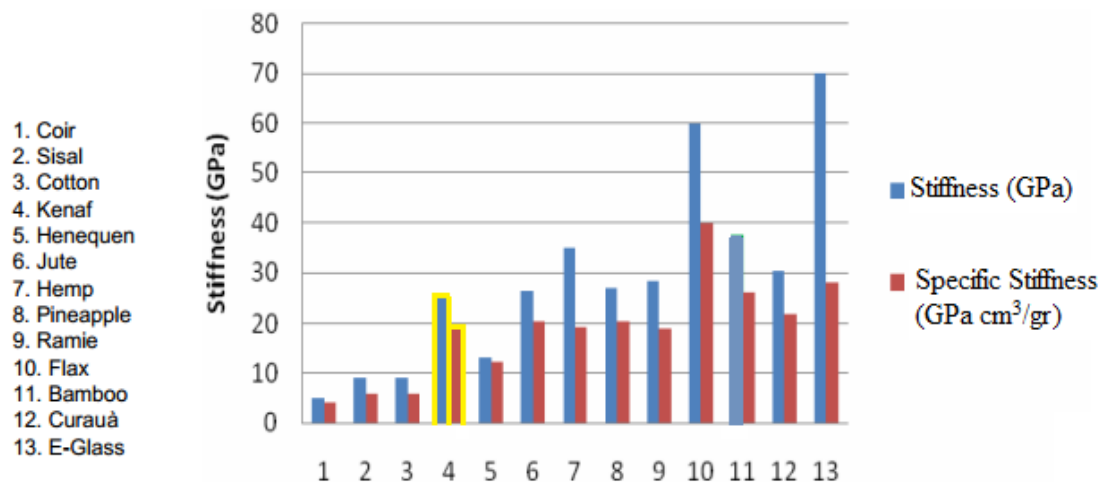


Figure 2.5: Comparison of different natural fibres and E-Glass.

Table 2.2: Advantages and disadvantages of kenaf fibres [46].

| Advantages | Disadvantages |
|--|---|
| <p>Low specific weight resulting in a higher specific strength and stiffness than glass.</p> <p>Renewable resources, production require little energy and low CO₂ emission.</p> <p>Production with low investment at low cost.</p> <p>Friendly processing, no wear of tools and no skin irritation.</p> <p>High electrical resistant.</p> <p>Good thermal and acoustic insulating properties.</p> <p>Biodegradable.</p> <p>Thermal recycling is possible.</p> | <p>Lower strength especially affects strength.</p> <p>Variable quality, influence by weather.</p> <p>Poor moisture resistant, which causes swelling of the fibre.</p> <p>Restricted maximum processing temperature.</p> <p>Lower durability.</p> <p>Poor fire resistant.</p> <p>Poor fibre/matrix adhesion.</p> <p>Price fluctuation by harvest results or agricultural politics.</p> |

2.3.3 The fibre's surface modification

Kenaf fibers as reinforced polymer composites depend on several factors that affect its performance. These factors are the incompatibility between the hydrophilics of the fibre and the hydrophobic polymer matrices, the fibres content regarding tensile properties and the processing parameters which are affecting the properties and interfacial characteristics [34]. Kenaf fibres have high moisture absorption due to the large amount of the hydroxyl group in cellulose that gives it the hydrophilic properties. When it is used as a reinforcement combine with hydrophobic matrix the result is a very poor interface and poor resistance to moisture absorption [47]. Studies have shown that chemical modifications are usually used to optimize the interface of fibres.

There are several types of chemical modifications used on natural fibres to expedite the adhesion of natural fibres to the polymer matrix such as Alkaline Treatment, Silane Treatment, Acetylation of Natural Fibres, Benzoylation Treatment, Maleated Coupling Agents, Isocyanate Treatment, Permanganate Treatment and Acrylation and Acrylonitrile Grafting [48]. However, previous studies have shown that only a few chemical treatments were used on Kenaf fibres by researchers. The most widely used was the Alkali treatment, which is consisted of soaking the Kenaf fibres in a Sodium Hydroxide (NaOH) solution in a controlled temperature for a certain period of time and later rinsing it to remove any excess NaOH from the fibre's surfaces. The previous studies show that 5–6% by weight of NaOH was the optimum concentration under different temperature and soaking time [17, 38, 49]. The reason for using NaOH solution is to clean the fibre surface, chemically modify the surface, stop the moisture absorption process and increase the surface roughness [50]. This would subsequently increase the effectiveness of the fibre's surface area in adhering well with the matrix.

A study by Chao et al. [49] showed that an increase of tensile strength by Kenaf fibres when treated with 5% NaOH but there was no difference with Young's modulus and fracture strain. This shows that NaOH treatment will increase the strength of kenaf fibres and improve the compatibility between the fibres and matrix adhesion. However, there was also finding that show a decline of mechanical properties when using alkali treatment. El-Shekeil et al. [51] reported on the Kenaf

fiber-reinforced thermoplastic polyurethane (TPU/KF) composite fabricated with melt-blending method. The result shows the tensile, flexural and impact properties of untreated TPU/KF as superior compared to treated TPU/KF composite showing unsuitability for the composite. Apart from the use of individual alkali treatment, there were also reports showing a combination of alkalization with silane treatment. It was found that both treatments of alkali and silane offered superior mechanical properties compared to untreated fibre reinforced composite or individual treatment [52].

Still, previous reports have shown that most of the chemical modifications on Kenaf fibres are in the form of randomly oriented or fibre mats but not in structural formation. Therefore, it is interesting to evaluate the conditions of kenaf fibres that occur in the form of packing fibres twisted strands with structural interlacement of textile composite.

2.3.4 Kenaf fibres in polymer composites

Over the past few decades, interest in kenaf as a reinforced fibre for natural based composites had focused on the characteristics of kenaf fibres and the manufacturing process. Researchers more likely preferred random fibre orientation, compressed mat and prepeg versions. Most of the issues investigated dealt with the mechanical properties, thermal properties and moisture absorption using different kinds of polymer matrix and techniques.

Lee et al. [53] studied the effects of volume fraction on the mechanical properties on mixed and long discontinuous kenaf fibres with polypropylene (PP) using the carding and punching process. The result showed an increase of tensile and flexural modulus but it reached an optimum nominal fibre fraction of 30%. The result was similar with the findings of El-Shekeil et al. on Kenaf fibre-reinforced thermoplastic polyurethane (TPU/KF) composite fabrication using the melt-blending method [54]. Ochi used the prepeg method by placing emulsion-type PLA resin in the surface of unidirectional kenaf fibres and fabricated it using the hot press. It indicated stability of thermal properties in the PLA but found that the tensile strength of kenaf fibres decreased when kept at 180°C for 60min in moulding condition [16].

Rashdi et al. [15] did a study on a kenaf fibre and unsaturated polyester composite. The composite was tested in three different conditions; water immersion, soil buried and natural weather and was compared to dry kenaf fibres. The results showed that relative humidity (RH) was higher in the case of water immersion, and soil buried conditions, whereas in case of natural weather the effects of RH was slightly lower leading to high tensile strength. This has led to suggestions on kenaf as a candidate for outdoor application. Azrin et al. [55] studied woven composites consisting of coir and kenaf fibres in relation to its mechanical properties of impact and flexural. Woven composites were prepared using hand lay-up coupled with vacuum bagging. The results showed that woven coir composites displayed better mechanical properties compared to kenaf composites.

Even though there was a study on woven Kenaf reinforced composite, effect on the woven structure was not emphasized. Researchers are keen on random kenaf fibres, as the studies have shown some weaknesses with the composite, which are:

- i. Fibre breakage during processing especially in injection moulding.
- ii. Uncontrollable fibre orientation.
- iii. Uneven fibre dispersion making it ineffective in distributing loads from polymer to reinforced material.
- iv. Uncontrollable fibre loading.
- v. Low in drapeability, which causes difficulty during the moulding process.

Most of the drawbacks from random fibres can most likely be overcome using a structurally reinforced material. It is currently being used in synthetic fibre composites for industrial purposes and various other applications.

2.4 Textile composite

Textile composite materials consist of textile reinforcements with polymer matrix of either thermosetting or thermoplastic. The textile reinforcement material is in the form of interlaced structures consisting of yarns with various preform constructions such as woven, braided, knit or stitched [56-57]. Generally, the continuous fibres might be constructed in the form of preform that is randomly oriented, uniaxial or biaxial according to the technique and the properties concerned. It is one of the

promising technologies and its application in composites is tremendously increasing in various fields such as aerospace, marine, automotive, etc. [58].

Textile composites can be characterized by the formation of the reinforced materials as seen in Figure 2.6. The textile preform is separated into two different preforms consisting of 2-Dimensional (2-D) planar textile preform (single layer fabric) and 3-Dimensional (3-D) textile preform (multilayer interlock fabric). The 3-D preform has highly damage tolerance and impact resistance as the trend to delamination which been diminished due to the existence of reinforcements in the thickness direction [57]. However, it is less popular than 2-D since the making involving special mechanism and complex design. The woven preform is currently the most widely used with glass, carbon and aramid reinforced woven composites and in a wide variety of applications.

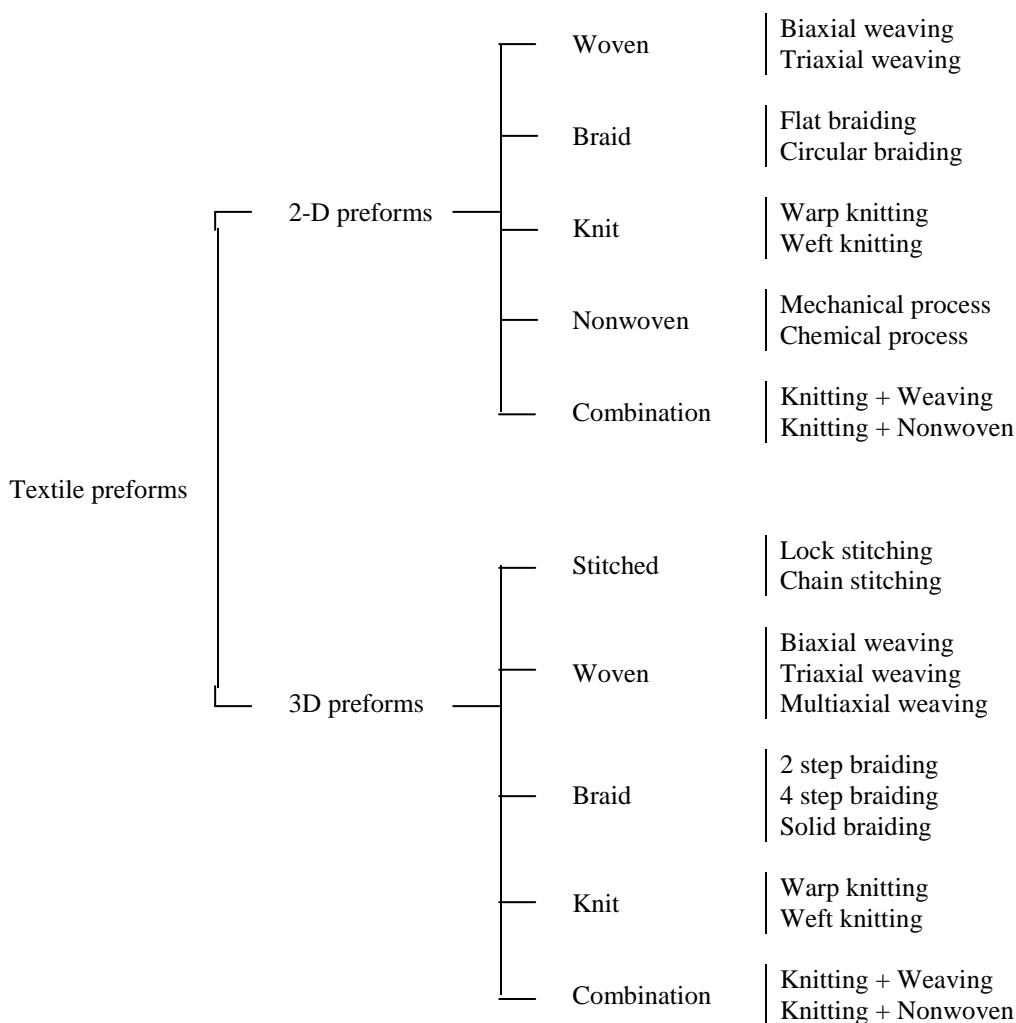


Figure 2.6: Textile preform for composite materials [59].

The advantages of textile composites are its low density, high strength, high stiffness to weight ratio, good chemical resistance, excellent durability, and design flexibility [60]. It is also found that the process of spinning has randomised fibre defects that is deleterious to fibre properties and gives rise to composite microstructural failure [61]. Even though it has various advantages but the main reason is ease of handling and low cost fabrication [62-63]. The textile reinforced materials can be manufactured in high production limits with advanced automated manufacturing systems that are being implemented by traditional fabric presently. The disadvantages of textile composite include lower fibre volume fraction, the existence of resin-rich volumes between yarns and degraded in-plane properties (as a result of the non-straight path that the yarns must accommodate) [64]. Studies also found that the introduction of twist during spinning has lead the reinforcement “off-axis” and thus not able to provide maximum reinforcement. The yarn crimp in the preform reduced the reinforcement efficiency and possible problems with poor resin penetration into the yarn [61]. Although there are some disadvantages, the textile reinforced composite is still acceptable in terms of properties, production cost and ease of production.

The mechanical properties of textile composites are controlled by two parameters, which are the textile preforms and laminate parameter [65-66]. The parameters for textile perform will be discuss in subtopic 2.4.2. A laminate composite is a number of layers or lamina and the orientation of the fibres depend on the application of the load direction. The parameters that influence the mechanical properties of laminate composites are usually the stacking orientation and overall fibre volume fraction, V_f . Hence, if the laminate is subjected only to an axial load that causes tension, the fibres in all layers should have the same orientation of the load in order to obtain the greatest possible strength. However, if the load is in a different direction, such as in a compression, it is more stable by positioning some of the layers of the fibres perpendicular to the load. Positioning some layers so that their fibres are oriented at 30° , 45° , or 60° to the load may also be used to increase the resistance of the laminate to the in-plane shear [67].

2.4.1 2D woven preform

The 2D woven preform can be defined as an interlacement of two set yarns known as warp yarn in the vertical axis and the weft yarn in the horizontal axis. It can be divided into three different fractions consisting of yarns that are single or a bundle of fibres, sets of yarns in preform and lastly the preform itself. The fibres are in form of continuous and discontinuous, which are called filament and staple or short fibres, either synthetic or natural and being twisted to strengthen the yarn. Figure 2.7 shows the interlacement of warp yarn and weft yarn with sectional view following the arrangement of weave design.

The yarn been determined according to linear density, which is the mass of a yarn per unit length and the inverse form, is called yarn numbering system or yarn count (Table 2.3). Spun yarn and natural fibres are impossible to be used in diameter as a dimension since it varies from point to point along the length making it weaker in strength [68]. The unevenness, or coefficient of variation of linear density for yarns made of short and stiff fibres such as flax, have an unevenness that can be as high as 15-20% [69]. If both yarns are being compare, the spun yarns tend to be hairy and fuller handled while filament yarns are more smooth and lustrous.

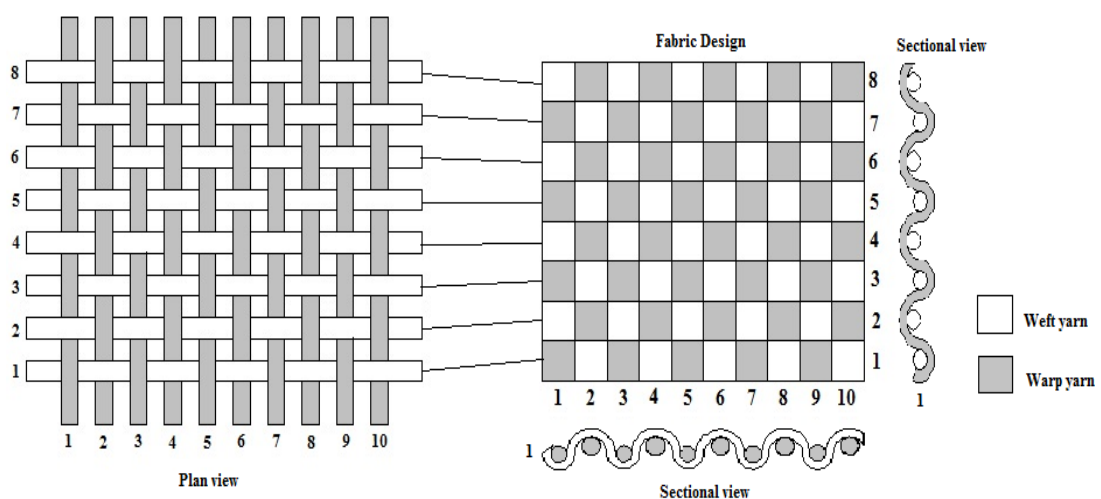


Figure 2.7: Interlacement of warp yarn and weft yarn according to the preform design.

Table 2.3: Examples of Linear Density and Yarn Count System.

| Linear Density (Direct system) | Definition | Yarn Count (Indirect system) | Definition |
|-----------------------------------|--------------------------------|---------------------------------|----------------------------------|
| Tex | No. of grams per kilometres | Metric Count (Nm) | No. of kilometres per kilograms |
| Decitex (dtex) | No. of grams per 10 kilometres | English Cotton Count (Ne) | No. of 840 yard hanks per pounds |
| Denier (Den) | No. of grams per 9 kilometres | Glass (UK and US, N_G) | No. of pounds per yards |

The fabrication of textile structure for 2D woven preform in textile composites can be produced using modern weaving loom. Historically, the weaving machine starts from shuttle loom, where the picking system or the weft insertion system uses the shuttle (Figure 2.8). The development of textile has introduced the shuttle picking system, which is classified into four different types of systems; i) air-jet ii) water-jet iii) rapier and iv) projectile. This system operates under automated control, which makes the quality of the fabric much higher compared to the shuttle system and is able to produce several hundreds of kilograms per hour. The pattern controlling system is the heart of the weaving system and categorized into three different systems; i) cam ii) dobby and iii) jacquard. The cam system is the basic system and produce simple patterns usually for plain fabric. Meanwhile, the Dobby system produces patterns that are more complex but still has limitations and can only reach as many as 32 harnesses. The jacquard system can produce unlimited patterns but still depends on the capability of the weaving machine.

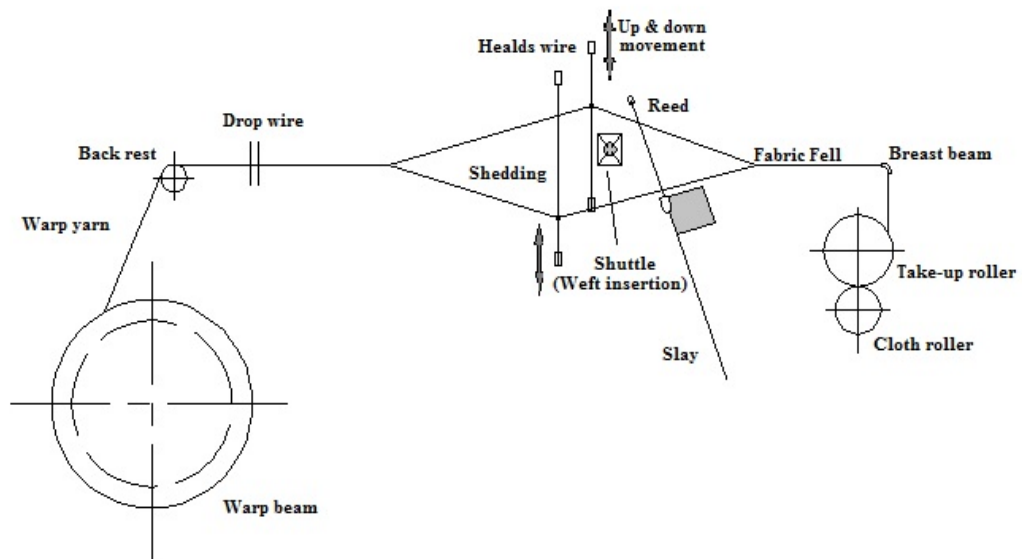


Figure 2.8: Schematic diagram of shuttle loom weaving machine.

2.4.2 Weaving structure

Weaving structure is a manner of construction or the arrangement of two set yarns determined by three main elements, namely the i) yarn properties in terms of thickness, surface characteristics, fibre content, strength, extensibility, etc. ii) fabric count or the density (threads per inch or per centimetre, and iii) weave design [70-71]. The manipulation of the elements will produce different mechanical properties, physical properties, chemical properties and the aesthetic value of the fabric.

The basic pattern of woven structure consists of plain, twill and satin or sateen weave. The plain weave is the simplest weave where the threads interlace in alternate order. The weave construction can be represented in a design paper consisting of square paper or checker board. Referring to Figure 2.7, the blank square indicates that the weft thread is placed over the warp and vice versa. The weaves are classified as balanced and unbalanced preform whereas balanced weave have the same linear density and fabric count for both warp and weft direction. Plain weave is the most highly interlaced preform that causes tightness and the most resistant to in-plane shear movement, sometimes it is difficult to wet out during densification. However, it can be relied on to give reproducible laminate thickness [71]. Plain

weave is usually used as a woven structure in textile composites for synthetic fibres such as glass and carbon fibres.

The twill order of interlacing as showed in Figure 2.9 (a), produces diagonal lines on the preform. The purpose is to make the preform heavier, with a closer setting and better draping. It is more pliable than plain weave and with better drapability and stability compared to the satin weave [72]. In pure sateen weaves, the surface of the preform consists almost entirely of weft floats. This has lessen the yarn crimps and improved the preform strength according to the function of a reinforcement materials in textile composites. It has a smooth surface with lots of floated warp yarns, good drapability, very pliable weave and used for forming curved surfaces [73]. Figures 2.9 (b) shows examples of Sateen 3/2 or 3-harness and Sateen 4/3 or 4-harness or crowfoot that can be found as a reinforcing structure in textile composites [69].

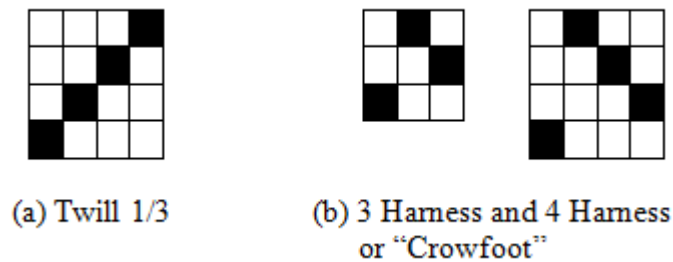


Figure 2.9: Examples of designs of Composite Reinforcing Materials (a) Twill 2/2
(b) Sateen.

The fundamental weave is the basis of more complex patterns in preform construction used for upgrading the design effect or the mechanical properties of the preform. Figure 2.10 shows some examples of weave design based on the fundamental weave.

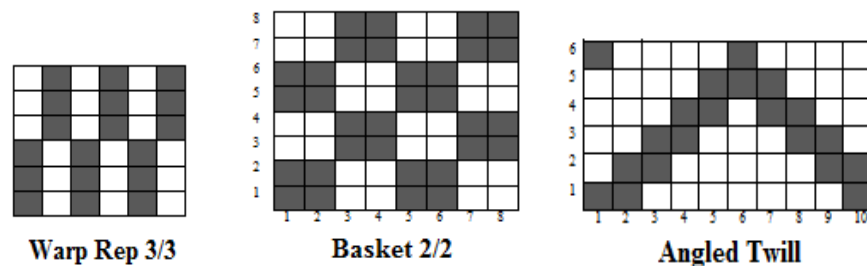


Figure 2.10: Examples of modified and complex design weave (continued).

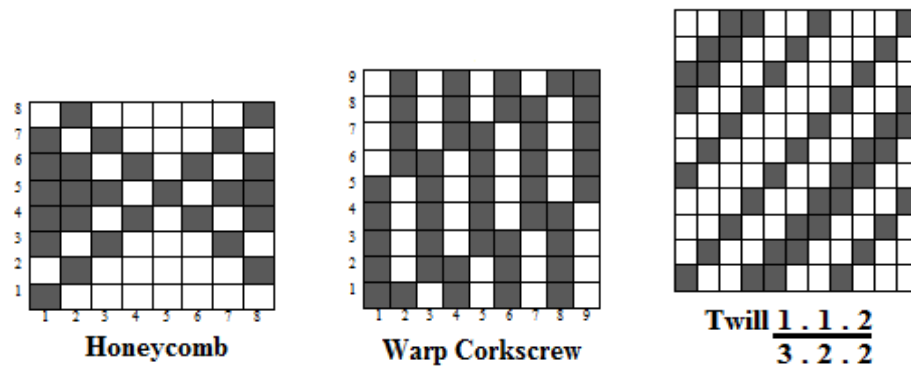


Figure 2.10: Examples of modified and complex design weave (continuation).

Therefore, in order to indicate that the weave design is based on the preform properties, weave tightness can be used as an indicator. The weave tightness or connectivity is determined by weave design and it quantifies the freedom of yarns to move. To characterize the weave tightness, the equation (2.1) is used [69];

$$Tightness = \frac{2}{f_{wa} + f_{we}} \quad (2.1)$$

where; f_{wa} = the number of warp intersections

f_{we} = the number of weft intersections

Lower tightness value indicates fewer fixations of the yarns in a preform, less stability and better drapability. As the preform is less stable, it tends to be distorted easily, while higher tightness means higher crimp and this deteriorates preform strength.

Yarn crimp is the waviness of warp yarn and weft yarn interlacing together to produce preform construction as shown in Figure 2.11. It is defined as a percentage of the excess length of the yarn axis over preform length [74]. Thus, it has great influence on the preform performance and the geometry of the preform. Therefore, crimp is effected by yarn count, preform structure and weaving tensions. If the weft yarn (or the preform in the weft direction) is kept at a low tension whilst the tension in the warp direction is high, then there will be considerable crimp in the weft and very little in the warp [74-75]. In summary, the build-up of crimp is caused by:

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