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27 Enhancement of Mechanical and Water Resistance Characteristics of Pineapple Fiber Polymer Composites through Nano SiC Reinforcement

T. Maridurai[1], V. Muthuraman[2]
Department of Mechanical Engineering, Vels Institute of Science,
Technology and Advanced Studies (VISTAS), Chennai, Tamil Nadu, India
P. Gurusamy[3]
Department of Mechanical Engineering,
Chennai Institute of Technology, Chennai, Tamil Nadu, India
S. Thirugnanam[4]
Department of Mechanical Engineering,
SRM Valliammai Engineering College, Chennai, Tamil Nadu, India

ABSTRACT: The research described in this article focuses on combining fiber and nano SiC into epoxy matrices to create advanced composite materials. Our investigation has revealed significant advancements in the mechanical characteristics and water resistance of these composites following a series of exhaustive tests. Tensile testing showed that as the percentage of fiber increased, tensile strength significantly improved. Remarkably, Material 2, which is composed of 40% fiber and 60% epoxy, showed the reinforcing effect of fiber dispersion with a tensile strength of 138 MPa. Materials 3, 4, and 5 were then treated with micro SiC to increase their tensile strength; Material 5 reached a maximum of 156 MPa. Similar trends were shown in impact tests, where Material 2's impact resistance surpassed that of pure epoxy. Effective composite preparation is necessary, as evidenced by the even better impact resistance of later composites with nano SiC added. These results were validated by hardness testing, which showed that materials containing nano SiC and fiber had improved hardness values, suggesting a greater resistance to deformation. The research revealed that altering the composite compositions led to a decrease in water absorption, highlighting the materials' appropriateness for use in environments that are resistant to moisture. SEM examination has validated the uniform dispersion and strong bond between the fibers and nano SiC particles; thus, the quality of the composite production is confirmed by the results obtained. Therefore, the proposed epoxy composite with pineapple fiber and SiC nanoparticles can be used in various industries, such as aerospace, automotive, and construction.

KEYWORDS: Scanning electron microscopy, Mechanical testing, Water absorption, Pineapple fiber, Nano SiC.

1. Introduction

Composite materials have attracted the interest of many Polymer composites are regarded as the most widely used materials in many industries due to their exceptional mechanical properties and wide applications. To improve the properties of composites, scientists have endeavored to develop natural fibers and various reinforcing fillers in

[1]maridurai.mechanical@gmail.com, [2]drvmuthuraman.se@velsuniv.ac.in, [3]guru8393@gmail.com, [4]thirugnanams.mech@valliammai.co.in

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polymer matrices[1], [2]. It was reported that the addition of nanoscale reinforcements made of natural fibers to composites has achieved extraordinary mechanical properties and water resistance of the composite materials. Thus, the purpose of this report is to study the advantages of adding narrow-diameter-silicon carbide to an epoxy matrix for the purposes of reinforcing the mechanical and water properties of pineapple fibers of polymer composites[3], [4].

Natural fibers are the key alternatives for being added of varying applications taking into account their easy availability at moderate expense. Pineapple fibers are particular among natural fibers for justifying significant performance as they are made from the pineapple leaves' waste. It was reported that the fibers have high strength and low density as well as considerable heat stability. Adding pineapple fibers to polymer matrices can increase the tensile strength, impact resistance, and hardness. Nonetheless, natural fibers have different disadvantages as well, including diminished dimensional stability as well as higher water absorption. The fiber-matrix interface may be wrecked due to water incorporation that can subsequently reduce the mechanical properties of the composites. Therefore, the composites should be waterproof to guarantee a natural fiber composite's new spectrum of applications[5], [6].

Thus, nanotechnology is used to solve the above problem and improve the characteristics of a natural fiber composite. For instance, when a nanoscale reinforcement is included in a polymer matrix, such as nano SiC particles, the mechanical properties increase significantly. Owing to the outstanding mechanical properties and high aspect ratio, nano SiC can be used as an effective reinforcement to enhance the stiffness and strength of composite materials [7]. Moreover, SiC nanoparticles can serve as obstacles that make it difficult for moisture to penetrate and improve their water resistance. Recently, the use of so-called nano-reinforcement to increase the parameters of a natural fiber composite gained recognition, and in the research the mechanical properties of the epoxy composites inclusively containing kenaf fiber and nano-sized SiC were studied[8], [9]. The researchers found that the tensile and flexural strengths of the composites were a lot better due to effective load transfer between the fibers and the matrices that was observed. In some research, the mechanical properties of epoxy composites reinforced with the carbide SiC nanoparticles as well as jute fiber were presented. It was found that the inclusion of nano SiC in the tested samples had a positive impact on the impact resistance, flexural, as well as tensile strengths. It was explained by the better transfer of the stresses and the interfacial bonding of the fiber and the matrix.[10], [11].

Based on our study, we found that adding micro SiC to the fabricated natural fiber composites leads to increased mechanical properties and water absorption compared to without micro SiC. The enhancement effect is expected to the formation of a barrier and enhancement in interfacial bonding of micro SiC. The aim of our project is to investigate the mechanical properties and water absorption of pineapple fiber polymer composites with nano SiC. These goals, in turn, should provide some insights into the potential applications of the newly developed composite material in various spheres.

2. Methodology

2.1 Material Preparation

The main materials examined in this work include TETA hardener and diglycidyl ether of biphenyl A. These elements create the composite of interest. To ensure that the pineapple fibers and particles were of the highest quality and purity, a strict cleaning approach is required. Initially, the pineapples were placed in an ethanol solution to ensure that all the dirt and impurities that stuck to their fibers extracted before they were put in an oven for complete drying. For the cleaning solution, a combination of 95% ethanol and 5% water was mixed well to form a thinner solution. A vitally important process of salinization was also applied to increase the compatibility of the pineapple fibers with the polymer matrix. During that process, 3-Aminopropyltrimethoxysilane, or APTMS, was added to 4% of the solution, and a gentle stirring motion was applied to mix the solution properly as shown in Fig. 27.1. Consequently, 240g of pineapple fibers cleaned and 10g of particles associated with them were affected, and they were put into the solution containing silane with water for a short period. By cleaning the pineapple fibers properly and applying a careful process to prepare the surface of the pineapple fiber, the adherence of the pineapple fiber in the matrix is increased.

The fiber was carefully put into the mould after being cleaned and the silane treatment was done to prepare it for

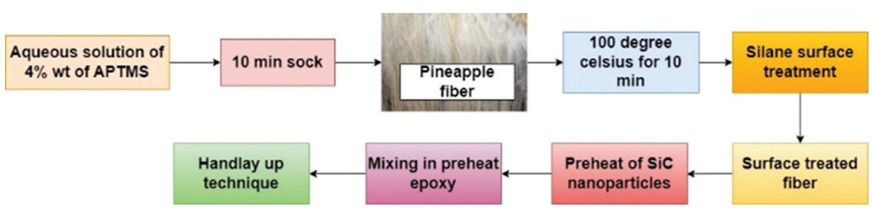

Fig. 27.1 Material preparation of the fiber

the next steps of investigations. The SiC particle of 40 nm in diameter is preheated to 200 degrees Celsius. Simultaneously, a epoxy resin is heated to 60 degree Celsius. The next step was to transfer the nanoparticles into the heated epoxy resin after both the epoxy resin and the nano-sized SiC particles had attained their respective temperatures. A stirring was done to guarantee that a homogenous dispersion was produced.

Five different composite materials with varying compositions were created in this experiment as shown in Table 27.1. Pure epoxy was the first component of the formulation. The second material was a 40% fiber and 60% epoxy combination. The third material consisted of 40% fiber, 58% epoxy, and 2% nano SiC. The final product was a blend of 40% fiber, 4% nano SiC, and 56% epoxy. Lastly, the fifth material was made up of 6% nano SiC, 40% fiber, and 54% epoxy. These diverse compositions provide a large variety of samples for this research's additional investigation.

Table 27.1 Material preparation in this research

Material	Epoxy (%)	Fiber (%)	Nano SiC (%)
Material 1	100	0	0
Material 2	60	40	0
Material 3	58	40	2
Material 4	56	40	4
Material 5	54	40	6

2.2 Novelty and Application

The novelty of this research lies in the integration of the pineapple fiber and the nano-sized SiC particles. The process of preparations like cleaning and the salinization process for the pineapple fiber increases the fiber adhesion with the prepared composites. The addition of SiC nanoparticles results in novel approach to the reinforcement of the composites results in increase in tensile, impact and hardness of the material. The proposed material can be used in the construction materials, automotive components, or aerospace structures.

2.3 Various Testing used in this Research

In order to perform the materials' examination, tensile, impact, hardness, and water absorption tests were conducted. Every procedure for testing was precisely performed with the use of contemporary and advanced machinery to obtain accurate and reliable results. Tensile testing, which was one of the methods applied in mechanical evaluation, provides an understanding of materials' resistance to pulling forces. Universal testing machine is used to perform this procedure by applying the load to the specimen, which is controlled throughout the specific test. The exact values of tensile strength, yield strength, and elongation quantified by the UTM helped to comprehend the mechanical materials' behavior. Another important research of mechanical materials' property concerns the resistance to the sudden, high-velocity pressing forces, which is impact testing. The procedure was performed with the use of Izod or a Charpy impact tester, which used to tap the specimen and measure the energy absorbed during its fracture with a hammer or a pendulum. This method provided the description of the impact materials' resistance and hardness. Brinell hardness test was carried out in order to get the hardness of the experiment . In the course of the experiment, a force of a specific weight was used to tap an indenter, while the diameter of the indentation that was obtained was measured. Brinell hardness was used to determine the material's resistance to wear and surface deformation.Water absorption was also examined to understand the composites' long-term interaction with water, which is a crucial characteristic of the materials for the cases when they have to be exposed to moisture. The water absorption test had two aspects, one of which was the weight of the specimens after they stayed in the water for some time. The water absorption was also measured with the use of a precision balance, which allowed for the detailed examination of composite materials and moisture absorption along with the changes in their characteristics. Figure 27.2 provides the materials and specimens prepared in this research for the experiment.

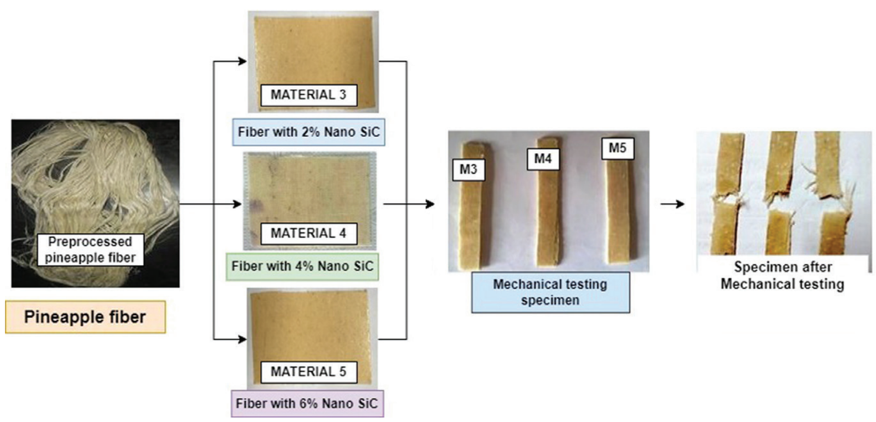

Fig. 27.2 Material prepared and the specimen

3. Result and Discussion

The findings of the tensile tests, shown in Fig. 27.3, which shows the mechanical characteristics of the 5 different composites. The tensile strength of pure epoxy is only 58 MPa. But when the 40% of the pineapple fibber is added the tensile result improved drastically. Tensile strength increased to 138 MPa, which is a far higher value compared to pure epoxy. The improved distribution of fibers inside the epoxy matrix is responsible for this significant increase in tensile strength. A larger concentration of fibers ensures the better connection between the fibers and the resin. Such components interact to reinforce the structural integrity of the composite, and the latter's tensile strength increases. Then, the tensile strength in composites with epoxy at 2%, 4%, and 6% was increased. The composites exhibit great performance achieving tensile strengths of 140 MPa, 152 MPa, and 156 MPa, respectively . Such findings indicate that nano SiC has an extra effect on the mechanical strength of the composite. However, the reason why the tensile strength is higher is the uniform distribution of nano SiC in the entire composite . These nanoparticles are known to contribute to the strength of the material. Finally, it is the effective connection between nano SiC, fibers, and resin that raises the tensile strength in such established composites.

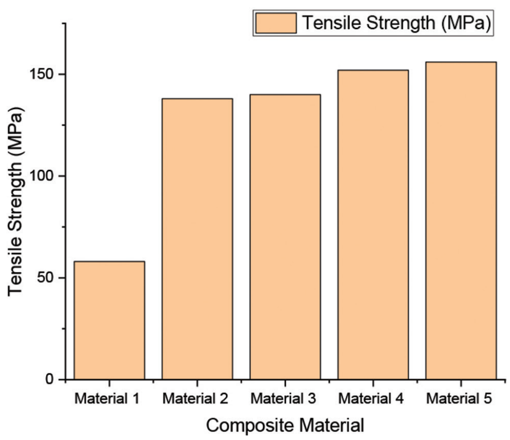

Fig. 27.3 Enhancement in the tensile strength of epoxy composites

Overall, it can be concluded that there is a need in adding nano-SiC and fibers to improve the mechanical properties of composites in the epoxy matrix. It is evident that in this particular case, due preparation of components and their mixing, the composites with high tensile strength have been established. Now the latter can be used in a number of applications requiring strength.

The findings of the impact test, as illustrated in Fig. 27.4, reveal an extraordinary impact resistance for the composite materials under consideration. Notably, Material 1, composed of 100% epoxy, had an impact energy absorption of 0.88 J, proving it could resist forces applied at high speeds and velocities . Conversely, Material 2, consisting of 40% fiber and 60% epoxy, has an impressive resistance to impact as it measured 4.4 J. The enhanced ability to absorb impact energy of the composite is a result of the fiber dispersion in the epoxy matrix, as seen by the notable improvement in impact strength. Even greater impact resistance was shown by materials 3, 4, and 5, whose compositions of epoxy, fiber, and nano SiC varied. In that sequence, they were 7.6 J, 8.9 J, and 9.2 J. This intriguing trend emphasises the need of a well-dispersed, tightly bound nano-SiC phase within the composite and shows the extra function that nano-SiC contributes in raising the materials' impact resistance. All of these results show the importance of composite composition for impact resistance, which makes the materials desirable for applications where critical resistance to sudden forces is needed.

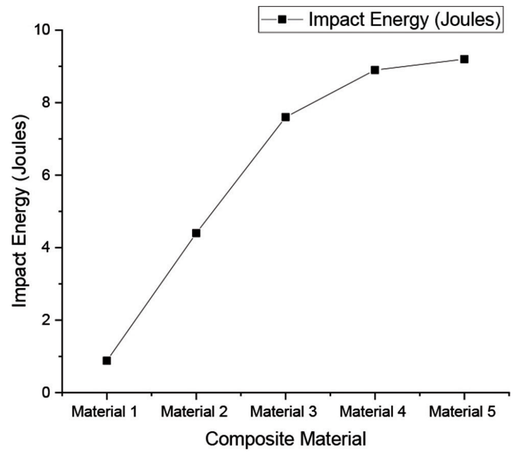

Fig. 27.4 Impact resistance evaluation of composite materials

The impact test results, which are shown in Fig. 27.5, offer important new information on the different composite materials under investigation in terms of their hardness. Despite being made completely of epoxy, the first material initially had a 78 Shore D hardness grade, which indicates its stiffness. Nevertheless, Material 2, which is composed of 60% fiber and 40% epoxy, showed a significant improvement in hardness, measuring 110 Shore D. The extra fibers provide a strengthening effect that increases the material's resistance to indentation, which explains the significant increase in hardness.

The hardness values increase as we move on to Materials 3, 4, and 5, which have different amounts of epoxy, fiber, and nano SiC. These materials have Shore D values of 113, 117, and 120, respectively. There are several reasons for the observed increase in hardness in these materials. To begin with, a higher percentage of epoxy creates a stiffer matrix,

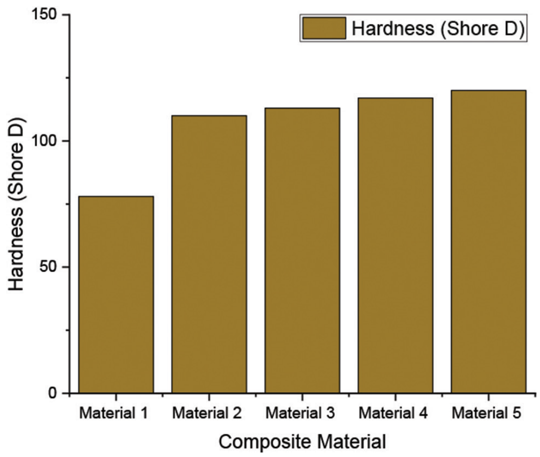

Fig. 27.5 Hardness test result of the epoxy composites

which is further reinforced by the fibers. Additionally, the hardness is further enhanced by the introduction of micro SiC particles. The uniform distribution of micro SiC in the composite matrix adds structural stiffness, which improves the material's resistance to deformation. The composite's overall toughness is increased as a result.

Figure 27.6 displays the results of the water absorption test and illustrates the composite composition affects the materials' resistance to water penetration. Despite being made entirely of epoxy, the first material had a 1.5% water absorption rate and substantial water infiltration. Upon examining Material 2, we observe a 1.2% decrease in water absorption. Of Material 2, fiber comprises up 40% and epoxy up to 60%. The barrier that reinforcing threads form to keep water out can help to explain this drop. Considering that Materials 3, 4, and 5 had different amounts of fiber, epoxy, and nano SiC, their water absorption dropped significantly more. Material 3 showed enhanced resistance to water infiltration at a water absorption rate of 0.8%. Material 3 consists of 58% epoxy, 2% Nano SiC, and 40%

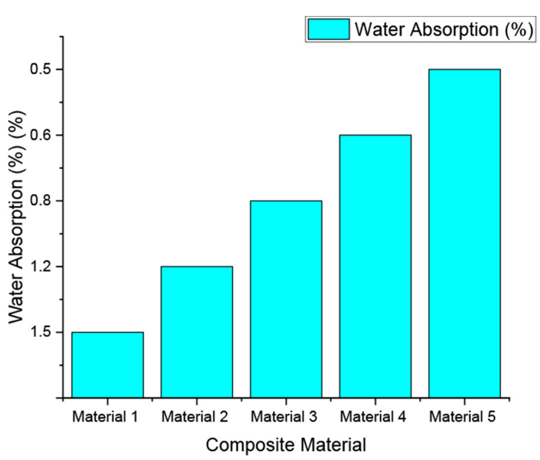

Fig. 27.6 Water absorption result of the epoxy composites

fiber. One aspect of this reduction is the insertion of small SiC particles, which improve the composite's structural integrity and decrease porosity. With a water absorption rate of 0.6%, Material 4, composed of 56% epoxy, 40% fiber, and 4% Nano SiC, demonstrated the ongoing impact of the nano SiC reinforcement in preventing water penetration. The least quantity of water absorption was shown by Material 5 at 0.5%. It is composed of 54% epoxy, 6% Nano SiC, and 40% fiber. This decline occurs because the fiber, epoxy, and nano SiC all work together to lessen the material's sensitivity to water.

The results of a SEM analysis of the composites that were created are shown in Fig. 27.7. Important information about the microstructure and dispersion of the component materials is provided by this analysis. There is a discernible even dispersion of micro SiC particles within the fiber matrix of the composite reinforced with 2% SiC.The uniform distribution of the nanoparticles across the composites is a sign of successful mixing and preparation, and, in turn, superior material properties. The SEM analysis shows that in both models, nano SiC reinforced 4% and 6% granddaughter scale composites were uniformly distributed with the nanoparticles. This promotes the materials' maximum potential in terms of superior mechanical and structural properties and indicates a high-quality manufacturing process and well-balanced composition assembly. The possession of a strong bond with the fibers, as demonstrated in both the SEM images of the tested samples and the composite with 6% nano SiC, is most intriguing. This bond enhances the material

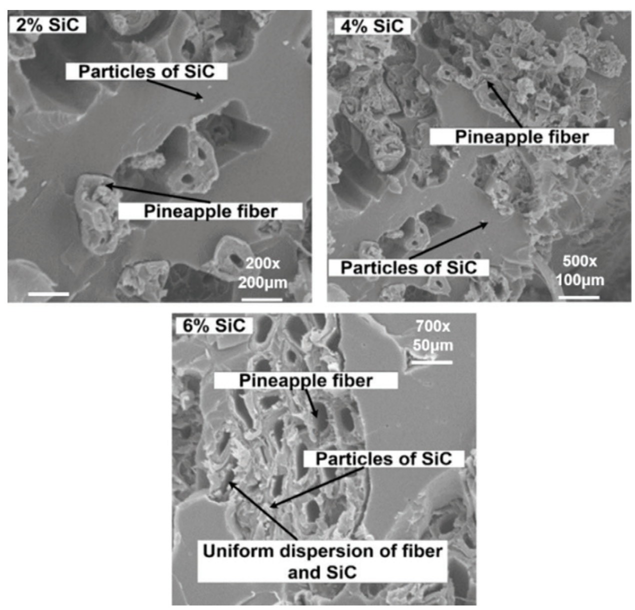

Fig. 27.7 SEM images of epoxy composites with varying percentage of SiC

and its overall structural strength. Therefore, the strong bond between fibers and nano SiC should have a positive impact overall on the material's mechanical strength and endurance.

4. Conclusion

Our research has yielded promising results for the development of composite materials with notably improved water and mechanical resistance. After experimentation, we were able to see significant improvements in the composite materials' hardness, impact resistance, and tensile strength. From the testing the following conclusions are made.

- The test findings for Material 2 shown a significant improvement in terms of hardness, tensile strength, and impact energy absorption: 4.4 J, 110 Shore D, and 138 MPa, respectively.
- Material 2 is composed of 60% epoxy and 40% fiber. Nano SiC was added to Materials 3, 4, and 5 to improve their properties even more. Material 5 demonstrated remarkable properties, including a tensile strength of 156 MPa, an impact energy absorption of 9.2 J, and a hardness grading of 120 Shore D. Moreover, our research demonstrated that modifying the composite composition led to a significant decrease in water absorption.
- Materials like fiber and nano SiC, which have noticeably lower rates of water absorption, suggest possible applications where moisture resistance is crucial. These outcomes signify a noteworthy progression in the manufacturing of materials with superior performance.
- The SEM analysis further validated the strong fusion and effective dispersion of the fibers with the small SiC particles, demonstrating the materials' use and the potency of our composite production techniques. Our work contributes to the ongoing search for materials that may one day grow into stronger, more resilient materials by assisting in the discovery of novel materials that can get over a range of technological challenges.

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Note: Every figure and table was created using the experimental work; none of them were taken from any publications or online.