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Research Article

Optimization of Tensile Strength in Pineapple Leaf Fiber Composites: A Study of Fiber Volume Fractions with Clear Polyester Resin

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ABSTRACT

The utilization of pineapple leaf fiber is still relatively small, only used as a basic material for various types of furniture products, fabrics for fashion products, crafts and composites as forming materials. This study aims to analyze the tensile strength of pineapple leaf fiber composites with variations in volume fractions using clear polyester resin. In this study, composites were made using three different volume fractions, namely 60% fiber: 40% resin, 70% fiber: 30% resin, and 85% fiber: 15% resin. After the test specimen manufacturing process, the specimens were then tested for tensile strength on each volume fraction. The results of this study indicate variations in tensile strength on each volume fraction used, where using a volume fraction of 85% fiber: 15% resin produces higher tensile strength compared to the volume fraction of 60% fiber: 40% resin and 70% fiber: 30% resin. Pineapple leaf fiber reinforced composites with variations in the volume fraction of pineapple leaf fiber 60%: resin 40%, pineapple leaf fiber 70%: resin 30%, and pineapple leaf fiber 85%: resin 15%. From the percentage variations, the highest tensile strength is in pineapple leaf fiber 85%: resin 15% with an average value of 105.69 MPa, elastic modulus strength of 1571 MPa, and elongation of 6.74%. While the lowest tensile strength value is in pineapple leaf fiber 60%: resin 40%, with an average value of 74.30 MPa, elastic modulus strength of 1231 MPa, and elongation of 6.04%, it can be concluded that the higher the percentage of fiber, the higher the tensile strength value. Variations in the volume fraction of pineapple leaf fiber can affect the mechanical properties of clear polyester resin composites. The composite strength value often increases with the increase in the fiber volume fraction. However, a high fiber volume fraction does not always have a good effect on the strength of the composite. The strength of the composite is not only influenced by the number of fibers but is also influenced by the binding factor, namely the matrix.

Keywords: Volume fraction, composite, pineapple leaf fiber, tensile strength

1. INTRODUCTION

The development of material science, especially in the field of materials, has continually progressed in tandem with human efforts to improve the quality of life by utilizing raw materials and advanced technologies. As one of the supporting materials, natural fibers have gained significant attention, with pineapple leaf fiber emerging as a promising candidate. This natural fiber is abundant and widely distributed throughout Indonesia, yet its utilization remains relatively limited. Currently, pineapple leaf fiber is primarily used as a raw material for various products such as furniture, fashion fabrics, handicrafts, and composites for automotive components. Previous research conducted by Paryanto (2012) titled The Effect of Orientation and Fraction of Pineapple Leaf Fiber (Ananas comosus) on the Tensile Strength of Composites explored its potential, indicating its relevance as a reinforcing agent in composite materials.

In this study, pineapple leaf fiber is expected to serve as an alternative raw material for composite reinforcement due to its high potential. The use of pineapple leaf fiber as a reinforcing material in composites holds significant promise, especially from the perspective of optimizing the waste from pineapple plantations in Indonesia, which has not yet been fully exploited economically. This underutilization represents a missed opportunity in terms of both environmental sustainability and economic value, as these fibers could be processed into high-value composite materials. Furthermore, the strategic use of agricultural waste like pineapple leaves can contribute to reducing dependence on synthetic fibers, which often come with high environmental costs.

The primary objective of this research is to investigate the influence of fiber volume fraction on the tensile strength of composites made from pineapple leaf fibers using the hand lay-up method. This research will also analyze the mechanical properties of the resulting composites, particularly focusing on their tensile strength when using polyester resin as the binding agent. By exploring these aspects, the study aims to provide valuable insights into the potential applications of pineapple leaf fiber as a sustainable, eco-friendly alternative for reinforcing composite materials. The findings could pave the way for broader utilization of this natural fiber, contributing to both environmental sustainability and the economic empowerment of local communities in Indonesia.

2. RESEARCH METHOD

2.1 Research Location and Duration

This research was conducted at two locations: the Material Engineering and Energy Conversion Laboratory, Department of Mechanical Engineering, Faculty of Engineering, Malikussaleh University in Lhokseumawe, Aceh, and the Material Testing Laboratory at Lhokseumawe Polytechnic, Aceh. The study spanned eight months, beginning in January 2024 and concluding in August 2024.

2.2 Research Procedures

The research followed several detailed procedures to ensure the successful extraction of fibers, composite fabrication, and testing.

1. Pineapple Leaf Fiber Extraction Process

The fiber extraction process started with shredding the pineapple leaves using a shredder, which had been thoroughly cleaned and dried beforehand. Afterward, the extracted fibers were immersed in a 5% NaOH solution for 2 hours to remove impurities. Once the soaking was complete, the fibers were rinsed with distilled water, combed out, and then dried under direct sunlight. After the drying process, the fibers were cut into sizes that fit the specifications required for the study.

2. Composite Fabrication Process

For composite fabrication, the hand lay-up method was used. Initially, the mold was cleaned, and a release agent was applied to it to ensure easy removal of the composite after curing. The fiber layers were then added step by step, ensuring they fit the mold's volume and met the required size for tensile testing. A resin-catalyst mixture was prepared and thoroughly mixed. Next, the pineapple leaf fibers were carefully arranged in the mold, followed by the pouring of resin into the mold using the hand lay-up method. A brush was used to evenly spread the resin from top to bottom and from side to side. To prevent warping during the drying process, a lubricated glass sheet was placed over the mold. The composite was allowed to dry at room temperature, and once dry, it was carefully removed from the mold and cut according to the standard testing dimensions. The specimens were then prepared for tensile testing.

3. Experimental Procedure

The composites were subjected to tensile testing to assess their tensile strength. The specimens were first prepared according to ASTM D3039 standards, with dimensions of 250 mm × 25 mm × 2.5 mm. Once the specimens were ready, the testing machine was set up, ensuring all equipment was clean, functional, and free of damage. The specimen was then attached to the machine's grips, which were tightened carefully to avoid damaging the material. An extensometer was affixed to the specimen, and both the elongation and load values were set to zero. The testing speed was adjusted, and the machine was activated by pressing the start button twice, followed by the down button to initiate the test. After completing the test and obtaining the results, the process was repeated for other composite specimens.

3. RESULTS AND DISCUSSION

Tensile testing was conducted using a Universal Testing Machine (UTM) in the Material Testing Laboratory of the Department of Mechanical Engineering at Malikussaleh University. This method is widely recognized for its ability to precisely measure the tensile strength and mechanical properties of materials under controlled conditions. The UTM allows for the application of a uniaxial tensile force to the specimen, enabling the measurement of various key parameters such as elongation, ultimate tensile strength, and the material's behavior under stress.

For the testing process, the specimens, which were prepared in accordance with the required standards, were carefully positioned in the grips of the UTM to ensure accurate and reliable results. The machine was calibrated to ensure precise measurement of load and elongation, and the test was performed under specified conditions to simulate real-world forces that the composite materials would experience. The data collected from the test provided valuable insights into the performance of the pineapple leaf fiber composite material, specifically regarding its strength and ductility.

The results of the tensile testing, including the visual representation of the specimens before and after testing, can be seen in **Figures 1, 2,** and **3**. These images show the condition of the specimens before testing, the setup of the test, and the deformation or failure modes observed after the tensile force was applied. These visual records are crucial for understanding the material's response to stress and provide a clear illustration of how the pineapple leaf fiber composites behave under tensile loading. The analysis of these results is essential for evaluating the feasibility of using pineapple leaf fiber as a reinforcing material in composite applications, as it directly correlates with the material's potential for use in industries such as automotive, construction, and other fields where high-strength materials are required.

Figure 1. Specimen 60%: 40% after the tensile test

Figure 2. Specimen 70%: 30% after the tensile test

Figure 3. Specimen 85%: 15% after the tensile test

3.1 Data on the results and discussion of tensile testing

Based on the results of the tensile testing that has been carried out using the ASTM D3039 standard on the pineapple leaf fiber amplifier composites and with the akali treatment (5%NaOH) with the optimization of the fiber volume fraction (60%: 40%, 70%: 30%, and 85%: 15%), with random fiber orientation with tensile stress, tensile strain and modulus of elasticity.

Data from this test results, the results are presented in the form of a composite tensile curve.

Table 1. Data Testing Testing Pull Fiber Volume Pineapple Leaf Volume Fraction 60%: 40%

Specimen	Area (mm²)	Maks Force (kgf)	Tensile Strenght (Mpa)	Elongation (%)	Modulus of elasticity (Mpa)
1	62,50	469	73,54	5,72	1285
2	62,50	466	73,05	5,95	1227
3	62,50	458	71,78	6,16	1165
4	62,50	504	79,08	5,99	1320
5	62,50	472	74,04	6,38	1160
Average	62,50	474	74,30	6,04	1231

The tensile testing data for the five specimens, which were tested with a volume fraction of 60% pineapple leaf fiber and 40% resin, reveal significant variation in tensile strength and elastic modulus. The lowest tensile strength was observed in specimen number 3, which recorded a tensile strength value of 71.78 MPa, coupled with an elastic modulus of 1165 MPa. This specimen exhibited a relatively lower resistance to tensile stress compared to the others, indicating that the fiber-resin matrix in this particular specimen may not have been as effective in distributing the applied load. On the other hand, the highest tensile strength was found in specimen number 4, which showed a tensile strength of 79.08 MPa and an elastic modulus of 1320 MPa. This specimen demonstrated the best performance in terms of resisting deformation under stress, suggesting that the specific combination of pineapple leaf fiber and resin in this specimen was optimal for enhancing material strength and stiffness. The average tensile strength across all five specimens was calculated to be 74.30 MPa, and the average modulus of elasticity was 1231 MPa. These values represent the general performance of the composite material with a 60% fiber and 40% resin ratio, indicating a moderate level of strength and stiffness that is suitable for applications where durability and load-bearing capacity are essential. In addition to these results, further testing was conducted with specimens containing a 70% volume fraction of pineapple leaf fiber and 30% resin. The data for these specimens are summarized in Table 2, providing additional insight into how the increased fiber content affects the mechanical properties of the composite. By comparing these results, it will be possible to evaluate the impact of varying fiber-resin ratios on the overall performance of the material, ultimately helping to determine the optimal composition for different application scenarios.

Table 2. Data Testing Results of Penalty Pineapple Leaf Fiber Volume Fraction 70%: 30%

Specimen	Area (mm²)	Maks Force (kgf)	Tensile Strenght (Mpa)	Elongation (%)	Modulus of elasticity (Mpa)
1	62,50	608	95,32	5,91	1612
2	62,50	662	103,85	6,15	1688
3	62,50	464	72,76	5,91	1231
4	62,50	564	88,45	5,67	1559
5	62,50	560	87,86	6,74	1303
Average	62,50	572	89,65	6,08	1479

The tensile test results for the five specimens, which were tested with a 70% volume fraction of pineapple leaf fiber and 30% resin, show a significant range of tensile strength and modulus values, reflecting the impact of fiber content on the material's mechanical properties. The specimen with the lowest tensile strength was specimen number 3, which had a tensile strength of 72.76 MPa and an elastic modulus of 1231 MPa. This specimen exhibited a moderate ability to withstand tensile stress, indicating that while the fiber content was relatively high, the balance between the fiber and resin might not have been ideal for optimal strength performance. In contrast, specimen number 2 demonstrated the highest tensile strength at 103.85 MPa, accompanied by an impressive elastic modulus of 1688 MPa. This specimen showed exceptional performance in resisting tensile stress, highlighting the significant role that the fiber-to-resin ratio plays in enhancing the material's mechanical properties. The higher fiber content in this specimen appears to have contributed to improved strength and stiffness, making it particularly suitable for applications where high tensile strength and durability are critical.

The average tensile strength across all five specimens was calculated to be 89.65 MPa, with an average modulus of elasticity of 1479 MPa. These results suggest that composites with a 70% volume fraction of pineapple leaf fiber and 30% resin offer a balanced combination of strength and flexibility. The material demonstrates a considerable increase in tensile strength compared to the 60% fiber variant, highlighting the positive effect of higher fiber content on the mechanical properties of the composite. Further testing was conducted with specimens containing a higher volume fraction of 85% pineapple leaf fiber and 15% resin. The results for these specimens are summarized in Table 3, offering a deeper understanding of how the material's performance improves with even higher fiber content. Comparing these findings with those from the 60% and 70% fiber variants will provide valuable insights into the optimal fiber-resin ratio, helping to determine the best composition for specific applications where high mechanical strength and durability are desired.

Table 3. Data Testing Results of Penalty Fiber Volume Fraction Pineapple Fraction 85%: 15%

Specimen	Area (mm²)	Maks Force (kgf)	Tensile Strenght (Mpa)	Elongation (%)	Modulus of elasticity (Mpa)
1	62,50	673	105,61	6,66	1585
2	62,50	703	103,85	7,28	1426
3	62,50	636	99,83	6,38	1564
4	62,50	663	104,05	6,79	1532
5	62,50	734	115,13	6,58	1749
Average	62,50	682	105,69	6,74	1571

The tensile testing data for the five specimens, which were tested with a volume fraction of 85% pineapple leaf fiber and 15% resin, demonstrates a clear improvement in both tensile strength and modulus of elasticity compared to previous compositions. Among these specimens, the lowest tensile strength was observed in specimen number 3, which recorded a tensile strength of 99.83 MPa and an elastic modulus of 1564 MPa. Despite being the lowest in this group, this specimen still exhibited relatively strong mechanical properties, indicating that the 85% fiber content already contributed significantly to the material's strength. Conversely, specimen number 5 exhibited the highest tensile strength in this set, with a value of 115.13 MPa and an elastic modulus of 1749 MPa. This specimen showed remarkable performance, suggesting that the higher fiber content—85% pineapple leaf fiber—contributed substantially to enhancing the material's ability to withstand stress and deformation. The higher modulus value indicates increased stiffness, making this composite particularly suitable for structural applications where both strength and rigidity are crucial. The average tensile strength across all five specimens was calculated to be 105.69 MPa, with an average modulus of elasticity of 1571 MPa. These results reflect the superior mechanical performance of the composite when utilizing 85% pineapple leaf fiber, showcasing a notable increase in both strength and stiffness. This suggests that a higher fiber content leads to a more robust and rigid composite material, making it an attractive option for various engineering applications where durability and resistance to stress are essential. In comparison to the previous composite formulations (60% and 70% fiber), the 85% fiber composition clearly demonstrates an enhanced performance, particularly in terms of tensile strength and modulus of elasticity. This highlights the crucial role of fiber content in determining the material's overall mechanical properties. The findings suggest that further optimization of the fiber-resin ratio could yield even stronger composites, providing valuable data for industries seeking to replace synthetic fibers with sustainable, natural alternatives.

3.2 Comparison of Tensile Strength Based on Volume Faction

To better understand the differences in tensile strength between various fiber volume fractions, a comparison of the average tensile strength values for pineapple leaf fiber composites at different fiber-resin ratios (60% fiber: 40% resin, 70% fiber: 30% resin, and 85% fiber: 15% resin) is presented in Figure 7. This figure visually illustrates the trend in tensile strength as the fiber content increases, allowing for a clear comparison of the material's mechanical performance across these three different compositions. As seen in the figure, the tensile strength of the composites significantly improves with higher fiber content. The 60% fiber: 40% resin mixture serves as the baseline, showing moderate tensile strength. As the fiber volume fraction increases to 70%, the composite demonstrates a notable improvement in tensile strength, reflecting the enhanced role of pineapple leaf fibers in reinforcing the resin matrix. The highest tensile strength is observed in the 85% fiber: 15% resin composite, where the material achieves its peak performance, exhibiting the most robust ability to resist tensile stress. This increase in strength corresponds with a higher modulus of elasticity, suggesting that the material not only becomes stronger but also stiffer as the fiber content rises. **Figure 4** clearly highlights the direct relationship between fiber volume fraction and tensile strength, underscoring the importance of fiber content in enhancing the mechanical properties of composite materials. By comparing the average tensile strength values for each composition, it becomes evident that higher fiber content leads to more favorable outcomes in terms of both strength and stiffness, which are key parameters in material selection for engineering applications. This comparison provides valuable insights for optimizing the fiber-resin ratio to achieve the desired balance of performance characteristics in natural fiber composites.

The average tensile strength values for the three variations of pineapple leaf fiber volume fractions (60% fiber : 40% resin, 70% fiber : 30% resin, and 85% fiber : 15% resin) show a clear trend of increasing strength with higher fiber content. The composite with 60% pineapple leaf fiber and 40% resin exhibited an average tensile strength of 74.30 MPa. When the fiber content increased to 70%, with 70% pineapple leaf fiber and 30% resin, the tensile strength rose to 89.65 MPa. The highest tensile strength was observed in the composite with 85% pineapple leaf fiber and 15% resin, which reached an impressive 105.69 MPa. This data highlights the significant influence of fiber volume fraction on the mechanical strength of the composite material, with higher fiber content leading to stronger composites.

In terms of elongation, the composites also demonstrated some variation across the different fiber-resin ratios. The composite with 60% pineapple leaf fiber and 40% resin had an average elongation value of 6.04%. The elongation slightly increased for the composite with 70% fiber and 30% resin, which had a value of 6.08%. The highest elongation was observed in the composite with 85% pineapple leaf fiber and 15% resin, where the average elongation reached 6.74%. This increase in elongation indicates that the higher fiber content contributes not only to increased strength but also to greater flexibility, which may enhance the composite's ability to absorb stress without failure. The average modulus of elasticity, which indicates the stiffness of the material, also improved with higher fiber content. For the composite with 60% pineapple leaf fiber and 40% resin, the average modulus of elasticity was 1231 MPa. As the fiber content increased to 70%, the modulus increased to 1479 MPa. The highest modulus of elasticity was recorded for the composite with 85% pineapple leaf fiber and 15% resin, which had an average modulus value of 1571 MPa. This trend further supports the notion that higher fiber content enhances the composite's rigidity, making it more suitable for structural applications where stiffness is essential.

To analyze the statistical significance of these results, normality tests were first conducted to determine the appropriate statistical methods. If the normality test results indicated a significance value (p-value) greater than 0.05, the data was considered normally distributed, and an ANOVA (Analysis of Variance) was applied. If the p-value was less than 0.05, indicating non-normal distribution, the Kruskal-Wallis method was used instead. The results of the normality test for the pineapple leaf fiber composites showed that the data followed a normal distribution, and therefore, ANOVA was employed for further analysis. Homogeneity tests were also conducted to check if the variances across the groups were equal. The homogeneity test ensures that the assumption of equal variances is met before applying ANOVA. The results indicated that the data did not meet the homogeneity assumption, with a significance value of less than 0.05, suggesting that the variances were not equal. As a result, the ANOVA test was conducted on the tensile testing data for the pineapple leaf fiber composites. ANOVA compares the variance within the groups with the variance between the groups. If the variance between groups is significantly larger, it suggests that there is a significant difference between the group means. The results of the ANOVA test for the pineapple leaf fiber composites showed that the p-value was less than 0.05, indicating a significant difference between the groups based on the tensile strength data.

Post-hoc tests were then conducted to further explore the significant differences between the groups. The post-hoc tests revealed that there was no significant difference between the 60% fiber : 40% resin and 70% fiber : 30% resin composites, as the significance value was 0.054, which is above the 0.05 threshold. However, there was a significant difference between the 60% fiber : 40% resin and 85% fiber : 15% resin composites, with a p-value of 0.008, which is below 0.05. This indicates that the 85% fiber composite has significantly higher tensile strength compared to the 60% fiber composite. Additionally, there were no significant differences between the 70% fiber : 30% resin and 85% fiber : 15% resin composites, as their significance values were above 0.05. This suggests that the difference in tensile strength between these two groups is not significant, and the two compositions may perform similarly in terms of mechanical properties. These statistical findings provide a deeper understanding of how the fiber-resin ratio affects the performance of pineapple leaf fiber composites, confirming that higher fiber content generally leads to stronger and stiffer materials. However, the comparison also suggests that there are diminishing returns beyond a certain fiber content, as evidenced by the lack of significant differences between the 70% fiber : 30% resin and 85% fiber : 15% resin composites. This information is valuable for optimizing composite formulations in various applications.

4. CONCLUSION

The composites reinforced with pineapple leaf fibers were tested with different fiber volume fraction variations, namely 60% fiber : 40% resin, 70% fiber : 30% resin, and 85% fiber : 15% resin. Among these variations, the composite with 85% pineapple leaf fiber and 15% resin demonstrated the highest tensile strength, with an average value of 105.69 MPa. Additionally, it showed an elasticity modulus of 1571 MPa and an elongation of 6.74%, indicating the material's ability to resist deformation before failure. In contrast, the composite with 60% pineapple leaf fiber and 40% resin exhibited the lowest tensile strength, with an average value of 74.30 MPa, an elasticity modulus of 1231 MPa, and an elongation of 6.04%. These results clearly indicate that as the percentage of fiber increases, the tensile strength of the composite also increases. This suggests that pineapple leaf fibers play a significant role in enhancing the mechanical strength of the composite as the fiber content rises. However, while there is a clear increase in tensile strength with the increase in fiber volume fraction, it is important to note that a higher fiber content does not always yield a proportionate improvement in the composite's strength. The results show that while the tensile strength of the composite improves with more fiber, very high fiber content does not necessarily result in a better overall composite strength. Other factors, such as the matrix material, also play a crucial role in determining the composite’s strength. In this case, the resin acts as the binding agent, holding the fibers together and distributing the applied load. Without a proper and strong matrix to support the fibers, the composite's strength may decrease, even with a high fiber fraction. Therefore, although higher fiber fractions tend to improve tensile strength, the selection and proportion of the resin are critical in ensuring optimal material performance. Overall, this study emphasizes the importance of the balance between fiber and matrix in forming strong and effective composites. While pineapple leaf fibers significantly contribute to enhancing tensile strength, the role of the resin as the matrix is also crucial in determining the material's overall performance. Further research into the influence of different resin types and their ratios on the mechanical properties of the composite is essential for optimizing their use in various industrial applications.

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