

Research Article

Snail shell powder-filled polypropylene composites: Mechanical properties and engineering potential

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Abstract

The rising demand for thermoplastics in engineering has sparked research into innovative materials. This study explores the impact of incorporating snail shell powder (SSP) into polypropylene (PP) composites. SSP was made by crushing snail shells, calcining them at 600°C for 2 hours, and grinding them into fine powder. It was then mixed with PP at weights from 2% to 10%. Using melt mixing and compression molding, composite samples were fabricated, and their mechanical properties, such as tensile strength, tensile modulus, elongation at break, hardness, wear resistance, and impact strength, were determined using an Instron machine, durometer, Taber abrasion tester, and Charpy impact tester, respectively. The results showed significant improvements in tensile strength (35.50 N/mm² to 39.08 N/mm²), tensile modulus (1019.97 N/mm² to 1024.45 N/mm²), and hardness (76.21 Shore A to 113.64 Shore A) compared to pure PP. However, elongation at break decreased with higher SSP content, with the 10 wt% sample at 181.32% against 288.87% for pure PP. The 10 wt% SSP also enhanced wear resistance (55.21 mm³/rev). Conversely, increased SSP content led to reduced impact strength due to agglomeration, with the 10 wt% composite showing 89.01 J/mm² compared to 134.05 J/mm² for pure PP. SEM analysis indicated a shift from a smooth to a rougher surface in SSP-filled composites. In comparison, moderate SSP improved dispersion; excessive amounts caused irregularities that could weaken mechanical properties. Optimizing SSP content is essential for achieving desired properties in SSP-filled PP composites. SSP-filled PP composites provide a lightweight, effective material for use in automotive, furniture, packaging, and construction applications.

Keywords: Composite, Hardness, Engineering, Polypropylene, Snail Shell Powder

1. Introduction

The growing demand for petroleum and the rapid depletion of these resources have sparked significant interest among engineers and industrial experts. Concerns over environmental pollution and climate change have driven innovation in sustainable materials, including natural polymer composites. Industries such as automotive, construction, and aerospace depend heavily on advanced composites, typically made from carbon and glass fibers. However, the limited recyclability of these materials poses a significant challenge. In response, researchers have turned to natural fillers as an environmentally friendly alternative to traditional petroleum-based materials. Polymer matrix composites (PMCs) consist of reinforcements embedded within thermoplastic, thermosetting, and elastomeric matrices, offering a unique combination of properties. These include design versatility, high stiffness-to-weight ratio, enhanced strength, improved corrosion resistance, and excellent thermal and acoustic insulation. As a result, PMCs have expanded their application scope across various

industries (Ugale, 2016; Prabhakar *et al.*, 2018). Specifically, they are increasingly substituting traditional materials like wood, metal, and ceramics in applications where weight reduction is crucial (Kabir *et al.*, 2012).

The advantageous properties of particle-reinforced polymer composites, including affordability, favorable physicochemical and mechanical attributes, and eco-friendliness, have expanded their application scope (Elkhouly *et al.*, 2018). Consequently, researchers have been motivated to explore biodegradable alternatives. A diverse array of natural fillers, encompassing both organic and inorganic materials, has been investigated, including eggshell (Venkatamuni *et al.*, 2016), rice husk (Tran *et al.*, 2013), fish bone (Igwe and Onuegbu, 2012) and bagasse (Perdana *et al.*, 2017). The environmental impact of disposing of agricultural waste has raised concerns about public health and ecological balance (Murugan *et al.*, 2017). By integrating these wastes into polymer materials as a reinforcer, researchers can create innovative materials with enhanced properties, including low

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density, high impact strength, thermal stability, specific stiffness, and conductivity (Hassen *et al.*, 2015; Hoffmann *et al.*, 2019; Fathy *et al.*, 2020). These advancements have positioned natural fillers as a viable alternative to conventional reinforcements like glass fibers and talc in thermoplastic composite applications (Patel *et al.*, 2024).

The widespread adoption of plastics across industries, including packaging, textiles, and biomedical engineering, can be attributed to their adaptability and diverse properties. This has led to the development of specialized plastics for specific applications (Watt *et al.*, 2020; Sotohou *et al.*, 2023; Santos *et al.*, 2023). For example, PP and high-density polyethylene (HDPE) are preferred materials in environments where chemical resistance is crucial, such as in industrial settings and household cleaning products (Oladele *et al.*, 2024). The environmental impact of petroleum-based plastics has fueled interest in developing sustainable composites. Incorporating natural fibers and agricultural by-products, such as lignocellulosic fibers and waste materials like coffee grounds and eggshells, offers a potential solution for creating eco-friendly materials without sacrificing performance (Quais *et al.*, 2015; Arya *et al.*, 2021; Ghazvini *et al.*, 2022; Karaoui *et al.*, 2025a). PP stands out as a prominent material in various industries, attributed to its exceptional mechanical properties, chemical stability, and cost-effectiveness. Its widespread adoption in automotive and packaging applications underscores its versatility (Oladele *et al.*, 2020a; Chiou and Lin, 2023). As a globally prevalent plastic, PP's advantages include remarkable corrosion resistance, ease of processing, and superior electrical insulation properties (Oladele *et al.*, 2020b; Santos *et al.*, 2023; Banu *et al.*, 2024). To optimize its performance and expand its uses, PP is frequently reinforced with fillers to create tailored composite materials (Hu *et al.*, 2024).

Snail shells (SSs) are prevalent component of household waste, yet their potential remains underutilized. Recently, there has been a growing interest in leveraging SS as a biological resource, driven by the need for sustainable waste management (Ihli *et al.*, 2013). The abundance and affordability of SS have sparked research into its characterization and potential applications, including its use as a reinforcing material. The hard calcium carbonate (CaCO_3) phase in SS makes it an attractive filler for polymers (Tepsila and Suksri, 2018). By incorporating SS into polymer composites, waste can be converted into valuable resources, reducing environmental pollution (Liuzzi *et al.*, 2017).

Research has investigated the influence of different agricultural waste materials on the properties of PP. A study by Igwe *et al.* (2012) investigated PP composites reinforced with eggshell and fish bone particles at different concentrations, revealing improved tensile strength, flexural strength, and hardness, but reduced elongation at break, with increasing filler content. According to Ofora *et al.* (2016),

the addition of bamboo-corn husk filler to PP resulted in enhanced mechanical properties, highlighting the potential of this hybrid filler in composite materials.

Durowaye *et al.* (2014) examined the microstructure and mechanical properties of PP composites reinforced with sisal aggregates of varying sizes (150 and 300 μm). The composites were fabricated through a combination of rheomixing and compression molding. Tensile testing, following ASTM D412 (1983) standards, revealed that the smaller particle size (150 μm) yielded higher tensile strength compared to the larger size (300 μm). This improvement was attributed to the increased surface area and uniform particle distribution, which enhanced particle-matrix interaction and reduced matrix deformation.

Onuoha *et al.* (2017) explored the impact of periwinkle shell powder on the mechanical properties of recycled PP composites. The researchers tested different particle sizes (150, 300, and 425 μm) and filler contents (0-25 wt%), finding that the addition of periwinkle shell powder improved tensile strength, flexural strength, tensile modulus, and hardness. Optimal performance was observed at filler loadings of 15-20 wt%, with properties declining beyond this range. In contrast, elongation at break decreased consistently with increasing filler content. Notably, the 150 μm particle size yielded peak tensile strength at 15 wt% and peak flexural strength at 20 wt%.

Durowaye *et al.* (2018) investigated the development of sustainable hybrid bio-composites by reinforcing PP with carbonized almond and periwinkle shell particles. The researchers evaluated the mechanical properties, water absorption, and microstructure of the composites at various reinforcement levels (5-25 wt%). The results indicated that tensile strength peaked at 20 wt% reinforcement before decreasing due to poor adhesion. In contrast, hardness and impact resistance reached optimal levels at 10-15 wt% reinforcement. The hybrid composite exhibited significant improvements in flexural strength, reaching 6.89 MPa at 15 wt%. Furthermore, the hybrid composites demonstrated reduced water absorption rates, with the lowest rate observed at 25 wt% reinforcement.

SS, a substantial waste material, can be valorized as a reinforcement in polymer composites, contributing to environmental sustainability and economic growth. This research seeks to evaluate the influence of SSP on the mechanical properties of PP matrix composites, exploring their potential utility in engineering applications.

2. Materials and Methods

2.1. Materials

The polymer matrix utilized is a commercial PP homopolymer obtained from Eleme Petrochemical Company Limited, Rivers State, Nigeria. It had a melt flow index of 2.5 - 3.5 g/min and a density, 0.926 g/cm³. The SS were sourced locally from a local seafood restaurant in Auchi, Edo, Nigeria. The mould releaser (silicon oil) was purchased from

a commercial supplier (Pascal Scientific and Laboratory Equipment) in Auchi, Edo, Nigeria.

2.2. Methods

2.2.1. Preparation of snail shell powder (SSP)

The preparation of SSP involved a multi-step process. SSs were thoroughly washed with warm water to remove

impurities and then sun-dried for 4 hours. The dried shells were crushed and calcined at 600°C for 2 hours, followed by cooling and grinding into a fine powder with an automated grinding machine. The resulting powder was then sieved to obtain the desired particle size.



Figure 1 Pictorial of the filler (a) raw snail shell (b) crushed snail shell (c) snail shell powder

2.2.2. Production of SSP-Filled PP Composites

The preparation of PP matrix composites involved mixing SSP with PP at various weight fractions (2, 4, 6, 8, and 10 wt%). The mixture was then subjected to compression molding at 160°C for 30 minutes under a pressure of 0.2 kPa.

This process yielded test samples with different SSP content, including a control sample without SSP. To ensure smooth demolding, the mold surfaces were coated with silicone oil, and Teflon sheets were placed between the mold and the composite samples. Table 1 shows the formulation for the compounding of SSP-filled PP composites.

Table 1. Formulation for the SSP-PP Composites

Ingredients		Quantity (Part by weight)					
PP	100	98	96	94	92	90	
SSP	0	2.0	4.0	6.0	8.0	10.0	

2.3. Mechanical Properties of the SSP-PP Composites

2.3.1. Tensile Test

The tensile properties of the SSP-filled PP composite samples were evaluated using an Instron machine (Series 3369) with a 50 kN load cell, in compliance with ASTM D638. (2014) standards. Dumbbell-shaped specimens, moulded according to the specified process, were subjected to tensile testing. Each tensile property was subjected to three replicate tests to ensure result accuracy and reliability. The main parameters measured during the tensile tests included ultimate tensile stress, elastic modulus, strain at maximum stress, stress at rupture, and rupture strain.

2.3.2. Impact Test

A material's reliability can be assessed by evaluating its

resistance to fracture, encompassing both ductile and brittle fractures, as well as its fracture toughness. To determine the impact strength of the developed composite samples, a Charpy impact test was performed using a CAT NR412 model testing machine, following the guidelines outlined in ASTM F2231-02 (2013). The test specimens were prepared according to the standard, with precise dimensions, gauge length, and V-notch specifications. During the test, the specimen was placed in a sample holder with the notch aligned vertically towards the impact point and was subsequently struck by a pendulum-mounted "tup." The impact caused the specimen to fracture at the notched section, and the energy absorbed was calculated based on the pendulum's swing, yielding results in Joules (J) (Jacob and Yamta, 2021).

2.3.3. Hardness Test

The test method measures the resistance of a material to indentation, providing a quantitative measure of the hardness for plastics and elastomers. This test determined the hardness of all samples using a Shore Hardness Tester (Durometer). The test measures the penetration of a specified indenter into the material under controlled conditions of force and time. The tests were conducted according to ASTM D2240. (2015). Samples with dimensions of 30 mm x 30 mm x 5 mm were tested. Measurements were taken at three different points on each sample, and the average value was reported as the composite's hardness.

2.3.4. Wear Resistance Test

Abrasive wear resistance was evaluated using a Taber abrasion tester (Model ISE-AO16) in accordance with ASTM F732-17 (2017). Specimens were mounted on a rotating turntable (1000 rpm, 20 minutes) and subjected to controlled pressure, generating a sliding rotational motion that created a crossed arc pattern of abrasion marks. Weight

loss was determined by measuring the specimens' weights before and after testing using an analytical balance. The difference in weights quantified the wear, and average values from each sample were reported as representative results.

2.3. Morphological Property

Surface morphology of the SSP-filled PP composites was investigated using SEM. Specimens from each composite were sectioned and prepared for analysis. A thin layer of gold was applied using a Quorum Q150RES sputter coater to improve surface conductivity. SEM examination was conducted on the coated samples using a Phenom ProX microscope with an integrated EDS detector at an accelerating voltage of 15 kV.

3. Results

Results of the mechanical properties were obtained and presented in Table 2 and Figures 2-8.

Table 2: Mechanical Properties

Properties	SSP loadings (w%)					
	0	2	4	6	8	10
Tensile Strength (N/mm ²)	29.0087	35.5001	39.2100	43.5705	46.0020	39.0756
Tensile Modulus (N/mm ²)	1003.2310	1019.9709	1037.3207	1039.0031	1057.0889	1024.4512
Elongation @ Break (%)	288.8706	223.4503	219.7503	210.4207	187.2110	181.3212
Hardness (Shore A)	65.5300	76.2100	84.5505	90.7008	96.0408	113.6411
Wear Resistance (mm ³ /rev.)	93.7645	87.0023	85.3532	69.3112	60.1135	55.2115
Impact Strength (J/mm ²)	134.0500	123.2208	119.5243	109.1552	93.1227	89.0097

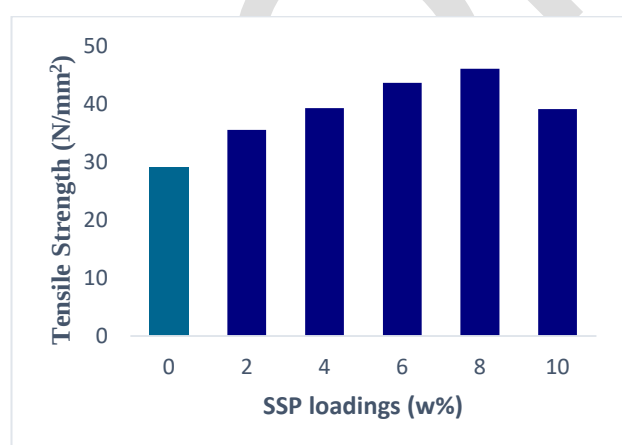


Figure 2. TS variation in SSP-filled PP composites

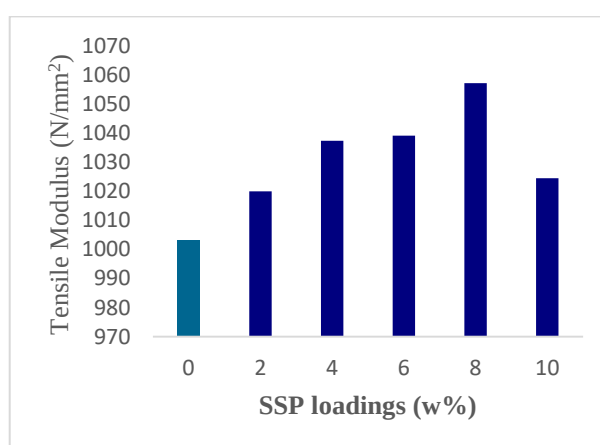


Figure 3. TM variation in SSP-filled PP composites

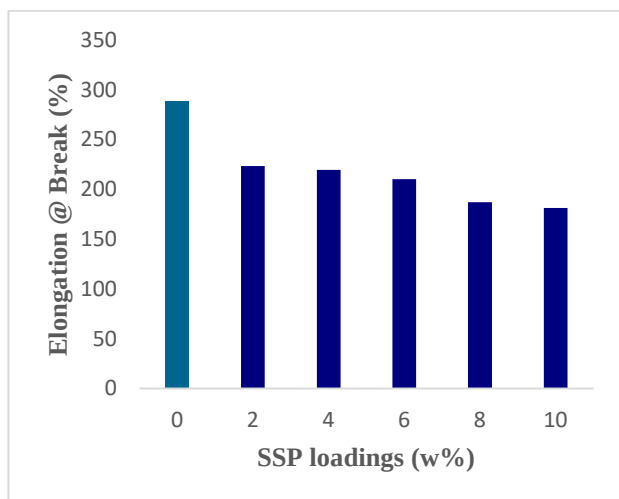


Figure 4. EAB variation in SSP-filled PP composites

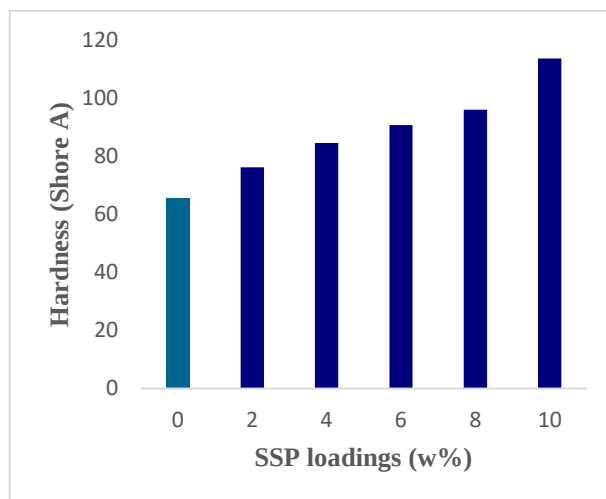


Figure 5. Hardness variation in SSP-filled PP composites

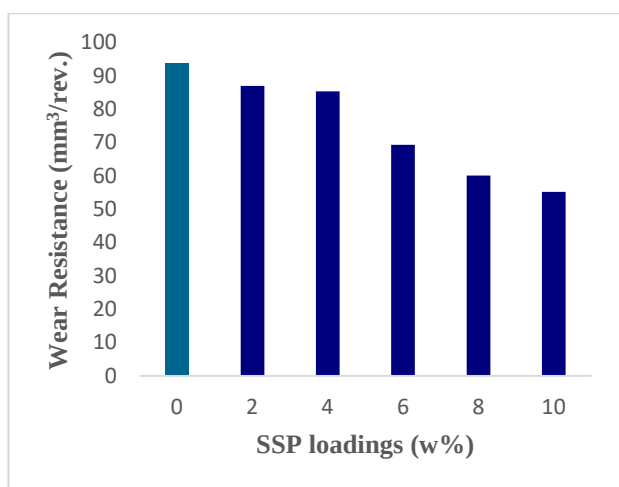


Figure 6. Wear resistance variation in SSP-filled PP composites

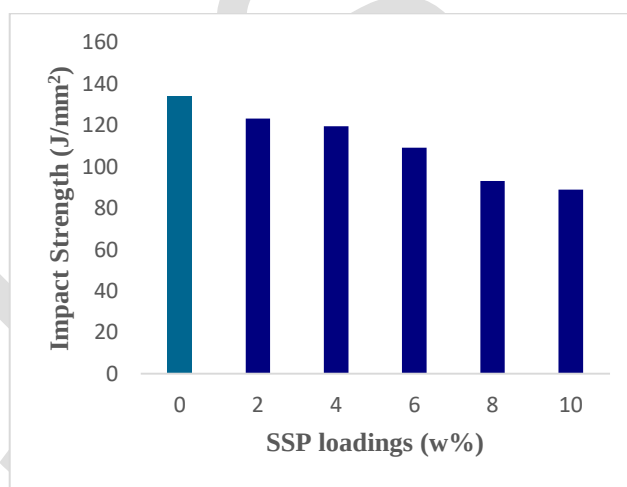
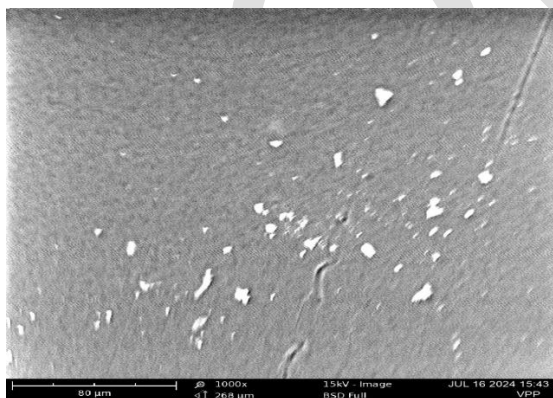
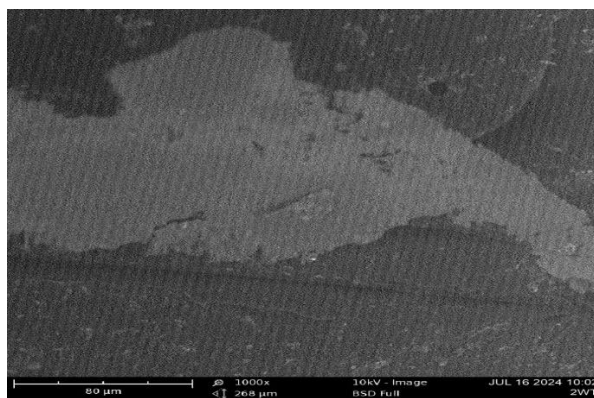


Figure 7. Impact strength variation in SSP-filled PP composites

3.2 Morphology



(a)



(b)

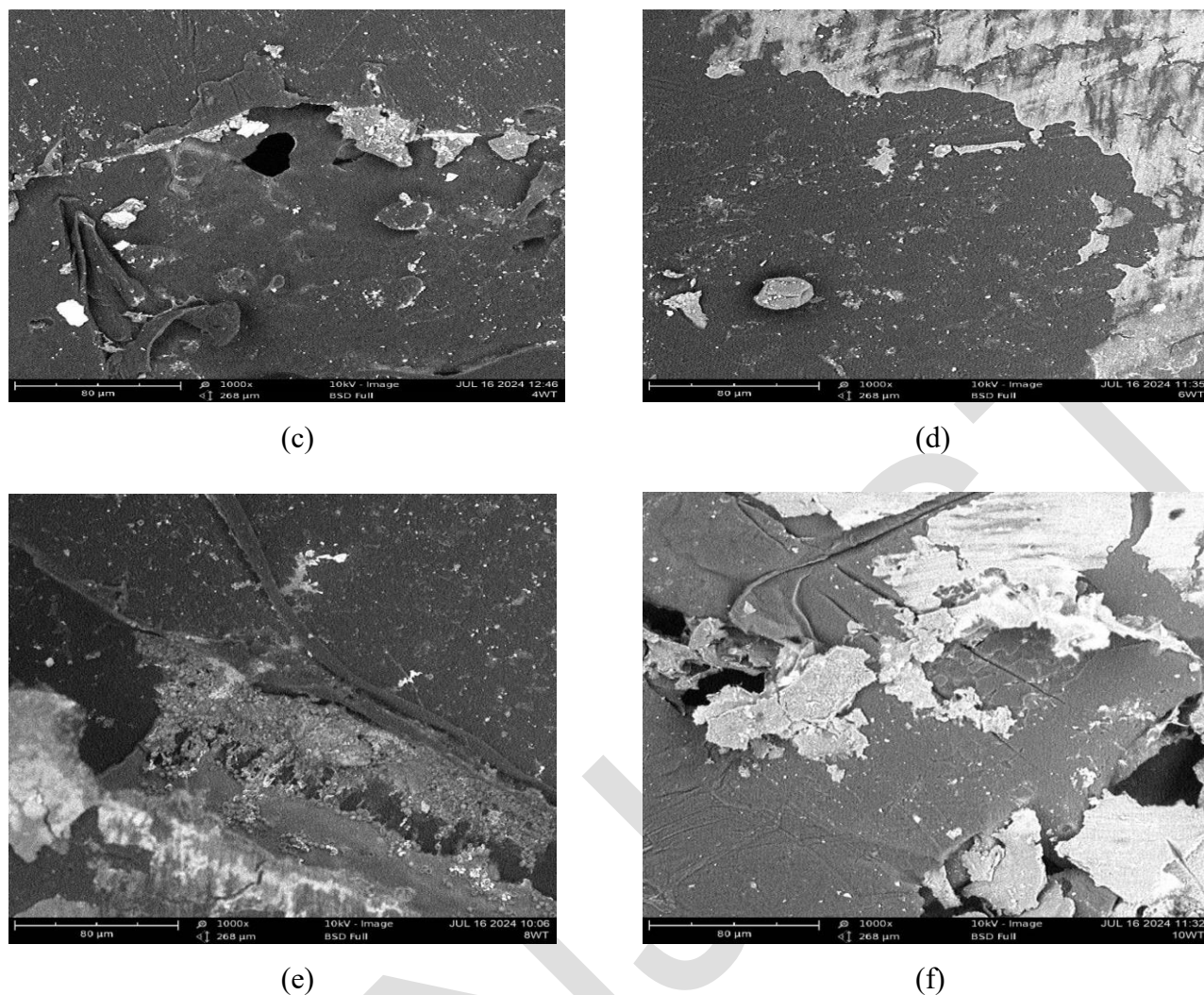


Figure 8. SEM micrograph of (a) 100 % of PP (b) 98w% PP/2w% SSP (c) 96w% PP/4w% SSP (d) 94w% PP/6w% SSP (e) 92w% PP/8w% SSP (f) 90w% PP/10w% SSP

4. Discussion

4.1. Tensile Strength

The tensile strength of SSP-PP-filled composites is influenced by SSP content, as shown in Table 2 and Figure 2. The composites exhibit increased tensile strength with SSP loading up to 8 wt%, with a peak value of 46.0020 N/mm², before declining. Nevertheless, all SSP-filled PP composites have higher tensile strength than pure PP. The enhancement in tensile strength can be attributed to the reinforcing effect of SSP, which facilitates efficient stress transfer due to improved interfacial interaction (Essabir *et al.*, 2017). The rigid nature of SSP, partly due to its calcium carbonate content (Oladele *et al.*, 2020; Tepsila and Suksri, 2018), also contributes to the composite's resistance to deformation. Furthermore, the interdiffusion and entanglement of polymer chains at the SSP-PP interface may play a role in enhancing tensile strength, as observed in previous studies (Daramola *et al.*, 2015). High SSP loadings compromise the tensile strength of SSP-filled PP composites due to weakened interfacial bonding between the SSP and PP matrix. As a result, stress transfer becomes inefficient, and the

composite's ability to withstand stress is reduced. Excessive SSP content leads to particle debonding or agglomeration of SSP, which negatively impacts the composite's strength. This observation is consistent with previous research, highlighting the importance of optimal filler loading in achieving desired composite properties (Onuoha *et al.*, 2017).

4.2. Tensile Modulus

The relationship between SSP content and tensile modulus in SSP-filled PP composites is illustrated in Table 2 and Figure 3. The tensile modulus increases with SSP loading up to 8 wt%, reaching a maximum value of 1057.0889 N/mm², before decreasing to 1024.4512 N/mm² at 10 wt%. Despite this decrease, all SSP-filled PP composites exhibit higher tensile modulus than pure PP (1003.2310 N/mm²), indicating improved stiffness (Onuoha *et al.*, 2017). The enhancement in stiffness is likely due to the reinforcing effect of SSP, which restricts polymer chain mobility through good interfacial bonding (Bhat *et al.*, 2019). However, the reduction in tensile modulus at 10 wt% SSP content may be attributed to particle agglomeration, leading to inefficient stress transfer (Karaoui *et al.*, 2025b).

4.3. Elongation at Break

The incorporation of SSP into PP led to a reduction in elongation at break, as evident from Table 2 and Figure 4. As the SSP content increased from 2 to 10 wt%, the elongation at break of SSP-filled PP composites decreased compared to pure PP, which exhibited the highest elongation at break value of 288.8706%. In contrast, the 10 wt% SSP-filled PP composite showed a significantly lower elongation at break of 181.3212%. The decrease in elongation at break suggests that SSP incorporation compromises the flexibility and plastic deformation capacity of the polymer matrix. Similar findings have been reported in previous studies (Chris-Okafor *et al.*, 2018; Karaoui *et al.*, 2023), where the addition of fillers led to reduced mobility of polymer chains and an anti-plasticizing effect. Marques *et al.* (2022) also observed a decrease in strain at break in composites, indicating material embrittlement.

4.4. Hardness

The relationship between SSP content and hardness in SSP-filled PP composites is illustrated in Table 2 and Figure 5. The results indicate a direct relationship between SSP filler loading and composite hardness, with higher SSP content leading to increased hardness, aligning with previous research (Syamimi *et al.*, 2020). The SSP-filled PP composites exhibit a significant increase in hardness as the SSP content increased from 2 to 10 wt%, compared to pure PP. Specifically, the 10 wt% SSP-filled PP composite recorded a hardness value of 113.6411 Shore A, while pure PP had a value of 65.53 Shore A. This improvement in hardness is consistent with studies on various fillers, including kaolin (Adeniyi *et al.*, 2021), snail shell particles (Karaoui *et al.*, 2023), and spent coffee grounds (Karaoui *et al.*, 2025b), which have demonstrated enhanced hardness in polymer composites.

4.5. Wear Resistance

The wear behaviour of SSP-filled PP composites and pure PP is compared in Table 2 and Figure 6. As the SSP content increases from 2 to 10 wt%, the wear resistance decreases, with a notable decline between 4-6 wt%. The SSP-filled PP composite with 10 wt% SSP exhibits wear resistance (55.2115 mm³/rev) compared to pure PP (93.7645 mm³/rev). The improved wear resistance is attributed to the load-bearing capacity of SSP particles, which reduces reinforcement detachment during abrasion. This observation is consistent with previous research by Oladele *et al.* (2020), which demonstrated that incorporating agro-wastes can mitigate abrasion effects in composites.

4.6. Impact Strength

The relationship between SSP content and impact strength in SSP-filled PP composites is illustrated in Table 2 and Figure 7. As the SSP content increases from 2 to 10 wt%, the impact strength decreases. Pure PP exhibits the highest impact strength value of 134.05 J/m², while 10 wt% SSP content records the lowest value of 89.0097 J/m². The increase in SSP concentration reduces the PP matrix's ability to absorb energy, leading to decreased toughness (Bolasodun *et al.*, 2020). The impact strength of filled polymers depends on the degree of interfacial bonding between the polymer

matrix and the filler (Adeyanju *et al.*, 2017; Oladele *et al.*, 2020). The decrease in impact strength can be attributed to poor bonding resulting from increased SSP content, promoting agglomeration and easy crack propagation (Aruniit *et al.*, 2011; Chokkalingam *et al.*, 2017; Oladele *et al.*, 2020), as well as inadequate bonding between the matrix and reinforcements (Das and Biswas, 2016).

4.7. Morphological Properties

The composites' surface morphology was examined using Scanning Electron Microscopy (SEM) at a magnification of 1000x, as shown in Figure 8. The SEM micrographs revealed distinct features for each composition. The pure PP matrix exhibited a smooth and homogeneous surface. Introducing 2 wt% SSP resulted in a slightly rougher surface, indicating initial interactions between the PP matrix and SSP. As the SSP content increased, the surface roughness and particle visibility also increased, suggesting improved dispersion and bonding between the PP matrix and SSP. However, at higher SSP concentrations (8 wt%), the surface exhibited significant irregularities, potentially compromising the material's mechanical properties. The highest SSP content showed a dense particle distribution, which might lead to agglomeration and negatively impact the composite's overall performance.

5. Conclusion

This research examined the mechanical characteristics and potential engineering applications of PP composites filled with SSP. The findings indicated that the incorporation of SSP significantly enhanced the tensile strength, tensile modulus, and hardness of the PP composites when compared to pure PP. Both tensile strength and tensile modulus reached their highest points at an 8 wt% SSP content, measuring 46.0020 N/mm² and 1057.0889 N/mm², respectively, before showing a decline at 10 wt%. This improvement is attributed to SSP's reinforcing effect and rigid nature, which promotes efficient stress transfer. Hardness consistently rose with increased SSP content, reaching 113.6411 Shore A at 10 wt% SSP, in contrast to 65.53 Shore A for pure PP, showing enhanced resistance to indentation. Wear resistance also improved as the SSP content increased, with the 10 wt% SSP-filled PP composite demonstrating the highest wear resistance at 55.2115 mm³/rev. Conversely, the composites' elongation at break and impact strength diminished with higher SSP content. The 10 wt% SSP-filled PP composite displayed the lowest elongation at break (181.3212%) and impact strength (89.0097 J/mm²). This reduction is linked to decreased polymer chain mobility, increased brittleness, and SSP agglomeration, which leads to poor interfacial bonding and makes crack propagation easier. SEM analysis revealed increased surface roughness and particle visibility at higher SSP concentrations. This suggests improved dispersion and bonding up to a certain point, but also indicates considerable irregularities and potential agglomeration at greater concentrations (8 wt% and 10 wt%). With their unique properties, SSP-filled PP composites are well-suited for a

range of applications, from automotive and furniture manufacturing to packaging and building materials, offering a promising solution for industries seeking lightweight yet effective materials.

Recommendation

The recommendations for advancing SSP-filled PP composites are to pursue commercialization in sectors that demand high hardness and wear resistance, including automotive, furniture, packaging, and construction materials. Future work should explore chemical surface treatments, such as maleic anhydride-grafted PP and silane coupling agents, to enhance interfacial adhesion between SSP and the PP matrix and thereby reduce the loss in impact strength and elongation at break at elevated filler loadings. Long-term performance should be assessed through creep, fatigue, and environmental aging tests under UV and moisture exposure to confirm engineering viability beyond short-term data. Additionally, a cost-benefit analysis against conventional fillers like talc and calcium carbonate is needed to establish economic feasibility and promote industrial uptake. Finally, establishing a sustainable supply chain for the collection and processing of SSs can convert agricultural waste into a valuable feedstock for the plastics sector.

Abbreviations

SSP	Snail shell powder
PMCs	Polymer matrix composites
SS	Snail Shell
HDPE	High-Density Polyethylene
SEM	Scanning Electron Microscopy
TS	Tensile Strength
TM	Tensile Modulus
EAB	Elongation @ Break
CACO ₃	Calcium Carbonate
UV	Ultraviolet
PP	Polypropylene

Author Contributions

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Austine Amoke: Data Curation, Investigation, Formal Analysis, Writing - original draft, Supervision.
Momoh Jimoh Umoru: Data Curation, Investigation, Formal Analysis, Writing - original draft, Supervision.
Inusa Obomeghie: Writing-Review & Editing
Mark Dada Ayo: Writing-Review & Editing
Osi Gabriel Tenebe: Writing-Review & Editing

Conflicts of Interest

The author(s) declare that they have no known competing financial interests, professional affiliations or personal relationships that could have appeared to influence

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