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Development and Study of Mechanical Properties on Bamboo Fiber & Egg Shell Powder Reinforced Polypropylene Used for Prosthetic Applications: A Review

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Abstract: ***Polypropylene (PP) is an attractive thermoplastic matrix for lightweight engineering components because of its low density, chemical resistance and compatibility with conventional melt-processing methods. Its mechanical response can be modified through fibre and particulate reinforcement. This review examines the potential of combining chopped bamboo fibre and eggshell powder in PP, with maleic-anhydride-grafted polypropylene (MAPP) as a compatibilizing agent, and considers the relevance of this material family to external lower-limb prosthetic components. The discussion covers natural-fibre/PP composites, bamboo-fibre reinforcement and surface modification, eggshell-derived calcium-carbonate fillers, hybrid reinforcement, processing effects and prosthetic performance requirements. Bamboo fibre may contribute reinforcement when fibre length, treatment, orientation and interfacial stress transfer are controlled, whereas eggshell powder can act as a mineral filler whose effects depend on particle size, loading and dispersion. The combination offers a potential route to valorize renewable and waste-derived feedstocks, but increased stiffness may be accompanied by reduced elongation or impact tolerance. MAPP is a potential compatibilization strategy, although its effectiveness depends on fibre treatment and processing conditions. The review identifies a need to evaluate hybrid PP composites containing bamboo fibre, MAPP and varying eggshell-powder contents using matched controls and consistent mechanical, microstructural and durability testing. Current evidence supports further material development but does not establish clinical suitability or the safety of a finished prosthetic device.***
Keywords: Polypropylene; bamboo fibre; eggshell powder; hybrid composites; maleic-anhydride-grafted polypropylene; natural-fibre composites; prosthetic foot; mechanical performance; interfacial adhesion.

I. INTRODUCTION

Polymer-matrix composites are engineered by combining a continuous matrix with a reinforcing phase in the form of fibres, particles or other dispersed constituents. The matrix maintains the component geometry and transfers load to the reinforcement, while the reinforcement modifies stiffness, strength, dimensional stability and other functional properties. Natural-fibre composites have attracted sustained interest because they can reduce reliance on conventional synthetic reinforcement and may offer low density, availability and cost advantages [1,4,5]. Their performance, however, is sensitive to natural-fibre variability, moisture uptake, processing-induced damage and interfacial adhesion.

Polypropylene (PP) is a widely processed thermoplastic with relatively low density, chemical resistance and compatibility with extrusion and injection moulding. It is therefore a useful matrix for evaluating short natural fibres and mineral fillers. The non-polar character of PP contrasts with the polar, hydrophilic surface chemistry of lignocellulosic fibres. Without suitable treatment or compatibilization, this mismatch can limit wetting and stress transfer and may promote fibre pull-out or interfacial voids [9–11].

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Bamboo is a renewable lignocellulosic reinforcement with potential for short-fibre thermoplastic composites. Eggshell waste, in turn, is a calcium-rich feedstock that can be processed into a particulate filler. Combining these phases in PP is a hybrid reinforcement strategy: fibres may provide load-bearing reinforcement, while particles may alter stiffness, hardness, dimensional response and wear. The same combination can also increase processing complexity and the risk of agglomeration. This review synthesizes published findings and identifies technical questions that should guide further experimental investigation.

II. REVIEW SCOPE AND APPROACH

This narrative review synthesizes published studies addressing natural-fibre-reinforced PP, bamboo-fibre/PP composites, eggshell-filled PP, hybrid reinforcement, processing and microstructural characterization, and prosthetic or biomedical material applications. The discussion is organized thematically to compare reported mechanisms, processing considerations and performance limitations, with particular attention to the complementary roles of bamboo fibre and eggshell-derived mineral particles.

This article is a literature review and synthesizes published findings; it does not report new experimental measurements.

III. POLYPROPYLENE AS A COMPOSITE MATRIX

PP provides a melt-processable continuous phase that binds reinforcement and transfers applied loads. Its low density and ease of moulding are useful for complex geometries, but neat PP can be limited by relatively low modulus, viscoelastic creep and sensitivity of its mechanical response to temperature, strain rate and processing history. The literature on PP additives and biofillers shows that an increase in stiffness does not necessarily imply an increase in tensile strength, elongation or impact resistance [6–8].

For natural-fibre composites, compounding and moulding history influence fibre attrition, orientation and distribution. Barkoula et al. [2] and Sun et al. [3] are included in the literature as examples demonstrating the importance of compounding and injection-moulding conditions. These variables must be controlled when comparing formulations, because differences attributed to filler content may instead arise from fibre-length loss, void formation or orientation.

IV. BAMBOO FIBRE REINFORCEMENT AND SURFACE MODIFICATION

Bamboo fibres contain cellulose, hemicellulose and lignin. Cellulose-rich reinforcement can contribute stiffness and strength, but the fibre surface is hydrophilic and chemically dissimilar to non-polar PP. Chattopadhyay et al. [9] investigated short bamboo-fibre PP composites using chemically modified fibres and maleic-anhydride-grafted PP (MA-g-PP) as a compatibilizer. Their work is directly relevant because it links fibre modification, coupling-agent use and fracture/interface characterization in the same broad material family.

Reviews by Abdul Khalil et al. [10] and Ibrahim et al. [11] discuss bamboo-fibre composite processing and the importance of fibre treatment and coupling agents. The literature also cites work on bamboo-containing hybrid polymers, organic-acid modification and injection-moulded bamboo/PP systems [12–17]. Across these studies, reinforcement effectiveness depends not simply on fibre mass fraction but on fibre aspect ratio, fibre-length retention, orientation, moisture content, surface chemistry and the ability of the matrix to transfer load.

Alkali treatment is commonly considered to remove surface impurities and some non-cellulosic constituents, potentially increasing surface roughness and improving mechanical interlocking. However, treatment severity is important: excessive chemical exposure can damage the fibre structure and reduce its reinforcing capacity. A defensible comparison should therefore report the chemical concentration, temperature, duration, liquor-to-fibre ratio, washing endpoint, neutralization procedure and final fibre moisture content.

V. EGGSHELL POWDER AS A MINERAL FILLER

Eggshell powder is a waste-derived, calcium-carbonate-rich particulate material. It offers a potential alternative source of mineral filler and a route for using a biological waste stream. The mechanical effect of eggshell powder depends on its particle-size distribution, morphology, surface condition, concentration and dispersion within the polymer. A well-dispersed particulate phase may restrict local matrix deformation and increase modulus or hardness; agglomerates and poorly bonded interfaces may instead act as stress concentrators.

Ghabeer et al. [18] studied PP/chicken-eggshell composites containing untreated and stearic-acid-treated eggshell at 10–40 wt.%. Their reported trend was an increase in tensile modulus accompanied by decreases in tensile strength, strain at break and impact strength relative to neat PP. This is an important caution: eggshell loading cannot be treated as an automatic route to simultaneous improvement of all mechanical properties.

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Other studies reported in the literature examine chemically modified eggshell filler, compatibilization, calcium-carbonate/eggshell-filled PP and hybrid organic/inorganic filler systems [19–24]. Collectively, these studies support the need to characterize particle size and surface condition and to examine fracture morphology. They also show why filler loading should be optimized against a multi-property target rather than selected on stiffness alone.

VI. HYBRID BAMBOO-FIBRE/EGGSHELL/PP SYSTEMS

A hybrid composite combines reinforcement phases that contribute through different mechanisms. In a bamboo-fibre/eggshell/PP system, chopped bamboo may contribute tensile load transfer when fibre alignment and interfacial bonding are favourable. Eggshell particles may modify matrix stiffness, hardness and local deformation. The balance between these contributions is affected by the total reinforcement fraction, particle/fibre distribution and the quality of the fibre–matrix and particle–matrix interfaces.

A formulation range proposed for further investigation comprises a specific formulation window for further investigation: 5 wt.% chopped bamboo fibre, 3 wt.% MAPP and eggshell powder varied between 10 and 15 wt.%, with PP making up the balance. This is a useful controlled comparison because bamboo and MAPP are held constant while eggshell loading changes. However, the literature basis alone cannot determine the optimum composition. That conclusion requires matched experimental controls, replication and statistical analysis.

Hybridization may also create competing effects. Increasing mineral filler can raise resistance to deformation while reducing tensile elongation or impact energy. If the filler is not dispersed uniformly, particle clusters can create local stress concentrations. If fibre–matrix adhesion is poor, fibres may pull out rather than carry load. Thus, a meaningful hybrid-composite study should relate measured properties to fibre length, particle size, void content, dispersion and fracture morphology rather than infer a mechanism from composition alone.

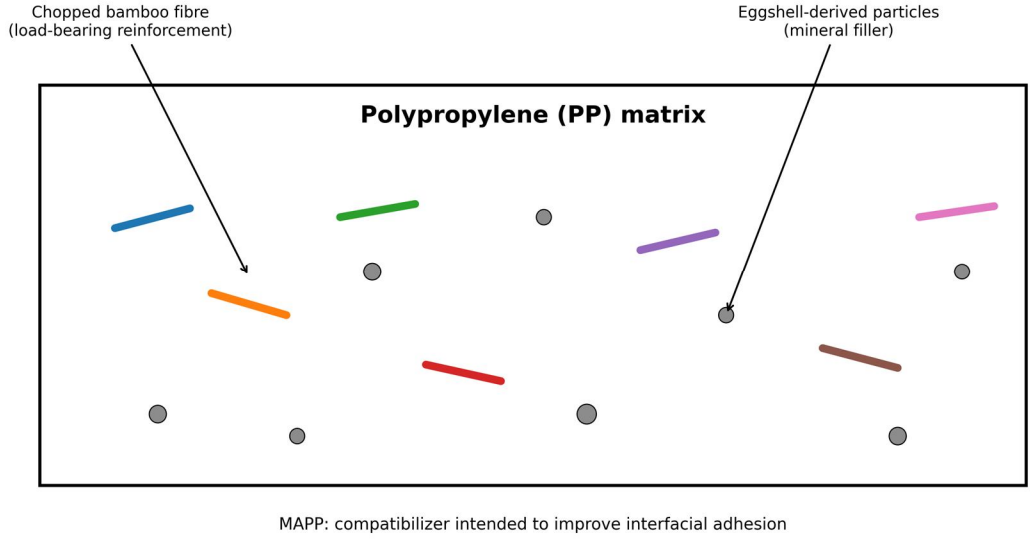


Fig. 1. Conceptual architecture of the bamboo-fibre/eggshell-powder/PP hybrid composite and the intended role of MAPP; conceptual schematic

VII. COMPATIBILIZATION AND INTERFACIAL MECHANISMS

MAPP is used in PP/natural-fibre systems because its PP-compatible backbone can interact with the matrix while its maleic-anhydride functionality can interact with polar fibre surfaces. Work on bamboo/PP composites cited in the report supports the relevance of coupling agents to interfacial stress transfer [9,11,16,17]. The amount and molecular characteristics of MAPP, fibre pretreatment and processing conditions all influence the result.

Compatibilization should be assessed experimentally. SEM fracture images may reveal fibre pull-out, gaps, cracks and matrix adhering to fibres, but qualitative images alone do not measure interfacial shear strength. More direct approaches can include single-fibre pull-out or microbond tests, alongside quantitative image analysis. EDS can identify elements such as calcium in eggshell-containing regions, but it does not by itself prove chemical bonding or quantify bulk filler distribution.

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VIII. PROCESSING AND CHARACTERIZATION CONSIDERATIONS

Injection moulding is attractive for producing repeatable thermoplastic parts and standardized test specimens, but it can shorten fibres and produce orientation gradients.

The review literature on injection-moulded natural-fibre composites emphasizes fibre breakage, moisture, dispersion and process conditions as determinants of mechanical reliability [2,3,26,27,29]. A research article should report the PP grade and melt-flow information, drying conditions, compounding sequence, screw configuration and speed, melt and mould temperatures, residence time, injection pressure/speed and specimen conditioning.

Mechanical characterization should include tensile testing (for example, ASTM D638), flexural testing (ASTM D790), compression testing (ASTM D695) and an appropriately selected abrasion method. Impact resistance and fatigue testing are particularly important for prosthetic structures exposed to repeated loading. The exact standard edition, specimen dimensions, test speed, span-to-depth ratio, conditioning, number of specimens and data-reduction method should be stated. Means should be accompanied by dispersion measures and, where appropriate, statistical comparisons. SEM is useful for observing fracture-surface morphology, including fibre pull-out, matrix tearing, particle clusters and voids.

EDS/EDAX provides local elemental information and can support identification of calcium-rich eggshell regions. These methods should be used with representative sampling and consistent imaging conditions. Quantitative image analysis, elemental mapping and multiple fields of view strengthen interpretation; a single image or local EDS spectrum is not sufficient to establish bulk dispersion or interfacial strength.

IX. RELEVANCE TO LOWER-LIMB PROSTHETIC COMPONENTS

Material selection for a prosthetic foot or other lower-limb component is a device-level engineering problem. Weight, stiffness, strength, impact tolerance, fatigue life, energy storage and return, environmental durability, manufacturability, repairability and cost may all be relevant. The review by Castro-Franco et al. [33] specifically examines natural-fibre-reinforced composites for lower-limb prosthetic designs and discusses mechanical performance, computational modelling and the challenges of durability and validation.

Evidence from polymer composites used as bone analogues or biomedical materials [30–32] should not be conflated with evidence for an external prosthetic foot. An external prosthesis does not necessarily have the same biological-contact requirements as an implant, but it must meet the mechanical and safety requirements of its intended use. If the material contacts skin or other tissues, the nature and duration of contact should guide biological evaluation. Natural origin and eggshell content do not, by themselves, establish biocompatibility.

Coupon-level tensile or flexural strength cannot establish the safety of a complete prosthetic device. A prototype requires structural design, finite-element assessment where appropriate, static and cyclic component testing, impact evaluation and user-relevant functional validation. The review therefore treats bamboo–eggshell/PP as a candidate material system for further study, not as a clinically validated prosthetic material.

X. RESEARCH GAPS AND RECOMMENDED EXPERIMENTAL FRAMEWORK

The reviewed literature supports several unresolved questions. First, combined bamboo-fibre and eggshell-powder reinforcement in PP has received less systematic attention than either reinforcement considered separately.

Second, the influence of eggshell content within a fixed bamboo-fibre/MAPP formulation needs to be established using consistent controls. Third, the relationship between interfacial morphology and tensile, flexural, compressive and wear behaviour requires stronger quantitative evidence. Fourth, prosthetic relevance requires impact, fatigue, creep and component-level tests beyond static coupon properties [29,33–35].

A future experimental study should use a neat-PP control produced from the same grade and under the same processing and conditioning conditions as all reinforced formulations. A factorial or response-surface design could vary bamboo content, eggshell content and MAPP content independently.

Fibre length after compounding, eggshell particle-size distribution, moisture content and void fraction should be measured. At least five specimens may be used as an initial replication target, but final sample size should be justified by variability and statistical power rather than adopted automatically.

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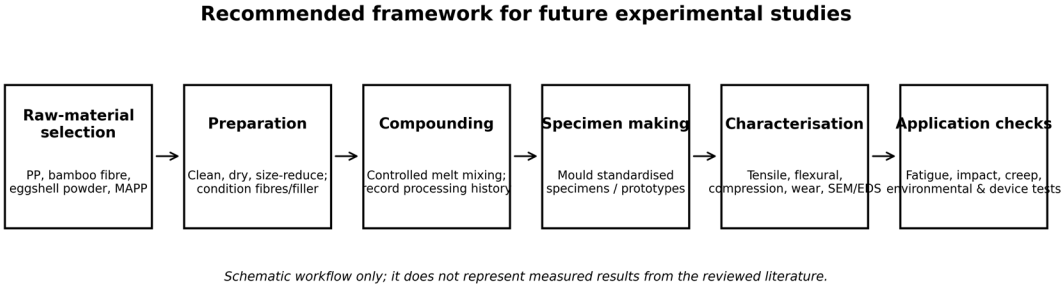


Fig. 2. Recommended workflow for future experimental evaluation of bamboo-fibre/eggshell-powder/PP composites. proposed framework

Mechanical testing should include tensile, flexural, compression, impact, abrasion and cyclic fatigue measurements, with creep and environmental conditioning added for service relevance. Report individual data, means, standard deviations, confidence intervals and statistical tests. SEM/EDS should be performed on multiple specimens and locations, with quantitative image analysis where possible. If a prosthetic component is developed, its geometry and loading should be based on a defined use case and tested at the component level using applicable standards and risk assessment.

XI. CONCLUSIONS

The literature reviewed indicates that bamboo fibre and eggshell powder are promising complementary reinforcement candidates for polypropylene, but their effects are governed by interfacial compatibility, fibre and particle geometry, dispersion and processing history. Bamboo-fibre/PP studies emphasize the importance of surface modification and MAPP compatibilization, while eggshell-filled PP studies show that stiffness gains may be accompanied by losses in tensile strength, elongation or impact resistance. The hybrid system must therefore be optimized for a balanced set of properties.

The formulation range identified in the related project—5 wt.% bamboo fibre, 3 wt.% MAPP and 10–15 wt.% eggshell powder—provides a focused experimental question for a subsequent original research paper. The literature review alone does not establish which formulation is optimal, nor does it establish prosthetic-device suitability. Future work should use matched controls, fully reported processing parameters, statistically supported mechanical testing, quantitative microstructural analysis and component-level validation before any application claim is made.

XII. FUTURE RESEARCH DIRECTIONS

Priority directions include independent optimization of bamboo-fibre, eggshell-powder and MAPP contents; measurement of fibre length and filler particle-size distributions; comparison of alkali and alternative surface treatments; and systematic evaluation of processing-induced fibre breakage and void formation. Thermal analysis and dynamic mechanical analysis may help establish processing windows and temperature-dependent behaviour.

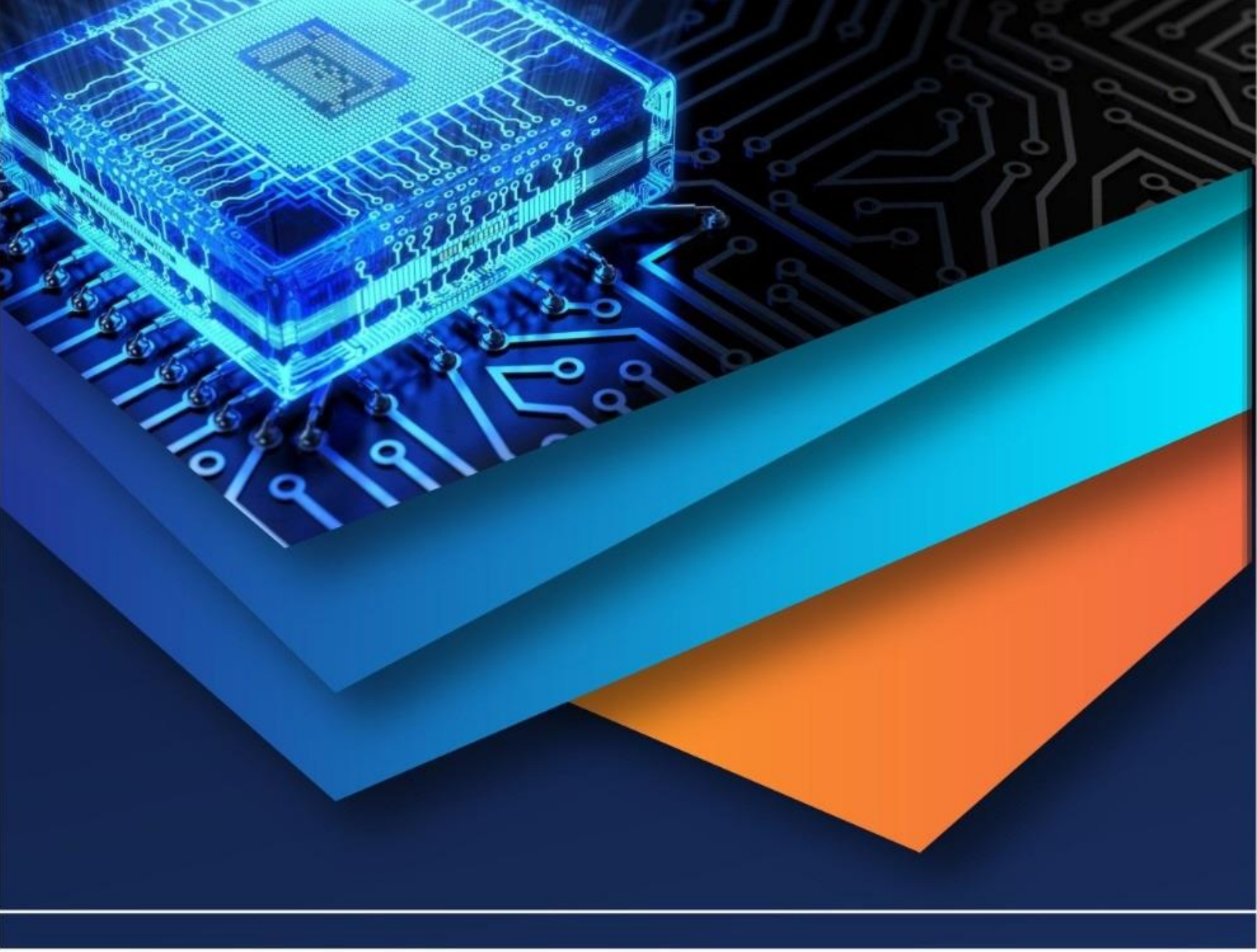
Impact, fatigue, creep, stress relaxation, moisture absorption, thermal ageing and accelerated environmental exposure should be evaluated before the material is considered for a load-bearing prosthetic component. Quantitative SEM/EDS mapping and direct interfacial tests can strengthen structure–property interpretation. Finally, prototype design, finite-element modelling and standardized component testing should be conducted for a clearly defined prosthetic application.

REFERENCES

[1] Malkapuram, R., Kumar, V. and Negi, Y.S. (2009). Recent development in natural fiber reinforced polypropylene composites.
[2] Barkoula, N.M., Garkhail, S.K. and Peijs, T. (2010). Effect of compounding and injection molding on the mechanical properties of flax fiber polypropylene composites. Journal of Reinforced Plastics and Composites. DOI: 10.1177/0731684409104465.
[3] Sun, Z.Y., Han, H.S. and Dai, G.C. (2010). Mechanical properties of injection-molded natural fiber-reinforced polypropylene composites: Formulation and compounding processes. Journal of Reinforced Plastics and Composites, 29. DOI: 10.1177/0731684408100264.
[4] Pickering, K.L., Efendy, M.G.A. and Le, T.M. (2016). A review of recent developments in natural fibre composites and their mechanical performance. Composites Part A: Applied Science and Manufacturing, 83, 98–112. DOI: 10.1016/j.compositesa.2015.08.038.
[5] Rajak, D.K. et al. (2019). Fiber-reinforced polymer composites: Manufacturing, properties, and applications. Polymers, 11, 1667.
[6] Hidalgo-Salazar, M.A. et al. (2019). Mechanical, thermal, viscoelastic performance and product application of PP–rice husk Colombian biocomposites.

[7] Rabbani, F.A. et al. (2022). Experimental study of mechanical properties of polypropylene random copolymer and rice-husk-based biocomposite by using nanoindentation.
[8] Yousef, N.S. (2022). Statistical study on additives used to improve mechanical properties of polypropylene.
[9] Chattopadhyay, S.K., Khandal, R.K., Uppaluri, R. and Ghoshal, A.K. (2011). Bamboo fiber reinforced polypropylene composites and their mechanical, thermal, and morphological properties. Journal of Applied Polymer Science, 119, 1619–1626. DOI: 10.1002/app.32826.
[10] Abdul Khalil, H.P.S. et al. (2012). Bamboo fibre reinforced biocomposites: A review. Materials & Design, 42, 353–368.
[11] Ibrahim, I.D., Jamiru, T., Sadiku, R.E. et al. (2015). The use of polypropylene in bamboo fibre composites and their mechanical properties – A review. Journal of Reinforced Plastics and Composites, 34, 1347–1356. DOI: 10.1177/0731684415591302.
[12] Yang, F., Long, H., Xie, B. et al. (2020). Mechanical and biodegradation properties of bamboo fiber-reinforced starch/polypropylene biodegradable composites. Journal of Applied Polymer Science, 137, 48694. DOI: 10.1002/app.48694.
[13] Martijanti et al. (2021). Polymer composite fabrication reinforced with bamboo fiber for particle board product raw material application.
[14] Cabrera de Lima, L.P.F. et al. (2021). Use of organic acids in bamboo fiber-reinforced polypropylene composites: Mechanical properties and interfacial morphology.
[15] Zhao et al. (2024). Forming performance and environmental impact of bamboo fiber reinforced polypropylene composites based on injection molding process for automobiles.
[16] Koutsawa, Y., Chrysafi, I., Berthé, V. et al. (2026). Experimental and numerical characterization of the tensile behavior of short-bamboo-fiber-reinforced polypropylene composites. Composite Structures, 397, 120805. DOI: 10.1016/j.compstruct.2026.120805.
[17] Xia, L. et al. (2026). Rapid screening of maleated polyolefin coupling agents for high-strength short bamboo fiber-reinforced polypropylene composites.
[18] Ghabeer, T., Dweiri, R. and Al-Khateeb, S. (2013). Thermal and mechanical characterization of polypropylene/eggshell biocomposites. Journal of Reinforced Plastics and Composites, 32(6), 402–409. DOI: 10.1177/0731684412470015.
[19] Kumar, R., Dhaliwal, J.S. and Kapur, G.S. (2014). Mechanical properties of modified biofiller-polypropylene composites. Polymer Composites. DOI: 10.1002/pc.22714.
[20] Hassen, A.A., Dizbay-Onat, M., Bansal, D., Bayush, T. and Vaidya, U. (2015). Utilization of chicken eggshell waste as a bio-filler for thermoplastic polymers. Polymers and Polymer Composites, 23, 653. DOI: 10.1177/096739111502300908.
[21] Mustapha, K., Ayinla, R., Ottan, A.S. and Owoseni, T.A. (2020). Mechanical properties of calcium carbonate/eggshell particle filled polypropylene composites. MRS Advances.
[22] Hayajneh, M. et al. (2021). Hybrid green organic/inorganic filler polypropylene composites: Morphological study and mechanical performance investigations.
[23] Younis and El-Wakil (2021). New composites from waste polypropylene/eggshell characterized by high flame retardant and mechanical properties.
[24] Barbaz-Isfahani, R. et al. (2023). Synergistic effects of egg shell powder and halloysite clay nanotubes on the thermal and mechanical properties of abacá/polypropylene composites.
[25] Akhtar, M.N. et al. (2016). Influence of alkaline treatment and fiber loading on the physical and mechanical properties of kenaf/polypropylene composites for variety of applications.
[26] Aridi, N.A.M. et al. (2016). Mechanical and morphological properties of injection-molded rice husk polypropylene composites.
[27] Md Radzi et al. (2018). The effect of kenaf filler reinforcement on the mechanical and physical properties of injection moulded polypropylene composites.
[28] George, J. et al. (2020/2021 as reported in the literature). Biocarbon reinforced polypropylene composite: An investigation of mechanical and filler behaviour through advanced dynamic atomic force microscopy and X-ray micro-CT.
[29] Rabbi, M.S., Islam, T. and Islam, G.M.S. (2021). Injection-molded natural fiber-reinforced polymer composites – A review. Journal of Materials Science: Materials in Engineering, 16, 15.
[30] Liu, Y. and Wang, M. et al. (2007). Fabrication and characteristics of hydroxyapatite reinforced polypropylene as a bone analogue biomaterial.
[31] Chan, K.W. et al. (2015). Polypropylene biocomposites with boron nitride and nanohydroxyapatite reinforcements.
[32] Obaid, M.N. et al. (2021). Characteristic of polypropylene nanocomposite material reinforcement with hydroxyapatite for bone replacement.
[33] Castro-Franco, A.D., Siqueiros-Hernández, M., García-Angel, V. et al. (2024). A review of natural fiber-reinforced composites for lower-limb prosthetic designs. Polymers, 16(9), 1293. DOI: 10.3390/polym16091293.
[34] Mijar, A.N. (2024). Exploring materials and techniques in Jaipur Foot manufacturing: A review.
[35] Lamesgin, H.B. and van der Stoel, K. (2026). Bamboo medical application: A state-of-the-art review. Advanced Materials Technologies. DOI: 10.1002/admt.71014.

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