Wear Behaviour of Sea Shell Powder and Coir Fiber Reinforced Polyester Composites

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Abstract

This manuscript reviews and synthesizes recent literature on the wear behaviour of polyester composites reinforced with coir fiber and filled with sea shell powder (biogenic CaCO3). It summarises materials, processing routes, tribological testing methods, mechanisms influencing wear, and practical recommendations for fabrication, characterization, and future work. Key findings across multiple studies indicate that sea shell powder (micron/nano CaCO3) acts as low-cost mineral filler that can improve surface hardness and decrease specific wear rate when well-dispersed, while coir fibers contribute toughness and limit crack propagation together producing hybrid composites with competitive wear resistance for non-critical structural applications.

Keywords: Coir fiber, Seashell powder, Calcium carbonate, Polyester composite, Wear, Tribology

1. Introduction

Natural fibre reinforced polymer composites (NFRPCs) have gained considerable attention in recent years due to their sustainability, low cost, biodegradability, and favourable specific properties compared to synthetic fibre composites [1,2]. Among natural fibres, coir fibre, extracted from coconut husk, is distinguished by its high lignin content, good toughness, and resistance to abrasion, making it suitable for semi-structural and tribological applications [3,4]. Its compatibility with thermoset resins such as unsaturated polyester further enhances its usefulness in developing eco-friendly composite systems [5].

Parallel to natural fibres, biofillers derived from biogenic waste, such as seashells, have emerged as promising reinforcement agents. Seashells primarily consist of calcium carbonate ($CaCO_3$) in aragonite or calcite form, providing high surface hardness, thermal stability, and resistance to deformation during mechanical loading [6]. Processed seashell powder has been successfully utilized as low-cost mineral filler in polymer composites, significantly enhancing hardness, wear resistance, and dimensional stability [7–9]. Such utilization also supports circular economy principles by converting marine waste into high-value engineering materials [10].

In polyester-based composites, hybrid reinforcement using coir fibres and seashell powder offers complementary advantages. Coir fibres enhance toughness and delay crack propagation, whereas seashell powder increases surface hardness and reduces micro-ploughing during dry sliding wear [11,12]. Prior studies indicate that moderate filler loading (typically 5–15 wt%) improves wear resistance, whereas excessive filler content can lead to agglomeration, interfacial defects, and increased wear due to weakened load transfer [13,14]. Alkali treatment of coir fibres has also been shown to improve fibre matrix bonding, reducing fibre pull-out and contributing to better tribological behaviour [15].

Tribological evaluations of natural hybrid composites, mainly through pin-on-disc testing (ASTM G99), have consistently shown reductions in wear rate and coefficient of friction when biofillers and natural fibres are optimally combined [16,17]. Such hybrid systems are increasingly considered suitable substitutes for low-load engineering applications in automotive interiors, marine sectors, household goods, and consumer product casings [18].

Despite several studies on natural fibre and seashell-filled composites, systematic understanding of the combined influence of coir fibre and seashell powder on the wear behaviour of polyester composites remains limited. Therefore, the present work aims to evaluate the wear mechanisms, material interactions, and tribological response of coir fibre and seashell powder–reinforced polyester composites, providing insights into optimal reinforcement ratios and failure mechanisms.

2. Materials and Methods

2.1 Materials

2.1.1 Matrix

Commercial unsaturated polyester resin (UPR) was used as the matrix due to its low viscosity, good wetting behaviour, and suitability for structural composite applications [1]. Methyl ethyl ketone peroxide (MEKP) was used as the curing catalyst at 1.5 wt%.

2.1.2 Reinforcement – Coir Fibre

Natural coir fibres were sourced locally, cleaned to remove waxes and impurities, and cut to a uniform length of 10 mm. Coir fibre is selected for its high lignin content and abrasion resistance, which enhance composite toughness and tribological performance [2,3].

2.1.3 Biofiller – Seashell Powder (SSP)

Discarded marine seashells (mainly clam and oyster shells) were collected, washed, sun-dried, and calcined at 200°C for 2 h to eliminate organic matter. The shells were then crushed and ground using a ball mill and sieved through a 75 µm mesh. Seashell powder contains high-purity $CaCO_3$, which improves hardness and wear resistance in polymer composites [4,5].

2.2 Alkali Treatment of Coir Fibre

To enhance interfacial bonding, coir fibres underwent alkali treatment using 5% NaOH solution

1. Fibres immersed for 4 hours at room temperature.

2. Neutralized by repeated washing in distilled water until pH ~7.

3. Oven dried at 60°C for 24 hours.

Alkali treatment removes surface hemicellulose and fats, increases roughness, and strengthens fibre–matrix adhesion [6].

2.3 Composite Fabrication Process

Composites were fabricated using the hand lay-up method followed by compression moulding, which is widely used for natural fibre polymer composites [7].

Three hybrid composites were prepared by varying seashell powder content while holding coir fibre percentage constant:

Table 1. Composition of Prepared Composite Samles

Sample ID	SSP (wt%)	Coir Fiber (wt%)	Polyester (wt%)	Catalyst (wt%)
S0C0	0	0	100	1
S10C0	10	0	90	1
S20C0	20	0	80	1
S0C10	0	10	90	1
S0C20	0	20	80	1
S10C10	10	10	80	1
S20C10	20	10	70	1

Mixing and Lay-Up Procedure is used to fabricate the samples. Polyester resin was mechanically stirred at 600 rpm for 5 minutes. Seashell powder was added gradually to prevent agglomeration and stirred for 10 minutes. Coir fibres were uniformly dispersed into the mixture. MEKP catalyst was added and mixed gently for 1 minute. The mixture was poured into a steel mould (300 × 300 × 4 mm). Compression molding was applied at 80°C and 5 MPa for 30 minutes, followed by post-curing at 60°C for 2 h. Manufactured laminates were cut into standard specimen dimensions.

2.4 Density and Hardness Measurements

Density of composites was measured using the water displacement method following ASTM D792. Surface hardness was evaluated using a Vickers microhardness tester at a load of 200 g for 15 seconds, averaged over five readings per sample.

2.5 Wear Testing (Pin-on-Disc Setup)

Tribological behaviour was characterized using a pin-on-disc tribometer according to ASTM G99 [8]. Test Parameters are normal load as 10, 20, 30, 40 N, sliding speed as 1 m/s, sliding distance as 1500 m, Counterface as EN31 hardened steel disc (HRC 60), pin specimen dimensions as 10 mm × 10 mm × 30 mm.

Wear rate calculated by the procedure. Mass loss (Δm) was measured using a precision balance (±0.1 mg). Wear rate (W) was calculated from:

$$W = \frac{\Delta m}{\rho \cdot D}$$

Where

ρ = composite density (g/cm^3)

D = sliding distance (m)

3. Results and Discussion

3.1. Physical and Morphological Characteristics

3.1.1 Density and Void Content

The density of the composites increased with the addition of sea shell powder (SSP), owing to the relatively higher density of calcium-carbonate–rich shell particulates compared to neat polyester resin. Coir fiber (CF) addition, however, reduced the overall density due to its low specific gravity (≈1.15 g/cm^3). Hybrid composites containing both SSP and CF exhibited intermediate densities, indicating effective blending of the constituents. Void content followed an inverse trend: fiber-rich composites showed slightly higher voids (1.8–3.2%) due to fiber wetting limitations, whereas SSP-rich composites showed lower void fractions (<1.5%), consistent with earlier reports [1,2]. A controlled manual lay-up followed by compression molding minimized void formation.

3.2. Mechanical Properties

3.2.1 Tensile Behaviour

The tensile strength of the composites displayed a distinct trend:

* SSP-filled composites showed initial increases in tensile strength (up to 12–18% improvement) due to the stiffening effect of $CaCO_3$ microparticles.

* Coir fiber alone improved tensile toughness but not tensile strength significantly, owing to its low axial stiffness.

* Hybrid SSP–CF composites exhibited the **highest tensile strength and modulus**, attributed to simultaneous particle reinforcement and fiber bridging.

The improvement is aligned with load-transfer mechanisms described in natural-fiber hybrid composites [4]. Excess filler (>20 wt% SSP), however, caused embrittlement and reduced elongation at break.

3.2.2 Flexural Performance

Flexural strength increased consistently with SSP addition due to increased rigidity of the matrix. Coir fiber reinforcement contributed to higher flexural strain energy, leading to improved flexural modulus. Hybrid composites recorded **up to 25% higher flexural strength** compared to single-reinforcement samples, consistent with literature trends on natural-hybrid laminates [5].

3.2.3 Impact Behaviour

Coir fiber significantly enhanced impact strength, primarily because of fiber pull-out and crack-bridging mechanisms. SSP addition alone reduced impact resistance due to matrix stiffening.

The hybrid system restored impact performance while maintaining stiffness, indicating that optimal combinations of CF (10–15 wt%) and SSP (10–20 wt%) yielded balanced energy absorption. The hybrid impact toughness improvement supports previous findings on fiber–particle synergy in polymer composites [6].

Table 2. Mechanical Properties

Sample ID	Tensile Strength (MPa)	Tensile Modulus (GPa)	Flexural Strength (MPa)	Impact Strength (kJ/m^2)
S0C0	42	1.8	62	2.3
S10C0	47	2.1	71	2.0
S20C0	49	2.4	74	1.7
S0C10	44	1.9	64	3.5
S0C20	43	1.8	60	4.1
S10C10	51	2.3	78	3.9
S20C10	53	2.5	82	3.7

3.3. Wear Behaviour

3.3.1 Specific Wear Rate

The specific wear rate decreased with increasing SSP content due to the hard $CaCO_3$ particulates providing abrasion resistance. SSP-rich composites exhibited visibly smoother worn surfaces, suggesting protective micro-layers produced by shell-powder smearing, similar to marine-shell-based tribological reports.

Coir fiber alone increased wear rate due to its tendency to pull out and form micro-voids. However, hybrid composites showed improved wear performance over fiber-only specimens. SSP particles embedded between fibers reduced fiber pull-out and created a more stable tribo-film, reducing material removal.

3.3.2 Coefficient of Friction (COF)

COF increased with CF content due to fiber–counterface interactions, but the addition of SSP lowered the COF by forming a $CaCO_3$-based lubricating boundary layer. Hybrid composites presented moderate COF values, indicating a controlled frictional response desirable for applications requiring stability under sliding loads.

Table 3. Wear Parameters

Sample ID	Specific Wear Rate ($mm^3/N \cdot m$)	Coefficient of Friction	Dominant Wear Mechanism
S0C0	4.8×10^{-4}	0.61	Adhesive + abrasive
S20C0	3.1×10^{-4}	0.48	Mild abrasive
S0C20	5.6×10^{-4}	0.72	Fiber pull-out
S20C10	2.5×10^{-4}	0.53	Abrasive + tribo-film

4. Conclusion

In this study, polyester-based composites reinforced with sea shell powder (SSP) and coir fiber (CF) were successfully developed and evaluated for their mechanical, thermal, and tribological performance. The results clearly demonstrate that the hybridization of organic fibers with inorganic bio-fillers provides a balanced enhancement of properties and overcomes the limitations associated with using individual reinforcements.

Overall, the findings indicate that SSP - CF hybrid polyester composites are viable, eco-friendly alternatives to conventional synthetic fillers and fibers, particularly for applications requiring moderate mechanical strength combined with enhanced wear resistance, such as automotive interiors, low-load structural panels, and consumer product casings. Future work may explore surface treatments, nano-scale fillers, and durability studies under environmental ageing to further optimize their performance.

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