P-ISSN 2586-9000
E-ISSN 2586-9027
Homepage : *https://tci-thaijo.org/index.php/SciTechAsia* Science & Technology Asia
Vol.29 No.4 October - December 2024 Page: [235-246]
Original research article

The Optimization of Mechanical Properties of HDPE-Pineapple Fiber Composites Using the Taguchi Method

Tumpal Ojahan Rajagukguk[1], Anang Ansyori[1], Kusno Isnugroho[2], Yusup Hendronursito[2,*]

[1]Department of Mechanical Engineering, Faculty of Engineering, Universitas Malahayati, Bandar Lampung 35152, Indonesia
[2]Research Center for Mining Technology, National Research and Inovation Agency, Lampung 10340, Indonesia

Received 24 June 2023; Received in revised form 19 October 2024
Accepted 4 November 2024; Available online 27 December 2024

ABSTRACT

This research investigates the potential of High-Density Polyethylene (HDPE) waste as a polymer matrix and reinforcing filler from pineapple leaf fibers (PLFs). This experiment uses the Taguchi orthogonal array L9 design with parameters of fiber volume (5%, 10%, and 15%), fiber direction (0°, 45°, and random), and fiber length ratio (continuous, 1:2, and 1:3). Taguchi analysis is used to determine the optimization of parameters on the mechanical properties of the composite. In contrast, analysis of variance (ANOVA) is used to determine significant parameters. Tensile strength test according to ASTM D638-04 and three-point bending according to ASTM D790-02 are conducted. Based on Taguchi, the maximum tensile strength obtained from this composite is 1.48 N/mm^2 from 5% fiber volume, while the flexural strength is 1.61 N/mm^2 obtained from the 0° fiber direction. The S/N ratio shows the composite with 5% fiber, 0° orientation, and 1:3 fiber length ratio together provides the greatest tensile strength. For flexural strength, the best choice is a composite with 15%, 0° fiber direction, and 1:3 fiber length ratio. The fiber volume parameter has the most significant influence in producing a composite with high mechanical strength. The amount of fiber filler used is influenced by the direction of the load acting on the composite. The composites from this research are suitable for use on materials that receive low to medium loads and provide an alternative composite option.

Keywords: ANOVA; Bending; Composite; HDPE; Plastic; Tensile strength; Taguchi

***Corresponding author:** yusuph_ugm07@yahoo.com
doi: xx

1. Introduction

Indonesia is the largest producer of plastic waste after China [1]. Plastic waste is widely recognized as the most critical environmental problem [2]. Plastic contains toxic compounds in phthalates, polyfluorinated chemicals, bisphenol A (BPA), and antimony trioxide, which can dissolve can harm health and the environment [3]. The most widely used plastic is the type of polyethylene (PE). One type of PE plastic is high-density polyethylene (HDPE). HDPE is a heat-resistant plastic produced from petroleum. HDPE waste is obtained from bottles of detergent, shampoo, toys, milk containers, and types of grocery bags. HDPE does not contain phthalates or BPA but becomes harmful when exposed to sunlight for a long time [4].

Several programs to overcome the waste problem have been carried out. Reuse, recycle, and reduce are the 3R program to address the problem of plastic waste [5]. Several studies have reused plastic waste for goods that have high efficiency. Wood-plastic composites for automotive applications have been widely developed. This composite type improves mechanical strength and acoustic performance, reduces weight and fuel consumption, has low cost, improves shatterproof performance due to extreme temperature changes, and is biodegradable [6]. Natural fiber composites are used in the automotive sector in furniture, construction, packaging, and shipping pallets [7, 8]. Cellulose in natural hydrophilic fibers affects the interfacial bond between the fiber and the hydrophobic polymer matrix.

Indonesia, especially in Lampung Province, has a pineapple agro-industry which produces 200,000 metric tons annually. Pineapple cultivation has reached 81, 510 hectares and continues to increase [9]. This pineapple plant provides excellent potential for using PLFs as reinforcement composites.

Agro-based fiber-reinforced polymer matrix composites are a viable alternative with low density, high specific properties, and non-abrasion, allowing the high-volume filling of the composite [10]. Many factors, including volume fraction, orientation, fiber size, type of polymer, processing temperature, and injection speed, impact the mechanical characteristics of fiber-reinforced polymer composites [11].

Many researchers study the behavior of composites by varying the fiber volume fraction and their mechanical properties. Gloria et al. used 10% to 30% pineapple leaf fiber (PLF) variations in their research. The results showed that the composite's tensile strength and elongation increased with the increase in PLF content. However, in this study, the behavior of the composite with a fiber content below 10% was not known. The fiber content of PLF also affects the flexural strength of the composite [12]. Flexural strength increases markedly when the volume fraction is 10% to 20%. It is necessary to study the behavior of PLF-reinforced composites at volume fractions slightly below and slightly above 10%. Fiber length has an impact on fiber-reinforced composites in addition to fiber content. It was found that the composites with long-fiber PLFs were more potent than those with short-fiber PLFs. Long fibers are more uniformly dispersed in the polymer matrix than tiny fibers. In addition, there are differences in mechanical properties produced by different fiber orientations [13]. The fiber direction can be made at the angle of 0°-90° to the longitudinal direction of the composite [14]. Three different directions, namely 0°, which is in the direction of the composite length; 45°, which is in the direction of the composite diagonal; and random, can be used to represent other directions. The 90° direction refers to the perpendicular of the composite length, sometimes resulting in poor mechanical properties.

It is still challenging to accurately know the control parameters in fiber-reinforced composites made by molding processes [11]. Therefore, in this study, the relationship between independent and dependent variables was studied using Taguchi and analysis of variance (ANOVA). Independent variables in these experiments include fiber volume (5%, 10%, and 15%), fiber direction (0°, 45°, and random), and fiber length ratio (1:1 or continuous, 1:2, and 1:3). Each factor and level were studied for its effect on the dependent variables, namely tensile strength and bending strength.

Taguchi design can reduce the number of specimens made, reducing time and costs. Even though the specimens made were not fully factorial, the Taguchi analyzer could fully predict everything and estimate the optimum parameters that could be achieved. ANOVA is a statistical analysis tool for data analysis. ANOVA includes design parameters that significantly affect the output results. In the ANOVA method, the sum of squares (SS), mean square (MS), and p-value are calculated to determine the significant independent parameter that influences the dependent parameter, and the percentage of contribution is calculated [15].

2. Materials and Methods

2.1 Materials

HDPE plastic ore is obtained from the recycling process of HDPE waste through the injection method, with a size of 10 mm. Pineapple fiber is obtained from pineapple agricultural waste in the Lampung area. Pineapple stems (*Ananas comosus L.*) are washed until clean and dried for three days. The fiber is taken from the stem using a wire brush. The fiber that has been obtained is then soaked in a 5% NaOH solution for 2 hours. The soaked fiber is then washed using deionized water until clean and the pH is neutral. Composite making with the help of hot molding. The composition of pineapple fiber follows the design of the experiment (DoE).

2.2 Design of Experiment (DoE)

Table 1. The experimental parameters.

Name	Level Values		
Volume of Fibers	5%	10%	15%
Fibers Direction	0°	45°	Random
Ratio of Fibers Length	1:1	1:2	1:3

The experimental parameters include the volume of fibers, fiber direction, and the ratio of fibers versus composite length, as shown in Table 1. DoE was selected based on the literature study of previous studies [12-14, 16]. The fiber volume ratio was selected at 5%-15%, above and below 10%. Three directions represent the fiber direction: parallel to the composite length (0°), parallel to the composite diagonal (45°), and random. At the same time, the fiber length was selected 1:1, which is along the composite; 1:2, which is half the length of the composite; and 1:3, which represents short fibers. The names of the specimens in this experiment followed the Taguchi design orthogonal array L9, as shown in Table 2.

2.3 Tensile and bending strength test

Tensile strength tests and three-point bending were performed using universal UTM testing machine brand HT 2404 capacity 100 kN. The specimen preparation is according to ASTM D638-04 for tensile

Table 2. Specimen naming according to Taguchi design L9.

Name	Volume of Fibers (%)	Fibers Direction (degree)	Ratio of Fibers Length
Specimen 1	5	0	01:01
Specimen 2	5	45	01:02
Specimen 3	5	Random	01:03
Specimen 4	10	0	01:02
Specimen 5	10	45	01:03
Specimen 6	10	Random	01:01
Specimen 7	15	0	01:03
Specimen 8	15	45	01:01
Specimen 9	15	Random	01:02

strength, as shown in Fig. 1, and ASTM D790-02 for three-point bending, as shown in Fig. 2.

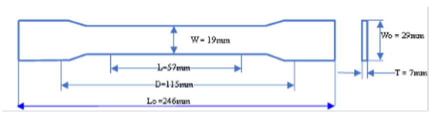

Fig. 1. Specimen dimension for tensile strength testing [17].

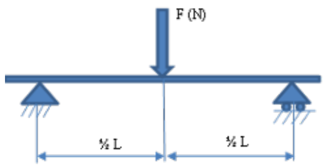

Fig. 2. Three point bending testing procedure [19].

Eqs. (2.1)-(2.2) calculate ultimate tensile strength (UTS) and strain (ε).

$$\sigma = \frac{F}{A}, \tag{2.1}$$

where, σ is ultimate tensile strength (N/mm^2), F is maximum force (N), A is area (mm^2), ε is the strain (%), L_1 is the length of the composite after testing (mm), and L_0 is the initial length of the composite (mm).

$$\varepsilon = \frac{L_1 - L_0}{L_0} \times 100\%. \tag{2.2}$$

The bending strength from the results of the three-point bending test is calculated using Eq. (2.3), [18].

$$\sigma_b = \frac{3FL}{2bd^2}, \tag{2.3}$$

where, σ_b is the composite bending stress (N/mm^2), F is the maximum load (N), L is the spacing between supports (mm), b is the specimen width (mm), and d is the specimen thickness (mm).

2.4 Analysis of variance

Anova for UTS and bending stress using S/N ratio larger is better, where the highest value is the desired value, using Eq. (2.4).

$$\frac{S}{N} = -10 \log \sum \frac{\frac{1}{y^2}}{n}. \tag{2.4}$$

3. Results and Discussion

The results of making HDPE-PLF composite specimens according to test standards are shown in Fig. 3.

Fig. 3. HDPE-PLFs composite specimens.

3.1 Tensile strength

The tensile test produces a graph of the tensile load on the Y axis to the composite elongation on the X axis. These two data are then processed using Eqs. (2.1)-(2.2). The stress-strain graph of the tensile test results is shown in Fig. 4. The ultimate tensile strength (UTS) and standard deviation values for three repetitions of the tensile test versus strain are shown in Fig. 5.

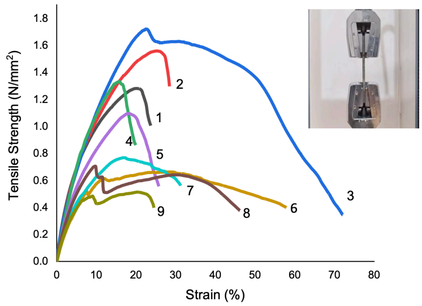

Fig. 4. The tensile Strength (N/mm^2) versus Strain (%).

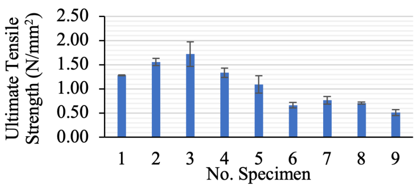

Fig. 5. The ultimate tensile Strength (N/mm^2) and deviation standard for three repetitions.

3.1.1 Taguchi analysis for ultimate tensile strength

The calculated UTS value was then analyzed by Taguchi design to obtain the means and S/N ratio graphs, as shown in Figs. 6-7. From most excellent to lowest, the amount of fiber that creates tensile strength is composed of 5% fiber (1.48), 10% fiber (1.05), and 15% fiber (0.69).

In this study, it is known that increasing fiber volume decreases tensile strength. The fiber volume in the composite decreases tensile strength. The addition of fibers results in a decrease in the amount of polymer matrix. The function of the matrix to support the fibers and transfer loads between the fibers is reduced. The decrease in polymer volume indicates a decrease in adhesion. Optimization of fiber volume is required to achieve high tensile strength. Furthermore, the strength of the composite becomes loaded on the strength of the fibers. The fibers and the matrix interfacial interaction dramatically affect the strength of the composite. High fiber volume results in an increase in the adhesion load of the fibers and polymers. If the adhesion interaction is optimal, it can prevent the bond from being released at a relatively low load [20].

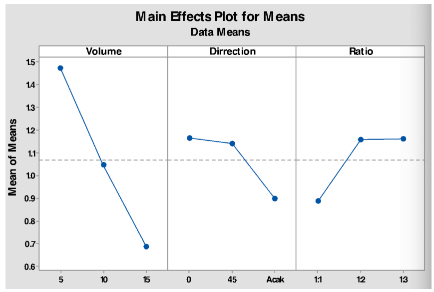

Fig. 6. Main effect plots for means.

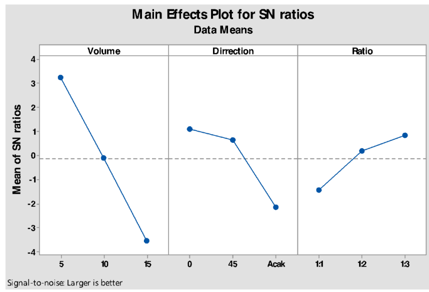

Fig. 7. Main effect plots for SN ratios.

The best choice of fiber direction is 0°, with a value of 1.17. The second place is 45° direction with a value of 1.14, and the lowest is the random fiber direction with a value of 0.90. All tensile strengths are in N/mm^2. Please note that the direction of the tensile load in the test is in the direction of the 0o fiber. The composite with 0o fiber direction can withstand greater loads. The direction of the dynamic load acting on the composite affects the strength of the fiber reinforced by the fiber. The results of the influence of fiber orientation on the tensile strength test results of fiber-reinforced composites show these effects. The rigidity of the composite along the fiber direction depends on the fiber alignment. It decreases with increasing offset degrees of the fiber direction so that the toughness of the composite decreases [21].

The addition of fiber volume fraction into the composite was not accompanied by an excellent interfacial bond between the fiber and the polymer (HDPE). Please note that the composite made is single-layer, with the fiber in the middle of the HDPE matrix. Therefore, when the fiber volume increases, the matrix volume decreases. When the tensile force acts on the composite, low stress can be held due to the interfacial connection between the matrix and fiber becoming brittle [22].

Increasing fiber volume further leads to decreased properties due to lower fiber-matrix adhesion and total fiber content of the matrix [22]. From Eq. (2.1), it is known that tensile stress is the result of the division of the load acting on the composite area. The larger the cross-sectional area of the composite due to the increased fiber volume, the lower the tensile stress will be. The tensile strength of pineapple fiber is highly dependent on the previous fiber treatment. Alkali treatment of the fiber dramatically affects the properties of the fiber used as a composite filler [23].

Adding fiber with a ratio of 1:2 gave the highest tensile strength with a value of 1.162. The second is by a ratio of 1:3 with a value of 1.160. The lowest is a ratio of 1:1, with a value of 0.89. The values in the 1:2 and 1:3 ratios are similar and higher than the 1:1 ratio. The shorter fibers can withstand higher tensile stress than the longer fibers. According to Sajin et al. [24], the decrease in the tensile strength of longer fibers is caused by the alignment of fibers in a linear direction and resistance to tensile loads acting in one direction.

Based on Fig. 7, the S/N ratios for tensile stress, it can be shown that the three factors of 5% fiber volume, 0° orientation, and a fiber length ratio of 1:3 together give the greatest tensile strength. There are negative values, including a ratio of 1:1, a volume parameter of 15%, and a random orientation. Negative values of S/N indicate measurement results that are below the desired target. The larger the S/N equation is the better it is, where the best is the highest. A decrease in value from 5% to 15% on the S/N plot shows that the more fiber used, the lower the tensile strength produced. Utilizing the negative parameter while creating composites using HDPE pineapple fiber filler is not advised.

3.1.2 Analysis of variance (ANOVA) for ultimate tensile strength

Analysis of Variance (ANOVA) makes knowing each parameter's contribution easy. It draws a hypothesis on the relationship between the independent parameters and the dependent parameters based on the p-value shown in Table 3. Variance analysis was performed by entering the factors: "volume," "Direction," and "Ratio" to the average ultimate tensile strength value. The ANOVA results for ultimate tensile strength show that the highest contribution to Tensile strength Composite was obtained when fiber volume is equal to 58.55%, followed by fiber direction of 21.68%, and the lowest obtained was from fiber ratio of 16.96%.

The error value of this study is below 2.82%, which means that the error in the experiment is still below the reasonable value, namely α = 5%. Based on the p-value, the

Table 3. ANOVA for ultimate tensile strength of composite.

Source	DoF	Seg SS	Contribution	Adj SS	Adj MS	F-Value	p-Value
Volume	2	2.9625	58.55%	2.9625	1.48123	20.77	0.046
Direction	2	1.0969	21.68%	1.0969	0.54845	7.69	0.115
Ratio	2	0.858	16.96%	0.858	0.429	6.01	0.143
Error	2	0.1426	2.82%	0.1426	0.07132		
Total	8	5.06	100.00%				

fiber volume parameter significantly affects the tensile strength. However, with a p-value higher than $\alpha = 5\%$, the fiber direction and fiber ratio parameters did not significantly affect the tensile strength.

The level of confidence in the distribution of data from the Tensile test results is shown by the regression value or R-sq, as shown in Table 4.

Table 4. Model Summary for Transformed Response.

S	R-sq	R-sq (adj)	Press	R-sq (pred)
0.264557	97.23%	88.94%	2.83462	43.99%

p-value on tensile strength in this study is a parameter that significantly influences results. Another parameter that significantly influences results is the fiber volume in the composite, with a p-value of 0.046. Other parameters, direction and fiber length ratio, do not significantly affect results. The weak influence of these two parameters can be caused by the fiber volume parameter, which is superior in influencing the tensile strength of the composite. It can be seen that the contribution of fiber volume reaches almost 60%, so other parameters can be ignored. The data distribution for tensile test results is quite good, as indicated by the R-sq value approaching 100%. This value is from the results of ANOVA, where the error is 2.82%.

3.2 Three-point bending

Graphic bending load versus displacement from three-point bending testing is shown in Fig. 8. Based on Fig. 8, the composite bending stress area can be divided into three groups. The first group with the highest bending stress is specimens 1, 2, and 3. The second group is specimens 7, 8, and 9. In contrast, the group with the lowest bending stress value is specimens 4, 5, and 6. However, to calculate the bending strength, the load received is divided by the cross-sectional area of the specimen.

The results of the three-point bending test, as shown in Fig. 8, are used as the basis for calculating the bending strength using Eq. (2.3). Furthermore, the bending strength is obtained as shown in Fig. 9. The bending strength test was repeated three times, and the deviation value was obtained between 0.09-0.21 N/mm^2.

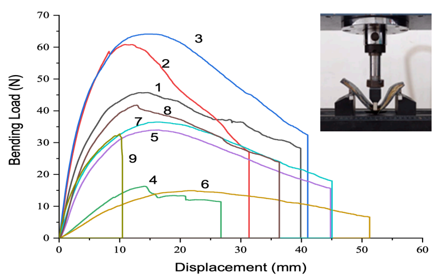

Fig. 8. Bending strength vs displacement.

3.2.1 Taguchi analysis for bending strength

The main effects plot for means is shown in Fig. 10. Pineapple fiber vol-

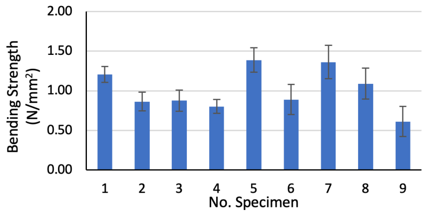

Fig. 9. Bending Strength and standard deviation.

ume of 15% gave the highest average value of composite bending stress, 1,22 N/mm^2, followed by a 5% volume of 1,06 N/mm^2. The lowest value was 10% pineapple fiber, which was 0,95 N/mm^2. The fiber direction parameter gives the highest bending stress value in the 0° direction with a value of 1.25 N/mm^2, followed by the 45° direction with a value of 1.17 N/mm^2. The lowest is in the 45° direction because the three-point bending test provides a force perpendicular to the length of the composite.

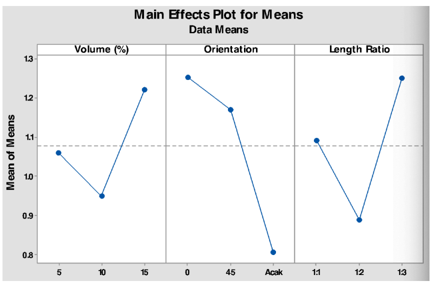

Fig. 10. Main effect plots for means.

In contrast to tensile loading, bending loading causes deflection in the composite. Increasing the fiber volume increases the load-bearing capacity of the composite. Fibers have more robust properties to receive bending loads than the matrix, so the more fibers there are, the more resistant they are to bending loads. With more fiber volume, the stress applied to the composite during bending is distributed evenly. These distribution loads result in a reduction in local stress concentrations that cause failure [25].

The 0o fiber direction gives a higher compressive force reaction during testing than the other directions. Shorter pineapple fibers provide greater bending stress values than longer fibers. Shorter fibers will make the composite more rigid and more robust. The 15% fiber volume parameter value, 0° fiber orientation, and 1:3 fiber length ratio produced the best bending strength. The alignment of fibers in the direction of the composite length impacts reducing shear stress in the matrix during bending so that premature failure can be minimized [25]. Shorter fibers increase toughness due to the ability to absorb energy during deformation. Short fibers also provide the advantage of increasing fiber-pulling mechanisms and crack bridging, thereby dissipating energy during bending and increasing bending strength [26].

Based on Fig. 11, the S/N ratio for the bending stress of the composite, the optimum combination is obtained at the parameter fiber volume of 15%, fiber direction of 0o, and fiber length ratio of 1:3. A negative S/N value indicates that the value is below the expected average. This negative value means that the factors at each level can be ignored. Where the selection of factors from each level is based on ”larger is better.”

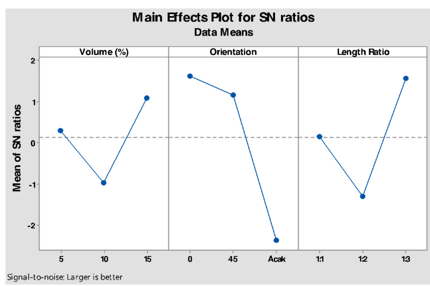

Fig. 11. Main Effect plots for S/N ratios.

Table 5. Analysis of variance for transformed response.

Source	DoF	Seg SS	Contribution	Adj SS	Adj MS	F-Value	p-Value
Volume	2	7.9741	67.83%	7.9741	3.987	19.58	0.049
Direction	2	2.4265	20.64%	2.4265	1.2133	5.96	0.144
Ratio	2	0.9478	8.06%	0.9478	0.4739	2.33	0.301
Error	2	0.4072	3.46%	0.4072	0.2036		
Total	8	11.7556	100%				

Table 6. Model Summary for Transformed Response.

S	R-sq	R-sq (adj)	Press	R-sq (pred)
0.451229	96.54%	86.14%	8.2461	29.85%

3.2.2 Analysis of variance (ANOVA) for bending strength

Variance analysis was performed by entering: ”Volume,” ”Direction,” and ”Ratio” to the average bending strength value. The two main contributors were the fiber volume parameter, which contributed 67.83% to the bending strength, and the fiber orientation which contributed 20.64%. The fiber length ratio made a minor contribution. All factors substantially impact the bending stress, according to the p-value. With this bending stress, the error value is 3.46%. Table 5 displays ANOVA for bending strength. The level of confidence in the distribution of data shown in Table 6.

The superiority of the volume parameter is again proven in the bending strength test, which produces a contribution of almost 70% so that other parameters can be ignored. This superiority is also shown by the p-value, which is below 5% or 0.05 only for the volume parameter.

3.3 Cost analysis and development approaches

The production cost of PLF reinforcement composites depends on many things, such as the availability of raw materials and the methods used. The availability of abundant raw materials that have yet to be utilized optimally will give PLF added value. In addition, the use of natural fibers will reduce material costs by substituting for synthetic fibers. Even previous studies have shown that using PLF can reach 30% [27].

PLF can be made traditionally or using a spinning machine. This spinning machine does not affect cost much because it does not change the parameters of the spinning machine. PLF yarn production can be done using conventional hemp spinning. Compared to cotton spinning, this will reduce production costs. Therefore, the cost of capital investment can be reduced. The abundant availability of raw materials makes collecting pineapple leaf raw materials cheaper than cotton and hemp fibers. PLF can be sold commercially as high-value-added goods as derivative products such as burlap sacks, car dashboards, soundproof composite boards, indoor and outdoor furniture, food containers, etc.

As a polymer reinforcement product, PLFs have a competitive price compared to sawdust materials. PLFs have the advantage of higher tensile strength compared to composites with sawdust. The uniform size and length of PLFs provide superior mechanical properties compared to composites with wood fibers.

Table 7 compares pineapple fiber prices with various other materials taken from online stores in Indonesia. The comparison of PLF production costs with hemp is the same: USD 0.15-0.2 processing cost/lb. This cost is cheaper than the cotton production, which reaches USD 0.75-0.85 per lb [28].

Table 7. Model Summary for Transformed Response.

Natural Fiber	Price	Reference
PLfs	IDR120,000/kg	Indonesia online market
Rami	IDR370,000/kg	Indonesia online market
Banana Stem	IDR329.000	Indonesia online market
Cotton	$2.15/kg	iwto-org
Silk	$64.50/kg	iwto-org

Modernization and effective new technology can increase income through better farming, pineapple leaf collection from field to factory, and waste management. Furthermore, new job opportunities and the emergence of new economic points can be created along with traditional weaving tools on a large scale. Competition between natural fibers and synthetic fibers will still occur. Therefore, PLF natural fibers can be a better solution in pure composition or combined with other natural fibers.

Indonesia is the 9th largest pineapple-producing country [28], and until now, Lampung Province has been the largest pineapple-producing area in Indonesia, reaching 23% of national production [29]. Through this research, the utilization of pineapple fiber waste in composites with superior mechanical properties is expected to open up opportunities for added value of pineapple fiber. Therefore, practical actions and policies such as planning from technical and economic institutions must occur, together with support from the government to change waste into added value, in this case, pineapple fiber.

4. Conclusion

The experiment has successfully made composites from waste high-density polyethylene (HDPE) reinforced with pineapple leaf fibers (PLFs). Based on Taguchi design analysis and ANOVA, PLF volume dramatically influences the mechanical properties of HDPE composite. HDPE composites with the best mechanical properties are made of 5 w.t% of HDPE. The mechanical properties of pineapple fiber-reinforced HDPE composites are inversely proportional to the volume of pineapple fiber. The more pineapple fiber filler used, the lower the mechanical properties of the composite. The fiber content of 5% and a 1:3 fiber length ratio are the best parameters to obtain high mechanical properties.

HDPE composites based on plastic waste with pineapple fiber filler provide an alternative composite option that reuses unused goods. HDPE composites reinforced with PLF fibers with a tensile strength of around 3N/mm^2 and a bending strength of 2 N/mm^2 are suitable for low to moderate-load applications. They can withstand bending stress without significant deformation or failure. Therefore, HDPE composites reinforced with pineapple fibers are suitable for interior panels, dashboards, door trims, insulation panels, packaging materials, plant pots and garden furniture.

Acknowledgements

The authors acknowledge the facilities, scientific and technical support from Advanced Characterization Laboratories Lampung, National Research and Innovation Agency through E- Layanan Sains, Badan Riset dan Inovasi Nasional. All authors fully and equal contributed, and there is no conflict of interest for the manuscript.

References

[1] Jambeck JR, Geyer R, Wilcox C, Siegler TR, Perryman M, Andrady A, Narayan R, Law KL. Plastic waste inputs from land into the ocean. Science. 2015;347(6223):768-71.

[2] Rochman CM, Browne MA, Halpern BS, Hentschel BT, Hoh E, Karapanagioti HK, Rios-Mendoza LM, Takada H, The S, Thompson RC. Classify plastic waste as hazardous. Nature. 2013;494(171):6-8.

[3] Okunola A A, Kehinde I O, Oluwaseun A, Olufiropo E A. Public and Environmental Health Effects of Plastic Wastes Disposal: A Review. J Toxicol Risk Assess. 2019;5(2).

[4] Proshad R, Kormoker T, Islam S, Haque MA. Toxic effects of plastic on human health and environment: A consequences of health risk assessment in Bangladesh. 2018;6(1):1-5.

[5] Sufia R, Arisona RD. Introducing environmental education to early children through 3R activities (an effort for Indonesia free trash) R. In: 3rd International Conference on Environmental Geography and Geography Education. IOP Conf. Series: Earth and Environmental Science 747; 2021.

[6] Ashori A. Wood-plastic composites as promising green-composites for automotive industries. Bioewsource Technol. 2008;99:4661-7.

[7] Lau K, Hung P, Zhu M, Hui D. Properties of natural fibre composites for structural engineering applications. Compos Part B. 2018;136 (November 2017):222-33.

[8] Oksman K. High Quality Flax Fibre Composites Manufactured by the Resin Transfer Moulding Process. Reinf Plast Compos. 2001;20(07):621.

[9] Arbintarso ES, Muslim M, Rusianto T. Simulation and Failure Analysis of Car Bumper Made of Pineapple Leaf Fiber Reinforced Composite. IOP Conf Ser Mater Sci Eng. 2018;306(1).

[10] Rowell RM, Anand R, Caul-DF, Jacobson RE. Utilization of Natural Fibers in Plastic Composites: Problems and Opportunities Department of Forestry , 1630 Linden Drive. pp. 23-52.

[11] Zhong Y, Liu P, Pei Q, Sorkin V, Louis A, Su Z, Guo T, Thitsartarn W, Lin T, He C, Zhang Y. Elastic properties of injection molded short glass fiber reinforced thermoplastic composites. Compos Struct. 2020;254(April):112850.

[12] Gloria GO, Teles MCA, Neves ACC, Vieira CMF, Lopes FPD, Gomes M de A, Margem FM, Monteiro SN. Bending test in epoxy composites reinforced with continuous and aligned PALF fibers. J Mater Res Technol. 2017;6(4):411-6.

[13] George Jayamol, Thomas Sabu. Short Pineapple-Leaf-Fiber-Reinforced Low-Density Polyethylene Composites. Appl Polym Sci. 1995;57:843-54.

[14] Hao X, Zhou H, Mu B, Chen L, Guo Q, Yi X, et al. Effects of fiber geometry and orientation distribution on the anisotropy of mechanical properties, creep behavior, and thermal expansion of natural fiber/HDPE composites. Compos Part B Eng. 2020;185(August 2019):107778.

[15] Hendronursito Y, Rajagukguk TO, Safii RN, Sofii A, Isnugroho K, Birawidha DC, Amin M, Muttaqii MA. Analysis of Aluminium Basalt Particulate Composite Using Stirring Casting Method Through Taguchi Method Approach. IOP Conf Ser Mater Sci Eng. 2020;807(1).

[16] Chollakup R, Tantatherdtam R, Ujjin S, Sriroth K. Pineapple Leaf Fiber Reinforced Thermoplastic Composites: Effects of Fiber Length and Fiber Content on Their Characteristics. J Appl Polym Sci. 2010;119(5):1952-60.

[17] ASTM D638-14. Standara Test Method for Tensile Properties of Plastics. 2014.

[18] Monazzah AH, Pouraliakbar H, Bagheri R, Morteza S, Reihani S. AC SC. Compos Part B. 2017.

[19] ASTM D790-17. Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials. Vol. 17. 2017.

[20] Huang S, Fu Q, Yan L, Kasal B. Characterization of interfacial properties between fibre and polymer matrix in composite materials-A critical review. J Mater Res Technol. 2021;13:1441-84.

[21] Rao P, Doddi V, Chanamala R, Dora SP. Effect of fiber orientation on dynamic mechanical properties of PALF hybridized with basalt reinforced epoxy composites Effect of fi ber orientation on dynamic mechanical properties of PALF hybridized with basalt reinforced epoxy composites.

[22] Venkateshwaran N, Elayaperumal A, Jagatheeshwaran MS. Effect of fiber length and fiber content on mechanical properties of banana fiber/epoxy composite. 2011.

[23] Izani MAN, Paridah MT, Anwar UMK, Nor MYM, H PS. Composites: Part B Effects of fiber treatment on morphology, tensile and thermogravimetric analysis of oil palm empty fruit bunches fibers. 2012.

[24] Sajin JB, Aurtherson PB, Binoj JS, Manikandan N, Saravanan MSS, Haarison TM. Materials Today: Proceedings Influence of fiber length on mechanical properties and microstructural analysis of jute fiber reinforced polymer composites. Mater Today Proc. 2020.

[25] Papanicolaou GC, Portan D V., Kontaxis LC. Interrelation between fiber-matrix interphasial phenomena and flexural stress relaxation behavior of a glass fiber-polymer composite. Polymers (Basel). 2021;13(6).

[26] Jiang L, Zhou Y, Jin F, Hou Z. Influence of Polymer Matrices on the Tensile and Impact Properties of Long Fiber-Reinforced Thermoplastic Composites. Polymers (Basel). 2023;15(2).

[27] Sethupathi M, Khumalo MV, Skosana SJ, Muniyasamy S. Recent Developments of Pineapple Leaf Fiber (PALF) Utilization in the Polymer Composites-A Review. Separations. 2024;11(8).

[28] Jalil MA, Parvez MS, Siddika A, Rahman MM. Characterization and Spinning Performance of Pineapple Leaf Fibers: An Economic and Sustainable Approach for Bangladesh. J Nat Fibers. 2021;18(8):1128-39.

[29] Dinas Komunikasi informatika dan SPL. Lampung Produsen Nanas Terbesar di Indonesia Tahun 2023 . Diskominfotik Prov. Lampung. 2024 [cited 2024 Oct 15]. https://diskominfotik.lampungprov.go.id/-detail-post/lampung-produsen-nanas-terbesar-di-indonesia-tahun-2023.