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Effect of alkaline treatment on the tensile properties of oil palm empty fruit bunch (OPEFB) fibre

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Abstract
The use of oil palm empty fruit bunch has gained worldwide attention and acceptance among the researchers as eco-friendly materials. Hence, oil palm trees has been one the most flourishing and fruitful economic trees in the West Africa and beyond. OPEFB is nothing but a waste material obtained after the extraction of palm fruits. In other to process OPEFB, the fruits are stripped from the bunches leaving the empty bunches as rejects/waste materials. These waste materials, are usually abandoned or dumped in the oil mill industrial site which has created a lot of environmental degradations or implications such as soil acidification, air pollution and others which are harmful to man and his natural environment. It was also observed that the measurement of the tensile properties of fibres enhances the proper utilization as well as the mechanical strength of the fibre strands/bundle. Therefore, this paper addressed the effect of using the following concentrations of NaOH 7%, 10%, 15% and 17% on the mechanical properties of OPEFB fibres with time variations of 24hrs, 72hrs and 120hrs. Finally, the test was performed using D1445 in accordance with ASTM standard which selects 15%w/v of NaOH as the optimized concentrations after 120hrs. Therefore, it was observed that the treatment of OPEFB fibre at 15%w/v of NaOH at 120hrs improves the fibre most when compared with the result of untreated fibres and other treatments and their time variations. The so-called waste can be utilized in the reinforcement of soils thereby converting waste to wealth for the benefit of mankind. In other words, the treated material is competent enough to serve as reinforced composites in geotechnical engineering applications.

Keywords: Alkaline solution (NaOH), OPEFB, Mechanical properties, ASTM, time variations, reinforcement.

1. Introduction

Geotechnical Engineers have been on continuous research in order to find alternative materials that should be used as renewable material with other important qualities/ values such as availability, affordability, poor density, acceptable insulating and thermal properties. However, natural fibre is the most outstanding material with the above qualities including biodegradability and small energy demanding. The above properties/qualities would only be activated when subjected to chemical treatment such as NaOH solution above all. Researchers have reported that the chemical treatment improves the tensile properties of OPEFB fibres by converting its brittle nature to ductile behavior which enabled it to negotiate a strong bond (interfacial bonding) with the composites. (Chowdhury and Hossain 2020; Hassan et al, 2020; Kandemir et al, 2020).

Practically, OPEFB fibres have been known and also used as a source of fuel in the oil mill site or industry Industry, M.-G. C. (2017). However, OPEFB fibre has been found to have a wider application as a reinforcement material in polymer composites and its applications in building constructions as a result of its thermal insulation capacity as well as its sustenance ability as reported by Hamad et al (2017). Many countries in the world are known for their larger production of oil palm waste materials such as Malaysia, Ecuador, Nigeria to mention but a few. Researchers have also reported that there are other sources of raw materials from palm trees other than fruit biomass. Kozlov et al, (2015) has established that the production of oil palm originated in both west and central Africa, but today some countries in Asia continents like Malaysia, Thailand and others are practicing it in a larger scale. Therefore, the mass production oil palm trees in the aforementioned countries have led to environmental degradation due to all round activities such as pruning, milling, and others which are left to decay in the sites as reported by Onoja et al (2019). Momoh and Osoforo (2020) have found also that fibre may be obtained from palm trees at different stages up to the life time of the tree. It was obvious that the quality of waste generated during oil palm extraction was more than enough which are dumped as waste materials in the site. Besides, out of the million tons of OPEFB fibre produced yearly according to the universal report, it is only the small quantity that are been utilized or converted to human advantage otherwise the rest are being abandoned or thrown away as total waste material as reported by Tao et al (2018).

For instance, it was also universally reported by Anyaoha,et al (2018) that in 2014 about 22.4 million tons of OPEFB were generated as waste materials. Also, the waste generated poses a serious threat to the environment hence it causes air pollution and thereby leading to environmental degradation because of the heap of waste materials scattered indiscriminately within the site premises as found by Sudradjat and Diansyah, (2021). The only way to keep the environment clean is to manage the waste properly. In other words, all these wastes littered all over the site will attract some bad insects whose activities are dangerous to the health of man as reported by Odenz et al 2020. Faizi et al (2017) discovered OPEFB fibre as an important viable and renewable resource that is very useful to man. However, the waste materials are challenged with a disposal problem of which if nothing was done about it, the environment becomes polluted without exception. Luckily for us, researchers have discovered that it can be converted to wealth, hence it can be applied in geotechnical engineering to reinforce soil to the advantage of man thereby saving the cost of disposal and at the same time adds to environmental cleanliness. But in the other hand, (Raut and Gomez, 2016) have reported about the lower strain values for treated fibres with NaOH solution which can as well affect the ductility of the material when used as a composite material. In this case, the compatibility could be hindered.

The research effort on natural fibre geared towards making it a good bonding material with the matrix. In addition, past researches have shown that a treated fibre has greater help to the compatibility of a matrix and also to other mechanical contents of fibres as reported by MPOB (2019). Furthermore, the secret of getting this achieved lies on the chemical treatment preferably the alkaline treatment which have been found worthy of improving the mechanical properties of this fibre as found by Witayakran et al. (2017). Therefore, the reports recorded by many researchers were an indication that the mechanical performances of OPEFB fibre is an important property that draws a big attention whenever natural fibres are mentioned (Faizi et al.,. 2018; Rama-Rao and Ramakrishna, 2022; Witayakran et al., 2017). Hence, the treatment is capable of removing some of the impurities in the fibre which are set backs to its mechanical properties such as oil on the external surfaces, wax, lignin etc. This information was also confirmed by Hassen et al (2016) that the chemical treatment of OPEFB fibre reduces its water absorption which is instrumental to poor performance of the mechanical properties of the composite. In other words, the strength developed by the composite is strong enough as a result of the roughness enhanced due to chemical treatment of the natural fibre.

However, table 1 has shown different individual tensile strength for the single treated OPEFB fibres by different researchers. Therefore, the table above, summarizes a host of researches carried out by different researchers on the positive influence of NaOH solution on the OPEFB fibre when it comes to the increase in its mechanical properties such as ultimate tensile strength, modulus of elasticity and others as reported by Witakaya et al (2017). However, one can still observe a wide variation in the result obtained by the researchers as shown in the same table 1 about the mechanical properties of OPEFB fibre. These variations in their result maybe as a result of the nature of the surface treatment applied or how it was done during the treatment processes. Other factors that should be considered include the origin of the palm tree, time taken by the OPEFB before it was extracted, the nature of its surface after extraction, the length of time the OPEFB stayed or the number of days it was allowed for retting to take place and finally the method applied in the testing of fibre can as well affects its mechanical properties as found by witayakran (2017). Therefore, one can simply said that the mechanical properties of OPEFB fibre depends on the method of extraction, the rate of retting, which may also cause fracture to OPEFB fibre diameter. It has been found that the fibre diameter is a very important factor which influences the fibre tensile strength Danso,(2017), has reported deferent changes/variations in the fibre diameter with respect to the fibre length with a deviation of 0.08.

Besides, any damage or fracture done to the fibre during the process also increases its rate of water absorption. In other words, all these would affect the mechanical properties of the treated fibers as discovered by Witayakran et al (2017). Therefore, these factors may cause a serious variation on the result obtained by different authors/ researchers while investigating the effect of chemical treatment on the OPEFB fibre.

Table(1). **Former research on mechanical properties of OPEFB fibre**

S/N	Tensile strength (MPa)	Names of authors and year of publication
1.	110	Danso,2017 , Abdulla et al, 2019
2.	80	Yu xiang et al,2015 , Ramlee et al,2019
3.	248	Rama Rao and Ramakrishna 2021,
4.	137.6	Kroehong et al, 2018
6.	35.33	Raut and Gomez ,2016
7.	145	Lim et al, 2018

2.0 Materials and methods

2.1 Processing of OPEFB fibre

The material (OPEFB) fiber for this research was provided by Uwaoma oil mill industry from Chokoneze Mbaise in Imo State. The manually extracted fibre were obtained after retting process (soaking of OPEFB in water) for a week. The individual fibres were obtained as seen in Fig.1. However, the remaining drops of oil impurities were removed by subjecting the OPEFB fibre to further washing using distilled water. After which, it was put in a container to avoid further

2.2 Treatment of OPEFB fibre

exposure to direct sunlight with clear labeling prior to chemical treatment. The chopped 10mm of OPEFB fibre was introduced into the following concentrations of alkaline solutions, 7%, 10%, 15%, and 17 %.(w/v). In order to achieve a uniform mercerization, the mix was stirred for 30mins. The mercerized fibres were air-dried for 24hrs in a room temperature. The fibre strands/bundles tensile tests were performed using Monsanto Transometer Testing machine with crushed-head speed of 0.0025cm/min to 100cm/min at room temperature of 25°C (Made in England S/N 8889). The treated and untreated samples were cut into 10mm and their bundle diameters were measured using digital venier caliper of 0.001mm precision. Five (5) replications were conducted for each fibre length and conditions. The gripping technique was in accordance to ASTM with D1445 standard.

Fig (1) **The untreated extracted dried OPEFB fibre**

2.3 Surface Morphology of treated OPEFB fibre

The already processed OPEFB fibres in its physical appearance were treated using (7%, 10%, 15%, and 17%) before combining it with the matrix. However, the main aim of the test is to ensure that a high tensile strength was achieved. Secondly, to ensure that the test carried out changed the physical appearance of the fibre, in other words the surface of the fibre should appear to be rough when examined with a scanning electron. Therefore, the surface roughness of the fibre will ensure a very strong bond between the treated fibre and the matrix. Hence, the result of both treated and untreated fibres with different concentrations and variable times were shown in the Fig. below. The physical appearance of the treated fibre simply indicates the extent the treatment has removed the impurities which are hindrances to the mechanical properties of OPEFB fibre by considering both the concentration and the variable times as shown in the fig. below. From Fig2a to 2e, the surface morphologies appear to be rougher in the 15% after 120hrs treatment. It is therefore very clear that treatment of fibre done at 15% after 120hrs would yield the best result in terms of ultimate tensile strength and as well as strong interfacial bond between the fibre and the matrix provided the fibres rough surface is still within the range of tolerable limit as found by Mbeche and Omara,(2020) ; Raia, and Iwakiri, (2021) ; Ridzuan et al (2015).

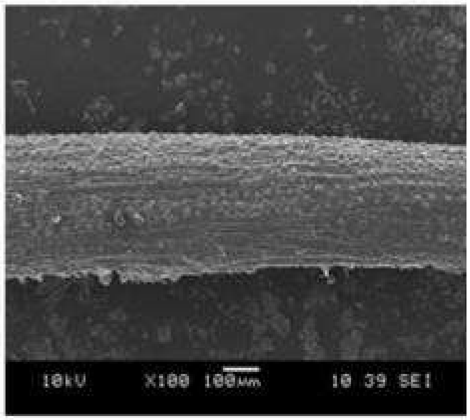

Fig.(2a) Surface morphology of 7% treated fibre

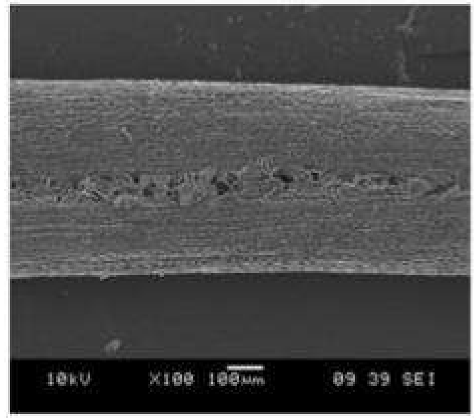

Fig.(2b) Surface morphology of 15% treated fibre

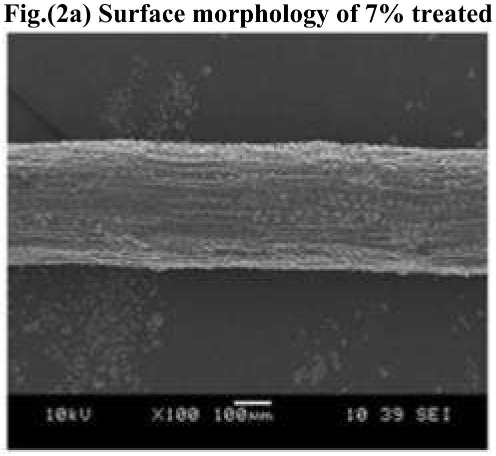

Fig.(2c) Surface morphology of 17% treated fibre

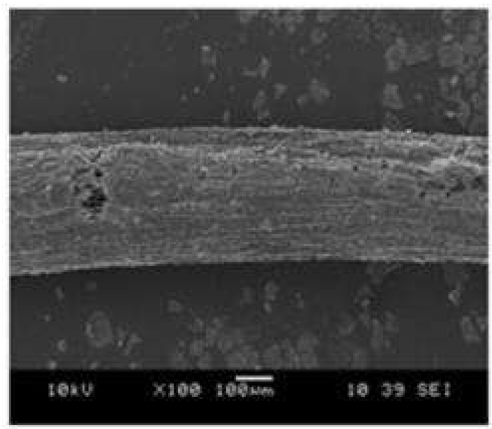

Fig.(2d) Surface morphology of10% treated fibre

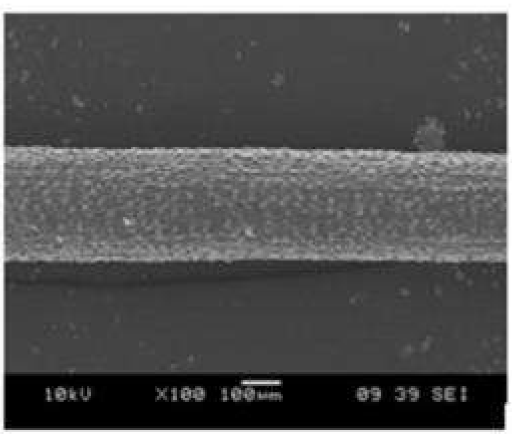

Fig. 2e Surface morphology of 17% treated fibre

3.0 Result and Discussion

In the ongoing findings with both treated and untreated fibres, the treated fibres have first been examined by comparing their surface morphologies after multiple treatment with 7%, 10%, 15% and 17% of NaOH with time variation of 24hrs, 72hrs and120hrs. It was observed that the untreated fibre appears to be smoother when compared with every other treated fibres not excluding their time of variations. Therefore, their morphologies clearly indicate how the fibre responded to chemical treatments of variable concentrations and time respectively. The investigation was conducted on two types of fibres that is untreated OPEFB fibres and treated fibres with 7%, 10%, 15% and 17% of NaOH considering their time of soaking of 24hrs, 72hrs and 120hrs respectively. The elasticity curve of the OPEFB fibre obtained in the single fibre tensile test after 24hrs was shown in Figure3a. The curve actually shows how the individual fibres have responded to chemical treatment after 24hrs with different concentration of NaOH solution. However, the curve indicates the relationship between the magnitude of the applied stress on a material and the resulting strain including the untreated fibre with the least tensile strength. Therefore, the elasticity curve shows that the untreated fibre exhibited elastic deformation and also highly brittle. After 24hrs, fibre with 15%w/v NaOH solution recorded the highest tensile strength of 5.4N/mm^2 and the least was untreated fibre which has a tensile strength of 0.42N/mm^2.

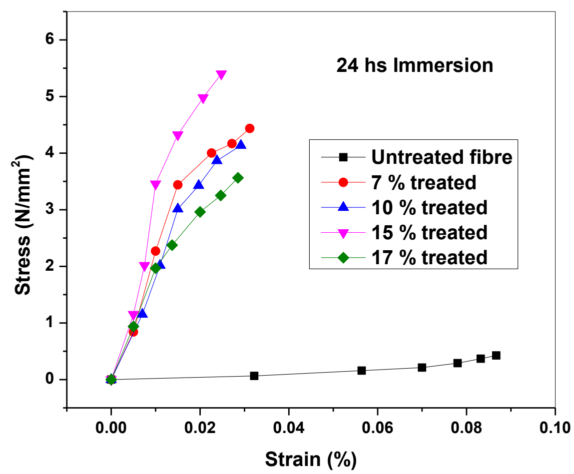

Fig.(**3a). Elasticity curve of OPEFB fibre after 24hrs.**

From Figure3b above, the fibre soaked in the solution of 15% NaOH recorded the highest tensile strength after 72hrs with a value of 6.2N/mm^2 with a strain of 0.025 and the tensile strength followed by the fibre soaked in 7% NaOH solution also gave a value of 5.3N/mm^2 and a strain of 0.022. It was also observed that among the treated individual fibres, the fibres immersed in 17% of NaOH recorded the least tensile strength. However, fibre treated in 10%w/v of NaOH gave the highest tensile strength with a negligible difference in strain when compared with other treated fibres in the same category.

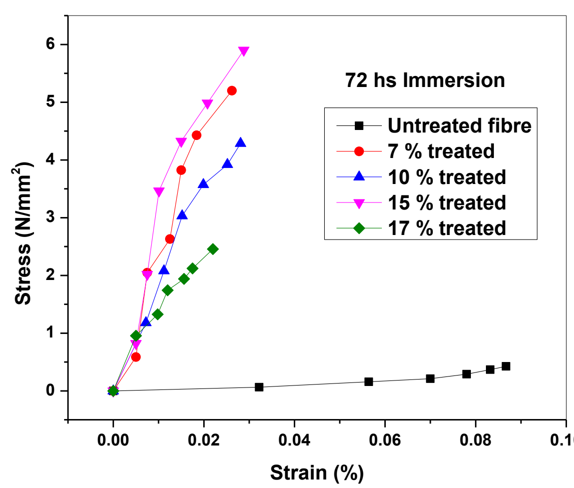

Fig.(3b) Elasticity curve of OPEFB fibre after 120hrs.

The above elasticity curve shows the behavior of individual single fibres at different concentrations of NaOH after 120hrs. The peak tensile strength was recorded by fibre at 15%w/v of NaOH with a value of 7.02N/mm^2 and strain of 0.022 followed by fibre immersed at 10%w/v of NaOH with a tensile strength of 4.4N/mm^2 and a strain of 0.024. However, following the elasticity curve from the first immersion after 24hrs, it appears that the treatment was instrumental to the increment in the ultimate tensile strength of fibre soaked in 15%w/v NaOH solution as the day increases. Hence at 24hrs, 72hrs and 120hrs the tensile strength recorded by the individual fibres at 15% NaOH were, 5.4N/mm^2, 6. 2N/mm^2 and 7.2N/mm^2 respectively.

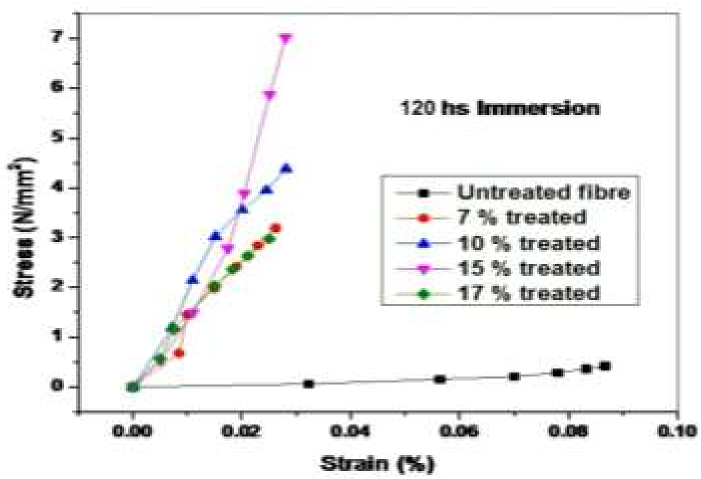

Fig.(3c) Elasticity curve of OPEFB fibre after 120hrs.

Table (2). Mechanical properties of OPEFB fibre after 24hrs treatment

24hrs Duration treatment	Peakforce(N)	Elongation at peak (mm)	Tensile strength (N/mm^2)	Area of fibre (mm^2)
7%	25.60	1.75	4.434	5.07
10%	28.48	2.75	4.386	6.83
15%	30.24	2.66	5.40	5.60
17%	20.00	2.80	3.560	5.62

Table (3). Mechanical properties of OPEFB fibre after 72hrs treatment

72hrs Duration treatment	Peak force (N)	Elongation at peak (mm)	Tensile strength (N/mm^2)	Area of fibre (mm^2)
7%	30.2	2.80	6.66	6.20
10%	35.2	2.60	4.29	7.10
15%	36	2.75	5.40	6.50
17%	18.6	2.90	3.56	5.20

Table(4). Mechanical properties of OPEFB fibre after 120hrs treatment

120hrs Duration treatment	Peak force(N)	Elongation at peak (mm)	Tensile strength (N/mm^2)	Area of fibre (mm^2)
7%	28.6	1.85	3.189	7.10
10%	30	2.12	4.385	6.80
15%	39.48	2.42	7.02	5.60
17%	15.60	2.82	2.98	5.03

In the ongoing investigations, the untreated fibre was found to be 2.62mm in average. In the same vein, the average diameter for treated fibres was also found to be 2.62mm, 2.985mm, 2.88mm, and 2.92mm for 7%, 10%, 15% and 17% for NaOH solution. The tensile strength for the treated fibre was recorded as 5MPa whereas the case of a single treated OPEFB fibre was also recorded as 218MPa after 24hrs. However, after 72hrs of soaking the tensile modulus was recorded as 338MPa in 7% NaOH solution followed by a single fibre soaked in 15% NaOH which was found to be 209MPa. Lastly, after 120hrs, the single fibre soaked in 15% NaOH was found to be 251MPa. Therefore, there was a concrete evidence that the pulling stress and young's modulus of OPEFB fibre has been improved by the chemical treatment using 7% NaOH solution and therefore confirmed the information already given by Witayakran et al. (2017). In the same vein, the same observation were made at 15% NaOH solution after 120hrs soaking of the fibre. Considering all the result obtained in the on-going research, the strength of OPEFB fibre was optimized at 15%w/v of NaOH after 120hrs soaking of the fibre. From the above result, the treatment championed by NaOH improved the single fibre treatment by 92% and 98% respectively when compared with the untreated OPEFB fibre after 24hrs. Besides, after 72hrs both the tensile strength and its modulus of elasticity were found to increase by 34% and 58% at 7% NaOH solution. Furthermore, the strength of OPEFB fibre was optimized at 15% NaOH as seen in Fig3c above of which the maximum mechanical pulling stress and young modulus expanded by 23% and 18% in 120hrs soaking in NaOH solution as already seen in the literature Hassan et al,(2020).

These was achievable because the alkaline treatment of a fibre made a serious impact in the removal of hemicelilous , lignin and other contents. Therefore, since 15% NaOH solution gives the highest maximum pulling stress after 120hrs of soaking. It can be observed that the water absorption rate of the fibre under these treatment condition would be the least, hence it would permit interaction between the composites leading to a very strong bond as found by Preet et al (2017) and Kandemir et al, (2020). At this juncture, it is very important to state the reason why the tensile strength of OPEFB fibre was improved at 15% instead of 17%w/v. This could be as a result of so many factors such as over treatment caused by 17%w/v NaOH concentration which made cellulose content of the fibre to be completely removed from the surface of the fibre also cause it be stiff. nature of the surface treatment during the treatment processes, the origin of the palm tree, time taken by the OPEFB before it was extracted, the nature of its surface after extraction, method of extraction, the rate of retting, fibre diameter and finally the method applied in the testing of fibre as earlier seen in the literature also have a great influence in the mechanical properties of OPEFB fibre witayakran (2017).

Besides, the value of strain for various concentrations of NaOH solutions does not vary much from (7 - 17%) in the findings as earlier seen in the literature (Raut and Gomez, 2016). The peak force for the entire treatment was emerged in table2.as 41.6kgf at 7% followed by 39.8kgf at 15% after 72hrs and 120hrs immersion respectively. Whereas the fibres subjected to 17% NaOH solution recorded the highest elongation as 2.9mm after 72hrs immersion into NaOH solution.

4.0. Conclusion

This research focused on the effect of chemical treatment on the OPEFB fibre, precisely alkaline treatment was adopted in the treatments of fibre strands/single of OPEFB fibre using the following concentrations, 7%, 10%, 15% and 17%w/v with the time variations of 24hrs, 72hrs, and 120hrs respectively. Generally, it was observed that alkaline treatment of OPEFB fibre really improves the mechanical properties/contents of the fibre marginally when compared with the untreated fibres. However, among all the treatments given to the fibre specimen for 120hrs, the highest tensile strength was obtained at 15%w/v after 5days immersion. Therefore, it is obvious that the mechanical properties of the fibre were optimized at 15%w/v in 120hrs while the 17%w/v of the alkaline concentrations gave the lowest mechanical properties after 120hrs. Since the treatment improves the mechanical properties of OPEFB fibre, it means that the treatments delays deteriorations of the fibre,by ensuring that the moisture affinity is reduced when properly treated. Therefore, the fibre can be incorporated into automotive or modern construction works as reinforcement materials once adequately treated. Finally, it was also observed, that the higher concentrations of alkaline does not improves the mechanical strength of fibre as seen in this research maybe simply because of over-treatment or some other factors pointed out in the literature. Further research on palm trees is very important in order to find out the optimum result by applying the same chemical treatments. Also, the usage of other plant fibres are highly recommended in order to get best performed fibres to be used as a fibre- reinforced composites. It will also be favorable for the natural fibres to be pre- treated with some physical treatment techniques such as corona, bleaching, etc. before the application of alkali treatment.

5.0 Recommendation

Further research on palm trees is very important in order to find out the optimum result by applying the same chemical treatment. Also, the usage of other plant fibres are highly recommended in order to get best performed fibres to be used as a fibre- reinforced composites.

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Nomenclature

OPEFB = oil palm empty fruit bunch fibre
NaOH = Sodium Hydroxide solution
ASTM = American Society for Testing and Materials

References

Anyaoha, K.E, Sakrabani, R, Patehigolla, U and Mirozan, A.N.(2018) Evaluating oil palm fruit bunch processing in Nigeria. Waste Management and Research; vol. 36 [3] 236-246. DOI. 10.1177/073s4242x17751848

Awalludin, M.F.; Sulaiman, O.; Hashim, R.; Nadhari, W.N.A.W.(2015) An Overview of the Oil Palm Industry in Malaysia and Its Waste Utilization through Thermoche Conversion, Specifically via Liquefaction. *Renew. Sustain. Energy Rev.* , *50*, 1469–1484, https://doi.org/10.1016/j.rser.2015.05.085.

Cabrales, H and Araque, O.(2020) The effect of moisture content, fibre length and compaction time on African oil palm empty fruit bunches briquette quality parameters. Heliyon , Vol.6, Issue 12, e05607

Chowdhury, M.A.; Hossain, S.(2020) A Review on Tensile and Flexural Properties of Fiber-Reinforced Polymer Composites.J. Polym. Sci. A Polym. Chem. 2 7, 16–26, ps://doi.org/htt10.9790/019X- 07051626.

Danso, (2017) .Properties of coconut, oil palm and bagasse fibres: as potential building materials .Procedia Eng., 200 (2017), pp. 1-9, 10.1016/j.proeng.2017.07.002 .View PDF articleView in ScopusGoogle Scholar

Faizi, M.K, Shahriman A.B, Majid M.S.A, Shamsul B.M.T., Zunaidi I, Ng Y.G, Razlan Z.M., Wan W.K.. (2018)..The effect of alkaline treatments with various concentrations on oil palm empty fruit bunch (OPEFB) fibre structure.IOP Conference Series: Materials Science and Engineering, 429 (Nov. 2018), p. 012006.CrossrefView in ScopusGoogle Scholar.

Faizi, M.K.; Shahriman, A.B.; Abdul Majid, M.S.; Shamsul, B.M.T.; Ng, Y.G.; Basah, S.N.; Cheng, E. M.; Afendi, M.; Zuradzman, M.R.; Wan, K.; Hazry, D.(2017). An Overview of the Oil Palm Empty Fruit Bunch (OPEFB) Potential as Reinforcing Fibre in Polymer Composite for Energy Absorption Applications. MATEC Web Conf., 90https://doi.org/10.1051/matecconf/20179001064 *Prog. Polym. Sci.*, *37*, 1552–1596, https://doi.org/10.1016/j.progpolymsci..04.003.

Hamad,S.F.,Stehling,N.,Holland,C.,Foreman,J.P.,Rodenburg,C.(2017)Low-Voltage SEM of Natural Plant Fibers Microstructure Properties (Surface and Cross-Section) and Their Link to the Tensile Properties.Procedia Eng., Vol. 200, 2017, pp. 295–302. doi:10.1016/j.proeng.2017.07.042

Hasan, K.M.F.; Horv, G.; Alp, T.(2020) Potential Natural Fiber Polymeric Nanobiocomposites : A Review. Polymers , 12, 1072, https://doi.org/10.3390/polym12051072.

Hassan CS, Chellaiah NR, Sahari B, Salit MS, Abdul AN (2016) Effect of chemical treatment on oil palm empty fruit bunch (OPEFB) fiber on water absorption and tensile properties of opefb fiber reinforced epoxy composite. Key Engineering Materials 701: 295-299.

Kandemir, A.; Pozegic, T.R.; Hamerton, I.; Eichhorn, S.J.; Longana, M.L.(2020) Discontinuous Fibre Composite Materials. Materials , 13, 2129, https://doi.org/10.3390/ma13092129.

Kozlov A.M, Aberer, A.J. Stamatakis A. (2015) ExaML version 3: a tool for phylogenomic analyses on supercomputersBioinformatics, 31 (2015), pp. 2577-2579

Mbeche, S.M.; Omara, T(2020). Effects of Alkali Treatment on the Mechanical and Thermal Properties of Sisal / Cattail Polyester Commingled Composites. *PeerJ Mat. Sci.* , *2*, https://doi.org/10.7717/peerj-matsci.5.

Md Yunos, K.F.H, Samsu Bahamddin, A., Md Yunos, K.F, Hafid, H.S., Buzu, Z, Mokhtar, M.N, Sulaiman, A., Md Son, A.(2015). The Physico-chemical characteristics of residual oil and fibres from oil palm empty fruit bunches, BioRes. ; 10[1], 14-29

Momoh,E.O and Osofero, A.I .(2020) Recent development iin the application oil palm fibres in cement composites, Frontier of Structural and Civil Engineering; Vol.14, 94-105

Odenz Frias, E.J, Azama, A, Mata-Zey, L.E, Hermandez, S.(2020) Bioenergy potential and technical feasibility assessment of residues from oil palm processing. Biomass Energy; 142, 1056-1068. DOI:10.1016/j.biombode2020105668

Industry, M.-G. C.(2017) of C. and. *Oil Palm Biomass & Biogas in POTENTIALS FOR EUROPEAN SMES*; 2017.

Onoja, E, Razak, F.I.B, Chadran, S,Mahat, N. A and Wahab, R.A.(2019) Oil palm (Elaeis guineensis) biomass in Malaysia: Present and Future Prospects, Waste and Biomass Volorisation 10(28. DOI: 10.1007/s12649-018-0258-1

Preet Singh, J.I.; Dhawan, V.; Singh, S.; Jangid, K (2017). Study of Effect of Surface Treatment on Mechanical Properties of Natural Fiber Reinforced Composites. *Mater. Today Proc.* , *4*, 2793–2799, https://doi.org/10.1016/j.matpr.2017.02.158.

(MPOB), M. P. O. B. (2019) *Oil Palm Planted Area 2019*; 2019; Vol. 2019.
Rama Rao, P., Ramakrishna, G.(2022) "Effect of alkali treatment on behavior of oil palm empty fruit bunch fibers," in 2nd International E-Conference on Novel Innovations and Sustainable Development in Civil Engineering (NISDCE'22), vol. 5, no. 42, p. 1.Google Scholar

Sudradjat and Diansyah, A.N.(2021) International e-Conference o Sustainable Agriculture and Farming System. In Proceedings of IOP Conference Series:Earth and Environmental Science Vol.694, 24-25 September,Bojor, Indonesia

Raia, R.Z.; Iwakiri, S.(2021) Effects of Alkali Treatment on Modification of the Pinus Fibers. *Matéria* , *26*, https://doi.org/10.1590/S1517-707620210001.1236.

Ridzuan, M.J.M.; Abdul Majid, M.S.; Afendi, M.; Aqmariah Kanafiah, S.N.; Zahri, J.M.; Gibson, A.G.(2015) Characterisation of Natural Cellulosic Fibre from Pennisetum Purpureum Stem as Potential Reinforcement of Polymer Composites. *Mater. Des.* , *89*, 839–847, htStps://doi.org/10.1016/j.matdes.2015.10.052.

Raut and Gomez,(2016).Thermal and mechanical performance of oil palm fiber rein forced mortar utilizing palm oil fly ash as a complementary binder.Constr. Build. Mater, 126 (2016), pp. 476-483, 10.1016/j.conbuildmat.2016.09.034

Tao, H, Sheddon, J.L, Slade, E.M, Ludovic, H, Cul, J.R and Willis, K.J. et al. (2018). Application of oil palm empty fruit bunch effects on soil biota and functions: A case study in Sumatra, Indonesia. Agriculture, Ecosystem & Environment; Vol156 105-113

Witayakran S, Kongtud W., Boonyarit J., Smitthipong W., Chollakup R.(2017) Development of oil palm empty fruit bunch fiber reinforced epoxy composites for bumper beam in automobile Key Eng. Mater., 751 (2017), pp. 779-784, 10.4028/www.scientific.net/KEM.751.779View in ScopusGoogle Scholar.