Development and characterization of sugarcane bagasse fiber and nano-silica reinforced epoxy hybrid composites

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Abstract. This paper presents an experimental study on the mechanical performance of sugarcane bagasse fiber reinforced epoxy composite. Tensile and flexural properties of the composites were investigated in this research. Different weightage of short fiber and fiber particulates were utilized to study their effects on the mechanical performance of the composites in terms of tensile and flexural properties. 1% of nano-silica was reinforced to investigate its effect on the mechanical performance of the composites. Hand lay-up composite molding process was used to fabricate the composite samples. During fabrication, ultrasonic mixing was carried out to study the effects on mechanical performance of the fiber particulate reinforced composites. In overall, ultrasonic mixing and addition of nano-silica particles has improved the mechanical performance of the fiber particulate composites. Morphology analysis on surface of composites has shown the removal of air bubbles and deagglomeration. 1wt% of short fiber reinforced composite exhibits the highest tensile and flexural properties among all the samples. Sugarcane bagasse particulates reinforced composites were shown to have better performance compared to short fiber reinforced composites when the wt% of the fiber increase.

Keywords: composite; sugarcane bagasse fiber; epoxy; nanosilica

1. Introduction

Nowadays, increase in sustainability and environmental concerns have evoked the interest in research and development of high performance and biodegradable composite. Efforts have been made to develop natural fibers and particulate reinforced composites as it is one of the most effective ways to satisfy the “eco-material” concept which serve as a basis to sustain the environment. One of the alternatives solution that attracts interest is utilization of abundantly natural fiber as reinforced materials in polymer matrix composite.

Composite is hybrid material which consists of two or more chemically distinct constituents. There is continuous phase which created by matrix and embedded by discontinuous phase, the reinforcement medium. The matrix phase is usually made up from fundamental material such as metals, ceramics and polymers. Meanwhile, the reinforcing phase is widely in the form of fibers, whiskers and particulates [1]. The reinforcing phase is usually stronger, lighter and stiffer than the matrix to enable the composites to possess better mechanical properties. Polymer matrix composites
are utilized nowadays as they have good versatility, high performance and cost effective [2]. Epoxies are one of the most important matrices which are widely used for fiber-reinforced polymer due to its unique properties. Epoxy is relatively high strength, high modulus, low shrinkage, high chemical, heat and electrical resistance [3].

As the awareness has greatly increased the world responsiveness towards natural fibers, an investigation has been carried out to study natural fiber reinforcements. These natural fibers which have been utilized in reinforcement can be found in numerous applications in various fields such as automobile, furniture, packing and construction. Besides, compared to conventional reinforcing fibers, the advantages of natural fibers are found out to be low density, fully biodegradable, environmentally friendly, renewable, non-toxicity, low cost, high toughness, good insulation against heat and noise, good thermal properties, reduced tool wear, reduced dermal and respiratory irritation, ease of separation and lower abrasiveness [4].

Sugarcane is one of the major crops in tropical region which has a total plantation area of 34500 acres in Malaysia [4] while the amount of sugarcane produced is approximately 1.3 to 1.6 million tons annually [5]. Bagasse fibers gathered through the sugarcane milling process after the extraction of the sugar-bearing juice from sugarcane. Sugarcane bagasse fiber-reinforced composites are found to exhibit better specific mechanical properties, such as stiffness, flexibility, and modulus compared to those reinforced by glass fibers [6]. It can be perfect alternatives for reinforcing bio-composites as it is renewable and less expensive sources due to its abundance as well as low preparation cost of the fibers [7].

Table 1. Mechanical properties of commercially important lignocellulosic fibers

| Fibers      | Density (g/cm³) | Tensile strength (MPa) | Young’s modulus (GPa) | Elongation at break (%) |
|-------------|-----------------|------------------------|-----------------------|-------------------------|
| OPEFB       | 0.7-1.55        | 248                    | 3.2                   | 2.5                     |
| Flax        | 1.4             | 800-1500               | 60-80                 | 1.2-1.6                 |
| Hemp        | 1.48            | 550-900                | 70                    | 1.6                     |
| Jute        | 1.46            | 400-800                | 10-30                 | 1.8                     |
| Ramie       | 1.5             | 500                    | 44                    | 2                       |
| Coir        | 1.25            | 220                    | 6                     | 15-25                   |
| Sisal       | 1.33            | 600-700                | 38                    | 2-3                     |
| Abaca       | 1.5             | 980                    | -                     | -                       |
| Cotton      | 1.51            | 400                    | 12                    | 3-10                    |
| Kenaf (bast)| 1.2             | 295                    | -                     | 2.7-6.9                 |
| Kenaf (core)| 0.21            | -                      | -                     | -                       |
| Bagasse     | 1.2             | 20-290                 | 19.7-27.1             | 1.1                     |
| Henequen    | 1.4             | 430-580                | -                     | 3-4.7                   |
| Pineapple   | 1.5             | 170-1627               | 82                    | 1-3                     |
| Banana      | 1.35            | 355                    | 33.8                  | 5.3                     |

From the table above, sugarcane bagasse is shown to have a density of 1.2 g/cm³ and a maximum tensile strength of 290 MPa. While its Young’s modulus achieved 27.1 GPa at its highest and the elongation of break is found to be 1.1%. The mechanical properties of sugarcane bagasse fibers are found to be the main focus of the researchers. Common mechanical properties attributed to the sugarcane bagasse fibers are the tensile strength, modulus of elasticity, density and elongation at break [8]. The age of the fibers, the source of the fibers and different techniques of surface treatment of the bagasse fibers are the factors which will affect the mechanical properties of the sugarcane fiber [9].
Aspect ratio has a considerable effect on composite properties, hence it is important to conserve fiber length as much as possible during composite processing operations. Furthermore, the aspect ratio means an average length over diameter of the fibers is varied from plant species to species [8]. They [8] conducted a work regarding the effect of chemical compositions and particle size on reinforced polypropylene composite. They concluded that the improvement in mechanical properties achieved can be attributed to higher fiber length and aspect ratio. According to their finding, fiber aspect ratio must be in the range of 100–200 for optimum effectiveness. In a short fiber composite, tensile load is transferred into a fiber from the matrix through shear at the fiber/matrix interface. The tensile stress is zero at the ends of the fiber and increase along the fiber length. Thus, the length of the fiber should greater than its critical length for efficient reinforcement. The influence of fiber length on tensile strength and Young’s modulus of sisal fiber reinforced polyester composite was investigated by [11]. They found that tensile strength and Young’s modulus increase with an increase in the fiber length. Similar trend was reported by [12] in the case of short oil palm fiber with different lengths (2, 6, 10 and 14mm) into a natural rubber matrix. Tensile strength, elongation at break, and tensile modulus at 100% elongations were at a maximum when the length of the oil palm fiber was 6 mm. At higher fiber lengths, a decrease in the properties was found. This was due to the fiber entanglements prevalent at longer fiber length.

Apart from fibers, there are also other fillers such as particulates being used in reinforcement of composites. Nanoparticles have been utilized as reinforcing phase in composites. Several studies indicate that modulus, strength and toughness can be simultaneously increased with the addition of Nano-scale fillers [13]. They are generally organic polymer composites mostly filled with inorganic fillers, which combine the advantages of the inorganic filler material (i.e., rigidity, thermal stability) and of the organic polymer (i.e., flexibility, ductility, processability). There are different types of nanoparticles which have been developed and used in various areas due to their multifunctional properties, such as anti-bacteria, UV resistant, anti-wrinkle finishing and water repellent to fibers [14] [6].

Among different available nano-particles, silica nanoparticles are more useful for the fabrication of composites due to their amorphous structure, SiO2 content (more than 99 % purity in most products), and highly specific surface area (which leads to the super pozzolanic property) [19]. They are mostly reported in the literature and being extensively used in various applications including electronics, automotive and aerospace industries. Chen et al. (2008)[13] have investigated the thermal and mechanical properties as a function of the silica percentage with spherical silica particulates of size 12-nm. Characterization techniques utilized in order to investigate the morphology are transmission electron microscopy (TEM) and ultra-small-angle X-ray scattering (USAXS). It is found that nanoparticles can be dispersed with minimal aggregation when the amount used is up to 25 wt%. It is reported that there is an increase of 25% in tensile modulus and 30% in fracture toughness for samples less than 10 wt% of silica.

Yet there are some challenges faced by these natural fiber-polymer composites such as the poor interfacial adhesion between fibers and the binding matrix. Thus, the alkaline surface treatment is applied to improve the adhesion. Besides, use of longer fibers can further increase their tendency to agglomerate. The reinforcement efficiency could be reduced due to poor fiber dispersion as fiber may get tangled during mixing. As the fiber content is being increased in the matrix, the bonding between the fiber and the matrix start to deteriorate as the fiber become too close to each other. Besides, agglomeration of fibers within matrix creates poor stress transfer efficiencies due to poor interfacial bonding between them thus a decrease in the mechanical properties. The hand-mixing method also leads to agglomeration of fibers within matrix, which also contributes in decreasing the mechanical performance of the composite.
Therefore, this study will focus on minimizing the agglomeration problems of the particulates as well as enhancing interfacial properties between the fiber and the matrix, by investigating the mechanical properties (tensile and flexural properties) and morphology analysis of hybrid composite consisting of epoxy matrix reinforced with treated sugarcane bagasse (SCB) fibers and Nano-silica particulate. Besides, this research also includes the effect of ultrasonic mixing on mechanical performance of the fiber particulate reinforced composite.

2. Experimental Procedure

2.1. Materials

The bagasse was obtained from the local supplier. The fibers were washed and separated to obtain the inner parts, followed by drying in oven at 150 for 24 h. The fibers were extracted manually. Epoxy and hardener (Miracast 1517A/B) were procured from Miracon Sdn. Bhd. and were used as matrix resin while nano-silica particulate was procured from Sigma Aldrich Malaysia.

2.2. Preparation of composites

2.2.1. Alkaline Treatment of Bagasse Fiber

Bagasse fiber was cut into pieces and soaked in 2% NaOH for 24 h. The fibers were rinsed then soaked in distilled water for 1h. The alkaline-treated fibers were dried at 100˚C for 3h, and kept in air-tight container to prevent moisture.

2.2.2. Obtaining of bagasse in fibrous form and particulate form

Bagasse short fiber was first cut into 5-10mm. Bagasse fiber particulates were obtained through a disk mill machine. Endecott EFL 2000 test sieve shaker was used to obtained fiber particulates which were less than 0.6mm. All the bagasse was kept in containers separately until used to prevent moisture.

2.2.3. Determination the weights of fillers and epoxy

The mix ratio of epoxy resin and hardener is 30:10. The different filler loading of sugarcane bagasse short fibers and particles are calculated by the weight percent (w/v) formula as shown as below:

Hand mixing method:

\[
\text{Mass of filler (g)} = \frac{\text{Resin and Hardener Required (g)}}{100} \times 40\text{g (mass of epoxy + hardener)}
\]  

Ultrasonic mixing:

\[
\text{Mass of filler (g)} = \frac{\text{Resin and Hardener Required (g)}}{100} \times 160\text{g (mass of epoxy + hardener)}
\]  

The weight percent (w/v) formula as shown as above was used to find the masses of filler loading of sugarcane bagasse fibers (g) required to mix with epoxy and hardener while using hand-mixing method and ultrasonic mixing. The required filler loading to be obtained are 1wt%, 2.5wt%, 3.5wt% and 5wt%. The only required filler loading for nano-silica particles is 1wt%, which is same as 1wt% of sugarcane bagasse fibers used in ultrasonic mixing.

2.3. Preparation of SCB short fiber and particulates composites by hand-mixing
Different weight percentage of 1%, 2.5%, 3.5%, and 5% of sugarcane bagasse fibers particles and short fibers were used in this experiment. Predetermined weight of epoxy resin and its hardener were poured into two separate disposable cups. Epoxy was shown to be in the bottom layer while hardener was shown in the top layer. The treated bagasse fibers particles were added according to their weightage into the epoxy and hardener mixture. The mixture was stirred for 2 minutes. The mold release agent was applied on the surface of the molds to serve as a parting agent between layers of the matrix and the mold surface, enable the hardened composite to be removed easily without causing damage to the mold. The composite mixture was then poured into the tensile and flexural molds by applying hand lay-up method. The specimens were put into the desiccator, and vacuum gas pump was switched on for 15 minutes to remove air bubbles in the composite. Later, the mold was left to air dry and cure for 24 hours then put into oven for post-curing for 3 hours.

2.4. Sonication of SCB fiber particulates/ nano-silica and epoxy mixture

In present work the SCB fiber particulates and nano-silica were dispersed in epoxy resin using a high intensity ultrasonic processor. The viscosity of the polymer increased while the weight percentage of SCB particulates increased. Although the weight percentage of nano-silica and fiber particulates is low, there is still high possibility to cause agglomeration. Thus, the sonication parameters stated below are carefully selected based on literature review to ensure better dispersion and deagglomeration:

- The sonicator probe is placed in the middle and the immersion depth is 2cm above from the bottom of the beaker. The sonication time was fixed to 20 min for epoxy, SCB fiber particulates and nano-silica.
- The mixture was placed inside the small diameter beaker (250ml), which immersed in ice-cooling bath to roughly the same level of the mixture to aid in the dissipation of heat.
- The sonication amplitude was set at 30% for 20 min to avoid damaging of SCB fiber particulates and nano-silica.

2.5. Mechanical Analysis

The tensile and flexural properties (strengths and moduli) of SCB short fiber composite, SCB fiber particulate composite, SCB fiber particulate composite using ultrasonic mixing and SCB fiber particulate composite with nano-silica are characterized experimentally. The mechanical tests are performed using LR Plus LLOYD Universal Testing Machine. The results obtained during the tensile and flexural tests were recorded. Morphology characterizations of sugarcane bagasse fibers were conducted by an optical light microscope. The resolution was adjusted to obtain the clearest micrographs for microstructure studies.

3. Results and Discussion

3.1. Effect of SCB short fiber and fiber particulates on mechanical performance of composites

Figure 1 shows the results of the tensile and flexural properties for various samples produced. SCB short fiber reinforced composites and SCB particulates reinforced composites are both shown to decrease gradually from the lowest fiber weightage (1%) to the highest fiber weightage (5%) in tensile strength. It was observed that the tensile strength and modulus is higher for 1wt% short fiber composite while compared to higher fiber content samples. 1wt% of short fiber composite has attained the best tensile strength and modulus, which is 7.3% and 14.6% better than 1wt% SCB fiber particulate composites. This might be happened as the fiber content increases, the tendency for the fiber/ matrix bonding strength to decrease is high. Both SCB short fiber and particulate reinforced
composites shown to have a better result as at low fiber content, the bagasse fibers are wetted properly by the epoxy resin and the fibers are in contact with one another [12].

Excluding 1wt% of short fiber composite, the strength and modulus of 2.5wt%, 3.5wt% and 5wt% short fiber composite are shown to be lower compared with the particulate composite with the same fiber loadings. This is suspected that at higher short fiber content, the fibers are touching one another also reducing proper fiber wetting and bonding between the bagasse fiber and epoxy matrix. Besides, due to the light weight of the bagasse fiber, the mixture was overflowed when 5wt% of bagasse short fiber was used. The attachment between matrix and the reinforced fibers became lesser. It was observed that the epoxy resin was insufficient to cover all the surface of bagasse fiber in the composite [13]. The functional effectiveness of epoxy matrix to act as the binder material to transfer external loads to internal loads was affected. Therefore, the capabilities of stress transfer has been weaken at higher fiber loading. This was also proved by previous study that poor fiber-matrix adhesion was prominent at high fiber content [7].

In addition, minor entanglements and agglomeration has been induced among the fibers due to high evaporation of water in the drying process of SCB fiber. Therefore, the mechanical testing has been affected. Rough surface finish of the composite specimen due to the overflowed short fibers was also one of the factors that affect the mechanical properties of the composite.

However, in the case of particulate composites, the overflowing of the mixture is less likely to be happened and the epoxy resin was still sufficient to cover all the bagasse fiber in the composite due to the particle geometrical shape. The surface finish obtained is also shown to be better than short fiber composites thus the mechanical performance of particulate reinforced composite is higher than short fiber reinforced composite in 2.5wt%, 3.5wt% and 5wt%. Therefore, 2.5wt%, 3.5wt% and 5wt% shows better mechanical performance in tensile strength and modulus. The improvement is ranged from 8% to 23.8% as it overcome the shortage of short fiber composite during the increase of fiber weightage as mentioned above. The same case also applied in flexural strength, SCB fiber particulate composites were improved from 10% to 34%. However, the increase in fiber weightage still induce the problem of agglomeration therefore the mechanical performance of the particulates decreases gradually.

As for flexural properties, it was noticed that a higher flexural strength and modulus were obtained compared to tensile strength and modulus. This proved that the SCB short fiber composites were shown to give ideal performances in enduring forces than to resist opposing tensile stresses. Through this study, it was revealed that 1wt% of SCB fiber loading are more superior in giving relatively ideal mechanical properties while compared to specimens with other fiber loading. SCB short fiber has shown improvement in flexural strength and modulus, which is 9.7-18.5% higher while compared to SCB fiber particulates at different weightage of fiber. Short fibers were more capable in preventing the deformation under the presence of bending loads and fatigue stresses. It is more effective for the fibers to lock into the epoxy matrix thus improved the stress transfer from the matrix to the fibrous fillers.
Figure 1. Tensile and flexural properties of SCB short fiber and particulate composite
SCB fiber particulates were shown to have less function in improving flexural properties compared to tensile properties. According to Aruniit et al 2011 [2], the flexural strength could only remain steady or make decrease due to their unfavourable geometrical features. However, samples which reinforced with fiber particulates has shown significant improvement in flexural strength, which is 34.2% and 33.2% higher for 2.5wt% and 3.5wt% respectively. This could be said that SCB particulates has overcome the problems of short fiber being too compact to be dispersed well within the matrix while increasing the fiber weightage. As the weightage of the short fiber increased, the capabilities of stress transfer weakened.

Deploying the hand lay-up method which require low cost tooling and minimal power usage will reduce the pollution to the environment. It is also economical as it requires low cost manufacturing tools compared to other conventional method. However, a random orientation alignment of the fibers in the composite is obtained and overflowing of fibers are unpreventable. The maximum reinforcement efficiency can hardly be achieved. Therefore, it is hard to obtain maximum strength due to the impossibility to achieve 100% uniformity in fiber orientation and distribution. According to Luz S.M et al (2007)[9], the compression and injection moulding processes were performed for better evaluation of sugarcane bagasse. Through injection moulding under vacuum process, a homogenous distribution of fibers without blister could be obtained. According to Torres et al. (2017) [12], composite panels were manufactured by vacuum assisted resin transfer moulding (VARTM) on a rectangular tool plate. The fibers distribution in the composite are controlled in the manner that the overflowing of fibers in the composite were prevented. This overcame the issue that is caused by the hand lay-up method.

In overall, the short fiber reinforced composite only show better mechanical performance at lowest fiber weightage (1wt%) due to minor entanglement, agglomeration, insufficient coverage of epoxy resin with the fiber at higher fiber weightage. Specimen manufacturing and technical issues are also one of the factors. Maximum reinforcement efficiency can hardly be achieved due to the restriction of hand lay-up method. The mechanical performance of the composites at higher fiber weightage could be improved using fiber in particulate form.

3.2. Effect of ultrasonic mixing and addition of nano-silica on mechanical performance of composites

In this study, tensile and flexural properties of SCB fiber particulates composites were compared using two different fabrication methods and one with addition of nano-silica. Refer to Figure 2, tensile strength and modulus of the composites using ultrasonic mixing were improved, which is ranged from 3.5-15.9% and 3-9% respectively. This could prove that ultrasonic processor had aid in deagglomeration as well as in enhancing dispersion of fiber particles. From the results, 5% weightage of fiber particles was shown to have 9% and 15.9% of improvement in tensile strength and tensile modulus respectively, which were the highest among all. In the case of flexural strength and modulus, the mechanical performance of SCB fiber particulate reinforced composite has also improved, which ranged from 3.8-20.8%. In overall, it can be concluded that the mechanical performance of the composites was elevated as the agglomeration was minimized while ultrasonic mixing was applied.
Figure 2. Tensile and Flexural Properties of SCB composites using hand-mixing, ultrasonic mixing and with addition of nano-silica.
With the addition of nano-silica, it can be observed that the tensile strength and tensile modulus of the SCB fiber particulate composite have been successfully improved, which ranged from 5.4% to 33.17% and 14.7% to 16.2% respectively. As for results of flexural testing, it was noticed that the trends were in line with the tensile properties testing results. The improvement ranged from 0.6% to 5.2% for flexural strength and 2% to 14.4% for flexural modulus. From the results, it can be concluded that the nano-silica particles have elevated mechanical performance especially tensile properties of the composite due to its extremely large surface area and its smooth nonporous surface. The results obtained was in line with the research done by Dittenber et al. 2012 [13], which indicated that the addition of nano-silica particles is able to increase stiffness around 10% as the particles fill in the voids in the composites and minimized the agglomeration. Although the improvement was insignificant for flexural strength, it was concluded that the addition of the nano-silica particles has improved the mechanical performance of the composite. The agglomeration was minimized and the presence of the voids in the composite reduced.

4. Morphology Analysis

Figure 3. Optical microscopy pictures taken of the composites
It can be observed from Figure 3 that 5wt% SCB short fiber composite showed overflowing of the fiber and results in a rough surface finish as well as some fiber pulled out while compared to 1wt% SCB short fiber composite. The attachment between matrix and the reinforced fibers is lesser in 5wt% SCB short fiber composite. The epoxy matrix in 1wt% SCB short fiber composite was shown to be more sufficient to cover all the surface of bagasse fiber which results in higher capabilities of stress transfer. The bagasse fibers are wetted properly by the epoxy resin. Secondly, 1wt% and 5wt% SCB fiber particulate composite was significantly shown to have more air bubbles while compared to the SCB fiber composites using ultrasonic mixing. The use of ultrasonic mixing has proved to reduce air bubbles successfully. Moreover, ultrasonic mixing was also attributed to better fiber dispersion and reducing agglomeration in 1wt% SCB fiber particulate composite. Figure 4 presents the fractured region after tensile tests were performed to the composites. The differences between particulate SCB and fibrous SCB composites were observed. It was once again verified that fibers distribution in the epoxy matrix and pull out of fibers, characterized the mechanism of fragile fracture. It would appear that the bonding between matrix and particulate SCB is superior to that of the fibrous SCB composite due to the dispersion of particulates was better compare to fibers form when the weightage of SCB is higher.

5. Conclusion

The summarization of the findings from the study on the mechanical performance (tensile and flexural properties) of the sugarcane short fiber reinforced epoxy composites, sugarcane fiber particulate reinforced epoxy composites, sugarcane fiber particulate with nano-silica reinforced epoxy composites and the effect of using ultrasonic mixing are stated as below:

- All the sugarcane short fiber reinforced epoxy composites obtained higher flexural modulus compared to sugarcane fiber particulates reinforced epoxy composites.
- Among all the sugarcane short fiber composites, 1wt% of sugarcane short fiber composite exhibits the highest tensile and flexural properties compared to 2.5wt%, 3.5wt% and 5wt%.
- Sugarcane fiber particulates reinforced composites were shown to have better performance when the wt% of the fiber increase while compared to short fiber reinforced composites.
- The sugarcane fiber particulates composites fabricated using ultrasonic processor showed improvement in both tensile and flexural properties due to the deagglomeration of the fiber particulates.
The addition of nano-silica particles has further elevated the mechanical performance of the alkali treated sugarcane fiber particulate composites due to the reduction of micro-voids in the epoxy resin and agglomeration is reduced.

The morphology study has revealed that ultrasonic mixing has successfully reduced the air bubbles and agglomeration. The epoxy matrix in 1wt% SCB short fiber composite was shown to be more sufficient to cover all the surface of bagasse fiber compared to 5wt% of SCB short fiber composite.

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References

[1] Callister, William D. (2007). *Materials Science and Engineering: An Introduction*. https://abmpk.files.wordpress.com/2014/02/book_maretial-science-callister.pdf

[2] Aruniit A., Kers J., Tall K. (2011). "Influence of filler proportion on mechanical and physical properties of particulate composite." *Agronomy Research Biosystem Engineering Special*.

[3] Alamri, H., and I. M. Low. (2013). "Effect of Water Absorption on the Mechanical Properties of Nanoclay Filled Recycled Cellulose Fibre Reinforced Epoxy Hybrid Nanocomposites." *Composites Part A: Applied Science and Manufacturing* 44: 23-31.

[4] Salit, M. S. (2014). Tropical natural fibres and their properties In *Tropical natural fibre composites* (pp. 15-38). Springer Singapore.

[5] Kadir, A. and N. Maasom. (2013). "Recycling sugarcane bagasse waste into fired clay brick." *International Journal of Zero Waste Generation*, 1(1), 21-26.

[6] Mulinari, Daniella R., Herman J. C. Voorwald, Maria Odila H. Cioffi, Maria Lúcia C. P. da Silva, and Sandra M. Luz. (2009). "Preparation and properties of HDPE/sugarcane bagasse cellulose composites obtained for thermokinetic mixer." *Carbohydrate Polymers* 75 (2):317-321. doi: 10.1016/j.carbpol.2008.07.028.

[7] Cao, Y., S. Shibata, and I. Fukumoto. (2006). "Mechanical properties of biodegradable composites reinforced with bagasse fibre before and after alkali treatments." *Composites Part A: Applied Science and Manufacturing* 37 (3):423-429. doi: 10.1016/j.compositesa.2005.05.045.

[8] Jawaid, M., and H. P. S. Abdul Khalil. 2011. "Cellulosic/Synthetic Fibre Reinforced Polymer Hybrid Composites: A Review." *Carbohydrate Polymers* 86 (1): 1-18.

[9] Luz, Sandra Maria da, Adilson Roberto Goncalves and A.P. Del’Arco. (2007). “Mechanical behaviour and microstructural analysis of sugarcane bagasse fibers reinforced polypropylene composites.” *Composites Part A Applied Science and Manufacturing* 38(6):1455-1461. doi: 10.1016/j.compositesa.2007.01.014

[10] Oladele, I.O. (2013). “Effect of Bagasse Fibre Reinforcement on the Mechanical Properties of Polyester Composites”, *The Journal of the Association of Professional Engineers of Trinidad and Tobago*, Vol.42, pp.12-15.

[11] Shibata, Shinichii, Rahman M. Bozlur, Isao Fukumoto and Yasuyuki Kanda. (2010). “Effects of Injection Temperature on Mechanical Properties of Bagasse/ Polypropylene Injection Molding Composites" *BioResources* 5(4).

[12] Torres, J., Vandi, L.-J., Veidt, M., & Heitzmann, M. (2017). The mechanical properties of natural fibre composite laminates: A statistical study. *Composites Part A: Applied Science and Manufacturing*, 98, 99-104.

[13] Dittenber, David B and Gangaraao HVS. (2012). “Critical review of recent publications on use of natural composites in infrastructure.” *Composites Part A Applied Science and Manufacturing* 43(8):1419–1429. doi: 10.1016/j.compositesa.2011.11.019