Available online at
https://jmeche.uitm.edu.my/

e-ISSN: 2550-164X

Journal of Mechanical Engineering 22(1) 2025, 1 – 16.

Journal of Mechanical Engineering

Preparation and Characterization of Ramie Fiber Reinforcement on Acrylonitrile Butadiene Styrene/Cassava Starch Hybrid Bio-Composites

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ARTICLE INFO

Article history:
Received 20 April 2024
Revised 27 June 2024
Accepted 07 August 2024
Online first
Published 15 January 2025

Keywords:
ABS
Ramie fiber
Cassava starch
DMA
Bio-degradable properties

DOI:
10.24191/jmeche.v22i1.4551

ABSTRACT

The rising demand for materials that can be sustained over time and the growing worries about the decline of the environment have resulted in a noteworthy rise in the attention towards environmentally friendly composites in recent times. This study aims to develop a bio-composite by reinforcing ramie fiber (RF) within the ABS/CS blend matrix, to enhance the mechanical characteristics and biodegradability. The surface roughness of the fibers increased by chemical treatment using sodium hydroxide (NaOH). The ABS/CS/RF composites underwent compounding through a two-roll mill, and sheets containing different weight percentages (5, 10, 15, 20) of RF were produced using a hot compression molding machine. The prepared composites were tested to evaluate their biodegradability, water absorption, mechanical properties, and viscoelastic characteristics. The biodegradation test results demonstrated that there was a positive correlation between the concentration of fibers in neat ABS and the degree of biodegradation. The tensile strength and modulus of the ABS/CS blend increased by 60% and 14.28% respectively. The impact strength improved by 117% when 20 wt% of the RF was added. The degradation of the ABS/CS/RF composite increased by 1.375% after 45 days. However, the DMA results showed an adverse effect on the storage modulus.

INTRODUCTION

The manufacturing of environmentally friendly materials is becoming increasingly popular as environmental concerns grow. The addition of starch to banana fibers (BF) improved its mechanical properties and enhanced its thermal stability due to the presence of hydrogen bonds (Aburpa et al., 2022). The accelerated depletion of petroleum resources, in conjunction with increased awareness of the global environmental issues related to the use of petroleum-based plastics, serves as a significant driver for the adoption of natural fibers and biopolymers as environmentally friendly materials. The eco-friendly and enduring characteristics of natural fibers and biopolymers garner considerable interest from researchers and

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https://doi.org/10.24191/jmeche.v22i1.4551

businesses. Natural fibers attract considerable interest from researchers and industry due to their environmentally friendly and sustainable nature. The addition of nanoclays improved the tensile strength, and glass transition temperature of cassava starch (CS) mixed with natural rubber, although the percentage of elongation decreased (Jareerat et al., 2022). Composites based on starch are potential materials for packaging applications. Composites of starch and biochar - ZnO (C-ZnO) improved shelf life and electrical conductivity (Zelia et al., 2024). The thermal stability, mechanical characteristics, and biodegradation rate of thermoplastic cassava starch and durian peel fiber composites have improved, and these materials have been used for packaging applications (Jumaidin et al., 2023).

The characterization results of the PBS/CS composites revealed an increase in the biodegradability, hardness, and Young’s modulus (Nithikarnjanatharn & Samsalee, 2022). When biofilms are produced from CS and corn husk, both the tensile strength and elongation at break are reduced (Zully et al., 2023). The combination of CS and high-density polyethylene (HDPE) improved both the biodegradability and Young's modulus (ranging from 400 MPa to 470 MPa) (Cassiano et al., 2020). The addition of RF to polystyrene and polyethylene terephthalate glycol improved the mechanical properties (Jaiganesh et al., 2023; Xingzu et al., 2020). RF reinforcement in the epoxy matrix increases the flexural strength and biodegradability (Xin et al., 2023). The thermal and mechanical properties of bio-based polyurethane and RF were investigated, and was found that the thermal stability improved, along with the tensile strength and modulus (Manggar et al., 2022). To enhance the mechanical and thermal characteristics of ramie cellulose nanofibers strengthened with tapioca starch, glycerol was used as a plasticizer. The crystallinity index increased by 30.76%, with a maximum tensile strength of 12.84 MPa (Edi et al., 2020). The tensile strength of RF-reinforced polyamide composites was improved using an injection molding process (Toyoki et al., 2018). The tensile strength, flexural strength, inter-laminar shear strength, hardness, and impact strength increased. It has been reported that hybrid RF/epoxy/TiO_2 may find use in wear-prone situations (Mohapatra & Satpathy, 2023).

It has been demonstrated that the mechanical strength of acrylonitrile butadiene styrene (ABS) solution, a commonly used material in various industries, can be significantly enhanced and augmented by incorporating and integrating layers of natural woven fibers into its structure (Siti et al., 2023). It has been suggested that the properties of these composites can be further enhanced through the use of additives, as indicated by previous studies (Paritosh et al., 2023). In light of these findings, it is evident that the utilization of natural fibers in bio-composites holds tremendous promise for the advancement of sustainable materials. The amplification of the constructive interference that results from the composition of the ABS/Carbon Nano Tubes (CNT) foam, wherein a layer of standard porous foam is positioned between the nanoporous foam and microporous foam, significantly improves the electromagnetic wave absorption capabilities (Milena et al., 2022). Since the mechanical characteristics of these materials are superior, and the expenses remain relatively minimal for ramie fibers in contrast to those for numerous alternative natural fibers, circular tube composites were fabricated and it was the greatest increase in torsion of 10% was accompanied by a 14% decrease in cost (Hai et al., 2023).

Scientists are currently engaged in an innovative quest to fabricate bio-composites that possess the remarkable quality of feather-light, a significant breakthrough in the realm of unmanned aerial vehicle (UAV) technology. By integrating lignin macromolecules extracted from the shells of cashew nuts into acrylonitrile butadiene styrene (ABS), a substantial improvement in the inter-laminar shear strength, tensile strength, and flexural strength of these materials has been observed (Jun et al., 2024). ABS and polylactic acid (PLA) are the reigning champions in the realm of filament materials for the fused filament fabrication (FFF) process (Arun Prakash et al., 2023).

The objective of this research is to create a blend of ABS and CS using a two-roll mill, followed by the addition of RF in four varying ratios (5%, 10%, 15%, and 20%) using the same two-roll mill, then to produce composite sheets through compression molding. Subsequently, to investigate the biodegradability, mechanical properties, and viscoelastic characteristics of the ABS/CS/RF composites. The inclusion of

https://doi.org/10.24191/jmeche.v22i1.4551

cassava starch in ABS polymer led to a reduction in mechanical properties, but it enhanced biodegradability. To counteract the degradation of mechanical properties, RF was added at varying percentages (5, 10, 15, 20 wt%) to the ABS/CS blend in a ratio of 80:20. Experiments were carried out to evaluate the mechanical characteristics including tensile strength, modulus, and impact strength. The results showed enhancements in all properties when ramie fiber was incorporated into the ABS/CS blend. The viscoelastic properties were assessed, and morphological analysis was carried out using scanning electron microscope (SEM) analysis. Dynamic mechanical analysis (DMA) studies indicated a negative impact of the blend. The degradation percentage of ABS/CS/RF composites increased as the amount of ramie fiber and duration of soil burial test increased. To the best of our knowledge, there is no existing research on the combination of ABS, cassava starch, and ramie fiber through compression molding.

MATERIALS AND PREPARATION METHOD

Materials

The ABS polymer in granule form was obtained from Formulated Polymers in Chennai, India, and their glass transition temperature was 105 °C. It is an amorphous tri-polymer composed of three different monomers acrylonitrile, butadiene, and styrene. Go Green Products, a natural fiber supplier in Chennai, India, supplied the ramie fiber to prepare the composites. Chem-o-Chem, a chemical supplier in Chennai, India provided fumed silica, glycerol, maleic anhydride, and paraffin oil.

Sample preparation

The neat ABS material was subjected to a drying process at a temperature of 100 ℃ for 3 hours before being processed in a two-roll mill. Initially, a blend of ABS and CS was created, and before this blending process, the CS in powdered form underwent drying using a hot air oven at 80 ℃ for 3 hours. Subsequently, 10 ml of glycerol was manually introduced to the dried CS. The starch was then left at room temperature for 24 hours, allowing ample time for plasticization of the starch before further processing in the two-roll mill. Then, the ABS and the CS were blended in a two-roll mill.

The utilization of sodium hydroxide (NaOH) for the modification of natural fibers is a common practice in the preparation of polymer composites. This process aims to enhance the bonding between the fibers and the matrix by eliminating impurities, enhancing surface roughness to facilitate mechanical bonding, modifying the crystalline structure of cellulose in the matrix, and introducing reactive groups onto the fiber surfaces. Additionally, it serves to decrease the fiber diameter to increase the surface area-to-volume ratio and enhance wettability.

The chemical treatment of the fiber began with the dilution of sodium hydroxide (NaOH) in distilled water, followed by several washes with clean water, to remove any contaminants present. The fibers were then dried before being immersed in sodium hydroxide water for 24 hours. The excess water was drained after the 24 hour period, and the fiber was properly rinsed with clean water. After the fibers had completely dried for 48 hours in sunlight, they were cut into 1 cm lengths and ground into a fine powder in a mixer jar. During the compounding process of ABS/CS blend with RF at different weight percentages, 10 ml of paraffin oil was added during milling to achieve a uniform mixture between the fiber and matrix. Paraffin oil acts as a lubricant in this process. Subsequently, 10 ml of maleic anhydride was integrated into the blend to finalize the compounding process. The incorporation of maleic anhydride aims to enhance the compatibility between the hydrophobic polymer and hydrophilic natural fiber, thereby improving the interfacial adhesion between the fiber and matrix. The two-roll mill played a crucial role throughout the procedure by providing the necessary mechanical forces and heat to aid in blending and dispersing the

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components effectively, resulting in a well-compounded material ready for further processing. The schematic of the compression molded sheet preparation is presented in Fig 1.

Fig.1. Schematic of sheet preparation; (a) ABS material in hot air oven, (b) cassava starch,(c) Ramie fiber dried in sunlight, (d) plasticization of CS, (e) compounding in two roll mill, (f) hot press for compression molding, (g) removal of the sheet from hot press, and (h) compression molded sheet.

The ABS/CS/RF sheets were prepared using the hot compression method using a steel mold of 150 x 150 x 3 mm in size. The temperature and pressure were maintained at 260 ℃ and 3000 bar, respectively.

Testing and characterization of samples

Mechanical properties

Test specimens in the shape of a dumbbell were utilized to examine tensile properties, subjected to a vacuum oven at 80 ℃, and subsequently placed in a sealed desiccator for 24 hours before testing. Tensile assessments were conducted employing the Universal Testing Machine (UTM) Instron Instrument in accordance with ASTM D638 standards, with a crosshead speed of 50 mm/min and a gauge length of 50 mm. The Izod impact strength of the composite samples was assessed following ASTM D256 guidelines.

Dynamic mechanical analysis

The storage modulus, loss modulus, and damping factor (*Tan D*) were determined using DMA. Analysis of the storage modulus provides insight into the load-bearing capacity of the ABS/CS/RF composite, while *Tan D* reveals the mechanical loss characteristics of the composite materials. The experimental procedure involved 3-point bending mode testing at a heating rate of 3°C/min, with a frequency of 1 Hz, spanning the temperature range from 35 ℃ to 130 ℃.

Water absorption test

ASTM D570 standard was followed to measure the water absorption percentage. The specimens were placed in an oven at a temperature of 50 ℃ for a duration of 24 hours and subsequently cooled in desiccators. Following this, the specimens were submerged in regular water at room temperature. After a

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period of 96 hours, the specimens were taken out of the water, dried with a cotton cloth, and weighed. The percentage of weight variation attributed to water absorption was then computed.

Soil burial test

The biodegradability of the ABS/CS/RF composites was evaluated using a soil burial test. A mixture of garden soil and cow dung was utilized for this biodegradation assessment. Prior to burial, the weights of the samples were recorded. Subsequently, the samples were buried 10 cm below the soil surface. Regular watering was carried out to maintain soil moisture around the buried samples. The weights of the samples were measured after 15, 30, and 45 days of burial. Biodegradation of the composites was determined by analyzing the weight difference of the buried samples.

SEM analysis

A scanning electron microscope was utilized for the analysis of the physical structure of fracture surfaces in ABS/CS/RF composites following the completion of tensile tests.

RESULTS AND DISCUSSION

Tensile strength

The tensile strength represents a fundamental characteristic that offers valuable information regarding the composition, structure, and potential behavior of the material. This parameter aids in the comprehension of the relationships between the polymer matrix and the reinforcing components present in the polymer composite. The impact of the cassava starch content on the tensile strength of the pure ABS is illustrated in Fig 2(a). When the weight percentage (wt%) of CS increased, the tensile strength of the pure ABS polymer decreased. Specifically, upon the addition of 20 wt% CS, the compression molded pure ABS exhibited a decrease in the tensile strength from 17.7 MPa to 4 MPa. Similar results were reported for low density polyethylene (LDPE)/CS composites (Iheoma et al., 2022) and cassava starch/corn husk composites (Zully et al., 2023). When the CS is incorporated into the ABS matrix as a filler, it may not yield reinforcing outcomes comparable to those of alternative fillers. Indeed, starch is not commonly acknowledged for its capacity to enhance mechanical properties, such as tensile strength, within polymer composites. Starch exhibits hygroscopic properties, which implies its ability to absorb moisture from the surrounding environment. This moisture absorption has the potential to induce plasticization within the ABS matrix, thereby diminishing its mechanical properties, including its tensile strength. Blends prepared from different sources of starch showed a decrease in tensile strength (Cassiano et al., 2020). To improve the properties of the 80:20 ABS/CS blend, natural ramie fibers were reinforced with 0, 5, 10, 15, and 20 wt% ramie fibers.

The impact of different weight percentages of ramie fiber on the tensile strength of the ABS/CS blend is depicted in Fig 2(b). The introduction of ramie fibers into the ABS/CS blend resulted in an increase in the tensile strength from 4 MPa to 6.4 MPa. Although the addition of cassava starch to pure ABS led to a reduction in tensile strength, the gradual reinforcement of natural RF in the blend ultimately improved the tensile strength. It is reported that the inclusion of chemically treated oil palm fiber with a neat ABS matrix enhanced the tensile strength (Ong et al., 2019). Similar results were observed in the research of other researchers (Mohapatra et al., 2023; Siti et al., 2023; Paritosh et al., 2023). The utilization of bamboo fibers led to a rise in the tensile strength of the ABS matrix (Singh et al., 2023; Piyush et al., 2022).

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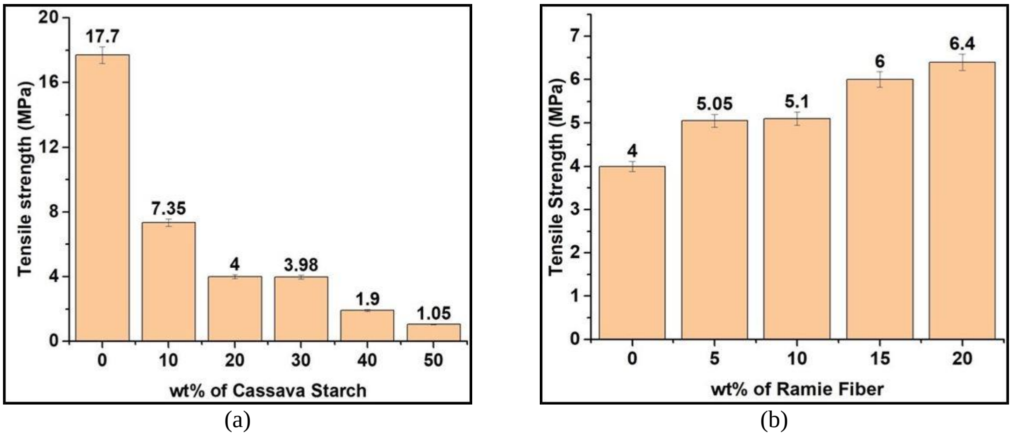

Fig.2. (a) Effect of CS on the tensile strength of neat ABS and (b) effect of the RF content on the tensile strength of the ABS/CS (80/20) blend.

Tensile modulus

The tensile modulus serves as a quantitative indicator of a material's response to deformation when subjected to tensile forces. The utilization of tensile modulus by plastic product designers facilitates the selection of suitable materials for particular applications. A heightened tensile modulus suggests that the material possesses rigidity and the capacity to endure increased forces without distortion, characteristics that may be favored in structural elements. The influence of the cassava starch content in the ABS matrix is illustrated in Fig 3(a). As the cassava starch content in the pristine ABS increased, the tensile modulus increased for all ratios. Nevertheless, the highest tensile modulus of 386.13 MPa was attained at a ratio of 10 wt% cassava starch in the pristine ABS. The tensile modulus corresponding to 20 wt% CS was 257.55 MPa, whereas the tensile modulus of neat ABS was only 88 MPa. It was reported that an increase in banana fibers in the ABS matrix improved the tensile modulus by 20% (Dragon et al., 2020). The impact of the weight percentage of the fibers on the tensile modulus of the ABS/CS (80:20) blend is illustrated in Fig 3(b). The tensile modulus of the ABS/CS (80:20) blend was 257.55 MPa, whereas, at 5, 10, 15, and 20 wt% of the ramie fiber in the blend, the tensile moduli were 267.47, 293.89, 294.34, and 269.77 MPa, respectively.

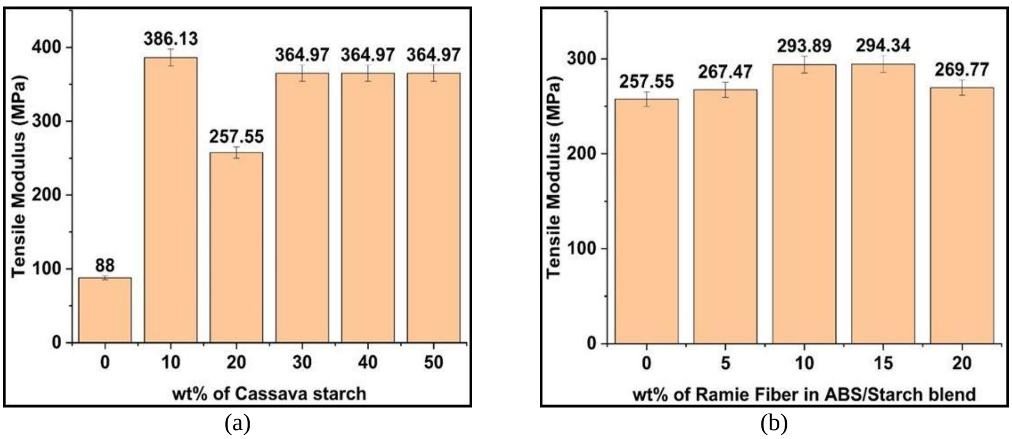

Fig.3. (a) Effect of CS on the tensile modulus of neat ABS and (b) effect of RF on the tensile modulus of the ABS/CS (80/20) blend.

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Impact strength

Impact strength is a critical property for polymer composites because it indicates how well the material can withstand sudden shocks without failing. Many polymer composites are used in applications where they may experience sudden impacts, such as automotive components. Understanding the impact strength helps ensure that these materials can perform reliably in end-use applications. The influence of the RF quantity in the ABS/CS blend is illustrated in Fig 4. When the RF was introduced onto the ABS/CS blend by the compression molding method, the impact strength increased to 78.32 J/m from 36.03 J/m (at an ABS/CS blend ratio of 80:20). Ramie fibers are known for their high tensile strength and stiffness. When they are incorporated into a polymer blend, such as ABS and CS, they act as reinforcing agents. The fibers distribute stress more effectively throughout the material, enhancing its overall mechanical properties, including impact strength. The other reason could be the toughening mechanism, in which the presence of RFs can enhance the toughness of the composite by providing a mechanism for energy absorption during impact.

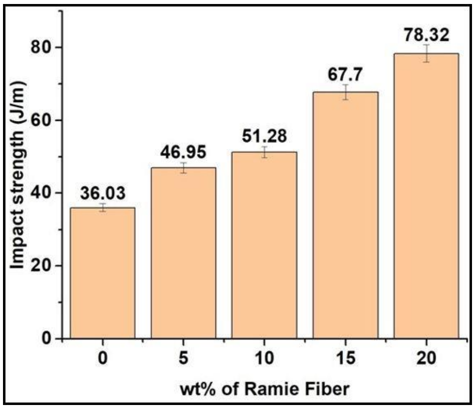

Fig.4. Effect of the RF content on the impact strength of ABS/CS (80/20) blend.

Water absorption

Polymer composites, specifically those fabricated using natural fibers and polymers can intake moisture, regardless of whether they are exposed to a humid environment or submerged in water. This occurrence has a direct effect on the interaction between the ABS/CS blend and the RF, resulting in an inadequate transfer of stress from the matrix to the ramie fiber. Moreover, the quantity of water that is absorbed by these composites significantly impacts their physical, mechanical, and thermal properties. This behavior can be attributed to the highly hydrophilic nature of the chemical components found in natural fibers. Hemicelluloses, a component of the plant cell wall that is linked to cellulose, serve as the fiber constituent responsible for water absorption. A higher proportion of hemicellulose leads to an increase in moisture absorption and biodegradation. The presence of hollow cavities within the natural fibers contributes to a reduced bulk density, thereby resulting in lighter fibers with an enhanced capacity for water absorption. The water absorption percentage of the ABS/CS/RF composites has a direct influence on the degree of crystallinity, orientation, transverse strength, bulging of the fibers, and porosity of the fibers. Fig 5 shows the water uptake by the matrix resulting from the incorporation of ramie fiber contents with diverse ratios. The ABS/CS blend matrix exhibited a greater water absorption capacity when the weight percentage (wt%) of the ramie fiber was increased. Specifically, the matrix composed of the ABS/CS blend exhibited an absorption of 4.77% water. Subsequently, as the RF content increased, the quantity of absorbed water also increased accordingly. Remarkably, the maximum amount of water was observed to be absorbed when the RF constituted 20 wt% of the matrix material.

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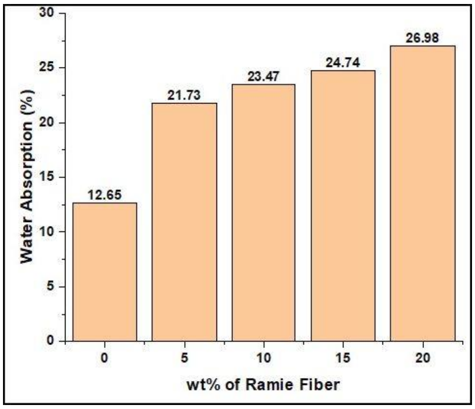

Fig.5. Effect of RF content on the water absorption (%) of ABS/CS (80/20) blend.

Degradation (%)

The ABS/CS/RF composite samples were subjected to prolonged periods of exposure to the soil, spanning 15, 30, and 45 days, to assess the extent of biodegradation. To quantify this phenomenon, the percentage of biodegradation was meticulously calculated. The outcomes of this comprehensive analysis are visually represented in Fig 6, which shows the percentage of biodegradation of the composites. Upon careful examination of the graph, it became evident that the biodegradation percentage gradually increased as the wt% of ramie fiber in the ABS/CS blend increased. Notably, the point at which the maximum percentage of weight loss was observed coincided with the presence of 20 wt% ramie fiber. Specifically, the percentage of degradation was found to be 1.215% after 15 days as in Fig 6(a), 1.286% after 30 days as in Fig 6(b), and 1.379% after 45 days as in Fig 6(c), similar to the results reported by another researcher (Iheoma et al., 2022). The increase in the percentage of biodegradation of the composite material, resulting from the incorporation of RF into the blend of ABS and CS, can be ascribed to a variety of factors. One such factor is the increased microbial activity that is facilitated by the presence of ramie fiber. The natural composition of RF serves as a substrate that promotes the growth and proliferation of microorganisms. Additionally, the synergetic effect resulting from the combination of the ramie fiber with the ABS/CS blend plays a significant role in this phenomenon. This synergetic effect enhances the compatibility between the components and consequently leads to an increase in the percentage of biodegradation of the composite. Moreover, the inclusion of the RF in the matrix of the composite material increases its surface area. This increased surface area allows for greater accessibility of microorganisms to the material, thereby facilitating the initiation of the biodegradation process. Overall, the incorporation of RF into the ABS and CS blend has a multitude of effects that contribute to the observed increase in the percentage of biodegradation. The biodegradability of the bio-composites prepared from plasticized cassava starch with an LDPE matrix improved (Iheoma et al., 2022).

Dynamic Mechanical Analysis (DMA)

Dynamic mechanical analysis (DMA) is a technique employed to gauge the stress or strain that arises from the application of stress or strain with dynamic fluctuations to a sample, thereby enabling the evaluation of the viscoelastic properties of materials, particularly polymers, and composites. The customary DMA parameters of significance for composite materials include the storage modulus, loss modulus, and damping factor, which are dependent on time, temperature, or frequency. The storage modulus, also referred to as the dynamic modulus (E'), characterizes a material's stiffness and elastic behaviour. Conversely, the dynamic loss modulus, also known as the loss modulus (E''), offers insight into the dissipation of heat energy in the sample and exemplifies the viscous response of a material. The storage

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modulus (*E'*) is an assessment of a material's elastic behaviour and its capacity to hold onto energy. It offers details on the material stiffness, rigidity, and the bonding between the fiber and matrix. As the temperature increases, *E'* splits into three regions. They are rubbery, glassy, and glass transition regions. Although the molecules of acrylonitrile butadiene styrene are tightly packed together, the composite is rigid and *E'* is high in the glassy region. The flexible nature of the ABS polymeric chain leads to a sharp reduction in *E'* near the glass transition temperature (T_g) in the glass transition region. Because of the additional mobility of ABS molecules at higher temperatures in the rubbery zone, *E'* varies significantly. Fig 7 represents E' vs. temperature for the ABS and the composites prepared with cassava starch and ramie fiber reinforcement at a fixed frequency of 1 Hz. The storage modulus decreased with increasing fiber content.

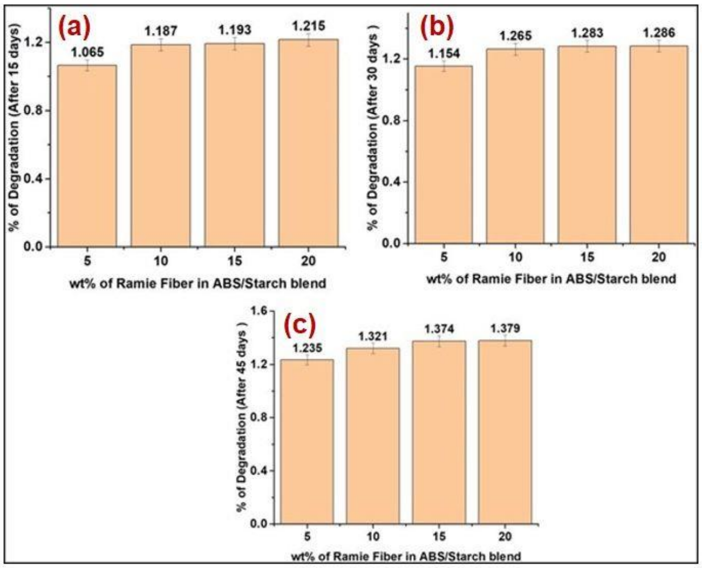

Fig.6. Effect of the RF content on the degradation percentage of the ABS/CS (80:20) blend (a) after 15 days, (b) after 30 days, and (c) after 45 days.

Fig 7 shows the effect of temperature and the weight percentage of the RF in the ABS composites. The storage modulus gradually decreased as the temperature increased for all the composites that were prepared. This decrease in reduction in the storage modulus can be attributed to the relaxation of the amorphous phase of the composites, which occurs as the temperature increases. The inclusion of CS further contributed to a decrease in the storage modulus of the ABS. Moreover, when RF was added to the ABS/CS composites, it had a detrimental effect on the storage modulus of the matrix. However, the addition of BF to the ABS matrix by the injection molding method enhanced the storage modulus (Dragon et al., 2020). Therefore, the processing method influences the mechanical properties of polymer composites. The decrease in the storage modulus of the ABS/CS blend caused by the inclusion of RF can be attributed to the disruption of the molecular arrangement within the blend, which in turn reduces the compatibility between the ABS, CS, and RF phases. This reduction may lead to a decrease in interfacial adhesion. Furthermore, the incorporation of RF results in the formation of voids within the composite structure. These voids act as points of stress concentration and consequently diminish the stiffness. The inadequate adhesion between the matrix and fiber causes slippage and debonding of the fibers from the matrix, thereby weakening the transfer between the matrix and fiber.

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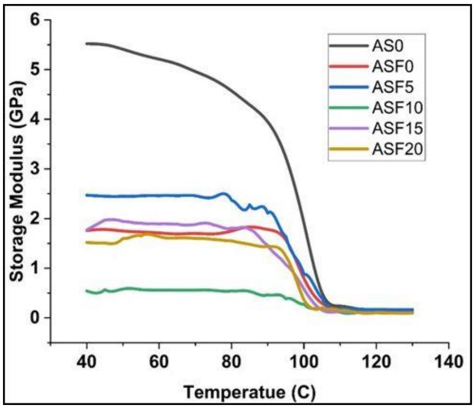

Fig.7. Effect of the Ramie Fiber Content on the Storage Modulus of ABS/CS (80:20 Blend).

The visualization of how the structural characteristics of the composites were altered by the incorporation of fibers was achieved through the use of the Cole-Cole plot (Hindalgo-Salazar et al., 2020; Chang et al., 2017). This plot effectively depicted the homogeneity of the system. The presence of a poor interfacial connection between the fiber and matrix was evident by the formation of semicircles in the composites, while an imperfect semicircle indicated a heterogeneous system (Rathinasabapathy & Krishnamoorthy, 2022). The Cole-Cole plot is depicted in the Fig 8. In the case of neat ABS, a closed, semi-circular curvature was observed. However, due to the presence of fibers and interfaces, the curve deviated further from a semicircle with increasing fiber content. This observation suggested that ramie fibers and CS contribute to the formation of heterogeneous systems with more intricate viscoelastic characteristics. The incorporation of both RF and starch into the composites had a notable impact on the configuration of the Cole-Cole plot.

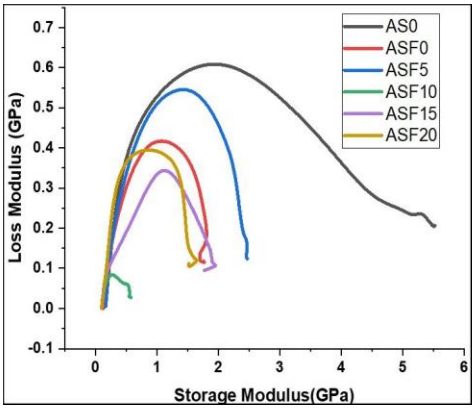

Fig.8. Effect of the RF content on the Cole–Cole Plot of the ABS/CS (80:20 blend).

One crucial indicator that illustrates the characteristics of viscoelasticity and the ability to dampen vibrations is the tangent of delta (*Tan D*). This value is obtained by dividing the loss modulus by the storage modulus observed during a cycle of dynamic loading. Fig 9 shows the dependent variable *Tan D* vs. temperature for each composite. *Tan D* increases with temperature for ABS and all composites during β-relaxation (glassy-rubbery transition area) until it reaches a critical value, at which point it decreases. The *Tan D* values near the *Tg* are lower when the ramie fiber is incorporated than when the ABS is used neatly,

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as shown in Fig 9. It was noted that when the fiber content increased, the glass transition temperature of the matrix decreased.

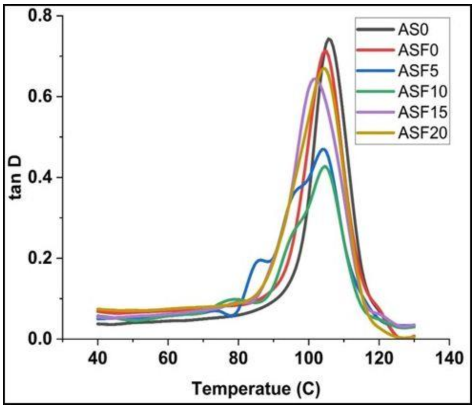

Fig.9. Effect of the RF Content on the *Tan D* of ABS/CS (80:20 Blend).

SEM analysis

SEM micrographs play a crucial role in the analysis of natural fiber composites by revealing the microstructure through images. The fractured samples under tensile stress were examined microscopically, and the resulting images are displayed in Fig 10 and Fig 11. The presence of RF in the ABS/CS blend led to the discovery of a cleavage structure on the fracture surface based on the obtained results. The micrographs clearly show the existence of pores and visible gaps, indicating the occurrence of debonding at the interface. The presence of voids observed in the composites in SEM images can be attributed to inadequate interfacial adhesion. When the bond between the fiber and matrix is weak, voids develop at the interface. A significant factor contributing to this issue may also be the inherent incompatibility between hydrophilic natural fibers and hydrophobic polymer matrix. Additionally, the formation of voids and fiber pull-out can be caused by a shrinkage mismatch between the fiber and matrix. The disparity in thermal coefficient expansion between fibers and matrix can lead to contraction at different rates, resulting in fiber separation and void formation. Moreover, an uneven distribution of fibers within the matrix can lead to fiber agglomeration, causing stress concentration and void formation. Natural fibers such as RF tend to absorb moisture, which vaporizes during processing and contributes to void formation. Similar results were observed by researchers reinforcing ramie fiber into PP, nylon, and epoxy matrices (Yi et al., 2011; Djafar et al., 2020; Chen-Yang et al., 2019). The development of this model uses a longitudinal dynamic vehicle; the vehicle model is assumed to move straight and ignores lateral and vertical movements. The force resulting from the bends and slopes of the road in this model is still there but in the form of a resultant force on the terrain conditions. The input in this model is a speed reference, which is determined based on decreases and increases in speed caused by road slopes and curves. Where the reference speed is in the form of a vehicle operating cycle, namely speed data in a cycle or speed cycle, the input speed reference determined for the model will then validate the success of model development, with the speed response produced by the model being similar to the input speed reference.

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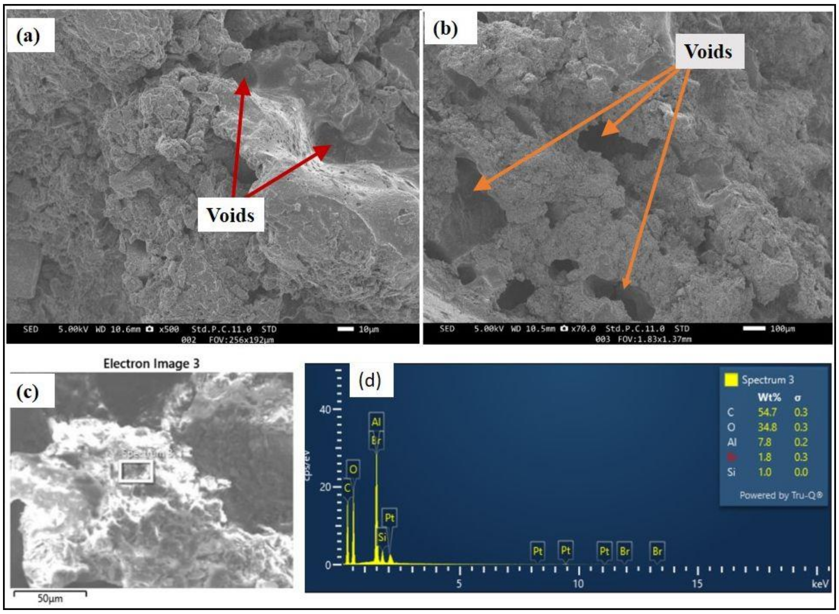

Fig. 10. SEM micrographs of ABS/Cassava starch blend (a) 10 µm, (b) 100 µm, (c) electron image (50 µm), and (d) EDX image.

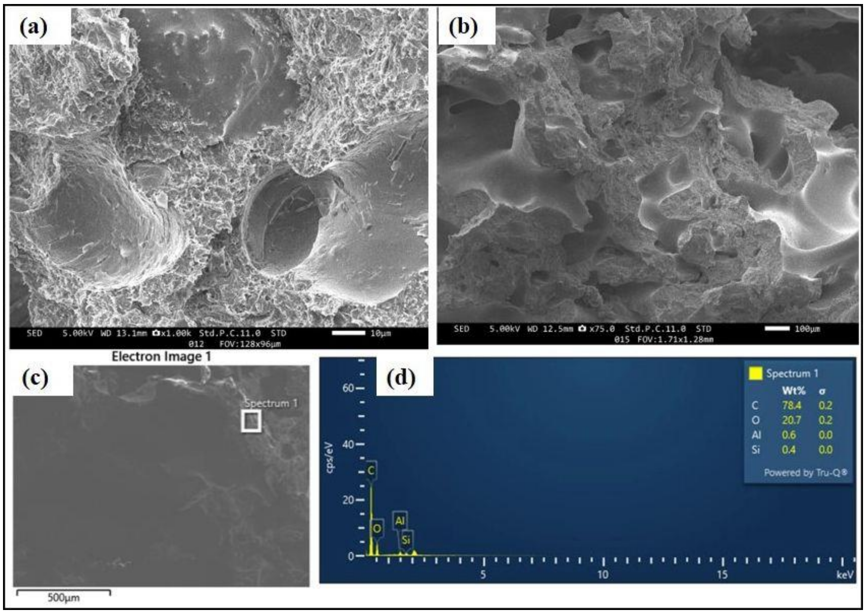

Fig. 11. SEM Micrographs of ABS/Cassava Starch blend (80:20)/ramie fiber (a) 10 µm, (b) 100 µm, (c) electron image (50 µm), and (d) EDX image.

https://doi.org/10.24191/jmeche.v22i1.4551

CONCLUSION

A polymer composite material was developed by synthesizing thermoplastic ABS/CS blends with the reinforcement of ramie fibers using a compression molding technique. Several evaluations were conducted to evaluate its mechanical properties, viscoelastic behavior, biodegradability, water absorption, and scanning electron microscopy (SEM) characteristics. The results of the tensile tests revealed a notable improvement in the tensile strength of the ABS/cassava starch blend, with a 60% increase (from 4 MPa to 6.4 MPa) attributed to the inclusion of 20 wt% RF. Additionally, the tensile modulus of the ABS/CS blend at an 80:20 ratio increased by 14.28% when 15 wt% ramie fiber was added to the blend. The introduction of CS to the ABS decreased the impact strength, however, when RF was added into the ABS/CS blend, the impact strength increased by 117% (from 36.03 J/m to 78.32 J/m) at 20 wt% RF in the blend. The incorporation of RF into the ABS/CS blend increased the degradation percentage to 1.215% after 15 days, 1.286% after 30 days, and 1.379% after 45 days. Nevertheless, the presence of RF in the ABS/CS blend had an adverse effect on the hardness, storage modulus, and loss modulus. SEM analysis illustrated the existence of voids in the matrix due to the addition of the RF. The water absorption increased from 12.65% to 27% owing to the incorporation of 20 wt% RF in the matrix due to the hydrophilic nature of the natural fibers. According to the findings from the evaluation of ABS/CF/RF composites, it is possible for these composites to serve as alternative materials to glass fiber and carbon fibers in the development of bio-composites suitable for use in automotive, aerospace, and home appliances.

While the primary emphasis of this study focused on the biodegradability, mechanical, and viscoelastic characteristics of polymers, it is also feasible to explore additional properties such as thermal and electrical behavior. Furthermore, the evaluation of mechanical properties can be conducted by fabricating bio-composites with identical ratios utilizing 3D printing technology.

ACKNOWLEDGMENTS/ FUNDING

The author wants to express his deepest gratitude to all my department colleagues who have encouragedme to complete this research work.This work received no specific grant from any funding agency.

CONFLICT OF INTERESTS STATEMENT

The author declares that they have no conflicts of interest.

AUTHORS’ CONTRIBUTIONS

All the work of this work is by a single author Basanta Kumar Behera.

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