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Physical and Mechanical Characterisation of Recycled Pet/Coconut Shell Powder Composite for Assistive Device Applications

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ABSTRACT: This study investigated the mechanical and physical properties of recycled polyethylene terephthalate (PET) reinforced with coconut shell powder, with the aim of assessing its suitability for assistive device applications such as crutches. Composites were produced by mechanically mixing PET and coconut shell powder at various weight fractions (0–25%) followed by compression molding. Physical tests conducted included density and water absorption measurements, while mechanical evaluation comprised of tensile, flexural, compressive and impact strength tests. The results showed that the density of the composites increased from 1.18 to 1.32 g/cm³ as the reinforcement increased, reflecting the higher density of coconut shell powder compared to the PET matrix. Water absorption also increased with reinforcement, with sample E recording above 50 % absorption after prolonged immersion, while the unreinforced sample absorbed less than 10 %. This behavior was linked to pores created at higher fibre content. Tensile strength ranged from 2.53 to 9.07 MPa, with the optimum performance at 15 % reinforcement (sample D). Young's modulus varied from 2.85 MPa in the control to 159.09 MPa in the highest reinforcement sample, indicating improved stiffness with reinforcement. Flexural results showed modulus of elasticity values between 2205.5 and 4135.3 MPa, and modulus of rupture values from 18.9 to 36.5 MPa, again with sample D showing the best performance. Compressive strength ranged from 0.60 to 1.48 MPa, with the highest value at 15 % reinforcement. Impact strength increased from 0.2 J in the unreinforced sample to 2.5 J in sample D. These findings demonstrate that moderate reinforcement with coconut shell powder enhances both stiffness and toughness without significantly increasing weight. The developed composite showed improved mechanical properties that make it a candidate material for lightweight assistive devices. Its low density, reasonable strength and improved impact resistance suggest potential for use in crutch production, contributing to comfort, user safety, and sustainable material application

KEYWORDS: Recycled PET, Coconut shell powder, Mechanical properties, Physical properties, Tensile strength, Flexural strength, Compressive strength, Impact strength, Assistive devices, Biomedical materials, Lightweight composites

I. INTRODUCTION

Crutches are essential assistive devices that enable mobility for individuals with lower-limb injuries or disabilities. Conventional crutches are typically made of aluminium, steel, or hardwood, which are strong but transmit vibrations and shocks directly to the user during walking. Prolonged use can cause discomfort, fatigue, and even secondary injuries to the upper limbs (Hosseini, Mortazavi & Torabi, 2018; Zahedi, Sapuan & Jawaid, 2019). Therefore, there is a critical need to develop crutches that are lightweight, durable, and capable of absorbing vibrations to improve user comfort and reduce musculoskeletal strain.

One promising approach is the use of composite materials reinforced with natural fillers, which combine low density with good energy dissipation. Natural fillers such as coconut shell powder have been shown to enhance damping, stiffness, and impact resistance in polymer matrices, while also being environmentally sustainable (Jalali, Vedani & Vedani, 2020; Ramesh et al., 2022). Recycled polymers such as PET offer additional benefits, including reduced environmental impact, availability, and ease of processing into composite forms. Studies on natural fibre-reinforced polymer composites have demonstrated improved dynamic mechanical behavior, including higher damping factors and thermal stability, making them suitable for applications subjected to cyclic and impact loading (Saba et al., 2016; Rahman & Xu, 2023).

In addition to experimental evaluation, numerical simulation techniques like Finite Element Analysis (FEA) are increasingly used to optimize assistive device design. FEA can predict stress distribution, deformation, and potential failure points under realistic loading conditions, reducing the risk of overdesign or early failure (Müzel et al., 2020). Recent studies have successfully used FEA to assess crutch materials, ensuring safe load-bearing capacity while minimizing weight (Chami et al., 2019; Reddy, 2017).

Given these considerations, the present study investigates the mechanical and physical performance of recycled PET reinforced with coconut shell powder, focusing on its potential as a material for crutch production. The study combines experimental characterization (density, water absorption, tensile, flexural, compressive, and impact tests) with FEA to evaluate structural integrity and energy dissipation, aiming to develop a lightweight, durable, and user-friendly composite for assistive devices.

II. MATERIALS AND METHODS

This study employed experimental and numerical approaches to evaluate the mechanical and physical properties of recycled PET/coconut shell powder composites for assistive device applications. The methodology was designed to characterize density, water absorption, tensile, flexural, compressive, and impact properties, as well as simulate structural behavior using Finite Element Analysis (FEA).

A. Material and Composite Preparation

Recycled polyethylene terephthalate (PET) pellets and coconut shell powder were used as matrix and reinforcement, respectively. The coconut shell powder was sieved to 150 µm particle size to ensure uniform distribution, following procedures described by Thomas et al. (2017). Both materials were dried in an oven at 80 °C for 24 hours to remove moisture.

Composites were produced using mechanical mixing followed by compression moulding at different weight fractions of coconut shell powder (0%, 5%, 10%, 15%, 20%, and 25%). Rectangular samples were prepared for mechanical and physical testing, cooled to room temperature, and conditioned for 48 hours. This method follows procedures in natural fibre-reinforced polymer composite fabrication (Ramesh et al., 2022; Jalali et al., 2020).

B. Physical Characterization

Density: The density of the composites was measured using the ASTM D792-20 standard, employing the water displacement method. Density provides an indicator of lightweight suitability for assistive devices (Hamad et al., 2022).

Water Absorption: Water absorption tests were conducted according to ASTM D570-98 (2018). Samples were immersed in distilled water at room temperature, and the percentage increase in weight was measured at intervals up to 240 hours. This evaluates the composite's resistance to moisture, which is critical for durability in biomedical applications (Jacob et al., 2019; Sesugh et al., 2025).

C. Mechanical Characterization

Tensile Test: Tensile strength and Young's modulus were measured using a universal testing machine according to ASTM D638-14. Samples were tested at a crosshead speed of 5 mm/min. Tensile tests indicate the material's ability to resist axial loading, which is essential for crutches under user weight (Tile & Nyior, 2023; Murugan, 2020).

Flexural Testing: Flexural properties (modulus of elasticity and modulus of rupture) were determined using a three-point bending test as per ASTM D790-17. Flexural tests assess the material's resistance to bending and deformation under load, reflecting real-life crutch loading conditions (Brown et al., 2020).

Impact Testing: Impact strength was measured using ASTM D256-10 (Izod impact method). Samples were notched and subjected to pendulum impact to evaluate energy absorption and toughness. High impact strength ensures resistance to sudden forces, which improves safety during crutch use (Sattar et al., 2023).

III. RESULTS AND DISCUSSION

A. Physical Properties of the Composites

Density: The results of the densities of the produced composites with different reinforcements of coconut shell powder are presented in figure 1. It is observed that as the reinforcement increased, the corresponding density of the composite increased. This is because the fibres used for the reinforcements have higher density compared to epoxy (1.4 g/cm3 for epoxy, 1.6 g/cm3 for coconut shell powder, 1.41 g/cm3 for PET powder). The densities are in the range of 1.18-1.32 g/cm3 which agrees with the findings of Hamad et al. (2022) on Investigation of Some Properties for Laminated Composite Used for Biomedical applications. Density measurement for composite is an important indicator to know the light composite materials. Typically, natural fibre composite materials are lighter than synthetic composite materials. This is one of the reasons behind the use of natural fibre composite materials for Biomedical applications such as Crutches (Hamad et al., 2022).

According to Singhal et al. (2014) low density materials are a requirement for materials used in Biomedical applications. The light weight nature of the produced composites reduces the overall weight burden on the body, which can be beneficial in load bearing applications. This helps minimize stress and facilitates users' comfort and mobility.

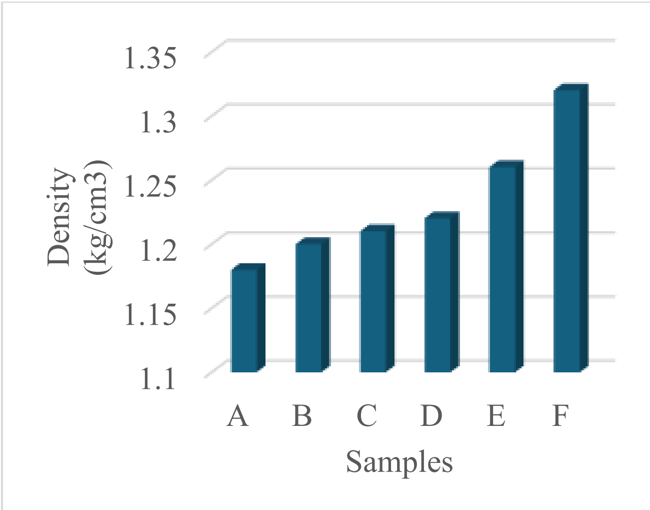

Figure 1: Density of the Samples

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Percentage Water absorption of the composite: Variation of water absorption with the reinforcement at room temperature is shown in the figure 2. The percentage of water absorption in the composites depended on fibre content in the samples. The results show that water absorption increased with increase in the percentage of reinforcements in the composite. It can be observed from the figure that, samples A, B, and C have significantly lower percentage water absorption compared to samples D, E, and F which have noticeably higher percentage water absorption. Sample E recorded the highest percentage water absorption with value above 50%, in comparison with sample A with percentage water absorption below 10%. The increased water absorption as the reinforcement increased is due to void content created at higher fibre loading leading to increased number of pores. It could also be observed that after 240 hours of immersion, there was no further increase in water absorption, which is evident from the linearity of the test values after 216 hours. According to Jacob *et al.* (2019), this could be attributed to the fact that the pores created may have been saturated with water, thus giving rise to such behaviour. This may be attributed to lower void content in the composite arising from better interfacial bonding between the PET powder and coconut shell and the epoxy matrix. According to Sesugh *et al.* (2025) chemical treatment removes non-cellulosic materials like lignin, pectin, hemicelluloses, and natural fats which make natural fibres prone to water absorption. The result implies that, of the two constituent materials used in this research, PET is a more potent constituent material than coconut shell powder, in determining the percentage water absorption of the sample filters.

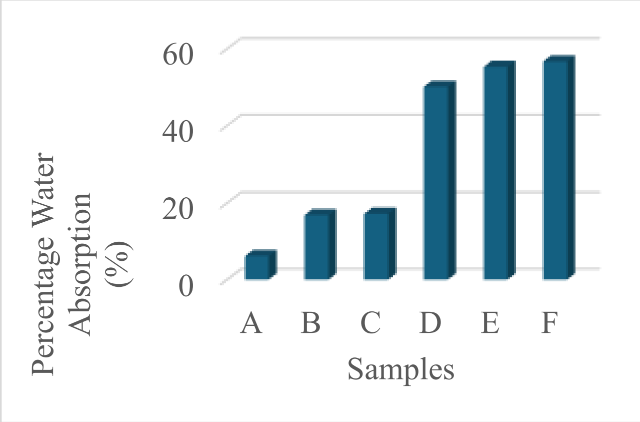

Figure 2: Percentage water absorption of the samples

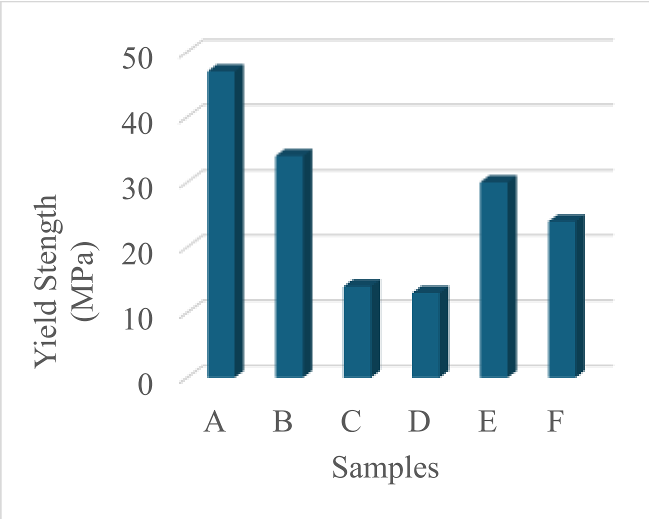

Figure 3: Yield strength of the samples

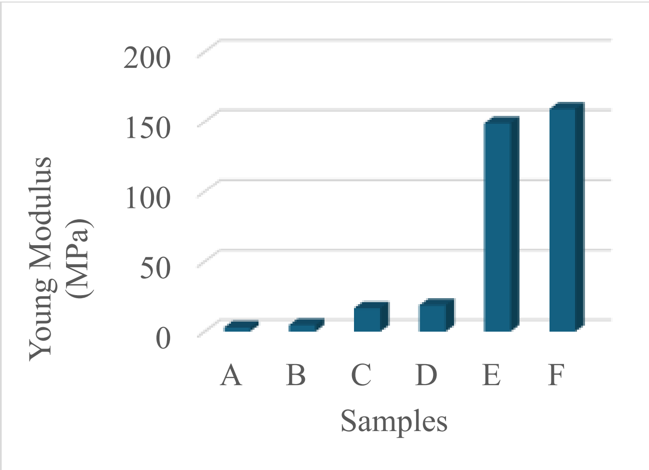

Figure 4: Young modulus of the samples

Tensile Properties: Figure 3 and 4 shows the summary of the tensile properties of the composite. The experimental results showed that, maximum tensile strength of the various composite samples is in the range of 2.53- 9.07 MPa. Sample D with 15% coconut shell powder had a maximum tensile strength of 9.07MPa. increase in tensile strength in the composite could be attributed to the good compaction thus eliminating pores in the sample. According to Tile and Nyior

(2023) tensile test is useful in determining tensile strength, Young’s modulus, elongation and other mechanical properties of materials. This can be used to identify and select materials with the best mechanical properties for specific applications. According to Murugan (2020) tensile strength of a material is one of the mechanical properties considered in assessing the quality of materials the higher the tensile strength of a material, the better for its employability as engineering material. According to Ramesh *et al*. (2025) the strength and performance of composite materials are influenced by a number of factors; the adhesion at the resin-fibre interface, the mechanical properties of the resin and fibre, fibre treatment and manufacturing process have a significant effect on composite performance.

The Young’s modulus is an indication of stiffness in the material, and can be determined from a stress–strain graph. Samples with a high Young’s modulus value suggest high stiffness in the material. The Young’s modulus result of the composite ranged from 2.85 - 159.09 MPa (Figure 8). Sample F with 25% coconut shell powder gave the highest Young’s modulus value of 159.09 MPa, followed by sample E with a Young’s modulus value of 148.94MPa. Sample D, which is the optimum sample, has a Young’s modulus value of 18.91MPa. Sample A with no reinforcement gave the least Young’s modulus value of 2.85 MPa. This could be attributed to the large strain at maximum tensile strength in the sample as a result of zero reinforcement and insufficient compaction pressure during the production of samples, thus creating pores in the composite, weakening the material. During tensile testing, these pores are enlarged and propagated quickly in the material, leading to poor tensile strength (Nyior *et al.* 2018). According to Brown *et al.* (2020) material for Crutches should have high stiffness to withstand users' loads. The composites produced in this study have shown excellent Young’s modulus to be employed in the production of Biomedical devices such as Crutches. This implies that the material under the weight of a user will sustain and retain its shape under tensile stresses without breaking.

B. Flexural Properties of the Composites

Flexural (bending) strength is the second criterion in assessing the quality of a material after the tensile strength. According to Brown et al. (2020) bending strength is used to assess the suitability of the material when receiving load distribution, and this is directly related to the performance of the Crutches. The results of the flexural properties, comprising modulus of elasticity and modulus of rupture of the composite, are shown in Figures 5 and 6.

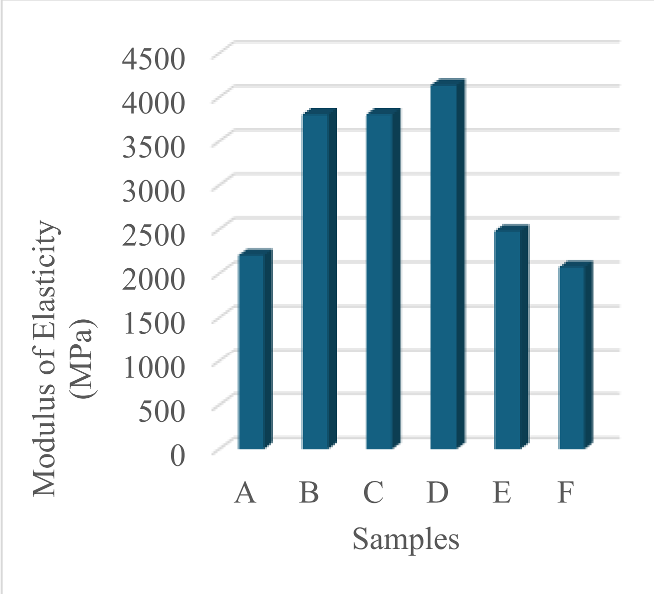

Figure 5: Modulus of elasticity of the samples

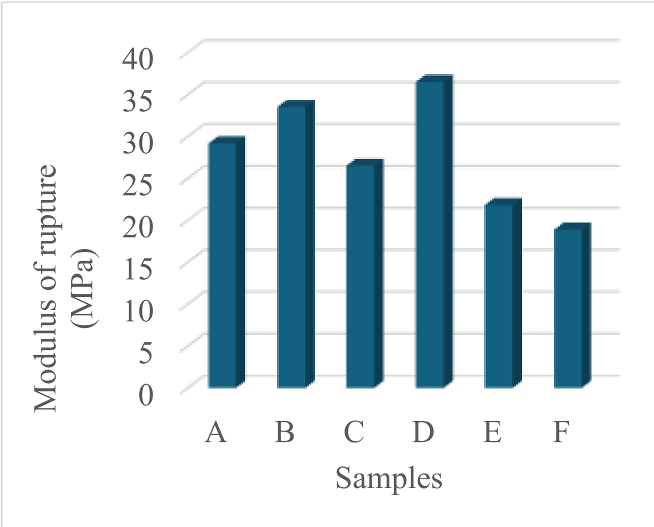

Figure 6: Modulus of rupture of the samples

Modulus of Elasticity (MOE): Modulus of elasticity (MOE) is a measure of a material’s stiffness or its ability to deform under stress. The results of MOE are shown in Figure 9. The results show that the values ranged from 2205.5- 4135.3 MPa in the composites. Sample D gave the highest MOE value of 4135.3 MPa. Materials with high modulus of elasticity tend to be more rigid and may offer better durability over time (Harris *et al*., 2016). These results confirm that sample D is a potential alternative material in crutch applications

Modulus of Rupture (MOR): The results of the modulus of rupture (MOR) are shown in Figure 10. The modulus of rupture (MOR), also known as flexural strength, is the maximum stress a material can withstand before fracture or breaking when subjected to bending forces. In Crutches, the modulus of rupture is important because it indicates the crutch's ability to resist deformation and failure under load (Brown *et al.,* 2020). Values of MOR obtained from the composite samples ranged from 18.9-36.5 MPa. It is observed that sample D gave the highest MOR value of 36.5 MPa. While F gave the lowest MOR value of 18.9 MPa. Generally, the results of the modulus of rupture of the composite shows that, the MOR of the composites increases with weight fraction of reinforcement up to 15 % and decreases on further reinforcement. This is an indication of insufficient adhesion and poor stress transfer between the resin and the reinforcements with higher reinforcements. A high MOR is desirable for Crutches as it ensures the crutch can bear the weight and forces of the user without breaking or deforming, enhancing the mobility and comfort.

C. Discussion on the compressive strength of the composite

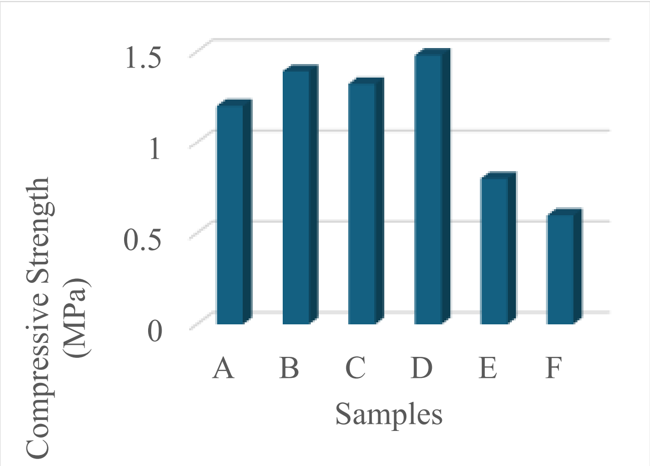

Figure 7: Compressive strength of the samples

The compressive strength of a material is its ability to withstand compressive force (load), which are forces that squeeze or tend to compress the material. It's a measure of the material's resistance to deformation and crushing under external pressure.

The results of the compressive strength of the composites are presented in Figure 7. The results show that compressive strength values ranged from 0.60- 1.48 MPa. The details of the result show that sample D had a maximum compressive strength of 1.48 MPa. Sample F had the lowest compressive strength of 0.60 MPa.

Comparing the compressive strength with the tensile results showed that, the composite gave higher tensile strength than compressive strength. Sample D exhibited highest maximum tensile strength and the highest compressive strength, this suggest that, the sample's suitability to be employed as alternative material in crutch production.

D. Impact Strength of the Composite

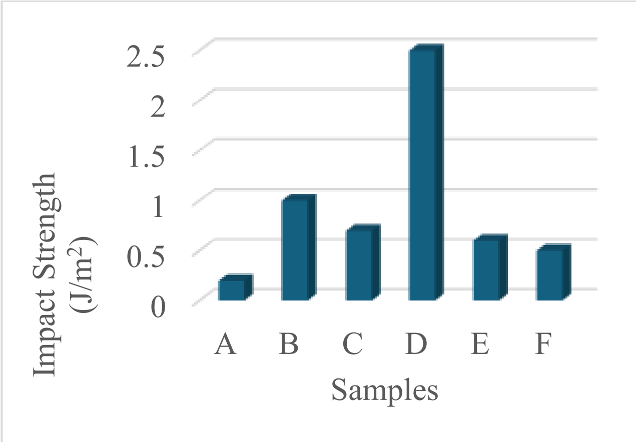

Figure 8: Impact strength of the samples

Impact strength is a measure of toughness. The higher the impact strength of a material, the higher the toughness and vice versa. The results of the impact strength of the composite are presented in Figure 8. The results show that, impact strength values ranged from 0.2 – 2.5 J in the composites. The details of the results show; sample A had lowest impact strength of 0.2 J. Sample D gave the highest value of 2.5 J. According to Sattar *et al.* (2023) high impact strength in a sample indicates that, the material can absorb and dissipate impact forces effectively, reducing the likelihood of sudden failure or fracture. This leads to a more durable crutch that can withstand the stresses in addition to sudden impacts without fracture. This is essential for safety and durability.

IV. CONCLUSION

This study has demonstrated that the recycled PET/coconut shell powder composite exhibits excellent mechanical and physical properties, making it a promising material for assistive device applications such as crutches. The experimental results show that the inclusion of 15 wt% coconut shell powder (Sample D) provided an optimal balance between strength, stiffness, and toughness. Specifically, the tensile strength reached 9.07 MPa, the Young's modulus was 18.91 MPa, the flexural modulus of elasticity (MOE) was 4135.3 MPa, the modulus of rupture (MOR) was 36.5 MPa, the compressive strength was 1.48 MPa, and the impact strength was 2.5 J. These values indicate sufficient stiffness, durability, and energy absorption capacity, critical for supporting body weight and resisting dynamic and accidental loads during crutch use.

Physical characterization revealed that the composite's density ranged from 1.18–1.32 g/cm³, confirming its lightweight nature, which is advantageous for user comfort and mobility (Hamad et al., 2022). Water absorption increased with reinforcement content, reaching over 50% in the highest fibre fraction; however, the optimum sample maintained moderate water uptake, indicating acceptable dimensional stability and reduced risk of moisture-related degradation (Jacob et al., 2019; Sesugh et al., 2025).

The performance of the composite compares favorably with conventional crutch materials. For instance, aluminium crutches typically exhibit high stiffness but very low damping ($\tan \delta \leq 0.01$) and higher density (~2.7 g/cm³), while wooden crutches have limited mechanical reliability and lower moisture resistance ($\tan \delta$ ~0.005–0.02) (Choudhary & Kaur, 2015; Brown et al., 2020). The PET/coconut shell composite combines lightweight, improved energy dissipation, and adequate strength, offering better vibration absorption and long-term comfort for users.

Finite Element Analysis confirmed that the crutch design using this composite can safely support a 90 kg adult user, with a maximum Von Mises stress of 4.28 MPa and minimal deformation, ensuring structural integrity and durability. These findings highlight the composite's suitability for ergonomic, safe, and sustainable crutch production.

The recycled PET/coconut shell powder composite demonstrates a balance of mechanical strength, stiffness, impact resistance, and lightweight characteristics, while also being environmentally sustainable. The material is well-suited for biomedical assistive devices, and its use can enhance user comfort, durability, and accessibility, providing a viable alternative to traditional metallic and wooden crutches. Future work may focus on long-term fatigue testing, surface treatment, and optimization of filler content to further improve performance in real-life applications.

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