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# Mechanical Properties of Environment-Friendly Sugar Palm Fibre Reinforced Vinyl Ester Composites at Different Fibre Arrangements

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## Abstract

A study on mechanical properties of sugar palm fibre reinforced vinyl ester (VE) composites at different fibre arrangements is presented in this paper. Hand lay-up method was used in preparing the composites and the mechanical properties were determined using the INSTRON universal testing machine. Some fractured specimens from the impact test were tested under scanning electron microscope (SEM) to study the interfacial adhesion between fibres and matrix. Results revealed that unidirectional fibre composites demonstrate excellent performance in tensile modulus, flexural strength, flexural modulus, and impact strength, with value of 2501 MPa, 93.08 MPa, 3328 MPa, and 33.66 kJ/m$^2$, respectively. It is only for tensile strengths, that the highest value was given by ±45° woven fibre composites (15.67 MPa). Therefore, composites with fibres in unidirectional direction can be considered as the best fibre arrangement for sugar palm fibre reinforced VE composites compared with other fibre arrangements such as 0°/90° woven fibres, and ±45° woven fibres based on the results obtained throughout the tests.

***Keywords**:* Fibre arrangements; Vinyl ester; Sugar palm; Mechanical properties; Natural fibre composites

## 1. Introduction

Polymeric (Tang *et al.*, 2006) and polymer based composite materials (Yahaya *et al.*, 2015) have been used extensively in different industries such as automotive, aerospace, marine, telecommunication, and furniture industries due to their excellent properties such as lightweight, excellent strength and stiffness properties and corrosion resistance. Apart from polymer matrices, composite materials also employed different types of matrices such as metal and ceramics (Sapuan *et al,* 2002; Chawla, 1997). However, in this paper, polymer based composites are reported and the reinforcement used are natural fibres. Natural fibres are environmentally friendly fibres recently used to replace synthetic fibres, which generally pose some environmental concerns. Natural fibres, or biofibres gain special attention among the researchers who are dealing with these materials as reinforcements in polymer-matrix composites. Natural fibres are alternative materials used to replace synthetic fibres such as glass, carbon, and aramid and natural fibres, and they are comparable to glass fibre in many aspects (Bachtiar *et al.,* 2010a). The growing interest in employing natural fibres as reinforcement in polymer-based composites is mostly because of the availability of natural fibres from natural resources, meeting high specific strength and modulus (Zainudin *et al.*, 2009), lightweight, low cost and biodegradability (Baley, 2002). Although natural fibres are not as strong and stiff as synthetic fibres, their low cost, lightweight and environmental friendliness are the major reasons to select them as alternative materials for some products (Rashdi *et al.*, 2009); Anwar *et al.,* 2009).

However, natural fibres suffered from some disadvantages. Their properties are not constant and they are rather scattered because of different growing environments of the plant such as rain and soil conditions. These conditions may vary with the maturity of the plant, which caused inconsistencies in their mechanical and other properties compared to synthetic fibres. To solve the problem, it is recommended to combine the group of fibres from parts of a single plant or from several harvests (Sanyang *et al,* 2016).
Sugar palm (Figure 1) is one the most fascinating palm species as about the whole parts of the tree can be benefitted; and the most vital product of sugar palm tree is palm sap. In Malaysia, the sugar palm plantation can be found in commercial scale at Tawau, Sabah. The purpose of the plantation is for making sugar palm syrup from sugar palm tree.

Another important part of sugar palm tree is fibre. Sugar palm fibres had been used as commercialized products as early as 1946 during the era of Malacca sultanate. Then in 1800s, British East India Company cultivated the sugar palm tree in Penang to produce ropes and ship cordages from sugar palm fibres, which possessed high durability and suitable to be used in harsh marine environment. Sugar palm fibres are known to be seawater-resistant fibres. Sea water that contains sodium hydroxide (NaOH) improves the bond between fibres, hence, suitable to be used to anchor the ship at the pier. In Indonesia, traditionally sugar palm fibres are used to make traditional headgears, ropes, roofs, brooms, and brushes. For example in Kampung Naga, Tasikmalaya, Indonesia, a village protected by UNESCO, the houses in the entire village used sugar palm fibres as materials for roofs for a long time and these roofs can last for over 25 years.

Nowadays, sugar palm fibres (black hair-like fibres) are used as reinforcements in polymer composites and it has initially been reported by Mogea *et al.* (1991). The exterior morphology of sugar palm fibres is similar to that of oil palm and coir fibres (Razak and Ferdiansyah, 2005; Sahari *et al.,* 2012; Ishak, 2012).

The density of sugar palm fibres, had been reported in earlier publications, to be varied from 1.29 g/cm$^3$ (Razak and Ferdiansyah, 2005) and 1.05 g/cm$^3$ (Bachtiar *et al.*, (2010b). Bachtiar *et al.* (2010b) conducted the research to evaluate the tensile strength and tensile modulus of sugar palm fibres and the results obtained were 190.29 MPa and 3690 MPa, respectively. Sahari *et al.* (2012) determined the tensile properties of sugar palm fibres at different parts of sugar palm tree, which are frond, bunch, black fibre (known locally as ijuk) and trunk. They found that the highest tensile strength and tensile modulus are from frond fibres (443.24 and 8400 MPa, respectively), then followed by bunch (315.35 and 6600 MPa, respectively), ijuk (266.39 and 2860 MPa, respectively), and trunk (167.84 and 1130 MPa, respectively). Latest study on sugar palm fibres obtained from different location was done by Huzaifah *et al.* (2017) and found that geographical location doesn't have great impact on tensile strength and tensile modulus. From the studies fiber obtained from Kuala Jempol fiber had the highest average tensile strength, 233.28 ±71.17 MPa, while Indonesia and Tawau fibers were 219.30 ±79.71 MPa and 211.04 ±81.19 MPa, respectively.

Suriani *et al*. (2007) and Siregar (2005) reported their work on tensile properties of sugar palm fibre reinforced epoxy composites.

It was concluded that long fibre composites possessed higher impact strength than short fibre composites. Woven fibre composites have higher tensile and flexural properties than long and short random fibre composites. It was observed that woven fibre composites have excellent interlocking between fibres and matrix compared to long and chopped random reinforced epoxy composites (Suriani *et al.*, 2007; Siregar, 2005).

VE used as matrix and sugar palm fibre used as reinforcement in polymer composites had been studied and recorded in past, where in this study, the effect of fibre modification through vacuum resin impregnation on tensile properties was investigated in detail (Ibrahim *et al.*, 2013). Mohammed *et al.* (2016) studied the effect of sodium hydroxide on the tensile properties of sugar palm fibre reinforced thermoplastic polyurethane composites. The sodium hydroxide treatment of the fibres provided a good tensile modulus of 440 MPa at 2% of NaOH, and strain of 41.6% at 6% NaOH of the composites. However, the tensile strength was decreased, where the highest amount of 5.49 MPa recorded at 6% NaOH. Meanwhile, the tensile modulus and strain of the composites are found to be much better than those of untreated ones. In contrast, the tensile strength was still not improved.

Rashid *et al.* (2017) studied the influence of fibre treatments on the mechanical and thermal properties of sugar palm fibre reinforced phenolic composites. The alkaline treatment resulted in improved flexural and impact strengths of the composites. In the contrary, the sea water treatment had the best results for improving the compressive strength. Morphological analyses indicated that the surface treatments improved the fibre-matrix bonding. The thermal degradation analysis showed that both the sea water and alkaline treatments of the SPF slightly affected the thermal stability of the composites. Consequently, sugar palm fibres can be effectively used as alternative natural fibres for reinforcing bio-composites.

The purpose of this paper is to unveil the potential of sugar palm fibres used as reinforcements in VE composites. The study of mechanical properties of sugar palm fibre reinforced VE composites at different fibre arrangements is presented.

**Figure 1.** Sugar palm tree

## 2. Experimental

*2.1 Materials*

The sugar palm fibres were obtained from Kampung Kuala Jempol, Negeri Sembilan, Malaysia as reinforcements in polymer matrix composites with vinyl ester (VE) was used as matrix. VE resin, methyl ethyl ketone peroxide (MEKP), and cobalt were procured from Berjaya Bintang Timur Sdn. Bhd, in Cheras, Kuala Lumpur, Malaysia. MEKP and cobalt were used as catalyst and accelerator, respectively.

*2.2 Composite Preparation*

The mould with the size of 150mm x 150mm x 3mm was used and the method used in the fabrication process was hand lay-up process. In the current study, fibres arrangements in the composites were set in three ways; unidirectional direction (0°), in 0°/90° woven arrangement and in ±45° woven arrangement.

The long sugar palm fibres were soaked in tap water for 24 hours to remove the dirt from the core section. Then fibres were further washed and let dried at room temperature (25-30 °C) for two weeks. After the fibres were completely dried, they were ready to be used in fabrication process. 10 wt% of fibre loading were arranged into mould in each composites according to previous study (Aprilia *et al.* 2014). Then, the matrix was poured in the mould.

VE resin was mixed evenly with MEKP before the cobalt was added. The ratio used for mixing VE, MEKP, and cobalt was 100:2.4:1. VE and MEKP systems were made ready and cobalt was added. The mixture was stirred for about 30 seconds. Then, the mixture was poured onto the fibres already placed inside the mould. Once the mixture was fully transferred inside the mould, the mould was covered by a metal sheet. The composites were cured for 24 hours at room temperature of 25-30 °C.

After the curing process, the mould was opened and the composite plates were taken out. From the composite plates, composite specimens were cut using a small band saw with the dimensions of 150 mm x 15 mm x 3 mm and five replicates were prepared for each test.

*2.3 Testing Methods*

All composite specimens were tested based on the standards; ASTM D638, ASTM D790 and ASTM D256 for tensile, flexural, and impact tests, respectively. Testing was carried out at the temperature of 23 ± 2 °C with relative humidity of 50 ± 10 %.

Tensile tests were conducted by using Instron machine model 5567. The specimens were tested at crosshead speed of 2 mm/min and the tests were carried out was at 22.5°C and at relative humidity of 50%. The equations used for tensile strength and tensile modulus calculation are: $S_\tau=F/A$ and $E=\sigma/\varepsilon$, respectively, where $S\tau$ = tensile strength (MPa); F = pulling force (kN), A = cross sectional area ($mm^2$), E = tensile modulus (MPa), $\sigma$ = stress (MPa), and $\varepsilon$ = strain.

Flexural tests were also carried out by using Instron machine model 5567. The specimens were tested at crosshead speed of 2 mm/min and the tests were performed at 22.5°C and at relative humidity of 46%. The equations used for bending stress calculation are: $\delta=WL^3/48EI$ where, $\delta$ = displacement (mm), W = load at yield (N), L = length between support span (mm), E = tensile modulus ($N/mm^2$), and I = moment of area ($mm^4$).

The impact strength was measured using Instron 9050 Impact Pendulum which used Izod impact test method. Unnotched samples were used for impact properties evaluation. The specimens were cut with the dimensions of 60 mm x 30 mm x 3 mm. The specimens were stroked at an angle of 150°. Scanning electron microscope (SEM) Hitachi S-3400N operating at an acceleration voltage of 0.3 - 30 kV was used to study the fracture surface morphology of the specimens. The micrographs were taken at magnifications 100 μm and 500 μm. The samples were coated with gold to provide electrical conductivity, which did not significantly affect the resolution, allowing for high-quality results.

## 3. Results and Discussion

*3.1 Tensile Properties of Sugar Palm Reinforced VE Composites*

The effects of fibre arrangements on the tensile strength and modulus of sugar palm fibre reinforced VE composites were determined and the data are shown in Figure 2. The most interesting aspect of this figure is that neat VE, demonstrated the highest tensile strength among composites. A possible explanation for this might be that the neat VE consisted of 100% resin, whereas composition of composites, which consisted of the mixture of fibres and matrix. Highly cross-linked neat VE caused the material to be rigid and brittle. Thus, the results showed the neat VE had outstanding performance in tensile strength i.e. 38.84 ±11.95 MPa, followed by ±45° woven, unidirectional and 0°/90° woven; with the values of 15.67 ±2.28 MPa, 15.41 ±4.94 MPa, and 11.65 ±2.06 MPa respectively. From the literature, there are also studies that reported the minimum fibre contents are better (Aji *et al.* 2011; Haque *et al.* 2009). It might because of weak interfacial area between the fibre and matrix as the fibre content increase, resulting in low tensile performance (Haque *et al.*, 2009).

One way to improve the tensile strength is by treating the fibres with some treatment agents like alkali treatment and other chemical treatments. The hydrophobic nature of VE made it difficult to be bonded with hydrophilic sugar palm fibres. Treating the fibres with some chemical may increase the affinity between fibres and polymers, and improvement in tensile strength of sugar palm fibre reinforced VE composites can be expected.

Among composites, there is slight difference between ±45° woven and unidirectional orientation with difference of 0.26 MPa. This condition may cause by the number of fibre involved in event of tensile to withstand load. On the contrary, the 0°/90° woven arrangement of fibre involving only certain fibres to withstand tensile load than unidirectional and ±45° woven, which contribute to lower experimental result. From the previous study, woven roving of sugar palm fibre reinforced epoxy has tensile strength of 51.717 MPa (Sastra *et al.*, 2006), and impregnated chopped random sugar palm fibre reinforced unsaturated polyester has 344.71 MPa (Ishak *et al.*, 2014). The highest tensile strength of composites in this study is lower than result reported by Sastra *et al.* (2006) and Ishak *et al.* (2014), which respectively use same fibre with different matrix.

For tensile modulus, neat VE has the lowest result compared with the composites because it does not have fibre as reinforcement. With reinforcement, composites have high tensile modulus which indicates composites need more force to deform. External force was transferred to reinforcing fibres by matrix that causes composites is hard to deform. For effect of fibre orientation, high to low value of composite tensile modulus is unidirectional, 0°/90° woven and ±45° woven orientation with value of 2501 ±128.99 MPa, 2413 ±134.06 MPa, and 2369 ±93.97 MPa, respectively. The highest tensile modulus in this study is much higher than Sastra *et al.* (2006) i.e. 1010.322 MPa, and lowers than Ishak *et al.* (2014) i.e. 3980 MPa. Tensile modulus is important to ascertain the capability of material to resist deformation. Therefore, the reinforcement of VE by sugar palm fibre is proven enhance its mechanical properties.

### *3.2 Flexural Properties of Sugar Palm Fibre Reinforced VE Composites*

The purpose to carry out flexural test is to measure flexural strength and flexural modulus of the composites. Figure 3 presents the results of flexural strength and flexural modulus by taking the average results of five replicates for each fibre arrangement. For flexural strength, the highest result is obtained for unidirectional fibre composites, followed by 0°/90° woven fibre composites and ±45° woven fibre composites, with the values of 93.08 ±16.13 MPa, 46.12 ±19.54 MPa, and 42.46 ±6.01 MPa respectively. Interestingly, the unidirectional fibre composites were observed to give the highest value because tension and compression loads from flexural load were aligned with the direction of fibres (Figure 4). All fibres had been involved in contributing to withstand the test specimen from breakage. Previous studies found flexural strength of long random sugar palm fibre reinforced epoxy was 92.65 MPa, and impregnated short sugar palm fibre reinforced unsaturated polyester is 35.49 MPa (Siregar, 2005; Ishak, 2012). Results of both research works (Siregar, 2005; Ishak *et al.*, 2014) had flexural strength lower than the flexural strength of unidirectional fibre VE composites determined in the current research.

For flexural modulus, the trends of the results are similar to that of flexural strength, where the highest value is demonstrated by unidirectional fibre VE composites followed by 0°/90° woven fibre and ±45° woven fibre VE composites. The values of unidirectional, 0°/90° woven and ±45° woven fibre reinforced VE composites are 3328 ±178.18 MPa, 3206 ±161.93 MPa, and 2848 ±125.16 MPa respectively. Previous research performed by Ishak (2012) shows that flexural modulus of impregnated short sugar palm fibre reinforced unsaturated polyester was 3130 MPa (Ishak, 2012), which is lower than the flexural modulus of the unidirectional fibre reinforced VE composites obtained in the current research. Upon comparing with the results of flexural modulus of long random sugar palm fibre reinforced epoxy composites i.e. 3997.38 MPa (Siregar, 2005), the results are comparable with the current study, i.e. 3328 MPa for unidirectional fibre reinforced VE composites. Among the three fibre arrangements in the VE composites,

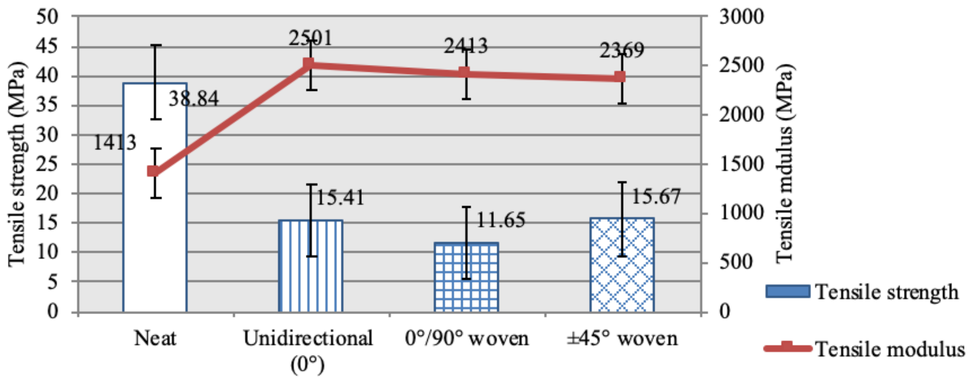


**Figure 2.** Average data of tensile strength and tensile modulus

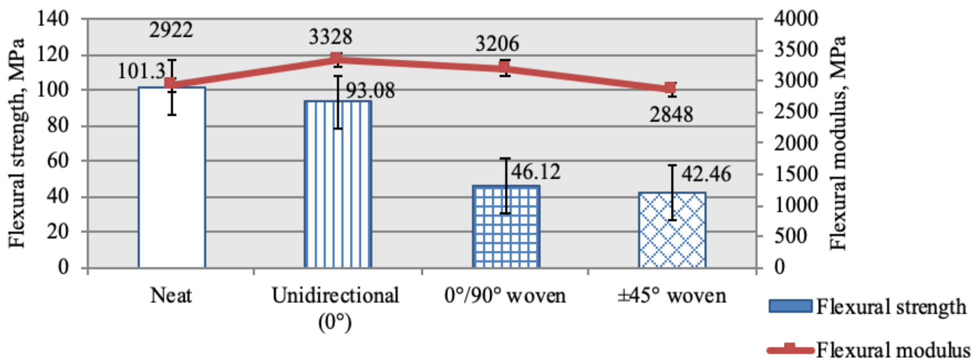


**Figure 3.** Average values of flexural strengths and flexural moduli of sugar palm fibre reinforced VE composite

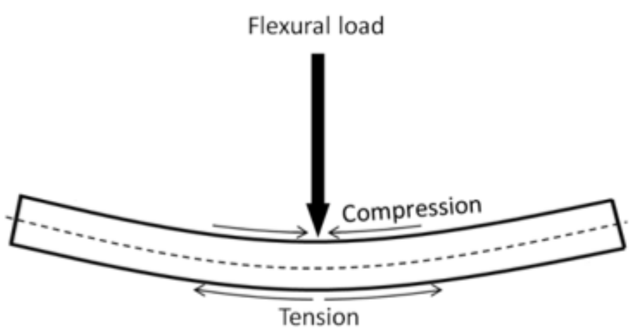


**Figure 4.** Schematic diagram of flexural stress distribution

*3.3 Impact Strength of Sugar Palm Fibre Reinforced VE Composites*

The aim of impact testing is to determine the capability of composites to withstand high rate loading. Figure 5 shows the results of impact strength of sugar palm fibre reinforced VE composites at three different fibre arrangements. From this study, it is found that unidirectional sugar palm fibre reinforced VE composites gave the highest impact strength, which is 33.66 ±9.78 $kJ/m^2$, followed by 0°/90° woven fibre and ±45° woven fibre reinforced VE composites, which are 18.05 and 7.38 $kJ/m^2$, respectively. The trends of the results are similar to that of the results of flexural strengths found in the previous section. The condition of unidirectional fibre composites in which the fibres are aligned with the tension and compression loads made the unidirectional fibre composites to demonstrate the best performance to withstand impact load compared other arrangement (Agarwal, Broutman, & Chandrashekhara, 2006). The 0°/90° woven fibre reinforced VE composites had parts of the fibres aligned with tension and compression loads, which caused them to demonstrate the impact strength value lower than that of the unidirectional fibre composites. However, the ±45° woven fibre reinforced VE composites showed the lowest impact strength as their fibre direction is not aligned at all with tension and compression loads. Study performed by Leman *et al*. (2009) on long sugar palm fibre reinforced epoxy composites revealed that long fibre composites is 114.27 J/m. To comparable value of impact strength in J/m for unidirectional fibre reinforced VE composites obtained in the current research is 479.46 J/m. In the study by Sahari *et al.* (2011), it was revealed that the impact strength of sugar palm frond fibre reinforced unsaturated polyester composites was 8.09 $kJ/m^2$. From the current work, it is shown that unidirectional sugar palm fibre reinforced VE composites had an excellent attribute to withstand impact load (33.66 $kJ/m^2$).

*3.4 Morphological Analysis using Scanning electron microscopy (SEM)*

The morphology of impact test specimens of sugar palm fibre reinforced VE composites at three different fibre arrangements were observed using SEM.

<u>*A. Fibre arranged in UnidirectionalDirection*</u>

The impact strength of unidirectional fibre reinforced VE composites was 33.66 kJ/m2, and it was better than the results of that of 0°/90° woven and ±45° woven fibre reinforced VE composites. This finding showed that the orientation of fibres in unidirectional direction is suitable for impact test of sugar palm fibre reinforced VE composites. Loads in impact tests were well transferred from matrix to fibres, which caused the fibre breakage. The direction of load distribution is aligned with the unidirectional direction of fibres in the VE composites, which had good tendency to protect the composites from being broken. Figure 6 describes the schematic diagram of load distribution inside the samples. Figure 7 shows the condition of fibre after impact test was carried out. Broken fibres (Figure 7 (a)) indicate that fibres performed their roles to successfully withstand impact until the specimens were broken. The strength of the interface between fibres and matrix is also quite good that caused the load to be transferred well from matrix to fibres. Figure 7 (b) shows small gap, which described the effect of impact load on the composite.

<u>*B. Fibres Arranged at 0°/90° in Woven Form*</u>

The impact strengt of the 0°/90° woven fibre reinforced VE composites was 18.05 kJ/m2, which is the second highest impact strength after unidirectional fibre reinforced VE composites. Upon comparing the fibre orientation of the composites with the unidirectional fibre composites, about half of the fibres were able to withstand the composites from being broken because there are two directions of fibres were found i.e. vertical and horizontal directions. Vertical direction was aligned with the distribution of load, whereas not for the case of the horizontal direction. This condition caused the 0°/90° woven fibre reinforced VE composites to have lower impact strength than that of unidirectional fibre VE composites. In addition

Figure 8 (a) shows there are more fibres being pulled out in the case of vertical fibres. Figure 8 (b) depicts the fibres in horizontal direction in the VE composites, which were not broken as they were not aligned with the load distribution.

*C. Fibres Arranged at ±45° in Woven Form*

Impact strength of the ±45° woven sugar palm fibre reinforced VE composites was 7.38 kJ/m$^2$, which is the lowest impact strength among the three cases being studied. The orientation of fibres, which were not aligned with distribution of load contributed to poor result of impact strength. Thus, the orientation of fibres in the ±45° direction in VE composites is not helpful in enhancing the impact strength of the composites. Figure 9 shows that the matrix was ruptured and had various vacant slots that revealed very poor impact strength among the three composites being studied.

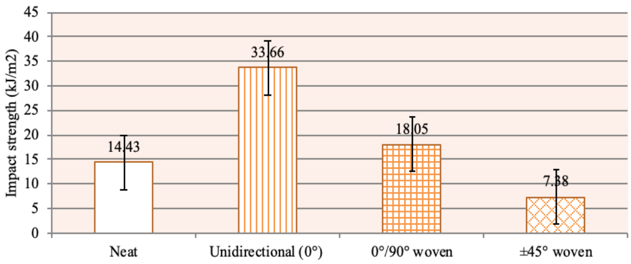


**Figure 5.** Average results of impact strength of sugar palm fibre reinforced VE composites at different fibre arrangements

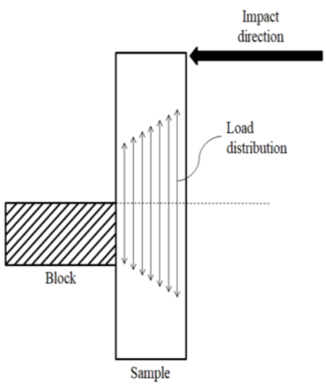


**Figure 6.** Schematic diagram of load distribution during impact test.

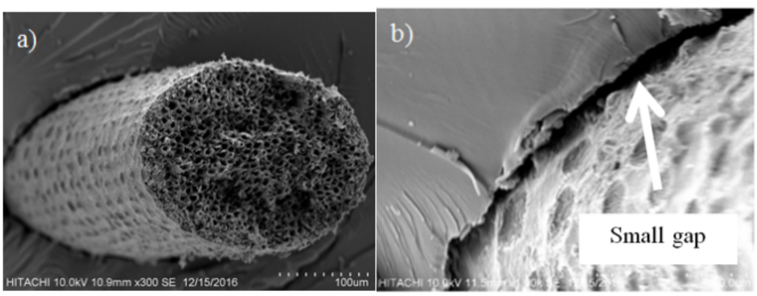


**Figure 7.** Occurrence of a) broken fibre, and b) small gap; of fractured surfaces of samples in impact test (SEM image)

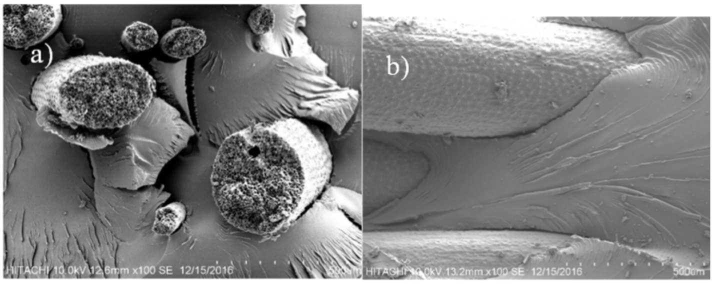


**Figure 8.** SEM image of 0°/90° woven VE composites with a) fibres in vertical direction and b) fibres in horizontal direction

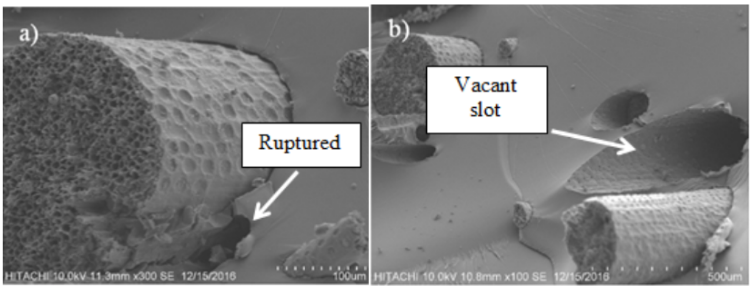


**Figure 9**. SEM of ±45° woven fibre VE composites showing some flaws i.e. a) ruptured matrix and b) vacant slots

## 4. Conclusions

In this paper, the mechanical and morphological properties of sugar palm fibre reinforced VE composites were studied at three different fibre arrangements. Among the three orientations, unidirectional fibre composites demonstrated the highest values in terms of tensile modulus, flexural strength, flexural modulus, and impact strength. It is only the ±45° woven fibre VE composites showed the highest tensile strength. These findings revealed that the unidirectional direction of fibres in the sugar palm fibre reinforced VE composites is the most suitable orientation of sugar palm fibres in reinforced VE composites. The results were supported by the morphological analysis of the fractured specimens of the impact tests.

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## References

Agarwal BD, Broutman LJ, Chandrashekhara K. Analysis and Performance of Fiber Composites, Third Edit. John Wiley& Son, New Delhi. 2006.

Aji IS, Zainudin ES, Khalina A, Sapuan SM, Khairul MD. Studying the effect of fiber size and fiber loading on the mechanical properties of hybridized kenaf/ PALF-reinforced HDPE composite. Journal Reinforced Plastic Composite 2011; 30:546–553.

Anwar, UMK, Paridah MT, Hamdan H, S.M. Sapuan SM, Bakar SE. Effect of pressing time on physical and mechanical properties of bamboo strip fibre reinforced phenolic composites. Industrial Crops and Products 2009; 29: 214-19.

Bachtiar D, Sapuan SM, Zainudin ES, Khalina, Dahlan KZM. The tensile properties of single sugar palm (Arenga pinnata) fibre. IOP Conference Series: Materials Science and Engineering 2010a; 11: 12012.

Bachtiar D, Sapuan SM, Hamdan MM. Flexural properties of alkaline treated sugar palm fibre reinforced epoxy composites. International Journal of Automotive and Mechanical Engineering 2010b; 1: 79 - 90.

Baley C. Analysis of the flax fibres tensile behaviour and analysis of the tensile stiffness increase. Composites Part A: Applied Science and Manufacturing 2002; 33: 939-48.

Chawla KS. Composite materials: Science and engineering. Springer Science & Business Media, New York, USA 1997; 1-10.

Haque MM, Hasan M, Islam MS, Ali ME. Physico-mechanical properties of chemically treated palm and coir fiber reinforced polypropylene composites. Bioresource Technologies 2009; 100: 4903–4906.

Huzaifah MRM, Sapuan SM, Leman Z, Ishak MR. Comparative Study on Chemical Composition, Physical, Tensile, and Thermal Properties of Sugar Palm Fiber (Arenga pinnata) Obtained from Different Geographical Locations. BioResources 2017; 12: 9366–9382.

Ibrahim AH, Leman Z, Sapuan SM. Tensile properties of impregnated sugar palm (Arenga Pinnata) fibrecomposite filled thermosetting polymer composites. Advanced Materials Research 2013; 701: 8-11.

Ishak MR. Enhancement of physical properties of sugar palm (arenga pinnata merr.) Fibre-reinforced unsaturated polyester composites via vacuum resin impregnation, Ph.D. Thesis, Universiti Putra Malaysia. 2012.

Ishak MR, Leman Z, Sapuan SM, Rahman MZA, Anwar, UMK. Enhancement of physical and mechanical properties of sugar palm fiber via vacuum resin impregnation. in: Advanced materials for agriculture, food, and environmental safety (Ed: Tiwari A). John Wiley & Sons, Inc., Hoboken, New Jersey, USA 2014; 121-144.

Leman Z. Mechanical Properties of Sugar Palm Fibre-Reinforced Epoxy Composites, Ph.D. Thesis, Universiti Putra Malaysia. 2009.

Mogea J, Seibert B, Smits W. Multipurpose palms: the sugar palm (Arenga pinnata (Wurmb) Merr.). Agroforestry Systems 1991; 13: 111-29.

Mohammed AA, Bachtiar D, Siregar JP, Rejab M. Effect of sodium hrdroxide on the tensile properties of sugar palm fibre reinforced thermoplastic polyurethane composites. Journal of Mechanical Engineering Sciences (JMES) 2016; 10: 1765-77.

Rashdi AAA, Sapuan SM, Ahmad MMHM, Khalina A. Water absorption and tensile properties of soil buried kenaf fibre reinforced unsaturated polyester composites (KFRUPC). Journal of Food, Agriculture and Environment 2009; 7: 908-11.

Rashid B, Leman Z, Jawaid M, Ghazali MJ, Ishak MR. Influence of treatments on the mechanical and thermal properties of sugar palm fibre reinforced phenolic composites. BioResources 2017; 12: 1447- 62.

Razak HA, and T. Ferdiansyah T. Toughness characteristics of Arenga pinnata fibre concrete. Journal of Natural Fibers 2005; 2: 89-103.

Sahari J, Sapuan SM,, Ismarrubie ZN, Rahman MZA. Investigation on bending strength and stiffness of sugar palm fibre from different parts reinforced unsaturated polyester composites. Key Engineering Materials 2011; 471: 502-6.

Sahari J, Sapuan SM, Ismarrubie ZN, Rahman MZA. Physical and chemical properties of different morphological parts of sugar palm fibres. Fibres and Textiles in Eastern Europe 2012; 91: 21- 4.

Sanyang ML, Sapuan SM, Jawaid M, M.R. Ishak MR, J. Sahari J. Recent developments in sugar palm (Arenga pinnata) based biocomposites and their potential industrial applications: A review. Renewable and Sustainable Energy Reviews 2016; 54: 533-49.

Sapuan SM, Jacob MSD, Mustapha F, Ismail, N. A prototype knowledge-based system for material selection of ceramic matrix composites of automotive composites of automotive engine components. Materials and Design 2002; 23: 701-08.

Sastra HY, Siregar JP, Sapuan SM, Hamdan MM. Tensile properties of Arenga Pinnata fibre reinforced epoxy composites. Polymer-Plastics: Technology and Engineering 2006; 45: 149-55.

Siregar JP. Tensile and flexural properties of Arenga Pinnata filament reinforced epoxy composites, Master of Science. Thesis, Universiti Putra Malaysia. 2005.

Sri Aprilia NA, Abdul Khalil HPS, Bhat AH, Dungani R, Hossain MS. Exploring material properties of vinyl ester biocomposites filled carbonized Jatropha seed shell. BioResources 2014; 9:4888–4898

Suriani MJ, Hamdan MMHM, Sastra HY, Sapuan SM. Study of interfacial adhesion of tensile specimens of Arenga Pinnata fiber reinforced composites. Multidiscipline Modelling in Materials and Structures 2007; 3: 213-224.

Tang SH, Kong YM, Sapuan SM, Samin R, Sulaiman S. Design and thermal analysis of plastic injection mould. Journal of Materials Processing Technology 2005; 171:259-67.

Yahaya R, Sapuan SM, Jawaid, M, Leman Z, Zainudin ES. Effect of layering sequence and chemical treatment on the mechanical properties of woven kenaf-aramid hybrid laminated composites. Materials and Design 2015; 67: 173-.79.

Zainudin ES, Sapuan SM, Abdan K, Mohamad MTM. Thermal degradation of banana pseudo-stem filled unplasticized polyvinyl chloride (UPVC) composites. Materials and Design 2009; 30: 557-62.