MECHANICAL PROPERTIES OF GLASS FIBRE WASTE/KENAF CORE REINFORCED UNSATURATED POLYESTER ECO-FRIENDLY COMPOSITES

Umar Abdul Hanan
Faculty of Mechanical Engineering,
Universiti Teknologi Malaysia, 81310 Johor Bahru, Malaysia
Email: umarhanan@yahoo.com, Tel: 013-229 0611

Shukur Abu Hassan
Faculty of Mechanical Engineering, UTM, Johor Bahru, Malaysia
Email: shukur@utm.my, Tel: 019-762 6585

Mat Uzir Wahit
Centre for Composites, UTM, Johor Bahru, Malaysia
Email: mat.uzir@cheme.utm.my, Tel: 012-701 2001

Ahmad Raizal Md Rozali
Caw. Kejuruteraan Elektrik, Ibu Pejabat JKR, Kuala Lumpur, Malaysia
Email: ARaizal@jkr.gov.my, Tel: 019-262 5287

Hj. Kamarul Bahrin Mohamad
Caw. Kejuruteraan Elektrik, Ibu Pejabat JKR, Kuala Lumpur, Malaysia
Email: kamarul@jkr.gov.my, Tel: 03-2610 8888

Mohd Arif Mat Lazi
Faculty of Mechanical Engineering, UTM, Johor Bahru, Malaysia
Email: ariflaz@gmail.com, Tel: 019-217 6810

ABSTRACT

The waste of glass fibres from industries need to be scrapped and recycled. In this regard, the main purpose of this study is to determined the mechanical properties (tensile and bending) of recycled Glass Fibre Reinforce Polymer (GFRP) hybrid with kenaf core fibre composites using vacuum assisted resin transfer moulding technique (VARTM). In this study, GFRP waste was crushed into particles which are known as recyclates (rGFRP). The recyclates (20 vol.%) were added into unsaturated polyester resin to create a new composites plate. Other than that, hybrid composites using rGFRP with kenaf core chips was also fabricated. Each composites formulation will be subjected to tensile and bending load. Samples of rGFRP composites shows better result than rGFRP/Kenaf composites in terms of tensile and bending loads. For instance, Young's modulus of rGFRP is 4.0 GPa which is 33% higher than rGFRP/Kenaf. While the bending strength of rGFRP and rGFRP/Kenaf was found to be 54 MPa and 32 MPa, respectively. However, rGFRP/Kenaf is more light weight than rGFRP by 10%. Microstructure analysis of fractured area of failed samples was based on Scanning Emission Microscope (SEM) indicates inconsistent fibre distribution which affected the result of tensile and bending test. SEM also shows air bubbles and microvoids in the resin. Furthermore, high moisture content factor in natural fibres propagate debonding between fibre and resin which negatively affected the properties rGFRP/Kenaf. The experiment results indicated that rGFRP composites will never get the initial strength of composites using new glass fibres but can be an alternative as new product without high capabilities in terms of strength and costing. Furthermore, the low density of rGFRP/Kenaf composites can be a good alternative for products using fibreboard.

Keywords:-Tensile Properties, Flexural Properties, Recycled Glass Fibre, Kenaf Core Fibre, VARTM

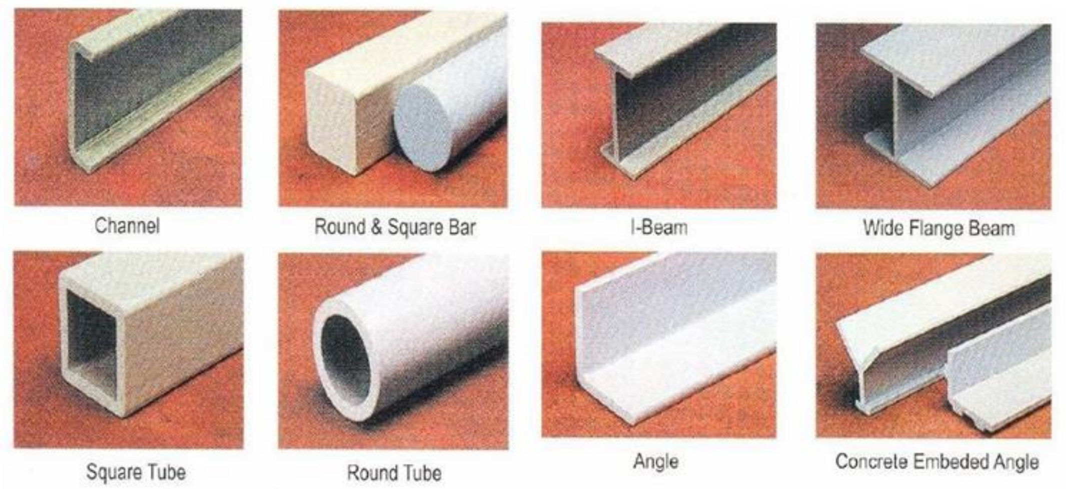
Introduction

Strength and durability are always considered as a main criteria for design and select the materials. Recently, various types of structures have suffered from corrosion problem. Many reports have highlighted the seriousness corrosion and deteriorated infrastructure (Shreir, 2013). Many countries are spending a big amount to rehabilitate and retrofit existing deteriorated infrastructure. In order to address these issues, civil engineers and researchers have been searching for alternate material to overcome the cost and maintain the damage structures by corrosion (Popoola et al., 2013). In this regard, a new durable material Fibre Reinforced Polymer (FRP) was found in the field of civil engineering (Hensher, 2016).

FRP is a combination of continuous fibre embedded in resin matrix and introduced as a better alternative for conventional materials in some applications. FRP does not only possesses high tensile strength but also has high durability, corrosion resistance and excellent fatigue behavior (Azmi et al., 2013). Carbon, aramid and glass fibre are the three type of fibre commonly used in the manufacturing of FRP products. In the early days, the FRP is being developed and studied for aerospace application. However, due to the advantages associated with the FRP, it has been used and looked into in many different areas including agriculture, appliances and business equipment, building and construction, civil engineering and transportation (Bai, 2013).

Glass Fibre Reinforced Polymers (GFRPs) are increasingly being used in construction due to their light weight, ease of installation, low maintenance, tailor made properties, and corrosion resistance. Many GFRP items are tailored in nature, being especially designed for a particular application or building. Due to the versatility of FRP composites material, the demands for GFRP composites products are steadily increasing in Malaysian (Sam et al., 2008). The GFRP products were manufactured in various structural shapes for civil engineering applications such as in rebars, plates, and structural sections. It can be used as concrete reinforcement to replace steel, strengthen the existing structure, and as structural member, as shows In Figure 1 (Sam et al., 2008).

Figure 1: FRP types in different structural shapes



Despite the many advantages of GFRP, these materials are thermosetting composites which cannot be remelted or remoulded into another recycled product. However, there are several potential recycling methods for GFRP waste including mechanical grinding, pyrolysis, hydrolysis and chemical recycling (Asmatulu et al., 2014). The mechanical recycling technique reduces the size of the scrap composite components into particulates by some crushing and grinding process. Particulate fillers from FRP scraps can enhance the manufacturing and mechanical properties of compounds. Particulate fillers can also be used to decrease the weight of the manufactured composite part (Goodship, 2009). Currently, legislation has put more pressure on solving FRP waste management through recycling and reuse (Ribeiro et al., 2016). Hence, more research in FRP recycling can encourage manufacturer to reuse their GFRP scraps into alternative products. Figure 2 shows GFRP waste from trimmings of GFRP water tank fabrication process (left) and end of service life boat (right).

Figure 2: Examples of GFRP waste

Recently, natural fibre-reinforced polymer composites has generated much interest as a potential alternative for environmentally friendly and cost effective way to make materials of low cost engineering (Madurwar et al., 2013). Researches in kenaf-plastic composite are growing along with the demand for the plastic industry to produce petroleum-based materials (Bernard et al., 2011). One of the commercialized natural fibres in Malaysia is kenaf (Jonoobi et al., 2009). Kenaf have excellent properties for reinforcing composites as it has low densities, no abrasion during processing, high filling levels, high specific mechanical properties and biodegradability. The plantations of kenaf (*Hibiscus Cannabinus*) in Malaysia were initiated by its government as potential resources for pulp and paper, foods for livestock, natural fibre plastic composites and chemical absorbent. Upon harvest, the whole kenaf stalk is processed in a decorticator which functions as a mechanical fibre separator, similar to a cotton gin. The separation of the bast and core fibres allows for independent processing and provides raw materials for numerous types of products. The utilization of kenaf core can provides several benefits such as reduce dependency of forest tree for timber and increase income for kenaf farmers.

Previous study that compares between kenaf core with kenaf bast reinforeced polyester composites shows that kenaf core has a lower mechanical properties compared to kenaf bast fibres (Ishak et al., 2010). For example, the bending strength of kenaf core polyester composites ranges between 25-30MPa at its optimum fibre weight percentage of 10%. Other studies by Saad and Kamal (2012), shows that kenaf core particle board using phenol formaldehyde and urea formaldehyde as the binder has bending strength around 5 to 20 MPa. Therefore, it is expected that rGFRP/kenaf composites in this research to achieved bending strength as good as or better than previous research.

In this paper, our focus is to analyzed the mechanical properties of hybrid glass fibre recyclate with kenaf fibre. The main objectives of this paper are as follows:

1) To discuss the mechanical (tensile and bending) properties of rGFRP/kenaf composites produced by using vacuum assisted resin transfer moulding (VARTM) technique.
2) To analyze the microstructure of the rGFRP/kenaf composite.

Research Methodology

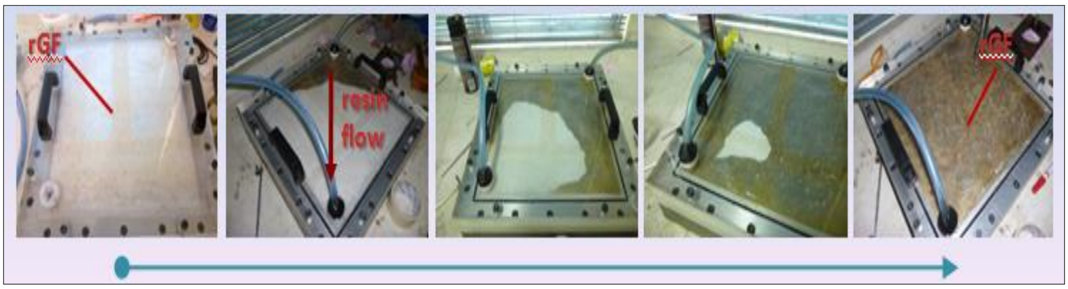
The glass fibre polyester wastes were cut into smaller pieces and shredded into a mechanical recycler machine. The waste was fed into the crusher machine to produce smaller waste and transported by screw conveyor to hammer mill machine. Then, the rGFRP was put into a sieve shaker to removes powders and impurities (eg: wood chips, metals and gravel). Thermoset resin (unsaturated polyester) was used as a polymer matrix of rGFRP/kenaf polyester composite. Unsaturated polyester (UP) resins mostly used in mass production and for large structures due to its low cost and low viscosity features. The catalyst used to crosslink the resin is methyl ethyl ketone peroxide at 1 phr (part per hundred resin). Table 1 shows the formulation of each composites developed in this study. The volume ratio of rGFRP:kenaf in the composites is 50:50. The density of kenaf core is approximately 0.2 g/cm^3 (Rozman et al., 2011). While, rGFRP was found to be approximately 1.4 g/cm^3 by using a density meter.

Table 1: Samples name and it formulation with volume percentage

Sample Name	%Volume			rGFRP size (mm)	Kenaf size (mm)
	UP	rGFRP	Kenaf		
rGFRP	80	20	0	1 - 3	3 - 8
rGFRP+Kenaf	80	10	10	1 - 3	3 - 8

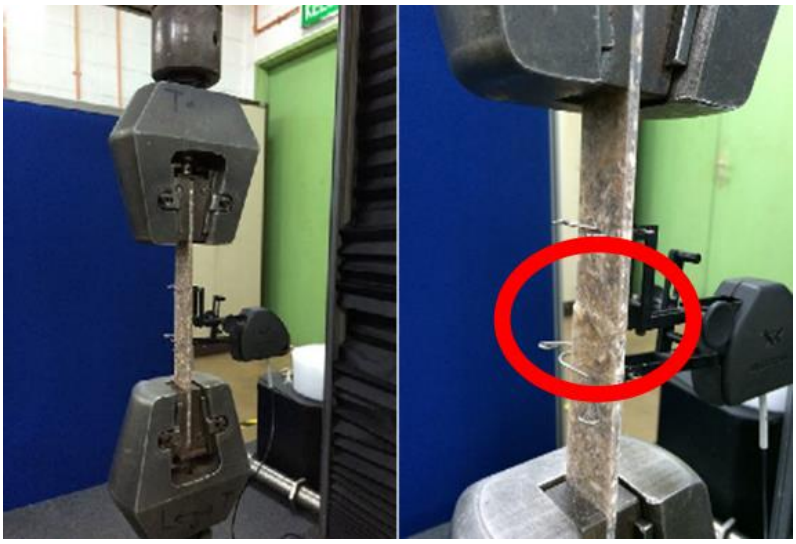
Fabrication of composites plates uses VARTM method. The VARTM mould is made of aluminium for its base and acrylic for its cover to observe the flow of the resin. The plate's dimension produced from this mould is 36cm x 36cm x 0.4cm. As the vacuum pump starts to operate, vacuum inside the mould will create suction for the resin to flow from the inlet to the outlet of the mould as shown in Figure 3. The weight and density of the composites plate was also measured after the VARTM process.

Figure 3: VARTM process



Each composites formulation was subjected to tensile and bending loading. The test was ran using Universal Testing Machine, Instron 5982. The three point bending test was conducted according to ASTM D790. While tensile test, specimens was prepare according to ASTM D3039. The tensile test conducted with the crosshead speed of 2mm/min and gage length of 50mm. The specimens were subjected to tensile loading until failure as shows in Figure 4.

Figure 4: rGFRP/Kenaf specimen under tensile loading



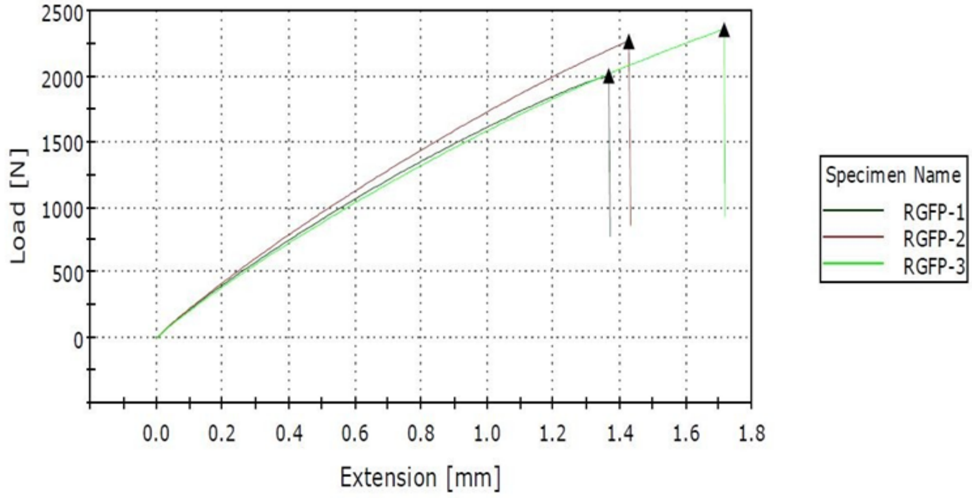
Result And Discussion

The experimental results of tensile strength for rGFRP are shown in Table 2. While, Figure 5 depicts the tensile load versus extension graph for rGFRP composites. As expected, the rGFRP tensile strength at maximum load is lower than GFRP that uses virgin glass fibre (DeRosa et al., 2005). Tensile strength of a newly produced glass fibres ranges between 1.4 - 2 GPa. However, the recycled GFRP could have loss its integrity and strength during the crushing process of recycling. Furthermore, the length of the recycled particulates is only around 1-3 mm which does not provide much reinforcement due to its low aspect ratio (length-to-diameter ratio).

Table 2: Tensile test data for Rgfrp

No	Specimen Label	Max Load (N)	Extension at Max Load (mm)	Tensile Strain at Max Load (mm/mm)	Tensile Stress at Max Load (MPa)	Modulus (GPa)
1	rGFRP-1	2,001.87	1.37	0.0052	19.16	4.00
2	rGFRP-2	2,268.53	1.43	0.0057	21.47	4.15
3	rGFRP-3	2,356.47	1.71	0.0065	22.05	3.82
Mean		2,208.96	1.50	0.006	20.90	3.99

Figure 5: Tensile test data graph for rGFRP

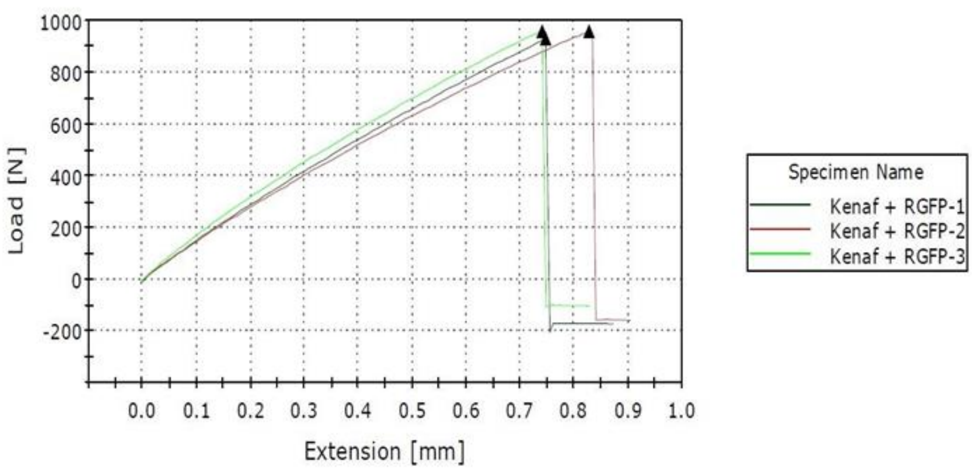


The tensile strength for rGFRP/kenaf results is presented in Table 3. The rGFRP/kenaf tensile strength at maximum load is about 50% lower compared to rGFRP. The tensile strain of rGFRP/Kenaf is also half of rGFRP. The Figure 6 shows tensile load versus extension graph for rGFRP/Kenaf.

Table 3: Tensile test data for rGFRP/Kenaf

No	Specimen Label	Max Load (N)	Extension at Max Load (mm)	Tensile Strain at Max Load (mm/mm)	Tensile Stress at Max Load (MPa)	Modulus (GPa)
1	rGFRP/ kenaf-1	930.40	0.75	0.0036	8.93	2.70
2	rGFRP/ kenaf-2	959.40	0.83	0.0044	9.01	2.27
3	rGFRP/ kenaf-3	960.98	0.74	0.0034	9.18	2.96
Mean		950.26	0.77	0.0038	9.04	2.65

Figure 6: Tensile test data graph for rGFRP/Kenaf



Tensile properties for rGFRP was higher than rGFRP/kenaf due to some factor such as aspect ratio (length-to-diameter ratio) of kenaf core is smaller than rGFRP, high moisture content of kenaf, low wettability of resin onto kenaf core and low tensile strength of kenaf compared to rGFRP. However, the inclusion of kenaf core into rGFRP/kenaf reduces the weight of composites due to the low density of kenaf.

The results of bending strength for rGFRP is shown in Table 4. It is concluded from results, that the rGFRP bending strength at maximum load is lower compared to virgin GFRP (Derosa et al., 2005). Flexural strength of virgin GFRP (12mm fibres) was found to be 115 MPa which approximately is twice the strength of rGFRP.

Table 4: Bending test data for rGFRP

No	Specimen Label	Maximum Load (N)	Extension at Max Load (mm)	Flexural Stress at Max Load (MPa)
1	rGFRP-1	136.76	2.68	54.64
2	rGFRP-2	120.64	2.25	46.05
3	rGFRP-3	157.76	2.87	60.22
Mean		138.39	2.60	53.64

The experimental results of bending strength for rGFRP/kenaf are shown in Table 5. The general conclusion can be said that the rGFRP/kenaf bending strength was decreased compared to rGFRP. Bending strength of rGFRP/kenaf has slightly improved when compared to previous research on kenaf core polyester composites (Ishak et al., 2010).

Table 5: Bending test data for rGFRP/Kenaf

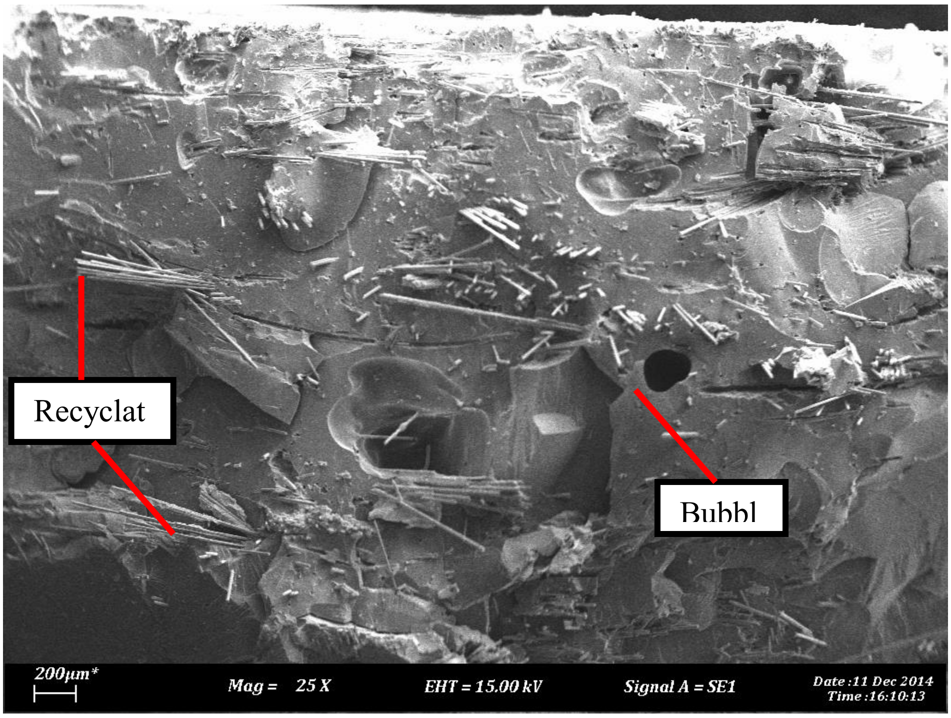
No	Specimen Label	Max Load (N)	Extension at Max Load (mm)	Flexural Stress at Max Load (MPa)
1	Kenaf /rGFRP-1	71.77	1.76	29.05
2	Kenaf /rGFRP-2	82.08	2.29	34.98
3	Kenaf /rGFRP-3	80.34	1.79	30.99
Mean		78.06	1.95	31.67

As discussed in aforementioned sections, bending strength for rGFRP/kenaf was lower than rGFRP due to factor such as high moisture content of natural fibre (Kabir et al., 2012). Moisture within the composites can initiates debonding between the kenaf and polyester interface, hence reducing its mechanical performance. Kenaf core can be treated by alkalization to reduced the hydroxyl group and improve interfacial adhesion of kenaf fibre (Yousif et al., 2012). Other factor could possibly caused by the soft porous structure of kenaf core fibre which ineffectively absorb the compression load during bending test.

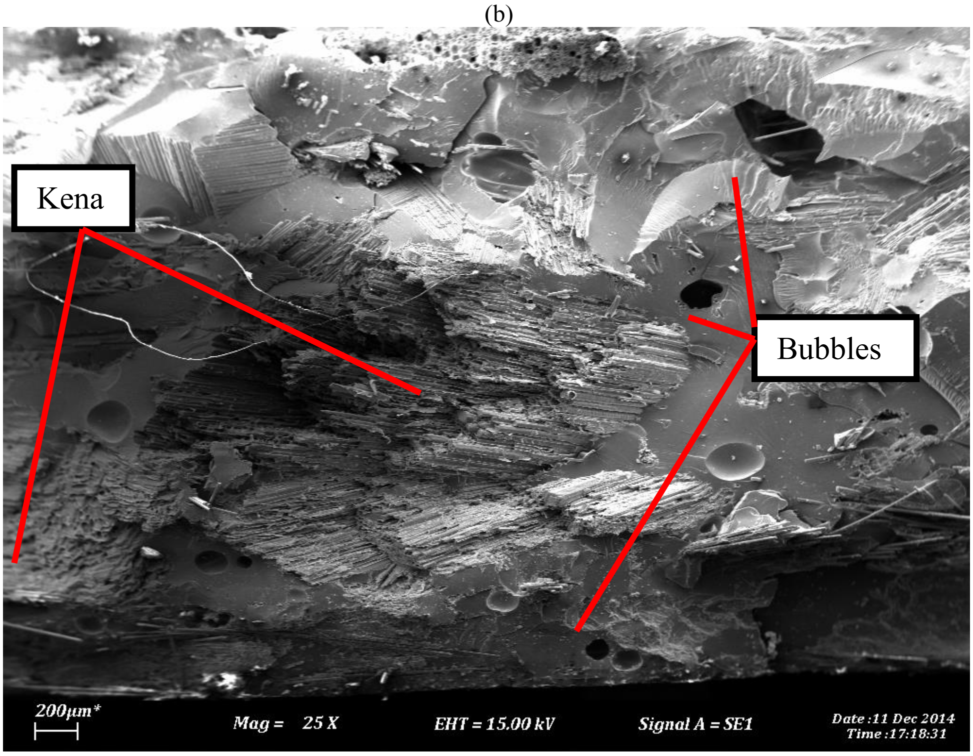
The density of rGFRP was found to be 1.16g/cm^3. On the other hand, rGFRP/Kenaf has a lesser density of 1.03g/cm^3 due to the content of kenaf core fibre. The density and mechanical performance data of rGFRP/Kenaf meets the requirement for hardboard or medium density fibreboard (MDF) applications (Cai and Ross, 2010). Construction application such as floor underlayment, house siding and concrete form board can utilize rGFRP/Kenaf. Furthermore, rGFRP/Kenaf is free from phenol-formaldehyde which are highly volatile, toxic and carcinogenic (Foyer et al., 2016).

Scanning Electron Microscope (SEM) was used to observed the microstructure of fractured area of composites as shown in Figure 7. Morphological features was observed such as fibre distribution, fibre-matrix debonding, fibre fracture, fibre pull-out, bubbles, matrix cracking, kenaf fibres and GFRP recyclates.

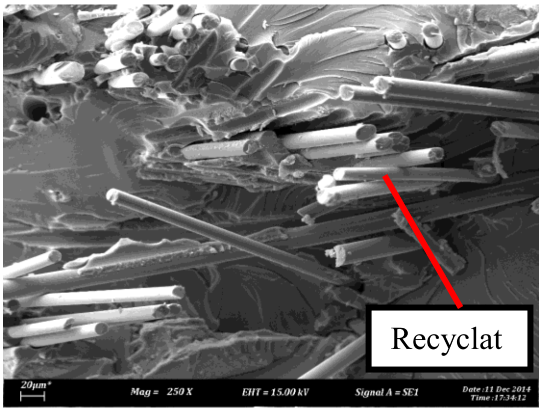
Figure 7: SEM observation for rGFRP and rGFRP/Kenaf after tensile test. and after bending test.



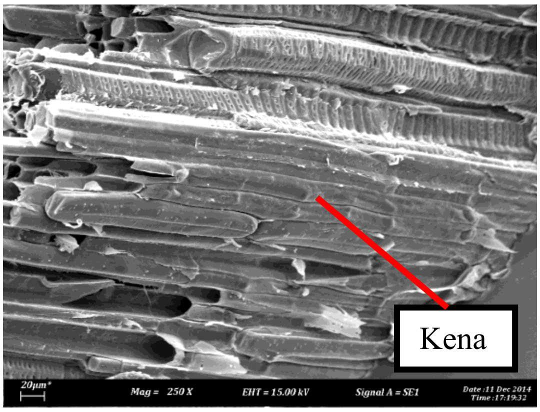
(a) SEM observations for rGFRP after tensile test
(b)



(b) SEM observations for rGFRP/Kenaf after tensile test



(c) SEM observations for rGFRP after bending test (250x zoom)



(d) SEM observations for rGFRP/Kenaf after bending test (250x zoom)

Figure 7 (a) and (b) shows uneven fibre distribution. Breakage of specimens under tensile loading tends to happens at area with less reinforcing fibres, hence composite failure below the expected maximum load. Voids or bubbles were also detected through the microscopy. Short fibres such as recyclates tends to agglomerate and creates air pockets inside composites and cannot be access by the flowing resin during the VARTM process. The fibre architecture or arrangement of recyclates resembles that of short fibre where fibre volume fraction higher than 20 vol. % does not permit a thorough flow of resin inside the VARTM mould. The author suggest using compression moulding process to achieve higher fibre volume fraction of recyclates or kenaf fibre. Figure 7 (c) shows that existing resin are still intact on the glass fibre of the recyclates. The content of fibre and resin in recyclates will vary depends on the type of GFRP waste that been recycled. Therefore data regarding recycled GFRP composites can have different result due to the large improbability where different GFRP products has different fibre-resin ratio. To overcome this problem, it is suggested that the recyclates are being tested using thermal gravimetric analysis (TGA) to determine the composition of fibre and resin of the recyclates.

Conclusion

As a conclusion, waste of GFRP need to be recycled from industries and developed into new composites product. In this paper, we compared mechanical properties of two types of composites: rGFRP and rGFRP/Kenaf. After experiments, the rGFRP shows the better result than rGFRP/Kenaf in terms of tensile and bending loadings. We observed that recyclate glass fibre has decrease its initial strength due to crushing and hammering during the recycling. Fibre distribution based on SEM observation shows inconsistent fibre distribution which affected the mechanical testing result. SEM also shows numerous amount air bubble or micro-voids inside the resin of both rGFRP and rGRP/Kenaf composites. The VARTM process cannot achieve higher fibre loading than 20 vol.% due to the fibre arrangement of short fibres. Besides that, high moisture content in rGFRP/kenaf due to the hydrophilic nature of kenaf could have weakens the interfacial adhesion of kenaf core, thus the decrease in mechanical performance. For the time being, this research recommends the use of rGFRP/kenaf to be developed as new product for low capabilities in terms of strength and costing. The advantage of rGFRP/kenaf is its light-weight quality which can be use as fibreboard such as flooring, wall panels and furniture. Future research should utilize kenaf core at a higher volume in their composites to obtain a much lighter material.

Acknowledgment

The authors would like to thank Universiti Teknologi Malaysia for funding this research and UTM Research Management Centre (RMC) for managing the research activities under Vot 4B163. The authors also wish to acknowledge the assistance of Atostech Fibreglass Sdn. Bhd., Terengganu, Malaysia in the recycling process of GFRP.

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