

THE EFFECT OF FILLER LOADING ON PHYSICAL AND MECHANICAL PROPERTIES OF MAIZE STRAW AND WASTE POLYPROPYLENE PARTICLE COMPOSITE

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ABSTRACT

This study investigates the effects of maize straw as a filler material in polypropylene composites, with a focus on understanding the influence of filler loading on the material's mechanical and physical properties. Maize straw was prepared by drying and grinding before being compounded with polypropylene using a two-roll mill. The resulting composite samples were subjected to property evaluations. The findings revealed that an increase in filler loading enhanced the hardness of the composite. Conversely, the impact strength decreased with higher filler loading, reaching its lowest value at 40% filler content. Similarly, tensile strength diminished as the filler content increased, with the most significant reduction observed at 40% filler loading. In contrast, both the density and water absorption of the composite increased with higher filler loading, peaking at 40% filler content. These findings suggest that maize straw-polypropylene composites could be tailored for applications requiring specific property profiles. Potential areas of application include construction materials, automotive components, and packaging products where optimized hardness, density, and water absorption are critical considerations.

Keywords: Maize Straw, Polypropylene, Hardness, Impact, Strength, Density.

INTRODUCTION

Wood-polymer composites (WPCs), which combine wood fibres with thermoset or thermoplastic polymers, are among the fastest-growing segments of the plastics industry. In North America, WPCs have exhibited an impressive annual growth rate of approximately 18%, while in Europe, the growth rate is about 14% (Satyanarayana *et al.*, 2009). These composites are widely recognized for their versatility and potential to substitute conventional materials in various applications. The term WPC broadly refers to any composite material that incorporates wood fibres and either thermoset or thermoplastic matrices. The integration of wood fibres as reinforcement in thermoplastic polymers is particularly appealing due to their unique properties, including low density, high strength, cost-effectiveness, renewability, abundance, and biodegradability (Jawaid and Abdul, 2011). Such attributes make wood fibres a promising alternative to traditional reinforcing materials, offering a pathway to more sustainable and eco-friendly composite solutions.

Despite these advantages, the primary source of wood fibres—forests—is experiencing rapid degradation. In developing countries, forests are being lost at an alarming rate of approximately 13 million hectares per year (Kalia *et al.*, 2009), a trend that threatens the long-term availability of wood as a resource. This deforestation crisis has driven a heightened focus on sustainability and eco-efficiency in technical applications over the past two decades. The growing awareness of environmental issues, new legislative regulations, and the influence of environmental advocacy groups such as Greenpeace have further underscored the importance of developing materials that align with ecological and sustainability objectives (Njuguna *et al.*, 2008).

Petroleum-based synthetic polymers remain a dominant material class in modern society, with widespread applications in packaging, bottles, moulding products, and other commodities. However, the disposal of approximately 170 million tons of petrochemical plastics annually presents a significant environmental challenge. The continuous increase in the production and

consumption of these plastics exacerbates issues related to waste management and pollution (Schadler *et al.*, 2007). These concerns have spurred research into alternative materials and innovative composites that address these challenges while maintaining desirable mechanical and physical properties.

This study investigates the potential of maize straw, an agricultural by-product, as a sustainable filler material in composites with waste polypropylene particles. The research focuses on evaluating how variations in filler loading influence the physical and mechanical properties of the resulting composite material. By utilizing waste polypropylene and renewable agricultural residues, this work aims to contribute to the development of sustainable, eco-efficient materials that offer viable alternatives to conventional composites. Such materials hold promise for diverse applications, including construction, automotive components, and packaging, aligning with global efforts to promote circular economies and reduce the environmental footprint of materials production and disposal.

MATERIALS AND METHODS

The materials and equipment used in this research include waste polypropylene (WPP), maize straw (MS), distilled water, and silicon oil.

EQUIPMENT

The equipment utilized during this research are: A Muverdurometer, sourced from NILEST Zaria, was employed for hardness testing, while a Charpy impact tester, also from NILEST Zaria, was used to assess impact strength. Additionally, a Monsanto tensometer, obtained from Ahmadu Bello University (ABU) Zaria, was used to evaluate the tensile strength of the samples.

METHODOLOGY

Preparation and Characterization of Maize Straw

The maize straw (MS) filler was prepared and characterized to evaluate its suitability as a reinforcement material for composite fabrication. This process involved systematic steps to ensure the filler material met the desired specifications for subsequent mixing and testing. Preparation included drying and grinding the maize straw into defined particle sizes (72 μm , 100 μm , and 150 μm), followed by the washing of waste polypropylene (WPP) to remove impurities. These steps were critical to enhance compatibility and uniformity during the mixing phase.

Mixing and Compounding of Composites

The prepared maize straw filler was mixed with waste polypropylene in specific proportions as outlined in the formulation tables. The mixtures were compounded using a two-roll mill at standard operating temperatures to achieve homogeneous dispersion of the filler within the polymer matrix. This step ensured consistent mechanical and physical properties across the composite samples. Proper compounding of the materials was essential to maintain the integrity and performance of the composites during subsequent testing.

Sample Preparation and Testing

After compounding, the composite materials were cut into specific dimensions based on ASTM standard test methods. These samples were then subjected to various tests to evaluate their physical and mechanical properties, including hardness, impact strength, and tensile strength. The testing procedures adhered to standardized methodologies to ensure accuracy and repeatability of results, thereby providing reliable data on the performance of the maize straw-polypropylene composites.

MOISTURE CONTENT

The moisture content of the filler was determined following the ASTM D1509 standard. A known weight of 5 g of the air-dried maize straw was placed in a petri dish and subsequently heated in a hot air oven maintained at a temperature of $150 \pm 5^\circ\text{C}$. The sample was removed from the oven at 30-minute intervals and allowed to cool to room temperature in a desiccator. This process was repeated until no further change in weight was observed, as specified by ASTM D1509 (1983).

The moisture content was calculated as the average percentage change in weight of the sample, representing the proportion of moisture removed during the drying process. This method ensured precise and repeatable measurements of the filler's moisture content, which is critical for maintaining consistency and reliability in composite production.

TABLE 1: FORMULATION TABLE FOR MS AND WPP

S/N	1	2	3	4	5
SAMPLE	A	B	C	D	E
WPP	100	90	80	70	60
MS	----	10	20	30	40

TEST METHODOLOGY

The test methodology employed included impact strength (ASTM D-256), water absorption (ASTM D-570-98(2005)), hardness (ASTM D1415, 1983),

tensile strength (ASTM D-412), and density (ASTM D-792) tests.

TENSILE STRENGTH

The tensile strength was carried out using an advanced material testing machine following the ASTM D412 method. The test piece for the tensile test was of the dimensions 30mm x 2mm x 4mm. The sample was clamped vertically at both ends with the jaws of the equipment and then stretched vertically to failure and the results were recorded since the equipment was computerized (ASTM D412, 1983).

HARDNESS

The hardness was carried out according to the ASTM method by placing the indenter on the composite materials and an average of six runs was taken as the hardness. (ASTM D1415, 1983)

IMPACT TEST

The samples were prepared following the (ASTM D-256) method with sample dimensions of 100mm x 4mm x 10mm. The sample was placed on the sample holder and the hammer was released to strike and the impact strength was recorded.

WATER ABSORPTION TEST

A water absorption test is used to determine the amount of water absorbed under specific conditions for the water absorption test the initial weight of the samples was removed after 24 hours and the final weight was taken to determine the amount of water absorbed by the samples.

DENSITY TEST

The densities of the samples were determined using ASTM D-792. The mass and volume were obtained by first taking a clean sample and weighing it in air using a digital weighing balance in the laboratory and then suspending it in water. The volume of the sample when immersed in water was determined by measuring the volume of the water displaced. The density was then calculated from the expression:

$$\text{Density} = \text{mass/volume (g/cm}^3\text{)}.$$

The result of the percentage water uptake of MS/PP was illustrated in Figure 1 the percentage water sorption of MS/PP composite at different filler loadings for 24 hours. The general trend was that an additional increase in filler loading resulted in the water absorption property increasing for the composites as well; the sample exhibited higher water absorption. This may be because the maize straw is hydrophilic (having -OH groups). It is a

well-known fact that fibres from the natural origin are generally hydrophilic, containing several hydroxyl groups (-OH) in the structure of the filler leading to the formation of many hydrogen bonds, whereas, polymer molecules are hydrophobic i.e. they do not contain any polar group as such, the polymer does not easily bond to water molecules explaining its ability to stay dry (Pukanzsky, 2011). It was observed that the control sample absorbed less water which might be due to the hydrophobic nature of PP. A similar trend was reported by Isaiah, 2013.

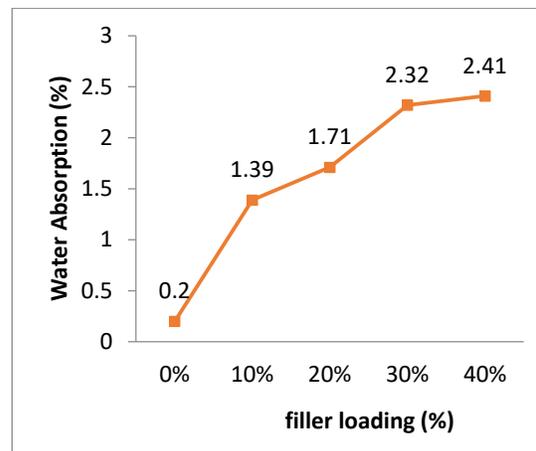


Figure 1: Percentage of water absorption of MS/PP

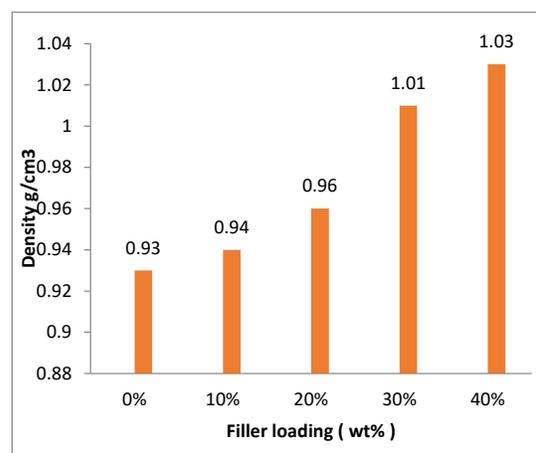


Figure 2: Density measurement of maize straw-filled PP

The densities of composite materials are fundamental, and it is the essence of choosing them in place of metals. Engineers often prefer materials with high specific strength over those with lower mass density. Figure 2 shows the effect of density on PP/MS composites, The unfilled sample gave the lowest value of 0.93 g/cm³ which increased to 1.03 g/cm³ at 40 wt% filler loading. The density of

the composites increased with increasing filler loadings. with marginal values. This increase might be a result of the density of the filler particles. The same scenario was reported by Heuzé, 2016.

The tensile strength of PP/MS was shown in Figure 3: it observed that, the tensile strength decreased as the filler loading increased. The tensile strength of the control sample had a value of 10.14 MPa. Which is a little better than the filled composites. By loading in Figure 3, it can be seen that the tensile strength is higher at 10% of MS loading.

After this value, the tensile strength decreases. However, the enhancement of the properties is only observed for composite with 10% MS by weight, exceeding which, the strength decreases as the percentage MS (by weight) is increased. The decrease could be a result of filler-filler interaction at higher filler content whereby load was not effectively transferred through the matrix to the filler. Pukanzsky (2011), stated that there is usually a reduction in the particulate composite's tensile strength with increasing filler content which obeys a power law due to matrix-filler poor bonding relationship. At higher filler content, the poor bonding strength between the matrix and the filler may occur because of excess fillers. Similar behaviour was reported by Foidl et al., (2001).

Figure 4 shows the effect of filler loading on the impact strength of the composite. The unfilled composite had the highest impact strength value of 0.71 and the lowest value was at 40% filler loading with a value of 0.2 KJ/mm. this is to say the impact strength decreases as the filler loading increases as expected, a similar scenario was reported by Rajangam (2001).

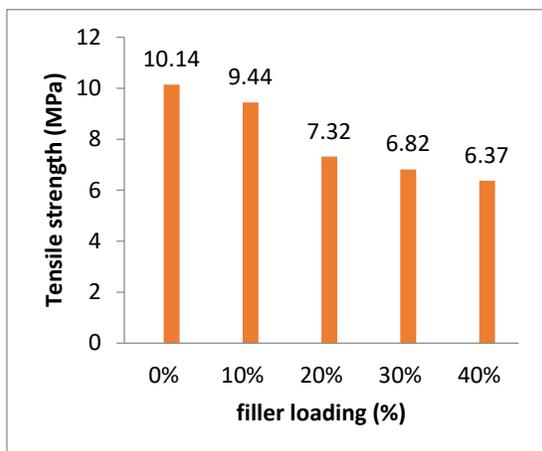


Figure 3: Tensile strength of MS / PP

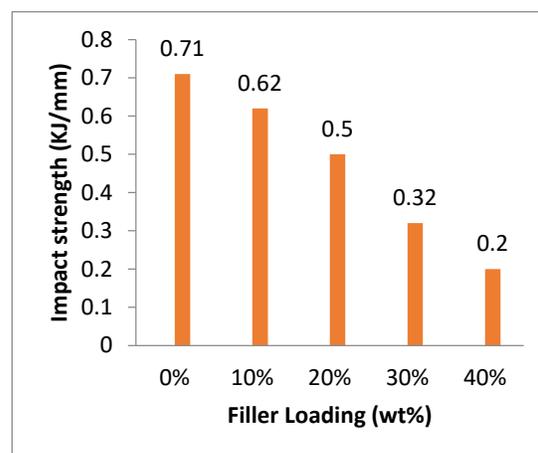


Figure 4: Impact strength of maize straw-filled PP

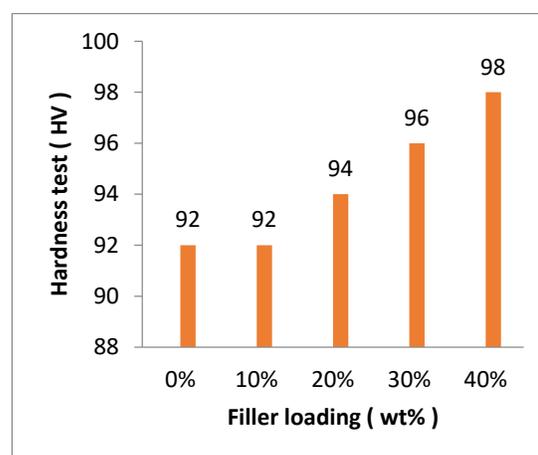


Figure 5 hardness test result of PP/MS

The hardness test result in Figure 5: shows a clear effect of filler on the composite. Figure 5: shows an increase in the hardness property of the composite, the hardness test value is higher at 40% loading with a value of 98 HV and lowest at 10% loading with a value of 92 HV. This is to say the higher the filler loading, the harder the composite becomes. This behaviour agrees with the trend obtained by values obtained by Ndubuaku et al., (2014), in their particulate coconut shell and recycled polypropylene matrix.

CONCLUSION

This study investigates the effects of maize straw as a filler material in polypropylene composites, with a focus on understanding the influence of filler loading on the material's mechanical and physical properties. Maize straw was prepared by drying and grinding before being compounded with polypropylene using a two-roll mill. The resulting composite samples were subjected to property evaluations. The findings revealed that an increase in filler loading enhanced the hardness of

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