RECYCLING OF PLASTIC WASTE IN COCONUT FIBRE AND COAL AS REINFORCEMENT: A REVIEW

Ifeanyi Finian Obasi[1], Obiukwu Osita Obineche[1], Peace Ugochinyerem Nlemedim[2], Friday Nwankwo Archibong[*3], Luvia Uchenna Ezeamaku[4].

[1]Mechanical Engineering Department, Federal University of Technology, Owerri, Imo State, Nigeria,

[2]Department of Chemical Engineering, Alex Ekwueme Federal University Ndufu-Alike Ikwo, Ebonyi State, Nigeria.

[3]Department of Mechanical Engineering, Alex Ekwueme Federal University Ndufu-Alike Ikwo, Ebonyi State, Nigeria.

[4]Polymer & Textile Engineering Department,, Federal University of Technology, Owerri, Imo State, Nigeria,

*Corresponding author's, email: fridayashibong@gmail.com

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Abstract
In the twenty-first century, researchers face difficulty searching for high-quality, lightweight, and biodegradable materials. Researchers started a vigorous paradigm shift from synthetic polymers to natural fibers and minerals as a result of this. One advantage is that these fillers are widely available in our nation. Waste made of plastic is strewn all over Nigerian streets, landfills, and dumpsites. There are a lot of studies on recycling plastic waste in the literature, but not much is known about ternary composites made of coal and fiber in thermoplastic. The qualities of non-waxy coconut fiber are impacted by the loss of interfacial adhesion, whereas waxy coconut fiber improves thermal and mechanical attributes without compromising the melting behavior of polymers. Additionally, a combination of coal and polymer exhibits gaps and cracks, indicating that the coal's interfacial adhesion is weak. Coal or coconut fiber adheres better to polymers when compatibilizers or binding agents are added. The characteristics of coal and fibers from coconut as reported by the authors will be thoroughly examined in this study.

1. Introduction

A paradigm shift from synthetic polymers to natural fibers was brought about by the need for low-energy-consuming equipment and the increasing need for sustainable materials (Mohanty et al., 2022; Thapliyal et al., 2023; Sharma et al., 2024). The change is a result of synthetic fibers' detrimental effects on the environment and public health. Obviously, a synergistic effect is produced when two or more materials are chemically combined, with a discernible dividing interface of constituents (Gupta et al., 2016; Atinafu et al., 2021). These natural fibers make excellent candidates for industrial uses in the modern era (Kumar et al., 2019). Their primary uses are in the furniture and automotive sectors (Rajak et al., 2019; Li et al., 2020).

Metal, ceramic, and polymers are the materials' constituents, and their qualities cannot compete with those of the mixtures. According to Adamu et al. (2022), natural fibers have several advantages over synthetic ones, including biodegradability, feather-light weight, affordability, low viscosity, sound isolation, and enhanced life-cycle performance features. Sadly, to the detriment of our ecosystem, these natural agro-waste fibres are disposed of in trash cans, gutters, and landfills, and some are burned. In Africa, agricultural waste ends up in these ways. Agro-waste fibers with polymeric composites started to gain traction at our research institutions not too long ago. Numerous publications have clarified the performance characteristics of binary and ternary natural fibers in diverse industries (Sun, 2018; Verma et al., 2022; Jalaee & Foster, 2023).

Soybeans, coconuts, bambara nuts, rice and maize husks, sawdust, flax, sugar palm, palm oil, cotton, and other natural fibers have demonstrated suitable qualities in a range of engineering, automotive, and household applications (Peças et al., 2018; Huda & Widiastuti, 2021; Chauhan et al., 2022). Natural minerals, such as coal, are frequently used in recent research to reinforce natural fibers and polymeric materials (Silva et al., 2020; Mahmood et al., 2021; Liu & Lv, 2022; Birniwa et al., 2023). rHDPP-coded recycled high-density polypropylene is the polymeric substance that will be utilized. This substance is a waste product from plastic seats that are disposed of at different landfills. Residents in the vicinity of the landfills purposefully set fire to the plastic debris that is present there. This garbage takes a long time to burn before it is quenched. The smoke from burning plastic waste contributes to global warming, releases harmful compounds into the atmosphere, and seriously harms soil fauna and flora (Evode et al., 2021; Dey et al., 2023). According to Ajayi et al. (2016) and Mithun et al. (2023), the majority of these microplastics end up in water bodies, contaminating them to the detriment of aquatic life and humans. Consuming water from such polluted rivers may cause this microplastic material to build up inside the body, which could result in allergic reactions, diabetes, and cancer (Udovicki et al., 2022; Lin et al., 2023). When we recycle plastic waste into useful materials and strengthen it with fibres and natural minerals, we can prevent or reduce these human-caused activities (Mohajerani et al., 2019; Abdur Rahman et al., 2023).

The current review aims to clarify, primarily, the research on coal and modified and unmodified natural fibers in the recycling of waste plastics, with or without coupling agents, by examining the development of composites with suitable qualities. The impact of coupling agents on the composition and characteristics of plastic waste, coconut fibre, or coal is given special attention.

2. Plastic waste

The amount of plastic garbage that was recently discovered in Nigerian dumpsites has been concerning. More plastic and things made from plastic are used and thrown away as the world's population grows. Due to the need brought on by growing populations, the production of plastic is rising globally (Katrin Jogi, 2020; Ebner & Iacovidou, 2021; Babaremu et al., 2022). As a result, more than 4.2 million tonnes of plastic waste will be produced in 2022 alone (Shukla et al., 2022). More plastic debris has been dumped into the world's waterways and land by the United States (Law et al., 2020). Nigeria is the ninth-most plastic-pollution-producing country in the world (Agberemi, 2020; Yalwaji et al., 2022). Unfortunately, a larger percentage of Nigeria's plastic garbage is not recycled. Instead, a large portion of the plastic garbage finds its way into the ocean, rivers, lakes, drains, and lagoons. While the majority of microbes break down plastic debris, some linger in the environment for years (Ekanayaka et al., 2022). This is due to plastic's hardness, with polypropylene (PP) and LDPE having the biggest obstacles to natural degradation (Faraca & Astrup, 2019).

However, it can be recycled chemically or mechanically. While sorting and pre-treatment limit mechanical recycling, successful chemical recycling produces feedstock for a variety of uses, including the replacement of petrochemicals (Thiounn & Smith, 2020). Since only education has the power to alter people's attitudes, knowledge, and behaviour, good teaching can help reduce this plastic waste (Chow et al., 2017; Silva et al., 2018). Through recycling, this plastic trash can be systematically converted into energy and other useful compounds, providing a solution for waste sustainability management (Idumah & Nwuzor, 2019). Several techniques, such as liquid spark cracking, microwave-assisted pyrolysis, and heat and spark pyrolysis, have been deemed superior to landfills for turning plastic waste into fuel (Wong et al., 2015). The population of poorly managed plastic garbage creation in a certain enclave can be projected with at least -1 km resolution from now until 2060 with the use of country-level waste management data collection (Lebreton & Andrady, 2019).

2.1. Sources of Plastic Garbage Material

The production of many different types of plastic commodities has increased significantly because of industrialisation. Due to their many uses that are focused on affordability and adaptability, waste is produced either directly or indirectly. The main sources of plastic entering the ecosystem are land-based and ocean-based sources. Consumer goods such as packaging and household items are the most common plastic debris found in rivers and on land, and the density, surface area, and size of plastic all have an impact on how it is transported (Schwarz et al., 2019; Ncube et al., 2021). Electronics, building materials, and construction materials are additional sources of plastic (Butturi et al., 2020; Nyika & Dinka, 2022). Individuals burn these plastic wastes, releasing harmful chemicals into the atmosphere that harm aquatic and human health (Dey et al., 2023).

Additionally, polymers added to the buildup of trash in our surroundings (Rosenboom & Langer, 2022; Meester & Eugene, 2023).

2.2. Plastic waste disposal

The slow rate at which plastic garbage degrades causes environmental disasters as billions of marine and terrestrial living things perish. This is due to certain toxic chemical components used in the production of plastics that contaminate our food, water, air, and land, resulting in a range of illnesses (Okunola et al., 2019; Adeniran & Shakantu, 2022). Similar research was done on the detrimental effects of plastic trash disposal on groundwater quality and biodiversity in dumpsites (Singh & Sharma, 2016). To protect the environment and public health, strict regulation is necessary. These wastes can be disposed of in a variety of ways, such as landfilling, recycling, incineration, bitumen-plastic mixtures for road building, and biodegradation techniques (Shahnawaz et al., 2019). Many issues related to the disposal of plastic waste can be resolved using the biodegradation approach by employing fungi and bacteria concurrently for appropriate, targeted substrates (Moharir & Kumar, 2019). There are numerous opportunities to convert plastic trash into valuable feedstock for global industry (Lange, 2021; Yadav, 2023). As an alternative to synthetic plastic, which is primarily responsible for environmental toxicity, biodegradable plastic has been promoted in numerous nations (Ling et al., 2021). Using plastic waste as coarse aggregate while building roads could help create cleaner energy sources and lessen pollution (Singh & Ruj, 2016). There is almost no data on the use of plastic materials in Nigeria, such as city population, disposal, collection, and recycling (Duru et al., 2019). In Nigeria, passing legislation to control the usage and disposal of plastic waste will be a positive step.

2.3. Dangers of plastic garbage on the ecosystem

One of the main causes of pollution in the air, water, and land is the open burning of plastic waste. Because most of Nigeria's plastic waste is burned, harmful substances like furans, dioxins, mercury, and polychlorinated biphenyls are released into the environment. Just burning polyvinyl chloride (PVC) releases harmful halogens into the atmosphere, which influence climate change. Greenhouse gas emissions are greatly increased by burning waste materials such as plastic and rubber (Chen, 2018; Kristanto & Koven, 2019). Aquatic life and human health suffer greatly when plastic garbage and other unclean materials are dumped into rivers or the ocean (Bhat et al., 2022; Kumar et al., 2021). Although gasification and pyrolysis are methods for recycling plastic waste, they introduce secondary contamination into the environment (Dogu et al., 2021).

3. Coconut fibre waste disposal

Every community produces a variety of trash because of the daily processing of agricultural products. One of those goods that is mostly grown in southern Nigeria is coconut. Fig. 1 illustrates the procedure for making coconut fiber in a polymer blend. While many people use it as fuel for cooking, its waste is carelessly dumped (Yerima & Grema, 2018; Lawal et al., 2019).

Figure 1. Schematic process for extracting fibre from coconut seed

Biomaterials are helping to reduce greenhouse gas emissions and the depletion of oil reserves by replacing synthetic and plastic waste (Kumar & Saha, 2022). For example, CH_4 emissions might be significantly reduced between 10.2 t and 20.9 t per year if waste coconut shells are used to make valuable materials (Nunes et al., 2020). To make concrete and sisal fiber blends lighter, it was studied whether to incorporate coconut shell (CS) waste as coarse aggregate (Prakash et al., 2020). According to the results, the modulus of elasticity in a coconut shell/concrete blend fell as the weight percentage of sisal fiber grew. Still, it increased significantly as the mass fraction of sisal fiber increased. Table 1 provided additional clarification on this outcome.

Table 1. Modulus of elasticity of sisal fibre-reinforced CS concrete (Prakash et al., 2020)

Mixture ID	Modulus of elasticity (GPa)
CSC	15.17
CSC1	15.24
CSC2	15.37
CSC3	16.02
CSC4	14.38

Radioactive liquid waste has been actively treated with coconut fiber (Ferreira et al., 2018). The outcome demonstrated the effectiveness of biosorption using activated coconut fiber in the treatment of radioactive liquid wastes containing cesium-137, uranium, and americium-241. The impact of coconut fiber on the soot produced by burning municipal solid waste for non-bearing masonry units was investigated by Tabyang et al. (2022). SEM pictures reveal that in opposition to samples without CF, samples with CF distribute heavy alkali-activated matrices. This is because adding CF content causes a sample to undergo geo-polymerization, which raises the absorption of liquid alkaline activators (L) in endlessly replicated CF (Fig. 2). Improve the normal-weight concrete bearing while keeping strain-strain characterisation in mind. Scattered coconut fibers are utilised (Shcherban et al., 2022). According to the results, the modulus of elasticity was 16%, the strain characteristics rose by 46%, and the deformation under axial tension was 51%. The process of combining coconut fibre and polymer to make bricks with great strength has been explained (Kanna & Dhanalakshmi, 2018).

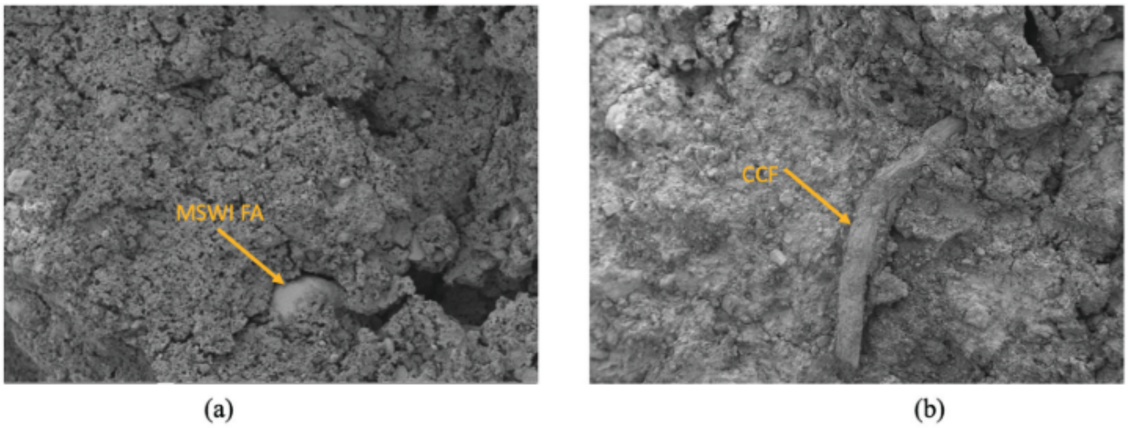

Figure 2. 500x-magnified SEM images of CF reinforced LS-MSWI FA geopolymer at LS/MSWI FA ratio of 1/1, Na_2SiO_3/NaOH of 80/20, NaOH concentration of 5 M, and (a) CF = 0, and (b) CF = 0.5% (Tabyang et al., 2022).

3.1. Thermoplastic matrix with a coconut fibre blend

Because of the growing human population, the quest for new materials has continued to expand. The development of hybrid fiber from natural fiber has several benefits because of its low density, biodegradability, ease of recycling, affordability, and capacity for renewal (Mawardi et al., 2019). To create new materials with lightweight, affordable, and effective mechanical qualities, several crop fiber types have been employed (Ahmad et al., 2015). A study by Brahmakumar et al. (2005) examined the use of coconut fiber as reinforcement in low-density polyethylene (LDPE). The outcome demonstrates that fiber/LDPE matrices form a strong interfacial bond thanks to the waxy surface layer of coir. To extend the critical fiber length by 100% and decrease the composite tensile strength by 40% and modulus by 60%, this waxy surface was removed, which resulted in weak interfacial adhesion. Under injection molding, the performance of a polyolefin combination (PP-HDPE) including coir coconut fibers was investigated (Hidalgo-Salazar et al., 2020). The outcome demonstrates that coir improved the mechanical and thermal characteristics of PP-HDPE without compromising its melting behavior. Additional results indicated that CF might be utilized in place of other additives, such as talc, calcium carbonate, or forming agents, that are used to reduce injection moulding flaws. The function of coir fiber in the mixture of thermoplastic cassava starch and poly (lactic acid) was examined in the study of Chotiprayon et al. (2020). The thermoplastic starch (TPS) and poly (lactic acid) blend, as well as its combination with coir fiber (CF), demonstrated good adherence, according to SEM data. In the meantime, CF inclusion improved the shear viscosity by reducing the melt flow ability. While other parameters, such as the Tg, Tcc, Tm, and Td of PLA of the TPS/PLA composites, increased, it also noted a loss in tensile strength, extensibility, and impact strength. The characteristics of coir fiber packed with polypropylene bio-composites were examined in a study by Ichim et al. (2022). The outcome demonstrates that the bio-compositions' weak bonding reduced the fiber/matrix interface's tensile and bending strength. According to the TG/DTG, the degradation temperature rises as the mass percentage of coir fiber increases.

Bonding agents' impact on the systemic characteristics of blends of polypropylene coconut fiber was examined by (Pisanu et al., 2019) in their study. The outcome showed that sticky agents significantly influence blend properties. Blends with CF and bonding agents also improved the morphological, mechanical, and thermal characteristics. Structural engineering, home furnishings, ornaments, automobiles, and household goods can all employ this combination. The effect of CF on the poly(Ɛ-caprolactone) (PLC) and PLA blend used to create package printing plates was examined (Priselac et al., 2022). The results indicated that adding CF increased all composites' hardness, which is essential for relief plate embossing applications, as indicated in Table 2. According to the DSC results, adding PLA matrix significantly lowers the amount of PLC crystallinity in composites.

Table 2. Hardness of PLC/PLA/CF composites (Priselac et al., 2022)

PLC/PLA/CF (wt%)	ºShD	SD
100/0/0	53.3	1.0
100/0/0.5	54.2	0.7
100/0/3.0	54.4	0.9
80/20/0	55.0	1.1
80/20/0.5	58.7	1.3
80/20/3.0	58.9	1.4
70/30/0	58.7	1.3
70/30/0.5	60.0	1.1
70/30/3.0	60.1	1.9

The increase in the mass fraction of PLA and CF somewhat enhanced the blends' resistance to aging. Furthermore, it is shown that CF caused PLC/PLA composites to begin thermally decomposing at lower temperatures, but a higher 3wt% PLA concentration in the composite resulted in the blend's thermal resistance stabilising during extended ageing, as illustrated in Figs. 3 and 4. The effectiveness of CF reinforced with hybrid mixes of thermoplastic starch and beeswax was examined (Mogan et al., 2023).

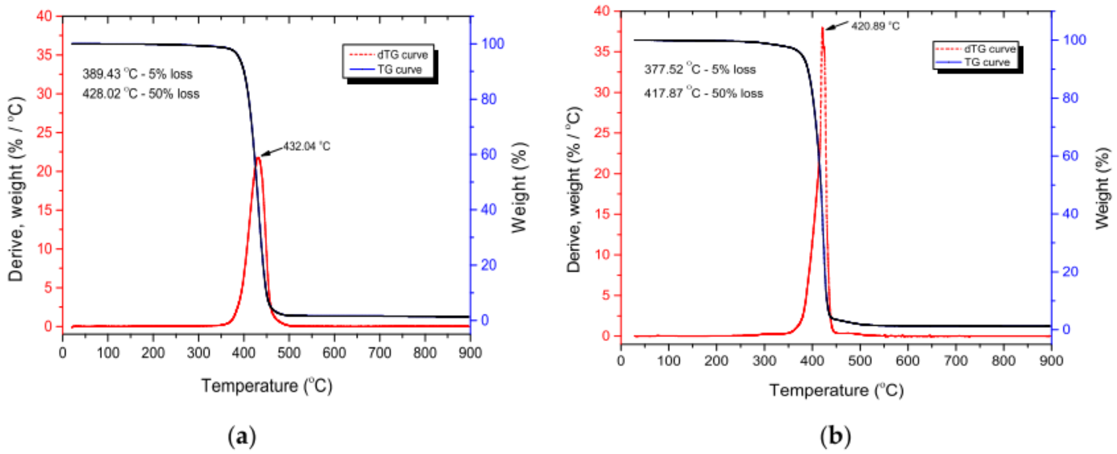

Figure 3. TG and DTA curves of (a) neat PLC and (b) PLC/PLA/CF 100/0/3.0 composites (Priselac et al., 2022)

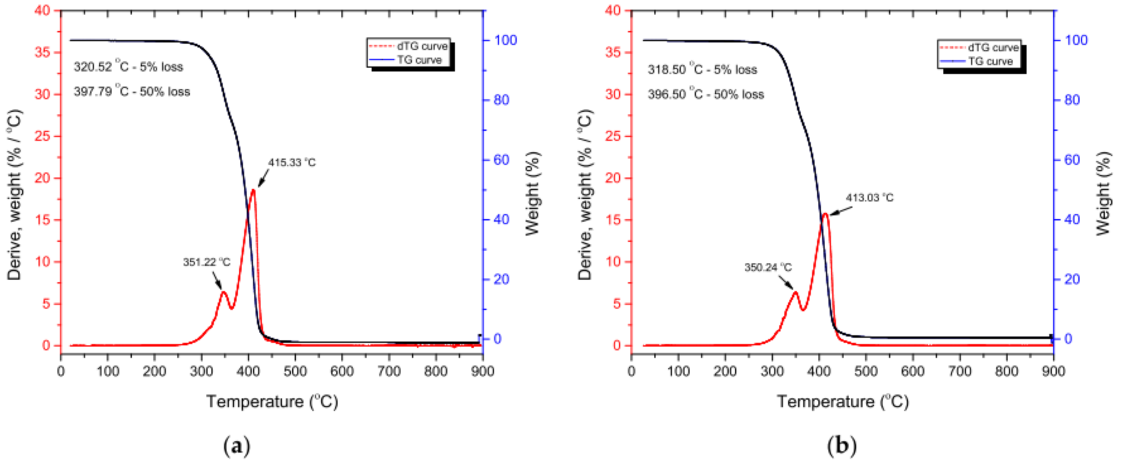

Figure 4. TG and DTA curves of (a) PLC/PLA/CF 70/30/0 and (b) PLC/PLA/CF 70/30/3.0 composites (Priselac et al., 2022).

According to the results, blends containing 50 w.t% of CF showed the lowest percentage of swelling and water absorption. Additional results indicated that adding 50% CF reduces weight loss for 30 days, whereas 50% yields the greatest solubility test results. An alkali-treated ternary blend of coconut husk, bagasse fiber, and calcium carbonate was used in a study by Verma et al. (2023) that used 5% w/v NaOH. Because the alkali on the phase is hydrophilic, functionalisation of the blends increased flexural strength by 70% and durability by 64.8%. Additionally, the fiber composite's compressive strength was enhanced by modification. The impact of adding coconut fiber on the characteristics of beeswax and reinforced thermoplastic starch (TPS) was investigated (Jumaidin et al., 2023). The findings demonstrated that adding CF improved the composites' thermal stability, which raised the residual content from lower to higher percentage values as the CF w.t% rose from 0 - 30. Tensile strength and modulus increased by 20.7 MPa and 2890 MPa, respectively, at a 50% mass fraction of CF (Fig. 5). The development of hybrid fibres reinforced with blends of polyvinyl chloride (PVC) for use as shoe soles was examined by Oladele et al. (2022). According to the results, the ultimate tensile strength of 47.00 MPa, young modulus of 3.52 GPa, hardness of 81.00 HS, and wear index of 0.06 mg were the best characteristics of CF at 20 w.t% reinforced with PVC. Additionally, CF with 15 w.t% and 5 w.t% corn cub ash (CCA) exhibited the best flexural and impact strength characteristics. Similar studies on CF and other fiber hybrids are documented in the literature (Obada et al., 2020; Johar & Ariff, 2022).

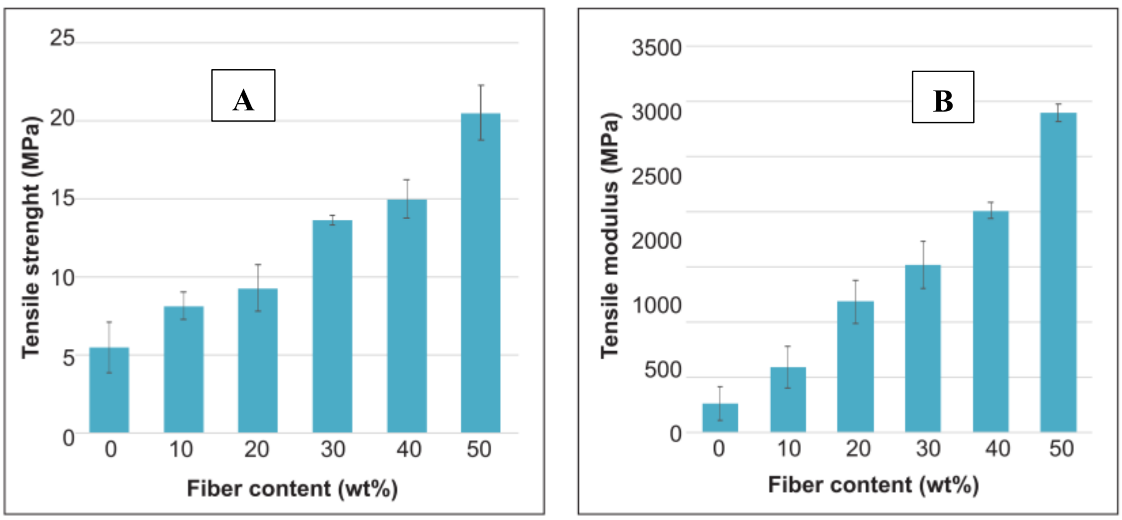

Figure 5. (a) Tensile strength (b) tensile modulus of TPS/Beeswax/CF (Jumaidin et al., 2023)

3.2. Use of coupling agents in natural fibres

Fiber derived from plants can be utilised as a reinforcing agent in a matrix made of polymers (Hasan et al., 2022). The thermoplastic and coconut fiber blend showed poor qualities (Rabe et al., 2019). This made it challenging to create a mold for this mixture. The silane coupling agent is essential for improving the interfacial adhesion of the coconut fiber/polymer blend (Anbupalani et al., 2020; Hu et al., 2020; Prakash et al., 2022). A study by Balan et al. (2017) used a silane coupling agent to enhance the qualities of powdered coconut shells mixed with natural rubber and synthetic polyurethane. According to the results, the coupling agent-induced interfacial adhesion in the coconut shell powder treated with glycidyloxypropyltrimethoxysilane resulted in a higher tensile strength in the matrix than the other modifier employed to treat the powder. The chemical alteration, however, has no impact on the blend's thermal characteristics. A study by Sabri et al. (2013) examined how a silane coupling agent affected the characteristics of coconut fiber mixed with polypropylene. A study was conducted utilising coconut shells and Styrofoam debris (Chun et al., 2022) when coupling agents were present. As the weight percentage of coconut shell grows, the viscosity and processing torque of recycled polystyrene/coconut shell (rPS/CS) also increase, according to the results. This demonstrates how maleated polystyrene helps to lower shear stress when rPS/CS blends are being made at high mass fractions. With a 30% mass fraction, the best flexural strength and modulus were achieved in a rPS/CS composite.

When coconut fiber was surface treated, its tensile strength significantly increased. The best treatment for a coconut/polyester composite made from recycled PET was 0.5% silane (Abdullah & Ahmad, 2012). Additional results demonstrated that the treatment reduces water uptake because of mix interaction, whereas microscopic data demonstrated improved matrix-fiber bonding. To improve the mechanical qualities of the blends, coconut and bamboo fiber have been surface-treated with sodium hydroxide (Raman et al., 2022). Fernandes et al. (2013) looked at how coupling agents and fiber loading affected the characteristics of blends of coconut fiber and polymers. The outcome indicates that fiber-matrix composites with a 2 w.t% maleic anhydride content have better adhesion. When 10 weight per cent coconut fibre was added with a 2 weight per cent coupling agent, the mechanical characteristics rose by 46 per cent. All manufactured blends had higher maximum strain values when a coupling agent was present. The several thermoplastic/CF/CA materials that were previously mentioned are summarised in Table 3.

Table 3. Thermoplastic/CF blends filled with different types of coupling agents

Blends	CF particle size	CF concentration range (wt%)	Coupling agent concentration (wt%)	Treatment method	Processing method	Properties analysed	Reference
PP/CF/CA	1-3 mm	0 - 40	3	3-APE	Melt-mixing	Tensile strength, water absorption,	(Sabri et al., 2013)
TPU/CSP/NR/CA	<60 μm	5 - 20	1	NaOH	Tw0-roll mill	FTIR, XRD, SEM, TGA, Mechanical properties.	(Balan et al., 2017)
LDPE/CF	150 – 250 μm	-	iso-cynate of cardanol	NaOH	Melt-mixing	SEM,optical fractographs, mechanical properties.	(Brahmakumar et al., 2005)
rPS/CS/CA	not more than 4 cm	30 -60	3	-	Brabender internal mixer	Rheological, flexural properties, morphological.	(Chun et al., 2022)
HDPE/CF/CA	277.4 μm	-	-	Maleic anhydride	Counter-rotating twin-screw extruder	Physical, morphological, mechanical.	(Fernandes et al., 2013)
PP/CF/CA	212.2 μm		1	Maleic anhydride	Twin-screw extruder	Mechanical, morphological, DSC, TGA.	(Pisanu et al., 2019)

Blends	CF particle size	CF concentration range (wt%)	Coupling agent concentration (wt%)	Treatment method	Processing method	Properties analysed	Reference
PLA/CSP/CA	38 μm	0-60 php	3	3-APE	Brabender	Tensile properties, morphological, Thermal properties, FTIR.	(Chun et al., 2012)
rPS/CS/CA/ WPC	149 μm	30, 60 phr	3 phr	Maleic anhydride	Melt-mixing	Tensile properties, morphological, TGA, DSC	(Ling et al., 2020)

*Note: CF- coconut fibre, CA- coupling agent, CSP- coconut shell powder, WPC-wood plastic composites, rPS-recycled polystyrene.

4. Coal as a mineral deposit in Nigeria

Coal is a kind of sedimentary deposit that is primarily made up of ready-to-burn carbon (Akinyemi et al., 2012; Mondal et al., 2021). It is black or brownish-black in colour and contains more than 70% by volume and more than 50% by weight carbonaceous elements (Jovanovski et al., 2023; Favourite et al., 2023). In several nations, it powers heavy machinery and produces energy (Edianto et al., 2022; Debiagi et al., 2022). Nevertheless, coal fly ash output is influenced by the type used in thermal power plants to produce electricity (Di Carli et al., 2022). Because of its complexity, coal can seriously erode and corrode an environment (Cui et al., 2019; Yu et al., 2023). Numerous minerals that are extremely valuable sources of censorious metal have been found in coal (Finkelman et al., 2019). Kaolinite crystallinity, for instance, is consistent with the hydrodynamic conditions and the initial sedimentary environment (Liu et al., 2022; Guan et al., 2023). Because it has been utilised as filler or reinforcement to create novel materials of interest, this mineral coal is currently generating a lot of attention (Eterigho-Ikelegbe et al., 2021).

4.1. Coal as a filler in thermoplastic blend

Overall, there is interest in using coal for purposes other than energy. The development of polymer composites that include coal as reinforcement or filler is gaining international and scientific attention. The documented experimental studies that use coal as reinforcement in polymeric blends will be examined in this paper. According to Phillips (2017), coal has acted as a particle filler in polymeric blends. According to research by Zhang et al. (2023), plastic trash was recycled using low-grade coal. Researchers investigated how the coal mass fraction affected the characteristics of recycled HDPE. As the mass percentage of coal rose, the results demonstrated a decrease in both compressive and modulus characteristics, as illustrated in Figure 6 and explained in Table 4. Coal-based thermoplastic composites' high ductility resulted in low compressive moduli of 1.35 GPa when compared to regular concrete. The microstructure data reveal holes and fractures, indicating poor coal-HDPE interface adhesion. In the life cycle assessment (LCA) study, the coal/polymer composites significantly improved economic and ecological planning. The development of construction materials benefits from this research.

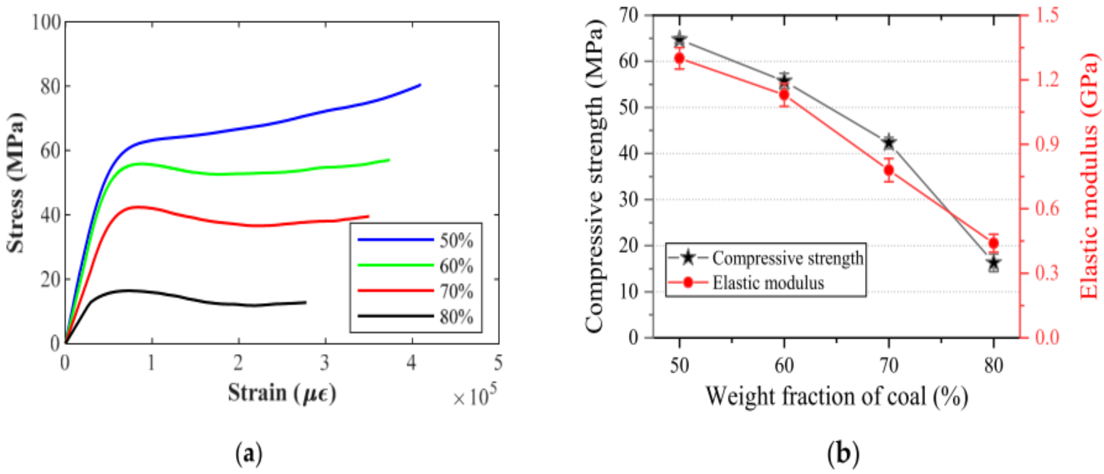

Figure 6. Compressive strength test (a) stress-strain curves; (b) strength & modulus vs. mass fraction of coal (Zhang et al., 2023).

Table 4. Summary of mechanical properties of coal-based thermoplastic composites (Zhang et al., 2023)

	Compressive strength (MPa)		Elastic modulus	
Coal fraction	Mean	SD	Mean	SD
50%	64.7	0.71	1.30	0.051
60%	55.7	1.70	1.13	0.055
70%	42.3	1.20	0.78	0.054
80%	16.3	1.92	0.44	0.040

A different study found that adding asphalt pitch to the coal mix reduced the low-circularity porosity of high-rank coal and texture (Hayashi et al., 2014). This most likely occurs because asphalt lowers the polymer's initial temperature and dilatation conductivity. One study (Marais et al., 2023) extruded coal particles using recycled polypropylene (PP) and low-density polyethene (LDPE) as a binder. According to the results, extrudate produced the best average compressive strength at 10 w.t% LDPE, with 17.5 MPa when dry and 18.0 MPa when wet. Every extrudate with a mass fraction of more than 10% merely distorted rather than broke. Depending on the blend application, keep in mind that both binder incorporations can be changed to provide noticeably different qualities. The two binders and coal particles interacted well, according to the TGA measurements.

Utilising 3D printing and fused deposition modelling, coal and polyamide 12 (PA12) mixes are created (Zhang et al., 2022). The findings demonstrated that because of the low interfacial adhesion between the anthracite coal and the PA12 matrix, all mechanical parameters were reduced. In the meantime, because of its positive interactions, the lignite coal improved the mechanical properties of the same mixes. Rheological and morphological analyses corroborated each of these. The thermal analysis of coal fuels, agro-biomass, forest biomass, and polyamide 6 recycling were compared in another study (Kijo-Kleczkowska et al., 2022). As indicated by the greatest DSC values in each curve, hard coal, sludge coal, biomass, and coal have the largest carbon contents and calorific values of all the fuels taken into consideration based on DSC. According to the paper, the organic substance might be used as a filler in polymer blends. High-density polyethene's mechanical characteristics, the impact of hybrid fillers, and its percentage contents were all examined in a study that was published (Alshammari et al., 2022).

The authors created their composites using both micro and nano-fillers. According to the results of the morphological test, both fillers preserved a strong interfacial link and experienced reduced agglomeration. With tensile, impact, and flexural strengths of 62 MPa, 90 MPa, and 81 MPa, respectively, this dispersion produced blends containing 74% HDPE, 25% CaCO3, and 1% fumed silica. This demonstrates that filler kinds and dispersion, rather than the quantity of ingredients, have a notable impact on blends' mechanical qualities. All of the characteristics point to the great performance of polymer blends for a wide range of applications, including wind turbine blades and building construction. Coal ash was combined with recycled high-density polyethene to create lightweight materials in order to preserve an environmentally friendly habitat (Alshabander et al., 2018). Impact strength significantly decreased when 30 weight per cent coal ash was added, it was found. The filler reduced the mixes' propensity to absorb deformation energy and increased their elasticity. As the bulk proportion of coal ash increases, so do the mixes' thermal characteristics. According to reports, coal quality has a significant impact on the polymer blend's characteristics (Sahoo et al., 2022). The vitrinite maceral group and its sub-macerals have the strongest positive correlation with coal plasticity among the specimens under study. In contrast, the intertinite group's fusinite macerals have the strongest negative correlation with coal fluidity. There are further studies on coal ash and thermoplastic blends in the literature, such as El-Tawil et al. (2021), Kaleni et al. (2022), and El-Tanani et al. (2022).

4.2. Use of coupling agents and compatibilisers in coal blends

Many authors have proposed the use of compatibilisers or coupling agents on the surface of coal particles to improve the adhesion of binary coal and polymer blends to overcome the persistent problem of poor interfacial adhesion between the coal particles and the polymer matrix (Zhang et al., 2013; Rojas-lema et al., 2021). To improve the interfacial bonds between coal filler and thermoplastic material, coupling agents are essential for reducing interfacial tension and preventing coal filler particles from clumping together. According to published reports, the addition of adhesive compounds increases blends' strength and fracture resistance (Raszewski et al., 2022; Serra-Parareda et al., 2022). Bonding agents are added to the coal/polymer composite to increase its functioning by increasing the likelihood of bonding.

Wang et al. (2022) looked into the usage of surfactant nanofluids to increase the surface wettability of coal particles after coupling agents were added when creating coal/polymer blends. They found that the coal particles are not evenly distributed and that spaces on the coal particle surface cause agglomeration to occur. Researchers looked at the efficacy of additional coupling agents, such as titanate (Ding et al., 2020), silane (Feng et al., 2020), stearic acid (Sengupta et al., 2013), and many more, to address this issue. According to the study, the coal particles' -OH groups reacted with the side groups of the coupling agent's main chain, preventing the particles from interacting with one another. The authors proposed employing coal particles modified with coupling agents in rubber or plastic mixtures to provide effective qualities that will extend the material's lifespan.

5. Conclusion

A reliable and promising method of recycling a lot of unwanted plastic is to blend waste plastic particles with coconut fibers to create biocomposites. The incorporation of renewable fillers further facilitates the development of recyclable bio-composites. Using coal or coconut fiber as reinforcement reduces the quantity of plastic waste produced and addresses environmental issues. For better performance, the final biocomposites' characteristics must be enhanced, particularly at larger mass fractions of coal and CF fillers. Biocomposites' interfacial adhesion has been enhanced for improved qualities using NaOH, a coupling agent, and waxy materials. Through these methods, crosslinked plastic waste molecules become more compatible with fiber or coal biocomposites, causing them to disperse and generate high-quality materials. The addition of coal or natural fibers to thermoplastic blends has created a novel material for use in both home and commercial settings. The created materials, for instance, have been used in a variety of engineering fields. For example, these materials have been employed in concrete matrices (Towheed Molvi & Singh, 2023) in the furniture and automobile industries (Kumar et al., 2019). Research on coal, coconut fiber, and recycled waste plastic must be vigorously pursued to create more competitive and inventive materials for human use.

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