

## POLYVINYL CHLORIDE INTO EPOXY MATRIX IN THE PRODUCTION OF BAMBOO COMPOSITE

Flora E.Firdaus<sup>1,\*</sup> and M. Dachyar<sup>2</sup>

<sup>1</sup>Department of Chemical Engineering, Jayabaya University, Jakarta 13210, Indonesia

<sup>2</sup>Department of Industrial Engineering, Universitas Indonesia, Depok 16420, Indonesia

✉ Corresponding Author: [flora\\_elvistia@yahoo.com](mailto:flora_elvistia@yahoo.com)

### ABSTRACT

The serious discussion about the continuity of natural resources has led to regenerate interest regarding biomaterial with the focus on renewable raw materials as the replacement of synthetic materials. Natural fiber composite (NFC) is gaining the attention of researchers and academicians due to its role to resolve the current ecological and environmental problems. Bamboo fiber has demonstrated its hydrophilicity which was similar to distinct natural fibers, it absorbs a meaningful amount of moisture. Adding filler polyvinyl chloride (PVC) to epoxy matrix covered the weaknesses adhesion of bamboo-matrix, showed the suitability of thermoplastics to a thermosetting matrix to the ultimate mechanical property of bamboo composite.

**Keywords:** Epoxy Matrix, Polyvinyl Chloride, Production of Bamboo Composite, Mechanical Properties.

*RASĀYAN J. Chem.*, Vol. 14, No.1, 2021

### INTRODUCTION

The ultrastructure and properties of bamboo fibers have a rising interest which allows providing high strength, stiffness, maximum tensile, and flexural strength in materials of plastic compared to other obvious natural fibers; coir, jute, straw, banana, and sisal.<sup>1</sup> Besides, the cellulose encased in lignin adjusted provides maximum flexural strength and tensile as well as rigidity along the length of the bamboo.

The gained popularity of natural fibers due to their eco-friendly and potential alternatives to synthetics. Despite the abundant availability of bamboo fiber and other benefits like faster growth rate, low cost, and low energy for processing, biodegradability<sup>2,3</sup> impacted the growing tendency of many engineering applications. Plant fibers in composites are used for reinforcement, a close examination of fibers strengthening and failure are needed. Since the matrix can be reinforced by the bamboo fibers in the forms of powder<sup>4</sup>, strips<sup>5</sup>, fibers<sup>6</sup>, fabrics, and woven mat. The role of natural fiber for commercial applications determined by their mechanical properties, like kenaf,<sup>7,8</sup> pineapple,<sup>9,10</sup> sisal, coir, and oil palm fiber<sup>11</sup> are studied by many researchers.

Bamboo has not yet been fully exploited for reinforcing polymeric composites, but from several studies, it has proven to be the most promising candidate fiber, compared to other natural. Composites are essential to our life. It employed various thermoset and thermoplastic matrix. The modified processings end up with modified properties that are extremely carried to more widespread applications in many industrial fields. The materials must typically satisfy many requirements, i.e., excellent mechanical properties, good chemical stability, which are playing an important role during manufacturing and the applications.<sup>12</sup>

The major drawback faced of using bamboo are the heterogeneity, non-uniformity, low processing temperature, low impact, and the strong hydrophilic character which absorbs a significant amount of moisture, leads to difficulties in fabrication<sup>13</sup> thus construct an anisotropic dimensional expansion in thickness and width direction<sup>14</sup> and increased water uptakes. Consequently, it will be caused by voids formation, poor interfacial bamboo fiber-matrix adhesion from exceedingly porous materials, and environmental degradation, which has deteriorated the mechanical properties. Thus, the hydrophobic properties of the matrix are required.

Modification on bamboo flour by acetylation using trichloroacetic acid. Several studies referring to hydrophobic modifications of bamboo flour,<sup>15</sup> adding silane coupling<sup>16</sup> to the composite formula will significantly improve adhesion. Implementing alkali treatment on fiber can increased adhesion, where the structure is found more stable which is affected by swelling of cellulose fibers and caused to the transformation of hydrophilic fiber into hydrophobics.<sup>17</sup>

The role of fillers on polymer materials is to elevate the characteristics of the processing capabilities and diminish the production cost.<sup>18</sup> In general, the physical and mechanical characteristics of the composite can be modified by adding a filler to the matrix, which can improve the quality of the product.

Epoxy resin is one of the most commonly-used thermosets in many engineeringis used as a matrix<sup>19</sup>, but the brittleness behavior is major drawbacks. Many attempts have been made by altering with additives such as thermosets, thermoplastics, and inorganic filler by incorporated in the matrix. PVC is used as a filler to improved the plasticity of the brittles.<sup>20</sup> Vinyl ester is another resin that also produces a brittle product<sup>18</sup>, which is solved by mixing with Carbon black; a particulate filler.<sup>21</sup> While montmorillonite clay in epoxy monomer matrix enhanced properties.<sup>22</sup>

The addition of aminopropyl trimethoxy silane (AS) and tetra methoxy orthosilicate (TMOS) on fiber after alkali pretreatment is determined to be the most effective method for improving adhesion of bamboo fibres-matrix PP. Therefore, bettered tensile, flexural, and impact strength.<sup>23</sup> Meanwhile, adding SiO<sub>2</sub> in the form of nanoparticles increased significantly in comparison to without SiO<sub>2</sub>.<sup>24</sup> Their major drawback of using nanofillers mineral is an agglomeration in the matrix and no chemical interaction with others.

The suitability between matrix and filler is acknowledged as the key to enhancing the properties of the composite.<sup>25,26</sup> Some studies have explored using hybrid fillers; mineral filler<sup>27</sup> and lignocellulosic fibers to improving thermal stability and weathering resistance,<sup>28</sup> the existence of maleate polyethylene (MAPE) filler in high-density polyethylene (HDPE) - bamboo fiber composite can improve tensile strength, bending modulus, and strength. However, if a 1% nanoclay filler is added to the composite system is led to reduced mechanical properties, which can be improved if the bamboo fiber surface is modified by suitable surfactants as coupling agents.<sup>29</sup>

Polyvinyl chloride (PVC) is being the third most widely used thermoplastics matrix, it can be blended into natural fibers besides polypropylene, polyethylene as well as thermosetting.<sup>30</sup> Hence less affected by the price of fossil fuel than other polymer, is less expensive compared to other polymers. The study of hybridization of thermosetting-thermoplastics, as well as epoxy resin to PVC, are still in limited number, analyzed the microstructure of the composite, and related to mechanical property.

## EXPERIMENTAL

### Material and Methods

The fibers of this work are long strip bamboo, are purchased from Kebumen bamboo plantation in central Java, Indonesia where previously chemically treated, it indicated from the brighter color compared to the originals and the smooth appearance of the bamboo, this considers minimizing the fungus formation. The PVC powder and biochar powder are from Makmur Abadi Sejahtera. The epoxy resin with catalyst methyl ethyl ketone peroxide (MEKP) was obtained from Natural, and the wax from megah Kimia, is performed as a releasing agent to demolding the composite. The stainless molding designs are made in the Cawang workshop.

### The Composite Processing

The fabricated techniques for manufacturing the bamboo fiber reinforced polymer composites are hand lay-up methods that involve dry fiber in the mold and apply the resin matrix and added onto the catalyzed resin using a roller to ensure fibers are impregnated to the resin.

The bamboo fibers are dried in an oven at temperature 30<sup>0</sup>C for an hour, let cool naturally in open air approximately for 1.5 days to ensure the dryness and moisture content which could eliminate the molding.

### Composite Measurement

#### Density and Composite Analysis<sup>31</sup>

The density of composite is based on ASTM D792-12 using Sartorius balance, it applied to sample 1, 2, 3, 4, 5, 6, 7, and 8. Measurement of the composition was based on ASTM D1131-15TGA. Thermograms were obtained using thermogravimetry Analyzer- Mettler Toledo. The heating program were done in three stages a) 50<sup>0</sup>C - 600<sup>0</sup>C min, 10<sup>0</sup>C/min in N<sub>2</sub> 50 mL/min ; b) 600<sup>0</sup>C, 5 min, N<sub>2</sub> 50 mL/min and c) 600<sup>0</sup>C – 900<sup>0</sup>C, 10<sup>0</sup>C/min, O<sub>2</sub> 50 mL/min.

### Element Analysis

The element analysis using instrument JEOL JSM-6510LA with ASTM E 1508-12.

### Composite Tensile Strength<sup>32</sup>

The composite tensile testing is using Universal Testing Machine AGS-X 10 kN Shimadzu. The purpose of tensile testing for fibers as if in a good condition similitude to the external rationale such as transportation, or maybe some fiber manipulation after the extraction where the good fiber condition will ascertain more soundable results.

### SEM Images<sup>33</sup>

The surface composite microstructure images of impact tested were performed using a scanning electron microscope (JEOL JSM 65 10LA) with amplification 5000; 10000; and 15000.

## RESULTS AND DISCUSSION

### Mechanical Properties of Epoxy - PVC filled Polymer Composites

Improving the property of the thermoset systems, other problems may be connected with environmental protection issues where the manufacturing expenses remained unsolved. The thermoplastic matrix alone was understood as often not attainable for composites, so it needs a fiber reinforcer for enhancing the strength. Nevertheless, It only can be accepted by an adequate stress transfer of fiber-matrix and vice versa from an appropriate bonding. Consequently, mechanical and physical properties depend on the structure and the fiber-matrix interface as the principal role for the composites. Fillers' behavior in the form of particulates and short fibers were frequently affected by particle size distribution, surface area, shape, and surface chemistry. The existence of PVC as the filler has a large effect on the physical and mechanical properties of the composites. Theoretically, the density can be increased with increased PVC content. In this research, it was found the reinforcing fibers can attain high strength if can fulfill adequate stress transfer by an appropriate bonding. The physical and chemical compatibility becomes necessitated to fiber and matrix. The neat epoxy has taken for this study possess a density of  $0.93 \pm 0.007 \text{ gr/cm}^3$  and increases to  $1.165 \pm 0.02 \text{ gr/cm}^3$ . With the reinforcement of hybridized epoxy-biochar-based bamboo, the density was increased with increasing fiber (%), but the density of bamboo-epoxy montmorillonite was even higher.

Table-1: The Density of the PVC- Epoxy Matrix of Bamboo Composite

Sample	Bamboo Fiber (gram)	PVC (gram)	Epoxy (gram)	Biochar of Bamboo (gram)	Montmorillonite (gram)	Density gr/cm <sup>3</sup>
1	30	15	60	5	0	1.013
2	40	0	60	5	15	1.0309
3	50	10	60	5	0	0.99
4	60	15	60	0	0	0.93
5	25	15	60	5	0	1.59
6	30	20	60	0	0	0.94
7	40	25	60	0	0	1.03
8	25	30	60	0	0	1.165

Fillers elevate the processability and mechanical properties, this can be considered as the way to reduce material expenses.<sup>34</sup>

The density of neat bamboo was in the range of 0.8-1.1 gr/cm<sup>3</sup>. The design formula of this work is tabulated in Table-1, with the average density of the composite within the dimension of 0.004 cm<sup>3</sup>.

### Composition Analysis

The composition of the composite was summarized in Table-2. The occurrence of highly volatile mass as if fabricated in the industry was must be less than 1%, where it will have a major impact on the processing, especially if blow molding or injection molding was chosen as fabricating process. In this work, only sample number seven met the condition, others are above one.

While the low value of residue was indicated the existence of material if applied at high temperature. As if observed the elemental content (% mass) of the composite. In general element, Na, Al, and K in the composite were not detected, while K was in a trace. The major elements are C and O as the main element of the thermosetting matrix, and Cl was an element of PVC categorized as the thermoplastic filler as can be seen in Table-3.

Table-2: The Composition of Volatile (% Mass)

Sample	Highly Volatile	Medium Volatile 1	Medium Volatile 2	Combustible Matter	Ash
1	1.1639	50.8496	31.1521	16.313	0.5214
2	ND	50.0929	40.5798	9.7593	ND
3	1.7101	49.9784	39.469	8.8406	ND
4	1.0521	42.4528	47.0185	8.208	0.5558
5	1.8103	41.5622	37.7614	16.7854	2.0807
6	1.6593	49.3974	36.7591	12.1841	ND
7	0.6128	55.7239	36.7673	6.8953	ND
8	2.3976	49.2674	36.311	11.6048	0.4192

Table-3: Elemental Composition of The Composite (% Mass)

Element	C	O	Si	Cl	Zr
1	66.18±8.11	25.53 ± 6.62	0.21 ± 0.19	4.3 ± 0.179	3.67 ± 3.22
2	66.08 ±4.51	31.67 ± 3.58	0.18 ± 0.31	1.87 ± 0.3	ND
3	64.54 ± 7.59	30.85 ± 9.12	0.36 ± 0.63***	3.52 ± 2.84	ND
4	69.31 ±5.22	24.77 ± 5.73	0.09 ± 0.16	4.19 ± 1.35	1.47 ± 2.55***
5	76.77 ± 1.56	18.84± 0.82	ND	2.76± 0.9	1.63±2.83
6	63.40 ± 1.3	31.86 ± 2.61	0.15 ± 0.27***	1.4± 1.03	2.88 ± 2.51**
7	72.04 ± 4.94	24.38 ± 4.47	0.12 ± 0.21***	3.21 ± 1.14	ND
8	68.15 ± 12.88	30.39 ± 14.12	ND	1.46 ± 1.33***	ND

ND: not detected

The synergetic of thermoplastic into a hybridized thermosetting matrix ends up to the ultimate tensile strength of the bamboo-based composite. The formula of the composite was designed to know the mechanical property of PVC filler into the epoxy matrix and also observed the PVC insertion into hybridized epoxy/bamboo/biochar and hybridized epoxy/ montmorillonite.

The result of the tensile test tends to increase aligned with the increasing concentration of PVC. It has reached the highest point of tensile strength 6.84 MPa by 50 gr fiber with 25 gr PVC but was decreased by 60 gr fiber even though PVC was added to the formula, this may be due to the failure of interfacial bonding between PVC and bamboo fiber.

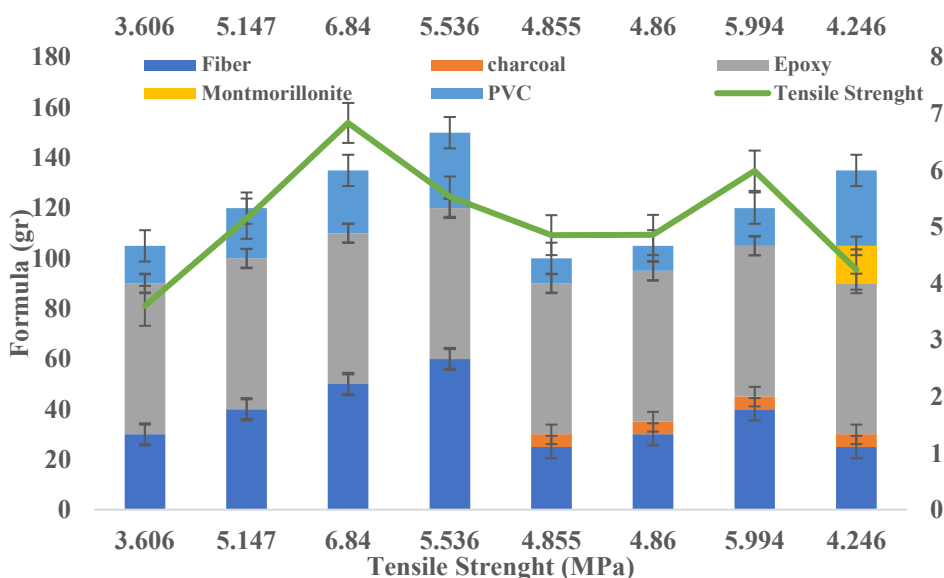


Fig-1: The Designed Formula to Tensile Strength of the Composite

The addition biochar in the formula Char/PVC 5:10 (gr/gr) does not seem compatible with neat PVC, but adding fiber content in the formula along with PVC content has increased tensile strength,

as confirmed in Fig-1. Before running the process, the seven samples out of eight were applied PVC to provide optimum cohesiveness. The blends of bamboo biochar-montmorillonite (mont), was prepared to be compared without PVC.

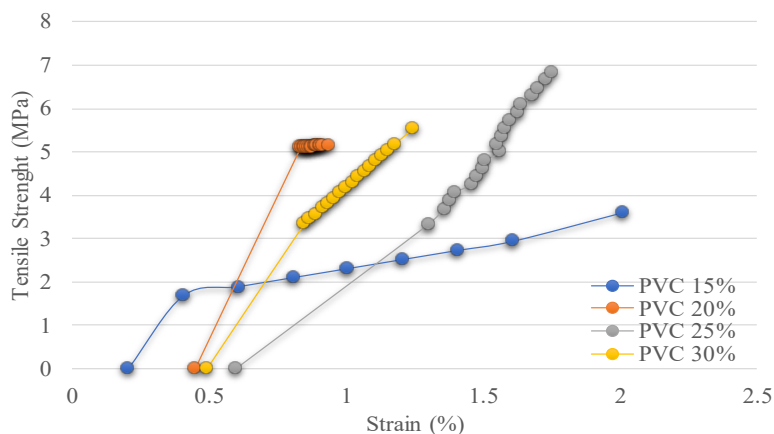


Fig.-2: The Strain (%) - Tensile of Bamboo-based Composite with Matrix Epoxy-PVC

The physical blending of PVC thermoplastic filler into the epoxy thermosetting matrix was suitable for rising its tensile strength. The amount of fiber is increased with an increase in PVC. Without meaning to leave aside the role of fiber in strengthening the composite, the same amount at each formula can be put aside to focusing on PVC/epoxy.

The highest tensile strength is reached by 25 gr of PVC, continue by 30 gr, 20 gr, and 15 gr. The tensile of hybrid Char/PVC (5:15) gr/gr was reached the highest. Almost close to neat PVC 25 gr. The curve of char/mont (5:15) was deviant to another formula, the existence of mineral montmorillonite in the formula contribute to unique material toughness, though it does not reach tensile as high as others (Fig.-2) and (Fig.-3).

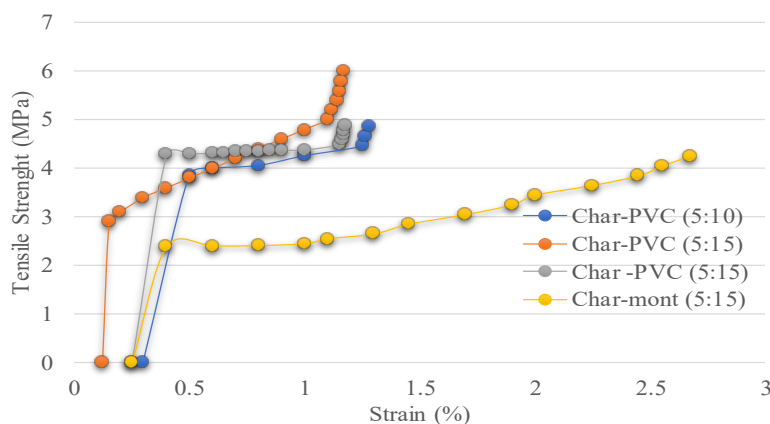


Fig.-3: The Strain (%) – Tensile of Bamboo Based Composite in Matrix Epoxy-PVC-Char

### Microstructure Images by SEM

The idea of designated bamboo to PVC at the initial stage of the mercerized bamboo surface was meant to maximizing the adhesion of matrix-fiber. This can be viewed from microporous images structure were justified to the material strength.

Strong interfacial bonding between fiber and matrix is considered to result in higher tensile strength. The dispersed PVC particles in the matrix will act as a mechanical interlocking between fiber-matrix which established a high friction coefficient. The initial failure of the composite to tensile yield cracks to applied load (Fig.-4). If PVC was beyond the composite, the strong bamboo fiber creates attractive van der Waals forces which cause a composite agglomeration leads to reduces the tensile strength of the composite.

In fact dispersion of resin and deagglomeration depends on van der Waals forces. Moreover, the composite failure can also be promoted by dispersion uniformity for a better fiber-matrix interface as seen in Fig.-5. The biochar in the composite formula results in rapid volatilization at the surface of the matrix. The surface was simply damaged and weak which does not effectively fiber from fire, it

assumed the movement of particles in nanosize to the surface of the matrix was impacted by volatile elements and the char layer.

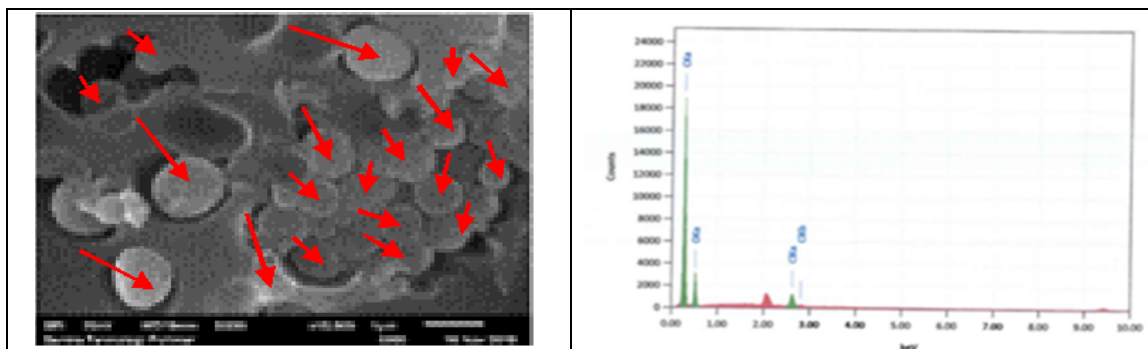


Fig.-4: Excellent Dispersion of Bamboo /Epoxy/PVC

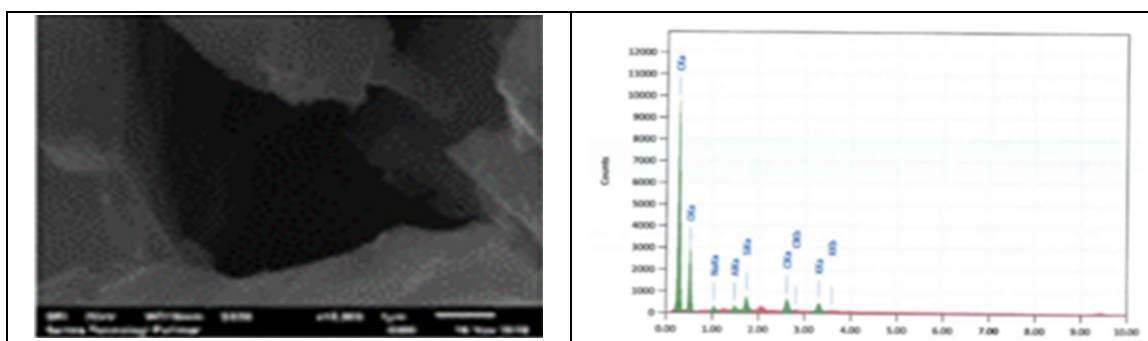


Fig.-5: The Agglomeration Leads to Material Failure of Bamboo/Epoxy/PVC

Besides, the compatibility of the bamboo fiber to PVC/biochar does not seem to result in adequate bonding, the material brittle and low tensile can be seen in Fig.-6. The density of bamboo composite/epoxy/PVC was quite similar, but the density of bamboo/epoxy-(PVC+ biochar is a little higher than neat PVC. The tensile strength of the composite bamboo fiber in this work was classified into two and will be compared: 1) tensile strength of composite bamboo fiber/epoxy/PVC reveal intends to increase with increasing weight fraction of bamboo along with  $W_f$  PVC = 20 and 25, this may assume the best weight fraction of PVC, as compatibilizer appearance.

It was declined if physically added above 25 because the material becomes brittle. 2) tensile strength of composite bamboo fiber/epoxy/PVC-biochar, as in general is lower than neat PVC, this may assume the blending PVC-carbonized was not maximized in roughing the fiber surface, so the inadequate dispersed of PVC-biochar into epoxy will also result in low tensile compared to neat PVC. The microstructure of the composite can enhance the quantitative data in property, qualitative, and visual analysis which was essential for previous material selection and material strength for various applications including infrastructure, automotive, sporting, etc.

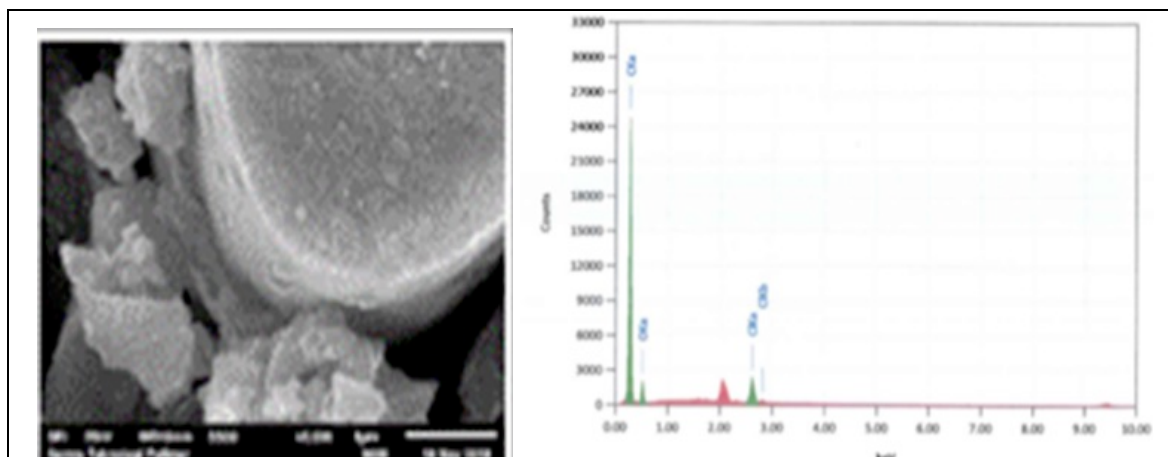


Fig.-6: The Microstructure and EDS of Bamboo Fiber/epoxy/PVC-biochar



## CONCLUSION

Currently, the rise of attention to environmentally-friendly materials, are generated in the growing interest of natural resources for composites. Adding chopped bamboo fiber into PVC then epoxy has improved the tensile strength, but the incorporation of bamboo fiber into PVC-biochar to epoxy, in general, has low tensile than neat PVC.

This work was done without thermal treatment throughout the process even though the PVC was adjustable to heat until 175<sup>o</sup>C, this to avoid the thermal decomposition of the thermoplastic matrix. Further research and investigation are required to cope with barriers such as insufficient toughness and stability reduction for outdoor applications. Furthermore, it was understood the natural fiber composites have the potential to be used in a substantial application that does not necessitate very high load-bearing capabilities or high-temperature working capacity.

## ACKNOWLEDGMENT

The authors would like to thank to Faculty of Industrial Technology Jayabaya University for funding this research.

## REFERENCE

1. F.E. Firdaus, *Indian Journal of Science and Technology*, **11(13)**,1(2018), DOI:10.17485/ijst/2018/v11i13/92794
2. H. P. S. A. Khalil, M. A. Tehrani, Y. Davoudpour, A. H. Bhat, M. Jawaid, and A. Hassan, *Journal of Reinforced Plastics and Composites*,**2(5)**, 331(2013), DOI: 10.1177/0731684412458553
3. F. M. Al-Oqla and M. A. Omari, *Green Energy and Technology*, **13**(2017), DOI:10.1007/978-3-319-46610-1\_2
4. H. Chen, M. Miao, and X. Ding, *Composites Part A: Applied Science and Manufacturing*, **40(12)**, 2013(2009), DOI:10.1016/j.compositesa.2009.09.003
5. A. Ali et al., *BioResources*, **11(4)**, 9143(2016), DOI:10.15376/biores.11.4.9142-9153
6. Chandana, *IOSR J. Mech. Civ. Eng.*, **9(6)**, 10(2013), DOI:10.9790/1684-0960714
7. Y. Nitta, K. Goda, J. Noda, and W. Il Lee, *Composites Part A: Applied Science and Manufacturing*, **49**, 133(2013), DOI:10.1016/j.compositesa.2013.02.003
8. S. Ochi, *Mechanics of Materials.*, **40(4-5)**, 447(2008), DOI:10.1016/j.mechmat.2007.10.006
9. W. O. Wan Nadirah, M. Jawaid, A. A. Al Masri, H. P. S. Abdul Khalil, S. S. Suhaily, and A. R. Mohamed, *Journal of Polymers and the Environment*, **20(2)**, 406(2012), DOI:10.1007/s10924-011-0380-7
10. M. Asim et al., *International Journal of Polymer Science.*, **2015**, 5(2015), DOI:10.1155/2015/950567
11. H. P. S. A. Khalil, M. S. Alwani, R. Ridzuan, H. Kamarudin, and A. Khairul, *Polymer - Plastics Technology and Engineering*, **47(3)**, 274(2008), DOI:10.1080/03602550701866840
12. R. Polanský, P. Prosr, and M. Čermák, *Polymer Degradation and Stability.*, **105 (1)**, 109(2014), DOI:10.1016/j.polymdegradstab.2014.03.043
13. X. Li, L. G. Tabil, and S. Panigrahi, *Journal of Polymers and the Environment*, **15(1)**, 27(2007), DOI:10.1007/s10924-006-0042-3
14. L. Du, Y. Li, S. Lee, and Q. Wu, *BioResources*, **9(1)**, 1191(2014), DOI:10.15376/biores.9.1.1189-1200
15. F. Yu, W. Yang, J. Song, Q. Wu, and L. Chen, *Wood Science and Technology*, **48(2)**, 290(2014), DOI:10.1007/s00226-013-0596-x
16. I. Van de Weyenberg, T. Chi Truong, B. Vangrimde, and I. Verpoest, *Composites Part A: Applied Science and Manufacturing*, **37(9)**,1372(2006), DOI:10.1016/j.compositesa.2005.08.016
17. Y. Xie, C. A. S. Hill, Z. Xiao, H. Militz, and C. Mai, *Composites Part A: Applied Science and Manufacturing*, **41(7)**, 809(2010), DOI:10.1016/j.compositesa.2010.03.005
18. N. A. Sri Aprilia, H. P. S. Abdul Khalil, A. H. Bhat, R. Dungani, and M. S. Hossain, *BioResources*, **9(3)**, 4895(2014), DOI:10.15376/biores.9.3.4888-4898
19. H. Ismail and R. M. Jaffri, *International Journal of Polymeric Materials and Polymeric Biomaterials*, **38(16)**, 4060(1997), DOI:10.1080/00914039708029418
20. H. S. Kim and M. A. Khamis, *Composites Part A: Applied Science and Manufacturing*, **32(9)**, 1314(2001), DOI:10.1016/S1359-835X(01)00098-7
21. H. P. S. Abdul Khalil, P. Firoozian, I. O. Bakare, H. M. Akil, and A. M. Noor, *Materials and Design*, **31(7)**, 3420(2010), DOI:10.1016/j.matdes.2010.01.044

22. M. Zammarano, *Flame Retardant Polymer Nanocomposites*, 247(2006), DOI:10.1002/9780470109038.ch9
23. S. Y. Lee, S. J. Chun, G. H. Doh, I. A. Kang, S. Lee, and K. H. Paik, *Journal of Composite Materials*, **43(15)**, 1649(2009), DOI:10.1177/0021998309339352
24. H. Z. Tabari, A. Nourbakhsh, and A. Ashori, *Polymer Engineering and Science*, **51(2)**, 274(2011), DOI:10.1002/pen.21823
25. Y. N. Wang, Y. X. Weng, and L. Wang, *Polymer Testing*, **36**, 123(2014), DOI:10.1016/j.polymertesting.2014.04.001
26. H. S. Kim, S. Kim, H. J. Kim, and H. S. Yang, *Thermochimica Acta*, **451(1–2)**, 184(2006), DOI:10.1016/j.tca.2006.09.013
27. O. Martikka, T. Huuhilo, S. Butylina, and T. Kärki, *Wood Material Science and Engineering*, **7(2)**, 110(2012), DOI:10.1080/17480272.2012.663408
28. J. Yang, Y. C. Ching, and C. H. Chuah, *Polymers*, **11(5)**, 5(2019), DOI:10.3390/polym11050751
29. T. Lu *et al.*, *Composites Part B: Engineering*, **62**, 195(2014), DOI:10.1016/j.compositesb.2014.02.030
30. F.E. Firdaus and M.Dachyar, *International Journal of Engineering & Technology*, **7(3.7)**, 114(2018), DOI:10.14419/ijet.v7i3.7.16250
31. S. Silviana and A. Subagio, *Rasayan Journal of Chemistry*, **12(3)**, 1475, (2019), DOI:10.31788/RJC.2019.1235240
32. G. Diju Samuel, J. Edwin Raja Dhas, G. Ramanan, and M. Ramachandran, *Rasayan Journal of Chemistry*, **10(3)**, 787(2017), DOI:10.7324/RJC.2017.1031748
33. S. Jothibasu, S. Mohanamurugan, and A. Vinod, *Rasayan Journal of Chemistry*, **11(3)**, 1260 (2018), DOI:10.31788/RJC.2018.1133096
34. D. Brown, V. Marcadon, P. Mélé, and N. D. Albérola, *Macromolecules*, **41(4)**, 1508(2008), DOI:10.1021/ma701940j

[RJC-6052/2020]