



Analysis of Immersion Time Variation on the Toughness and Macrostructure of Sansevieria Fiber Composites Using the Taguchi Method

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Article Info	Abstract
Keywords: Sansevieria Fiber; NaCl Solution; Toughness; Microstructure; Taguchi Method Received: 31 May 2025 Accepted: 29 September 2025 Published: 20 October 2025	Sansevieria fibers show potential as composite reinforcing materials due to their mechanical properties but require treatment to enhance compatibility with polymer matrices. This study investigated the effects of immersing Sansevieria fibers in NaCl solution for 5, 7, and 9 days. The fibers were dried and processed into composites with an epoxy resin matrix using the continuous lay-up method. Toughness testing was conducted via the Charpy impact test according to ASTM E23-56T, and macrostructure analysis was performed with an optical microscope. The results were analyzed using the Taguchi method, focusing on the Signal-to-Noise Ratio (S/N Ratio) to identify the optimal immersion time for toughness. Analysis of Variance (ANOVA) assessed the significance of immersion time on the mechanical properties. Results showed that longer immersion times improved composite toughness, with the 9-day immersion yielding the highest value of 0.0074 J/mm ² , compared to 0.0036 J/mm ² for 5 days and 0.0046 J/mm ² for 7 days. Macrostructure analysis indicated that increased immersion enhanced the bond between fibers and the matrix, reducing fiber pulling. This study confirms that soaking Sansevieria fibers in NaCl can improve the robustness and quality of natural fiber composites, providing insights for lightweight, high-performance structural applications.

1. Introduction

Analysis of the variation in immersion time on the toughness and macrostructure of Sansevieria fiber composites using the Taguchi method can provide in-depth insights into the optimization of fiber-based composite materials. Sansevieria, which is known for its good mechanical strength, is increasingly in demand in the field of materials engineering and engineering applications. This study evaluates how immersion duration affects toughness and microstructure of Sansevieria fiber composites. The immersion time plays an important role in the process of processing and characterizing composite materials. In a study by [1], it shows that the effect of soaking time on the quality of the gelatin of *Gracilaria verrucosa* suggests that variations in soaking time can affect the physical properties of the resulting product, such as gel strength and viscosity. The results of this study are in line with findings that suggest that soaking timing can improve material quality, which is also relevant for Sansevieria fiber composites. By utilizing optimization techniques such as the Taguchi method, researchers can identify the optimal soaking duration to improve the mechanical properties

of the composite, as described in gelatin optimization studies involving variations in soaking and extraction times [2].

Furthermore, other studies such as those conducted by Ambarwati et al, show a significant influence of time variation on gelatin extraction results, where optimal soaking time greatly affects the yield and physical characteristics of gelatin [2]. This discovery can be applied in the context of composites, where the proper immersion process will contribute to the improvement of the breaker stress and toughness of *Sansevieria* fiber-based composites. To support this statement, a more specific reference regarding the effect of immersion time on the toughness of *Sansevieria* composites should be added. In terms of the application of the Taguchi method, this technique has been proven to be effective in evaluating and optimizing parameters. For example, in studies dealing with soaking time variations and gelatin characteristics, the measured parameters showed significant variation depending on the soaking method chosen [3]. This approach can be applied to evaluate how different immersion times affect the microstructure and toughness of *Sansevieria* composites, providing direction for better material development.

Macrostructure is also crucial for determining the mechanical properties of composite materials. Research on the effect of soaking time variations on leaf fibers shows that different soaking times can alter the flexural strength of composites [4]. These findings suggest that changes in microstructure due to variations in immersion time can have direct implications for the mechanical performance of composites. Utilizing the Taguchi method, the analysis performed not only uncovered the relationship between immersion time and material toughness but also presented a systematic way to determine the best parameters that could be applied in the processing of *Sansevieria* fiber composites.

The utilization of Taguchi's analysis method in observing composite toughness is very relevant to optimize various parameters that affect the mechanical properties of composite materials. This method offers a systematic approach to designing experiments with a smaller number of experiments, thereby reducing the time and cost required for the research, without sacrificing the accuracy of the results [5]. In the context of composites, variations in parameters such as fiber type, processing procedure, and material composition can be explored to improve the toughness and other characteristics of the material. The application of the Taguchi method in the optimization of mechanical properties, including toughness, can be seen in various studies. For example, research by Kiran et al. showed that the use of the Taguchi experimental design to study the influence of process parameters on the mechanical properties of green composites showed a significant effect on the malleability strength of materials [6]. The results show that proper setting of optimized parameters can improve the toughness performance of composites.

The study by Alabi et al., [7] highlighted how the Taguchi approach can be used to increase the cracking inhibition potential of heated coconut fibers in a phenolic resin matrix. Using Taguchi analysis, this study found the optimal combination of factors influencing the toughness of such composites, which provides important insights for more durable and robust composite applications. This is in line with the findings of Jebran et al, who used the Taguchi method to evaluate the tribological performance of polytetrafluoroethylene composites, suggesting that modification of processing parameters can result in increased toughness and abrasion resistance [8]. Further analysis was also carried out by Stojanović et al., [9]. who optimized the tribological behavior of aluminum composites using the Taguchi method which included variance analysis to understand how various parameters such as shear speed and load affect the toughness of the material. The researchers note that the optimization of these parameters through Taguchi analysis provides valuable knowledge for the development of high-performance composites.

It is also important to note that in some studies, the use of a combination of Taguchi analysis with gray relational analysis showed better results in optimizing a variety of responses, including robustness [10]. The

utilization of the Taguchi analysis method in composite toughness studies not only facilitates parameter optimization but also provides a sustainable approach to the research and development of new materials with improved mechanical properties. In general, the use of the Taguchi method in the study of composite toughness leads to a better understanding of the interactions between parameters that affect mechanical performance, as well as allowing the identification of the best process arrangements that can be applied in the manufacture of more sophisticated and efficient composite materials [11, 12].

This study aims to identify the soaking conditions that produce composite materials with optimal toughness, better durability, and high macro structural homogeneity using the Taguchi method, so that it can be used as a reference in the development of natural fiber-based composite materials.

2. Research Methodology

2.1. Method

The flowchart illustrates a systematic approach to producing Sansevieria fiber-reinforced epoxy composites, emphasizing each phase's role in enhancing material performance. The process begins with the extraction of Sansevieria fibers, followed by immersion in sodium chloride (NaCl) solution for 5, 7, or 9 days. This treatment aims to improve the fibers' chemical and physical properties, facilitating better adhesion with the resin matrix. Post-immersion, the fibers are dried to achieve optimal moisture content before being combined with epoxy resin and hardener using the hand lay-up technique. The composite is then cured to solidify the matrix, resulting in a structurally robust material. After fabrication, the composites undergo testing and analysis to evaluate their mechanical properties and structural homogeneity.

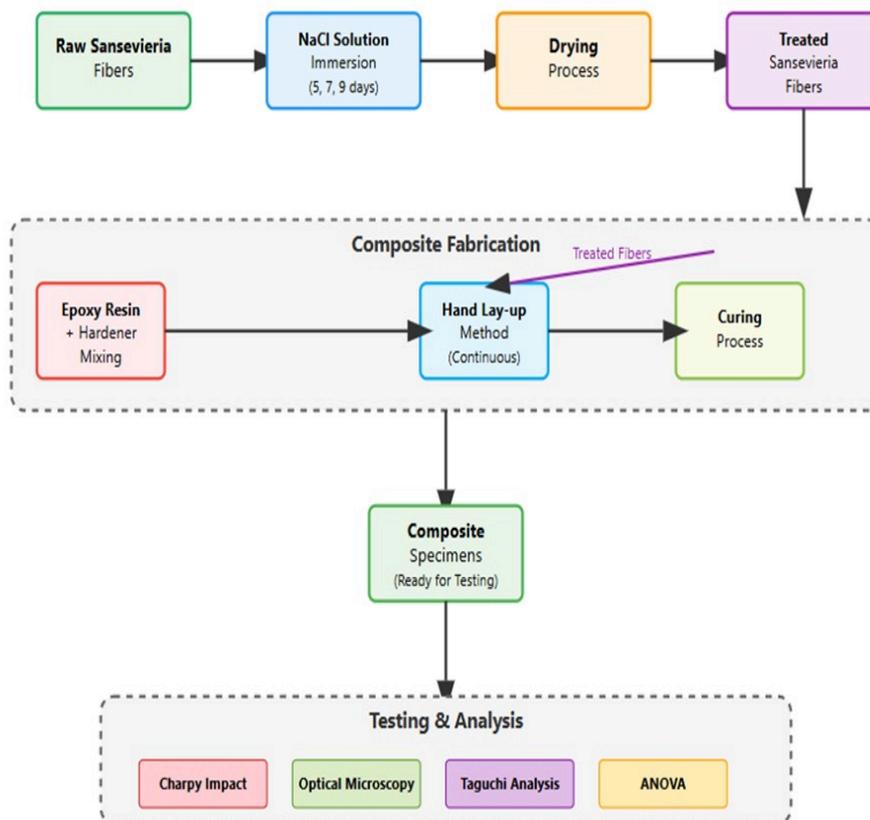


FIGURE 1. Sansevieria fiber composite processing methodology

This method ensures uniform distribution of the fibers within the resin matrix. The composite is then cured to solidify the matrix, resulting in a structurally robust material. After fabrication, the composites undergo

various testing and analysis to assess their mechanical and structural properties. The Charpy impact test measures the material's toughness, while optical microscopy examines the quality of fiber-matrix interactions. Additionally, Taguchi analysis is employed to optimize processing parameters, enhancing the understanding of how variations impact composite performance. Analysis of Variance (ANOVA) is utilized to evaluate the significance of treatment effects on the composite's properties. This comprehensive methodology provides a framework for producing high-performance *Sansevieria* fiber composites with tailored properties for specific applications.

2. 2. Materials and Tools

The main ingredient in this study is *Sansevieria* fiber obtained from the *Sansevieria trifasciata* plant. The matrix resin used is epoxy or polyester.



FIGURE 2. Fiber *Sansevieria*

The fiber used in this study is natural fiber from the *Sansevieria trifasciata* plant, which is known to have superior mechanical characteristics. *Sansevieria* fiber belongs to the category of lignocellulose fiber, which is composed of three main components, namely cellulose, hemicellulose, and lignin. The high cellulose content (~50–75%) provides good tensile strength properties, while lignin (~10–15%) plays a role in improving resistance to biological and thermal degradation. Morphologically, *Sansevieria* fibers have a long, flattened, and yellowish-white structure after being extracted from leaves. In this study, *Sansevieria* fibers underwent soaking treatment with time variations to improve their compatibility with the resin matrix. This treatment aims to remove amorphous components such as hemicellulose and other impurities that can interfere with the interaction between fibers and resins. This research not only aims to improve the toughness of composites but also to understand changes in the macrostructure of fibers after certain treatments.

In this study, epoxy resin and hardener were used as polymer matrices in *Sansevieria* fiber composites to form a homogeneous material structure that has optimal mechanical characteristics. Epoxy resins serve as a continuous phase that binds the fibers, distributes stress evenly, and improves structural cohesion and integration in composites. The hardener acts as a hardening agent that initiates and controls the resin polymerization process through a cross-bond formation reaction mechanism (cross-linking reaction), so that materials with superior mechanical properties are produced. Epoxy resin is a thermoset polymer that has a reactive epoxide (-C-O-C-) group, which when combined with hardener will undergo exothermic chemical reactions forming a strong and stable three-dimensional polymer network. The hardeners used in this study

can be aliphatic amines, aromatic amines, or acid anhydrides, depending on the specific needs in the composite fabrication process. The curing reaction that occurs between epoxy and hardener results in a polymer structure that is rigid, resistant to deformation, and has good chemical and thermal resistance. In *Sansevieria* fiber composites, the presence of an epoxy matrix plays an important role in improving the compatibility of the interface between the fibers and the resin, reducing the likelihood of delamination, as well as improving the transfer of load from the matrix to the fiber as the main reinforcer. The well-controlled curing process also ensures that epoxy has high adhesion to the fibers, thus optimizing the tensile strength, impact toughness, and resistance to environmental degradation of the resulting composite.



FIGURE 3. Resin and Hardener



FIGURE 4. NaCl Solution

In this study, a solution of sodium chloride (NaCl) was used as a soaking medium of *Sansevieria* fibers to modify the physical and chemical characteristics of the fibers prior to the composite fabrication process. The soaking process in NaCl solution aims to improve the adhesion between the fibers and the epoxy matrix, as well as optimize the mechanical properties of the resulting composite. Scientifically, soaking fibers in NaCl solutions can cause ionic diffusion into the fiber structure, potentially altering its morphological properties and chemical composition. The Na^+ and Cl^- ions contained in these solutions can interact with the hydroxyl (-OH) group in cellulose, thus contributing to the reduction of hemicellulose and lignin, two amorphous components in fibers that can weaken their mechanical properties. With the reduced content of lignin and hemicellulose, the fiber structure becomes more organized and better able to form strong bonds with the polymer matrix. NaCl solution also plays a role in cleaning impurities and non-cellulose substances that adhere to the surface of the fibers. These contaminants, such as wax residues, oils, or inorganic particles, can inhibit the optimal interaction between fibers and resins, so they need to be eliminated to improve interface compatibility within composites. The soaking process can also affect the macrostructure of the fibers, which can be observed

through changes in surface topography, increased porosity, as well as texture modifications that can facilitate resin penetration during the composite mixing process. Soaking treatment using NaCl solution is expected to produce *Sansevieria* fibers that are more homogeneous, clean, and reactive to the epoxy matrix, thereby contributing to the increased toughness, tensile strength, and dimensional stability of the resulting composite.

2. 3. Research Procedure

The research procedure involves the manufacture of a composite specimen based on *Sansevieria trifasciata* for toughness testing using the Charpy impact test method according to the ASTM E23-56T standard, which begins with soaking the fibers in NaCl solutions for 5, 7, and 9 days at room temperature in a closed container to ensure even penetration of the solution, followed by a drying process with direct sunlight to optimal moisture content while controlling temperature and humidity. In order to prevent degradation, the fibers are then arranged in a mold using the continuous lay-up method, given a mixture of epoxy resin and hardener in a certain ratio, molded under pressure so that the resin is perfectly impregnated, and left to cure at room temperature or in an oven according to the characteristics of the resin, then the specimen is cut and finished according to standards to be tested for toughness using an impact test tool with pendulum calibration. Setting the initial angle, and recording of the energy absorbed when the specimen breaks, then the test results are analyzed to assess the effect of soaking time variations on toughness, and macrostructure observations are made using a calibrated microscope, with high-resolution imagery to analyze fault patterns, failure mechanisms, fiber pull-out, and fiber-matrix interactions, which are then compared with impact test data to understand the relationship between fracture morphology and material toughness.

3. Results and Discussion

The Taguchi method was applied in this study to optimize the soaking time parameters to obtain maximum composite toughness. This approach uses an orthogonal array (OA) experimental design that allows simultaneous evaluation of various factors with a more efficient number of experiments than conventional methods. Data analysis was performed by calculating the Signal-to-Noise Ratio (S/N Ratio) to identify the optimal conditions that produced the best response to the variation in immersion time. The S/N Ratio in this study was used to minimize the variability of the results and improve more consistent data replication. Analysis of Variance (ANOVA) statistical analysis was applied to evaluate the significance of the influence of treatment factors on composite toughness, with the aim of determining the factors that have the greatest contribution to improving the mechanical properties of materials with a combination of Taguchi, S/N Ratio, and ANOVA methods.

Based on Table 1 and Figure 5, it can be seen that the treatment of *Sansevieria* tongue fibers with a volume fraction of NaCl is 200 grams/1 liter of water with a total of 600 grams/3 liters of water used which affects the toughness of composite materials as a reinforcing material. In the process of soaking *Sansevieria* fiber with normal treatment and variations of soaking time of 5 Days, 7 Days and 9 Days. Toughness testing from minimum to increased from zero to 9 days of soaking. Without immersion, toughness was 0.0032 J/mm². In 5 days of soaking, the level of resilience is 0.0036 J/mm². At 7 days, the level of toughness is 0.0046 J/mm². And in 9 days of soaking the level of toughness is 0.0074 J/mm². The level of toughness is increased due to variations in the soaking time of the *sansevieria* fibers. Where the soaking broom specimen was 0.0032 J/mm² and the highest level of toughness occurred at a variation of 9 days of soaking time with a toughness level of 0.0074 J/mm².

TABLE 1. Results of the Calculation of Resilience

Interval Immersion time	S	P (mm)	L (mm)	T (mm)	A (mm ²)	W (J)	K (J/mm ²)	K (J/mm ²) Average
5 Days	1	55	10	10	100	9	0.02	0.04
	2	55	10	10	100	9	0.04	
	3	55	10	10	100	11	0.06	
7 Days	1	55	10	10	100	10	0.05	0.0633
	2	55	10	10	100	13	0.06	
	3	55	10	10	100	13	0.08	
9 Days	1	55	10	10	100	25	0.08	0.084
	2	55	10	10	100	29	0.082	
	3	55	10	10	100	16	0.09	

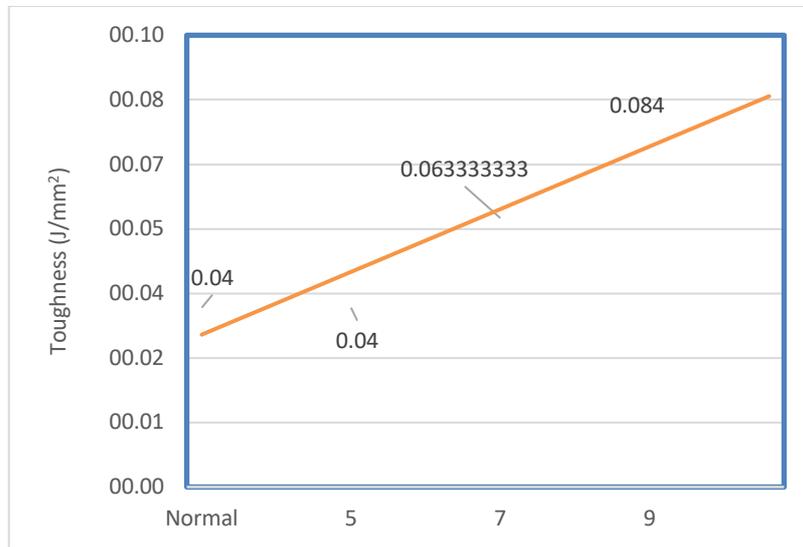


FIGURE 5. Effect of immersion time on toughness

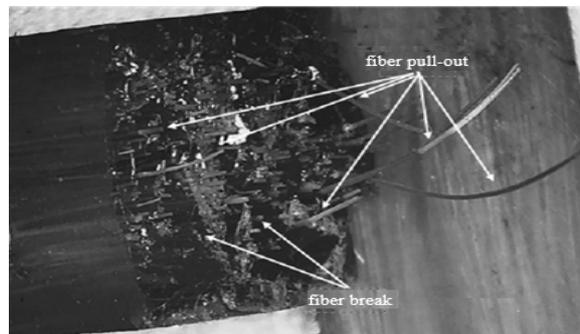


FIGURE 6. Non-immersion macrostructure specimens (NaCl)

Macrostructure testing on the composite material of the tongue fibers was not soaked and with a variation of immersion of 5, 7, and 9 days with soaking using salt water (NaCl).

In Figure 6, of the specimens above, the fracture shape of the fiber composite is shown without (sanaeviera) immersion in the brine solution (NaCl). The fracture begins with a brittle fracture and then a fiber *pull-out* occurs and fiber *Break* on composites. fiber *pull-out* in specimens due to the inability of the matrix to bind fibers due to the force received, while fiber break signifies the bond between the matrix and the strong fibers. In this specimen, fibers pull out and fibers break are formed, so that the toughness of the composite without soaking in brine solution (NaCl) is 0.0032 J/mm².

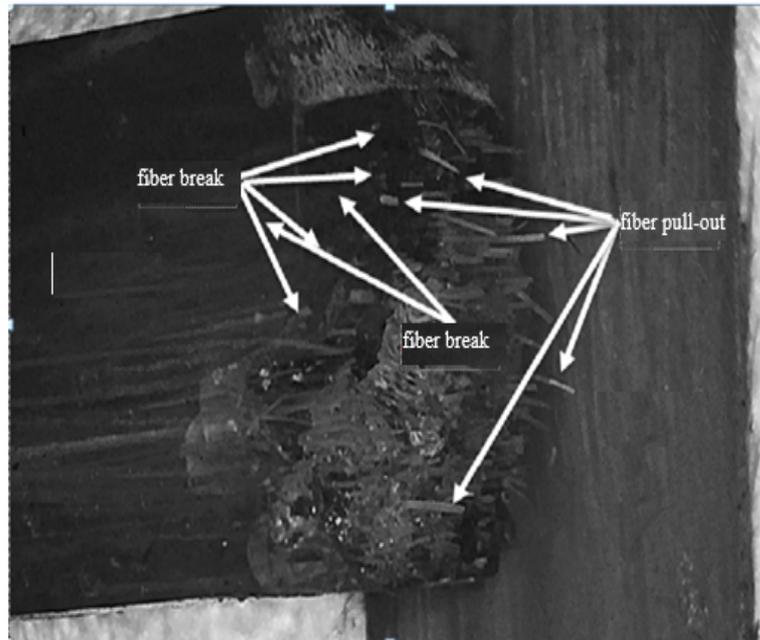


FIGURE 7. Macrostructure Specimens with 5 Days of Soaking.

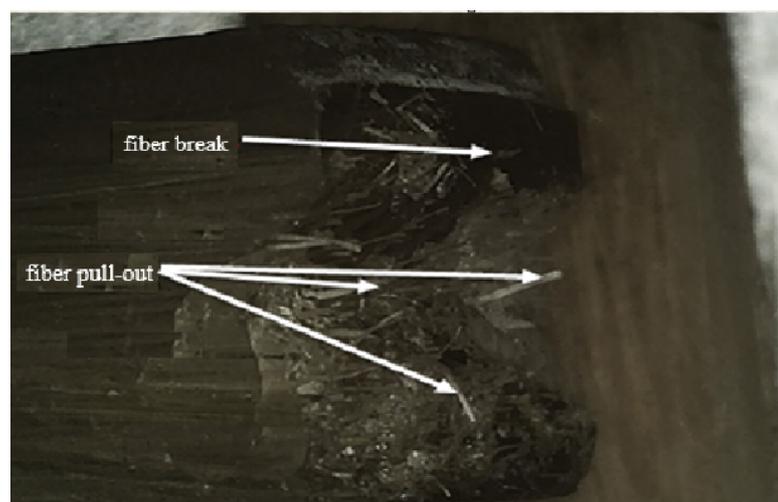


FIGURE 8. Macrostructure Specimens With 7 Days of Soaking

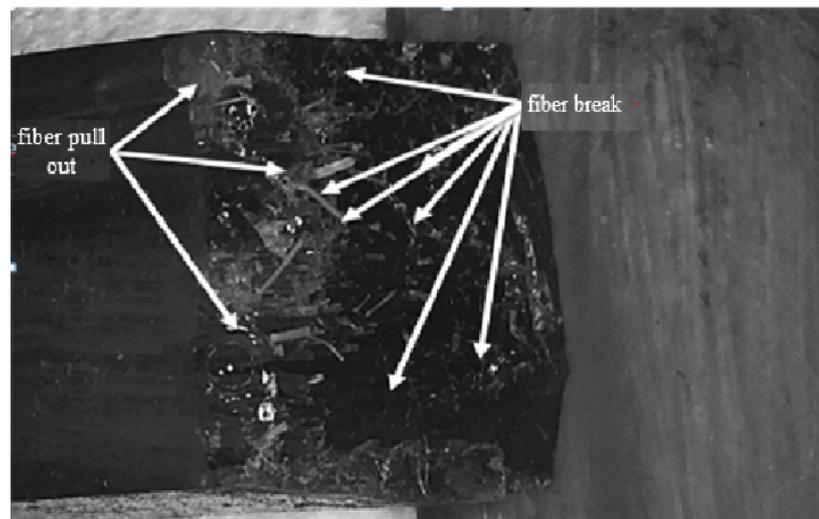


FIGURE 9. Macrostructure specimens with 9 days of immersion

In Figure 7, the fracture form of the fiber composite (*sanaeviera*) with 5 days of immersion in a brine solution (NaCl). Fractures begin with matrix fractures (*crak deflektion*) then there is fiber *Pull Out* and fiber *Break*. Where fiber pull out in specimens occurs due to the inability of the matrix to bind fibers due to the load it receives, causing the fibers to come loose and then break due to the force it receives [13]. In this specimen, a lot of fiber pull out, and a small amount of fiber break can be seen, so that it obtained a toughness value of 0.0036 J/mm^2 .

In Figure 8, the fracture is shown in the fiber composite (*sanaeviera*) with 7 days of immersion in a brine solution (NaCl). Where the fault that occurs begins with a matrix crack (*crack deflection*) then there is a fiber *Pull Out* and *Fiber Break*. In composite fractures, loose fibers are seen resulting from the inability of the matrix to bind fibers due to the load it receives and the fiber breaks. Indicates that the matrix and fiber are bound to each other so that it gets a toughness value of 0.0048 J/mm^2 .

In Figure 9, the fracture shape of the fiber composite (*sanaeviera*) with 9 days of soaking in a brine solution (NaCl). Where the fracture that occurs begins with the fracture of the matrix in the direction of the fiber (*Crack Defelction*) then there is *Pull Out* fiber and *Break* fiber. Where loose fibers are caused by the lack of the ability of the matrix to bind fibers due to the load that causes the fibers to come loose and then break because of the unidirectional force it receives, and the fibers break because the load and matrix bind to each other. So that the toughness of the composite material gets a value of 0.0074 J/mm^2 .

The macrostructure and toughness of *Sansevieria* fiber composites were systematically analyzed across different soaking durations, revealing noteworthy trends in mechanical performance. The untreated specimens, as shown in Figure 6, exhibited a toughness of 0.0032 J/mm^2 . The fracture pattern was characterized by brittle failure and significant fiber pull-out, indicating weak adhesion between the fibers and the matrix. In contrast, specimens soaked for 5 days (Figure 7) demonstrated a slight improvement in toughness to 0.0036 J/mm^2 . However, the presence of fiber pull-out persisted, with minimal fiber breakage observed. This suggests that the soaking duration was insufficient to enhance fiber-matrix bonding effectively. Further analysis of specimens soaked for 7 days (Figure 8) revealed an increase in toughness to 0.0048 J/mm^2 . This group exhibited both fiber pull-out and breakage, indicating enhanced interfacial adhesion. The occurrence of fiber breakage signifies that the matrix began to provide better support to the fibers under stress. Finally, the specimens soaked for 9 days (Figure 9) achieved the highest toughness value of 0.0074 J/mm^2 . The fracture

patterns showed a significant reduction in fiber pull-out and an increase in fiber breakage, demonstrating optimal bonding and load transfer between the fibers and the matrix.

The Taguchi method is used to determine the optimal parameters in the experiment by considering **the Signal-to-Noise Ratio (S/N Ratio)** [14]. In this study, we use the "Larger is Better" approach because we want to maximize the toughness of composites.

The L9 orthogonal array table presented here serves as an important tool in Taguchi's analysis, designed to understand the influence of various factors on the desired outcome. This table consists of nine experiments, each involving three factors, with each factor having three different levels. The structure of this table reflects the repetition of each level of the first, second, and third factors, where the values "1", "2", and "3" represent those different levels. This systematic experimental design ensures that each combination of levels of the factors tested is evaluated equally. This allows researchers to conduct more efficient analysis of the interaction and influence of each factor on the measured outcomes. The advantage of the orthogonal structure of this table is its ability to guarantee that variations in one factor will not affect variations in other factors, thus allowing for more accurate estimates of the effects of each factor [15].

TABLE 2. Orthogonal Array L9

Parameter 1	Parameter 2
1	1
2	1
3	1
1	2
2	2
3	2
1	3
2	3
3	3

TABLE 3. Immersion Time and Toughness Date

specimen	Immersion Time (days)	Toughness (J/mm ²)
1	5	0.020
2	5	0040
3	5	0.060
1	7	0.050
2	7	0.060
3	7	0.080
1	9	0.080
2	9	0.082
3	9	0.090

The data showed that at a 5-day immersion time, the toughness of the specimen varied from 0.020 J/mm² to 0.060 J/mm². When the immersion time increases to 7 days, the toughness of the specimen increases to between 0.050 J/mm² and 0.080 J/mm². Finally, at the 9-day soaking time, the toughness of the specimen showed the highest yield, ranging from 0.080 J/mm² and 0.090 J/mm². This indicates a positive trend where the increase in immersion time contributes to the increase in the toughness of the material. These findings provide a solid basis for further analysis in the context of process optimization using the Taguchi method, to understand the interaction between immersion time and toughness and to determine optimal conditions that can improve material quality.

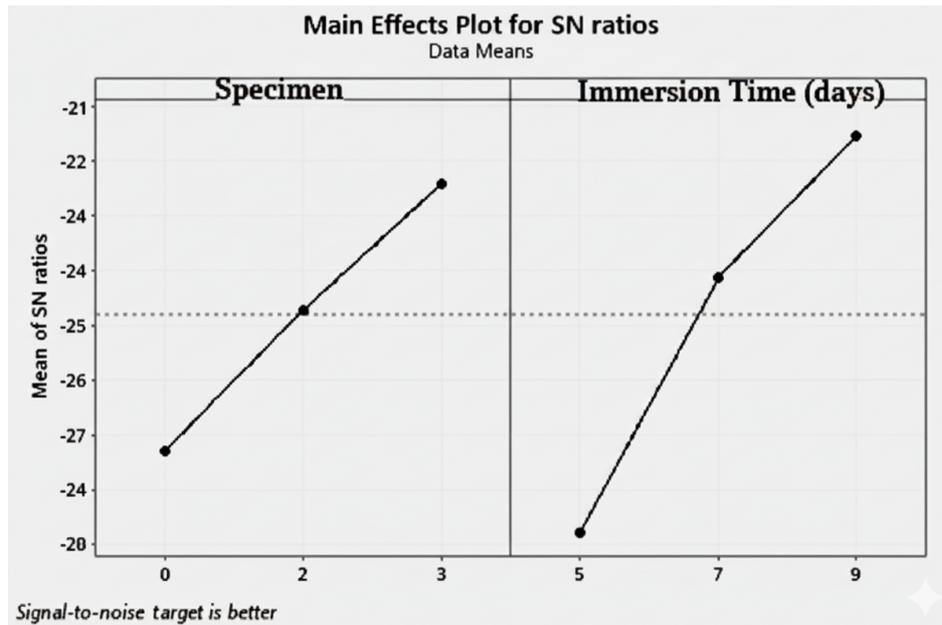


FIGURE 10. Main Effect Plot S/N Ratio at the time of the attack and the toughness

TABLE 4. Results of the calculation of S/N Ratio of the time of the clamp to the toughness
Larger is better

Level	Specimen	Immersion time (Days)
1	-27.31	-28.79
2	-24.71	-24.13
3	-22.43	-21.53
Delta	4.88	7.27
Rank	2	1

From the data presented, it can be seen that the delta value for the specimen is 4.88, while for the immersion time is 7.27. This delta value indicates the range of difference between the highest and lowest levels for each factor, indicating the significant influence of immersion time on resilience outcomes. By (rank), the soaking time ranked first, indicating that the soaking time had a greater influence on the toughness of the material compared to the specimen, which was ranked second.

In Figure 10, this plot shows a significant influence of both factors on the toughness of the material, with the soaking time having a greater impact than the specimen. The delta value for immersion time (7.27) was higher compared to the specimen (4.88), which suggests that the variation in immersion time had more effect on the increase in SNR values.

4. Conclusion

This study highlights the significant impact of immersion duration on the mechanical properties of Sansevieria fiber composites, especially their toughness. Using the Taguchi method, it was determined that immersion for 9 days in sodium chloride solution optimized the fiber-epoxy bond, resulting in increased toughness. These findings underscore the importance of treatment parameters in tailoring the performance of natural fiber composites for specific applications. This study was limited to a specific immersion time and the use of sodium chloride as the immersion medium. Future studies can investigate a wider range of immersion durations, alternative chemical treatments, and different resin matrices to better understand their effects on mechanical properties. Additionally, exploring the long-term durability and environmental resistance of these composites will provide valuable insights into their practical applications. Overall, this study lays the foundation for optimizing natural fiber composites, contributing to advances in sustainable materials engineering.

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Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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