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Effect of Liquid Smoke Treatment on Banana Stem Fibers as Composite Reinforcement

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Abstract

This study aims to identify the potential utilization of banana stem fiber (BSF) as a locally sourced composite material to support building infrastructure in North Maluku. The research focuses on analyzing the tensile and impact properties of the composite. An experimental method was used, incorporating different treatment durations for the fibers by immersing them in liquid smoke for 1, 2, and 3 hours. The treated fibers were then heated at 40°C for 30 minutes. The next step involved fabricating BSF-reinforced composite specimens by preparing the resin and fibers, with a fiber length of 10 mm and a composition of 30% BSF and 70% resin. Tensile and impact tests were conducted to evaluate the mechanical properties of the composites. The results showed that the tensile strength of the P3J composite increased to 88.351 MPa, representing a 3.79% improvement compared to the untreated composite (TP). Meanwhile, the impact strength showed the highest increase after 1 hour of immersion, reaching 10.911 KJ/m, which is 25.45% higher than TP. These findings indicate that liquid smoke treatment enhances the tensile and impact properties of the composite.

Keyword: Banana stem fiber, Liquid smoke, Mechanical properties, Composite

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1. Introduction

Natural fiber-based composites, particularly those utilizing banana stem fibers, have gained significant attention in the materials industry due to their environmentally friendly properties and broad application potential. The use of natural fibers as composite reinforcements not only reduces dependence on expensive and hazardous synthetic materials but also offers advantages in sustainability and waste reduction. Banana stem fiber (BSF), an agricultural byproduct, exhibits characteristics that make it a promising option for lightweight composite applications requiring high mechanical strength. Studies indicate that BSF possesses higher tensile strength compared to other

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natural fibers such as coir and sisal, making it an ideal material for various industrial applications [1] [2].

However, a major challenge associated with BSF is its susceptibility to moisture absorption and mechanical degradation, which can significantly impact composite performance [3] [4]. One effective method to improve the quality of natural fibers is liquid smoke treatment or pyrolysis. This process can reduce moisture content, enhance resistance to microbial degradation, and improve the mechanical properties of the fibers [5] [6]. Liquid smoke, derived from the partial combustion of biomass, contains compounds that bond with and strengthen natural fibers, providing better durability against degradation and increasing their tensile strength [7] [8].

Research has shown that this treatment not only enhances moisture resistance but also improves the mechanical properties of BSF-reinforced composites [9] [10]. Consequently, with appropriate treatment, BSF can achieve optimal properties as a reinforcement in composites, making it a more suitable choice for applications requiring high strength and durability [11] [12].

Overall, the development of BSF-based composites presents significant potential for creating more sustainable and eco-friendly materials. Addressing challenges related to moisture absorption and degradation through treatments such as liquid smoke can optimize BSF for various industrial applications, including building materials, textiles, and automotive composites [13] [14]. These findings demonstrate that BSF is not merely an agricultural waste product but also a valuable resource for advancing composite material technology.

BSF holds significant potential for composite applications due to its superior mechanical properties. It is known for its high tensile strength and flexibility, making it ideal for lightweight yet strong composite materials [15]. Additionally, BSF is an abundant, cost-effective, and renewable agricultural byproduct, supporting the development of environmentally friendly materials [16]. Despite its high mechanical strength, BSF is prone to degradation when exposed to high humidity, which can reduce its performance [17]. The use of BSF in composites aims to reduce dependence on synthetic materials such as glass and carbon fibers, which require high energy for production and generate hazardous waste [18].

Studies indicate that BSF can be used as a reinforcement in composites for automotive, construction, and textile applications, where its biodegradability offers an additional advantage [15]. However, the primary challenge is its susceptibility to moisture, which can compromise material integrity, highlighting the need for treatments to enhance its mechanical properties and durability [19]. One promising method to improve BSF's resistance is liquid smoke treatment. Liquid smoke, produced from biomass pyrolysis, contains phenolic compounds and organic acids that can strengthen fibers and enhance their resistance to moisture and microbial degradation [20]. Research has demonstrated that liquid smoke treatment enhances the mechanical properties of fibers, thereby extending the lifespan of the resulting composite materials [21] [22].

Thus, applying liquid smoke treatment to BSF can be an effective solution for improving the performance of these natural fiber-based composites [23]. The growing interest in natural fiber composites, including BSF, is driven by their sustainability and environmental benefits. Natural fibers such as BSF, hemp, and jute are increasingly used as alternative reinforcements in polymer matrices, replacing synthetic fibers that pose environmental hazards [24]. However, natural fibers face challenges related to moisture absorption and biological degradation, which can affect the quality and durability of composites. Therefore, treatments such as liquid smoke application and other processing methods are essential to enhance the performance of natural fiber composites in industrial applications, particularly in extreme environmental conditions.

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2. Materials and Method

The materials used in this study included banana stem fibers (BSF) obtained from agricultural waste in Ternate City, Yukalac 157 polyester resin, Mepoxe catalyst, and distilled water purchased from a chemical store in Ternate City. The research was conducted using an experimental method. The following figure illustrates the process:

Figure 1. Banana stem fibers: (a) BSF shredding process, (b) BSF drying and (c) purified BSF

The fiber extraction process involved cleaning the banana stem fibers thoroughly with clean water to remove impurities, followed by drying until completely dry. The dried fibers were then cut into 10 mm lengths. The fiber treatment process consisted of two methods: immersion in grade-three liquid smoke for varying durations (1, 2, and 3 hours) and an untreated control group. After immersion, the fibers were dried in a Memmert UN 55 oven (53L capacity) at 40°C for 30 minutes, as shown in the following table:

Table 1. Treatment Notation for Banana Stem Fibers

No	Sample	Code	Treatment
1	Untreated	TP	-
2	1-Hour Treatment	P1J	Liquid Smoke
3	2-Hour Treatment	P2J	Liquid Smoke
4	3-Hour Treatment	P3J	Liquid Smoke

Following the treatment process, the banana stem fibers were used as reinforcement in composite fabrication, with a composition of 30% fiber and 70% resin. The resulting composites were then subjected to tensile and impact testing.

3. Results And Discussion

3.1 Effect of Treatment Variation on Composite Tensile Strength

Tensile test results indicate that the untreated composite had an average tensile strength of 85.121 MPa. After 1 hour of treatment, the tensile strength slightly increased to 85.262 MPa, whereas after 2 hours, it decreased to 84.173 MPa. However, a significant increase was observed in the 3-hour treatment, with tensile strength reaching 88.351 MPa. The data trends are illustrated in the following figure 2.

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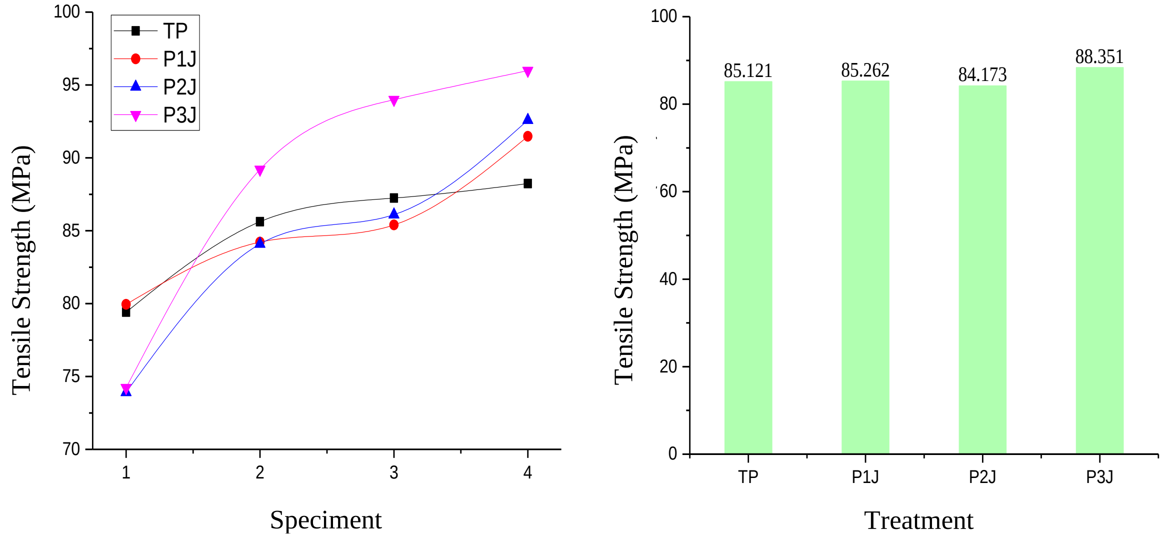

Figure 2. Effect of Treatment Variation on Composite Tensile Strength

The Figure 2 shows that banana stem fiber-reinforced composites subjected to different treatments exhibited significant variations in tensile strength depending on treatment duration. The untreated composite had a baseline tensile strength of 85.121 MPa, reflecting the natural properties of untreated fibers [24]. A slight increase of 0.17% after 1 hour of treatment suggests initial penetration of liquid smoke into the fiber structure, though this duration was insufficient for substantial modification [25]. Previous studies indicate that liquid smoke treatment can enhance fiber mechanical properties, but treatment duration and concentration must be optimized for maximum benefits [26]. After 2 hours of treatment, a tensile strength decrease of -1.11% was observed, possibly due to structural modifications such as over-treatment or fiber degradation caused by prolonged exposure [27]. This finding aligns with studies showing that excessive alkali treatment can reduce fiber tensile strength if not carefully controlled [28]. Conversely, the 3-hour treatment led to a notable 3.79% increase, indicating an optimal duration for enhancing fiber-matrix adhesion in composites [29].

This improvement may be attributed to the reaction between liquid smoke compounds and fiber components like lignin and hemicellulose, leading to amorphous layer modification and increased fiber crystallinity [26]. The findings support literature reports stating that liquid smoke treatment can enhance tensile strength when process parameters are optimized [30]. Additionally, this treatment contributes to better stress transfer between the fiber and matrix, a crucial factor in improving overall mechanical performance [31]. The increased adhesion may also result from surface cleaning, where active compounds in liquid smoke remove contaminants, enhance fiber roughness, and create active sites that promote hydrogen or covalent bonding with the polymer matrix [32]. Overall, these results highlight that appropriate treatment of banana stem fibers significantly influences composite tensile strength, with an optimal treatment duration contributing to enhanced mechanical properties.

3.2 Effect of Treatment Variation on Composite Yield Strength

Tensile test results show that the untreated composite had an average yield strength of 79.66 MPa. A slight increase to 79.93 MPa was observed after 1 hour of treatment, while the 2-hour and

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3-hour treatments resulted in decreases to 75.99 MPa and 78.80 MPa, respectively. The data trends are illustrated in the following figure 3

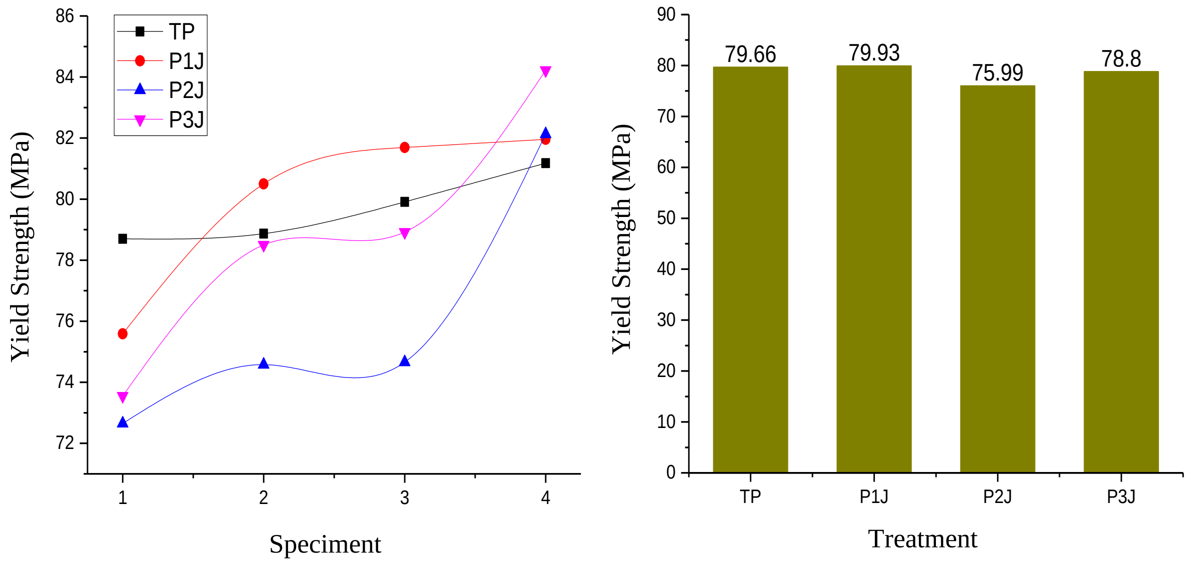

Figure 3. Effect of Treatment Variation on Composite Yield Strength

Banana stem fiber-reinforced composites treated with liquid smoke for 1 hour exhibited a significant improvement in yield strength, reaching 79.93 MPa, compared to 79.66 MPa in the untreated composite. This enhancement may be attributed to better fiber-matrix interaction due to surface modification induced by the chemical treatment. Studies suggest that chemical treatments improve fiber-matrix bonding, thereby increasing tensile strength [42] [43] [44]. However, prolonged treatments of 2 and 3 hours resulted in reduced yield strength, with values of 75.99 MPa and 78.80 MPa, respectively. The decline could be attributed to fiber degradation, leading to structural damage and reduced tensile properties. Previous research indicates that excessive treatment durations can make fibers brittle, negatively affecting composite mechanical properties [45] [46] [47]. This finding aligns with studies emphasizing the importance of optimizing treatment duration to maintain natural fiber composite strength [41] [48].

The yield strength data indicate that 1-hour treatment produced the highest tensile strength, while the 2-hour treatment resulted in the lowest values. This suggests that liquid smoke treatment duration directly impacts composite tensile strength, with 1 hour being the optimal duration for the best results. Prior research also supports the conclusion that appropriate treatment duration enhances composite mechanical properties [49][50][47]. The presented graph confirms that liquid smoke treatment can enhance yield strength in banana stem fiber composites, but excessive treatment leads to deterioration. Therefore, a 1-hour treatment is recommended for applications requiring high yield strength, while further research should investigate long-term effects and additional influencing factors [51][44].

3.3 Effect of Treatment Variation on Composite Elongation

Tensile test results show that the untreated composite had an average elongation of 3.33%. Elongation decreased after 1 and 2 hours of treatment to 2.83% and 3.08%, respectively, whereas the highest elongation of 3.43% was recorded for the 3-hour treatment. The data trends are illustrated in the following figure 4. Banana stem fiber-reinforced composites subjected to liquid

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smoke treatment exhibited increased elongation after 3 hours (3.43%) compared to the untreated composite (3.33%). However, the 1-hour and 2-hour treatments led to reduced elongation values of 2.83% and 3.08%, respectively. The average elongation data suggest that the longest treatment duration resulted in the greatest elongation, while the shortest duration yielded the lowest value. The graph confirms that liquid smoke treatment influences fiber-reinforced composite elongation.

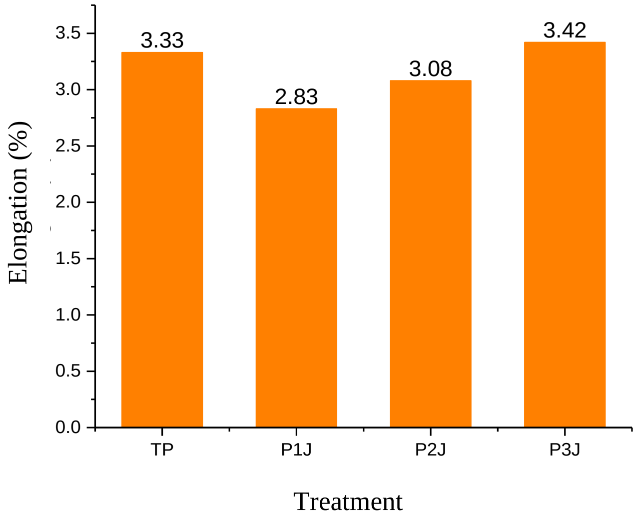

Figure 4. Effect of Treatment Variation on Composite Elongation

3.4 Effect of Treatment Variation on Composite Impact Strength

Impact test results indicate that the untreated composite had an average impact strength of 8.697 KJ/m. A significant increase was observed after 1 hour of treatment, reaching 10.911 KJ/m, followed by a decline to 8.215 KJ/m after 2 hours and a further decrease to 7.683 KJ/m after 3 hours. The data trends are illustrated in the following graph:

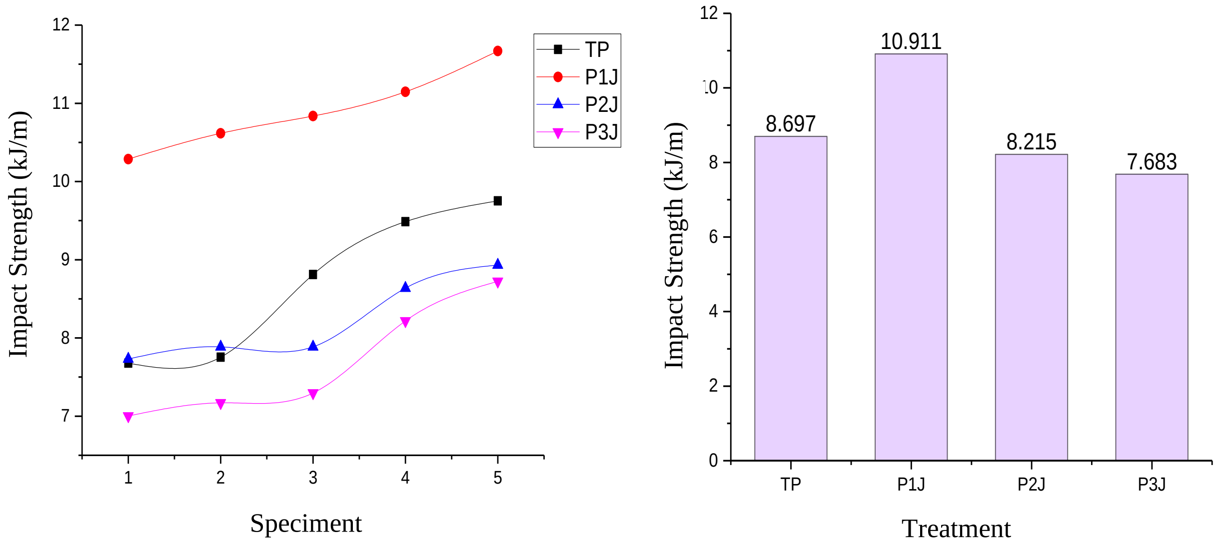

Figure 5. Effect of Treatment Variation on Composite Impact Strength

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The impact strength of banana stem fiber-reinforced composites was significantly influenced by liquid smoke treatment. Previous studies suggest that chemical treatments, including liquid smoke immersion, can enhance the mechanical properties of natural fibers, including banana fibers [33] [34]. In this study, the untreated composite (TP) had an average impact strength of 8.697 KJ/m, serving as a baseline for comparison. The 1-hour treatment (P1J) resulted in a substantial increase to 10.911 KJ/m, demonstrating the effectiveness of liquid smoke in enhancing composite mechanical properties [5] [35]. However, the 2-hour (P2J) and 3-hour (P3J) treatments caused a decline in impact strength to 8.215 KJ/m and 7.683 KJ/m, respectively. This suggests that prolonged immersion negatively affects material structure, possibly due to fiber degradation or altered adhesion between the fiber and matrix [7] [36]. These findings align with research by [37], indicating that excessive treatment may damage fiber structure and weaken mechanical properties.

Data analysis reveals some variability in test results, potentially due to inconsistencies in composite fabrication or specific testing conditions [34] [38]. Nonetheless, the overall trend confirms that 1-hour treatment is optimal for enhancing impact strength. This treatment increased impact strength by 25.45% compared to the untreated composite, whereas 2-hour treatment resulted in a 5.48% reduction. These results support the hypothesis that liquid smoke treatment improves impact strength in banana stem fiber-reinforced composites when applied for an optimal duration. This aligns with studies reporting that liquid smoke treatment enhances natural fiber mechanical properties [34]. However, further analysis is needed to understand the mechanisms behind impact strength reduction in longer treatments and to determine an ideal immersion duration to prevent fiber degradation [36] [40].

4. Conclusion

This study demonstrates that liquid smoke treatment significantly influences the mechanical properties of banana stem fiber-reinforced composites. The tensile strength of the composite increased with the P3J treatment, reaching 88.351 MPa, which is 3.79% higher than the untreated composite (TP). Additionally, impact strength testing showed a substantial improvement after 1 hour of immersion, reaching 10.911 KJ/m—an increase of 25.45% compared to TP. These findings indicate that liquid smoke treatment effectively enhances both the tensile and impact properties of the composite. Optimizing treatment duration is crucial to achieving the best mechanical performance, as excessive exposure may lead to fiber degradation. Therefore, liquid smoke treatment presents a promising method for improving the mechanical characteristics of natural fiber composites, making them more suitable for structural and industrial applications.

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