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A Review on Potential of Development New Weave Pattern Design using Glass Fiber and Kenaf Fiber for Intraply Composite

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Abstract: Mechanical properties of the laminated composite made from fabric type reinforcement can be affected by using the method of bonding and finishing due to the constructional parameter of each lamina. Hence, the new intraply between glass fiber and kenaf fiber for composite structure is proposed toward improving overall mechanical and physical properties of intraply composite structure. Implementation of natural fiber in synthetic fiber reinforced composite has high potential to be explored scientifically. This review is mainly focused on the theory and the knowledge of composite material which found over the years by various scientists and researchers as well as related studies based on the previous researches. The types and roles of matrix and fiber materials in composites are also discussed. Major findings in this review show that the characteristics of composite depend on the weave patterns and the structure of interply and intraply. Therefore, the new intraply for glass fiber and kenaf fiber in composite structure is expected to perform better in aspect of mechanical and physical properties, besides reduced the dependency to glass fiber (100%). Finally, it will propose the most effective weave pattern designs in the functional combination form of glass and kenaf fibers. The numerical results are compared with the experimental data available in literature.

Keywords: Weave pattern design, glass fiber, kenaf fiber, intraply, interply, laminated composite

1. Introduction

In Malaysia, there are abundant natural fibers that are available which can be economically processed into natural fiber polymer composites. One of the natural fibers is kenaf fiber. This fiber gains became the top national commodity crop under the supervision of the Malaysian National Kenaf and Tobacco Board [1]. This is due to the kenaf fiber has superior toughness and high aspect ratio compared to other natural fibers. In addition, kenaf based polymer composites can be produced using either thermoset or thermoplastic matrix [2].

In addition, the natural fiber is currently applied or mixed with synthetic fiber for composite material. The most common synthetic fiber used for polymer composites is glass fiber. This is due to the glass fiber has relatively low cost and good in mechanical properties. In order to reduce cost, this material is widely used in hybridization with other synthetic fibers while the hybridization with natural fiber will give positive effects on strengthening the tensile and compressive properties of natural fiber [3]. In brief, the effect of glass fiber in hybridization helps to enhance the properties of composite laminate [4].

Hybrid composites contain two or more different types of reinforcement materials which are bounded in the same matrix and depending on the way of constituents materials that are mixed together such as the fiber orientation. The most common hybrid composites used is interply hybrid where two or more layers homogeneous reinforcements are stacked together. Meanwhile, an intraply hybrid composite is tows of the two or more types of fibers interlaced in the same layer of matrix [5]. The authors investigated an improvement in the specific ultimate properties of polymer fiber reinforced composites with inorganic brittle reinforcements such as the carbon or glass fiber that was attempted by the incorporation of more ductile organic fibers, such as aramid. Hani *et al.* [6] studied the hybrid composite of woven coir and kevlar fiber in which coir fiber has the resistance to the high speed impact penetration by reducing the amount of synthetic fiber used in the composite.

Furthermore, Akhbari *et al.* [7] presented that woven fabric which is also known as the bi-directional reinforcement composite that able to provide a certain properties advantage to the different fiber reinforced composite. The authors also stated that the equal and balanced properties in warp and weft directions will enhance the woven fabric to be stiffer and impact resistance compared with unidirectional fiber composite. Likewise, the hybrid woven fabric that is made of glass and polyester fiber has increased the buckling strength of composite. The hybrid composite shows a greater strain to failure and better integrity after final failure. However, the woven fabric composite will degenerate the strength of fibers in woven fabrics which caused by non-straight linearity of warp and weft yarns upon weaving process. Based on this case, a special high module material can be used to minimize the deficiency of composite structure [8].

Since natural fiber composite has better ductility, toughness and increase tensile as well as flexural and impact strength significantly, Hani *et al*. [9] commented that the random orientation of fibers and compressed mat and woven fabric composite by using synthetic types fiber will give more advantages in mechanical properties. Previously, Nassif [10] investigated the different weft densities and plain, twill and satin weave designs were affected the mechanical and physical properties of micro polyester woven fabrics. The author summarized that the plain weave fabrics were superior to other designs in the breaking load, elongation, and the stiffness. In addition, satin weave fabrics have higher air permeability while in twill weave fabric has higher crease recovery.

The studies on the synthetic fiber reinforced woven fabric laminated composite such as glass, carbon, and kevlar were carried out by scholars a decade ago [10-12]. The studies were carried out to analyze the material performance in different ply and fiber orientation in laminated composite. Throughout this literature review, there is no scientific research on the intraply of fibers in lamina composite since the stacking sequence of lamina and fiber orientation in composite are related. Thus, the development a new intraply lamina composite using glass fiber and kenaf fiber in weave structure could be an interesting topic to be explored in detail for gaining more understanding under the mechanical testing and enhancing the mechanical and physical properties of the composite structure applications.

2. The Composites

According to Matthews and Rawlings [13], a composite is a mixture of two or more distinct constituents or phases. Both constituents should be present in reasonable ratios which greater than five percent. Both major constituents are reinforcement and matrix. The main advantages of composite materials are their high strength and stiffness along with low density as compared to with bulk materials. It produces lightweight finished part. The reinforcing phase which stronger and stiffer than the matrix can be provides the strength and stiffness for composite material. The reinforcement is usually fiber or particulate [14]. As highlighted by Callister and Rethwisch [15], the authors stated the advent of the composites as a distinct classification of materials began during the mid-20 century with the manufacturing of deliberately designed along with engineered multiphase materials such as fiberglass-reinforced polymers. There are different forms of constituents and distributions of the reinforcements in composite for example bidirectional layers, irregular reinforcement with long fiber and short fiber, reinforcement in particles and plate strapped particles, random arrangement of continuous fiber in laminate composite system using mats and woven fabrics. The Figure 1 demonstrated typical examples of composite in details [16].

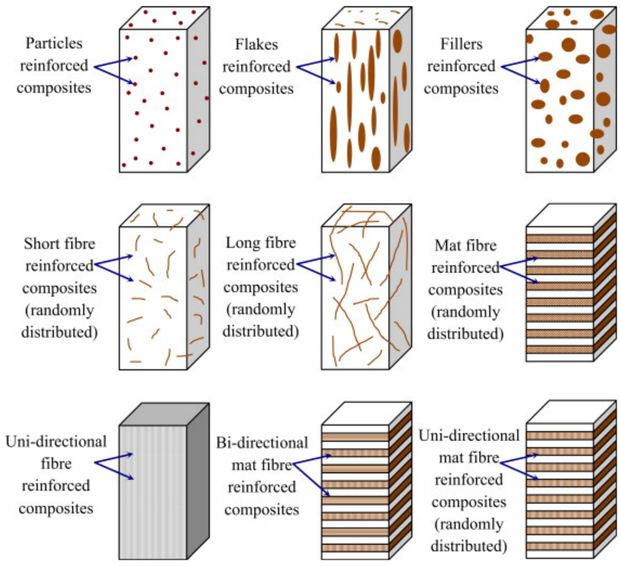


Fig. 1 Type of reinforcements [16].

Fiber-reinforced composite materials consist of fibers of high strength and modulus embedded to matrix with boundaries between them. Both fibers and matrix retain their physical and chemical properties and yet create a combination of properties that cannot be achieved with either of the constituents acting alone. Fibers are the principal load carrying members while the matrix keeps them in the desired location and orientation which acts as a load transfer medium. There are various type of fibers such as glass, carbon, boron are commonly used. All these fibers can be incorporated into a matrix either in continuous or discontinuous with short lengths [17]. The most used polymeric as matrix materials are from thermoset family like epoxy and polyester resin, secondly is thermoplastic family for example polypropylene and polyamide, and the last family of polymeric is elastomer such as natural rubber, neoprene and styrene butadiene rubber and so on.

2.1 Lamina

Unidirectional fiber reinforced composite ply as well as a single ply or a lay-up in which all of the layers or plies are stacked in the same orientation in composite called lamina [14]. The strength of lamina is an anisotropic property which varies with the orientation. Figure 2 shows the unidirectional continuous-fiber lamina and laminate. The authors explained the coordinate system that used to describe the ply is labeled the 1-2-3 axes. In this case, the 1-axis is defined to be parallel to the fibers (0°), the 2-axis is defined to lie within the plane of the plate and is perpendicular to the fibers (90°), and the 3-axis is defined to be normal to the plane of the plate. The 1-2-3 coordinate system is attributing as the principal material coordinate system. If the plate is loaded parallel to the fibers in which one- or zero-degree direction, the modulus of elasticity E_{11} approaches the fibers. If the plate is loaded perpendicular to the fibers in the two- or 90-degree direction, the modulus E_{22} is much lower, approaching that of the relatively less stiff matrix. The material is anisotropic when the modulus varies with direction within the material and E_{11} greater than E_{22}.

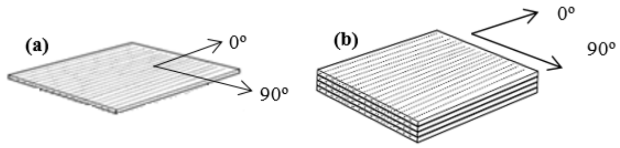


Fig. 2 Composite, (a) lamina, and (b) laminate.

Table 1 shows the number of plies of laminate that used by researchers to study on the properties of composite. The minimum number of plies used by previous study of researches is four plies and the common used reinforcement and matrix are glass fibers and epoxy resin respectively. Thus, this shows that is no scientific study has been done using different types of fiber in lamina while most of the studies are focused on laminate rather than lamina.

Table 1 Number of plies used in laminate composite.

No. of plies	Reinforcement	Matrix	References
4	E-glass	epoxy	[18]
4	E-glass	polyester	[19]
4	E-glass	polyester	[5]
10	Carbon, Glass	epoxy	[20]
10	E-glass, Kevlar	epoxy	[21]
10 & 16	Carbon, Graphite	epoxy	[22]
16	basalt	epoxy	[23]

2.2 Laminate

Each layer or ply for a continuous fiber composite has a specific fiber orientation direction and stack at different angles is known as laminate [24]. A typical laminate may have between 4 to 40 layers and the fiber orientation changes from layer to layer in a regular manner through the thickness of the laminate stated by Matthews and Rawlings [13]. In addition, unidirectional laminas are extremely strong and stiff in the 0° direction but very weak in the 90° direction due to the load are carried by weaker polymeric matrix. The longitudinal tension and compression loads are carried by the fibers, while the matrix distributes the loads between the fibers in tension and stabilizes the fibers to prevent them from buckling in compression was explained by Campbell [14]. The author also stated the effect of fiber orientation directly impacts the mechanical properties. It is also important to balance the load-carrying capability in a number of different directions, such as the 0°, +45°, -45° and 90° directions.

The thickness of the laminate will be affected the magnitude of induced residual stresses as thick walled parts have been shown to experience larger residual stresses. The prediction of residual stresses in thick-walled geometries is harder than in thin-walled laminates where near uniform through-thickness temperatures are experienced and uniform through-thickness in-plane stress/strain assumptions can be made [25]. Table 2 shows the comparative average mechanical properties of high performance fiber laminates.

Table 2 A comparative average mechanical properties of high performance fiber laminates [25].

Parameter Quantity	Fiber Glass	Kevlar-49	Spectra 1000
Laminate thickness (mm)	6.35	6.35	0.41
Density (kg/m³)	2000	1260	970
Tensile strength, (MPa)	344	337	1034
Tensile modulus, (GPa)	20	13	50
Flexural strength (MPa)	137	49	158
Flexural modulus (GPa)	17	3	22
Water Absorption (%)	0.75	2.50	< 0.10

3. Thermoset Matrix Materials in Laminate Composite

The purpose of the matrix is used to bind the reinforcements together, transfer load to and between reinforcements, and protect the reinforcements from environments and handling. It is also provides a solid form to the composite and this is particularly necessary in discontinuously reinforced composites due to insufficient length. Besides, the matrix holds fibers in the proper orientation to allow the ability of carrying the intended loads and distributes the loads more or less evenly among the reinforcements [24]. In addition, Singla and Chawla [26] stated resin that used in polymer matrix composites are classified into two groups which is thermoplastic and thermoset. Thermoplastics have good toughness, resilience and corrosion resistance but, they have fundamental disadvantage if compared to thermosetting resins. It has relatively low cost but not as strong as thermoset polymers due to the presence of cross link and formed with a network molecular structure. The advantages by using thermoset matrix are their thermal stability and chemical resistances because they also exhibited less creep and stress relaxation than thermoplastic matrix as stated by Mallick [17].

3.1 Epoxy Resin

Epoxy resin is the most common used in polymer matrix composites. Epoxy resins are a family of thermoset materials which do not give off reaction products when they cure and so have low cure shrinkage. It also has good adhesion to other materials, good chemical and environmental resistance, good chemical properties and good insulating properties [26]. Moreover, the properties of epoxy and polyester resin that used in Reis [27] research to investigate the effect of temperature on the performance of both resin materials and the epoxy resin are more sensitive to temperature changes compared to the unsaturated polyester resin. Furthermore, epoxy resins are cured by hardener for example, amine. In amine curing agents, each of the hydrogen on amine nitrogen is reactive and forms a covalent bond. The curing reaction which undergoes transformation from liquid to solid state is initiated by adding small amounts of a hardener. The curing time and temperature to complete the polymerization reaction depend on the type and amount of curing agent [26].

Nevertheless, Banakar *et al.* [28] presented the primarily of engineering composites materials consists of continuous fibers of glass or carbon reinforcement in thermosetting epoxy polymer. The polymeric composites have many advantages as higher fatigue strength, corrosion resistance and lower weight are susceptible to mechanical damages when they are subjected to tension, flexural, compression which can lead to material failure. Therefore, damage tolerance of epoxy polymeric composites can be enhanced in order to improve the interlaminar properties through the process of toughening matrix and reinforcement with bidirectional woven fabrics.

3.2 Polyester Resin

According to Ratna [29], unsaturated polyester (UPE) resin gained wide industrial applications due to their low viscosity, which offers easy processability, low cost and rapid cure schedules. This is because UPE consists of unsaturated polyester, a monomer, and an inhibitor that consists of a number of C=C double bonds. In addition, Matthews and Rawlings [13] showed the low viscosity of polyester which beneficial in many fabrication processes. The shrinkage on curing is larger and the cause of the difference in shrinkage between the resin and fibers results in uneven depression on the moulded surface. Although the physical properties of polyester composites are controlled by reinforcement, the physical properties of the polyester resin will also affect the durability and thermal performance.

The flexural properties of the unsaturated polyester resin were determined by Davallo *et al.* [30] which showed the polyester resins that without reinforcement are relatively brittle polymers and the fracture toughness, K_{IC}, and fracture energy, G_{IC} for the polyester resin lie between the typical values of K_{IC} and G_{IC} for epoxy resins are 0.5MPa $m^{1/2}$ and 100 J m^{-2} respectively. The matrix toughness has an important role in the fracture behavior of composites because the yield strength of the matrix decreases will increase delamination fracture energy through increasing the size of the plastic deformation.

4. Reinforcement Materials

The reinforcement is harder, stronger and stiffer than the matrix and the reinforcement is usually a fiber or a particulate. Fibers are the principal constituents in a fiber reinforced composite material and consists of thousands of filaments which each filament having a diameter of between 5 and 15 micrometers. The length-to-diameter (l/d) ratio is known as the aspect ratio and can vary greatly where the continuous fibers have long aspect ratios and discontinuous fibers have short aspect ratios [14]. The fibers are in bundle form which produced by gathering a large number of continuous filaments in untwisted or twisted form which due to the size of fiber filament is too small and hard to handle. For untwisted form is called strand or end for glass and Kevlar fibers respectively while tow for carbon fibers and twisted form is called yarn was explained by Mallick [17].

The purpose of reinforcement is provided superior levels of strength and stiffness to the composite, for example, the fibers provide the strength and stiffness in a continuous fiber-reinforced composite. There is also a significant advancement obtained in particle reinforced composites as mentioned by Miracle and Donaldson [24]. This is because of their small diameter and they contain fewer defects that are normally surface defects compared to the material produced in bulk. Generally, the smaller the diameter of the fiber, the higher its strength, but the cost often increases as the diameter becomes smaller.

In addition, smaller-diameter with high-strength fibers have greater flexibility and are more susceptible to fabrication processes such as weaving or forming. Typical fibers include glass, aramid, and carbon, which can be continuous or discontinuous. The most commonly used of fiberglass is known as E-glass and it has a useful balance of mechanical, chemical, and electrical properties at very moderate cost [24]. Table 3 has showed the properties of natural fiber and synthetic fibers which common uses as reinforcement material.

Table 3 Selected properties of fibers [31].

Fiber	Density (g/cm^3)	Specific Tensile Strength (MPa)	Specific Elastic Modulus (GPa)
Cotton	1.5-1.6	250-267	3.5-8.1
Kenaf	1.45	641	36.5
Sisal	1.50	341-423	6.3-14.7
E-glass	2.50	800-1400	28.0
Carbon	1.40	2857	164-171

4.1 Glass Fiber

Kumar *et al.* [19] stated fiberglass is the oldest, and most familiar and performance fiber. It is made from extremely fine fibers of glass which is a lightweight and strong material. The strength properties are lower and less stiffness compare to carbon fiber, but fiberglass is typically less brittle and least expensive. The bulk strength and weight properties of glass fibers are favorable than metals and easily formed during molding processes. Glass fibers are also available in woven form, such as woven roving or woven cloth that is a fabric in which continuous roving are woven in two mutually perpendicular directions. All of these forms of glass fibers are suitable for hand layup molding and liquid composite molding [17]. On the other hand, Jayabal *et al.* [4] investigated the mechanical properties of natural fiber woven coir composites were significantly improved by glass hybridization as well as in terms of stacking sequence which the two layers of woven glass at the extreme plies and coir mat exhibited higher value of mechanical properties. In contrast, the woven coir mat with two extreme woven glass plies exhibited slightly less value of mechanical properties. Table 4 stated there are many researchers studied the effect of glass hybridization on the behavior interply hybrid laminates. And, glass fiber is also widely used in hybridization of laminate and the incorporation of glass fiber with other types of fibers gives different properties to the composite.

Table 4 Type of fiber used in hybrid laminate system.

Fiber type (hybrid)	Matrix Resin Type	References
Carbon & S2 Glass	Epoxy	[32]
Coir & Glass	Polyester	[33]
E-glass & Basalt	Epoxy/vinyl ester	[34]
Glass & Kenaf	Epoxy	[3]

4.2 Kenaf Fiber

Kenaf which known in scientific name as Hibiscus Cannabinus L. is a traditional and is poised to be introduced as third world crop where is a new and renewable source of industrial purpose. Kenaf is a warm-season annual fiber crop growing in balmy and tropical areas. Besides, Malaysia's kenaf is composed of two distinct fibers, bast and core, with a makeup of about 35 % and 65 % respectively. The kenaf fiber is extracted from bark of the tree and the bark fibers extracted from the bast and core of the bark [35]. In Table 5 indicates the physical properties of kenaf fiber.

Table 5 Physical properties of kenaf fiber [36].

Kenaf Fiber	Length (mm)	Diameter (µm)	Lumen Diameter (µm)
Bast	2.32 ± 0.21	21.9 ± 4.6	11.9 ± 3.4
Core	0.74	22.2 ± 4.5	13.2 ± 3.6

Moreover, kenaf fiber consists of cellulose (56–64 wt. %), hemicellulose (21–35 wt. %), lignin (8–14 wt. %) and small amounts of extractives and ash. The kenaf plant can grow to more than 3 meter with stem diameter of 25–51 mm within 3 months. The long fiber is produced from this long stem which is a particular character of kenaf plant and fiber is extracted from its stalk [37]. With the same objective of study, kenaf is a fibrous plant, consisting of an inner core fiber 75–60 %, which produces low quality pulp, and an outer bast fiber 25–40 %, which produces high quality pulp, in the stem was investigated by Abdul [35]. Moreover, the study of Manap *et al.* [3] studied the orientation of kenaf fiber in longitudinal direction showed higher strength compared to transverse kenaf direction. In theoretical, longitudinal fiber alignment will produce the strongest attributes for tensile test as normally the fiber which usually is stiffer than matrix will bear the load applied as long as the volume fraction of the fiber of the fiber is sufficient for the composite as the load bearer. For transverse loading fiber direction, the strength predicted to be the lowest as the fibre will act as the hard inclusion in the matrix instead of the principal load-carrying member. In brief, Mahjoub *et al.* [37] found that the kenaf fibers which fabricated in unidirectional were almost broken in the fracture plane which due to the bending strength between kenaf and matrix is strong. The bonding between kenaf fiber and matrix is occurred due to physical bonding which the rough surface of kenaf fiber causes the better interlocking between matrix and fibers.

Therefore, there are numerous advantages of using natural fibers as reinforcements in the composite. Especially, kenaf is a well-known as a cellulosic source with economic and ecological advantages. This is because it exhibits low density, non-abrasiveness, good specific mechanical properties, and biodegradability was stated by Abdul [35].

5. Form of Woven Fabrics

A woven fabric is produced by interlacing warp and weft yarn and it is characterized by linear densities of warp and weft yarns and a weave pattern. A set of threads oriented along the fabrics is referred to as warp, while those across as weft. The type of woven structure is controlled by the order of mutual overlapping of the weft lateral yarns by the warp longitudinal. This order is critical for production of fabrics with structure, exterior and mechanic properties intrinsic to the particular weave type. In the similar finding, Robitaille [38] studied the both woven roving and cloth provide bidirectional properties which depend on the design of weaving as well as relative fiber counts in the length called warp and crosswise directions called as fill or weft. Figure 3 described the warp and weft direction of woven fabric.

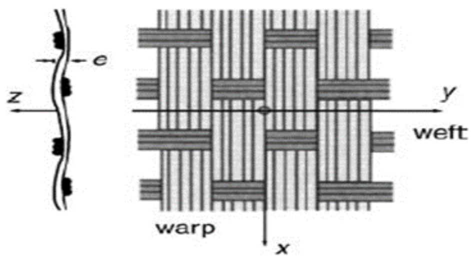


Fig. 3 Warp and weft direction of woven fabric [39].

In addition, fibrous materials produced by the textile industry techniques find wide application in many domains, due mainly to their unique physical-mechanical properties. Woven fabrics are characterized by sufficient stability of dimensions in fiber stacking direction and low shear stiffness, which ensure their good fitting and shaping capabilities. The strength, thickness, extensibility, porosity and durability of woven fabric can be varied and higher strengths and stability can be obtained where it offers the highest yarn packing in relation to fabric thickness in the warp and weft direction [40].

Moreover, the advantage of using woven fabric laminates is that they provide properties that are more balanced in longitudinal/transverse directions than unidirectional laminates. Multilayered laminates can be designed to produce balanced properties, but the fabrication time for woven fabric laminates is less than that of a multilayered laminate. With the presence of the fiber undulation in woven fabrics has decreased their tensile strength and modulus of a woven fabric laminate. It is also because of the fiber yarns in the fill direction cross over and under the fiber yarns in the warp direction to create an interlocked structure. When undergo tensile loading, high stresses in the matrix is created which allow those crimped fibers tend to straighten out and as a result of formed of micro cracks in the matrix at relatively low loads. The fibers in woven fabrics are subjected to additional mechanical handling during the weaving process which tends to reduce their tensile strength are one of the factors to be considered [3].

In Figure 4 which shows the woven fabrics are created by weaving yarn into a repeating pattern. Yarn is made of continuous or stretchable fibers with diameters typically in the order of micron meters. As highlighted by Cao *et al.* [41], the fabric is deformed into a desired shape by a punch with the fabric being subjected to a binder holding force or by machine or manual laying up where the fabric can be subjected. This can be performed at room temperature for dry fabric or at elevated temperatures, for example, thermoforming for fabrics which made of glass/carbon fibers commingled with thermoplastic fibers. The formed fabric can further be injected with resin and consolidated in a resin transfer molding (RTM) process, a liquid composite molding (LCM) process.

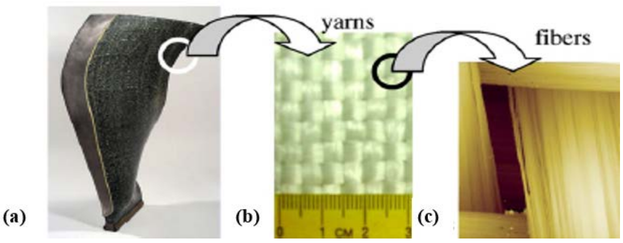


Fig. 4 A textile composite fan made by (a) SNECMA, (b) woven fabric, and (c) fiber in woven fabrics [41].

5.1 Weave Patterns

The diameter of each fiber constituting the textile composite reinforcements is very small around 5 to 7 µm for carbon, 5 to 25 µm for glass, 10 to 20 µm for aramid. A yarn is made up of several thousand juxtaposed fibers. These yarns are woven following standard weaves such as plain and twill in Figure 5 (a) and (b) or more complex structures like braiding or ply to ply interlock weaves as shown in Figure 5 (c). An alternative consists in stitching a ply made of parallel fibers which may lead to the so-called NCF reinforcement that known as non-crimp fabric in which the fibers are not undulated as shown in Figure 5 (d). The material resulting from this assembly of continuous fibers exhibits a very specific mechanical behavior since relative motions are possible between the yarns and the fibers was studied by Boisse [42].

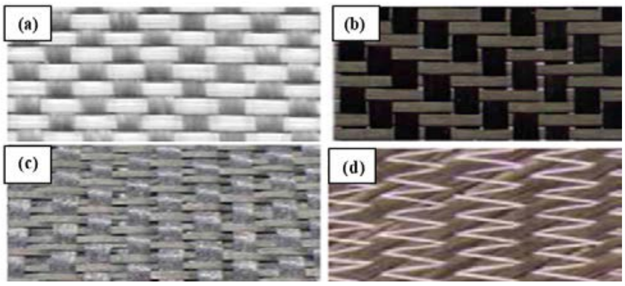


Fig. 5 Textile composite reinforcements (a) plain weave, (b) twill weave, (c) interlock, and (d) NCF [42].

Mallick [17] presented some common weave styles which are plain weave, basket weave and satin weave. Plain weave is which the warp and fill or weft yarns are interlaced over and under each other in a fabric. A group of two or more weft yarns in fabric is called basket weave and basket weave is fundamentally the same as plain weave except that two or more warp fibers interlace alternately with two or more weft fibers. Satin weave is which each warp yarn weaves over several weft yarns and under one weft yarn. Figure 6 shows the fabric construction diagram which common weave styles are used.

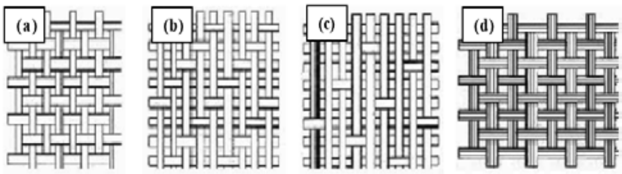


Fig. 6 Fabric weave construction diagram (a) plain, (b) twill, (c) satin, and (d) 3x3 basket [11].

According to Nassif [10], the physical and mechanical properties of different weft densities and plain, twill and satin weave structures in woven fabrics will affect the fabric breaking load, stiffness and crease recovery. The author also investigated that increasing weft density leads to an increase in fabric breaking load, stiffness and crease recovery. At the same time, it also decreased air permeability, and tearing strength. Plain weave fabrics were superior to other structures in fabric breaking load, breaking elongation and fabric stiffness; satin weaves have higher air permeability, whereas twill weaves have higher crease recovery. Besides, Chu and Chen [11] also stated that basket weave fabrics are more pliable and stronger but less stable than 1/1 plain weave. The weave patterns and fibers that commonly used by researchers in woven fabric composite is showed in Table 6.

Table 6 Fiber and weave patterns used.

Fiber	Weave Pattern	Thickness	References
Carbon	plain, twill 2/2, Q-UD	0.49	[43]
Cotton	plain, twill & satin	0.38	[45]
Glass/Carbon	plain, twill 2/2	2.5 - 3.5	[44]

6. Interply and Intraply in Composite System

Various laminas in a laminate which might be contained fibers either all in one direction or in different directions. An interply or intraply hybrid laminate will form in the combination of different kinds of fibers. The interply hybrid laminate consists of different kinds of fibers in different laminas while the intraply hybrid laminate is which consists of two or more different kinds of fibers interspersed in the same lamina explained by Mallick [17]. In the study of Hine *et al.* [46], the development of single polymer composites is light weight and has exceptional toughness even at low temperatures. High stiffness carbon fibers combine together with oriented Nylon 6 material to produce the hybrid composite. This is because of a self-reinforced nylon sheet is lightweight, has outstanding impact performance and strength. This material can be produced in high-volume processes with those of existing carbon fiber-reinforced composites which have superior stiffness but low toughness especially in thermosets.

The hybridization of lamina is showed in Figure 7. It is found that for the intra-layer hybridization strategy, the samples were found are brittle when the carbon fibers broke will influence the whole sample broke. However, the hybrid samples remaining load bearing up to a high failure strain even after the breakage of the carbon fibers in bending.

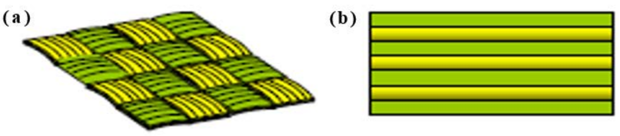
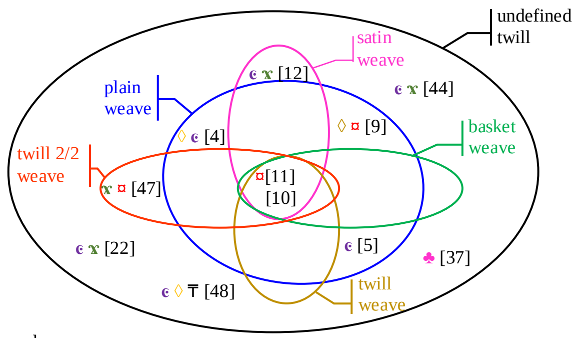


Fig. 7 Layer in hybrid composite (a) intraply, and (b) interply [46].

Nevertheless, the intraply and interply hybrid composites based on E-glass and poly (vinyl alcohol) woven fabrics on the behavior of tensile and impact properties, with particular regard to the effects of the plies stacking sequence and loading direction have studied by Pegoretti *et al.* [5]. This is due to the present of PVA fibers resulted in improving the specific impact energy of E-glass laminates and impact resistance for crack propagation was higher for intraply compared to interplay hybrid composites.

7. Review Summary

In this literature review, the information and knowledge which related to this research have been covered including the theory aspect as a guidelines and references to implement a new intraply for glass fiber and kenaf fiber in composite structure applications. In recent years, several researches are focused on the effect of fiber hybridization in composites laminate. There is broad research on composite was found using synthetic fibers, but awareness on environmental is increasing which allow researchers have been seeking for new replacement to reduce the use of synthetic composite materials. Figure 8 has showed several studies implemented natural fiber in composite and it has high potential to adopt ductility and increasing tensile, flexural and impact properties significantly. The common use of matrix is epoxy and polyester which is categorized as thermosetting polymer resin.



Legend:
¤, ȼ, ɤ, ◊, ♣, ₸ is Kevlar, Glass, Carbon, Coir, Kenaf, Human Hair respectively

Fig. 8 Graphically representing the overview of the study on weave designs.

In general, hybrid composites can be classified into two structures which are interply and intraply structure. There has been some study on the mechanical behavior and properties of unidirectional hybrid, cross-ply interply and intraply laminate composite. However, intraply of woven hybrid composites, type of fibers intermingling and the weaving structure have not been studied yet. It is found that the common used of weave types in woven composite are plain, satin, twill and basket weave have been widely studied. As highlighted in the Figure 8, there is no significant study on the kenaf fiber in intraply lamina composite while mostly is focused on laminate composite.

Furthermore, only few researches showed the changes in the weaving structure affecting the mechanical properties of composite significantly, but mostly are studied on the layers and thickness of composite laminates which gives impact on the composite structure like Zhang *et al.* [44]. In order to improve the better properties of composite, the high potential materials that can be developed are glass fiber and kenaf fiber. The widely used resins are epoxy and polyester where epoxy has good adhesion, good chemical and environmental resistance and insulating properties, but polyester has very good composite properties and low cost compared to epoxy. Therefore, there are high potential to conduct scientifically study for intraply hybrid lamina by using different weave patterns design.

8. Conclusion

Based on the previous studies, various types of fibers and weaving structures focus on the multilayer laminate composite. However, the woven fabric composites have attracted a significant amount of attention due to their highly specific strength and stiffness. Intraply hybrid composite is balanced in terms of strength, stiffness and mechanical properties. It also reduces the weight and cost, gives a better fatigue and impact resistance. Therefore, by creating a new possibility of intraply hybrid lamina composite which glass fiber and kenaf fiber as reinforcement, it is possible to obtain viable compromise between mechanical properties and cost in order to meet specified design requirement. Besides that, the new intraply hybrid lamina composite allows to generate deep understanding on the role of glass fiber and kenaf fiber in hybrid composite structure after undergo mechanical testing. It is also able to foster the interest to conduct research on intraply of different reinforcement in composite.

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