MECHANICAL PROPERTIES OF HYBRID WOVEN KENAF/RECYCLED GLASS FIBRE REINFORCED POLYESTER COMPOSITES

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ABSTRACT
The use of glass fibre reinforced polymer (GFRP) composite leads to waste management problems due to its non-biodegradable property. In Malaysia, most of the composite wastes end up in by landfills. This however is relatively low cost method of waste disposal which may cause the leaching of contaminants into local water supplies. Hence, an alternative method to handle the wastes is essential. One of the potential methods is by using GFRP waste as reinforcement in composite materials. In the present study, the mechanical properties of recycled GFRP (rGFRP) waste fibre hybridized with woven kenaf were investigated. Glass fibres were segregated from other constituents of GFRP waste through mechanical grinding. Results revealed that the mean flexural stress of hybrid woven kenaf/rGFRP polyester composites increased 46% compared to woven kenaf/glass fibre polyester composite. Tensile stress of hybrid woven kenaf/rGFRP composite results is comparable to woven kenaf and slightly lower compared to woven kenaf/glass composites, ranging at 70 MPa to 85 MPa. Failure analysis observed by Optical Microscope and Scanning Electron Microscopic (SEM) indicates that woven kenaf/rGFRP failure due to shear stress and compression after flexural test performed. Tensile fracture analysis observed rGFRP successfully interlocking in between 2 layer of woven kenaf. It can be concluded that rGFRP is potential to replace virgin glass fibre for reinforcing woven kenaf fibre composites. This study identifies an effective GFRP waste management solution with cost-effective which is beneficial for composite structural application purposes, hence contributed to sustainable fibre-reinforced polymer composites.

Keywords: Recyclate, Kenaf, rGFRP, Tensile, Flexural

Introduction

Even though there are many successful uses for composite materials, recycling at the end of the life cycle or composites waste is a more difficult issue. Composites are often manufactured in combination with other materials results in recycling barriers. Furthermore, for structural application thermosetting matrix polymers used will be cross-linked and cannot be remoulded. For an example, common thermosetting resins, such as polyester and epoxy are not practical to depolymerise to their original constituents[1]. Composite waste traditionally ends up as landfill, incineration and material recycling. In the European countries, a landfill is not a feasible of treating composite waste due to legalisation procedure, but in Asia pacific country such as Malaysia, the traditional method still practiced [2]. Although landfill is a relatively cheap method of waste disposal, the leaching of contaminants into local water supplies is causing major concern [3]. Thus, recycling GFRP waste is importance for sustainability and reduce environmental impact. Thus, recycling GFRP waste is importance for sustainability and reduce environmental impact.

RECYCLE GLASS FIBRE REINFORCED POLYESTER (rGFRP)

Glass fibre reinforced polymer (GFRP) application more than 50% used in composite consumption globally 2015 forecasted by Visiongain, The Composites Market Report 2014-2024 [4]. Primarily used in the automotive and transport sectors, the electrical/electronics industry and the construction industry due to its unique properties and low in cost [5]. As a review the global output of GFRP recorded increasing every year, as year 2000, the output of composites was at 7 million tonnes and

estimated to reach 10 million tonnes in 2006. In 1992, approximately 10%, or 12.6 million tonnes of waste generated by the United States, is plastic with only 1% being recycled. Most of composite waste end up by landfills or waste incineration. Manufacturer are enforced with law and regulation to save the mother earth, European Union (EU) was enforcing law and legislations to composites waste:

(i) Directive 1999/31/EC on Landfill of Waste,
(ii) Directive 2000/76/EC for Incineration of Waste and
(iii) Council Directive 2000/53/EC on End of Life Vehicles. [6]

Recycle glass fibre reinforced polymer (rGFRP) is the higher waste produce in composite, however because of its cheap and easy to produce its recycling process is not money back orientated. There are three main methods in recycling composite materials which are mechanical recycling, thermal recycling, and chemical recycling. In recycling glass fibre composites, mechanical recycling is the most potential method due to low-cost process. Successful study to recycle the rGFRP was studied by Aono, Murae, & Kubo, 2011 interleaf rGFRP in unidirectional glass fibre found that higher compressive strength compared with unidirectional glass fibre composite [7]. However, its tensile strength dropped 17% compared to composites without rGFRP interleaf. rGFRP improved compressive strength of cement and concrete composite revealed studied done by Asokan, Osmani, & Price, 2009 [8]. Souza et al. 2014, studied friction coefficient and wear rate glass fibre waste filler in polyester composites with sliding wear test enhanced its properties compare to control sample CaCO3 filler composites [9].

Environmental awareness and legal enforcement driven composite manufacturer to venture into environmental friendly fibre thus, natural plant fibres are the best alternative. The advantage of natural fibres over other established materials will be environmentally friendly, fully biodegradable, abundantly available, renewable and comparable low density. Furthermore, properties such as being lightweight, of reasonable strength and stiffness make it a material of choice when replacing synthetic fibres [10]. However natural fibre reported by many researcher, low in mechanical properties compared than glass fibres. Hybridization with glass fibre reported potentially solve this issue [11]. Glass fibre typically selected to be hybridize with natural fibres due to it cost reasons. An alternative to used rGFRP as a hybrid reinforcement will be beneficial to cost effective and environmental impact.

In this study the mechanical properties of rGFRP as hybrid reinforcement interleaf of woven kenaf are compared to hybrid virgin glass reinforcement. Woven kenaf polyester composite was selected to be a control sample. Mechanical properties such as tensile and flexural behaviour and properties will be analysed.

Experimental Set Up

Material

The following section describes the properties of all materials used in this research. There are three main fibres involved in this research, woven kenaf, recycle glass fibre (rGFRP) and E-glass fibre. Kenaf polyester composites and kenaf/glass (CSM-chop strand mat) composites selected as control sample, and all gathered data will be compared respectively. Kenaf (Hibiscus cannabinus L) is one of the most widely used natural fibre in composites, kenaf is Malaysia crop replacing tobacco plantation. Kenaf has good mechanical properties and can grow quickly, rising to as height as 4-5 m in within 4-5 month growing season with the kenaf's stalk diameter of 25-35 mm [12]. Extensive study on kenaf lead to higher potential application in the composite industry. Unsaturated polyester selected for matrix in the composites. Kenaf fibre used as reinforcement in composites supplies by Innovative Pultrusion Sdn. Bhd, Seremban, Malaysia. Spool of kenaf yarn with tex size 1000 then weaves using a lab scale self-designed handloom. The resin used in this study was unsaturated polyester wax resin supplied by S&N Chemicals Sdn Bhd. The density of polyester resin is 1.3 g/cm^3. Glass fibre chop strain mat was also supplied by S&N Chemical Sdn. Bhd. Milled recycle glass fibre reinforced polyester (rGFRP) was supplied by Astotech Sdn. Bhd. Kuala Terengganu, Malaysia. Table 1 shows the properties of reinforcement fibres involved in this study.

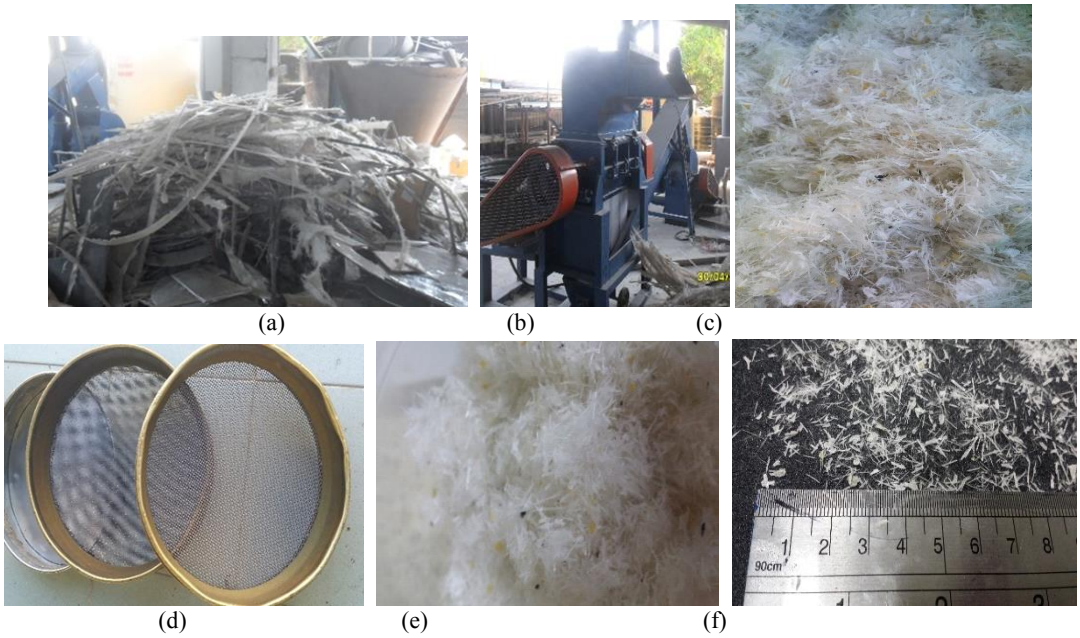
Table 1: Kenaf, rGFRP and E-glass properties

Property	*Kenaf*	*E-glass*	*rGFRP*
Fibre Diameter	1000 Tex	12.5 µm	
Binder Type	•	Styrene	-
Binder %	-	7%	-
Weight / Areal Density g/m^2	Woven density 1500g/m^2	30	-
Density g/m^3	1.27	1.57	1.35
Length	Long Fibre	2 mm	(>2mm) (<5mm)

Material Preparation

Glass fibre polyester industry wastes was cut into smaller pieces as shows in Figure 1(a) suitable to be fed into mechanical recycling machine Figure 1(b) and grind according to the machine hammer mill capabilities results as Figure 1(c). The raw milled rGFRP are then washed and oven dried before sieving process by siever size 0.2 mm to removed resin powder and impurities. rGFRP then weighted as same areal density of selected used glass mat fibre. The rGFRP length measured to identified it length range and weight density measured as 1.35g/m^3.

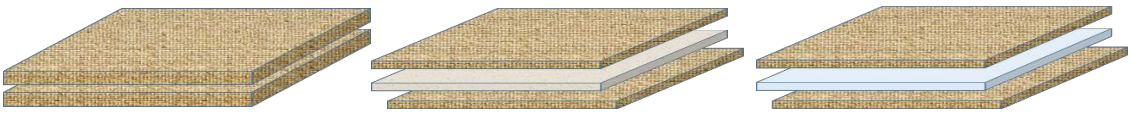
Figure 1: Preparation of recycle GFRP waste (a) GFRP waste before feeded into grinding machine (b) Grinding Machine Astotech sdn. Bhd.(c) Milled rGFRP (d)sieved (e) sieved rGFRP (f) rGFRP length measured



Preparation Of Composite Samples

Composites were design and fabricated in the laboratory with varying interlayer of kenaf composites as illustrated in Figure 2. Closed mould compression moulding method was selected for fabrication with polyester resin as the binder. Methyl ethyl ketone peroxide (MEKP) hardener with 1% wt percentage by the resin were mix prior of fabrication process. Composites sample fabricated by three types as illustrated in Figure 3, kenaf composites with 2 layer kenaf name as kenaf composites, kenaf/glass composites fabricated by 2 layer kenaf with virgin glass fibre interleaf and kenaf/rGFRP composites consist of 2 layer kenaf with rGFRP interleaf. rGFRP weighted as much as virgin glass fibre mat.

Figure 2: Kenaf and kenaf hybrid composites design



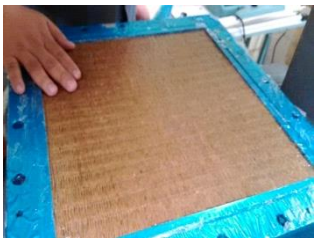
(a) Kenaf composites (b) Kenaf/glass composites (c) Kenaf/rGFRP composites

The fabrication process as shows in Figure 3, the polyester resin was poured and spread over fibre before compressing in the closed mould by hydraulic compressor at one bar pressure. The average composite fibre-resin fraction is 35% weight percentage and average thickness measured at 4 mm. the composite was let to cure for 24 hours at room temperature. The composite plate was cut using band saw into samples size of 250 mm x 25 mm and 150 mm x15 mm for tensile and flexural tests according to [13] and [14], respectively. Tensile test sample were tabbed at both end with woven glass/polyester composites size of 50 mm x 25 mm size.

Figure 3: Hybrid woven kenaf/rGFRP composites fabrication

(a) Woven kenaf cut into mold size

(b) rGFRP interleaf between 2 layer kenaf



(c) Cured sampled after 24 hours in room temperature

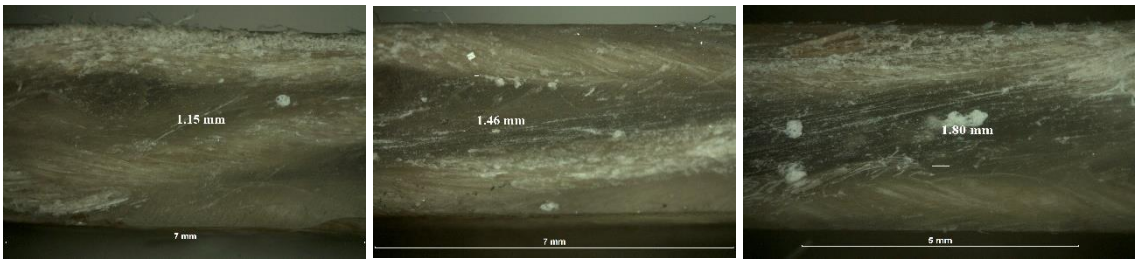
Mechanical Testing

Tensile test was performed at the crosshead speed of 2 mm/min using the universal testing machine. An extensometer was clipped on the specimen with gauge length of 50 mm to measure the elongation of the specimen. Three-point flexural test was performed at span to depth ratio of 16:1 as recommended by ASTM D 7264. Specimens were tested at a crosshead speed of 1.5 mm/min using the same universal testing machine as tensile test. Five replicates were repeated for both tests.

Results And Discussion

The experimental results of tensile strength is shown in Table 1. In general conclusion rGFRP reinforcement significantly affects the mechanical properties of the hybrid kenaf composites. The composite sample of tensile and flexural testing were cut, polish and measure its average thickness observed under optical microscope Ziess S2000. Interleaf virgin glass fibre and rGFRP in kenaf composites increase it thickness measured at 1.15 mm for kenaf composites, 1.46 mm kenaf/glass composites and 1.80 mm kenaf/rGFRP composites, as shown in Figure 4. Higher value in kenaf/rGFRP samples thickness of compared to kenaf/glass is due to residual resin bonded together with rGFRP fibre. The mechanical properties results obtained from both testing tabulated as in Table 2. Stress versus strain curves are plotted and shown in Figure 6 and 7, and typical failure modes in Figure 5.

Figure 4: Average Thickness of interleaf hybrid kenaf composites



(a) Kenaf composites (b) Kenaf/glass composites (c) kenaf/rGFRP composites

Flexural Properties

The flexural strength measured by three-point flexural test method using the universal testing machine Instron 5980. From the data tabulated in Table 3, shows results of flexural tests indicate significant improvements in flexural strength and modulus for rGFRP reinforced composites as compared to the control samples. Kenaf/rGFRP composite flexural strength calculated as 181.98 MPa 46.7 percent higher compared to kenaf/glass composites. Kenaf and kenaf/glass composites show comparable flexural strength measured at 123.39 MPa and 124.07 MPa respectively. The bar chart for maximum flexural strength as shows in Figure 6(b). Flexural modulus of kenaf, hybrid kenaf/glass and kenaf/rGFRP are measured at 4.9 GPa, 4.51 GPa, and 8.69 GPa respectively. The flexural deflection of kenaf/rGFRP shows lower value compared to control sample. The results of increasing in flexural properties for hybrid natural fibres with synthetic fibre kenaf/kevlar also found by R Yahaya et al. 2014, increased in flexural properties at 63% Kevlar weight percentage. For non-woven hybrid pineapple leaf/sisal and glass done by Mishra et al. 2003, flexural strength of hybrid composites sisal/glass were constant when reach 7- 8% weight percentage of glass [15][16]. In this study,rGFRP fibre glass content is lower compared to virgin glass due to residual resin improved it flexural properties. Garcia et al. 2014 studied on effect of incorporating rGFRP in microconcretes from different type of GFRP waste, the finding is inclusion of rGFRP reduce microconcrete flexural and compressive strength [17] .

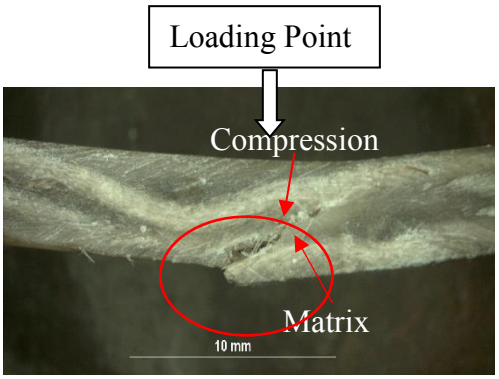
Table 3: Mechanical properties of the composites

Sample	*Tensile Strength (MPa)*	*Tensile Modulus (GPa)*	*Elongation (mm)*	*Flexural Strength (MPa)*	*Flexural Modulus (GPa)*	*Deflection (mm)*
Kenaf	81.82	8.96	4.28	123.39	4.90	5.19

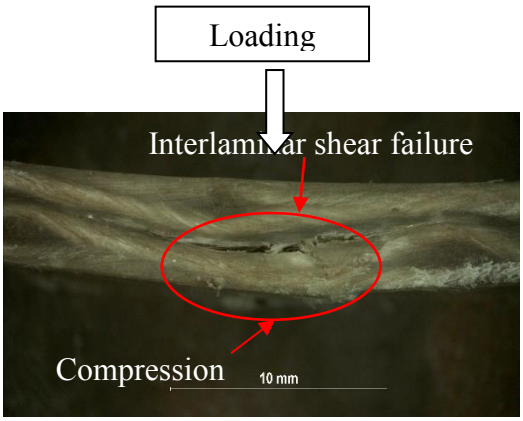
Kenaf/glass	85.49	9.88	3.69	124.07	4.51	5.42
Kenaf/rGFRP	73.66	6.40	4.75	181.98	8.69	4.50

From the image observed under an optical microscope, there are two types of failure observed on flexural test fracture, kenaf composites face severe damage due to compression failure as shows in Figure 6 (a). Kenaf/glass fibre composites flexural failure dominated by interlaminar shear failure with minor compression failure also observed in the fracture. Kenaf/rGFRP composites failure shows both interlaminar shear and compression failure about the same length.

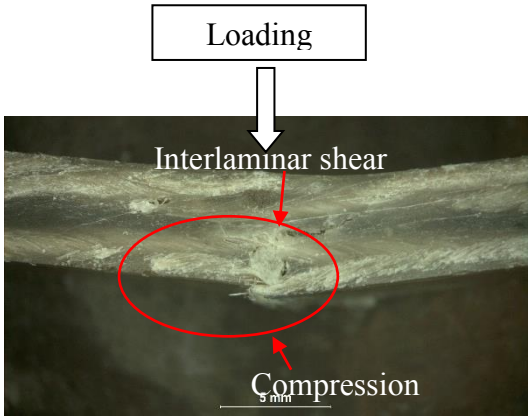
Figure 5: Flexural failure mode



(a) Flexural fracture kenaf composite



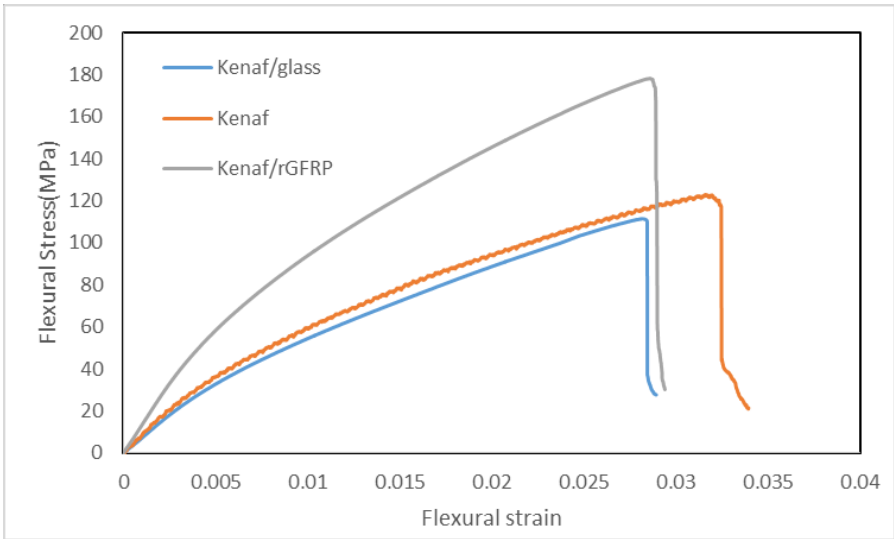
(b) Flexural fracture kenaf/glass composites



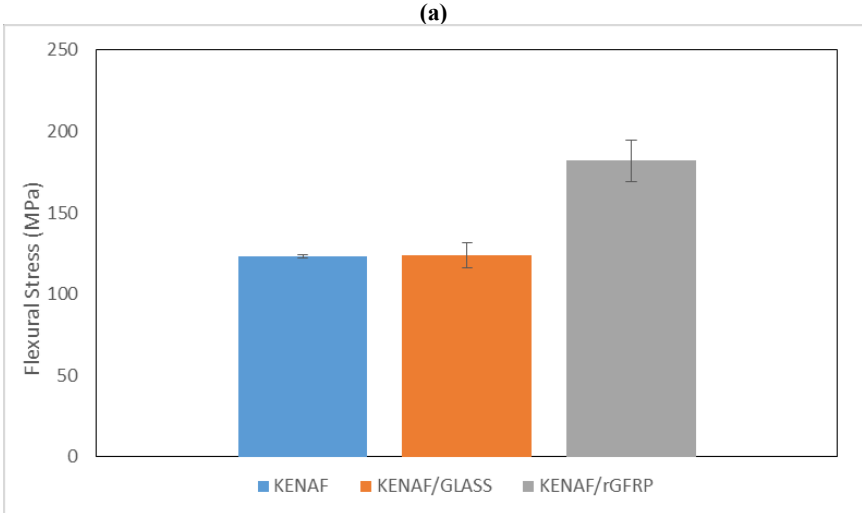
(c) Flexural fracture kenaf/rGFRP composites

Figure 6 shows the flexural stress versus flexural strain curve for kenaf/rGFRP composites compared with control sample. The curve for all sample are observed with slightly shows nonlinear trend and sudden dropped trend when peak load is attained signifies a brittle behaviour of the composites. Comparable curvature observed on kenaf and kenaf/glass sample, meanwhile kenaf/rGFRP samples shows higher flexural stress indicate its stiffer behaviour compared to other composites. Kenaf composites however shows higher in flexural strain denoted it's high in flexural elasticity.

Figure 6: Flexural properties of hybrid woven kenaf/rGFRP polyester composites comparing with kenaf and kenaf/glass composites **a)** Flexural stress-deflection curve **b)** Maximum flexural stress



(a)

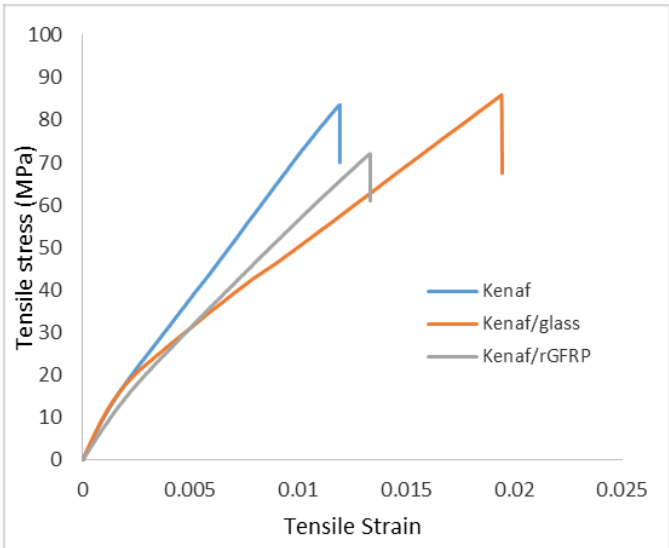


(b)

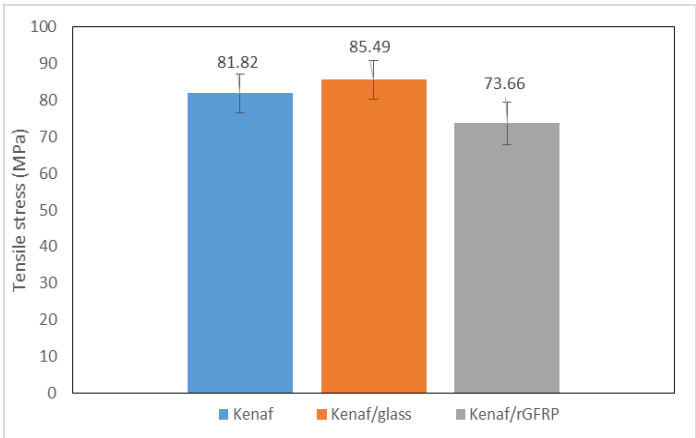
Tensile Properties

Figure 7 (a) shows the tensile load versus extension curves of the kenaf/rGFRP composite and its control samples. Comparable curvature observed of tensile behaviour, the graph is shows linear increment up to failure. The linear plot until sudden dropped when peak load is attained implies a brittle behaviour of the composites. Figure 7 (b) show maximum tensile stress for all samples, in general results shows comparable value for all samples. This shows that rGFRP are potential to be used as reinforcement in kenaf composites. Tensile properties of hybrid woven kenaf/glass is expected to increased, studied done by Sabeel Ahmed and Vijayarangan, 2008, woven jute/glass polyester hybrid shows increased in tensile strength up to 60% compared to jute polyester composites [18]. Other researcher such as Yahya et al. 2014, studied on kenaf/kelvar hybrid also found increased in tensile strength compared to kenaf composites but lower to Kevlar composite [19]. The increment in tensile strength recorded significant up to 100% with 30% kevlar fibre percentage. According to Swolfs et al. 2014, the hybrization effect for tensile strength is based on a bilinear rule of mixtures, the prediction is based on a displacement controlled test, in which iso-strain is assumed for both the low elongation and high elongation fibres [20]. However, hybrid woven kenaf/rGFRP is not agreed with the rules.

Figure 7: Tensile properties of hybrid woven kenaf/rGFRP polyester composites comparing with kenaf and kenaf/glass composites **a)** Tensile stress-deflection curve **b)** Maximum tensile stress



(a)



(b)

Morphology Studies

The fracture surfaces of the tensile and flexural specimens were investigated using a variable pressure scanning electron microscope – Hitachi S3400N. All specimens were sputter coated with gold prior to examination. Figure 8 shows the flexural fracture of rGFRP composite and its control sample. Figure 9 shows the tensile fracture surface of the composites. On the fracture surface fibre breakage, failure mode, matrix cracking, micro crack and fibre debonding observed.

Figure 8: SEM micrograph of flexural fractured (a)Kenaf composites (b)Kenaf/glass composites (c)Kenaf/rGFRP composites Kenaf/glass composites

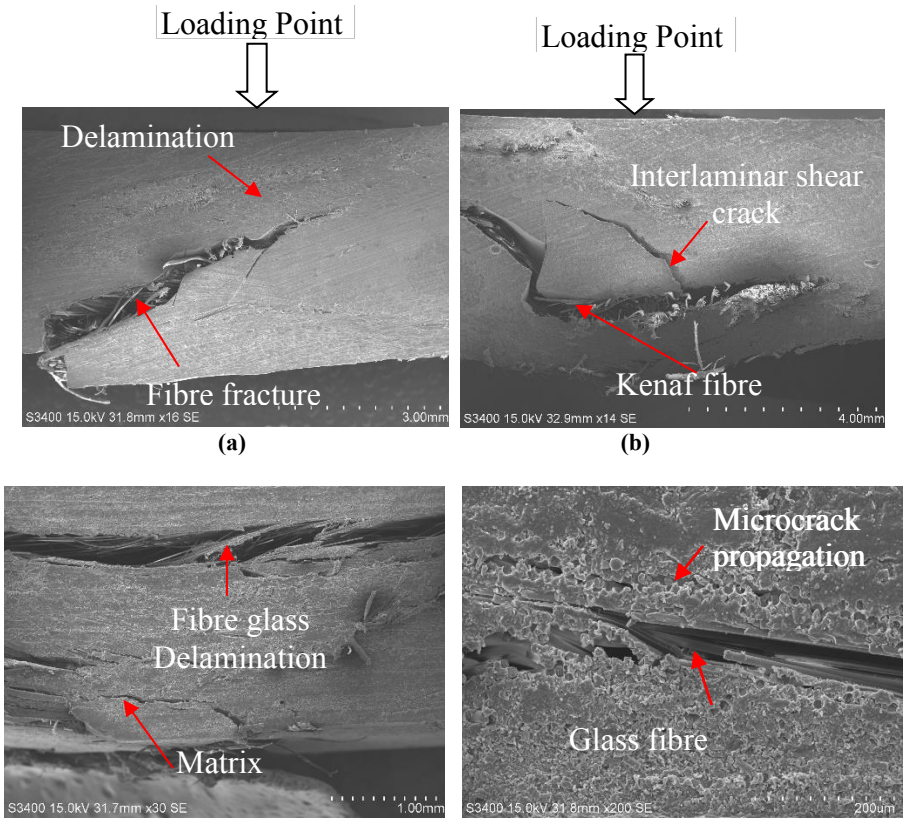
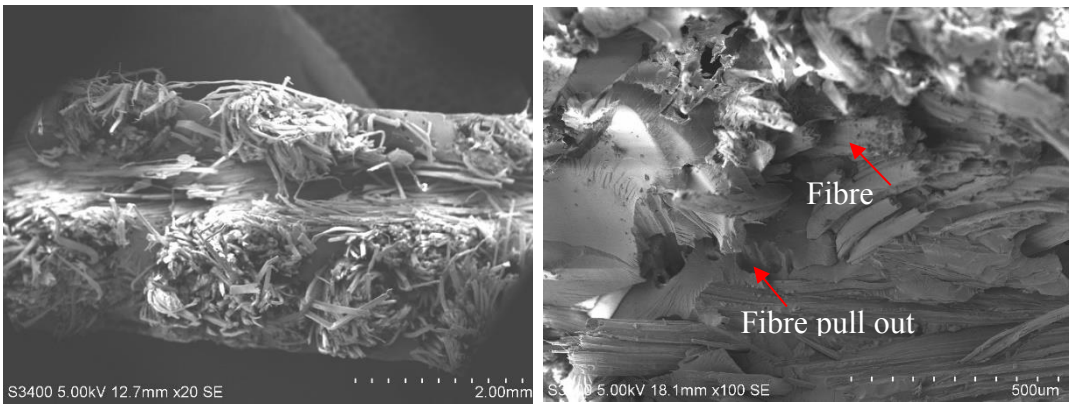
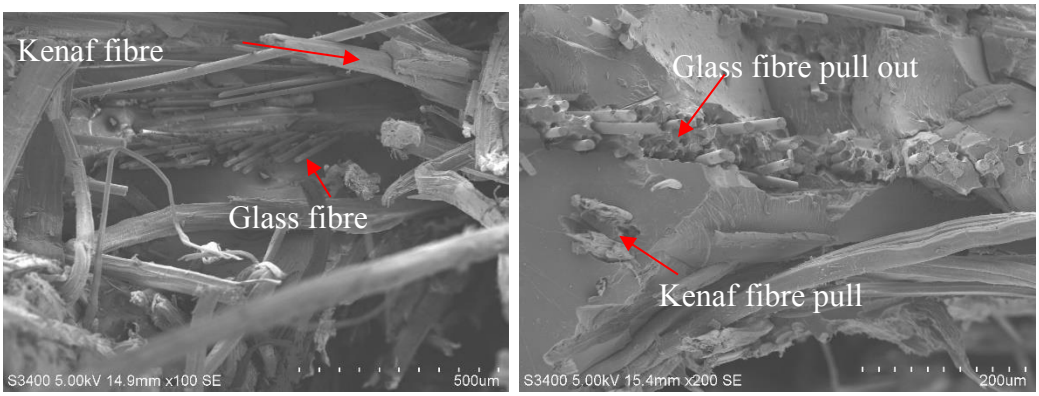


Figure 8 (a) show the SEM micrograph flexural fractured for kenaf composites, delamination and kenaf fibre fracture observed, matrix and kenaf fibre are in good contact this is because of kenaf hydrophilic properties and good fibre wetting with resin during fabrication. The fracture surfaces of kenaf/rGFRP composites shows in Figure 8(b), there are kenaf fibre fracture and interlaminar shear failure mode observed, glass fibre in rGFRP observed not to induce any microcrack and debonding compared to kenaf/glasss composites as in Figure 8 (c). Kenaf/glass composites shows severe damage due flexural test, this is because wetting properties of both fibre are different. Glass fibre hydrophobic properties results in less wetting with polyester resin initiate micro cracking hence induced interlaminar shear failure due to it low contact bonding.

Figure 9. SEM micrograph of tensile fractured (a)Kenaf composites (b)Kenaf/glass composites (c)Kenaf/rGFRP composites



(a)



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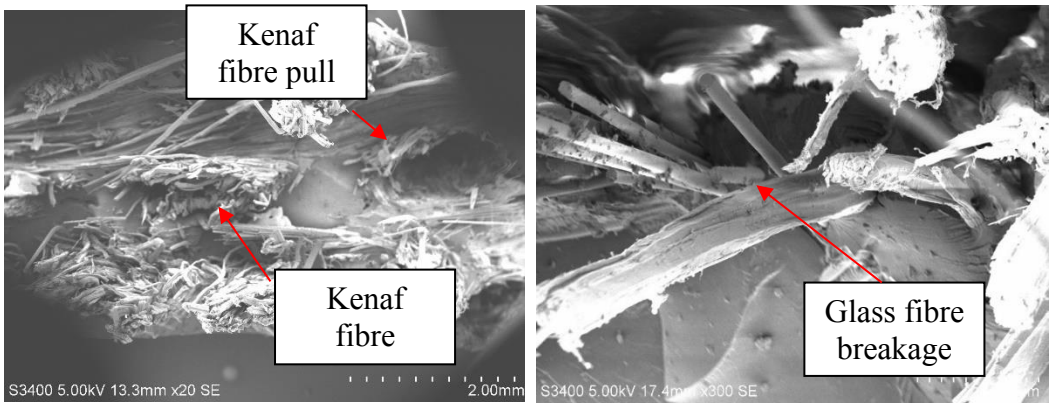

(c)

Figure 9 (a) show the SEM micrograph tensile fractured for kenaf composites, kenaf and glass fibre breakage and pull out observed on related sample. In kenaf/rGFRP samples, glass fibre observed in Figure 9 (c) interlock between kenaf fibre, thus improve its mechanical properties.

Conclusion

Mechanical properties and behavior of woven kenaf composites using GFRP waste as interleaf reinforcement has been successfully studied and their performance was compared to control sample kenaf composites and kenaf/glass composites. The incorporation of recycle GFRF proved to increased composites flexural strength and modulus. The failure fracture from flexural test revealed that increased in flexural strength of kenaf/rGFRP composites is because of improved in composites compression resistances. On the basis of the results obtained, the following conclusions can be drawn, recycled GFRP interleaf woven kenaf composites had proven to give significant effect on its mechanical properties.

1. rGFRP reinforcement shows higher in flexural strength, and flexural modulus compare to kenaf composites and kenaf/glass composites.
2. Comparable tensile strength of kenaf/rGFRP composites compared to the control sample.
3. Kenaf/rGFRP composites experiences less severe damage due to interlaminar shear on flexural fracture compared to kenaf/glass composites.

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