Advances in Materials Research, *Vol. 14, No. 5 (2025) 449-465*
https://doi.org/10.12989/amr.2025.14.5.449

The role of sugarcane bagasse and TiC particle on the characteristics improvement of polymer composites

Bakhrul Ilmi, Suprianto*, Tulus B. Sitorus, Ikhwansyah Isranuri and Taufiq B. Nur

Department of Mechanical Engineering, Faculty of Engineering, Universitas Sumatera Utara,
Jl. Almamater Kampus USU, Medan, 20155, Indonesia

(*Received February 14, 2025, Revised June 24, 2025, Accepted October 23, 2025*)

Abstract. Polypropylene (PP) composites are widely used in structural applications. However, few studies have explored the combined reinforcement of natural fibers and ceramic particles. This study addresses that gap by investigating the effects of sugarcane bagasse (SCB) fibers and titanium carbide (TiC) particles on the mechanical and physical properties of PP composites. SCB and TiC were pre-milled for 60 minutes and incorporated into the PP matrix using reflux synthesis, followed by hot pressing at 170 °C. The result shows that the composite containing 5 wt.% TiC and 5 wt.% SCB exhibited optimal performance, with a tensile strength of 25 MPa, flexural strength of 30 MPa, and impact strength of 10 kJ/m^2 - representing significant improvements over neat PP. The X-ray diffraction analysis revealed an increase in crystallinity with the addition of TiC, while SEM images showed a ductile fracture morphology and uniform TiC dispersion. These findings demonstrate that dual reinforcement with SCB and TiC effectively enhances the structural performance of PP, offering a sustainable and high-performance composite material.

Keywords: composite; reflux; mechanical properties; natural fibers

1. Introduction

The fiber-reinforced composites have attracted significant attention from many researchers due to their promising mechanical performance, environmental sustainability, and potential for lightweight structural applications. Besides these characteristics, the durability of materials is also important, especially for those used for long-term environmental exposure. Durability refers to a material's ability to retain mechanical integrity, resist moisture, maintain thermal stability, and sustain fiber-matrix adhesion under service conditions (Sanjay *et al*. 2018). Composites reinforced with natural fibers and Titanium Carbide (TiC) has been shown to significantly enhance the mechanical integrity of the material (Xiong *et al*. 2024). TiC acts as a key reinforcing filler that improves mechanical properties and wear resistance (Chelliah, 2019), and contributes to the microstructural stability of the composite (Radhakrishnan *et al*. 2021), resulting in enhanced performance across various applications.

The use of natural fibers such as sugarcane bagasse (SCB) contributes not only to improved fatigue resistance in polypropylene (PP) matrix composites (Pamudji *et al*. 2021), but also provides

---

*Corresponding author, Ph.D., E-mail: suprianto@usu.ac.id

http://www.techno-press.org/?journal=amr&subpage=5 ISSN: 2234-0912 (Print), 2234-179X (Online)

notable sustainability advantages. Although natural fibers typically exhibit relatively low inherent strength, their performance can be significantly enhanced through optimization strategies such as fiber loading, surface treatments, and the use of coupling agents (Monroy Vázquez *et al*. 2022). Rich in cellulose, SCB fibers provide effective mechanical reinforcement and can be processed into various forms, including fibers or nanocellulose, which are compatible with a range of polymer matrices (Mokhena *et al*. 2018, Wirawan *et al*. 2012).

However, natural fibers are inherently hydrophilic, leading to water absorption, dimensional instability, and mechanical degradation particularly in humid environments (Dogra *et al*. 2021). The presence of moisture can cause swelling, interfacial debonding, and strength reductions of up to 31% (Sanjay *et al*. 2018). Surface treatments such as alkali and silane modifications have been shown to reduce hydrophilicity, enhance surface roughness, and improve fiber matrix adhesion, thereby increasing tensile strength, stiffness, and thermal stability (Anggono *et al*. 2017, Correa-Aguirre *et al*. 2020, Vaneewari and Saranya 2023).

Hybrid reinforcements, such as the combination of natural fibers with ceramic or nano-fillers, have the potential to overcome moisture sensitivity, thermal instability, and interfacial weaknesses in natural fiber composites. The introduction of TiC nanoparticles into thermoplastic matrices has been shown to improve tensile strength and crystallinity (Tebeta *et al*. 2024, Vidakis *et al*. 2023). Similarly, nano-sized bio-fillers enhance compatibility, moisture resistance, and dimensional stability, mainly due to their reduced particle size, increased crystallinity, and improved thermal performance at the filler matrix interface (Shravanabelagola Nagaraja Setty *et al*. 2022). In particular, the integration of Titanium Carbide (TiC) via mechanical stirring into natural fiber-based composites significantly enhances mechanical strength and moisture resistance, highlighting the effectiveness of in-situ dispersion during synthesis (Arshad *et al*. 2021). In natural rubber composites, TiC nanocrystals dispersed in the solid phase during internal mixing enhance elasticity, tensile strength, and thermal resistance (Jayasinghe *et al*. 2020). Moreover, the introduction of TiC particles into a hemp-epoxy fiber matrix, fabricated by hot compression molding, has shown the substantial improvements in toughness, interfacial adhesion, and crack resistance (Karthikeyan *et al*. 2025). The synthesize of natural fiber composites with Titanium Carbide (TiC) and other nanostructured reinforcements can be carried out using the reflux method. This technique has proven effective for the synthesis of nanoparticles and nanostructured materials (Chandel *et al*. 2022). By modifying variables such as reaction duration, precursor concentration, and solvent type, this method allows precise control over particle size, morphology, and crystallinity (Vossmeyer *et al*. 1994, Zhang *et al*. 2006).

The synthesis of composite reinforced by natural and ceramic filler systems has been widely studied by many researchers, with a primary focus on the individual reinforcement effects of SCB and TiC. However, the interaction between SCB fibers and TiC particles within a PP matrix remains underexplored. Selecting an appropriate synthesis model selected for this composite remains a challenge, particularly in achieving desirable characteristics and interfacial uniformity. This study addresses the research gap by systematically investigating the dual reinforcement of PP composites using both SCB fibers and TiC particles, synthesized via the reflux method. Specifically, it examines how varying TiC-SCB compositions affect mechanical performance, crystallinity, moisture resistance, and thermal stability. By integrating bio-based and nano-ceramic reinforcements within a controlled synthesis framework, this research aims to develop a lightweight yet durable composite system suitable for demanding applications such as vortex turbine components where mechanical reliability, environmental durability, and weight efficiency are critical.

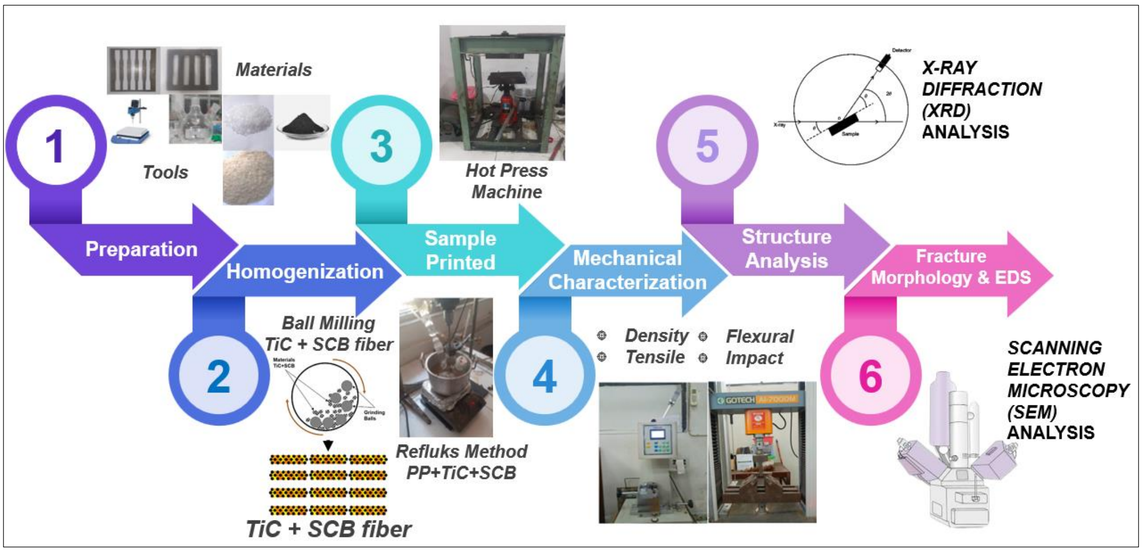

Fig. 1 Schematic of sample preparation and testing stages of PP/SCB and PP/TiC/SCB material

2. Material and method

The schematic diagram illustrating the composite fabrication and testing procedures in this investigation is shown in Fig. 1.

2.1 Material

Polypropylene (PP) was used as the matrix, with titanium carbide (TiC) and sugarcane bagasse fiber as reinforcement materials. In this study, PP was sourced from PT. Lotte Chemical Titan in Jakarta, Indonesia, and TiC particles (with an average size of 1.4 µm, a density of 4.94 g/cm^3, and a melting point of 3500 °C) were supplied by CHENGDU HUARUI INDUSTRIAL CO., LTD. in Chengdu, China. Sugarcane bagasse fibers were obtained from North Sumatra, Indonesia, the fibers were dried at 37.5 °C to remove moisture content and refined to a particle size of approximately 0.4 mm.

2.2 Synthesis of PP/SCB and PP/TiC/SCB composites

In this current study, different composites were designed with varying compositions as shown in Table 1. The reinforcement materials consist of TiC particles and SCB fiber. Specifically, for the PP/TiC/SCB composite, the mixing process and refinement of both TiC and SCB were performed using mechanical alloying (MA) with 5 mm diameter grinding balls at 300 rpm for 60 minutes. Furthermore, the model composites - PP/SCB and PP/TiC/SCB - were homogenized using the reflux method.

The reflux process was carried out using a CORNING PC-400D hotplate to dissolve PP with a xylene solution within a 1-liter three-neck flask, heated to 180 °C. The composites were prepared by stirring using an IKA-RW 20 electric stirrer running at 500 rpm for 80 minutes. The mixing process of SCB and TiC/SCB into PP polymer according to weight ratio is shown in Table 1.

Table 1 The model composite material's composition

Models composite	Composite designation	Composition		
		Polymer (wt.%)	TiC (wt.%)	SCB (wt.%)
PP/SCB-1	1A	95	PP/SCB-1	1A
PP/SCB-2	2A	90	PP/SCB-2	2A
PP/SCB-3	3A	85	PP/SCB-3	3A
PP/TiC/SCB-1	1B	90	PP/TiC/SCB-1	1B
PP/TiC/SCB-2	2B	83	PP/TiC/SCB-2	2B
PP/TiC/SCB-3	3B	76	PP/TiC/SCB-3	3B

Following the reflux treatment, the PP/SCB and PP/TiC/SCB model composites are cooled to room temperature, and the residual solvent is removed through evaporation or filtration. The resulting composite materials were formed using a hot press machine with predefined molds conforming to applicable standards. The hot pressing was conducted at a temperature range of 100 °C to 300 °C, using a conduction-based heating method, with pressure levels were controlled by a hydraulic system (Lyutyy *et al*. 2024). The hot press process was carried out for 20 minutes at 180 °C under a pressure of 12 MPa (Nadhari *et al*. 2020).

2.3 Mechanical characterization

The Investigation of mechanical characteristics was carried out using several standardized methods, including flexural and tensile strength tests, referred to ASTM D790-03 and D638-22 were performed by using a universal testing machine (UTM), 2 mm/min loading rate applied in flexural and tensile test at room temperature. The Archimedes' Method was utilized for the density measurement of the composite materials. Furthermore, the impact test was conducted using the Izod method in accordance with ASTM D256-10, performed on a GT-7045-MD machine at room temperature.

2.4 Structure analysis and morphology analysis

X-ray diffraction (XRD) analysis was conducted to examine the role of TiC particles on the crystallinity of polypropylene (PP) composites reinforced with sugarcane bagasse fibers. The measurements were performed using Cu Kα radiation ($\lambda = 1.5406$ Å) with a 2-theta (2θ) scan range of 40°-80°, a scanning speed ranging from 0.01° to 100° per minute, and a minimum step size of 0.005°. In addition, the morphologies of the polymer matrix composite fracture were observed with the aid of a scanning electron microscope (SEM).

3. Result and discussion

3.1 Physical and mechanical aspects

Fig. 2 illustrates the density values of varying PP composites reinforced with SCB and TiC particles. It was observed that the incorporation of TiC into the PP/TiC/SCB-1 composite led to a

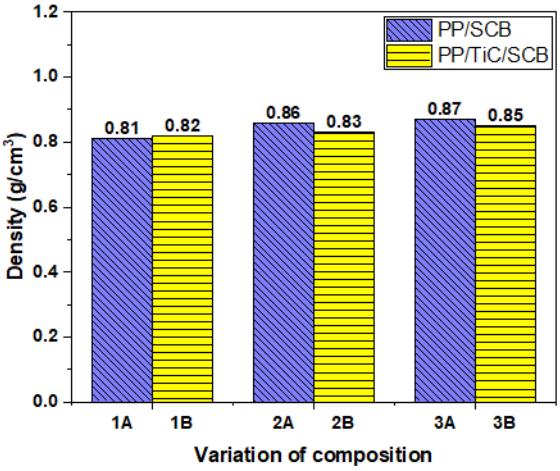

Fig. 2 The density of model composites with varying PP/SCB and PP/TiC/SCB compositions

slight increase in density compared to the PP/SCB-1 composite. However, the densities of PP/TiC/SCB composites were lower than those of PP/SCB composites with higher SCB content (10 and 15 wt.%), as seen in samples 2B and 3B (in Fig. 2), which recorded density values of 0.83 g/cm^3 and 0.85 g/cm^3, respectively. This difference may be attributed to the absence of pre-processing in the PP/SCB samples, resulting in SCB has a high moisture content (Chen *et al*. 2021). The retained moisture in SCB contributes to the increased density observed in the PP/SCB composites, making them denser than the PP/TiC/SCB variations. The change in density due to moisture affects the load capacity and overall performance of the composite material (P Subramaniyan *et al*. 2021). In fiber-reinforced polymer composites, moisture changes density and adds weight (Airale *et al*. 2016). Conversely, the PP/TiC/SCB composites variation involves the pre-milling TiC/SCB fibers using MA. The mechanical alloying (MA) process successfully synthesized composite materials with a uniform distribution of particles in both metal and polymer matrices (Oliveira *et al*. 2019). It is believed that the density of composites is influenced by the composition of SCB and TiC, distribution, the interfacial bonding between the PP matrix and the reinforcement, and also the homogeneity of the composites (Motaung *et al*. 2015). The density of the PP/TiC/SCB-2 composite did not vary significantly, likely due to the correlated with their small ratios between TiC/SCB with total density. Based on the results, the PP/SCB and PP/TiC/SCB composites have lighter densities than Polylactic Acid (PLA), which is commonly used as a material for vortex turbine impellers, with densities of 1.1 g/cm^3 (Khor *et al*. 2024).

The tensile strength of the composite materials, PP/SCB and PP/TiC/SCB, is presented in Fig. 3. The tensile strength of the composites tended to decrease with increasing amounts of SCB and TiC reinforcements. The highest tensile strength, 24 MPa, was achieved by 5 wt.% for TiC and SCB in the PP/TiC/SCB-1, while the lowest strength, 15 MPa, was recorded for PP/SCB-3 with 15 wt.% SCB. In this study, the tensile strength showed an increase of approximately 21.8%. These findings are in line with those of Vidakis *et al*. who reported a 17.1% improvement in tensile strength when TiC is added to the PP matrix (Vidakis *et al*. 2023). This enhancement is attributed to the intrinsic strength of TiC particles, which exhibit tensile strength values close to 140 MPa (Suraya *et al*. 2014). The increasing tensile strength in the PP/TiC/SCB correlated with TiC particles, which have superior mechanical properties and minimize micro-deformation in the PP matrix when subjected to tensile

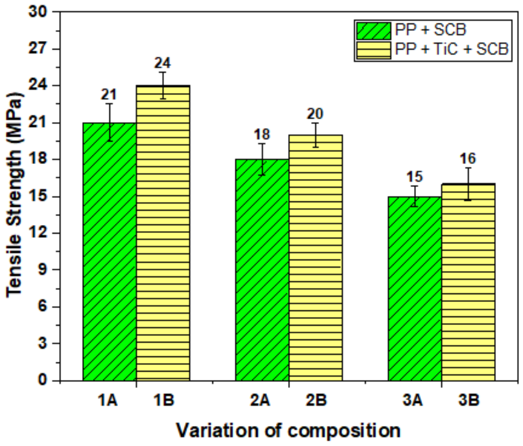

Fig. 3 Tensile strength test result of the composite materials

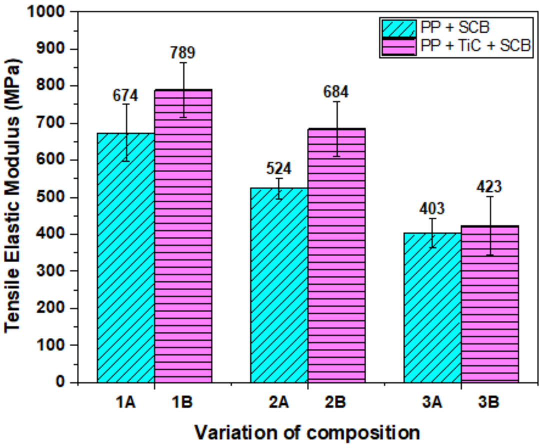

Fig. 4 Tensile elastic modulus result of the composite materials

load (Long *et al.* 2020). Not only originated from their strength, but the particle size and homogeneous distribution of TiC particles also play a crucial role in enhancing the mechanical performance of composite materials (Maziarz *et al.* 2020). Furthermore, the inclusion of TiC particles significantly affects the tensile elastic modulus, as illustrated in Fig. 4.

The PP/TiC/SCB composite model has a greater modulus than PP/SCB because of the increasing TiC content. The highest tensile elastic modulus of 789 MPa was observed in PP/TiC/SCB-1 (1B), in contrast, a low modulus of 403 MPa was obtained for PP/SCB-3 (3A). These results were higher than 124.4 MPa, which were reported for TiC particle-reinforced PP matrix composite (Vidakis *et al.* 2023). The inclusion of bagasse fiber is responsible for the increase in the tensile elastic modulus (Zakaria *et al.* 2020). The combined reinforcement of bagasse fiber and TiC particles was homogenized via ball milling, a method proven effective in improving the modulus of polymer composites (Gao *et al.* 2023). The tensile elastic modulus improved by TiC particles through the structure strengthened by particles, which causes more stiffness of the composites obtained (Vidakis *et al.* 2023). On the other hand, the excessive SCB percentage potentially promotes the

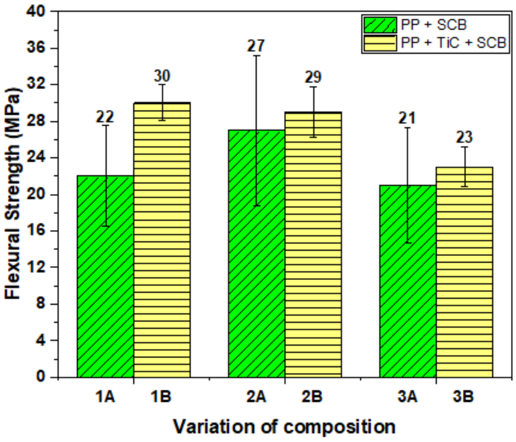

Fig. 5 Flexural strength test result of the composite materials

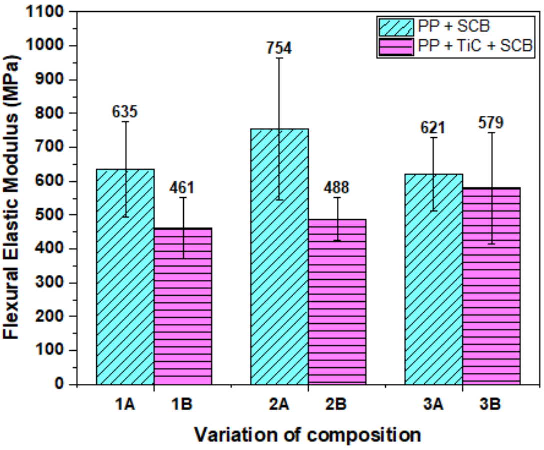

Fig. 6 Flexural elastic modulus result of the composite materials

agglomeration phenomenon, void formation, and poor adhesion between SCB and the PP matrix (Mustaffa *et al*. 2017). The tensile elastic modulus decreased due to more SCB content than TiC particles, and the fiber with more elasticity reduced the composite stiffness. It is known that the SCB elastic modulus is about 19 GPa, which is lower than TiC particles (Anidha *et al*. 2019). A 295~320 MPa tensile elastic modulus of the natural fiber-reinforced composite was reported in another research (Safri *et al*. 2019, Md Shah *et al*. 2021). In the present study, the highest tensile strengths 24 MPa and 21 MPa for PP/TiC/SCB-1 and PP/SCB-1 composites, respectively, are significantly higher than the PLA-Carbon Composite material, which has 10.7 MPa (Khor *et al*. 2024), and the biocomposite material of pine resin reinforced with starch and hemp fiber, 13.97 MPa (Sakhare *et al*. 2024). These results are likely associated with the pre-processing steps involving ball milling, followed by the reflux treatment applied to the PP matrix, SCB fibers, and TiC/SCB mixtures.

Fig. 5 presents the flexural performance of the composite models, with the highest and lowest flexural strengths recorded at 30 MPa and 15 MPa for PP/TiC/SCB-1 (1B) and PP/SCB-3 (3A), respectively. The flexural strength is influenced by many factors such as reinforced materials,

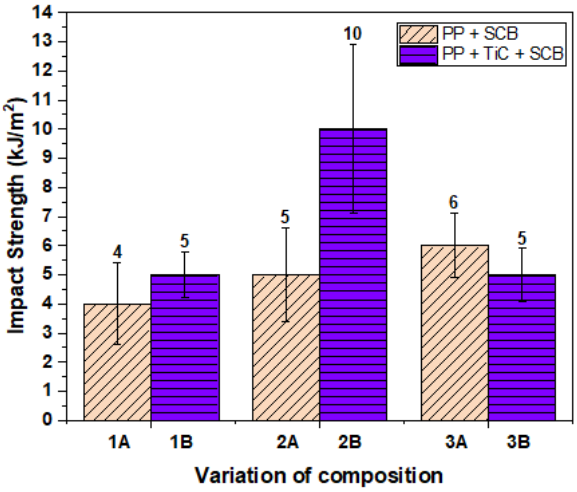

Fig. 7 Impact strength test result of the composite materials

homogeneity, and porosity (Simamora *et al*. 2023). In this current study, the flexural strength of PP/TiC/SCB-1 corresponds well with its microstructure, as lower porosity was observed, as shown in Fig. 10.

The presence of the porosities leads to a reduction in the flexural strength, contributing to uneven stress distribution within the composite (Kultayeva, 2024). Furthermore, it is believed that the unbalanced ratio between TiC particles and SCB fiber is closely associated with an ineffective interface bonding, the negative effects of unbalanced reinforcement materials were reported in other studies (Junaedi *et al*. 2020). The flexural modulus rises for PP/SCB-(1,2) but slightly decreases with higher SCB content, as observed in PP/SCB-3 (Fig. 6).

The decrease in flexural modulus associated with higher SCB content promotes formation during processing, causing imperfect fiber-matrix interaction and suboptimal interface bonding (Subramonian *et al*. 2016, Mohit and Arul Mozhi Selvan, 2018). Although the flexural modulus of PP/TiC/SCB is lower than that of PP/SCB, the addition of TiC particles still contributes to the improvement in the flexural modulus of PP/TiC/SCB composites. The results indicate that the flexural behavior of these PP composite models - including both strength and modulus - exhibits variability and instability. This phenomenon is influenced by many factors, including fiber composition, processing conditions, fiber-matrix interaction, and the presence of compatibilizers. One of the critical factors is the formation of atactic fractions or random polymer structures (Paukkeri and Lehtinen, 1993). It is believed that the molecular chains of the PP matrix become dispersed and disordered, which significantly influences the mechanical properties, morphology, and crystallization behavior of the material (Kiss *et al*. 2020).

In this current study, the impact strength of the PP composite models was evaluated using the Izod method, as shown in Fig. 7. With increasing SCB fiber content, a slight improvement in impact strength was observed. In contrast, a better strength of the composites with a combination of TiC particles and SCB fiber was observed, particularly for PP/TiC/SCB-2, which has 10 kJ/m² of impact strength. This result is better than neat PP, which has 5.4 kJ/m². Previous studies proposed that incorporating TiC into PP composites enhances mechanical performance (Vidakis *et al*. 2023). However, a further increase in SCB content, as in PP/TiC/SCB-3, led to a notable decline in impact strength.

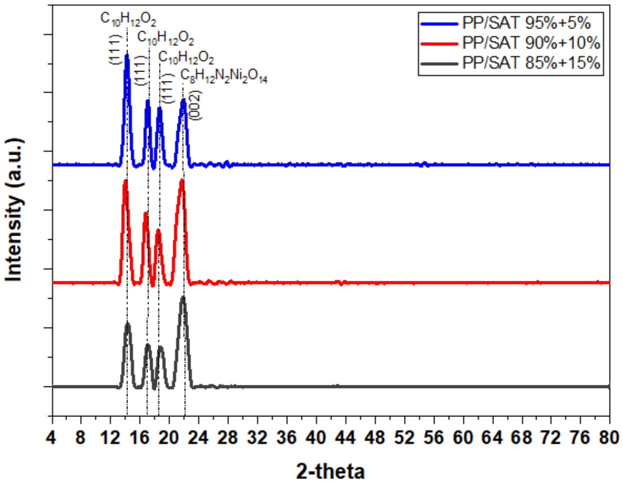

Fig. 8 XRD spectra of PP composite models reinforced with SCB

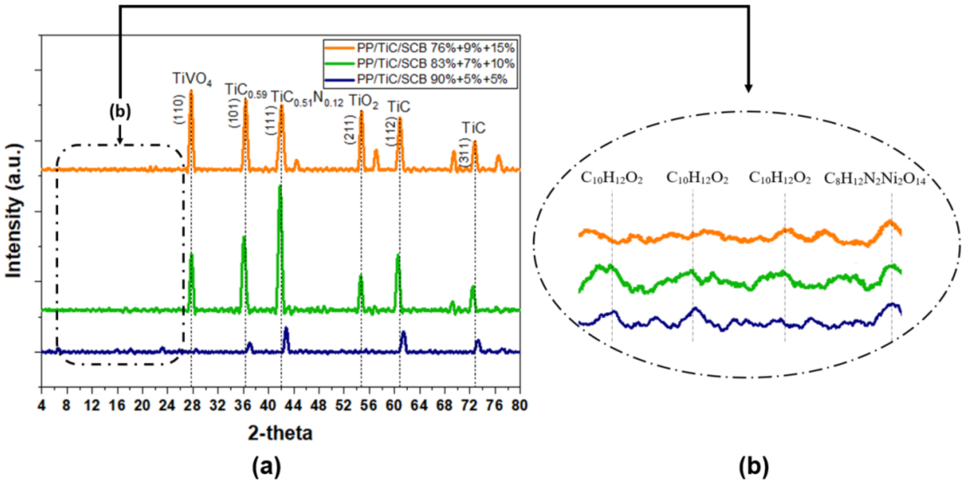

Fig. 9 (a) XRD pattern for PP/TiC/SCB composites, (b) Enlarged area A at low 2-theta

This phenomenon may be attributed to the formation of porosity, non-homogeneous interactions, and unstable interfaces between the PP matrix (Watanabe *et al*. 2018), the TiC, and bagasse fibers, which significantly contribute to the overall decrease in impact strength (George and Bhattacharyya, 2021). In contrast, the lowest impact strength (4 kJ/m²) for PP/SCB-1 which contains 5 wt.% SCB and no TiC particles.

Fig. 8 presents the XRD spectra of polymer composites containing varying amounts of sugarcane bagasse (SCB) fibers. The SCB percentage does not significantly affect the peak intensities. Four main peaks appear at low 2-theta (2θ) = 14.22°, 17.16°, 18.72°, and 21.96°, respectively. These peaks indicate that the PP/SCB composites exhibit a semi-crystalline phase, while the SCB itself is predominantly amorphous (Caliari *et al*. 2017, Aprilia *et al*. 2018). The increase of SCB fiber (15wt.%) reduced peaks, which correspond well with their origin characteristics. Furthermore, the XRD spectra of the PP/TiC/SCB composites are shown in Fig. 9. The combination of TiC particles

Table 2 The crystalline degree and crystallite size of PP/SCB and PP/TiC/SCB composite models

Composition	Crystalline Degree (%)	Average Crystal Size (*n*m)
PP/SCB-1	38.73	5.82
PP/SCB-2	39.62	5.09
PP/SCB-3	43.11	4.97
PP/TiC/SCB-1	43.19	10.43
PP/TiC/SCB-2	45.92	12.24
PP/TiC/SCB-3	46.51	16.66

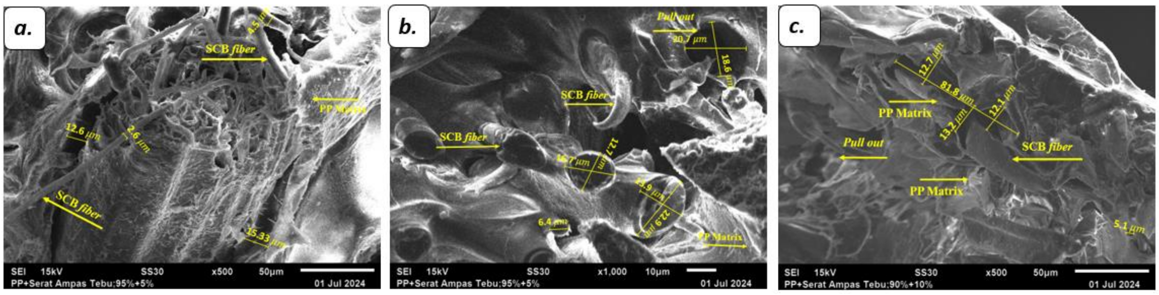

Fig. 10 presents SEM micrographs of PP/SCB fiber fractured surfaces, illustrating different SCB fiber concentrations: (a) 5 wt.%, (b) 10 wt.%, and (c) 15 wt.%

and SCB fibers induces significant changes in the XRD patterns, particularly due to the inclusion of TiC particles. Consequently, the PP-related diffraction intensities disappeared, however, due to the enlarged area at low 2-Theta, peaks were still detected (see Fig. 9b). The Ti-based crystalline was observed at 27.68°, 36.4°, 42.16°, 54.8°, 60.9°, and 72.76° which is indicated as $TiVO_4$, $TiC_{0.59}$, $TiC_{0.51}N_{0.12}$, TiO_2, and TiC. These findings closely resemble the TiC spectra reported by Zhang *et al.* (2022) in ZrC-SiC/TiC-NCs composite, which occurred at 2-Theta 36°, 43°, 61.9°, and 73.4°.

The increased TiC particle content within the PP matrix is evidenced by the increase in crystallinity and the average crystallite size, see Table 2. The highest crystallinity was observed in PP/TiC/SCB-3, which exhibited a value of 46.51%. The average crystallite size experienced a reduction from 5.82 nm to 4.97 nm with the increase of the SCB fibers percentage. More SCB fiber influences the interaction between PP and SCB, reducing PP molecular mobility during cooling and finally discouraging crystal formation (Lila *et al*. 2018). Both TIC/SCB have a different effect on the crystalline degree and crystallite size of the PP composite, TiC has a significant effect on increasing the crystallite size and microhardness, as well as the homogeneity of particle distribution (Alam *et al*. 2021). On the other hand, SCB reduces nanoparticles using ball milling, leading to a 55.2% enhancement in crystallinity (Kathiresan and Sivaraj, 2016). SCB-fiber changes the morphology and particle size during the ball milling process, which affects crystallinity (Sitotaw *et al*. 2023).

3.2 Morphological evaluation

The fracture morphology was examined to analyze the interfacial characteristics of PP/SCB and PP/TiC/SCB composites, as shown in Fig. 10.

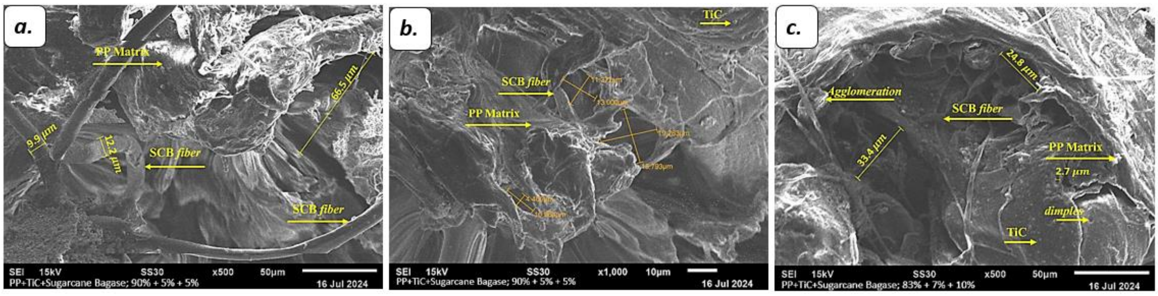

Fig. 11 presents (SEM) micrographs of the fractured surfaces of PP/TiC/SCB composites with varying TiC/SCB ratios, (a) 5/5 wt.%, (b) 7/10 wt.%, and (c) 9/15 wt.%

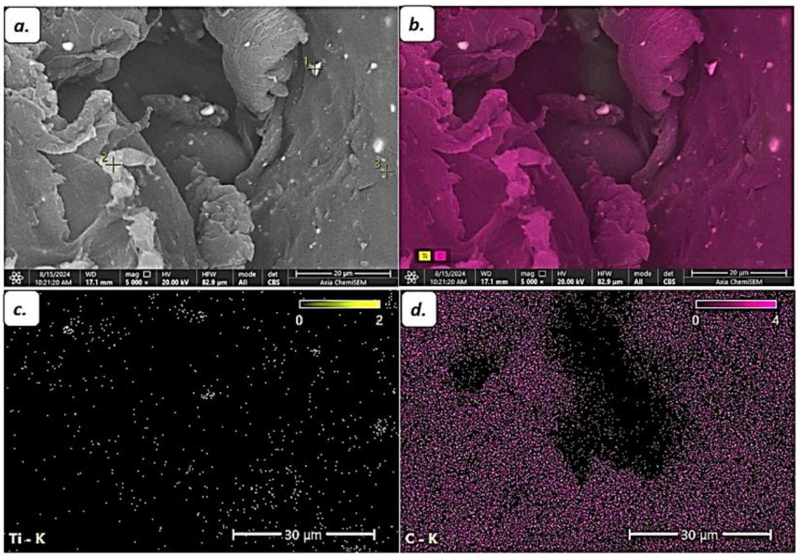

Fig. 12 (a) SEM image and EDS results showing (b) phases-map, (c) Ti-map, (d) C-map of the PP/TiC/SCB composite with a 7/10 wt.% TiC/SCB ratio

It is observed that unbroken SCB fibers are detached from the PP matrix, generating voids in the PP/SCB composite. These phenomena indicate that poor and unstable interaction between the matrix and the fiber occurred in some areas. These phenomena cause debonding, voids, and cracks in those areas. The largest void size 10.7 µm occurred in the area between the matrix and SCB (5 wt.%), see Fig. 10a. Due to fiber pull-out from the matrix, voids formed and were visible in the composite, see Fig. 10(a-c). An uneven and wavy fracture surface typically indicates good ductility in the composite material (Ez-Zahraoui *et al*. 2023).

The fracture morphologies of the PP/TiC/SCB composites are shown in Fig. 11. The fracture surfaces of the composite models reveal the presence of multiple air voids, as indicated in Fig. 11(a-c). Additionally, Fig. 11b shows agglomeration of the matrix and evidence of pull-out still occurring in some areas of composites, in which SCB fibers detach from the PP matrix, leading to void formation, as seen in Fig. 11(a-c). The void formation is probably influenced by poor adhesion and interaction between constituents (PP, TiC, SCB), as well as the non-homogenous distribution of both TiC particles and SCB fibers.

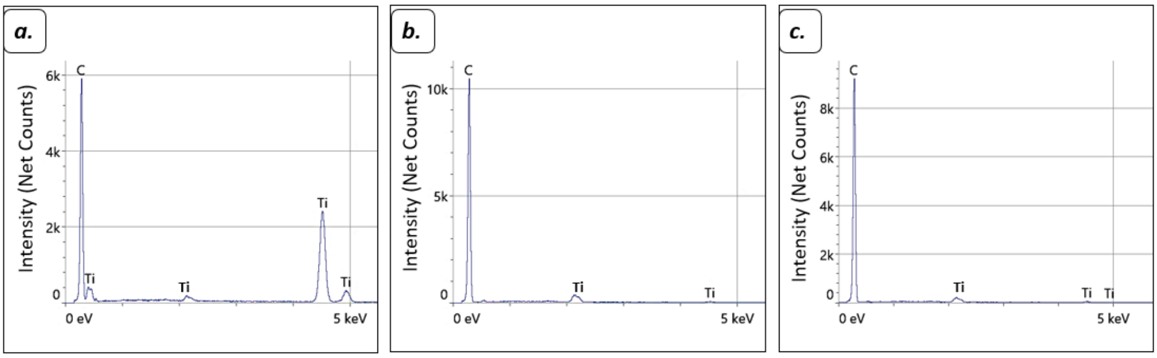

Fig. 13 EDS intensity of PP/TiC/SCB composites with 7/10 wt.% TiC/SCB ratio at different points in Fig. 12a, (a) point ‘A’, (b) point ‘B’, and (c) point ‘C’

Furthermore, EDS mapping of the PP/TiC/SCB composite was conducted, and the results are shown in Fig. 12.

The Ti elements are visible and more homogeneously distributed between the matrix and SCB (Fig. 12c), with only a small portion of TiC particles forming clusters, which indicates that pre-milling of TiC-SCB in the pre-processing was successfully refined and promotes homogeneous distribution of the TiC particles. The C element reflects the main constituent element of the PP matrix, which is dispersed in most areas of the composite.

Fig. 13 presents the EDS analysis of the polypropylene (PP)-based TiC/SCB composite containing a 7/10 wt.% TiC/SCB ratio, conducted at three regions (A, B, and C) in Fig. 12a. Point ‘A’ which contains small bright particles less than 5 µm consists of 50.8 wt.% of Ti and 49.2 wt.% C. This result confirms that the TiC particles were successfully dispersed within the PP matrix as reinforcement materials. The point ‘B’ and ‘C’ which were identified as the SCB fiber and PP-matrix, respectively, show that the C element is predominant (>98 wt.%) at both points. Only a small portion of Ti, or less than 2 wt.% within this region. This finding is consistent with the EDS intensity shown in Figs. 13(b-c). High C content at point ‘B’ is attributed to the SCB fibers, which originate from natural sources and are rich in carbon-based constituents (Devadiga *et al*. 2020).

4. Conclusions

This study effectively demonstrates that incorporating Titanium Carbide (TiC) and sugarcane bagasse (SCB) significantly enhances the mechanical performance of polypropylene (PP) composites. The optimal ratios of 5% TiC and 7% SCB deliver the highest tensile, flexural, and impact strengths. Nevertheless, morphological analysis reveals interfacial voids that may compromise bonding quality. These findings underscore the critical importance of optimizing filler and matrix materials to improve composite performance. Consequently, this research provides valuable insights for developing environmentally friendly composites with enhanced engineering capabilities, particularly for applications such as vortex turbine impeller materials.

Acknowledgement

The authors would like to express their gratitude to the Polymer Chemistry Laboratory of the

Faculty of Mathematics and Natural Sciences, as well as to the members of the Alloys and Metal Processing Research Center at Universitas Sumatera Utara.

References

Airale, A.G., Carello, M., Ferraris, A. and Sisca, L. (2016), "Moisture effect on mechanical properties of polymeric composite materials", *AIP Conference Proceedings*, **1736**, 020020. https://doi.org/10.1063/1.4949595

Alam, M.A., Ya, H.H., Azeem, M., Yusuf, M., Sapuan, S.M., Masood, F. (2021), "Investigating the effect of mixing time on the crystallite size and lattice strain of the AA7075/TiC composites", *Materwiss Werksttech*, **52**, 1112-1120. https://doi.org/10.1002/mawe.202000324

Anggono, J., Sugondo, S., Sewucipto, S., Purwaningsih, H. and Henrico, S. (2017), "The use of sugarcane bagasse in PP matrix composites: A comparative study of bagasse treatment using calcium hydroxide and sodium hydroxide on composite strength", *AIP Conference Proceedings*, **1788**, 030055. https://doi.org/10.1063/1.4968308

Anidha, S., Latha, N. and Muthukkumar, M. (2019), "Reinforcement of Aramid fiber with bagasse epoxy biodegradable composite: investigations on mechanical properties and surface morphology", *J. Mater. Res. Techn.*, **8**, 3198-3212. https://doi.org/10.1016/j.jmrt.2019.05.008

Aprilia, N.A.S., Mulyati, S., Alam, P.N., Karmila and Ambarita, A.C. (2018), "Characterization nano crystalline cellulose from sugarcane baggase for reinforcement in polymer composites: Effect of formic acid concentrations", *IOP Conf. Ser. Mater. Sci. Eng.*, **345**, 012033. https://doi.org/10.1088/1757-899X/345/1/012033

Arshad, M.N., Mohit, H., Sanjay, M.R., Siengchin, S., Khan, A., Alotaibi, M.M., Asiri, A.M., Rub, M.A. (2021), "Effect of coir fiber and TiC nanoparticles on basalt fiber reinforced epoxy hybrid composites: physico-mechanical characteristics", *Cellulose*, **28**, 3451-3471. https://doi.org/10.1007/s10570-021-03752-7

ASTM D790-03 (2017), Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials, American Society for Testing and Materials: West Conshohocken, PA, USA.

ASTM D638-22 (2022), Standard Test Method for Tensile Properties of Plastics, American Society for Testing and Materials: West Conshohocken, PA, USA.

ASTM D256-10 (2023), Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastic, *ASTM international*, West Conshohocken, PA, USA.

Caliari, Í.P., Barbosa, M.H.P., Ferreira, S.O. and Teófilo, R.F. (2017), "Estimation of cellulose crystallinity of sugarcane biomass using near infrared spectroscopy and multivariate analysis methods", *Carbohydr. Polym.*, **158**, 20-28. https://doi.org/10.1016/j.carbpol.2016.12.005

Chandel, V., Biswas, D., Roy, S., Vaidya, D., Verma, A. and Gupta, A. (2022), "Current advancements in pectin: extraction, properties and multifunctional applications", *Foods*, **11**, 2683. https://doi.org/10.3390/foods11172683

Chelliah, A. (2019), "Mechanical properties and abrasive wear of different weight percentage of tic filled basalt fabric reinforced epoxy composites", *Mater. Res.*, **22**. https://doi.org/10.1590/1980-5373-mr-2018-0431

Chen, X., Liang, J., Liao, P., Huang, W., He, J. and Chen, J. (2021), "Effect of process parameters and raw material characteristics on the physical and mechanical quality of sugarcane bagasse pellets", *Biomass Bioenerg.*, **154**, 106242. https://doi.org/10.1016/j.biombioe.2021.106242

Correa-Aguirre, J.P., Luna-Vera, F., Caicedo, C., Vera-Mondragón, B. and Hidalgo-Salazar, M.A. (2020), "The effects of reprocessing and fiber treatments on the properties of polypropylene-sugarcane bagasse biocomposites", *Polymers*, **12**, 1440. https://doi.org/10.3390/polym12071440

Cozzoli, P.D., Kornowski, A. and Weller, H. (2003), "Low-temperature synthesis of soluble and processable organic-capped anatase TiO_2 nanorods", *J. Am. Chem. Soc.*, **125**, 14539-14548. https://doi.org/10.1021/ja036505h

Devadiga, D.G., Bhat, K.S. and Mahesha, G. (2020), "Sugarcane bagasse fiber reinforced composites: Recent advances and applications", *Cogent Eng.*, **7**, 1823159. https://doi.org/10.1080/23311916.2020.1823159

Dogra, V., Kishore, C., Verma, A., Rana, A.K., Gaur, A. (2021). "Fabrication and experimental testing of hybrid composite material having biodegradable bagasse fiber in a modified epoxy resin: Evaluation of mechanical and morphological behavior", *Appl. Sci. Eng. Prog.*, **14**(4), 661-667. https://doi.org/10.14416/j.asep.2021.06.002

Ez-Zahraoui, S., Sabir, S., Berchane, S., Bouhfid, R., Qaiss, A.E.K., Semlali Aouragh Hassani, F. and El Achaby, M. (2023), "Toughening effect of thermoplastic polyurethane elastomer on the properties of fly a sh-reinforced polypropylene-based composites", *Polym. Compos.*, **44**, 1534-1545. https://doi.org/10.1002/pc.27186

Gao, Z., Han, Q., Liu, J., Zhao, K., Yu, Y., Feng, Y. and Han, S. (2023), "Dispersion of carbon nanotubes improved by ball milling to prepare functional epoxy nanocomposites", *Coatings*, **13**, 649. https://doi.org/10.3390/coatings13030649

George, J. and Bhattacharyya, D. (2021), "Biocarbon reinforced polypropylene composite: An investigation of mechanical and filler behavior through advanced dynamic atomic force microscopy and X-ray micro-CT", *Express Polym. Lett.*, **15**, 224-235. https://doi.org/10.3144/expresspolymlett.2021.20

Jayasinghe, J.M.A.R.B., De Silva, R.T., de Silva, K.M.N., de Silva, R.M., Silva, V.A. (2020), "Titanium carbide ceramic nanocrystals to enhance the physicochemical properties of natural rubber composites", *RSC Adv*, **10**, 19290-19299. https://doi.org/10.1039/D0RA01943G

Junaedi, H., Baig, M., Dawood, A., Albahkali, E. and Almajid, A. (2020), "Mechanical and physical properties of short carbon fiber and nanofiller-reinforced polypropylene hybrid nanocomposites, *Polymers*, **12**, 2851. https://doi.org/10.3390/polym12122851

Kathiresan, M. and Sivaraj, P. (2016), "Preparation and characterization of biodegradable sugarcane bagasse nano reinforcement for polymer composites using ball milling operation", *Int. J. Polym. Anal. Character.*, **21**, 428-435. https://doi.org/10.1080/1023666X.2016.1168061

Karthikeyan, S., Karthikeyan, A., Jose, B.K., Marimuthu, S., Sathish, T., Murali, J.G. (2025), "Influences of titanium carbide on behaviour of jute fiber made epoxy composite for automotive usage", *AIP Conference Proceedings*, **3267**, 020296. https://doi.org/10.1063/5.0264689

Khor, K.Z., Yeoh, C.K., Teh, P.L., Mathanesh, T. and Wong, W.C. (2024), "Physical and electrical properties of PLA-carbon composites", *Adv. Mater. Res.*, **13**(3), 211-220. https://doi.org/10.12989/amr.2024.13.3.211

Kiss, P., Stadlbauer, W., Burgstaller, C. and Archodoulaki, V.M. (2020), "Development of high-performance glass fibre-polypropylene composite laminates: Effect of fibre sizing type and coupling agent concentration on mechanical properties", *Compos. Part A Appl. Sci. Manuf.*, **138**, 106056. https://doi.org/10.1016/j.compositesa.2020.106056

Kultayeva, S. (2024), "Mechanical properties of porous silicon carbide ceramics: A review", *Bull. Kazakh Lead. Academy Architkulect. Constr.*, **92**, 108-121. https://doi.org/10.51488/1680-080X/2024.2-08

Lila, M.K., Singhal, A., Banwait, S.S. and Singh, I. (2018), "A recyclability study of bagasse fiber reinforced polypropylene composites", *Polym. Degrad Stab.*, **152**, 272-279. https://doi.org/10.1016/j.polymdegradstab.2018.05.001

Lyutyy, P., Bekhta, P., Protsyk, Y. and Gryc, V. (2024), "Hot-pressing process of flat-pressed wood-polymer composites: theory and experiment", *Polymers*, **16**, 2931. https://doi.org/10.3390/polym16202931

Maziarz, W., Bobrowski, P., Wójcik, A., Bigos, A., Szymański, Ł., Kurtyka, P., Rylko, N., Olejnik, E. (2020), "Microstructure and mechanical properties of in situ cast aluminum based composites reinforced with TiC nano-particles", *Mater. Sci. Forum*, **985**, 211-217. https://doi.org/10.4028/www.scientific.net/MSF.985.211

Md Shah, A.U., Sultan, M.T. and Jawaid, M. (2021), "Sandwich-structured bamboo powder/glass fibre-reinforced epoxy hybrid composites - Mechanical performance in static and dynamic evaluations", *J. Sandw. Struct. Mater.*, **23**, 47-64. https://doi.org/10.1177/1099636218822740

Mohit, H. and Arul Mozhi Selvan, V. (2018). A comprehensive review on surface modification, structure interface and bonding mechanism of plant cellulose fiber reinforced polymer-based composites. *Compos.*

Interfaces, **25**, 629-667. https://doi.org/10.1080/09276440.2018.1444832

Mokhena, T.C., Mochane, M.J., Motaung, T.E., Linganiso, L.Z., Thekisoe, O.M. and Songca, S.P. (2018), "Sugarcane Bagasse and Cellulose Polymer Composites, in: Sugarcane - Technology and Research", *InTech*. https://doi.org/10.5772/intechopen.71497

Monroy Vázquez, F., González Uribe, E., García Enríquez, S., Fernández-Escamilla, V., González Núñez, R., Canche Escamilla, G. and Moscoso Sanchez, F. (2022), "Influence of pretreated sugarcane bagasse fiber by steam explosion, soaking with caustic soda, and addition of coupling agent into polylactic acid biocomposites", *J. Compos. Mater.*, **56**, 4621-4633. https://doi.org/10.1177/00219983221136225

Motaung, T.E., Linganiso, L.Z., John, M. and Anandjiwala, R.D. (2015), "The Effect of Silane Treated Sugar Cane Bagasse on Mechanical, Thermal and Crystallization Studies of Recycled Polypropylene", *Mater. Sci. and Appl.*, **6**, 724-733. https://doi.org/10.4236/msa.2015.68074

Mustaffa, W.A., Ayob, A., Zainal, M. and Santiagoo, R. (2017), "Mechanical properties and chemical reaction of 3-aminopropyltriethoxysilane of polypropylene, recycle acrylonitrile butadiene rubber and sugarcane bagasse composites", *Int. J. Microstruct. Mater. Proper.*, **12**, 55. https://doi.org/10.1504/IJMMP.2017.10008649

Nadhari, W.N.A.W., Karim, N.A., Boon, J.G., Salleh, K.M., Mustapha, A., Hashim, R., Sulaiman, O. and Azni, M.E. (2020), "Sugarcane (Saccharum officinarium L.) bagasse binderless particleboard: Effect of hot-pressing time study", *Mater. Today Proc.*, **31**, 313-317. https://doi.org/10.1016/j.matpr.2020.06.016

Ndengue, M.J., Ayissi, M.Z., Noah, P.M.A., Ebanda, F.B. and Ateba, A. (2021), "Implementation and evaluation of certain properties of a polymer matrix composite material reinforced by fibrous residues of saccharum officinarum in view of an applicability orientation", *J. Miner. Mater. Character. Eng.*, **9**, 206-225. https://doi.org/10.4236/jmmce.2021.92015

Nemoto, S., Ueno, T., Watthanaphanit, A., Hieda, J. and Saito, N. (2017), "Crystallinity and surface state of cellulose in wet ball-milling process," *J. Appl. Polym. Sci.*, **134**. https://doi.org/10.1002/app.44903

Oliveira, A.G.F. de, Gomes, U.U., Lima, H.D. de, and Lima, M.J.S. (2019), "Obtaining composites powders of Al2 O3 / Ni and Al2 O3 / Nb by mechanical alloying", *Mater. Res.*, **22**. https://doi.org/10.1590/1980-5373-mr-2019-0299

Pamudji, G., Haryanto, Y., Hu, H.T., Asriani, F. and Nugroho, L. (2021), "The flexural behavior of RC beams with sand-coated polypropylene waste coarse aggregate at different w/c ratios", *Adv. Mater. Res.*, **10**, 313-329. https://doi.org/10.12989/amr.2021.10.4.313

Paukkeri, R. and Lehtinen, A. (1993), "Thermal behaviour of polypropylene fractions: 1. Influence of tacticity and molecular weight on crystallization and melting behaviour", *Polymer*, **34**, 4075-4082. https://doi.org/10.1016/0032-3861(93)90669-2

Radhakrishnan, M., Hassan, M., Long, B., Otazu, D., Lienert, T. anderoglu, O. (2021), "Microstructures and properties of Ti/TiC composites fabricated by laser-directed energy deposition", *Addit. Manuf.*, **46**, 102198. https://doi.org/10.1016/j.addma.2021.102198

Safri, S.N.A., Sultan, M.T.H., Jawaid, M. and Abdul Majid, M.S. (2019), "Analysis of dynamic mechanical, low-velocity impact and compression after impact behaviour of benzoyl treated sugar palm/glass/epoxy composites", *Compos. Struct.*, **226**, 111308. https://doi.org/10.1016/j.compstruct.2019.111308

Sakhare, K.M., Bamane, S.R. and Borkar, S.P. (2024), "A comparative study of pine rosin and glutaraldehyde cross linker on mechanical properties of jute corn starch based biocomposite", *Adv. Mater. Res.*, **13**, 269-283. https://doi.org/10.12989/amr.2024.13.4.269

Sanjay, M.R., Madhu, P., Jawaid, M., Senthamaraikannan, P., Senthil, S. and Pradeep, S. (2018), "Characterization and properties of natural fiber polymer composites: A comprehensive review", *J. Clean Prod.*, **172**, 566-581. https://doi.org/10.1016/j.jclepro.2017.10.101

Shravanabelagola Nagaraja Setty, V.K., Goud, G., Peramanahalli Chikkegowda, S., Mavinkere Rangappa, S. and Siengchin, S. (2022), "Characterization of Chemically Treated *Limonia Acidissima* (Wood Apple) Shell Powder: Physicochemical, Thermal, and Morphological", *J. Natural Fibers*, **19**(11), 4093-4104. https://doi.org/10.1080/15440478.2020.1853925

Simamora, P., Simanjuntak, J., Sinulingga, K. and Laksono, A.D. (2023), "Mechanical properties of polypropylene composites with different reinforced natural fibers - A comparative study", *J. Ecol. Eng.*, **24**, 311-317. https://doi.org/10.12911/22998993/164757

Sitotaw, Y.W., Habtu, N.G. and Van Gerven, T. (2023), "Evaluation of planetary ball milling and mild-alkaline pretreatment for enhanced fermentable sugar production from sugarcane bagasse", *Adv. Sci. Technol. Mater. Energy*, 309-327. https://doi.org/10.1007/978-3-031-33610-2_17

Subramaniyan, S.P., Imam, M.A. and Prabhakar, P. (2021), "Fiber packing and morphology driven moisture diffusion mechanics in reinforced composites", *Compos. B. Eng.*, **226**, 109259. https://doi.org/10.1016/j.compositesb.2021.109259

Subramonian, S., Ali, A., Amran, M., Sivakumar, L., Salleh, S. and Rajaizam, A. (2016), "Effect of fiber loading on the mechanical properties of bagasse fiber-reinforced polypropylene composites", *Adv. Mech. Eng.*, **8**, https://doi.org/10.1177/1687814016664258

Sun, X. and Li, Y. (2004), "Colloidal carbon spheres and their core/shell structures with noble-metal nanoparticles", *Angewandte Chemie.*, **116**, 607-611. https://doi.org/10.1002/ange.200352386

Suraya, S., Sulaiman, S., Nur Najmiyah, J. and Nor Imrah, Y. (2014), "Studies on tensile properties of titanium carbide (TiC) particulates composites", *Adv. Mat. Res.*, **903**, 151-156. https://doi.org/10.4028/www.scientific.net/AMR.903.151

Tebeta, R.T., Madyira, D.M. and Ngwangwa, H.M. (2024), "The experimental investigation of the effect of TiC nanoparticles on the thermal behavior and specific strength of LDPE and HDPE", *Int. J. Eng. Technol.*, 169-173. https://doi.org/10.7763/IJET.2024.V16.1276

Vaneewari, N. and Saranya, D.V. (2023), "Effect of silane coupling agent on the mechanical steel of sugarcane baggase and polypropylene composites", *Mater. Today Proc.*, **81**, 118-126. https://doi.org/10.1016/j.matpr.2021.02.579

Vidakis, N., Petousis, M., Mangelis, P., Maravelakis, E., Mountakis, N., Papadakis, V., Neonaki, M. and Thomadaki, G. (2022), "Thermomechanical response of polycarbonate/aluminum nitride nanocomposites in material extrusion additive manufacturing", *Mater.*, **15**, 8806. https://doi.org/10.3390/ma15248806

Vidakis, N., Petousis, M., Michailidis, N., Nasikas, N., Papadakis, V., Argyros, A., Mountakis, N., Charou, C. and Moutsopoulou, A. (2023), "Optimizing titanium carbide (TiC) ceramic nanofiller loading in isotactic Polypropylene for MEX additive manufacturing: Mechano-thermal and rheology aspects", *Mater. Today Commun.*, **37**, 107368. https://doi.org/10.1016/j.mtcomm.2023.107368

Vossmeyer, T., Katsikas, L., Giersig, M., Popovic, I.G., Diesner, K., Chemseddine, A., Eychmueller, A. and Weller, H. (1994), "CdS Nanoclusters: Synthesis, characterization, size dependent oscillator strength, temperature shift of the excitonic transition energy, and reversible absorbance shift", *J. Phys. Chem.*, **98**, 7665-7673. https://doi.org/10.1021/j100082a044

Watanabe, R., Hagihara, H. and Sato, H. (2018), "Structure−property relationships of polypropylene-based nanocomposites obtained by dispersing mesoporous silica into hydroxyl-functionalized polypropylene. Part 2: Matrix−filler interactions and pore filling of mesoporous silica characterized by evolved gas analysis", *Polym. J.*, **50**, 1067-1077. https://doi.org/10.1038/s41428-018-0096-9

Wirawan, R., Sapuan, S., Yunus, R. and Abdan, K. (2012), "Density and Water Absorption of Sugarcane Bagasse-Filled Poly(vinyl chloride) Composites", *Polym. Polym. Compos.*, **20**, 659-664. https://doi.org/10.1177/096739111202000710

Wnuk, M. and Iluk, A. (2017), "The Influence of Manufacturing Technology on the Mechanical Properties of Fiber Composites", *Proceedimgs of the International Conference on Renewable Energy Sources-Research and Business*, 589-595. https://doi.org/10.1007/978-3-319-50938-9_61

Xiong, Y., Wang, W., Ye, Z., Yang, J., Zhao, Y., Huang, J. (2024), "Fabrication and mechanical properties of TiC coated short carbon fiber reinforced Ti5Si3-TiC composites", *Mater. Sci. Eng. A*, **893**, 146135. https://doi.org/10.1016/j.msea.2024.146135

Zafeer, Mohd.K., Prabhu, R., Rao, S., Mahesha, G. and Bhat, K.S. (2023), "Mechanical characteristics of sugarcane bagasse fibre reinforced polymer composites: A review" *Cogent. Eng.*, **10**. https://doi.org/10.1080/23311916.2023.2200903

Zakaria, M.S., Musa, L., Nordin, R.M. and Halim, K.A.A. (2020), "Sugarcane bagasse reinforced polyester composites: effects of fiber surface treatment and fiber loading on the tensile and flexural properties", *IOP Conf. Ser. Mater. Sci. Eng.*, **957**, 012032. https://doi.org/10.1088/1757-899X/957/1/012032

Zhang, H., Wang, D., Yang, B. and Möhwald, H. (2006), “Manipulation of aqueous growth of CdTe nanocrystals to fabricate colloidally stable one-dimensional nanostructures”, *J. Am. Chem. Soc.*, **128**, 10171-10180. https://doi.org/10.1021/ja061787h

Zhang, Y., Sun, J., Guo, L., Fan, K., Riedel, R. and Fu, Q. (2022), “Ablation resistant ZrC coating modified by polymer-derived SiC/TiC nanocomposites for ultra-high temperature application” *J. Eur. Ceram. Soc.* **42**, 18-29. https://doi.org/10.1016/j.jeurceramsoc.2021.09.057

CC