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Cassava Peel - Cowpea Hull Blended Agro-Waste Fillers: Effect on Mechanical, Morphological and Degradation Properties of Polypropylene

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Abstract: This study is aimed at harnessing the effect of cassava peel and cowpea hull blended agro-waste on the mechanical, morphological and degradation properties of polypropylene and recycled polypropylene. Fine powders of mesh size of 75µm cassava peel and cowpea hull were homogeneously mixed at the ratio of 50:50 to form the hybrid filler. The virgin pellets of PP and recycled polypropylene (rPP) were filled with varying weight percentages (5, 10, 15, 20) of the blended filler and the composites produced via injection moulding technique. The mechanical properties; tensile strength, percentage elongation at break, hardness, compressive strength, and shear modulus were studied according to American Society for Testing and Materials (ASTM) standards. The morphological properties were studied with a Scanning Electron Microscope at 10,000 magnifications. The degradation study was achieved by soil burial method for one hundred and eighty (180) days period. The results of the mechanical properties showed increased tensile strength, hardness, compressive strength and shear modulus while the percentage elongation at break decreased as the filler load increases. The micrographs showed that the virgin PP has better adhesion and interfacial bonding with the filler than the rPP. Biodegradation test revealed a reduction in the mass of the composites after one hundred and eighty (180) days burial period indicating that the composite is degradable. From the findings, the cassava peel-cowpea hull blended filler can be used in materials where stiffness and strength is required. Hence, it is suggested that agro-wastes such as cassava peel and cowpea hulls could be used as fillers in production of degradable plastics as they are readily available, cheap and easy to use.

Keywords: Cassava peel, Cowpea hull, Polypropylene, Degradation, Mechanical properties, Morphological properties.

I. Introduction

The impact of polymer materials on man's daily activity for convenience and good living cannot be ignored. Some of these produced and used polymers include; polyethylene, polypropylene, polystyrene, Poly (Vinyl chloride). Polyethylene and polypropylene are the most widely produced polymer globally because they are utilized for many applications such as packaging, electrical insulations, construction and daily consumer products (Shaharuddin *et al.*, 2017). Although most of these polymeric materials appear to be single materials from their names, but they usually contain additives like modifiers, lubricants, fillers, flame retardants, plasticizers, heat and light stabilizers or aesthetic agents to achieve desired physical, mechanical or chemical properties on the finished products (Fried, 2009; Sindhu, 2010). They show remarkable stability under many environmental conditions which leads to accumulation and visible pollution (Glaser, 2019). This visible pollution has led to research on development of sustainable and environmentally friendly green materials based on renewable resources, recyclable and biodegradable (Thompson *et al*., 2009). The renewable materials which are basically organic biomass are capable of degrading within days/ weeks or months.

Hence, this research aims to study the effect on the mechanical, morphological and degradation properties of polypropylene (virgin and recycled) using blends of Cassava peel – Cowpea hull as biomass fillers incorporated into the polymer matrices.

II. Literature Review

Ofora *et al*., (2016a) studied the effects of bamboo-corn husk fillers on the mechanical properties in polypropylene and observed that the composites showed an increase in the compressive and flexural strengths, while the surface hardness and tensile strength showed irregular trends. Thus, concluded that the mechanical properties of composites depend on the polymer matrix-filler interaction, particle size, fibre population and distribution of the filler particles within the matrix. Ofora *et al*., (2016b) studied the Mechanical Properties of *Dioscorea Dumetorum* Starch Filled Linear Low Density Polyethylene Composites. The experimental test on mechanical properties such as tensile strength, elongation at break, hardness, flexural and compressive strength showed an increase in the tensile strength, hardness, flexural and compressive strengths with reduction in elongation at break. Also, the results showed that the filler had positive impacts on the mechanical properties as the filler volume increased and the optical microscopy showed an improvement on the dispersion of the filler in the composite matrix as the filler volume increases. Aisien and Ikenebomhe, (2017) investigated the effect of inorganic fertilizer N.P.K and microbial inoculants on the biodegradation

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process of cassava peel for twenty weeks at waste dump site. The results showed increased pH, decreased total soluble carbohydrate concentrations, protein, lipids, starch, cyanide and cellulose. This indicates biodegradation of cassava peels.

Ogudo, Chris-Okafor, Nwokoye and Anekwe, (2021) worked on mixed agro-waste biocomposites of low density polyethene; impact of fillers on mechanical, morphological, water imbibition and biodegradability properties. From the results, there was a reduction in tensile strength and increase in the percentage elongation at break of the LDPE composite as the filler loading increased. The hardness, compressive strength and shear modulus of the polymer composites increased with increasing filler loading. Morphological study of the composites showed a good adhesion and interfacial bonding between the filler and the polymer matrix due to good dispersion of the fillers in the polymer matrix. Biodegradation test showed a reduction in the mass of the composites, while the water imbibition test showed no increase in the mass of the composites after immersion in water. Onyenweaku, Nwokoye and Chris-Okafor, (2021) studied the mechanical and surface morphology properties of low density polyethylene composites filled with organic materials. Blends of coconut husk and mango seed shell were used as agricultural wastes. The results showed that the fillers had positive impacts on the flexural strength and hardness, while there were negative impacts on tensile strength and compression strength. Nwokoye, Okoye and Chris-Okafor, (2024) worked on impact of hybrid biomass fillers on the physico-mechanical and degradation properties of utility polymers which involved the use of varying percentage filler load of hybrid cassava peel-rice husk filler on low density polyethylene and polypropylene. The results showed improved tensile strength, compressive strength and hardness, reduced percentage elongation at break, irregular shear modulus, zero effect on LDPE creep rate, irregular creep behavior for PP composites and improved degradation of the composites.

From the reviewed literature, it could be seen that no research involving cassava peel- cowpea hull blend with any polyolefin has been done.

III. Methodology

Materials

Sample collection and preparation

Virgin polypropylene (PP) produced by Exon Mobil Nigeria and recycled polypropylene (rPP) were employed in this study. Cassava peel and cowpea hull were obtained from family farm at Ebenator Ezeoye, Nibo, Awka South Local Government Area, Anambra State, Nigeria. The agricultural waste materials were washed and air dried for fourteen days before being crushed and sieved locally and repeatedly using a grain mill machine M6FFC-270 and muslin cloth respectively to a fine powder of 75µm mesh size.

Preparation of Composites

The fine powders of cassava peel and cowpea hull were manually mixed at the ratio of 50:50 at room temperature to form homogeneous blend filler. The virgin crystalline pellets of PP and recycled pellets of polypropylene (rPP) were weighed at 200g, 190g, 180g, 170g, and 160g respectively and mixed with the blended filler of 0g, 10g, 20g, 30g, and 40g respectively, corresponding to 0%, 5%, 10%, 15%, and 20% filler loading. The homogeneous filler and polymer matrix mixture was put into the hopper of a TU150 200 gram injection molding machine. Production of the composites at 288^{o}C took average of 33 seconds.

Mechanical Properties Analysis of the Composites

The mechanical properties studied according to American Society for Testing and Materials (ASTM) standard include; tensile strength, hardness, shear strength and compressive strength.

Tensile Strength

This measures the ability of the material to elongate, stretch or pull under influence of external loads. The tensile strength of the composites was determined according to ASTM D-638-14 standard, using Hounsfield Monsanto Tensometer 8889 Made in England. The test piece was measured to 160mm x 19mm x 3.2mm dimension.

Hardness Test

This measures the depth of indentation on the surface of the composite when pierced with an indenter. The surface hardness was determined according to the ASTM D2240 method, using Shore Scale Durometer Hardness Tester, Made in England. The test piece was measured to 20mm x 20mm x 3.2mm.

Shear Strength

This is the measure of the materials ability to withstand forces that cause its internal structure to slide against itself. The shear strength of the composites was determined according to the ASTM D-732 using the Hounsfield Monsanto Tensometer 8889 Made in England. The test piece was measured to 20mm x 20mm x 3.2mm.

Compressive Strength

This refers to a composite's ability to withstand compression. It was determined according to the ASTM D-695 using the Hounsfield Monsanto Tensometer 8889 Made in England. The test piece was measured to 20mm x 20mm x 3.2mm.

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Morphological Analysis

This analyzes the surface compatibility of the matrices and the fillers. Morphological examination was carried out using a Scanning Electron Microscope (SEM) model: JEOL-JSM 7600F.

Degradation Test

This test was carried out to examine the rate at which composites degrade in the environment. Soil burial degradation test method was employed for this study. Composites were buried 10 cm depth into soil obtained from an automobile mechanic workshop mixed with poultry waste for one hundred and eighty (180) days with weighing done every thirty (30) days. The mass reduction of buried composites was used to determine degradation.

IV. Results and Discussion

Mechanical Properties

The results of the mechanical properties of the PP and rPP composites with cassava peel-cowpea hull fillers are shown in the figures below.

Tensile Strength

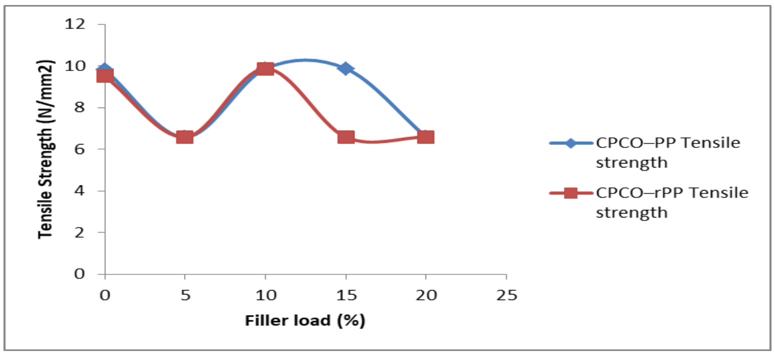

Figure1. Effect of filler loading on the tensile strength of PP and rPP composites

From Figure 1, the composites showed initial decrease in the tensile strength before an increase as filler content increases till maximum then subsequent decrease with increase in filler loading. The initial decrease could be as a result of insufficiency of the filler content. The peak values were observed at 10wt% filler load for rPP and 10wt% to 15wt% for PP. This increase in the tensile strength of the composites could be due to stronger adhesion between filler and matrix interface which leads to better stress transfer from the matrix to the filler, while the gradual decrease after attainment of peak could be due to weakening of the interfacial attraction of the constituent composition as the weight percentage of the matrix is reduced with increasing weight percentage of filler which tries to alter the inherent properties of the matrix. Also, the cellulosic nature of the fillers could attribute to this increased tensile strength. This is in agreement with the works of Chris- Okafor *et al.*, (2018); Jacob and Mamza, (2021) and Nwokoye *et al.*, (2024).

Percentage Elongation at Break

This measures the level a material can be drawn or stretched as a percentage of its original length.

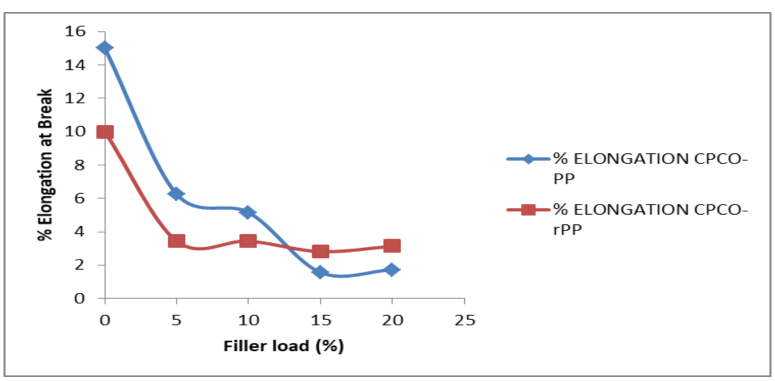

Figure2. Effect of filler loading on percentage elongation at break of PP and rPP composites

Figure 2 shows that the percentage elongation at break decreased with increase in filler loading. This indicates that increasing filler loading decreased the ductility/ elasticity of the polymer composites and makes it stiffer. This decrease indicates the filler ability to facilitate stress transfer from filler to matrix. This is in line with Chris-Okafor *et al*., (2018); Nwokoye *et al*., (2024).

Hardness

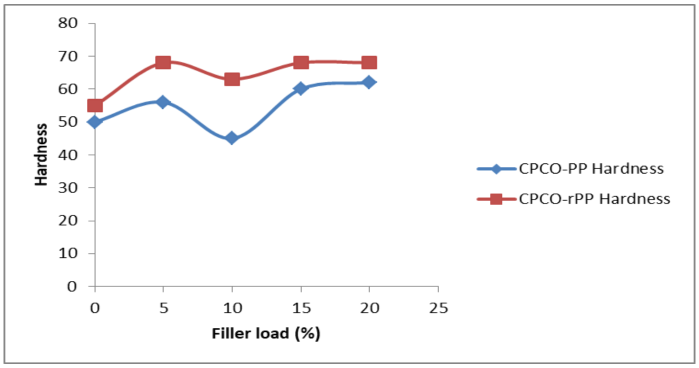

Figure3. Effect of filler loading on the hardness of PP and rPP composites

Figure 3 reveals an overall increase in hardness as the filler content increases for PP and rPP composites except for PP composite at 10wt% that showed reduced hardness. This is an indication that the fillers enhanced the hardness of the composites which could be attributed to the filler's tightening property on the composites' elasticity thereby strengthening and improving surface resistance to indentation in the polymer matrix. This is in line with the research of Onuegbu and Igwe, (2011); Chris-Okafor *et al.*, (2018) and Nwokoye *et al.*, (2024).

Compressive Strength

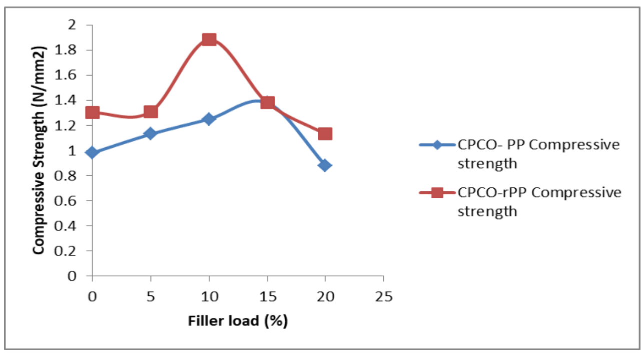

Figure4. Effect of filler content on the compressive strength of PP and rPP composites

Figure 4 shows that the composites' compressive strength increased, with the highest compressive strength at 10wt% filler load for rPP increasing by 44.6%. This increase could be attributed to the filler reinforcing characteristics, which improved the composite's mechanical properties due to its cellulosic nature, which is in agreement with the work of Ofora *et al.*, (2016a), Ofora *et al.*, (2016b) and Nwokoye *et al.*, (2024).

Shear Modulus

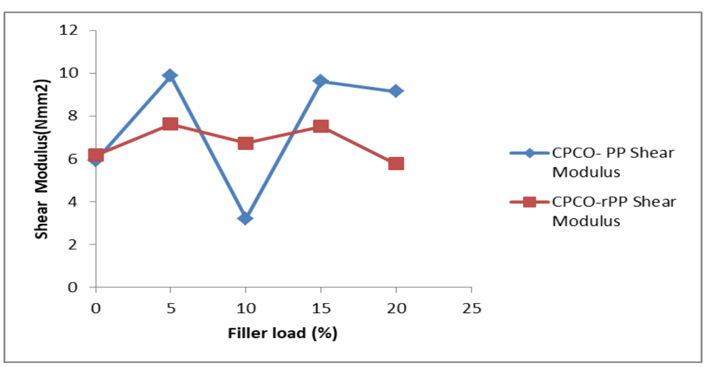

Figure5. Effect of filler loading on the Shear modulus of PP and rPP composites

In Figure 5, the shear modulus increases as the filler loading increases. This increase suggests that the fillers increased the rigidity of the composites and enhanced the load-bearing ability of the material thus a larger force is required to deform the composites along the plane of the direction of the force. This is in agreement with the work of Ogudo *et al.*, (2021). Only the shear modulus of CPCO-PP at 10wt% filler load showed a decrease indicating less rigidity. Obviously shear modulus is always in line with hardness property, thus the harder a material the higher its shear modulus value.

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Morphological Analysis

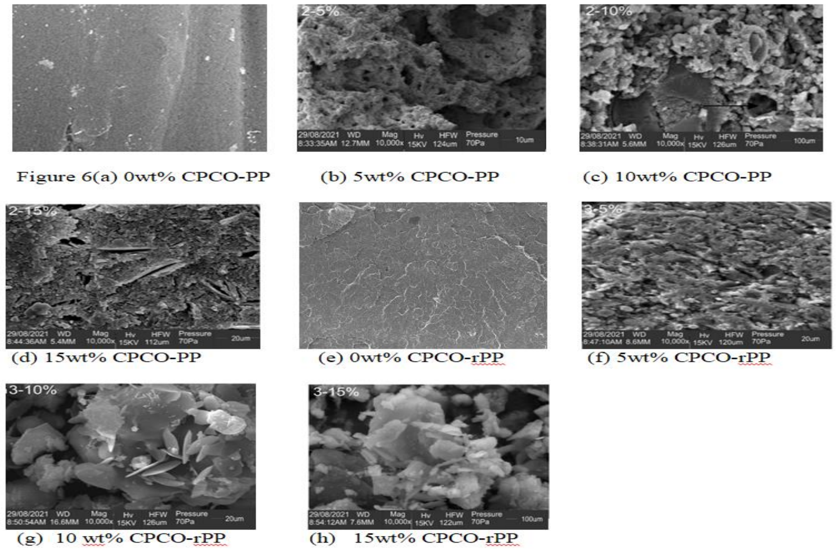

Figure6. (a-d) and (e-h) SEM micrographs of CPCO-PP and CPCO-rPP composites respectively

The Figures 6a and 6e are the micrographs of polypropylene and recycled polypropylene without fillers respectively. From Figures 6b-d, there was observed presence of filler in the composite with few voids and greater agglomeration at 5wt% filler loading which indicates that there was weak interfacial bonding between the filler and the matrix. The bonding improved as the filler loading increased to 10wt%, then to 15wt% where it showed more bonding with presence of few cracks. The presence of crack suggests matrix discontinuity which upon continuous filler load increment would produce pronounced effect (Jumaidin *et al.*, 2017). While from the Figures 6f-h, there was observed compatibility of the filler-matrix in the composite at 5wt% filler loading which indicates that the interfacial bonding between the filler and the matrix polymer was strong to yield near homogenous but rough material. As the filler loading increased to 10wt%, the fillers showed signs of agglomeration with little voids which became more pronounced at 15wt% loading, indicating that as the filler load increases the filler-filler interaction increases while the filler matrix interaction decreases. Thus, the strength of the rPP composites after 10wt% filler load decreases as the filler load increases due to increase in voids that acts as fracture initiation site and reduced interfacial contact between the hybrid fillers and the polymer matrix. This could be attributed to some factors such as the difference in the polarity of the filler and the matrix. The hybrid filler is hydrophilic with high mixing efficiency while the matrix is hydrophobic and nonpolar. Secondly, the matrix is a recycled one, thus must have had other reinforcements incorporated in it that increased its hydrophobic nature and made it less reactive with hydrophilic fillers. The interfacial contact between the hybrid fillers and the polymer matrix could be attributed to the cellulose contents of cassava peel and cowpea hull that lead to the mixing efficiency. The dispersion of the fillers in the polymer matrix improved the compatibility of the composites especially in PP composites. This is in agreement with the works of Chan *et al*., (2016); Jumaidin *et al*., (2017).

Biodegradation Test

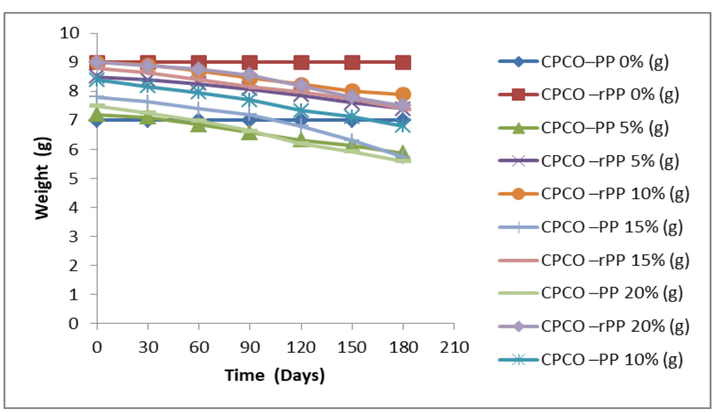

Figure7. Effect of filler loading on the degradation of PP and rPP composites

From Figure 7, there was no reduction in weight for 0% PP and 0% rPP during the 180 days test period. For other composites with biomass fillers, weight loss was observed after 30 days test period which continued as the burial time increased. There was a general reduction in weight for all the composites with fillers. It was also observed from Figure 7 that increased filler content led to higher degradation of the composites. This observation corroborates the research findings of Chamas *et al.*, (2020), Ogudo *et al.*, (2021) and Nwokoye *et al.*, (2024). These authors discovered that biodegradability of composites were well pronounced and enhanced if the composite contains higher percentage filler load of the natural fillers. The highest degradation rate was observed at 20wt% filler loading.

V. Conclusion

Cassava peel and Cowpea hulls were successfully incorporated as blend fillers into polypropylene (PP) and recycled polypropylene (rPP) matrices to make composites. The incorporation of this filler improved the tensile strength, hardness, compressive strength and shear modulus of the composites while the percentage elongation at break decreased. Thus, the synergy effect of the blend filler, the particle size as well as the dispersion of the fillers within the polymer matrix was observed to influence the mechanical properties of the composites. As opined by Rajesh *et al.*, (2018) mixing of hybrid composite increases the interface adhesion between the fibre and the matrix. The finding showed a common occurrence with lignocellulose fillers and is in agreement with some literature like Ofora *et al*., (2016a); Chris-Oka for *et al.*, (2018) and Nwokoye *et al*., (2024). The microstructural arrangements of the composites at 10,000 magnification showed that the PP composites has better interactions than the rPP composites as there were observed agglomeration with rPP composites indicating more of filler-filler interactions. After one hundred and eighty (180) days test period the observed composites were seen to have lost some weight indicating degradation. It was also observed that as the filler load increases the degradation rate increases. From the findings, it is accepted that agro-wastes like cassava peel and cowpea hull can be used as fillers in the manufacture plastics where strength is required because they are cheaper and readily available.

Recommendations

A study on varying the biomass filler ratio with constant matrix percentage is recommended. Also, studies on the effect of cassava peel-cowpea hull blend with other matrices are recommended. Furthermore, studies on addition of other additives or other treatments to improve polymer-filler interface is recommended.

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