Better Wettability of Pandanus Utilis Alkaline Treated Fibres Tead to Higher Tensile Strengths of Composites.

Laurent L'Entete (✉ laurent.lentete.888@gmail.com)
University of Mauritius  https://orcid.org/0000-0001-9959-2074

Hareenanden Ramasawmy
University of Mauritius

Research Article

Keywords: Tensile strength, contact angle, alkaline treatment, Pandanus utilis, fibre length

DOI: https://doi.org/10.21203/rs.3.rs-177109/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License
Abstract

Composite materials made with synthetic fibres like E-glass, Kevlar or carbon have helped to provide a wide array of products to society with specific engineering properties. However, these materials have a high carbon footprint as well as being non-biodegradable. The use of natural fibre, as a substitution to these man-made fibres, has been studied and encouraging results are being obtained.

In this study, the use of ‘Pandanus utilis’ fibre as a reinforcing agent in plastic was investigated with the aim of exploring specific properties such as the tensile strength of the fibre, its wettability and the effect of fibre length after treating the fibre with two different NaOH solutions. Results have shown that better reinforcement was obtained for the composites (11.10 ± 2.53MPa) with fibres subjected to a more aggressive treatment (2.5%NaOH for 2h) compared to the composite made with fibres having maximum tensile strength (168 ± 12MPa at 0.5% NaOH for 14h), due to a better hydrophilicity of the alkaline treated fibre (87.37° internal angle). Within the range of short chopped fibre length tested (6 to 15 mm), it was shown that there was a general decrease in the tensile strength of the composite.

Introduction

In this era where the world is facing a major problem of plastic pollution, people are converging their ideas towards the use of natural fibre in different composite applications. For the past few decades there has been an increasing use of natural plant fibres in the manufacture of polymer composites, mostly in the automotive sector. This is due to the relatively high specific strength, bio-degradability property, lower cost of production, and low abrasive properties.

For Small Island Developing States (SIDS), such as the Mauritius (part of Mascarene islands), the demand for glass-reinforced products (GRP) such as letter box, surfboard, kayaks, utility boxes, wind turbine blades, swimming pool furniture and water tanks are increasing year by year showing the significant use of glass fibres. However being a SIDS without much raw material resources, Mauritius has to import glass fibres, which involves high transportation cost and leading to a high carbon footprint. Glass fibre tends to cause additional machining cost of 2.65€/cm$^3$ since the tools required in the manufacturing process of GRP need to be replaced frequently given the abrasive nature of glass fibre. [1]

In order to meet the Sustainable Development Goals (SDGs), SIDS have to provide new opportunities for business development for their citizens in the sectors that are present locally such as agriculture, fishing and tourism. The creation of a fibre micro-industry would entail the creation of new job opportunities particularly in rural areas. This would help to alleviate poverty and minimise social inequalities. For the past 50 years, Mauritius’ economy has been based on the sugarcane industry (60 % of the export earnings in 1979, [2]) due to the preferential tariff and guarantee market in Europe Union (EU), causing the maximum development of the sugarcane plantation across the island. However in October 2017, EU has abolished all sugar quotas. Therefore, the local sugar planters are facing several difficulties in sustaining sugar cane plantation particularly with the rising labour cost, and it has been reported that there are more
than 9,000 hectares of abandoned sugar cane fields [3]. Some other farmers have started to shift towards pineapple and banana cultivation in order to generate an income while being more resilient to climate change. Thus, the creation of the micro industry for the production and extraction of the fibre from agro waste will not only prevent the farmers from losing their jobs but also allows the development on the agricultural sector.

Furthermore, many of the SIDS possess a rich flora of endemic plants, and for example the Mascarenes islands are a hotspot for the conservation of several endemic plants. As a mean to support the conservation effort, the leaves of many endemic plants such as Pandanus species, palm species are a goodsource offibres for the micro industry.

Natural fibre has proved to gain more strength under alkaline treatment as a reinforcing agent in biocomposites at proper concentration and soaking time. Alkaline treatment, which meets both time and cost constraints, allows natural fibre to be exploited efficiently and economically. Treated data palms fibre (DPF) with 5%w.t NaOH has an optimum tensile strength of 460MPa. [4] The optimum treatment for banana fibre was found to be 11g/L NaOH for 150 min at 90°C.[5] After being soaked for 10min at 55°C at 5%w.t NaOH, treated flax fibre has an optimum tensile strength of 611 MPa.[6]

However, the main idea after treating the natural fibre is to use the latter as a reinforcing element in the bio composite. But the optimum alkaline treatment for producing the strongest fibre may well differs from the treatment which will produce the stronger bio composite. This is because there are other factors, particularly the fibre to matrix adhesion which tends to play an important role in influencing the composite mechanical strength. The optimum treatment for producing a strong single Kenaf fibre was found to be 4%w.t NaOH for a period of 30min at 60°C but the author did not mention the specific alkaline treatment which leads to an increase in strength of 11.84% of the composites [7]. Taha et al (2007) did optimize the strength of date palm fibre (DPF) for its application in polymeric composites, mentioning that alkaline treatment does also modifies the surface of the fibre.[8] On the other hand, Rizal et al (2018) observed the relationship of the soaking time of alkaline treatment on Typha fibre with its wettability properties and as a result improving the tensile strength of the biocomposites.[9] The strength of Alfa reinforced polyester increases as the concentration of NaOH increases for the same soaking time. [10]

Few authors did consider the impact of optimizing the alkaline treatment in terms of the interaction between the base matrix and the treated fibre. Their main concern was to improve factors like the length or weight ratio of the fibre. Hemp fibre propylene composites proved to be stronger (47.2 MPa) with a weight ratio of 40% and a length of 1-3cm compared to fibre having length of 10cm. [11] At a weight ratio of 30% compare to 0%, 10% and 20%, sisal reinforced polypropylene has the highest tensile strength. [12] Ijuk fibre at a length of 50mm had a relatively higher tensile strength compare to a fibre length of 10mm according to Santhiarsa (2016). [13]

Research has also been conducted on the Pandanaceae species and their application in biocomposite. An optimum tensile strength of 17 MPa was obtained using ‘Pandanus Fascicularis’ in polyester composites while the potential application of ‘Pandanus utilis’ in epoxy composites as a substitution to
glass fibre was discussed by Deesoruth et al (2014) with a biocomposite having a compressive strength of 97.9 MPa for weight ratio of 10% of the optimum treated fibre (5% w.t NaOH for 45min at 75°C). [14, 15]

In this study, an investigation was performed in order to evaluate the effect of the alkaline treatment on the wettability of 'Pandanus utilis' fibre and the impact of this property on the tensile strength of the reinforced plastic composite produced by compression moulding. Furthermore, in the same process, the relationship of the tensile strength of the reinforced biocomposite with the fibre chopped length used for the biocomposite was studied and compared to the composite being produced industrially by a local company.

Methodology

Extraction

The extraction of the fibre was done using a Phoenix Decorticator, and all the 'Pandanus utilis' leaves were taken from the same tree to minimize the effect of external factors such as geographical location, temperature, the soil quality. The fibre were then cleaned and dried in an oven for 24h at 60°C.

Alkaline Treatment

The fibres were treated under two set of conditions; a first set with 0.5%wt NaOH for 14h (SFOT) as being the optimum alkaline condition to obtain the maximum fibre tensile strength of 160 MPa as per the published work Rafidison et al (2018). [16] Given that the objective is to improve the wettability of the fibre to the matrix, an exposure to a higher concentration of alkaline treatment would lead to the defibrillation of the fibre and increased its roughness. Thus, a second set of conditions, 2.5%wt NaOH for 2h (SFST) was conducted, which, according to Rafidison et al (2018), should result in a decrease of 40% in the tensile strength (120MPa). [16] A fibre to solution ratio of 1 to 30 was used and the fibres were completely immersed in the respective solution. After the appropriate soaking time, the fibres were neutralized using distilled water and dried in an oven for 24h at 60°C.

Manufacturing of the composites

The fibre composite was fabricated based on the method in place at one of the leading manufacturer of composite in Mauritius. The local manufacturer uses 6 mm chopped glass fibres to produce GRP for different commodity products by compression moulding. Thus the baseline for 'Pandanus utilis' fibre length was set at 6mm, and the effect of the two alkaline treatments on the 6 mm chopped fibres were evaluated by testing the composite tensile strength.
Subsequently, the effect of the alkaline (SFST) treated chopped fibre length of 6mm, 9mm, 12mm and 15mm on the tensile strength of the resulting composite was investigated. A fibre volume ratio of 15% was used, as per the local manufacturer's practice. The fibres were added slowly to the polyester resin during the mixing process and the resulting dough was mixed using a motorised Z-bladder for achieving homogeneity. The dough was then placed in a compression moulding machine (available at the local company used for producing GRP products) and a load of 1000kg/cm$^2$ at a temperature of 150°C for 1 min to produce rectangular plate of 315mm x 250mm x 4mm. The composite plates were then allowed to cool at room temperature.

**Tensile Testing**

The tensile test of the ‘Pandanus Utilis’ fibre was done according to the ASTM C-1557 with a load cell of 10kgf at a speed of 3.5mm/min (for failure of fibre to occur within 30 s) on a Testometric M500–50 AT. The gauge length used was 25.4mm and the overall fibre length was 30mm. 20 single fibre specimens were tested and their individual cross-sectional area was measured at the broken point (during the tensile test), along each fibre using ImageJ software with a USB connected microscope.

For the tensile testing of the fibre composite, the dumbbell shape was cut from the compression moulding composite plate using a CNC milling machine according to the Type 1 of the ASTM D-638. The tensile test was conducted on the above tensile machine with a load cell of 5000 kgf and a speed of 0.35mm/min with a sample size of 9 specimens. The average cross sectional dimensions of each of the 9 composite samples for each condition were measured using a Vernier caliper.

**FTIR**

FTIR tests were carried out on the untreated and mercerized fibres using a Bruker single bounce ATR-FTIR spectrometer, equipped with its OPUS software. Calibration was carried out before each measurement. All spectra were recorded in the range from 4000 to 500cm$^{-1}$.

**Wettability test**

Contact angle test was done at the Center for Biomedical and Biomaterials Research (CBBR), Mauritius. The specimens were prepared on a glass slide and the inter-fibre gaps were minimized thus increasing the accuracy of the testing method. The tests were carried out on Kruss Drop Shape Analyzer-DSA 100 using a water droplet of 2µL at 25°C with 5 samples being taken on each specimen and Young Laplace Fitting method was used.

**Results And Discussion**
The tensile strength of the single fibre obtained for the optimum treatment (0.5% w.t NaOH for 14h - SFOT) is 168.2 ± 12.6 MPa while the tensile strength of the untreated fibre is 152.5 ± 84.1 MPa. An increase of 22% in the tensile strength of the fibre is recorded similar to the findings of Rafidison et al (2018). [16] A. Oushabi et al (2017) have recorded an increase of 76% in the tensile strength of the date palm fibre after the latter was treated with its optimum alkaline treatment. [4] Jute fibre has an increase of 59% in its modulus after being treated with an alkaline treatment of 1% w.t NaOH. [17]

The second alkaline treatment (2.5% w.t NaOH for 2 h - SFST) has yielded a fibre tensile strength of 117.9 ± 12.3 MPa, about 30% lower as compared to the optimal NaOH treatment (SFOT). This shows that a higher concentration of the alkaline treatment as compared to the optimum condition produced a treated fibre with a lower tensile strength. The same observation was made by Pickering et al (2007) with hemp fibre. [11] With an increase of 5% w.t in its NaOH concentration in the alkaline treatment, a decrease of 45 MPa was recorded in the hemp fibre, although the soaking time was reduced by 30min.

Wettability test

The average internal contact angle obtained for the SFOT sample was 95.23° ± 3.49° and for the SFST specimen was 87.37° ± 4.97°, showing that the more aggressive alkaline treatment does affect the hydrophobicity of the fibre. The SFST condition allows the fibre to reach the hydrophilic state as compared to a hydrophobic state obtained with the SFOT condition. The same observation was made with Typha fibre by Rizal et al (2018) where the internal contact angle of the water droplet increases with an increase in the soaking time (from 2 hours to 8 hours) at a constant alkaline concentration of 5% w.t NaOH. [9]

In order to further understand the difference in the effect of the chemical treatments on the properties of the fibre the detection of specific chemical functional groups by the FTIR technique is presented in the next section.

FTIR results

The decrease in the peak at 1726 cm⁻¹ wavelength shows the significant removal of non-cellulosic component such as the lignin and hemicelluloses. This change has also been observed in Alfa fibre when treated with 5%NaOH. [10] Roy et al (2012) observed the same phenomena as the concentration of the alkaline solution is increased when treating jute fibre. [18] The absorbance peak at 1735 cm⁻¹ is reduced in Typha fibre after being treated with sodium hydroxide showing the successful removal of the carbonyl group present in hemicelluloses. [9] As these chemical groups are removed from the natural fiber after treatment, the treated fibre has a higher ratio of cellulose present in the fibre therefore having higher tensile strength as compared to untreated fibre. The SFST treated fibre showed a smaller peak around
1726 cm$^{-1}$ which would mean that there is better penetration of the alkaline solution into the wall of the fibres, thereby removing more of the hemicellulose and leading to higher defibrillation. This would then lead to an increased in the surface roughness of the fibres, which would yield a better wettability property.

Thus in the present study, it can be expected that the composite manufactured with SFST treated fibres would have a higher tensile strength as compared to composite with SFOT fibres. This will be discussed in the next section.

**Tensile strength of the fibre-based composite**

A first comparison of the tensile strength of the biocomposite and the glass reinforced plastic (GRP) produced using the industrial procedure (fibre chopped at 6mm length) present at the industry was made. Since the density of the ‘Pandanus utilis’ fibre is half the glass fibre, industrial volume ratio was used instead of the mass ratio for adequate mixing of the natural fibre and the polyester resin. [19] The tensile strength of the SFOT fibre polyester composite was 8.32 ± 1.30 MPa, and 11.10 ± 2.53 MPa for SFST fibre polyester composite. Based on a t-test, the calculated t value is 2.953 whereas the critical t value is 2.306, which confirms that there is a difference between the two mean values. These results of tensile strength confirm the results of the contact angle measurements where SFST fibres had a smaller internal contact angle as compared to the SFOT fibres. Thus the SFST fibres have a better wettability property with the polymer resin leading to better mechanical strength.

On the other hand the 6 mm chopped fibre glass polyester composite fibre has a tensile strength of 33.10 ± 2.48 MPa, which is 198 % higher than that of the SFST. However, the SFST composite does not represent an optimized condition for highest interfacial shear strength between the fibre and the polyester matrix. Furthermore the effective impact of the fibre length and fibre ratio in the matrix has also not yet been optimized in this study.

It is observed that although the SFST fibres have 40% lower tensile strength (118 MPa) as compared to the SFOT fibres (168 MPa); the SFST fibre composite has a tensile strength which is 33.7 % higher than SFOT based fibre composite. This implies that the adhesion of the treated fibre with the base polyester matrix plays a critical role in transmitting the load from the matrix to the fibres. The higher adhesion of the SFST fibre to the matrix is explained by the lower internal contact angle as compared to the SFOT fibre. The same observation was made by Rizal et al (2018) with Typhafibre, where the maximum tensile strength of the Typha fibre reinforced composite was recorded with an alkaline treatment of 5%w.t NaOH for 4h which had a contact angle lower than 87.5°. [9] This clearly showed that the hydrophilicity state of the treated fibre do affect the final strength of the biocomposite.

The above findings of the present study are further supported by the research work on jute fibres; by combining the observation made by Roy et al (2012) and those of Lakshmanan et al (2016). Roy et al (2012) observed that the optimum treatment for producing a strong single Jute fiber (610MPa) is 0.5% wt NaOH for 24h at ambient temperature, while Lakshmanan et al (2016) reported that the optimum
treatment for producing a strong biocomposite (48.3MPa), with based matrix unsaturated polyester resin, using treated Jute fibre is 1%w.t NaOH for 60min at 30°C. [17, 18] It is thus observed, that a jute fibre treated with a stronger alkaline solution, resulting in a lower tensile strength (25.7 %) but with better contact angle, will produce a stronger fibre based composite.

**Effect of the fibre length on the tensile strength of the composite**

The tensile strength of the respective fibre composite produced using the different fibre length is shown in the table below. As the length of the fibre is increased, the tensile strength of the biocomposite decreases to a minimum value of 3.23 ± 1.37 MPa at 15mm chopped length. Although Deesoruth et al (2014) have determined that the critical length of ‘Pandanus utilis’ fibre is $L_c = 2.64$mm, the present findings show that the tested lengths $L$ between $2L_c$ (6 mm) and $6L_c$ (15 mm) of the treated fibre lead to a reduction in the tensile strength of the composite. The same observation was made by Yang et al (2019). [15, 20]

Fig 3 Tensile strength of the different composites produced using different fiber length

Takagi and Ichihara (2004) observed fibre pull-out phenomenon when NaOH treated bamboo fibres of 8 mm length or less was used in a resin, whereas fibre fracture occurred when the fibre length was 15 mm or more. These authors concluded that the fibre critical length was about 12 mm whereas theoretically they calculated the critical length as being 30 mm. However, these authors did not perform any NaOH process optimization to determine the best fibre to resin adhesion. [21]

Iqbal et al (2017) had also investigated the effect of jute fibre length (10-30 mm) on the tensile strength of a polystyrene untreated fibre composite. According to the authors calculation the critical length ($L_c$) was 0.24 mm, and the minimum fibre length to be considered as a continuous fibre ($15L_c$) was 3.6 mm. They have reported no significant improvement in the tensile strength with fibre length of 10 mm but an increase of about 18 % at fibre length of 30 mm as compared to the pure unreinforced polymer. It can be observed that these authors have used fibre lengths much greater than the minimum continuous untreated fibre, and that a significant improvement in the TS of the composite was only achieved at very long length, typically $125L_c$. [22]

Bisaria et al (2015) investigated the effect of untreated jute fibres (5-20 mm) on the mechanical properties of the fibre epoxy composite.[23] These authors have reported a general decrease in the tensile strength of the resulting composite for fibre length between 5 and 20 mm as compared to that of the unreinforced polymer. These results are to some extent along the same line as those of Iqbal et al (2017) particularly for fibre length of 20 mm or less. Both Bisaria et al (2015) and Iqbal et al (2017) have used the hand lay-up technique to fabricate the composite, but each with a different procedure, and also with a different polymer. [22, 23]
From the findings of Takagi and Ichihara (2004), Iqbal et al (2017), Bisaria et al (2015), and the results of the present study, it is noted that there are several factors which would impact on the resulting tensile strength of the composite, namely, the optimized interfacial shear strength of the fibre to polymer, the fibre to resin ratio, the distribution of the fibres in the polymer (which would affect the void spaces in between the fibres network), presence of air bubbles, and the method of fabrication of the composite (which relates to the effective pressure applied to bind the fibre to the polymer). [21-23]

Alkaline treatment with NaOH will tend to modify the surface roughness of the fibre thereby increasing the area of contact with the polymer. But the NaOH has to be optimized for maximum fibre to matrix interfacial shear strength rather than maximum tensile strength of the fibre. Furthermore the shape and size of the fibres also play an important role in ensuring a proper adhesion to the matrix.

Conclusion

This study has shown that the ultimate goal in producing the strongest natural fibre based composite is to improve the interaction of the fibre with the base matrix and to achieve this goal, several factors need to be considered and optimised such as the hydrophilicity (appropriate treatment of the fibre), chopped length, fibre to resin ratio and fabrication among others. In this study it has been shown that the treated fibre with the highest tensile strength does not produce the stronger composite. The crucial role of the hydrophilicity of the natural treated fibre has been shown, and although not being optimised, has shown to have better effect on the resultant strength of the biocomposite being produced. Fibre lengths $L$ between $2L_c$ and $6L_c$ have shown to produced weaker biocomposite in this study leading to the fact that fiber length has an impact on the tensile strength of the fibre. It should be noted that the range of fibre lengths was chosen based on the current practice at the local composite manufacturing company, and also on the methodology of the mixing process for the dough preparation prior to the compression moulding process.

Finally, it would seem that using much longer fibre length than the critical length with the optimum NaOH treatment for maximum fibre to matrix interfacial strength, appropriate pressure for fibre wetting to the matrix, which would also remove air bubbles, effective fibre distribution in the matrix could potentially improve the tensile strength of the natural fibre composite.

Abbreviations

SFOT: Single Fibre Optimum Treatment

SFST: Single Fibre Second Treatment

Declarations

Funding:
This work was conducted at the University of Mauritius as a final year project for BEng Mechanical Engineering with Honors (Industrial) under the supervision of Associate Professor H. Ramasawmy in collaboration with a local manufacturer of composites. The required funding was provided by the university, and materials as well as composite manufacturing were provided by the manufacturer.

Conflicts of interest/Competing interests:

Not applicable

Availability of data and material:

All the data were obtained through calibrated machines available at the respective laboratory at the University of Mauritius.

Code availability:

Not applicable

Authors' contributions:

Not applicable

Ethics approval:

Not applicable

Consent to participate:

Not applicable

Consent for publication:

Yes

Statement of Novelty

This study highlights the benefits of using ‘Pandanus utilis’ fibres as a substitute to glass fibres in the industrial production of polyester composites by the compression moulding process. An experimental
work was carried out to compare the optimum alkaline treatments yielding highest fibre tensile strength with a slightly more aggressive alkaline treatment; and the tensile strength, FTIR analysis and contact angle measurement have shown better wettability of the fibres to the polyester matrix. A composite with a higher mechanical strength was thus obtained. The study has also shown that chopped short natural fibres within the close range of the commercial chopped fibre glass length do not lead to an improvement in the mechanical strength, but rather the opposite effect.

References

1. Kolar P, Masek P, Zenman P. Milling tools for cutting of fiber-reinforced plastic. Prague: Research Center of Manufacturing Technology Prague https://www.researchgate.net/publication/271517747_Milling_Tools_For_Cutting_Of_Fiber-Reinforced_Plastic (2014).
2. YeungLamko, L. The Economic Development Of Mauritius Since Independence. Sydney, N.S.W. (1998)
3. Mauritius Sugarcane Industry Research Institute. Research And Development Plan 2016-2020 For A Resilient Mauritian Cane Industry. Report, MSIRI, Mauritius. (2016)
4. Oushabi A, Sair S, OudhririHassani F, Abboud Y, Tanane O, El Bouari A. The effect of alkali treatment on mechanical, morphological and thermal properties of date palm fibers (DPFs): Study of the interface of DPF–Polyurethane composite. South African Journal of Chemical Engineering 2017;23:116-123. (2017) https://doi.org/10.1016/j.sajce.2017.04.005
5. Vishnu Vardhini KJ, Murugan R. Effect of laccase and xylanase enzyme treatment on chemical and mechanical properties of banana fiber. Journal of Natural Fibers, (2017) https://doi.org/10.1080/15440478.2016.1193086
6. Aly M, Hashmi MS, Olabi AG, Benyounis KY, Messeiry M, Hussain AI, Abadir EF. Optimization of alkaline treatment conditions of flax fiber using Box–Behnken method. Journal of natural fibers (2012) https://doi.org/10.1080/15440478.2012.738036
7. Othman MH, Hashim MY, Amin AM, Huat NC, Marwah OM, Johar MA, Jamal EF. Optimization of Alkali Treatment Condition on Tensile Properties of Kenaf Reinforced Polyester Composite Using Response Surface Method. International Journal of Integrated Engineering (2018)
8. Taha I, Steuernagel L, Ziegmann G. Optimization of the alkali treatment process of date palm fibres for polymeric composites. Composite Interfaces (2007) https://doi.org/10.1163/156855407782106528
9. Rizal, S., Ikramullah, Gopakumar, D., Thalib, S., Huzni, S. and Abdul Khalil, H., Interfacial Compatibility Evaluation on the Fiber Treatment in the Typha Fiber Reinforced Epoxy Composites and Their Effect on the Chemical and Mechanical Properties. Polymers (2018) https://doi.org/10.3390/polym10121316
10. Benyahia A, Merrouche A, Rokbi M, Kouadri Z. Study the effect of alkali treatment of natural fibers on the mechanical behavior of the composite unsaturated Polyester-fiber Alfa. Composites (2013)
11. Pickering K, Beckermann G, Alam S, Foreman N. Optimising industrial hemp fibre for composites. *Composites Part A: Applied Science and Manufacturing* (2007) https://doi.org/10.1016/j.compositesa.2006.02.020

12. Bassyouni M. Dynamic mechanical properties and characterization of chemically treated sisal fiber-reinforced polypropylene biocomposites. *Journal of Reinforced Plastics and Composites* (2018) https://doi.org/10.1177/0731684418798049

13. Santhiarsa IN. Effects of alkaline treatment and fiber length towards the static and dynamic properties of ijuk fiber strengthened–epoxy composite. *InAIP Conference Proceedings* 2016 Oct 26 (Vol. 1778, No. 1, p. 030022). AIP Publishing LLC. (2016) https://doi.org/10.1063/1.4965756

14. Vigneshwaran G, Jenish I, Sivasubramanian R. Design, Fabrication and Experimental Analysis of Pandanus Fibre Reinforced Polyester Composite. *Advanced Materials Research* (2014) https://doi.org/10.4028/www.scientific.net/AMR.984-985.253

15. Deesoruth A, Ramasawmy H, Chummun J. Investigation into the use of alkali treated screwpine (Pandanus Utilis) fibres as reinforcement in epoxy matrix. *International Journal of Plastics Technology* (2014) https://doi.org/10.1007/s12588-014-9082-z

16. Rafidison BH, Ramasawmy H, Chummun J, Florens FB. Tree Age, Leaf Maturity and Exposure to Sunlight Influence Tensile Strength of Fibres in Pandanus Utilis. *Journal of Natural Fibers* (2019) https://doi.org/10.1080/15440478.2018.1558145

17. Lakshmanan A, Ghosh R, Dasgupta S, Chakraborty S, Ganguly P. Optimization of alkali treatment condition on jute fabric for the development of rigid biocomposite. *Journal of Industrial Textiles* (2016) https://doi.org/10.1177/1528083716667259

18. Roy A, Chakraborty S, Kundu S, Basak R, BasuMajumder S, Adhikari B. Improvement in mechanical properties of jute fibres through mild alkali treatment as demonstrated by utilisation of the Weibull distribution model. *Bioresource Technology* (2012) https://doi.org/10.1016/j.biortech.2011.11.073

19. Ramasawmy H, Chummun J, Bhurtun A. Characterization of the tensile strength of chemically treated Pandanus utilis (screwpine) fibres for potential application as reinforcement in epoxy composite. *International Journal of Plastics Technology* (2017) https://doi.org/10.1007/s12588-017-9177-4

20. Yang Y, Pang J, Dai H, Xu X, Li X, Mei C. Prediction of the tensile strength of polymer composites filled with aligned short fibers. *Journal of Reinforced Plastics and Composites* (2019) https://doi.org/10.1177/0731684419839223

21. Takagi H, Ichihara Y. (2004) Effect of Fiber Length on Mechanical Properties of "Green" Composites Using a Starch-Based Resin and Short Bamboo Fibers. *JSME International Journal Series A* (2004) https://doi.org/10.1299/jsmea.47.551

22. Iqbal, Nafis & Mousumi, JannatulFerdous. Effect of Fiber Length on Properties of Jute Fiber Reinforced Polymer Matrix Composite. *International Journal of Industrial Engineering* 201-207. (2017).
23. Bisaria H, Gupta M, Shandilya P, Srivastava R. Effect of Fibre Length on Mechanical Properties of Randomly Oriented Short Jute Fibre Reinforced Epoxy Composite. *Materials Today: Proceedings* (2015) https://doi.org/10.1016/j.matpr.2015.07.031