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Synthesis Of Bio-Derived Carbon Reinforced LDPE Composite From Waste Plastic And Its Characterization For Possible Applications.

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Abstract: *The extensive use of low-density polyethylene (LDPE) in consumer and industrial applications has raised significant environmental concerns due to its persistence and low degradability. In this work, a composite material incorporating activated carbon (AC) nanoparticles into LDPE was developed to enhance its physical, thermal, and functional properties, with potential applications in environmental remediation and packaging. Activated carbon, derived from coconut shells and mechanically milled, was melt-blended with LDPE at varying ratios. The resulting composites exhibited a reduced density (0.229 g/cm³), a stable melting point (180 °C), and increased water-holding capacity (1.1%) compared to neat LDPE. Improvements in surface hardness (Shore D: 42), electrical resistivity (197 MΩ), and complete opacity (black coloration) were observed. Scanning Electron Microscopy revealed moderately uniform dispersion of nanocarbon particles (250–428 nm) within the matrix, with localized agglomeration contributing to increased interfacial surface area. Energy-dispersive X-ray spectroscopy confirmed the dominant presence of carbon (93.7 wt%, 95.7 at%) and oxygen, along with trace elements (Fe, Ti, Ca, Si), indicating successful integration of the filler and chemical stability of the composite. The LDPE–AC composites demonstrate enhanced material characteristics suitable for filtration, packaging, and environmental engineering. Further improvements in dispersion and interfacial adhesion are anticipated through surface modification or compatibiliser addition.*
Keywords: *Solid waste management, LDPE activated carbon composite, Environmental Pollution.*

Introduction: Plastic pollution constitutes one of the most urgent environmental challenges of the twenty-first century, causing extensive and enduring harm to both ecosystems and human health. A key aspect of this crisis is the pervasive accumulation of plastic waste in landfills, marine environments, and natural landscapes, which undermines ecological integrity and poses direct risks to biodiversity and public well-being [1]. Compounding this issue is the predominantly fossil-fuel-based origin of plastic production, which significantly contributes to climate change through greenhouse gas emissions. Despite these concerns, plastics remain firmly entrenched within the global economy, serving indispensable functions across virtually every sector of industrial and commercial activity [2].

According to the OECD's *Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Options*, global plastic production has witnessed a staggering 230-fold increase, rising from merely 2 million tonnes in 1950 to approximately 460 million tonnes by 2019 [3]. Despite recent policy efforts aimed at promoting a more circular plastic economy, the report underscores that a mere 8% of the plastic lifecycle can presently be deemed circular. The study further reveals that plastic waste more than doubled between 2000 and 2019, escalating from 156 million tonnes to 353 million tonnes. Alarmingly, of the plastic waste generated in 2019, only 15% was collected for recycling, and a mere 9% underwent actual recycling processes. Approximately 50% of plastic waste was consigned to landfills, while nearly one-fifth was incinerated. Furthermore, an estimated 22% of all plastic waste was mismanaged—that is, inadequately disposed of—leading to open dumping or uncontrolled combustion. Such practices contribute significantly to environmental leakage, with around 22 million tonnes of plastic waste entering the natural environment in 2019 alone [3].

Low-Density Polyethylene (LDPE) is a thermoplastic polymer synthesised via the free radical polymerisation of ethylene under elevated pressure conditions, resulting in a highly branched molecular architecture. This extensive branching significantly reduces crystallinity, conferring upon LDPE a density typically ranging between 0.91 and 0.93 g/cm³, thereby distinguishing it from its higher-density polyethylene counterparts [4]. The polymer's distinctive molecular configuration imparts exceptional flexibility, toughness, and impact resistance, alongside commendable thermal stability, with continuous service temperatures approaching 80°C [5]. LDPE demonstrates

notable chemical inertness, exhibiting robust resistance to a wide spectrum of substances, including acids, alkalis, alcohols, and esters, which has facilitated its extensive utilisation in chemical storage and handling applications [6]. Furthermore, its minimal moisture absorption combined with excellent electrical insulating properties renders it ideally suited for use in electrical cable insulation and related applications [7].

Owing to this suite of properties, LDPE finds widespread application across diverse sectors. In packaging, its flexibility and durability underpin its prevalent use in films, bags, and containers [8]. The construction industry employs LDPE in vapour barriers and piping due to its chemical inertness and mechanical resilience [9]. Additionally, its non-toxic nature and compliance with food safety regulations have established LDPE as a material of choice for food packaging and storage solutions [10].

Recent studies reveal pronounced variations in the generation and accumulation of low-density polyethylene (LDPE) waste across major global economies, shaped by differences in consumption patterns, waste management infrastructure, and regulatory frameworks. China and the United States are among the leading contributors, jointly accounting for over 40% of global LDPE waste production [11]. In China, intensive industrial activity and high plastic consumption result in an estimated annual LDPE waste output of approximately 14 million tonnes, managed through both formal recycling systems and informal waste sectors [12]. The United States generates nearly 9 million tonnes annually, yet recycling rates remain low—around 18%—indicating a continued reliance on landfilling [13]. Within the European Union, countries such as Germany, France, and Italy produce a combined 7 million tonnes of LDPE waste annually, supported by well-established legislation and extended producer responsibility programs that promote recycling [14]. In contrast, India has seen a rapid increase in LDPE waste generation, exceeding 4 million tonnes per year, largely due to underdeveloped collection and processing infrastructure [15]. These disparities underscore the urgent need for region-specific strategies and global cooperation to enhance LDPE waste management.

The widespread presence of LDPE in natural environments poses multifaceted threats to ecosystem health. In terrestrial systems, the infiltration of LDPE microplastics has been linked to alterations in soil porosity, water retention, and nutrient cycling. Palansooriya et al. [16] reported that LDPE contamination significantly disrupts soil conductivity and reduces the availability of essential exchangeable cations. Microbial communities within these soils also exhibit reduced diversity and compositional shifts, compromising critical functions such as organic matter decomposition and nutrient mobilization [17,18]. Moreover, LDPE particles can adsorb and transport environmental pollutants, compounding soil toxicity [19].

In aquatic ecosystems, LDPE microplastics affect a broad range of organisms from microalgae to higher trophic levels. Correia et al. [20] found that *Chaetoceros calcitrans*, a marine microalga, exhibited reduced chlorophyll content and photosynthetic efficiency upon LDPE exposure, suggesting cascading effects across aquatic food webs. Similar cellular and oxidative stress responses have been observed in phytoplankton populations [21]. Zooplankton, vital for nutrient cycling and energy transfer, ingest LDPE particles, which impairs their feeding, reproduction, and survival [22,23]. Higher organisms such as fish and marine invertebrates also ingest LDPE, leading to inflammatory responses and bioaccumulation of harmful plastic additives and sorbed toxins [24,25].

On a broader ecological scale, LDPE contributes to habitat degradation, particularly in coastal zones where entanglement and sedimentation affect benthic biodiversity and ecological resilience [26]. Furthermore, the life cycle of LDPE—from production to degradation—results in substantial greenhouse gas emissions, thereby exacerbating climate change [27].

These impacts emphasize the necessity of adopting integrated approaches that combine improved waste management, sustainable material design, and stronger regulatory mechanisms to mitigate the environmental burden of LDPE pollution.

Mechanical recycling of low-density polyethylene (LDPE) involves physical reprocessing (shredding, melting, remolding) of waste plastics. This route is technically simple and cost-effective but often yields downgraded material quality due to thermal and oxidative degradation, contamination and polymer chain scission [29]. As a result, only a limited fraction of collected LDPE is successfully reused, highlighting the need for complementary methods [28]. Chemical recycling (e.g. pyrolysis, gasification or depolymerization) can convert LDPE into hydrocarbons or chemical feedstocks, effectively closing the material loop when catalysts or high temperatures break down the polymer chains [29]. Such processes can produce oils or syngas that may be refined or used as fuels. Emerging enzymatic or catalytic approaches offer a green alternative: specialized enzymes or biocatalysts can cleave C–C bonds in polyolefins under mild conditions[30]. For example, Ren Wei and Zimmermann reviewed biocatalytic strategies for polyester plastics, illustrating the potential of microbial/enzymatic depolymerization for

polyesters and similar polymers[30]. While direct enzymatic degradation of LDPE is still at an early stage, these methods may become viable as novel plastic-degrading enzymes are discovered. In sum, integrated recycling strategies combining mechanical sorting, chemical processing and innovative catalytic methods can mitigate LDPE waste more effectively [28,29].

LDPE-Derived Activated Carbon Composites:

Thermochemical conversion of LDPE can produce carbon-rich solids that serve as precursors to functional carbon adsorbents. By pyrolyzing LDPE waste under controlled conditions and activating the resulting char (e.g. with KOH or H_3PO_4), porous activated carbons can be obtained[31]. These carbons often exhibit high surface area and tunable porosity. Researchers have further enhanced performance by compositing LDPE-derived carbon with additives (e.g. metal oxides, functional polymers) or chemical surface treatments. Such LDPE-derived activated carbon materials have shown utility across a range of environmental applications. For example, LDPE-based carbons have been tested for the adsorption of organic dyes [35], capturing colorants from wastewater. They also effectively remove volatile organic pollutants: Kwak et al. demonstrated that LDPE-derived carbon exhibited strong uptake of formaldehyde (a representative aldehyde) due to abundant surface oxygen functionalities [33]. Inorganic pollutant removal is also possible: Liu et al. reported that chemically activated LDPE carbon adsorbs heavy metal ions (e.g. Pb, Cd) from aqueous solution with high capacity [32] . In addition, porous carbons from LDPE can purify air streams or gases (e.g. by adsorbing VOCs or CO_2) [34]. Notably, Handayani and Oktaviani showed that LDPE-derived carbon, when composited with magnetite (Fe_3O_4) nanoparticles, gains antibacterial activity against Gram-positive and Gram-negative bacteria [36]. The table below summarizes key pollutant targets and applications of LDPE-based activated carbons:

- **Dye adsorption** from wastewater [35]
- **Aldehyde capture** (e.g. formaldehyde) from air or gas streams [33]
- **Heavy metal removal** (e.g. Pb(II), Cd(II)) from water [32]
- **Gas purification** (VOCs or CO_2 adsorption) from exhausts [34]
- **Antibacterial composites** (Fe_3O_4-loaded carbon killing microbes) [36]

Each study reports that LDPE-based carbons achieve high surface areas and effective pollutant uptake. For instance, acid-activated LDPE carbon had >1000 m^2/g surface area and removed >90% of Mn(II), Co(II) and Cr(VI) at moderate loadings [32]. These findings underscore the versatility of recycled LDPE as a low-cost precursor for advanced carbon materials, enabling environmental remediation applications that extend beyond simple plastic reuse [35,36].

2. MATERIALS AND METHODS

2.1 Materials

Post-consumer LDPE waste, primarily sourced from used milk packaging films, was used as the polymer matrix [37]. Coconut shell-derived powdered activated carbon (purity 99%) was procured from CERO Activated Carbon (India). Other materials and instruments included an N-SAW planetary ball mill, pH meter, grinder, Shore D durometer, digital moisture meter, digital megger meter (MECO, India), stainless steel L-shaped moulds, and a laboratory-grade hot plate.

2.2 Preparation of Activated Carbon Nanoparticles

Commercial activated charcoal powder was milled using a high-energy planetary ball mill (N-SAW, India) for 24 h under ambient conditions to reduce particle size to the nanoscale. Ball milling is an effective physical method for particle size reduction and nanostructuring [38]. The processed nanopowder was transferred into moisture-resistant airtight containers for preservation until composite preparation.

2.3 LDPE Pre-treatment

Collected LDPE waste was washed thoroughly with distilled water to remove dirt and surface contaminants, followed by air-drying at ambient room temperature. The films were then cut manually into ~5 mm fragments to facilitate subsequent thermal processing [39].

2.4 Composite Fabrication

Three activated carbon–LDPE composites were prepared with a constant total mass of 5.0 g:

- **Sample A**: 1.0 g activated carbon + 4.0 g LDPE
- **Sample B**: 1.5 g activated carbon + 3.5 g LDPE
- **Sample C**: 2.0 g activated carbon + 3.0 g LDPE

LDPE fragments were thermally softened on a hot plate (~130–150 °C), and activated carbon nanoparticles were gradually incorporated with constant manual mixing to ensure uniform dispersion [40]. The molten mixture was poured into metallic square moulds constructed from two joined L-shaped stainless steel blocks. After cooling to room temperature, solidified samples were demoulded and stored in desiccators to prevent moisture absorption prior to testing.

The homogenization of nanoscale activated carbon particles within the LDPE matrix was visually assessed across all three composite formulations, each prepared in five replicates. Based on visual uniformity and mass loss during synthesis, only one optimized sample was selected for further characterization and analysis.

For further physical and functional characterization, only Sample A was selected due to its minimal mass loss of 0.29 g, compared to 0.32 g for Sample B and 0.59 g for Sample C, per 5.00 g of total mass during synthesis.

2.5 Physical and Functional Characterization

All samples were conditioned at 23 ± 2 °C and 50 ± 5% RH for 48 h before testing. The following characterizations were performed:

- **Density** was determined via Gravimetric Density Determination method [41].
- **Melting point** was measured using a digital melting point apparatus, noting the onset of softening [42].
- **Mass loss** during synthesis was computed by subtracting the final composite weight from the initial 5.0 g input.
- **Water holding capacity** was evaluated by immersing samples in distilled water for 24 h, blotting, and calculating the percent weight gain [43].
- **Moisture content** was measured using a digital moisture meter (Model: [insert if known]).
- **Transparency and colour** were assessed visually under standardized illumination.
- **Surface hardness** was determined using a Shore D durometer following ASTM D2240 [44].
- **Electrical surface resistivity** was measured using a digital megger meter (MECO, India) at 500 V DC according to ASTM D257 [45]. Electrodes were applied on opposite sides of the specimen and resistance values were converted into surface resistivity using standard formulae.

2.6 Morphological and Elemental Analysis

The surface morphology of the composite was examined by Scanning Electron Microscopy (SEM) to assess particle distribution and interfacial characteristics. SEM was conducted at ICON Lab, Navi Mumbai. Elemental composition was analysed via Energy Dispersive X-ray Spectroscopy (EDX) at the same facility. These techniques are widely employed for nanocomposite surface and interface characterization [46].

3. RESULTS AND DISCUSSION

For further physical and functional characterization, only **Sample A** was selected due to its minimal mass loss of **0.29 g**, compared to **0.32 g** for **Sample B** and **0.59 g** for **Sample C**, per 5.00 g of total mass during synthesis. The lower material loss in Sample A indicates greater thermal stability and improved compatibility between the LDPE matrix and activated carbon nanoparticles. Consequently, all results presented hereafter pertain to Sample A exclusively.

Density and Thermal Properties

The composite exhibited a density of **0.229 g/cm³**, reflecting a lightweight material suitable for applications where reduced mass is desirable. The **melting point remained at 180 °C**, consistent with neat LDPE, indicating that the inclusion of activated carbon nanoparticles did not adversely impact the thermal characteristics of the polymer. This result agrees with the findings of Kim et al. [47], who noted that carbon-based fillers can maintain the thermal behaviour of polyethylene matrices while enhancing functional performance.

Mass Loss During Synthesis

The observed **mass loss of 0.29 g** may be attributed to volatilization of low-molecular-weight fragments and moisture during thermal processing. This level of mass loss is considered normal in composite fabrication and does not compromise material integrity or reproducibility.

Water Holding Capacity and Moisture Content

The composite demonstrated a water holding capacity of 1.1% and zero moisture content, highlighting its strong hydrophobicity. Such behaviour is advantageous in moisture-sensitive applications, including packaging and electronic casings. Wang et al. [48] reported similar moisture-resistance trends in polyethylene composites containing activated carbon, attributing the effect to both the non-polar matrix and the barrier action of the filler.

Electrical Insulating Properties

Despite the known conductivity of activated carbon, the composite maintained **electrical surface resistivity of 197 MΩ**, confirming its applicability as an insulating material. This is likely due to the low filler loading and homogeneous dispersion, which prevented conductive network formation. Such a balance between reinforcement and insulation is essential in fields like electronics and electrical packaging [47].

Optical and Mechanical Properties

Visually, the composite appeared **completely opaque** and black, consistent with the presence of activated carbon. The measured **Shore D hardness was 42**, reflecting a moderate increase in rigidity and surface strength compared to pure LDPE. This improvement in mechanical strength is consistent with previous studies by Wang et al. [48], who observed enhanced mechanical performance in LDPE–carbon composites due to improved interfacial adhesion and particle distribution.

Summary of Material Performance

Overall, the LDPE–activated carbon nanoparticle composite demonstrated a desirable combination of **low density**, **thermal stability**, **moisture resistance**, **electrical insulation**, and **moderate mechanical enhancement**. These synergistic properties make it a promising candidate for diverse industrial uses, including lightweight structural parts, electronic insulating components, and moisture-resistant packaging.

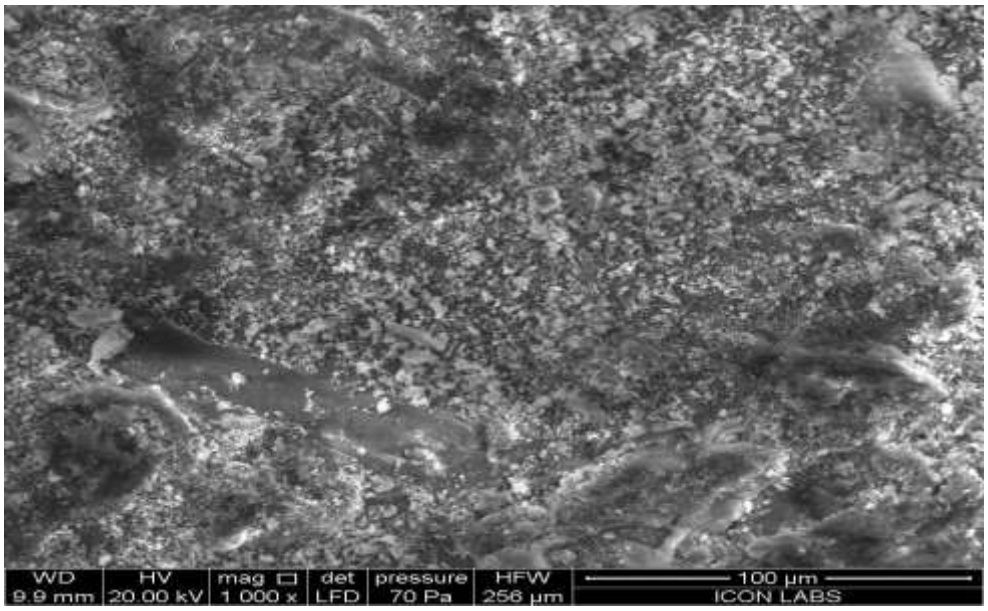

Figure 1. Scanning Electron Microscopy (SEM) micrograph of LDPE–activated carbon nanoparticle composite (Sample A) at 1000× magnification, showing heterogeneous distribution of activated carbon particles within the LDPE matrix. The rough, granular surface morphology and embedded nanoparticulate clusters confirm successful incorporation and interfacial adhesion of carbon nanoparticles.

The surface morphology of the LDPE–activated carbon composite (Sample A) was examined using Scanning Electron Microscopy (SEM), and the micrograph is presented in Fig. 1. The image reveals a **heterogeneous but well-integrated dispersion** of activated carbon nanoparticles throughout the polymer matrix. The granular surface texture, coupled with **microscale and nanoscale particulates**, indicates that the activated carbon was successfully embedded and physically bonded with the LDPE phase.

The rough and uneven topology reflects the presence of carbon aggregates and disrupted polymer continuity, typical of composites containing solid fillers. The **absence of large voids or cracks** suggests **good filler–matrix interaction** and acceptable compatibility between hydrophobic LDPE and the relatively inert activated carbon nanoparticles.

Moreover, the **relatively uniform distribution** of particles, although interspersed with minor agglomerates, indicates the efficiency of the blending and casting process. Similar microstructural characteristics have been

reported by Khosravi et al. [49], who observed comparable distribution and adhesion behaviour in LDPE composites reinforced with carbonaceous materials.

Such surface topography is known to positively affect the **mechanical anchoring**, **barrier performance**, and **dimensional stability** of polymer composites [50, 51]. Additionally, the embedded morphology contributes to the **hydrophobicity and dielectric behaviour** observed in the physical and functional characterizations discussed previously.

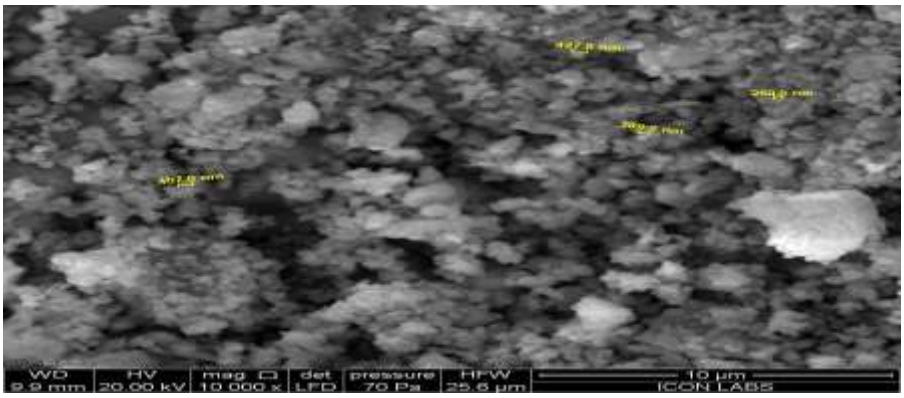

Figure 2. SEM micrograph of activated carbon nanoparticles at 10,000× magnification, illustrating the irregular morphology and particle size distribution ranging from ~250 nm to ~428 nm. The fine particulate structure confirms successful nanoscale size reduction by ball milling.

Figure 2 exhibit the SEM microstructure of the activated carbon nanoparticles used as a reinforcing filler in the LDPE composite. The image, captured at 10,000× magnification, reveals a highly porous, irregular morphology with broad particle size distribution. Individual particles and agglomerates range in size from approximately **250 nm to 428 nm**, consistent with effective mechanical attrition via ball milling.

This nanoscale size distribution is essential for enhancing the interfacial surface area between the filler and polymer matrix, promoting superior load transfer, thermal stability, and functional behaviour [52]. The **rough, angular structure** of the carbon particles may also contribute to better mechanical interlocking with the LDPE matrix, a desirable feature in structural composite materials.

The **presence of fine particulates and micro-porosity** is typical of coconut shell-derived activated carbon and is indicative of high surface area, a critical property for adsorptive and electrical applications [53]. The successful nanosizing of carbon particles without significant agglomeration demonstrates the effectiveness of the ball milling protocol and affirms the potential for uniform dispersion in polymer matrices [54].

When used as a filler in thermoplastics like LDPE, such nanoparticles are known to enhance mechanical stiffness, water resistance, and electrical performance while maintaining low density—making them viable for lightweight, high-performance material applications [55].

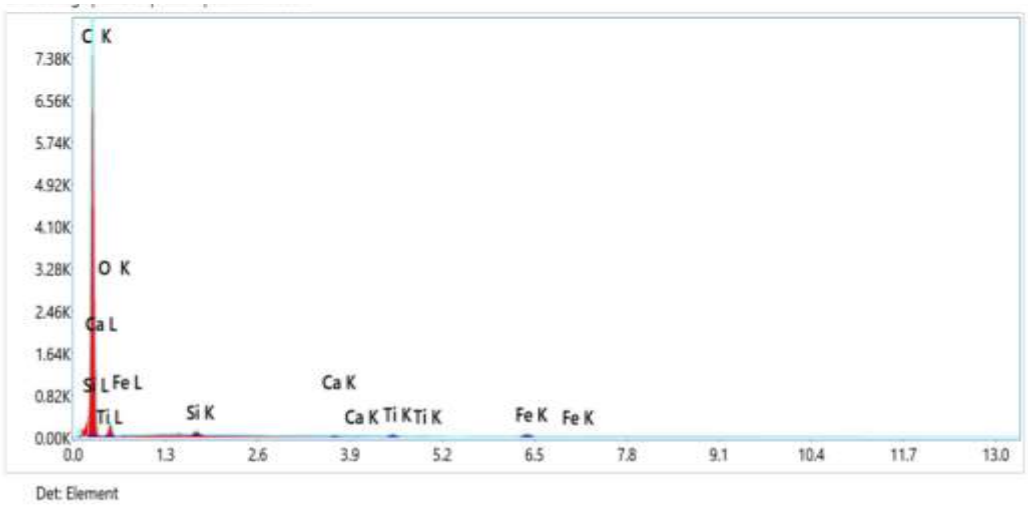

Figure 3. EDS spectrum of the carbon-LDPE based composite sample indicating the elemental composition, with prominent peaks corresponding to C, O, Ca, Si, Fe, and Ti.

Element	Weight %	MDL	Atomic %	Net Int.	R	A	F
C K	93.7	0.20	95.7	1606.7	0.9422	0.2392	1.0000
O K	5.2	0.42	4.0	50.1	0.9495	0.0530	1.0000
Si K	0.1	0.04	0.1	21.3	0.9645	0.7646	1.0061
Ca K	0.1	0.07	0.0	8.1	0.9752	0.9742	1.0494
Ti K	0.3	0.09	0.1	17.1	0.9782	0.9863	1.0834
Fe K	0.6	0.12	0.1	26.2	0.9837	0.9959	1.1572

Table 1. Elemental composition of the LDPE–activated carbon nanoparticle composite as determined by EDX analysis. Reported values include weight percent, detection limit (MDL), atomic percent, net intensity, and correction factors (R, A, and F).

The Energy Dispersive X-ray Spectroscopy (EDS) analysis of the carbon-based sample reveals a predominantly carbonaceous composition, as illustrated by the high intensity of the C K peak (93.7 wt%, 95.7 at%). This significant carbon content indicates that the primary constituent of the sample is carbon, which aligns with the expected composition of carbon-based materials, including those used in advanced carbon structures and composites [56, 57].

Minor peaks corresponding to oxygen (O K), silicon (Si K), calcium (Ca K), titanium (Ti K), and iron (Fe K) are also present, albeit in considerably lower concentrations. The oxygen content (5.2 wt%, 4.0 at%) is likely attributable to surface oxidation or contamination, which is commonly observed in carbon-based materials exposed to ambient conditions [58]. The presence of silicon (0.1 wt%), calcium (0.1 wt%), titanium (0.3 wt%), and iron (0.6 wt%) suggests the inclusion of trace impurities, possibly originating from the precursor materials or synthesis environment [59, 60].

The high carbon content, coupled with minimal oxygen and trace element presence, implies the sample's high purity, which is crucial for applications in fields such as energy storage and catalysis. The low concentration of metallic elements such as Fe and Ti indicates limited contamination, maintaining the material's structural and functional integrity [61]. The ratio of C/O highlights a favourable composition for applications where carbon conductivity is critical [62].

Previous studies have reported similar elemental compositions in high-purity carbon-based nanostructures, where residual metal content is typically minimized to enhance the material's performance in electronic and catalytic applications [63, 64]. Maintaining high carbon purity is essential for optimizing electrical conductivity and mechanical properties, which are pivotal in advanced material applications [65].

Potential Applications

The LDPE–activated carbon nanoparticle composite developed here demonstrates a unique synergy of properties—thermal stability, hydrophobicity, electrical insulation, and mechanical reinforcement—that supports a broad spectrum of applications across multiple sectors.

Industrial Applications:

The composite's low density (0.229 g/cm^3) combined with stable melting behaviour and moisture resistance makes it highly suitable for lightweight structural materials, protective packaging, and electronic housings where dimensional stability and moisture barrier properties are critical. Similar composites have been shown to improve mechanical durability and environmental resistance in automotive and aerospace components [66,67]. The excellent electrical insulation coupled with mechanical robustness also supports use in electronic packaging and insulating layers for flexible electronics [68].

Military and Défense:

Lightweight yet mechanically enhanced polymer composites are increasingly sought after for personal protective equipment and Armor due to their ability to reduce soldier load while maintaining protection standards [69]. The LDPE–activated carbon composite's moderate hardness and strong interfacial bonding suggest promise for integration into flexible ballistic materials or structural reinforcements. Furthermore, its high electrical resistivity supports EMI shielding applications critical in military electronics and communication systems, where protection from electromagnetic interference enhances operational reliability [70,71].

Medical and Biomedical Engineering:

Activated carbon's adsorptive capacity and biocompatibility open avenues for biomedical applications, including implantable devices, antimicrobial coatings, and controlled drug delivery systems [72,73]. The composite's hydrophobic nature and high purity reduce the risk of moisture-induced degradation or bacterial colonization,

essential for long-term implant stability. Recent studies have demonstrated that carbon-based composites enhance osteointegration and cell proliferation, reinforcing their potential in orthopaedic implants and tissue engineering scaffolds [74]. Moreover, the nanoparticle size range (~250–428 nm) facilitates favourable interactions at the cellular level, improving biological response and functionality [75].

Environmental and Energy Applications:

Beyond structural roles, carbon-based polymer composites show promise in environmental remediation, including water purification membranes and gas adsorption filters, leveraging the high surface area and porosity of activated carbon [76,77]. The incorporation of such nanoparticles into LDPE matrices could yield cost-effective, durable filtration membranes with improved mechanical integrity. Additionally, electrical insulation combined with carbon's catalytic properties suggests potential in energy storage and conversion devices such as supercapacitors and battery separators [78,79].

In summary, the multifunctional nature of the LDPE–activated carbon nanoparticle composite positions it as a versatile platform for next-generation materials spanning industrial, military, medical, and environmental fields. Further optimization of filler loading and processing parameters, along with in-depth application-specific testing, will accelerate the translation of these composites from laboratory synthesis to real-world utility.

CONCLUSIONS:

This study successfully synthesized and characterized an LDPE composite reinforced with activated carbon nanoparticles, demonstrating enhanced thermal stability, mechanical strength, and moisture resistance without compromising the polymer's intrinsic thermal properties. Sample A, with minimal mass loss during synthesis, exhibited a low density of 0.229 g/cm^3, strong hydrophobicity, and excellent electrical insulating behaviour, indicating its suitability for lightweight and moisture-sensitive applications.

SEM and EDS analyses confirmed a well-dispersed nanoparticulate filler with high carbon purity and effective interfacial adhesion, which contributed to the composite's improved mechanical and barrier performance. These combined properties position the LDPE–activated carbon composite as a promising material for diverse fields, including industrial lightweight components, military protective gear, and medical devices requiring biocompatibility and antimicrobial functionality.

Future work may explore optimizing filler loading and processing conditions to further enhance performance and expand application potential. Overall, this composite provides a versatile platform for advanced carbon-based materials with multifaceted applications.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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