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The application of 2D woven kenaf reinforced unsaturated polyester composite in automotive interiors

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Abstract. A 2D woven kenaf reinforced Unsaturated Polyester (UPE) has been successfully developed for pillar A and door panel for interior automotive parts. This study of woven kenaf fibers reinforced unsaturated polyester focused on application of 2D woven kenaf UPE for the purpose of automotive interiors parts. The reinforced preform selection was done based on the design with fixed and identified parameters. Plain weave design was selected as a reinforcement due to the stability and superior flexural and impact strength. Vacuum Infusion Process (VIP) was selected as a processing method to prepare the interior composite parts. Two different parts were selected in this study, which are pillar A and upper door panel, and the products show similar physical properties. The result indicates that the 2D woven kenaf UPE composite was proven capable to be applied as automotive interior parts.

1. Introduction

In recent decades, global automotive industries have been under pressure due to environmental issues where various regulation was introduced for the sake of environmental protection. One of the issues is recycling automotive interior parts, which has become difficult because most petro based polymer materials are mixed with composite structures. Current disposal methods for these auto interior parts are either garbage dumps or burning, both causing environmental concerns [1]. A substitution of common raw materials, which are currently largely produced from fossil (petrochemical) or mineral resources, to products produced from renewable (plant and animal based) resources is required.

Interior parts in automotive consists of door panels, pillar, cup holder, glove box cover, and dashboard. Traditionally, it used petroleum based material such as polypropylene (PP), Acrylonitrile Butadiene Styrene (ABS), polyethylene terephthalate (PET), polyoxymethylene (POM) and polyvinyl chloride (PVC) [2]. This is because automotive material use lighter material to reduce the weight of the vehicle but pure plastic is low in strength. Parts that require strength use reinforced plastic, which consist mostly of glass fibers due to its strength and ease of works. Pradeep [3] has listed some of the properties and the use of composite in door panel by automakers as shown in table 1.

Table 1. Properties and Use of composite in Door Panels by Various Automakers

Polymer	Tensile Strength (MPa)	Flexural Modulus (GPa)	Automaker
Glass fiber–PUR	253.8	0.4–0.5	VW
Long glass fiber reinforced–PP	151	9.36	Ford

However, due to environmental issues, the replacement with biodegradable material such as natural fibers reinforce composite is more preferable. At present, the use of natural fibers reinforced plastics for interior parts can be classified as low. Among the wide range of natural fiber that is being used as reinforcement, kenaf bast fiber is known to have the potential as a reinforcing fiber in plastic composites. This is because of its superior toughness and high aspect ratio in comparison to other fibers [4]. The use of kenaf fibers reinforced plastics for interior parts require several major technical considerations before it is accepted as a substitute for existing material. Most interiors parts require a high standard of mechanical performance but it is difficult to find an optimum material that can fulfil all requirements [5].

In general to improve the mechanical performance of kenaf fibers as reinforced material, it is necessary to transform it into more stable materials. Among natural polymer composite for long fiber is two dimension (2D) woven preform consisting of two yarns, a warp yarn in vertical direction and weft yarn in horizontal direction that are interlaced together. The advantages of 2D woven preform are good dimensional stability in warp and weft direction, high yarn packing density, high out-of-plane strength, low shear rigidity and a good formability [6]. To obtain the best woven preform for the reinforced in composite, consideration must be given to the strength, stiffness and lightweight of the material as shown in Figure 1.

The weave design plays an important role as it covers all the properties for the composite and that less crimp will lead to superior properties. Weave design with less yarn crimp has great influence on the mechanical properties of the textile composite. A good design with low tightness of pattern will contribute less crimp and increase the preform properties. The lightweight and stiffness properties have opposite parameters but when considering the composite, the stiffness becomes the priority. However, a drawback on linear density of the yarn may appear due to the use of bast staple yarn which is linked to irregularity. 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% [7]. However, it can be overcome by selecting suitable processing method.

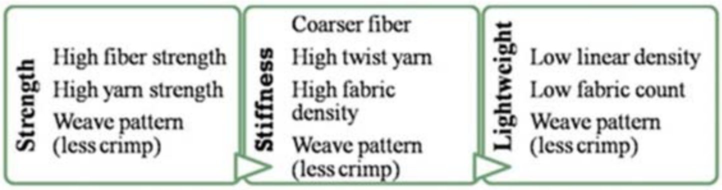


Figure 1. Diagram of the parameters affecting 2D woven preform

Typically producers of natural fiber-based used mat or other material forms with processing method of compression molding, injection molding, thermoforming, and structural reaction injection molding, which are all processes utilized to process natural-fiber composites [8]. In general, using injection molding to process 2D woven preform using thermoset resin and to transform it into composite is not suitable. Therefore, most studies have used resin infusion process which covers the use of RTM, SCRIMP, VARTM and VIP. An open mould application such as VIP has advantages, as it produced one side moulded with uniform surface while the uneven surface can be hidden. Other than that, it produces low voids composite, low cost and complex parts. In addition, VIP technology, which uses vacuum pressure to force resin into a composite, gets more attention due to its capability of large structures with excellent mechanical properties [9]. However, for small parts and mass production, it is less appropriate since it cannot be manufactured repeatedly, but for the purpose of study it is an option. Other than that, the main drawback to use VIP is that the resin must be very low in viscosity.

Unsaturated polyester (UPE) resin is a low cost thermoset resin which is preferred by manufacturers because of its capability to be processed, good mechanical properties and curing in ambient temperature. Thermoset UPE have many applications as in the production of components for automotive, aircraft, building and marine. The processing viscosity of UPE is controllable with the presence of styrene which make it preferable to process fiber reinforced composite. The purpose of styrene is to dilute the polyester which reduces the viscosity to facilitate the flow and it is compatible with the use of equipment for resin infusion process.

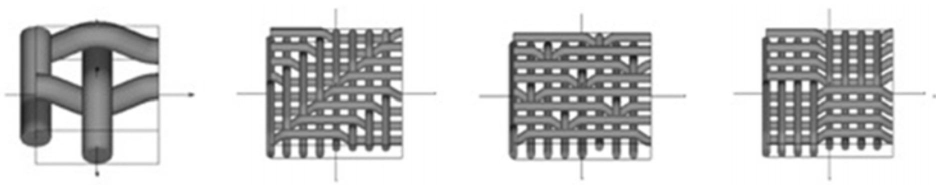
Therefore, in this work, a study on the structure of the composite has been done by fixing a certain parameters and focusing on the weave design as the independent variable. The best results will be selected to be used as a material for automotive interior parts.

2. Methodology

2.1 Materials.
Considering that various factors effecting 2D woven preform have been described in Figure 1, related information from the kenaf yarn as fixed parameters was taken through testing and applied to each sample.

2.1.1 Kenaf yarn. The kenaf yarn was supplied by Juteko Bangladesh Pvt. Ltd, Dhaka, Bangladesh with linear density of 759tex or 1mm in diameter with Z twist direction. The testing was conducted on the kenaf yarn to gain its properties. It consists of twists per meter using SDL Electric Twist Tester Y220B according to standard test ASTM D1422. The single yarn strength test used LLYOD, LR30K Universal Tensile Machine according to ASTM D2256.

2.1.2 Fabrication of Dry Preform and Composite. In this work, the selection of the reinforced material begins with the fabrication of 2D woven preform consisting of familiar weave design used in composite industries for man-made fibres. The design consists of Plain 1/1, Twill 4/4, Satin 8/3 and Basket as shown in Figure 2.



(a) (b) (c) (d)

Figure 2. Selected design of a) Plain 1/1 b) Twill 4/4 c) Satin 8/3 d) Basket 4/4

The fabrication of the preform as shown in Figure 3 begins by weaving the 759 tex of kenaf yarn into selected design using a floor loom. The density of the woven preform is 5 ends x 4 picks per cm with the length and the width according to the area of the sample for mechanical testing.

(a) (b) (c)

Figure 3. Fabrication of 2D woven preform (a) Kenaf yarn (b) Floor loom (c) 2D woven preform.

2.2 Fabrication of Composite Panel.
The composite panels were fabricated using vacuum infusion process. The matrix material used unsaturated polyester resin (2597P-I), and methyl ethyl ketone peroxide (MEKP) as the catalyst was provided by Wee Tee Tong Chemical Pvt. Ltd., Singapore.

2.3 Testing
2.3.1 Preform testing. The testing was conducted on 2D woven preform and was conducted only on warp direction. The woven preform thickness was tested using fabric thickness gauge. The testing for woven preform breaking strength used standard test ASTM D5035 and the fabric cover factor was calculated according to (1):

$$Cover\ factor\ (S.I) = \left(Yarns\ per\ cm\ \times \sqrt{Tex}\right) \div 10 \tag{1}$$

The crimp percentage is determined according to the formula below (2):

$$Percentage\ of\ Crimp = \frac{P-L}{L} \times 100 \quad (2)$$

where L = distance between two ends of a yarn onto the plane of the preform
P = actual length of the yarn

2.3.2 Mechanical testing on composite. The woven kenaf composites panel of 759tex of yarn were tested on the tensile and flexural using LLYOD, LR30K Universal Tensile Machine. The test sample was conducted on the warp direction. The tensile test for the composite was carried out according to ASTM D3039 at a crosshead speed of 1mm/min and the flexural test used ASTM D790. The impact test used ASTM D3763 using SHIMADZU Hydroshot Impact Test Machine HITS-P10 using test speed of 10 m/s. The high speed impact data processing program generated the impact energy value in Joule (J) at maximum load applied.

2.4 Fabrication of automotive interior component.

The fabrication of automotive interior composite parts begins with the preparation of fiber glass mould for pillar A and upper part door panel from *Proton Persona* as shown in Figure (a) & (b). The mould was made using hand lay-up method and used actual component as a pattern. The mould was placed in a flat surface with each empty space covered. A preform was then carefully placed on the fiber glass mould and ready for full set of VIP as shown in figure 4 (c).

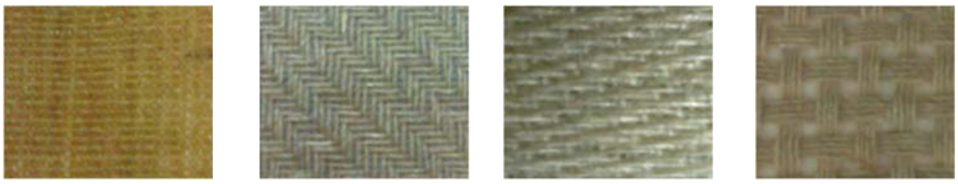
(a) (b) (c)

Figure 4. The fabrication of automotive interior parts (a) door panel (b) fabrication of mould (c) fabrication of door panel using VIP.

3. Results and Discussion

3.1 Composite panel

Figure 5 shows the composite panel from 759 tex of kenaf yarn with constant specification of yarn properties but different woven preform design. The panel used unsaturated polyester resin where it is transparent and capable to see the woven preform design structure. The entire composite panel has a stable structure after being processed using VIP, but basket 4/4 shows that the structure has changed. The adjacent yarns close between each other for each group of interlacement leaves a big space without any reinforcement. In this situation, two possible things might happen, as the space without reinforcement will become the weakest point while the tight yarns become jam structure making it difficult for resins to penetrate.



(a) (b) (c) (d)

Figure 5. The composite panel of (a) Plain 1/1 (b) Basket 4/4 (c) Satin 8/3 (d) Basket 4/4.

3.2 *The properties of preform and composite*

Table 2 shows the specification of woven preform taken in consideration following the parameters in Figure 1. The yarn twist is 153tpm with yarn strength of 97N obtained from the test on kenaf yarn supplied by JUTEKO. The value for cover factor shows that the structure is suitable to be woven into a preform with acceptable properties for composite processing. It is supported by Sondhelm [10] that when cover factor reached 16, it is a tight structure and starts to jam. This will affect the penetration of the resin between intra yarns and inter yarn during fabrication process.

As stated earlier, crimp percentage plays an important role on woven preform properties. The result shows that the plain weave preform has the highest crimp percentage which cause a significant result on the thickness of the preform. This is due to the design which made the preform more compact due to compression between yarns. It is different compared to the other preforms where it has more float causing the yarns to become loose. It is also found that a significant result on the areal density of the preform as the higher the crimp percentage, the heavier the preform is. This is because the higher the crimp, the longer the yarn being used and more fibers are inside the preform or the higher the fiber volume fraction is. However, between twill 4/4, satin 8/3 and basket 4/4, it can be seen that the value for thickness and areal density for the preforms are more likely to be influenced by external factors during the fabrication, while for all the composites, due to the VIP process which is an open mould, the result does not show a significant trend. Nevertheless, the values for thickness and areal density may serve as a guide during the fabrication for the automotive interior parts.

Table 2. The specification of preform and composite in warp direction according to suggested parameters.

			Thickness		Areal Density		Tensile Test		
							Preform	Composite	
Type of weave	Cover factor	Crimp %	Preform (mm)	Composite (mm)	Preform (g/m^2)	Composite (g/m^2)	Tensile strength (N/mm)	Tensile Strength (MPa)	Tensile Modulus (GPa)
Plain 1/1	13.77	16	2.77	2.50	868	2518	38	32	2.6
Twill 4/4	13.77	3	3.36	2.42	848	2613	42	35	2.9
Satin 8/3	13.77	4	3.37	2.35	825	2268	44	39	3.7
Basket 4/4	13.77	3	3.17	2.25	819	2703	49	33	5.8

The crimp percentage of plain woven preform also effect the preform strength where it has the lowest value. This is due to the behavior of a preform where yarns with crimp will use the initial load to consume straightening bent yarns and then take up the load, subsequently leading to low strength materials [11]. The result is also proportional with the tensile strength of the composite; the higher the woven preform strength, the higher the strength of the composite. However, it is different for Basket 4/4 as it decreases when it is transformed into a composite. This has already been explained in previous study as the structure of basket 4/4 changes after been process, which leads to a jammed structure and produces large empty spaces without any reinforcement [12]. The tensile modulus determines the stiffness of the composite and it is found that the strength of the woven preform is proportional to the stiffness of the composite. Therefore, in terms of tensile strength and the stiffness of the composite, it shows that satin 8/3 has the greatest strength while basket 4/4 has the highest stiffness properties.

Figure 6 shows the results on the flexural strength and the impact strength of the composite for different woven preform design. The results shows that the composite from plain weave has the highest strength either for flexural or on the impact strength. This means that the plain weave is superior to resist deformation and capable to withstand a sudden force compared to other designs. Both properties have been mentioned by Faris and Sapuan [13] as among properties which are important in the making of automotive parts from natural fiber composite.

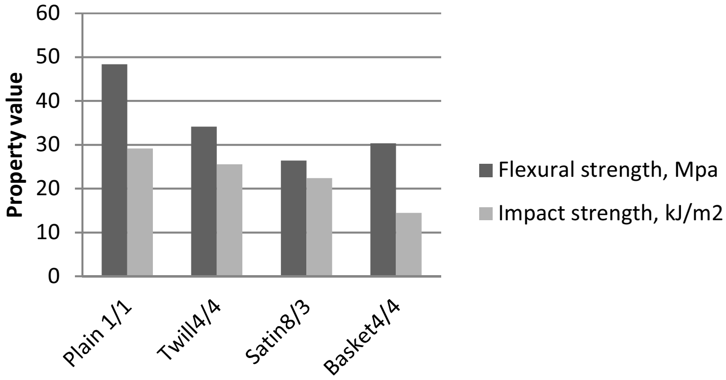


Figure 6. Flexural and impact strength of composite for different woven preform design.

Overall, the results have shown that the use of 2D woven plain composite is low in tensile strength and tensile modulus compared to the other designs. However, the structure of plain weave is more stable while the thickness and the areal density is still within acceptable limits. Moreover, the result from the flexural and impact strength shows that the plain weave is more superior. Therefore, the 2D plain woven preform has been selected as a material for the fabrication of pillar A and door panel.

3.3 Automotive Interior from 2D Woven Kenaf.

Figure 7 shows the result of 2D woven kenaf preform transformed into automotive material. As highlighted, the selected 2D woven plain preform was fabricated into pillar A (Figure 7 (a)) and upper part of the door panel (Figure 7 (b)). It shows that VIP can be produced for each part with dimensions as accurate as the original. However, there are areas that have voids which will effect the mechanical properties and the surface of the parts, especially when painted. Most of the voids are at the back, edges and end of the parts where it most probably occurs as a result of suction of vacuum infusion process.

(a) (b)

Figure 7. Automotive interior parts (a) actual pillar A from Proton Persona, pillar A composite before painting and pillar A after painting (b) parts of door panel composite painted green.

Figure 8 shows the pillar A and door panel made from 2D woven kenaf reinforced UPE composite was successfully assembled on the Proton Persona car. Each parts indicates that the dimension is like the original parts and it fits with the other parts when it is assembled. However, each part requires finishing process either surface finish or to obtain dimensional accuracy.

(a) (b)

Figure 8. Composite parts consists of upper parts of door panel and pillar A (a) left side of car door (b) right side of car door.

A review by Ashori [14] shows that the weight of automotive interior components made from plant fibers by many vehicles manufacturers is between 0.4kg to 2.5kg. It can reach 5kg depending on the component parts. The work has resulted in pillar A with weight of 245g and the thickness of 2.34mm, which is in the range of the panel samples. Compared with the actual pillar A for Proton Persona, the weight is 250g with the thickness of 2.55mm, which is almost the same. However, the thickness of the weight of the component depends on the kenaf yarn size, which will affect the other properties.

4. Conclusion

The 2D Woven Kenaf Reinforced UPE composite were successfully fabricated into automotive interior components. The selected plain weave design is low in tensile properties but it is structurally stable with superior flexural and impact strength compared to other weave designs suitable to be fabricated into composite for interior parts. Based on the output of this work, the 2D woven kenaf preform is capable to be used as interior parts but requires a process that is more suitable for large-scale production. The results also indicate that the composite has the same physical properties with the existing parts. In addition, natural long fibers reinforced composite has been considered a very interesting alternative to overcome the problems related to land pollution due to automotive interior parts. It is recommended for future study, to include on the processing technique such as sandwich structures as it may increase the strength on the natural fiber composite.

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