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Research paper

Evaluation of the Performance of Natural Fiber Reinforced Polymer Composites

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Abstract

Natural fibers provide an alternative to artificial fiber as composite reinforcement, which can transform the industrial trend into more eco-friendly. Hence an investigation of the mechanical properties of banana and kenaf fibers reinforced polymer composites were conducted. Two composite systems were prepared by using alkali treated Banana fibers at several Sodium Hydroxide concentrations (0%, 3%, 6% and 9%) and hybrid Banana fibers (BF) and kenaf fibers at various ratio of BF/Kenaf fibers (0/100, 30/70, 50/50, 70/30, 100/0). The composites were fabricated using banana fiber and hybrid BF/kenaf fiber to reinforce epoxy and unsaturated polyester composite respectively using hand layup method. The tensile and flexural tests were then performed on the composites specimen according to ASTM D3036 and ASTM D790 respectively. The result indicates that treated banana fibers have a significant effect on the Flexural strength and Tensile Modulus. Meanwhile, hybridisation has achieved the highest tensile strength of 0/100 composite composition while the lowest was by 100/0 which is 20.04 MPa and 10.33 MPa respectively. The tensile strength gradually decreases as the concentration of kenaf reduced. In comparison with the flexural test, it shows the same trend as the tensile test where flexural strength directly proportional to the concentration of kenaf fiber. The highest tensile modulus was achieved by 0/100 at 3.24 GPa while the lowest was achieved by 100/0. This was expected as the strength of kenaf was better compared to the banana fiber. For the hybrid composite, 30/70 had the highest toughness compare to the other specimen. In conclusion, the tensile and flexural strength directly influences by the percentage of kenaf fiber. The higher the percentage of kenaf fiber, the higher the tensile and flexural properties. Hybridization improves the specimen in term of strain and toughness. This indicates that the hybrid composite was able to absorb higher energy before failure.

Keywords: *Kenaf fiber; Banana fiber; Alkali treatment; unsaturated polyester; epoxy composite*

1. Introduction

Nowadays, people start to think the way of producing the material without causing any environmental hazard to our surrounding. Hence natural fiber that can be extracted from the local plant is the most suitable candidate as a reinforcement material for composite systems. Natural fiber has some advantages, such as low cost, low energy consumption, low density, high specific mechanical properties, non-abrasive and biodegradable as compared to the other types of fiber like synthetic fiber (glass, carbon) [1]. There are many applications of natural fiber that have already applied in the industry such as brick made of clay reinforced with straw, mud wall with bamboo shoots, concrete, concrete reinforced with steel rebar, granite consisting of quartz, mica and feldspar [1], [2]. Banana fiber which is extracted from the trunk part of a banana plant can be easily obtained and acquired since it is a local plant. Generally, banana was planted for food and the other part of a banana tree may be applied in various application. Banana trees only produce banana fruits once and after that was most likely to be cut down and let to waste. So that, other parts of banana trees, that rich in fiber contents such as trunk and leaf can be used as fiber sources that can reinforced polymer or normally known as composite materials.

Research on Kenaf fiber reinforced polymer composites have been successfully done that shows great improvement in mechanical properties. Kenaf plant has a single, straight, and branchless stalk and its stalk made up of an inner woody core and outer fibrous bark surrounding the core [1]. Kenaf is considered as natural fiber hence it greater use might transform industrial trend into more eco-friendly. Any other fiber that usually used is fiberglass but the disadvantage of fiberglass is it is not natural fiber and quite expensive compared to kenaf [2]. Kenaf has better tensile strength compared to banana fiber, which is shown in Table 1. The main component of natural fiber or lignocellulosic material consists of 3 major organic component which is cellulose, hemicellulose and lignin [3].

Hybridization in term of fiber reinforced composite means incorporating 2 types of fiber into the same composite. Having different types of fiber in the same matrix provide another dimension of potential to fiber reinforced composite, it may have balance properties between the advantages and disadvantages inherent in any of the fiber inside the composite [4]. There would be multiple consideration taken to improve the properties of hybrid composite. Its properties commonly governed by the length of the fibers, fiber's orientation, fiber/matrix interfacial bonding, the arrangement of both fiber, and fiber content [5]. There was past research about the hybridization of natural fiber, using short banana with sisal to produce a fiber reinforced polyester composite. According to M. Idicula et. al [6] Composite with a volume ratio of banana and sisal of 3:1 had the highest tensile strength. As the composition of banana increase, it's tensile strength increase. Theoretically, the hybrid reinforcing effect can be calculated using the law of the additive rule of the hybrid mixture [6]. In a previous paper, it had been proven that there were 3 physical mechanisms that governed and responsible for causing a hybrid effect in a hybrid composite [7]. The first mechanism involves the enhancement of the matrix through the fiber, it is largely dependent on the along-fiber property variation. The second mechanism is related to fiber to fiber property variation. Having the same type of fiber will lead the fiber to break gradually reducing the strength and elongation to break percentage. The second mechanism co-exists in hybrid and non-hybrid composite. The third mechanism is the cross-coupling effect between lower breaking elongation fiber and higher breaking elongation fiber. For this research, we can consider banana as higher breaking elongation fiber while kenaf as lower breaking elongation fiber.

Table 1: Properties of Natural Fiber [2]

Natural Fiber	Tensile Strength (MPa)	Elongation at break (%)	Young Modulus (GPa)
Flax	300 - 1500	1.3 - 10	24 - 80
Jute	200 - 800	1.16 - 8	10 - 55
Sisal	80 - 840	2 - 25	9 - 38
Kenaf	295 - 1191	3.5	2.86
Pineapple	170 - 1627	2.4	60 - 82
Banana	529 - 914	3	27 - 32
Coir	106 - 175	14.21 - 49	4 - 6
Oil Palm	130 - 248	9.7 - 14	3.58
Ramie	348 - 938	1.2 - 8	44 - 128

This research was carried out as an attempt to obtain composite systems with good mechanical properties. Hence two composite systems were prepared and their performances were evaluated based on their tensile and flexural properties respectively.

2. Materials and Methods

2.1. Preparation Of Banana Fiber

Figure 1 shows the banana stem of 5 cm x 40 cm taken from the trunk and the extracting process to obtain banana fiber. The banana stems were soaked in the water for 1 or 2 days to ensure that the pseudostem inside the banana stem was soft enough to be removed. Pseudo-stem inside the banana stem initially was a bit hard, soaking the stem in water will soften the pseudo-stem. It is necessary to remove some of the pseudo-stem first using a metal scraper to make sure that the water would absorb easily into the rest of the stem.

The next step was to scrap or remove the pseudo-stem using a metal scraper. The fiber extracted from the stem was then soaked again into the water to remove remaining pseudo-stem that was still attached to the fiber. The last step is to let the fiber dry through the heat of the sun. Throughout the entire process, it’s possible to extract banana fiber manually even though the process might take a lot of time.

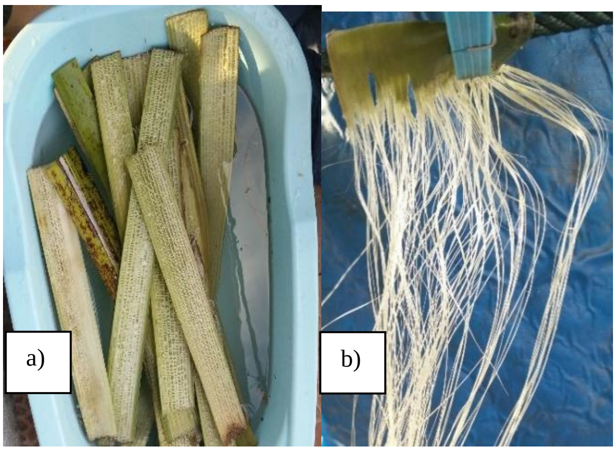

Fig. 1: a) Stack of Banana stem soak in water and b) extracting process of banana fiber

2.2. Banana Fiber Treatment

Fiber treatment was conducted by soaking the fibers in the Sodium Hydroxide (NaOH) solution at different concentration (3%, 6%, and 9%) at room temperature (27^o C) for 12 hours. After 12 hours, the banana fibers were taken out of the solution. The fibers were then washed with distilled water to remove any alkaline solution that sticking on their surface. Then the fibers were dried under sunlight for a day before dried in an oven at temperature 80^o C for 8 hours to eliminate the moisture content.

2.3. Preparation of Kenaf Fiber

The kenaf fiber was received from Material Composite Lab in the form of long fiber. The fiber needs to be separated from tiny pieces of core and stem fiber that is still attached to the fiber. All of this tiny pieces need to be removed and only kenaf fiber will be used to fabricate the composite. After that, kenaf fiber was cut using scissors to achieve a shorter length of fiber so that it will make the fabrication easier. The longer the fiber, the lower the tendency for the fiber to absorb the resin. So, the best way is to cut the fiber as short as possible. The best length to fabricate composite using short fiber was in the range of 0.5 – 1.0 cm.

2.4. Fabrication of the Composite

The method used to fabricate the composite were completely manual or hand lay-up. Prior to composite fabrication, the fibers were dried using an oven at 80 °C for 8 hours. For this experiment two composite systems were prepared, the details of the composites are as listed in Table 2. The first system used unsaturated polyester as matrix and combination of banana and kenaf fiber as reinforcement. The composition of Banana and kenaf fiber are as listed in Table 2.

Table 2: Composite Composition

Composite	Banana Fiber (BF) (% wt)	Kenaf Fiber (% wt)
BF/Kenaf/Polyester	0	100
	30	70
	50	50
	70	30
	100	0
BF/Epoxy	NaOH concentration	
	0%	
	3%	
	6%	
	9%	

The second composite system used epoxy as the matrix and banana fiber as the reinforcement. Four types of banana fibers that have been treated with different alkali concentration as listed in Table 2 was used as reinforcement. The material and apparatus required to fabricate the composites were the plastic sheets, steel mould, fiber, weight, resin and catalyst. The process of fabricating the composite was divided into 2 parts, the preparation of the mixture and preparation of the mould. The first step was to measure the weight of the fiber for each specimen by using a digital balance. The weight ratio of the fiber was referred based on Table 2. For each specimen, the percentage of total fiber loading was the same which is at 10% as the variable only changed on the ratio of Banana fiber to Kenaf fiber. The resin and hardener were mixed at a ratio of 9:1 by weight. Then 10 wt.% of fibers were added and mixed thoroughly to obtain a homogeneous mixture. The mixtures were then poured into the mould to produce a composite panel with the size of 230 mm x 250 mm x 7 mm. The arrangement of the mould is as shown in Figure 2. Both plastic sheets were sprayed with a release agent so that it would ease the removing process.

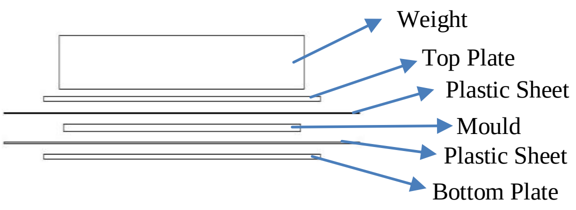

Fig. 2: Mould Arrangement

A roller was also used to flatten the surface to obtain a straight and flat surface. The composites were then cured at room temperature for 24 hours before being removed from the mould.

2.5 Tensile and Flexural Testing

Tensile and Flexural tests specimens were cut from the composites panel. A straight sided tensile specimen of 250 mm x 25 mm x 7 mm with 50 mm length of grip were prepared. Meanwhile, the flexural specimen has a dimension of 130 mm x 13 mm x 7 mm to be used on a 90 mm support span. Tensile and Flexural tests were then performed by using a universal testing machine, Instron (series-3382) according to ASTM standard ASTM D3036 and ASTM D790 respectively. The speed rate used for both tests were 1 mm/s and 5 specimens were tested for each composite type and each test.

3. Results and Discussions

3.1. Effect of NaOH Concentration

The effect of Sodium Hydroxide (NaOH) concentration during treatment was investigated by performing tensile and flexural tests on the treated specimens. The results were then compared to the untreated specimens (0%) as control samples.

3.1.1 Tensile and Flexural Behavior of BF/Epoxy Composites

The Flexural behavior of BF/epoxy composite at various NaOH concentrations is as shown in Figure 3. The composite shows the elastic bahavior indicating by the linear stress-strain curves up to failure. The evidence of brittle behavior as the NaOH concentration is increased during treatment also can be observed, indicating by the decrease of the strain. Significant reduction of about 53% in strain can be observed as the fiber was treated with 9% NaOH. This behavior is normally observed in polymer composite that used thermoset as the matrix [2], since thermoset is known to have crosslink hyperbranched structure that make the composite more rigid as compared to thermoplastic [5]. The tensile stress-strain behavior of BF/epoxy composite also has the same trend as its flexural stress-strain behavior.

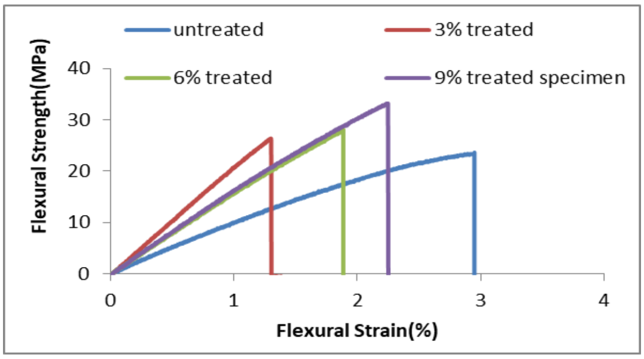

Fig. 3: Flexural stress-strain curves of BF/epoxy composites

3.1.2 Tensile and Flexural Strengths of BF/Epoxy Composites

The strength has improved as the fiber was treated with NaOH solution at both tensile and flexural test as can be seen from Figure 4. The highest improvement of 17% in tensile strength was observed at 3% NaOH concentration, however, decline trends were observed as the concentration of NaOH go beyond 3%. Modification of fiber surface by alkali treatment has resulted in a significant increase in flexural strength [1], [5]. This is because an alkali treatment has changed the properties of fiber to become rougher.

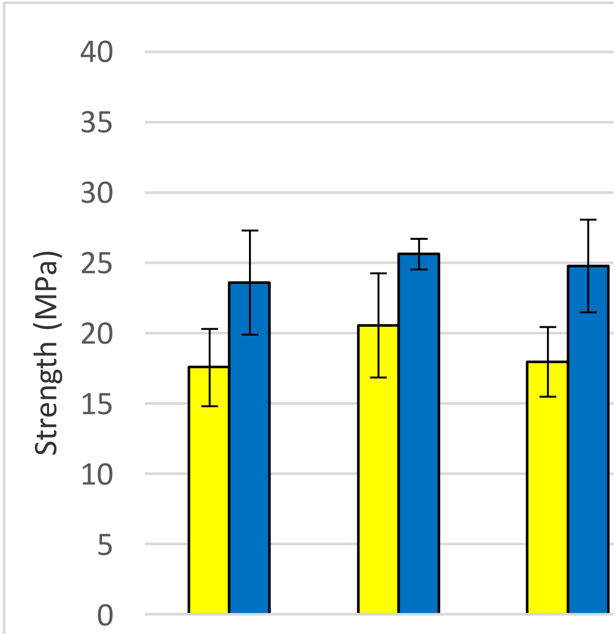

Fig. 4: Tensile and Flexural Strengths of BF/epoxy composites

As the concentration of NaOH solution increases the surface of fiber produced will be rougher. In this case, 9% treated specimen might be produced the roughest surface of fiber among the other specimen but it doesn't mean this specimen will be the strongest. The worsening of the fiber surface occurred when fiber having a treatment under high concentration and a longer period of treatment [10]. This scenario has explained why the tensile strength decrease beyond 3% concentration. Meanwhile, fiber treatment showed good improvement on flexural strength of about 13% at 3% NaOH concentration. The flexural strength keeps increasing with the increases of NaOH concentration up to 40% improvement at the highest NaOH concentration. The different trend as compared to tensile strength is because the flexure strength is contributed by tensile, shear and compressive properties [1]. The maximum stress at the outermost specimen surface either for tension or compression side has defined the flexural strength of the material.

3.1.3 Tensile and Flexural Modulus of BF/Epoxy Composites

Figure 5 shows the effect of NaOH concentration on the Tensile and Flexural modulus of BF/epoxy composites. The increase in modulus was obtained when banana fiber was treated with NaOH solution. There were increased of 100% in tensile modulus that was achieved by 6% treated specimen on its tensile modulus. Meanwhile, the maximum increase of the flexural modulus is 125% at 3% NaOH concentration. This is because, as the fibers are treated, the bonding between fiber and matrix have improved and subsequently increases its rigidity.

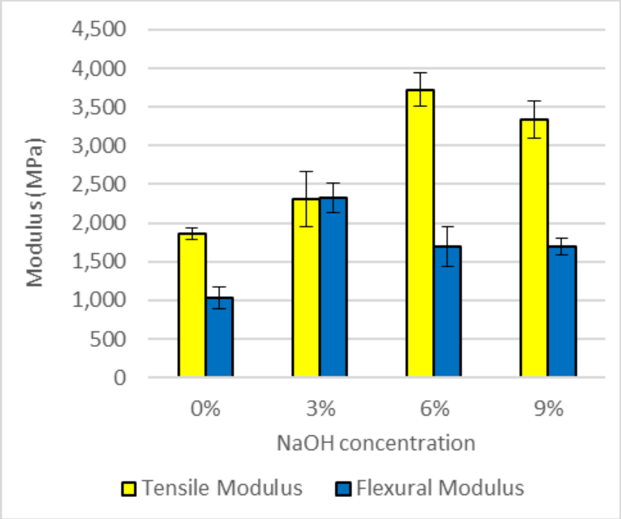

Fig. 5: Tensile and Flexural Modulus of BF/epoxy composites

The higher the value of the tensile and flexural modulus means that the specimen will be more rigid and result in its brittle characteristic as indicated in Figure 3. Higher modulus also means that these all treated specimen has the ability to resist high loading and less strain thus become more rigid [12].

3.1.4 Tensile and Flexural Toughness of BF/Epoxy Composites

The effect of fiber treatment on the toughness of BF/epoxy composites is shown in Figure 6. Tensile and flexural toughness values were obtained from the area under the stress-strain curve diagram. Figure 6 shows that the reduction in toughness value occurred as the specimen treated with NaOH solution on both tensile and flexural tests. The tensile toughness has further decreased as the NaOH concentration increases. On the other hand, the flexural toughness has increased with the increasing of NaOH concentration. A higher value of flexure toughness achieved by untreated (0%) specimen indicates that this specimen can distribute and absorb by itself for a large amount of energy for both tensile and flexural loadings. This finding suggests that untreated fiber in composites produced higher toughness in both tensile and flexural loadings which indicates the capability of absorbing energy, hence this composite can be suggested to be used as the energy-absorbing material.

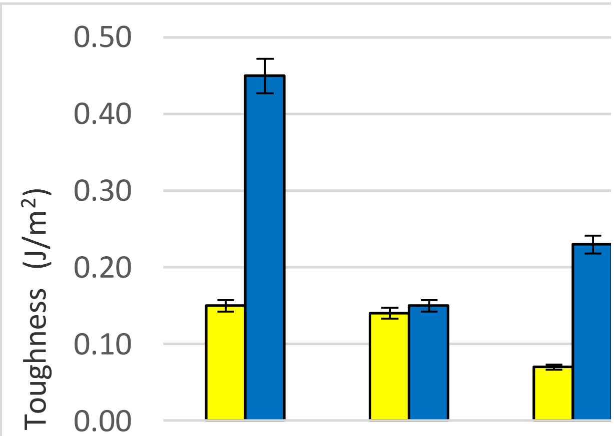

Fig. 6: Tensile and Flexural Toughness of BF/epoxy composite

3.2 Effect of Hybrid Fiber Content

As discussed before fiber treatment does not have a significant effect on the mechanical properties of BF/epoxy composites, especially its strength. Hence, Banana fiber was hybridised with kenaf fiber as an attempt to further improve the mechanical properties of the composites. The Tensile and Flexural tests were also performed to measure the effectiveness of fiber hybridization.

3.2.1 Tensile and Flexural Behavior of BF/Kenaf/Polyester Composites

Figure 7 provides the representative result for flexural stress-strain curves of BF/Kenaf/polyester composites. From the graph, the elastic behaviour of all composites is evidence as all the curves show a linear increase up to fracture. The tensile stress-strain behaviour also shares the same trends. Composite that contain fully kenaf fiber has the highest strength as compared to other specimens. This does not seem surprising as the strength of kenaf fiber is higher than that of banana fibers as listed in Table 1. Hybridization with more than one type of filler/fiber such as kenaf and banana fiber provide another dimension of the potential versatility of composite material. For example, kenaf fiber was proven better to sustain higher strain compare to banana fiber which is shown in Figure 7 and Table 1.

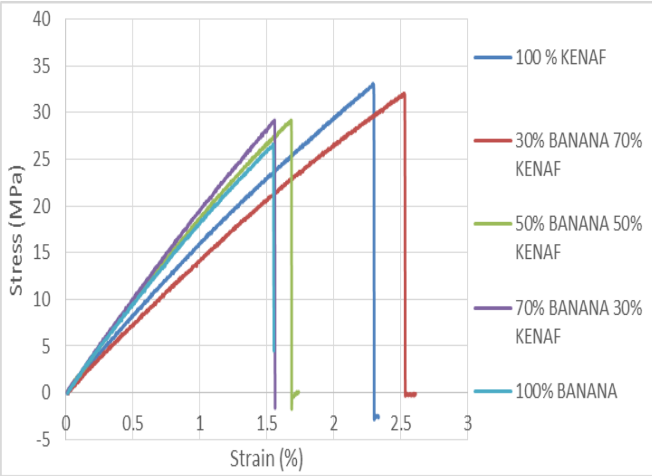

Fig. 7: Flexural Stress-strain Curves of BF/Kenaf/Polyester Composites

The presence of both kenaf fiber and banana fiber in the composite not only improve its strain but also the toughness that the composite would able to sustain before it breaks or fails. By incorporating kenaf and banana in the same matrix or better known as hybrid composite may not as stiff as kenaf fiber but slightly stronger than banana fiber. The weight ratio of banana fiber and kenaf fiber influence the stress and strain of the specimen, the higher concentration of banana fiber result in lower stress and strain meanwhile higher concentration of kenaf improve the ability of the specimen to sustain higher stress. The positive effect is the strain increase dramatically while the negative effect of hybrid is decreases of both the strength and modulus.

3.2.2 Tensile and Flexural Strength of BF/Kenaf/Polyester Composites

Figure 8 provides the evidence of hybridisation on the tensile and flexural strength of BF/Kenaf/Polyester Composites. Based on the graph, it is proven that 0/100 had the highest tensile and flexural strength. Both tensile and flexural tests provide the same pattern for tensile and flexural strength. The strength of the composite was directly influenced by the concentration of kenaf fiber. As shown in Table 1, kenaf fiber had better strength and elongation to break compared to banana fiber. As the concentration of kenaf fiber increase, tensile and flexural strength of the specimen will increase gradually. At the BF/Kenaf ratio of 100/0 had the lowest tensile strength because there was no kenaf inside of the specimen meanwhile 70/30 increase slightly due to 30% kenaf was added as a hybrid component inside the specimen. According to past research by Maries Idicula that use banana/sisal instead of kenaf/banana, the volume ratio of banana and sisal at 3:1 show higher tensile and flexural strength at all fiber loading as the research varies its fiber loading [6] this trend is believed due to the higher tensile strength of banana fiber as compared to sisal fiber as shown in Table 1.

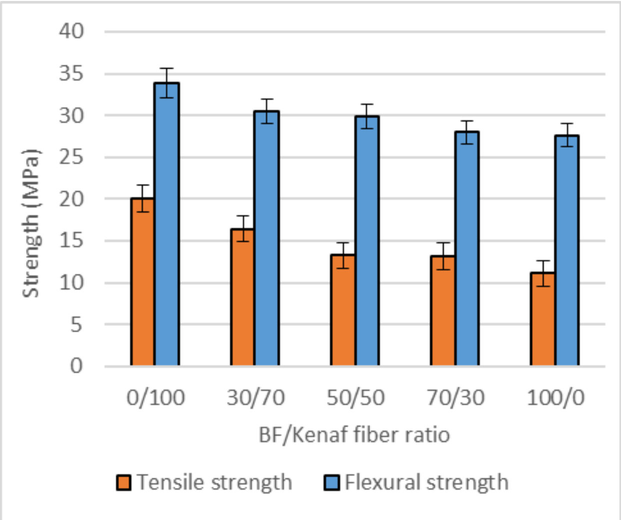

Fig. 8: Tensile and Flexural Strength of BF/Kenaf/Polyester composites

According to M. Thiruchitrambalam et al [8] that used the same fiber as this experiment, the result indicated that hybrid composite shows a significant increase in tensile and flexural strength due to densified kenaf fiber, it has better tensile and flexural strength than banana fiber. From their investigation, it was known that the composition and adhesion level of the fibers influenced the flexural properties of the hybrid composite. Meanwhile, in this investigation, both fibers didn't undergo any surface treatment. Therefore, the adhesion level of the fibers might be low due to lignin and hemicellulose.

The distribution of the fibers in the composite was investigated by flashing the bottom of the plate using bright light the captured images are as shown in Figure 9. The figure compares the distribution of all kenaf fibers and all banana fibers or BF/Kenaf fiber ratio of 0/100 and 100/0 respectively. It seems that the distribution among the fiber for all kenaf fibers Figure 9 a) was evenly distributed as compared to Figure 9 b) which belongs to all banana fibers. Bright or white section indicates that the light can pass through the panel easily. Matrix is likely transparent and light can easily pass through the panel. Meanwhile, the dark section indicates the agglomeration of fibers which seen more in Figure 9 b). According to J. L. Thomason, the lesser area with fiber means fiber concentration was low, its tensile and flexural strength increase as the concentration of fiber increase [9] provided all the fibers were surrounded by the matrix to make the stress transfer possible during loading.

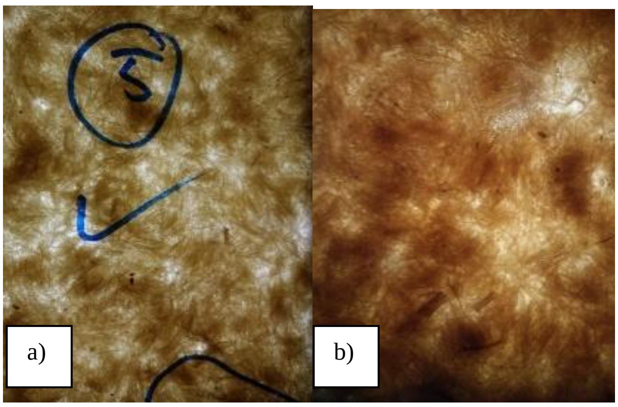

Fig. 9: Fiber distribution a) 0/100 and b) 100/0 BF/Kenaf fiber composites

Figure 10 shows the fracture specimen of BF/kenaf fiber ratio of 0/100 and 100/0. From the figure, the specimen with all kenaf fibers (0/100) showed several fibers pull out at the end of the breaking spot for tensile test meanwhile specimen of all banana fibers (100/0) didn't show any fiber pull out.

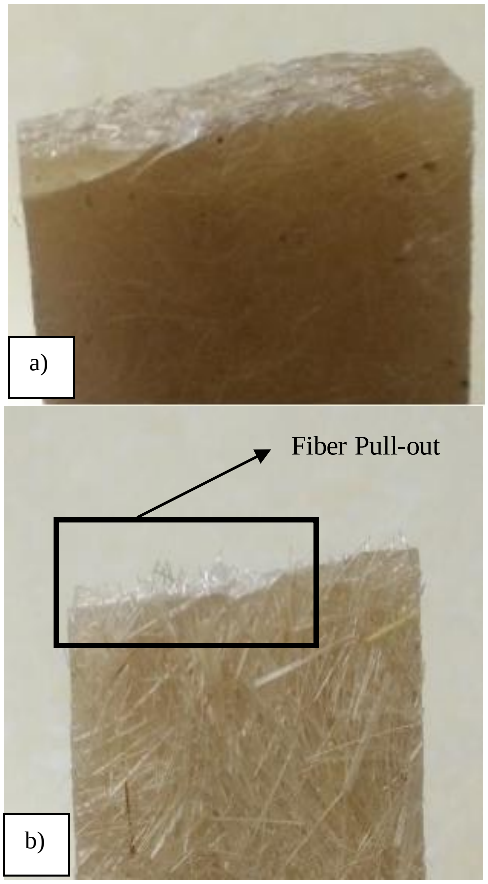

Fig. 10: a) Fractured Specimen a) 0/100 and b) 100/0 of BF/Kenaf/Polyester composites

This indicates that the bonding between fibers for the specimen of all kenaf fibers (0/100) was better compared to the specimen of all banana fibers (100/0). Extracting process for banana fiber and kenaf fiber was totally different where kenaf was extracted in mass production by the manufacturer using machine meanwhile banana was extracted manually. It is safe to assume that the quality of the banana fibers that were extracted manually didn't have the same quality as kenaf. Both fibers didn't undergo surface treatment, excess pseudo-stem that still attached at the banana fiber influence the bonding between fiber and matrix. The extracting process was a cumbersome process, it consists of recurring processes to remove the pseudo-stem. Lack of machinery and human error that leads to any excess pseudo-stem that failed to be removed completely.

3.2.3 Tensile and Flexural Modulus of BF/Kenaf/Polyester Composites

The effects of hybridisation on the tensile and flexural modulus were shown in Figure 11. The figure shows that the hybridisation shows no effect on tensile modulus, where the highest tensile modulus belongs to all kenaf fibers composite (0/100). The tensile modulus of the hybrid composite is almost the same at 2200 MPa. Meanwhile, the flexural modulus seems to slightly increase at 8% with the BF/Kenaf fiber ratio of 70/30, however at this ratio the composite has it lowest tensile modulus.

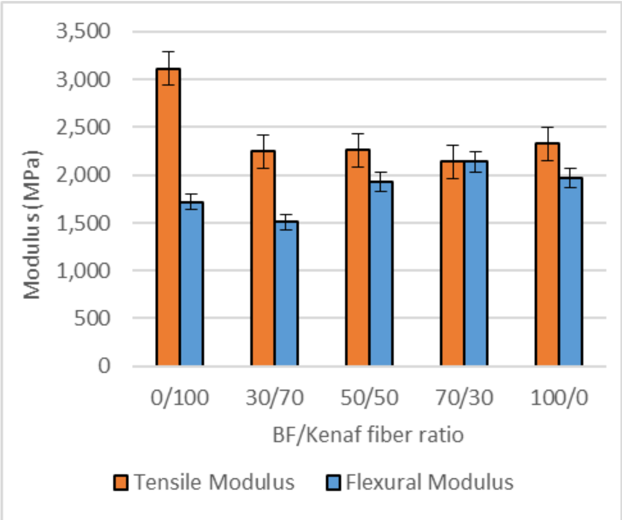

Fig. 11: Tensile and Flexural Modulus of BF/Kenaf/Polyester composites

3.2.4. Tensile and Flexural Toughness of BF/Kenaf/Polyester Composites

Figure 12, shows the toughness of the composite system due to the hybridisation. The trend is quite similar to the strength as shown in Figure 8. The addition of kenaf fiber into the composite has increased the energy absorbing capability. This is mainly due to the good energy absorbing capability of kenaf fiber, where the highest energy absorbed by the 30/70 of BF/Kenaf fiber ratio for both tensile and flexural tests. As explained before toughness means the ability of the material to absorb energy and deform without fracturing. The higher the toughness, the higher the energy can be absorbed by the specimen before fracture. Commonly, the specimen with higher strain will have better toughness. This evidence proves that hybridization improves the toughness of the specimen.

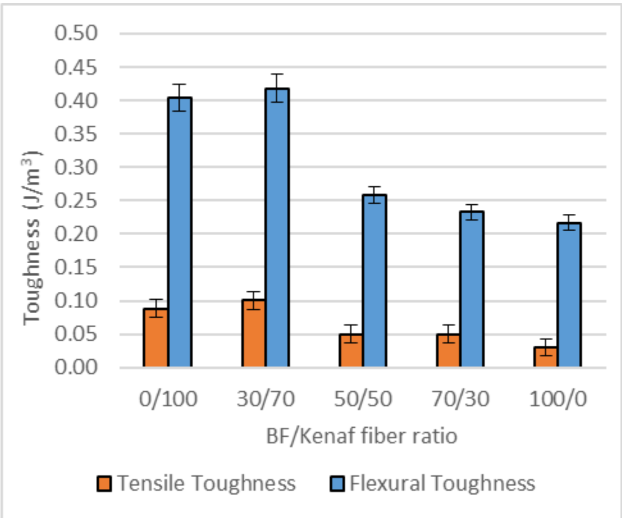

Fig. 12: Tensile and Flexural Toughness of BF/Kenaf/Polyester composites

4. Conclusion

In general, the improvement of each property due to the Sodium Hydroxide (NaOH) treatment occurred at different NaOH concentration. The treatment obviously changed the mechanical properties of BF/epoxy composite, especially its flexural strength which increased up to 40% at 9% NaOH concentration. The best tensile strength and flexural modulus are at 3% NaOH treatment which improved at 17% and 125% respectively. Meanwhile, hybridisation of banana with kenaf fiber showed good improvement as the kenaf content increased due to the higher tensile strength of kenaf fiber. The hybridization of fibers able to manipulate the ability of composites to sustain higher stress and absorb higher energy before fail.

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