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COMPARISON OF FLEXURAL PROPERTIES OF PINEWOOD WITH FEA SIMULATION FOR MARINE APPLICATION

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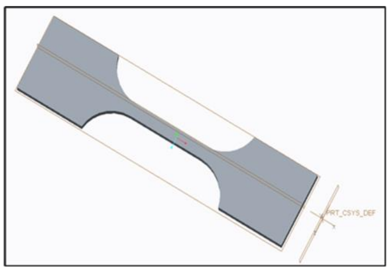
Graphical abstract



Abstract

Pine wood sourced from pellet packaging, being abundant, holds potential for utilization in creating bio composites, particularly as activated carbon for laminated coatings in structural applications. However, there is a current lack of research identifying its specific properties as a coating material for Fiber Reinforced Polymer (FRP) composites. Fiber Reinforced Polymer (FRP) composites provide a highly adaptable solution for reinforcing and revitalizing existing structures in challenging marine conditions. This study delves into investigating the flexural characteristics of FRP pine wood composites, comparing the findings with Finite Element Analysis (FEA) results. Furthermore, the activated carbon derived from pine wood exhibits potential for resisting barnacle attachment when immersed in saltwater. For the flexural analysis, samples were produced using a silicone rubber mold, incorporating varying weight percentages (wt.%) of activated FRP pine wood, ranging from 2 wt.% to 10 wt.%. The outcomes of the study reveal that the introduction of activated carbon from pine wood leads to an enhancement in ultimate strength, reaching a maximum of 2700 MPa. Nonetheless, the results also indicate a reduction in material strength as the proportion of activated carbon pine wood is increased.

Keywords: Activated carbon, resin, flexural, finite element analysis

Abstrak

Kayu pine yang diperoleh daripada pembungkusan pelet, yang banyak, mempunyai potensi untuk digunakan dalam menghasilkan biokomposit, terutamanya sebagai karbon teraktif untuk salutan berlamina dalam aplikasi struktur. Walau bagaimanapun, terdapat kekurangan semasa penyelidikan mengenal pasti sifat khususnya sebagai bahan salutan untuk komposit Fiber Reinforced Polymer (FRP). Komposit Fiber Reinforced Polymer (FRP) menyediakan penyelesaian yang sangat boleh disesuaikan untuk mengukuhkan dan menghidupkan semula struktur sedia ada dalam keadaan marin yang mencabar. Kajian ini menyelidiki ciri-ciri lenturan komposit kayu pain FRP, membandingkan penemuan dengan keputusan Analisis Unsur Terhingga (FEA). Tambahan pula, karbon teraktif yang terhasil daripada kayu pain mempamerkan potensi untuk menentang lampiran teritip apabila direndam dalam air masin. Untuk analisis lenturan, sampel telah dihasilkan menggunakan acuan getah silikon, menggabungkan peratusan berat yang berbeza-beza (berat%) kayu pain FRP diaktifkan, antara 2 wt.% hingga 10 wt.%. Hasil kajian mendedahkan bahawa pengenalan karbon teraktif daripada kayu pain membawa kepada peningkatan dalam kekuatan muktamad, mencapai maksimum 2700 MPa. Walau bagaimanapun, keputusan juga menunjukkan pengurangan dalam kekuatan bahan kerana perkadaran kayu pain karbon teraktif meningkat.

Kata kunci: Karbon teraktif, resin, lentur, analisis unsur terhingga.

1.0 INTRODUCTION

Marine structures used for construction materials in the sea water might be challenging such as steel, concreate and timber as a pile for jetty, bridges and others marine construction. The PileJax is a new type of stack repair system and concrete shaping jacket made of unique mechanical jointing systems for fiber composites. The locking key and locked dental compound are composed of high-fast, geometrically modeled composite resin. The Pilejax interlocking system can limit the corrosion stack and cause damage to the sea. Composite materials fiber-reinforced polymers (FRP) have become an exceptionally adaptable solution in the last 20 years, particularly in hostile maritime environments, to strengthen or re-enhance old constructions. Due to its exceptional features including high strength, corrigibility, lightweight, high fatigue resistance, nonmagnetic, high impact strength, and durability, this material was a chosen alternative. In truth, research and development have been the subject of years of strengthening and reinforcing civil infrastructures employing fiber composites. The overview of the jetty pile between pilejax and normal pile showed in Figure 1.

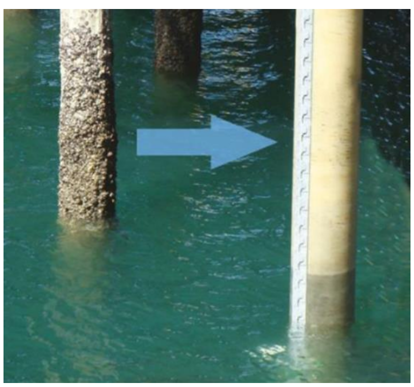


Figure 1 Differences between normal pile and interlock pilejax

Many transport authorities across the world are confronted with the huge difficulty of maintaining the current structures in good service due to the ongoing weather conditions and environmental distress [1]. This is due to the corrosion of the stainless-steel bars as chloride and moisture reach the surface of the steel rebar through crashes [2] and reduces the load-bearing capability and longevity of the armored concrete structure. The repair costs also place an enormous strain on the economy of nations. In terms of repairs and maintenance of roadway RC bridges impacted by steel corrosion, the United States, Canada, Europe, and Australia spend an amazing combined $30 billion a year [3]. Furthermore, many of the world's inadequate stainless-steel infrastructure needs structural rehabilitation to mitigate the harmful effects of corrosion, resulting in constraints on their intended use and load capacity [4]. The recurrent question of durability in conventional repair procedures like concrete [5] and steel jackets [6] compounds this issue since they are produced from the same materials employed in existing structural components that are again damaged by the same forces that attacked the original structure [7].

Moreover, the jackets are heavy and spread across the concrete and steel, adding weight to the repaired structures, and causing seismic occurrences to attract greater loads as separated components improve their strength [8]. It is also difficult, labor-intensive, and costly to implement these old underwater repair solutions. Alternative solutions are thus needed to overcome the inconvenience of employing traditional materials in a repair system. Due to their high strength, low weight, and ability to minimize durability problems associated with the use of the traditional material [9], fiber-reinforced polymer (FRP) composite products have grown popular in the past two decades. Traditional materials such as FRP composites are utilized as a repair method globally to rehabilitate damaged infrastructure, preserve its operability, and increase its service life. Prefabricated FRP Repair Systems have been a favorite option since they are quick to install and easy to construct under high-quality regulated settings. Depending on the application, they can be used as permanent formwork [10].

Wooden based materials such as a bio composite is higher potential to be commercialized for marine structures. There are two significant useful of wooden materials nowadays where first it could be utilized for renewal resources finally not become waste materials. Secondly, it can be transform into biodegradable materials. Wood powder is mainly used for composite namely particles board and has produced 93 Mm^3 and comprise 2.2% global wood production [11]. The size of the particles affects the physical and mechanical properties of the board [12, 13, 14,15, 16]. Therefore, the activated carbon pine wood has been used in this research to ensure it can be utilized for marine application such as Pilejax. In this study, the composition of activated carbon pine wood is ranging from 2wt% - 10wt%. The mechanical properties have been investigated such as flexural testing and has been compared with FEA stress analysis. The purposed of this study was to evaluate the performance activated carbon pine wood which is might be can be applied for marine application.

2.0 METHODOLOGY

This part of paper elaborates and explain about the steps, procedures and details about the experiment that will be conducted. The process of experiment start with the materials selection, flexural sample preparation while next was mechanical testing for activated carbon pine wood and finally comparison with FEA stress analysis for all fraction specimens. The methodology used to collect the primary data to method on processing the result and other related information with this research will be discussed further. It also discusses on how the research is designed and what are the instrument used in conducting the study. In general, this experiment is developed to obtain the data from mechanical testing and simulation analysis for activated carbon pine wood before it can be applied particularly for marine structures.

A. Design of Experiment

The activated carbon of pine wood is taken from the natural cat litter (Figure 1) as a material in this experiment. It has been purchased at pet shop house near to the Manjung district Perak D.R. This activated carbon will grind until they become powdered ash (Figure 2). Figure 3, the open mold type was used with a rectangular shape. Each mold can produce a maximum of 15 specimens at any one time. Resin and hardener were mixed in a container and stirred. Table 1 shows the characteristic activated carbon pine wood.

Table 1 Characteristic Activated Carbon Pine wood

Appearance	Diameter (mm)	Length (mm)	Moisture
Black	4 - 5	6-12	<10%

Figure 2 Activated Carbon of Pine wood

Figure 3 Powder of activated carbon

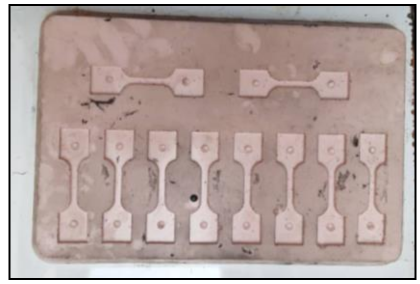


Figure 4 Silicon rubber mold (SRM)

B. Parameter of Experiment

Parameters or variables that will be used in this project, as well as its description, will be described below. The parameter is required to differentiate and compare result from the experiment for analysis. There are 25 specimens were fabricated with different amount of weight percentage of activated carbon. The overview of the specimen for 2wt% and 10wt% shows in Figure 5.

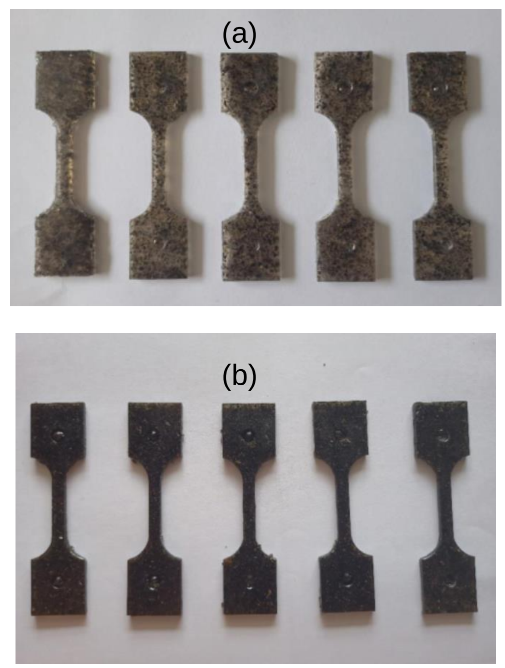


Figure 5 Specimen for (a) 2wt% (b) 10wt%

Therefore, the activated carbon pine wood has been used in this research to ensure it can be utilized for marine application such as Pilejax. In this study, the composition of activated carbon pine wood is ranging from 2wt% - 10wt%. The mechanical properties have been investigated such as flexural testing and has been compared with FEA stress analysis. The purposed of this study was to evaluate the performance activated carbon pine wood which is might be can be applied for marine application.

C. Flexural Test Activated Carbon Specimens

Five replicates from each of these composition types were tested for flexural testing based on ASTM D790-10. This method is required for a 3-point loading (TPB) with a mid-span and a total span length supported at 120 mm. The test was carried out with speed 2.5mm/s for samples having a span length of 20 mm. Figure 5 shows the UTM (Universal Testing Machine) at MIMET laboratory. The specimen has been used for flexural testing even though it is made for tensile testing as long as full fill to be measured for 3-point bending.

After completed initial setup, the specimens have been placed at the centre of UTM specimen holder. The machine will start the flexural test. Once the specimens are ruptured then the result has been generated and ready to be analysed for final results. The specification for dog bone shape show in Figure 6, followed the Formulae [17] in Equation (1):

$$\varepsilon = \frac{3PL_0}{2E_{ap}bh^2} \quad (1)$$

Where L_o=Span length, E_{ap} = Young's Modulus, b = width, h = thickness

Figure 6 UTM machine

D. Design of simulation

The specimens for simulation are designed use PTC Creo software. Creo is the 3D CAD solution that helps you accelerate product innovation so you can build better products faster. Easy to learn Creo seamlessly takes you from the earliest phases of product design to manufacturing and beyond.

The specimens are designed with dimension 100 mm x 25 mm x 3 mm (Figure 6). After finishing the sketch, the model will extrude into 3D model based on the thickness of specimens. (Figure 7). Lastly, the 3D model of specimen will assemble with base of flexure test machine to support during the simulation.

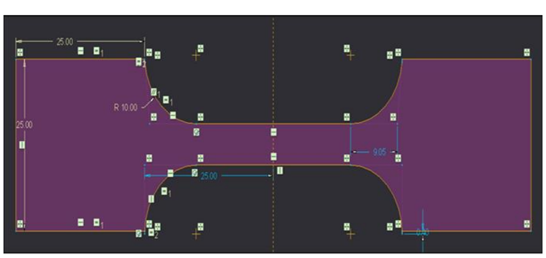


Figure 7 The sketch of model

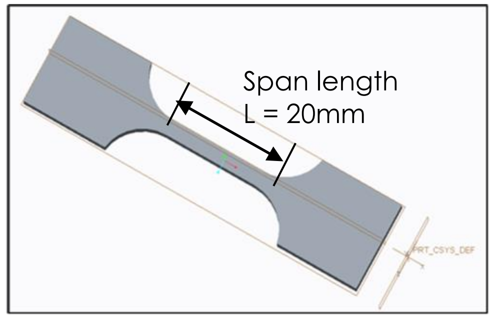


Figure 8 The 3D model of specimen

E. Finite Element Analysis (FEA)

In PTC creo software under simulation analysis, all the specimens have been assigned their material as the pine wood used in the simulation. The external forces and constrain on the specimen also need to be setting based on the mechanical test data. Before run the simulation, all the specimens need to check their meshing analysis. Then, setting up for the displacement to support the specimen during run simulation. Finally, the simulation result has been displayed and ready for analyse. Meshing involved is 2340 nodes with 0.05 min and CPU time 0.05 min. The properties in CREO for soft pine wood shown in Table 2 for details.

Table 2 FEA Characteristic Soft Pine wood

Type	Poisson Ratio	Young's Modulus	Coeff of Thermal Expansion
Isotropic	0.374	9.0×10^9 Pa	4.69×10^{-6}/K

3.0 RESULTS AND DISCUSSION

This part contains result and discussion for the project experiment that has been conducted and completed successfully. It is divided into several sections according to the variables to explain the data of the result. Each data is recorded into table and plotted into graph for better analysis and comparison throughout the experiment.

The all 25 specimens with different of weight percentage were tested in this study. The specimens with a T bone shape of length, L(100 mm), width, W(25mm) and thickness, t(3 mm). A summary of the results for flexural 3-point bending of all specimens are shown in Figure 10 and Figure 11. It can be observed that all specimens exhibited stress-strain with an ultimate individual stress. Various parameter was used to identify the best ultimate stress. This experiment tells that each parameter shows a different ultimate stress.

A. Flexure Test Result and Data

The Figure 9 shows the representative result of the strain- strain from 2% weight percentage of activated carbon specimens. As shown that in Figure 10 - 11, the higher ultimate stress is 2wt% (AC-3) with 2700.2329 MPa. While the lowest ultimate stress is 17.8297 MPa at 8wt% (AC-17). The average of ultimate stress for AC-10% weight percentage of activated carbon specimens are 28.3471 MPa. Mechanical properties such as 3-point bending results has been decreased when increased the filler contents.

All the specimens show exhibited their strain failure at the end of testing. The specimen also can be observed their texture for each using optical microscope (OM). The photo for sample taken from OM can clearly indicated plasticization characteristic in Figure 12 for specimen 2 wt%.

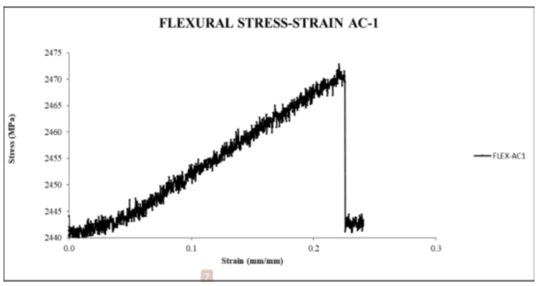


Figure 9 Flexural results for 2 wt%

Meanwhile, From Graph 13, representative result of the strain-strain from 8% weight percentage of activated carbon specimens. The specimens can be identified as AC- 16, AC-17, AC-18, AC-19, and AC-20. As shown in the graph also, the higher ultimate stress is AC-18 with 46.9093 MPa. While the lowest ultimate stress is 17.8297 MPa at AC-17. The average of ultimate stress for 8% weight percentage of activated carbon specimens are 5.7926 MPa.

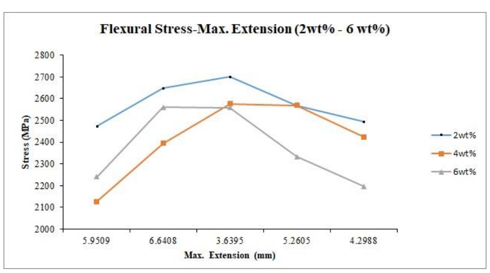


Figure 10 Ultimate strength for 2 wt% - 6 wt%

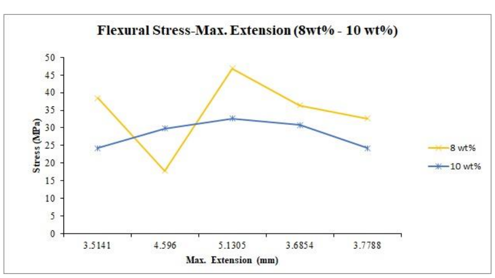


Figure 11 Ultimate strength for 8 wt% - 10 wt%

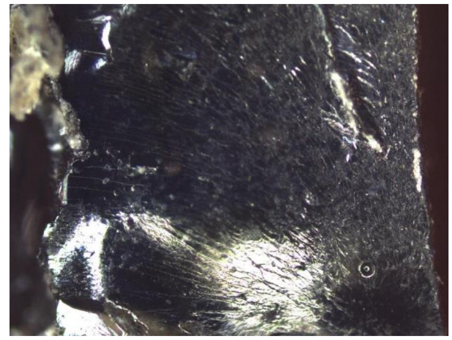


Figure 12 Optical Microscope for specimen 2 wt%

B. Finite Element Analysis Result

From FEA results shows that, all the specimens have encountered with fully stress distribution particularly with higher activated carbon content. The highest maximum stress and maximum displacement on 2wt% is model AC-3 with 3.45 x10^6 MPa and 28.6692mm. While, the highest maximum stress and maximum displacement on 4wt% is model AC-9 with 3.48 x 10^6 MPa and 28.9658 mm. Next, the highest maximum stress and maximum displacement on 6wt% is model AC-12 with 3.49 x 10^6 MPa and 29.0177 mm. The highest maximum stress and maximum displacement on 8wt% is model AC-18 with 6.85 x 10^4 MPa and 0.5696 mm. Lastly, the highest maximum stress and maximum displacement on 10wt% is model AC-23 with 4.99 x 10^4 MPa and 0.41517 mm. All the FEA specimens result shows in Figure 15 (a)&(b) for details.

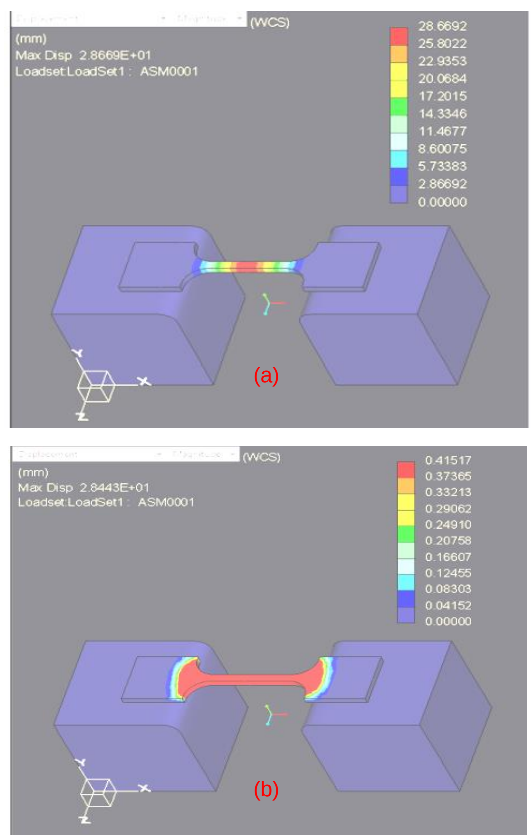


Figure 13 FEA results for specimens (a) 2wt% (b)10 wt%

The comparison between flexural testing result with FEA flexural result shows in graph Figure 14-15. The details data exhibit for all specimens 2 wt% - 10 wt%. Maximum stress at AC-18 for 8 wt% with the ultimate stress is 6.85 x 10^7 MPa. While the lowest ultimate stress belongs to specimen 2 wt% with 3.45 x 10^7 MPa for AC-3.

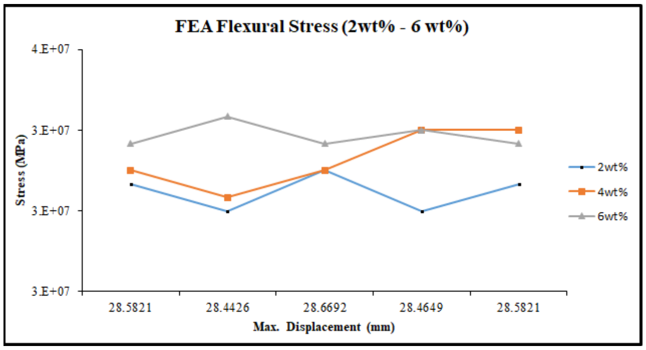


Figure 14 FEA Flexural Stress (2 wt% - 6 wt%)

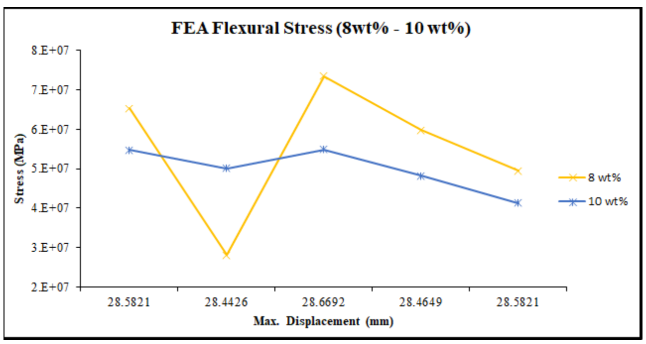


Figure 15 FEA Flexural Stress (8 wt% - 10 wt%)

4.0 CONCLUSION

Fabrication of the flexural samples from pine wood activated carbon using silicon mold has been produced successfully. The highest stress for flexural testing is specimen AC3 (2wt%). The maximum stress in flexural testing is higher strength when pine wood activated carbon are increased in the core materials compared to low amount of pine wood activated carbon. The sample is affected by factors such as particle size, shape, and the properties of the carbon surface. This outcome aligns with a prior study, which attributes it to the varying levels of AC (Activated Carbon) content [18]. For simulation result, the highest stress is specimen AC-12 (6wt%). The simulation result effect on the highest load from flexural test on the specimens. The ultimate stress comparison between experimental and simulation shows specimen with 8 wt% and 10 wt% are close to each other. Following to this result, it will be use used for boat fabrication embedded with FBG sensor need for strain analysis in the next research finding.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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References

[1] Chellis R. Deterioration and Preservation of Piles. *Pile Found*. 1961: 339-72.

[2] Li, X., Wang, J., Bao, Y., Chen, G. 2017. Cyclic Behavior of Damaged Reinforced Concrete Columns Repaired with High-performance Fiber-reinforced Cementitious Composite. *Eng Struct*. 136: 26-35.

[3] Azam, R., El-Sayed, A. K., Soudki, K. 2016. Behaviour of Reinforced Concrete Beams without Stirrups Subjected to Steel Reinforcement Corrosion. *J Civil Eng Manage*. 22(2): 146-53.

[4] Hollaway, L. 2008. Advanced Fiber Polymer Composite Structural Systems used in Bridge Engineering. *ICE Manual Bridge Eng*. 34525.

[5] Gholami, M., Sam, A. R. M., Yatim, J. M., Tahir, M. M. 2013. A Review on Steel/CFRP Strengthening Systems Focusing on Environmental Performance. *Constr Build Mater*. 47: 301-10.

[6] Manalo, A. C., Karunasena, W., Sirimanna, C., Maranan, G. B. 2014. Investigation into Fiber Composites Jacket with an Innovative Joining System. *Constr Build Mater*. 65: 270-81.

[7] Vandoros, K. G., Dritsos, S. E. 2008. Concrete Jacket Construction Detail Effectiveness when Strengthening RC Columns. *Constr Build Mater*. 22(3): 264-76.

[8] Beddiar, A., Zitoune, R., Collombet, F., Grunevald, Y., Abadlia, M., Bourahla, N. 2015. Compressive Behavior of Concrete Elements Confined with GFRP-Prefabricated Bonded Shells. *Eur J Environ Civil Eng*. 19(1): 65-80.

[9] AlAjarmeh, O., Manalo, A., Benmokrane, B., Karunasena, W., Mendis, P., Nguyen, K. 2019. Compressive Behavior of Axially Loaded Circular Hollow Concrete Columns Reinforced with GFRP Bars and Spirals. *Constr Build Mater*. 194: 12-23.

[10] Vijay, P., Soti, P. R., GangaRao, H. V., Lampo, R. G., Clarkson, J. D. 2016. Repair and Strengthening of Submerged Steel Piles using GFRP Composites. *J Bridge Eng*. 04016038.

[11] FAO. 2016. Global Forest Products / Facts and Figures. http://www.fao.org/3/i7034en/i7034en.pdf.

[12] Astari, L., K. W. Prasetiyo, and L. Suryanegara. 2018. Properties of Particleboard Made from Wood Waste with Various Size. *IOP Conference Series: Earth and Environmental Science*.

[13] Lias, H., *et al*. 2014. Influence of Board Density and Particle Sizes on the Homogenous Particleboard Properties from Kelempayan (Neolamarckia cadamba).

[14] Nasser, R. A., *et al*. 2014. Effects of Tree Species and Wood Particle Size on the Properties of Cement-bonded Particleboard Manufacturing from Tree Prunings. *Journal of Environmental Biology*. 35(5): 961-971.

[15] Miyamoto, K., S. Nakahara, and S. Suzuki. 2002. Effect of Particle Shape on Linear Expansion of

Particleboard. *Journal of Wood Science*. 48(3): 185-190.
[16] Sackey, E. K., *et al*. 2008. Improving Core Bond Strength of Particleboard through Particle Size Redistribution. *Wood and Fiber Science*. 40(2): 214-224.
[17] Mujika. F. 2020. Three-Point Bending Test Procedure: Rectangular Rectangular Cross Section. Materials and Technologies Group. University of the Basque Country.
[18] Salleh. Z., *et al*. 2014. Mechanical Properties of Activated Carbon (AC) Coconut Shell Reinforced Polypropylene Composites Encapsulated with Epoxy Resin. *APCBEE Procedia*. 92-96.