Optimizing Mechanical Properties in Biodegradable Composites: Polypropylene and Corn Stalk Powder Fibers

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***Abstract*—The purpose of this study was to investigate the microstructure and characteristics of biodegradable composites made from corn stalk powder fiber material and a polypropylene plastic matrix, using Scanning Electron Microscope (SEM) analysis. The issue of environmental pollution caused by plastic waste is a growing concern, with plastic waste accounting for an average of 10% of total waste production, and less than 1% of plastic waste being effectively decomposed due to the synthetic polymers used in their production. Developing biodegradable plastic materials, such as bioplastics, is one way to address this problem. In this study, different compositions of the composite materials were tested using SEM and microphotography. The composite materials consisted of a polypropylene plastic matrix with varying amounts of corn stalk powder fibers (5%, 10%, and 15%). The SEM results showed that the composition of 85% polypropylene plastic and 15% corn stalk powder had a more significant impact on the mechanical properties of the composites, due to a stronger bond between the plastic and polypropylene. Overall, this study provides important insights into the development of biodegradable plastic materials that can help mitigate the environmental impact of plastic waste.**

***Keywords*—natural fibre, plastic composite, corn stalk, polypropylene, biodegradation, sustainable materials**

I. INTRODUCTION

The issue of solid waste has become a pressing national problem in Indonesia, driven by population growth, economic expansion, and changing consumption patterns. Indonesia's population has increased significantly in recent years, reaching 261.89 million people in 2017, up from 206.26 million people in 2000. This rapid population growth has been accompanied by a rise in urbanization and changes in lifestyle, leading to increased consumption and waste generation. Moreover, Indonesia's economy has been expanding rapidly, with the manufacturing sector contributing significantly to economic growth. While this growth has created job opportunities and boosted living standards, it has also led to a surge in industrial waste and pollution, exacerbating the country's waste management challenge. To address this issue, the government has launched a number of initiatives and programs aimed at improving waste management, including increasing public awareness, promoting recycling, and investing in waste-to-energy technology. Despite these efforts, however, the challenge of solid waste management remains a major concern for the country (Ministry of Environment and Forestry of Indonesia, 2018).

To address the growing problem of environmental pollution caused by non-biodegradable plastics, one promising solution is the development of biodegradable plastic materials, commonly known as bioplastics. Bioplastics are designed to break down easily into simple compounds that are environmentally friendly and do not harm the ecosystem. This represents a significant advance over traditional plastics, which can persist in the environment for hundreds of years and pose a serious threat to wildlife and human health. One important strategy for developing bioplastics is the use of renewable natural materials, such as plant-based feedstocks, which are sustainable and can be grown in an environmentally responsible manner. The development of bioplastics from renewable resources has the potential to significantly reduce our reliance on fossil fuels and mitigate the impact of plastic waste on the environment. While there are still challenges to be overcome in the development and commercialization of bioplastics, they represent a promising avenue for addressing the urgent environmental problems facing our planet [1]. Biodegradable plastics can be made from a variety of natural materials, including polymer compounds derived from plants, animals, and other organic sources. These compounds include starch, cellulose, lignin, casein, chitin, and chitosan, among others. Starch-based bioplastics, for example, are made by extracting and processing starch from corn, potatoes, or other crops. Cellulose-based bioplastics are produced from the cell walls of plants such as cotton and wood, while lignin-based bioplastics are derived from the woody part of plants. Animal-derived bioplastics, such as casein-based

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plastics, are made from milk proteins, while chitin-based bioplastics are produced from the shells of crustaceans such as shrimp and crabs. The use of these renewable materials for bioplastics has the potential to significantly reduce our reliance on fossil fuels and mitigate the impact of plastic waste on the environment [2, 3].

As concerns about environmental sustainability continue to grow, industries around the world are increasingly turning to renewable natural resources as a way to reduce their environmental impact and increase their economic efficiency. One industry that has embraced this trend is the polymer composite industry, which is rapidly expanding the use of natural fibers as fillers in a wide range of products. Composites are formed through a process of mixing or combining two or more constituents, such as polymers and natural fibers, that differ in terms of shape, properties, and composition. By combining these materials, it is possible to create products that exhibit better mechanical, thermal, and chemical properties than the original materials. For example, natural fibers such as hemp, jute, and kenaf have been shown to improve the strength and durability of composite materials while also reducing their weight and cost. The growing use of natural fibers in polymer composites is a testament to the potential of renewable resources to drive innovation and sustainability in modern manufacturing [4, 5].

Plastic is a ubiquitous material that is used in countless products and applications due to its durability, flexibility, and low cost. However, most plastics are made from synthetic polymers that are derived from non-renewable sources such as petroleum, and these materials do not biodegrade in the environment. One of the most widely used types of synthetic plastic is Polypropylene (PP), which is valued for its chemical resistance and toughness. Unfortunately, polypropylene waste is also one of the top contributors to global plastic pollution. This is due in part to the fact that polypropylene is used in a wide range of applications, from packaging and consumer goods to automotive and construction materials. As a result, significant amounts of polypropylene waste end up in landfills, oceans, and other natural environments where it can persist for centuries without breaking down. This underscores the urgent need for more sustainable and biodegradable alternatives to polypropylene and other synthetic plastics, especially as global plastic production and consumption continue to rise [6].

Polypropylene is a versatile thermoplastic that is widely used in many different applications due to its unique combination of properties. It is made from the monomer propylene, which is a hydrocarbon that is produced from crude oil or natural gas. Polypropylene is known for its rigidity, toughness, and resistance to solvents, acids, and bases. It is also odorless and has a relatively low melting point, which makes it easy to process and shape using various methods such as injection molding, extrusion, and blow molding. Due to these properties, polypropylene is used in a wide range of products and industries, including automotive components, loudspeakers, laboratory equipment, food packaging, reusable containers, and many others. Additionally, polypropylene is often preferred over other plastics because it is relatively inexpensive and can be recycled. However, the growing concern over plastic waste and its impact on the environment has led to an increased interest in developing more sustainable alternatives to polypropylene and other synthetic plastics. Polypropylene is a thermoplastic with a melting point of approximately 160 °C (320 °F), which can be determined through techniques such as Differential Scanning Calorimetry (DSC). Although it has excellent mechanical strength and is widely used in many different applications, it is not biodegradable and can persist in the environment for centuries. In order to address this issue, researchers have developed biodegradable plastics by blending synthetic polymers with natural polymers. However, natural polymers have certain limitations, including poor mechanical properties, low resistance to high temperatures, and brittleness. To overcome these limitations, synthetic polymers can be combined with natural fibers to produce composite materials with improved mechanical properties and biodegradability. By optimizing the composition and processing conditions, these composites can be tailored for specific applications, such as packaging, construction materials, and biomedical devices, among others [7, 8].

Indonesia is a country with abundant agricultural resources, and the utilization of fibers from agricultural waste as a filler for plastic composites is a promising solution. However, during corn harvesting, farmers usually discard or burn corn stalks as they are considered waste. Corn stalks contain a high amount of cellulose, approximately 40%, which can be used as the main raw material for producing biodegradable plastics. Unlike synthetic plastics, biodegradable plastics can be decomposed naturally by microorganisms and decompose faster, making them a sustainable alternative. Several countries, including Japan, Germany, and America, have already begun using corn stalks as a raw material for biodegradable plastics, and Indonesia has the potential to follow suit. In 2015, Indonesia produced 19,612 tons of corn, making it an ideal candidate for developing biodegradable plastics [7].

The researchers conducted an important study on developing more environmentally friendly composite materials [9–11]. Natural fibers, particularly rice husk, were used as an alternative to glass fiber to analyze their effect on composite production. The research included three different volume fractions of rice husks: 10%, 35%, and 50%. To produce the composite, the researchers mixed rice husks with a 7% NaOH solution, alkalinized the mixture for two hours, and molded it using the Hand Lay Up method in accordance with ASTM D 638 standards. The composite's mechanical properties were tested through tensile testing, and its morphology was examined using a SEM. The results indicated that the highest tensile strength occurred at a volume fraction of 10% to 35%, namely 11.071 N/mm^2 to 11.387 N/mm^2. The SEM test results showed that the morphology of the 35% volume fraction was dominated by butek resin, which appeared to optimally bind rice husks. In contrast, the morphology of the 50% husk volume fraction showed air bubbles and larger cavities, indicating that the resin did not sufficiently bind rice husks. Therefore, it can be concluded that mixing rice husk fractions from 10% to 35% increase the tensile strength of the composite, while also improving its morphology, as compared to the 50% husk fraction [9, 12].

A researcher conducted a study on the impact of the composition of composite materials with a polypropylene matrix reinforced with natural fibers on the morphology and strength of physical properties [1]. Fiber-reinforced composites are commonly used for tools that require high strength-to-weight ratio. The objective of the research was to determine the effect of the composition of natural fibers in polymer composites on the fiber morphology and density of biocomposites with a matrix of polypropylene reinforced by bagasse and betung bamboo fibers. The matrix composition with fiber reinforcement was set at 80% polypropylene and 20% natural fibers. The dominant composition of the natural fibers was varied by weight to produce a comparison of the types of natural fibers that yielded better test values. The density values of the bamboo fiber and bagasse fiber composites with a polypropylene matrix were determined using the mass fraction of each component, namely PP 80%+B 15%+T 5% of 0.846427 g/m^3, PP 80%+B 10%+T 10% of 0.840983 g/m^3, and PP 80%+B 5%+T 15% of 0.84373 g/m^3. SEM testing was conducted to determine fiber morphology and perform density calculations as a physical test. The SEM results of the 15%B/5%T-80%PP composite material showed that the distance between the fibers was far apart, and the polypropylene matrix appeared dense and solid. On the 5%B/15%T-80%PP composite, a layer of the matrix was formed that produced voids, indicating that the fibers were scattered to fill the matrix, creating many black gaps between the fibers and the matrix, which showed the pores of the material. This explains why the 5%B/15%T-80%PP composite specimen had a higher density value than 15%B/5%T-80%PP [7, 13].

The research was conducted on the SEM testing of ebonite matrix composites reinforced by hemp and bamboo fibers, each with a content of 30 PHR and a sulfur content of 40 PHR. The aim of the study was to investigate the microstructure of the composite using SEM and identify the bonding characteristics of the constituent fibers that reinforce the composite. The study found that the ebonite matrix composite reinforced with hemp fibers exhibited stronger adhesion than the composite reinforced with bamboo fibers, which appeared to be detached from the ebonite. This finding suggests that hemp fibers are a better reinforcement material for ebonite composites than bamboo fibers. The SEM testing provided a detailed view of the microstructure of the composite, revealing the interactions between the fibers and the matrix. Overall, this research provides valuable insights into the selection of appropriate reinforcement fibers for ebonite composites, and highlights the importance of SEM testing in understanding the microstructure and bonding characteristics of composite materials [14].

Composite materials are engineered materials that are made by combining two or more materials with different properties and compositions to create a new material with superior properties. The constituent materials in a composite are typically insoluble in each other and do not react chemically to form other compounds. Composites achieve unique properties that are not present in the individual materials. In a composite material, one material acts as a matrix, while the other material(s) function as reinforcement. The formation of composites depends on the surface bond between the matrix and the reinforcement materials, which is achieved through adhesion and cohesion forces. The strength and other mechanical properties of the composite material are determined by the properties of both the matrix and the reinforcement materials, as well as the type and quality of the bond between them [15].

A composite is a material formed by combining two or more constituent materials through an inhomogeneous mixture, where each material has different mechanical properties. The resulting composite material has unique mechanical properties and characteristics that differ from those of the constituent materials. This allows us to tailor the strength and other properties of the composite material by adjusting the composition of the constituent materials [2]. Composites are engineered materials that consist of two or more constituent materials with different chemical and physical properties, which remain separate in the finished product. To achieve strong bonding between the constituent materials, the addition of a wetting agent is often necessary. A wetting agent is a compound that reduces the surface tension of a liquid, allowing it to more easily spread and bond with other materials. The strength of the bonds between the constituent materials is critical in determining the overall properties of the composite material [15].

Composite materials have become increasingly important in engineering applications due to their unique properties, which are derived from the combination of two or more materials. These materials are engineered to have enhanced physical and mechanical properties that are not achievable by individual materials alone. The combination of materials in composite structures allows for the creation of lightweight, strong, and durable materials that can be used in a variety of applications. The basic structure of a composite material consists of two main components: the filler and the matrix. The filler, also known as the reinforcement, is the component that carries the majority of the load in a composite structure. It provides stiffness, strength, heat stability, and other essential properties to the composite. The matrix, on the other hand, acts as a binder and is responsible for holding the reinforcement in place. It also protects the fibers from damage caused by environmental conditions and distributes the load to the fibers. The properties of the composite material are determined by the properties of the filler and matrix, as well as the bonding strength between them. The selection of the materials used as fillers and matrices is critical in the production of composite materials. Fillers can be in the form of fibers, flakes, powders, or other shapes, and they can be made from a wide range of materials, such as carbon, glass, aramid, and metal. The matrix can be made from a variety of materials as well, such as polymers, ceramics, and metals [16, 17].

One of the critical factors in the production of composite materials is the bonding strength between the filler and the matrix. This bonding strength is affected by several factors, including surface preparation, interfacial chemistry, and processing conditions. The use of wetting agents is often necessary to ensure strong bonding between the filler and the matrix. Wetting agents reduce the surface tension of the matrix material, allowing it to wet and adhere to the surface of the filler material [18]. The properties of composite materials can be tailored to specific applications by adjusting the composition of the filler and matrix. The amount, orientation, and shape of the filler material can be manipulated to achieve specific mechanical properties, such as stiffness, strength, and toughness. Similarly, the matrix material can be selected to achieve desired properties such as chemical resistance, thermal stability, and electrical conductivity [19, 20].

Fibers can be categorized into two main types: natural fibers and synthetic fibers. Natural fibers include materials like jute, cotton, wool, silk, and hemp, while synthetic fibers include materials such as glass, carbon, rayon, acrylic, and nylon. Generally, the ratio of fiber length to diameter plays an important role in determining the mechanical properties of a composite material. Smaller diameter fibers can reduce surface defects that can lead to brittleness, while longer fibers tend to enhance properties like strength and stiffness. When fibers are arranged in an orderly fashion, they produce excellent mechanical properties, as the forces acting on the composite are unidirectional. This is closely related to how forces are distributed across the composite structure and how well the matrix and fiber are bonded. Natural fibers are a diverse group of fibers that can be obtained from various sources, such as plants, animals, and minerals. Among these, plant-based fibers such as jute, rosella, flax, kenaf, and hemp are commonly used in industrial applications. Natural fibers have gained attention as potential reinforcing materials for lightweight, eco-friendly, and cost-effective composite materials [21–23]. Natural fibers have gained attention from composite material experts due to their environmentally friendly and biodegradable properties compared to synthetic fibers. They are also renewable and readily available in certain areas, making them an attractive choice as reinforcing materials in lightweight and cost-effective composite materials. Natural fibers have good mechanical properties, particularly in terms of tensile strength, and they are combustible, meaning that they can be burned and their combustion energy can be utilized. Additionally, natural fibers have a smaller specific gravity and are safe for health because they are free from synthetic chemicals and do not release toxic gases when burned [24].

However, natural fibers do have drawbacks that require further research to reduce their deficiencies. One disadvantage is that the quality of natural fiber varies depending on weather conditions, and fibers obtained during sunny and dry weather have lower moisture content, which is essential in the composite manufacturing process. Moist fibers cause the matrix to expand and voids to form. The process temperature is also limited due to the flammable nature of natural fibers, as excessive heat can cause them to burn. Natural fibers also have low adhesive ability due to their content of lignin and oil, which limits the junction between the fiber and the matrix, reducing their adhesive strength. In addition, the dimensions of natural fibers vary, even if they are of the same type, due to their hygroscopic nature, with fibers that have higher absorption capacity having larger dimensions than those with lower absorption capacity [8].

Biodegradable plastic is a type of plastic that can be decomposed by microorganisms into water and carbon dioxide gas after it has been used and disposed of in the environment. This makes it an environmentally friendly option for single-use plastics. In Japan, biodegradable plastic is also known as "green plastic." There are two main types of biodegradable plastics based on the raw materials used: those made from petrochemicals and those made from renewable natural resources like starch and cellulose. The former relies on non-renewable resources, while the latter utilizes renewable resources. Currently, most biodegradable plastic polymers produced are aliphatic polyester polymers [25]. While biodegradable plastics are a step in the right direction for reducing plastic waste and environmental pollution, it’s important to note that they still have limitations. For example, they may require specific conditions to decompose properly, and they may not necessarily break down completely if they end up in a landfill where oxygen and microorganisms are scarce. Additionally, producing biodegradable plastics still requires energy and resources, so reducing overall plastic consumption and promoting recycling are also important steps in mitigating the negative impacts of plastic waste on the environment [26, 27]. Biodegradable plastics can be classified into two groups based on their raw materials. The first group utilizes petrochemical-based materials, which are non-renewable natural resources. The second group uses plant-based materials, such as starch and cellulose, which are renewable natural resources. Aliphatic polyester polymers are currently the most commonly produced biodegradable plastic polymers. These polymers have shown promise in replacing conventional plastics in various applications while being environmentally friendly [2].

Polypropylene is a thermoplastic polymer produced by the polymerization of propylene monomers. The resulting product is commonly traded in the form of elongated pellets. Polypropylene is a versatile material used to manufacture a wide range of items, such as bottles, battery boxes, mats, raffia, and plastic sacks. The raw material used to produce polypropylene is derived from petroleum through a process similar to that used for ethylene. To obtain spatially ordered polypropylene, a low-pressure process similar to that used for polyethylene is employed, utilizing a Ziegler-Natta catalyst. Atactic polypropylene, which lacks spatial regularity and has a low softening point, can be separated from the spatially ordered polypropylene by extracting it with pentane and setting it aside [9, 28].

The corn stalk refers to the central part of the female corn where the ear is attached, including all parts of the female corn itself. The stalks are enveloped by a layer of corn husk known as kelobot. Morphologically, the corn stalk is a modified main stalk of the panicle, where the male organ can give rise to grains under certain conditions. Young corn stalks, commonly referred to as babycorn, are edible and used as a vegetable, while mature stalks are lightweight yet sturdy, and can be a source of furfural, a monosaccharide with five carbon atoms. Corn stalks are composed of complex compounds, including lignin, hemicellulose, and cellulose, each of which can potentially be converted into other compounds through biological processes [29, 30].

A company based in Iowa, USA has found a way to repurpose corn stalks into a range of eco-friendly products. Corn stalks possess unique properties such as being hard and absorbent in some parts, as well as a combination of several properties including being inert, biodegradable and lightweight. These qualities make corn stalks an excellent ingredient for various mixtures including animal feed, insecticides and fertilizers. They can also be used as a natural pet mat that is clean and effective in reducing odors [10, 31]. Corn stalks have enormous potential for fuel purposes, with around 90% of them being utilized for this purpose. However, there is still significant waste of the stems and leaves, which could contribute an additional 30% to this potential. This is because corn stalks have a high carbon content, which makes them an excellent source of fuel. In fact, studies have shown that in order to dry 6 tons of corn from a moisture content of 32.5% to 13.7% wb over a period of 7 h, approximately 30 kg of dry corn cobs per hour are required [32].

This research aims to investigate the potential of corn stalk powder as a biodegradable composite material when mixed with Polypropylene (PP) plastic. The Scanning Electron Microscope (SEM) test method and microstructure photo tests were used to examine the morphology of the corn stalk powder fiber material when combined with a PP plastic matrix. The study analyzed the microstructure of the resulting composite material and its characteristics as a biodegradable material.

II. Materials and Methods

The research conducted for the development of a natural fiber plastic composite, comprising corn stalk and polypropylene, is visually depicted in Fig. 1, illustrating the research flow chart. The initial stage involves acquiring the requisite raw materials, as outlined in Table I. These materials encompass polypropylene plastic and corn cob powder. Subsequent to the procurement of the raw materials, the subsequent stage revolves around the formulation of a recipe for the natural fiber plastic composite. This recipe delineates the specific proportions of the two constituents necessary to attain the desired composite properties. Following the formulation of the recipe, the two components are meticulously blended using a high-speed mixer to prepare the composite material. Subsequently, the composite material is molded into test specimens designed for conducting tensile and water absorption tests. These test specimens were utilized for the assessment of the composite material's mechanical characteristics and its resistance to water absorption.

The corn cob powder was prepared by drying the cobs in the sun for a week, crushing them using a machine, and then baking them at 60 ºC for 24 h to reduce their water content. The powder was then filtered through a mesh size of 60 to obtain an average size of 0.5835 mm through macro photography. Recycled drinking water bottles were used to obtain polypropylene plastic with code 5, which was cut into small pieces for the composite manufacturing process. A formula for the natural fiber plastic composite was then developed, specifying the appropriate proportions of the two materials. Three weight percentage ratios of polypropylene plastic and corn stalk powder (100:0, 95:5, 90:10, and 85:15) were used to produce composite specimens. The weight fraction was used due to weight fraction accounts for the actual mass of the reinforcement material within the composite, which is crucial for understanding the overall material behavior, particularly in biodegradable composites where the density of the components may vary.

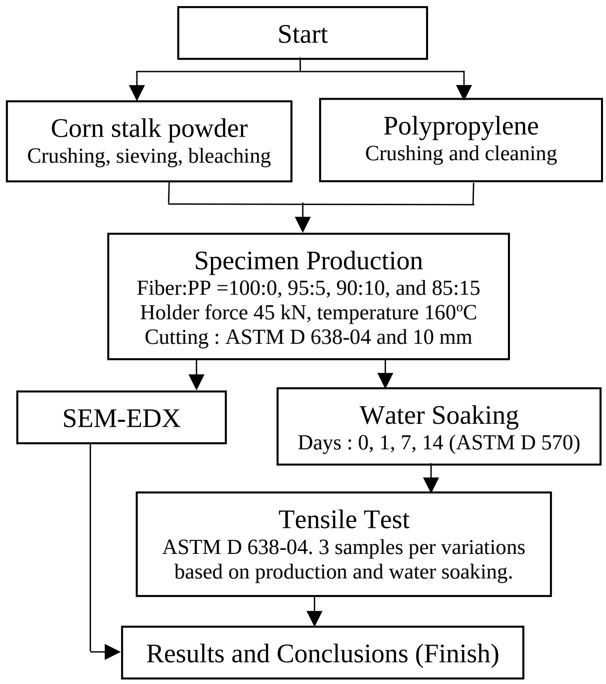


Fig. 1. Research flow chart.

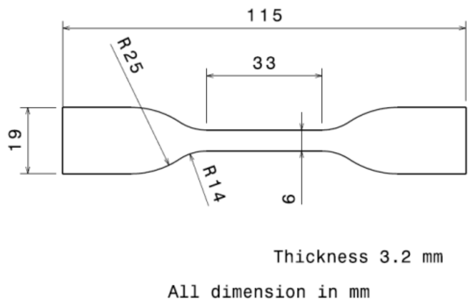
TABLE I. The Specimens Material

Specimen	Polypropylene (%Wh)	Corn stalk powder (%Wh)	PP Melting Temp. (°C)	Holder Force (kN)
1	100	0	160	45
2	95	5	160	45
3	90	10	160	45
4	85	15	160	45

To prepare the composite material, the plastic was melted at 160 ºC and then mixed with the corn stalk powder. The mixture was stirred until evenly distributed and printed on a mold with a hot press machine. The composite material was then formed into test specimens for the tensile test and water absorber tests. The test specimens were cut using a chainsaw according to ASTM D 638-04 standards for tensile tests. Each variation involved three specimens, such as the 85:15 ratio, which included 12 samples subjected to water soaking for 0, 1, 7, and 14 days. Consequently, the collective number of specimens reached a total of 48. The tensile test was performed using the Zwick Roel Universal Tensile Machine (UTM), as shown in Fig. 1(d).

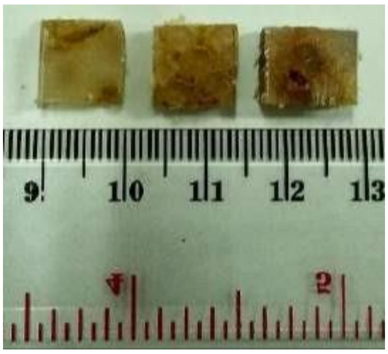
Finally, SEM testing was performed on specimens cut to a size of 1×1 cm^2 to analyze the structure of the composite material. Prior to the SEM analysis, the composite samples underwent a gold coating process, a widely preferred practice for SEM specimen preparation. Gold coating is esteemed for its ability to confer exceptional conductivity, thereby mitigating issues related to sample charging, and enhancing image contrast. This coating technique proves particularly advantageous when dealing with non-conductive materials like the plastic composite in this study. Numerous researchers have employed various methods in their endeavors [12, 16, 17].

The research team adhered to the ASTM D 570 standard when performing the water absorption test. This test method plays a vital role in evaluating the plastic material's susceptibility to moisture absorption over time, especially in applications where material integrity is of utmost importance. The typical procedure encompassed immersing the specimen in water at a specific temperature for a defined duration. Subsequently, the quantification of water absorption was achieved by measuring the alteration in weight or expressing it as a percentage relative to the initial sample weight [33]. Fig. 2(c) in the study depicted the specimens, each having dimensions of 10 mm.



(a)

(b)



(c)

(d)

Fig. 2. PP and corn stalk specimen. (a) Specimen dimension of ASTM D 638-04. (b) Specimens after cutting process. (c) Samples for SEM and water absorption. (d) The sample attached to the UTM.

III. Result and Discussion

Fig. 3 depicts the tensile stress behavior of a composite material containing varying weight fractions of corn cob powder and polypropylene. The composite specimens were subjected to water immersion for 1, 7, and 14 days, and their tensile stress was evaluated following the ASTM D 638-04 standards. Prior to immersion, the composite with a weight fraction of 95% exhibited the highest tensile stress of 17.41 MPa, while the lowest tensile stress of 13.14 MPa was observed in the 85% weight fraction. As an illustration, the tensile test conducted on the 95:5 fraction exhibited a load of 353.79 N. After 1 day of water immersion, the highest tensile stress of 16.94 MPa was still observed in the 95% weight fraction, whereas the 85% weight fraction demonstrated the lowest tensile stress of 11.77 MPa.

Upon prolonged immersion for 7 and 14 days, the 95% weight fraction continued to exhibit the highest tensile stress at 16.11 MPa and 13.59 MPa, respectively. Conversely, the 85% weight fraction displayed the lowest tensile stress, measuring 10.17 MPa after 7 days and 9.99 MPa after 14 days of water immersion.

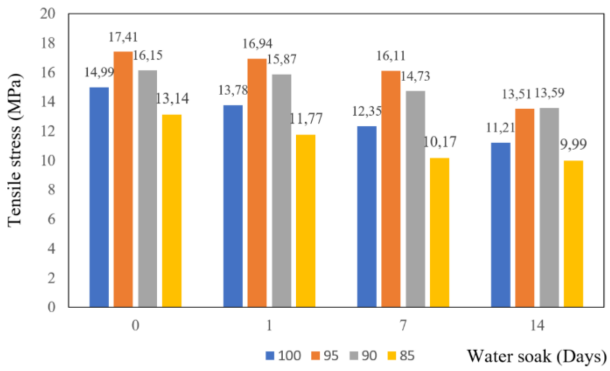


Fig. 3. The impact of water immersion on the tensile stress of each specimen.

The occurrence of voids within the specimens led to inadequate bonding between the plastic matrix and the corn cob powder, consequently diminishing the tensile strength of the composite [34, 35]. The findings of the study revealed that the optimal weight fraction of the composite was determined to be 95% plastic and 5% corn cob powder, attributing to the robust bond established between the matrix and the powder. Conversely, the weight fraction of the composite consisting of 85% plastic and 15% corn cob powder exhibited the lowest tensile strength due to the excessive amount of corn cob powder, which impeded the attainment of a perfect bond with the matrix.

Moreover, the diagram depicts a decline in tensile strength as the duration of water immersion increases. For the 100% plastic specimens, the decrease in strength can be attributed to the presence of voids within the specimen. In the case of other specimens, the reduction in tensile strength is primarily due to water absorption by the corn cob powder, leading to a weakening of the bond between the matrix and the powder [36].

The water absorption test was conducted in accordance with the ASTM D 570 standard, utilizing 36 specimens with three samples for each variation as shown in Table II. Prior to the test, the specimens were weighed and subsequently immersed in water for durations of 1, 7, and 14 days. The results obtained from this experiment are presented in the table.

TABLE II. THE WATER ABSORPTION TEST RESULTS

Immer-sion Time (Days)	Specimen (%PP)	Average Initial Weight (g)	Average Final Weight (g)	Percentage of Water Absorption (%)
1	100	14.12	14.12	0.000
	95	13.17	13.25	0.607
	90	14.02	14.22	1.427
	85	12.53	12.8	2.155
7	100	13.77	13.8	0.218
	95	13,62	13.82	1.468
	90	14.87	15.27	2.690
	85	12.95	13.44	3.784
14	100	13.75	13.8	0.364
	95	13,33	13.95	4.651
	90	13.87	14.6	5.263
	85	12.16	12.95	6.497

Water absorption primarily occurs at the cut edge of the specimen, where the corn cob powder is not completely enveloped by the plastic matrix. As the composite absorbs more water, its strength diminishes due to the presence of air voids within the bonds of the composite material and the water-absorbing nature of the corn cob powder. The test results substantiate this, as they indicate that the composite consisting of 85% plastic and 15% corn cob powder exhibits the highest water absorption, whereas the 100% plastic composite demonstrates the lowest water absorption. Furthermore, an increase in the proportion of corn cob powder within the composite amplifies its water absorption capacity.

Based on the conducted tensile test, it is evident that the incorporation of corn stalk powder in the polypropylene plastic composite material exerts a significant influence on both the mechanical properties and water absorption characteristics of the material. The results indicate that the composition featuring 95% polypropylene plastic and 5% corn stalk powder exhibits the highest tensile strength among the tested variations. This composition demonstrates superior mechanical performance and highlights the favorable bonding and synergistic effect between the polypropylene matrix and the corn stalk powder filler.

In contrast, the composition comprising 85% polypropylene plastic and 15% corn stalk powder displays the highest water absorption capacity. This finding suggests that the increased presence of corn stalk powder within the composite material leads to greater water absorption due to the nature of the filler. The higher water absorption observed in this composition may be attributed to the porosity and hygroscopic properties of the corn stalk powder, which can result in increased water uptake and swelling behavior [37].

These conclusions drawn from the tensile test and water absorption analysis shed light on the impact of the composition variations on the mechanical and water-related properties of the polypropylene plastic composite material. The optimal composition of 95% polypropylene plastic and 5% corn stalk powder demonstrates superior tensile strength, while the composition of 85% polypropylene plastic and 15% corn stalk powder exhibits increased water absorption. These findings contribute to a comprehensive understanding of the relationship between composition variations and the resulting properties of the composite material.

The composite materials composed of polypropylene plastic and corn stalk powder underwent thorough microstructural observations. Utilizing an optical microscope with a magnification of 100X, detailed examinations were conducted to capture microstructural photos that provide a closer examination of the composite material's internal structure. These microstructural photos serve a pivotal role in discerning the distribution of corn stalk powder throughout the plastic matrix and evaluating the bonding characteristics between the constituents. Furthermore, these photos serve as a means to identify the presence of voids and defects that can significantly influence the mechanical properties of the composite material [38].

By scrutinizing the microstructure of the composite material, valuable insights into its mechanical properties can be obtained. The microstructural photos enable the assessment of the uniformity in the distribution of corn stalk powder and plastic, which directly impacts the material's strength and stiffness. Additionally, the detection of voids and defects through microstructural analysis holds utmost importance as they can considerably diminish the material's strength. Hence, the comprehensive microstructural analysis stands as an indispensable step in comprehending the composite material's properties and its potential applications.

The microstructure photo test was conducted on the composite material comprising 95% polypropylene plastic and 5% corn stalk powder, as shown in Fig. 4. The photo clearly illustrates the distinctive color contrast between the plastic matrix and the corn stalk powder, with the plastic exhibiting a transparent hue and the corn stalk powder displaying a brownish yellow coloration. Additionally, the microstructure photo reveals the bonding between the polypropylene plastic matrix and the corn stalk powder fibers; however, visible gaps between these components result in voids within the composite. These voids are evident in the microstructure photo and manifest as blackspot defects. Importantly, it should be noted that these defects arise due to the infiltration of undesired external materials.

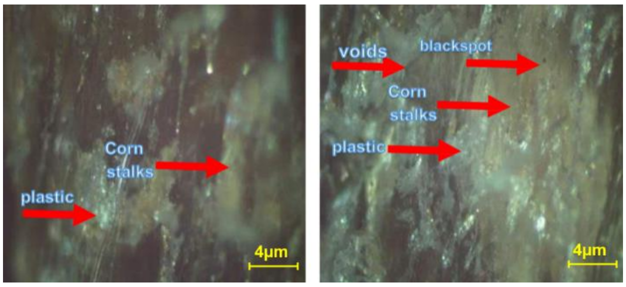


Fig. 4. A micrograph depicting the structure of the composite material with a weight fraction of 95% polypropylene plastic.

The microstructure photo test provides insight into the morphology of the composite material, revealing details that are not visible to the naked eye. The test shows that the corn stalk powder and the polypropylene plastic are not completely homogenized, and there are gaps and voids in the composite material. This information is important as it provides a basis for understanding the mechanical properties of the composite, such as its strength and durability. By studying the microstructure photo, it is possible to identify areas for improvement in the composite's manufacturing process, such as minimizing the amount of unwanted external material that enters the composite during production.

The microstructural photo test of the composition variation consisting of 90% polypropylene plastic and 10% corn stalk powder, as depicted in Fig. 5, reveals that the corn stalk powder prominently occupies the image. This suggests that the corn stalk powder content in this composition is higher compared to the composition of 95% polypropylene plastic and 5% corn powder. Nonetheless, observable voids are present in the image, attributed to the entrapment of air during the manufacturing process of the material. Despite the presence of voids, the matrix and fibers exhibit a strong bond, resulting in the formation of a composite structure.

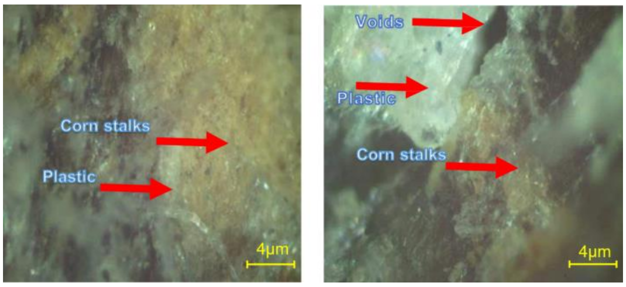


Fig. 5. The structure of the composite material with a weight fraction of 90% polypropylene plastic.

The visible voids in the microstructural photo do not compromise the overall bonding between the polypropylene plastic matrix and the corn stalk powder fibers. The successful bonding of these constituents indicates that the composite material remains structurally sound, despite the presence of air voids. The microstructural analysis highlights the influence of composition variation on the distribution and dominance of corn stalk powder within the composite, while also acknowledging the occurrence of voids as a byproduct of the manufacturing process.

It is important to note that voids in composite materials can affect their mechanical properties, such as tensile strength and durability. Therefore, it is necessary to minimize the presence of voids during the manufacturing process to ensure the quality and reliability of the composite material.

Based on the observations made from Fig. 6, a notable enhancement is discernible in the microstructure of the composite material containing 85% polypropylene plastic and 15% corn stalk powder. The micrograph reveals a uniform dispersion of corn stalk powder particles throughout the matrix, indicating an improved distribution within the composite. The incorporation of corn stalk powder has played a pivotal role in augmenting the mechanical properties of the composite material.

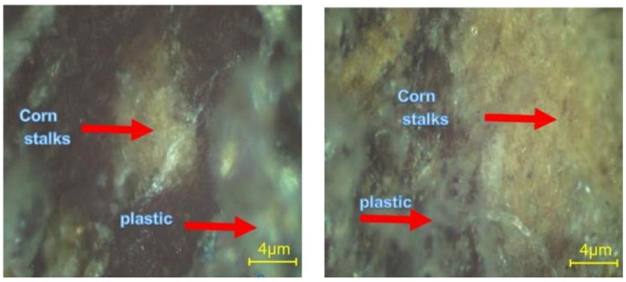


Fig. 6. A micrograph that illustrates the internal structure of the composite material composed of 85% polypropylene plastic.

The microstructural photo vividly demonstrates a stronger bond formed between the matrix and the filler, resulting in a more homogeneous structure. This improved bonding is crucial for enhancing the mechanical performance of the composite material. The uniform distribution and effective integration of the corn stalk powder within the matrix contribute to a more cohesive and well-integrated composite structure, which positively impacts its mechanical properties.

In addition to the enhanced mechanical performance, the inclusion of corn stalk powder in the composite material has expedited its biodegradation process. The microstructural photo exhibits a greater number of voids within the material, indicating the presence of microorganisms that have initiated the biodegradation of the composite. As a result, the utilization of corn stalk powder in the composite not only improves its mechanical properties but also renders it more environmentally friendly by facilitating its biodegradability. The presence of microorganisms actively degrading the material highlights the potential for the composite to undergo a natural decomposition process, contributing to its eco-friendliness and sustainable characteristics.

Furthermore, the microstructural analysis conducted on the composite material provided valuable insights into the influence of voids on its tensile strength. The presence of voids within the material can weaken its overall structural integrity, consequently diminishing its tensile strength. However, with the incorporation of corn stalk powder as a filler in the composite, an improvement in the adhesion between the polypropylene plastic matrix and the corn stalk powder filler was observed. This enhanced adhesion contributes to the overall enhancement of the mechanical performance of the composite material.

Moreover, the addition of corn stalk powder not only enhances the mechanical properties but also accelerates the biodegradation process of the composite. The microstructural analysis reveals that the presence of voids, attributed to the biodegradation activity, signifies the initiation of the composite material's decomposition by microorganisms. This indicates that the composite material has the potential to undergo a natural biodegradable process, thereby contributing to its environmental sustainability.

These compelling findings highlight the promising potential of utilizing corn stalk powder as a filler in polypropylene plastic composite materials. The incorporation of corn stalk powder not only improves the material's mechanical properties by enhancing adhesion and reducing voids but also supports the principles of environmental sustainability through the acceleration of biodegradation. These outcomes encourage further exploration and investigation of this composite material in various applications, including but not limited to packaging, construction, and other industries where enhanced mechanical performance and eco-friendliness are desirable. Additionally, future research endeavors could delve into the long-term durability and performance assessment of this composite material to ensure its suitability and reliability in practical applications.

Fig. 7 provides an SEM image showcasing the sample composition variation of 95% polypropylene plastic and 5% corn stalk powder. The SEM image allows for the observation of the sample's morphology, revealing noteworthy characteristics. Notably, the image indicates that the bonding between the corn stalk powder aggregates and the PP plastic matrix is suboptimal, leading to the occurrence of cracks within the empty areas of the matrix where no corn stalk powder fiber aggregates are present.

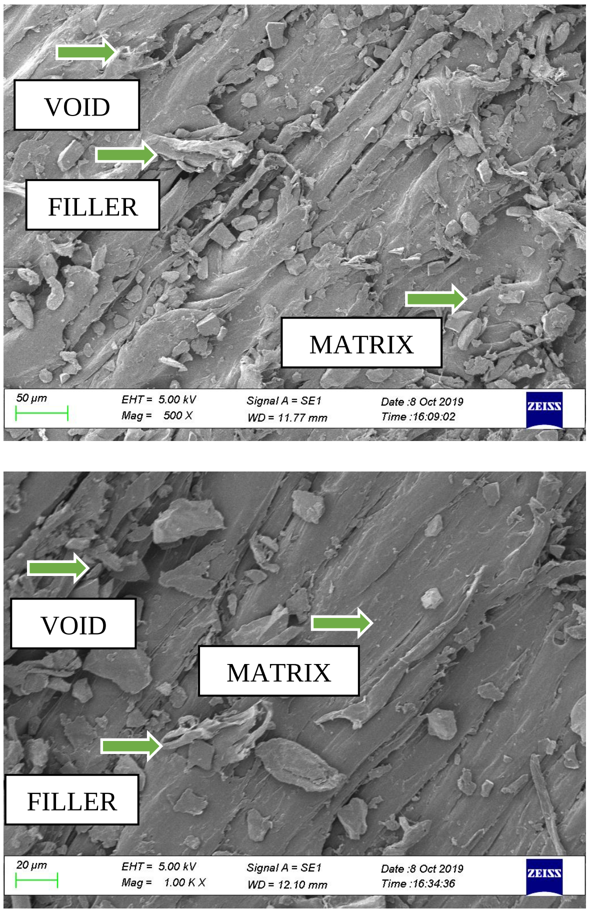


Fig. 7. SEM test results composite specimens of 95% polypropylene plastic weight fraction.

Once debonding occurs, stress concentrations may develop at the debonded sites. These stress concentrations can lead to crack initiation, where small microcracks form at or near the fiber-matrix interface. These microcracks can propagate through the material. This occurrence could potentially be attributed to air entrapment within the composite during the printing process, particularly due to the relatively small quantity of fibers. One of the initial stages of fracture in composite materials is often the debonding of the reinforcement fibers from the matrix. In our case, the corn stalk powder fibers may debond from the polypropylene matrix under load. This debonding can occur due to stress concentrations, poor interfacial adhesion, or other factors.

Based on Fig. 8, the SEM image of a sample composition variation of 90% polypropylene plastic and 10% corn stalk powder, it is evident that the addition of cornstalk fiber has a significant effect on the degree of cracks and the bond between the matrix and filler. As the load on the composite material increases, the microcracks can propagate, leading to crack growth within the composite. The direction and extent of crack propagation depend on various factors, including the applied stress, material properties, and the presence of any pre-existing defects.

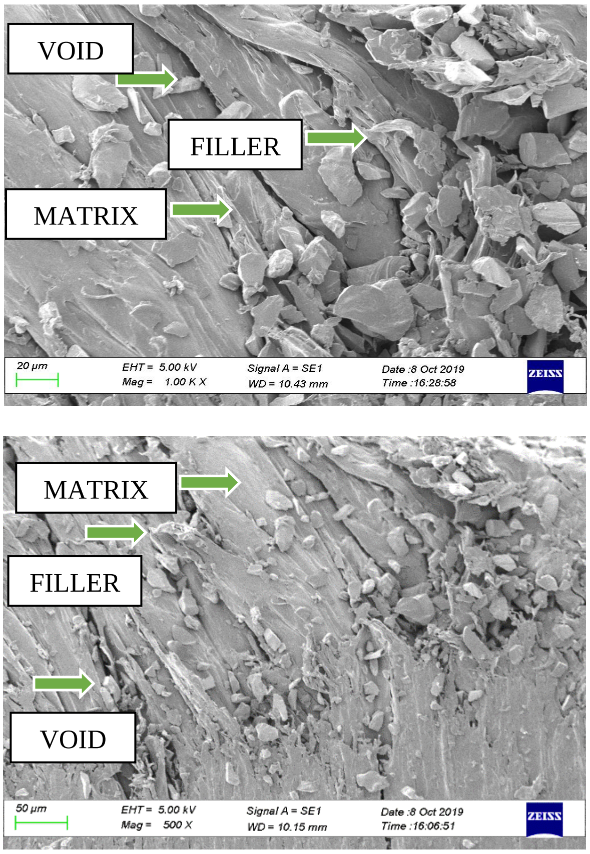


Fig. 8. The findings of the SEM test on composite specimens containing 90% polypropylene plastic weight fraction.

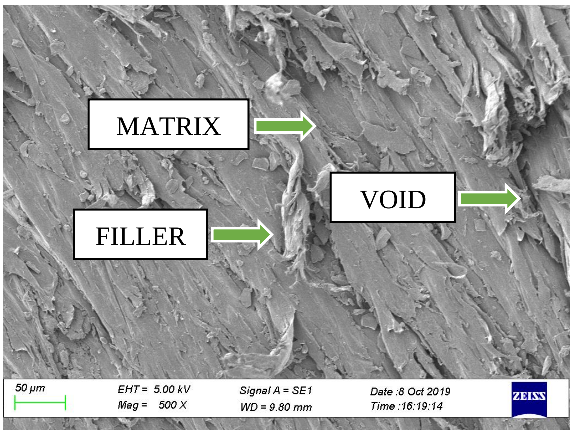
The SEM imagery clearly shows a reduced number of cracks in the sample, and a better bond between the matrix and filler can be observed. However, there are still a few cracks visible due to the uneven distribution of the fibers in the sample. The addition of cornstalk fiber not only improves the mechanical properties of the composite but also accelerates the biodegradable process.

Furthermore, the SEM image also shows that the cornstalk powder aggregates are well bonded with the PP plastic matrix, resulting in a better mechanical performance. However, there are still some voids visible in the sample due to trapped air during the manufacturing process. Overall, the SEM image of the sample composition variation of 90% polypropylene plastic and 10% corn stalk powder confirms the potential of using cornstalk powder as a filler in PP plastic, leading to improved mechanical properties and biodegradability.

Fig. 9 showcases an SEM image depicting the microstructure of the sample consisting of 85% polypropylene plastic and 15% corn stalk powder. The image distinctly illustrates a notable enhancement in the sample's morphology compared to previous compositions. The incorporation of 15% corn stalk powder has resulted in a significant reduction in the presence of cavities and pores within the material. This improvement can be attributed to the effective adhesion between the matrix and the corn stalk powder fibers, ultimately contributing to enhanced mechanical performance of the material. Moreover, the SEM image highlights that the material exhibits only a limited number of cracks and voids, indicating a higher level of homogeneity and a reduction in defects within the composite structure. Overall, the SEM analysis confirms the beneficial effects of adding 15% corn stalk powder on the microstructure of the composite, leading to improved material properties and a more structurally sound composition.

The SEM image offers valuable insights into the microstructure of the composite material, providing implications for its overall properties. The image suggests that enhancing the quantity of corn stalk powder fiber aggregates has the potential to improve the bonding between the filler and the matrix. This observation aligns with the findings derived from the tensile test and microstructural analysis, which consistently demonstrated that the composite material comprising 85% polypropylene plastic and 15% corn stalk powder exhibited superior mechanical performance and displayed favorable adhesion between the matrix and the filler. The correlation between the SEM analysis, tensile test results, and microstructural analysis substantiates the positive influence of increasing the proportion of corn stalk powder on the composite material's mechanical characteristics and interfacial bonding, thus highlighting the viability of this compositional adjustment for enhancing overall material performance.

The SEM image presented in Fig. 9 provides substantial evidence supporting the effectiveness of incorporating 15% corn stalk powder into polypropylene plastic composites to enhance material quality. The improved morphology observed in the composite indicates superior mechanical properties, which are of utmost significance for a wide range of applications, including biodegradable packaging, automotive components, and construction materials. The findings derived from the SEM image serve as compelling proof for the potential utilization of corn stalk powder as a filler material in polypropylene plastic composites. This research opens up promising avenues for further exploration and underscores the viability of leveraging corn stalk powder to optimize the properties and performance of composite materials.



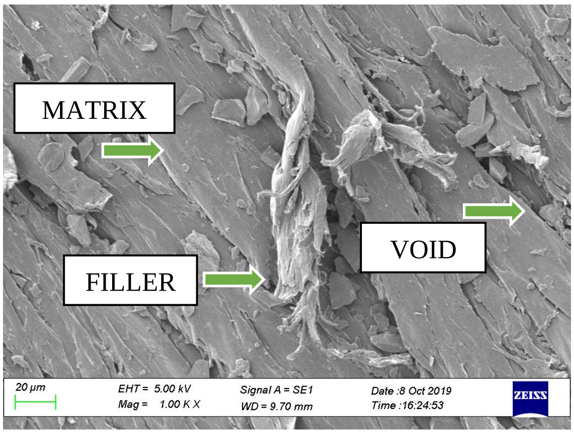


Fig. 9. The results of the SEM test conducted on composite specimens with a weight fraction of 85% polypropylene plastic.

IV. Conclusion

The study findings indicate that the incorporation of corn stalk powder into Polypropylene (PP) plastic yields a composite material with a strong bond between the matrix and the fibers. The Scanning Electron Microscopy (SEM) test results demonstrate uniformity across all three composition variations, although the 85%:15% ratio exerts a more pronounced influence on the mechanical properties, as evidenced by the enhanced fiber surface appearance in the SEM images. However, the composite manufacturing process still gives rise to defects such as voids, bubbles, black spots, and cavity gaps.

Furthermore, the composition comprising 85% polypropylene plastic and 15% corn stalk powder exhibits superior adhesion between the matrix and filler, consequently accelerating the biodegradation process. These findings collectively highlight the potential of the corn stalk powder and PP plastic mixture as a biodegradable material with enhanced mechanical properties. The study underscores the importance of further exploration in utilizing this composite for sustainable applications, promoting eco-friendly alternatives while maintaining desirable material performance.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

JS played a pivotal role in performing the critical Scanning Electron Microscope (SEM) analysis, which enabled the detailed examination of microstructures. ADA, with meticulous attention to detail, undertook the arduous task of manuscript composition, ensuring that our findings were eloquently and comprehensively documented. Meanwhile, AH and BW skillfully handled specimen preparation, guaranteeing the integrity of our samples for analysis. Lastly, Mas and RS demonstrated exceptional expertise by conducting both the photo micrography and tensile tests, providing invaluable insights into the mechanical properties of our composite materials. All authors had approved the final version.

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