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INVESTIGATION OF MECHANICAL PROPERTIES OF COW BONE AND POULTRY FEATHER REINFORCED rLDPE COMPOSITES FOR SUSTAINABLE MATERIAL APPLICATIONS

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ABSTRACT

Materials with an unusual mix of properties which cannot be satisfied by traditional polymeric materials are increasingly researched alongside the conversion of waste to wealth, promoting the sustainability of engineering materials. This study investigated the mechanical properties of cow bone (CB) and pyrolyzed poultry feather (PF) reinforced recycled low-density polyethene (rLDPE) composites to assess their suitability as substitutes for conventional polymers in industrial applications. CB was crushed and blended at different ratios with PF in an rLDPE matrix obtained from waste sachet water packs. The composites were developed and tested for hardness, tensile, flexural and impact strength as well as moisture absorption. Results obtained from the mechanical tests showed that the composite with 70% rLDPE and 30% PF resulted in the highest tensile strength and Shore-D hardness of 6.42 MPa and 94 respectively. The composite having 70% rLDPE and 30% CB resulted in the highest flexural strength of 10.81 MPa while the composite with 80% rLDPE and 20% CB absorbed the highest impact energy of 3.07 J. All samples except the composite having 70% rLDPE, 20% CB and 10% PF absorbed less than 5% moisture. The developed composites showed good lightweight characteristics with density values ranging from 0.74 g/cm^3 to 1.07 g/cm^3. Compared to traditional polymers, these composites offer improved sustainability and moderate mechanical properties but may have lower durability unless treated for moisture resistance. They can serve as cheap substitutes for synthetic polymers used in the manufacture of casings and packaging materials in the electronics, beverage and automobile industries.

Keywords: Biocomposite, Cow bone, Poultry Feather, Recycled Polymer**,** Sustainability

INTRODUCTION

The global demand for sustainable and eco-friendly materials has spurred extensive research into bio-reinforced composites, aiming to mitigate environmental degradation while maintaining structural performance (Ubi et al., 2024). Conventional synthetic polymers which are used in most industries today have detrimental effects on humans and the environment, because of the non-biodegradable nature of such materials (Abdulrahman et al., 2015; Kalia et al., 2011; Ubi et al., 2023). However, the production of green components with zero effect on the ecosystem is envisaged to solve these dangers. Furthermore, materials that possess lightweight characteristics have been asserted to make products economically viable for manufacturers with a greater focus on good mechanical properties especially in the absorption of impacts, producing low stress and life safety (Adah et al., 2024; Ajao et al., 2024). No wonder, in September 2015, the Sustainable Development Goal (SDG) summit made clear plans to promote sustainability and eradicate environmentally unfriendly products, replacing them with green products to ensure a safer planet by 2030.

In some developing nations, there is a rapid increase in agricultural waste, and this poses a serious threat to humanity and the ecosystem (Yawas et al., 2016). Open-air burning is prohibited because it pollutes the atmosphere and can be stored in excess. Consequently, waste from biomass and other agro-based products has recently been converted to carbon and used for the manufacture of engineering materials (Anosike-Francis et al., 2022; Chandran et al., 2024). Organic materials such as coal, wood, peat, coconut, shells and poultry feathers, are raw materials used for activated carbon. Granular carbon media are most commonly obtained by grinding the raw material, adding a suitable binder to give it hardness, re-compacting, and crushing to the correct size. The carbon-based material is converted to carbon by thermal decomposition in a furnace under a controlled atmosphere and heat. The resultant product has an incredibly large surface area per unit volume and a network of submicroscopic pores where adsorption occurs. The walls of the pores provide surface-layer molecules that are essential for adsorption. Due to environmental factors, natural carbon, such as carbon from chicken feathers has several benefits over conventional polymer fillers, including low cost, low energy consumption, non-abrasiveness, safety in handling and lightweight characteristics. Carbon obtained from natural sources has been proven to be very economical (Eichhorn et al., 2001). In our society, the use of plastic has increased rapidly, generating a lot of waste as a result of the constant production of plastic materials in the world today. Most of these plastics are commonly used as packaging items in the food industry for casings and storage.

Plastics Europe (2022) reported that over 10 million tonnes of post-consumer plastic waste were recycled in 2020 and approximately 5.5 million tonnes were reintroduced into the economy which accounted for over 20% increase compared to the 2018 reports. This confirms that plastics continue to hold great potential in various sectors such as in civil work, for structural materials (Kumar et al., 2017). Poultry feathers and cow bones are common waste found in abattoirs while sachet water packs are common waste products found in dump sites. The proper utilization of these materials towards satisfying the sustainability requirement can result in the qualitative substitution of conventional polymeric materials used in engineering manufacture today. In this context, rLDPE as a commonly discarded thermoplastic offers a compelling matrix for composite development due to its recyclability and adaptability. The incorporation of natural reinforcements such as cow bone and poultry feathers introduce a novel approach, leveraging the abundant availability and intrinsic mechanical properties of these biological materials. Cow bone, rich in calcium phosphate, contributes to rigidity and compressive strength (Norrrahim et al., 2024) whereas poultry feathers, composed of keratin, enhance the toughness and impact resistance of composites (Sapuan et al., 2024). Aside from the toughness and impact resistance provided by the keratin, studies have shown that it also enhances lightweight in materials and good thermal and acoustic insulating properties (Poole et al., 2009; Schmidt & Jayasundera, 2004). Similarly, cow bones have high contents of calcium hydroxyapatite, making them insoluble, and contributing to their unique properties for utilization in composites. Bones generally have a fibrous structural component owing to the presence of collagen thus exhibiting good composite behaviour (Ockerman & Hansen, 1999). Effective dispersion and surface modification of cow bone particles are crucial for enhancing compatibility with polymer matrices. Techniques such as surface treatment can improve the interfacial bonding between the biobased fillers and polymers (Jayabal et al., 2012; Norrrahim et al., 2024; Ubi & Abdulrahman, 2015). The synergistic integration of these reinforcements with rLDPE not only promotes circular economy principles but also addresses challenges in waste management. Studies have shown that cow bone-reinforced composites exhibit improved mechanical properties, including increased tensile and flexural strength, compared to unreinforced polymers (Dakarapu et al., 2023). Both cow bone and poultry feathers offer distinct advantages over synthetic fibres, such as lower cost and environmental benefits. However, achieving uniform dispersion and strong interfacial bonding remains a challenge (Chandran et al., 2024; Norrrahim et al., 2024) and the mechanical properties of these composites are highly dependent on the filler content (Onitiri & Ubi, 2021). A study by Oladele et al. (2014) examined the mechanical properties of natural fibre composites, finding that chicken feather fibres, when used in varying proportions (1-5 wt%), enhanced both tensile and flexural properties of high-density polyethene (HDPE). Lower fibre contents (1-2 wt%) significantly improved flexural strength, while 3 wt% optimized tensile properties. These results underscore the compatibility of animal-based fibres with polymer matrices, likely due to the structural and chemical properties of keratin in feathers and collagen in bone, which may act synergistically with polyethene to enhance composite performance. Extending this approach to rLDPE—a sustainable alternative to virgin polymers—could further advance eco-friendly material solutions by incorporating waste-derived fibres, thus reducing environmental impact and promoting circular economy principles.

Talabi et al. (2024) explored a novel method to enhance the mechanical properties of epoxy resin composites by using carbonized chicken feathers as a filler material. The feathers were carbonized at 600°C and incorporated into the epoxy matrix at 5-10 wt%. They reported that the composites with 10 wt% filler showed the best mechanical properties, including a 49% increase in tensile strength, a 16% rise in Young's modulus, a 40% improvement in flexural modulus, and a 57% increase in flexural strength. Another study (Akinwekomi et al., 2024) explored the use of agricultural waste materials, specifically waste snail shell particles (SSP) and chicken feather barb fibres (CFB), as hybrid reinforcements in an epoxy matrix. These materials were incorporated using a stir-casting technique. They noted that the incorporation of SSP and CFB as hybrid reinforcements led to significant enhancement of the wear resistance and hardness, with the most improvement observed at 18 wt.% SSP/CFB, achieving a wear index value of 0.104 and a hardness score of 50 HS. The tensile modulus was highest at 12 wt.% SSP/CFB, reaching 532 MPa. The authors further stated that at low concentrations (up to 6 wt.%) and high concentrations (15 and 18 wt.%), the ultimate tensile strength (UTS) decreased. However, at 9 wt.% and 12 wt.%, UTS improved by approximately 19% and 15% compared to the control sample. The decrease in UTS at higher concentrations was attributed to debonding and agglomeration of SSP particles.

While cow bone and poultry feather reinforcements offer significant improvements in mechanical properties, challenges such as processing difficulties and achieving optimal filler dispersion need to be addressed. Additionally, exploring hybrid composites that combine both cow bone and poultry feathers could yield further enhancements in mechanical performance. This study explored the mechanical properties of the developed composites for different filler ratios, focusing on tensile strength, flexural strength, and impact resistance, while also considering the moisture absorption properties, the challenges and potential applications.

MATERIALS AND METHODS

The materials used in the development of the composite include pyrolyzed poultry feathers, crushed cow bones, and recycled low-density polyethene obtained from waste sachet water packs. The poultry feathers were sourced from a livestock market located in Kakuri, Kaduna State, Nigeria, while the cow bones were sourced from an abattoir in Minna, Niger State. Waste sachet water packs were obtained from water packaging factories in Minna and Kaduna towns, Nigeria. The sachet water packs and chicken feathers were thoroughly washed and rinsed with water to remove any dirt that clanged them. The chicken feathers were further washed with 4 wt.% Sodium Hydroxide (NaOH) to improve their interfacial interaction with the matrix and enhance the mechanical and physical properties of the biocomposites (Jayabal et al., 2012; Kalia et al., 2011; Ubi & Abdulrahman, 2015). The rinsed feathers were dried for two days in open air after which they were burned in the absence of air at 400ºC in an industrial oven. The cow bones were crushed to granular sizes between 1 mm to 1.5 mm using a jaw crusher. Samples of the sachet water packs, pyrolyzed poultry feathers and crushed cow bones were packed and labelled according to the desired formulation ratios after weighing. An L9 Taguchi design was used to obtain the formulation used in this study. Figure 1 shows the steps involved in the development of the biocomposites.

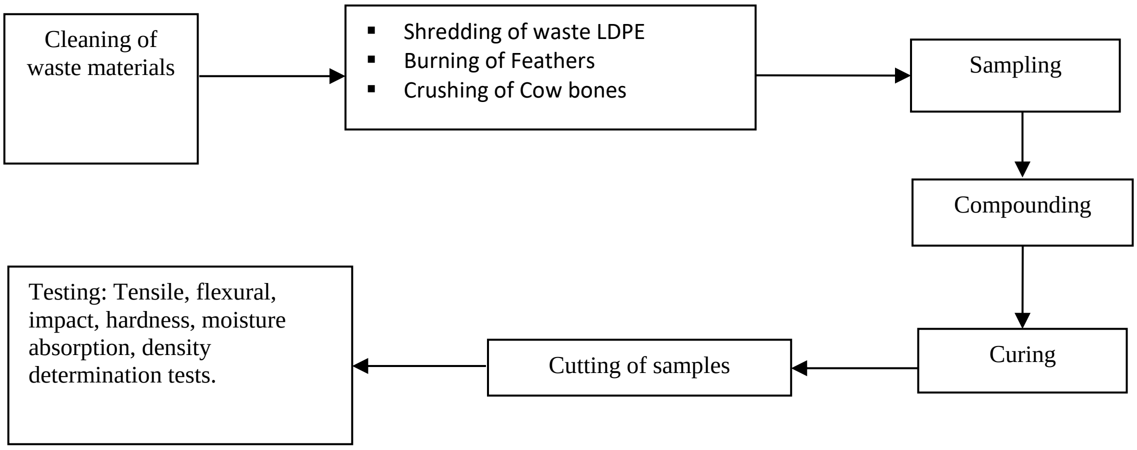

Figure 1: Steps carried out in the composite development

The samples were compounded on a two-roll mill using the formulations presented in Table 1. The temperature of the roll mill was set to 150°C. The compounded composites were placed on a 110 x 110 x 5 mm mould and cured on a hydraulic press at 150°C, under 13.7895 MPa for 3 minutes. The developed composites were cut into dumbbell and straight bar shapes for tensile and flexural tests. All tests were performed at room temperature.

Table 1: Formulation used in the development of the composite

Sample	rLDPE	CB	PF
C1	80	20	0
C2	70	20	10
C3	60	20	20
C4	50	20	30
C5	40	20	40
C6	70	30	0
C7	70	0	30
C8	80	0	20
C9	100	0	0

RESULTS AND DISCUSSION

Figure 2 shows the flexural and tensile strengths of the CB/PF composites. The rLDPE sample with no fillers (C9) showed the highest flexural strength owing to the flexible characteristics of polyethene chains. Among the biocomposites, C6 (70% rLDPE with 30% Cow bone) resulted in the highest flexural strength of 10.81 MPa while the lowest flexural strength was exhibited by C3 (60% rLDPE, 20% Cow bone, 20% PF). Consequently, samples C7 (70% rLDPE, 30% PF) and C8 (80% rLDPE, 20% PF) also showed very good flexural characteristics with flexural strength values of 9.86 MPa and 10.05 MPa respectively. The reasons for the flexural and modulus behaviour are likely due to the variation in the interaction of the bio-filled rLDPE. Figure 2b shows the tensile and flexural modulus of the samples. C5 (40% rLDPE, 20% Cow bone, 40% PF) resulted in the highest modulus both in tensile and flexural modes. C2 (70% rLDPE, 20% Cow bone, 10% PF).) could not be tested for strength and modulus due to the weak mechanical bonding which already existed in them after their development. C2 samples were brittle and broke off into fragments during the cutting process before testing.

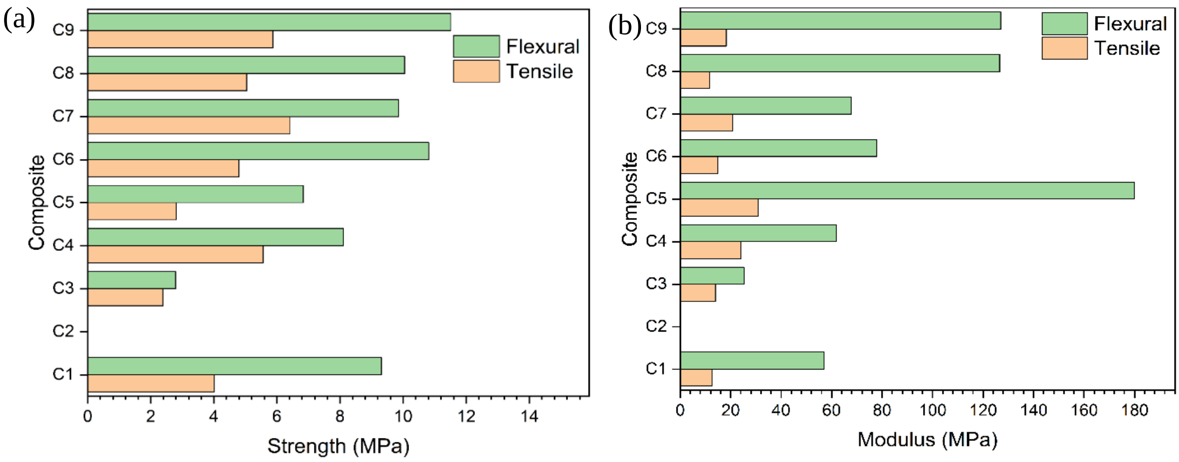

Figure 2: (a)Flexural and tensile strengths and (b) Modulus of the CB/PF composites

A decrease in the flexural strength and tensile strength was observed for sample C4 (50% rLDPE, 20% Cow bone, 30% PF). This is probably due to the equal amounts of matrix and reinforcement materials. It was noticed that samples with constant CB composition of 20% (C3, C4 and C5) and variation of PF from 20 to 40% at a step of 10% representing the combination of all three materials recorded a fair flexural and tensile strength and did not yield the better strength characteristics when compared with those with a combination of only two materials. C7 (70% rLDPE, 30% PF) exhibited the highest tensile strength of 6.42 MPa while C5 (40% rLDPE, 20% CB, 40% PF) and C3 (60% rLDPE, 20% CB, 20% PF) had very low tensile strengths compared with other samples. As similarly reported by (Salleh et al., 2013), the low tensile strength observed was a result of the prior sharp failure of the composites, indicating that the samples deformed plastically immediately after elastic deformation. Samples C4, C6, and C8 exhibited good tensile strength. C5 yielded the highest flexural and tensile modulus values of 180.04 MPa and 31.22 MPa respectively.

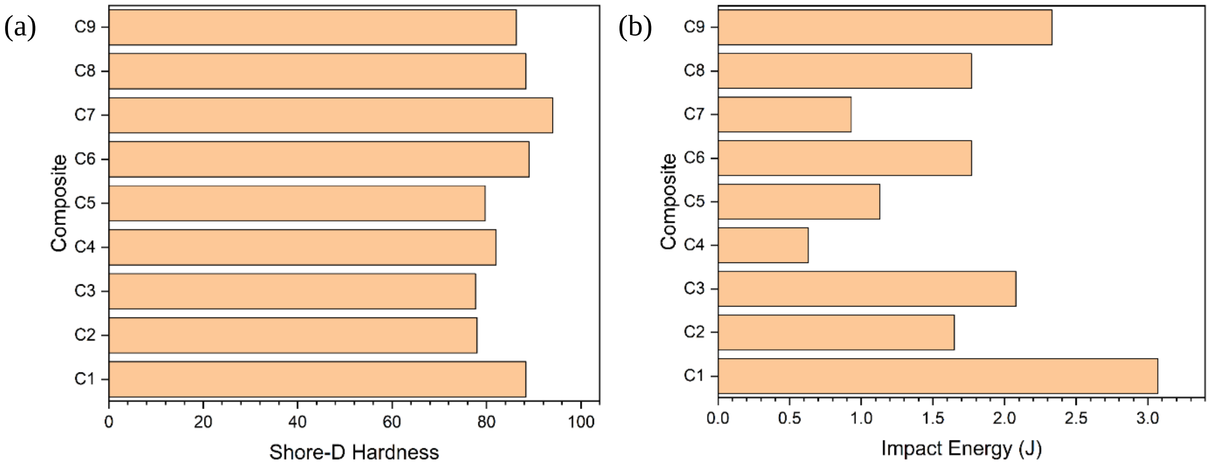

Figure 3: (a) Shore-D hardness and (b) Impact energy of the CB/PF composites

The composites showed good hardness properties (Figure 3a), with shore-D hardness values ranging from 77.67 to 94. This implies that the developed composites can compete favourably in applications that require hardness property in its application. C1 (80% rLDPE and 20% CB) absorbed the highest impact energy of 3.07 J. This suggests that, for applications requiring high-impact energy absorption, the percentage of carbon (from the pyrolyzed poultry feathers) should be kept low. However, the impact energy absorption values (Figure 3b) decreased with an increase in the weight fraction of the reinforcement, as observed by Hussein et al. (2011) who reported that the impact strength of the composites decreases with increasing weight fractions of the reinforcement from 0.15 J/mm^2 - 0.13 J/mm^2.

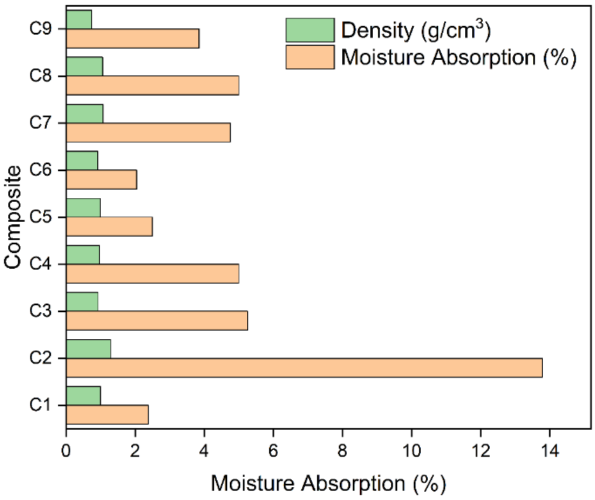

Figure 4: Density and moisture absorption properties of the CB/PF composites

Figure 4 shows the density and moisture absorption properties of the CB/PF composites. Among the biocomposites, C2 had the highest bulk density value of 1.29 g/cm^3 while samples C3 and C6 recorded the lowest bulk density values of 0.93 g/cm^3 and 0.92 g/cm^3 respectively. C2 also absorbed the most moisture, after 24 hrs, compared with the other samples which showed low moisture content. Rachtanapun (2015) reported that the moisture content of composites containing carbon (between 1.93 - 2.06%) was not significantly different and that there was a decrease in the moisture absorption of the developed composites with increasing carbon content. However, this is not the case for the composites investigated in this study. They also asserted that a continuous increase in density was observed as the carbon content increased. In another study, Darmawan et al. (2010) reported that the density of composites which they investigated decreased with increasing carbon content whereas moisture absorption increased with increasing carbon content.

The Composite C7 (70% rLDPE, 30% PF) developed in this study has a potential cost advantage over certain traditional polymers used in the automobile industry. Therefore, composite C7 can be used as a cheap substitute material for the production of automobile parts replacing traditional polymers such as polypropylene and acrylonitrile Butadiene Styrene, thereby reducing the overall weight of automobiles which in turn reduces the fuel consumption level. The developed composite can also serve as a cheap and sustainable substitute for conventional polymers used for the manufacture of several consumer products owing to its excellent lightweight and mechanical characteristics, in the food industry as packaging materials and cutleries and in the electrical industries as electronic casings. The CB/PF biocomposites developed in this study also have the advantage of low energy requirements during manufacturing compared with alternative materials in use. Low production costs, an abundance of base materials, less harm to operators and the environment, lightweight characteristics and good moisture resistance characteristics give the developed composites a clear advantage over the traditional polymers currently in use.

CONCLUSION

Pyrolyzed chicken feathers, cow bones and low-density polyethene wastes are potential materials for the development of biocomposites owing to their excellent mechanical and physical properties. In this study, sampler C7 (70% rLDPE, 30% PF) had the highest tensile strength of 6.42 MPa and C6 (70% rLDPE, 30% Cow bone) had the highest flexural strength of 10.81 MPa. All the samples exhibited good hardness properties with sample C7 yielding the highest shore-D hardness value of 94. Sample C3 (60% rLDPE, 20% CB, 20% PF) had the lowest tensile and flexural strength values compared to other tested samples. C1 (80% rLDPE, 20% CB) absorbed the highest impact energy of 3.07 Joules. All developed samples exhibited excellent lightweight characteristics with C2 having the maximum value of 1.29 g/cm^3. The moisture absorption tests showed that the developed composites had good water-resistance capabilities. C2 (70% rLDPE, 20% CB, 10% PF) exhibited the weakest mechanical and physical properties owing to its formulation, therefore suggesting that such formulation is not recommended for biocomposite development. The developed composite C7 can satisfactorily serve as a substitute for traditional synthetic polymers used in the interior of automobiles. Its use can also be extended to the electronics industry in the manufacture of electronic casings and to the food and beverage industry as packaging materials.

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