

## EFFECT OF FILLER LOADING ON THE MECHANICAL PROPERTIES OF WOOD PLASTIC COMPOSITES

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### Abstract

*Polypropylene plastic wastes and five types of wood sawdust were used to prepare wood plastic composites by the compression moulding process. The effects of filler loading (10, 20, 30, 40, and 50wt %) on the mechanical properties were investigated. All the filler loadings significantly influence these properties. Teak, African mahogany and Shea butter trees have the highest flexural modulus at 20 wt % filler loading, with values of 931.42 MPa, 1004.47 MPa, and 1141.21 MPa, respectively. The flexural strength of teak, African mahogany, shea butter tree, and parrot beak peaked at 20 wt% filler loading at 33.6 Mpa, 44.7 Mpa, 38.97 Mpa and 37.66 Mpa respectively. At 20 wt%, African mahogany and Shea butter has an increase in the tensile strength of 20.2MPa and 15.81MPa from 16.54MPa and 16.81MPa respectively. There is a reduction in the impact strength as the filler loading increases for all the samples, the impact strength of teak composites dropped from 0.75 J at 0% filler loading to 0.25 J at 50% filler loading, while the hardness value increases for all the samples as the filler loading increases. It can be concluded that the filler loadings affect the mechanical properties in different ways which will be useful in household and industrial applications. Also, since waste wood and plastic wastes were used, it will help in reducing environmental pollution.*

Keywords: Compression molding, filler, mechanical properties, polypropylene, saw-dust, wood-plastic composites

### Introduction

Wood plastic composites (WPC) are materials containing a wood component and polymer in the matrix offering a versatile and dynamic product range for various industrial and domestic uses. Lanzoni et al., (2025). Delviawan et.al (2019)

described wood plastic composite as a relatively new generation of composite material prepared from wood flour, particles, or fibers combined with thermoplastic materials under specific heating and pressure conditions either through extrusion, injection molding, and compression

molding or thermoforming (pressing). Wood plastic composite has several advantages, such as ease of maintenance, high durability, and long service life. Zhu et al., (2022)

Wood-based material is in the form of wood fiber/wood flour and polymers are thermoplastics such as Polyethylene/ Polypropylene/ Polyvinyl chloride/Polystyrene etc. Shankar et al (2020). Sawdust (waste from wood processing industries), bagasse, rice hull (agro-waste), and recycled plastic can be used as raw materials for WPC. Adegoke et.al., (2020) in one of their works, illustrate that sawdust materials are global wastes obtained from wood processing and exploitation activities, and are usually dumped/stored in uncontrolled conditions, thus becoming a major contributor to environmental pollution. Polypropylene (PP) is considered the most important material among polyolefins due to three main reasons. First, great properties of PP such as low density, high melting temperature, and chemical inertness with low cost make PP optimum for long-life applications. Second, polypropylene is a highly versatile material meaning that diversity in structural designs and mechanical properties are achievable. Third, different morphological structures of PP are possible by using fillers or reinforcing agents and blending PP with other polymers which yield superior characteristics. Maddah (2016)

Fortunati, et.al., (2019), asserted that one significant issue associated with wood source-polymer composites is the compatibility between

the flour and the polymer matrix which results in insufficient interaction between the wood flour and the matrix, leading to elevated water absorption and diminished stress transfer from the filler to the matrix. This problem of computability can be reduced to a minimum by the introduction of compatibilizer which serves as a chemical modifying agent. Venkatachalaiah et al., (2022) in one of their works confirm that composites produced with compatibilizer exhibited effective coupling/interfacial adhesion between the surface of areca fiber and polypropylene phase as evidenced by SEM microphotographs and FTIR spectroscopy. Also, Elamin et al., (2020) uses a mixture of Maleic anhydride grafted polyethylene octene elastomer (MPOE) and octadecyl organically modified montmorillonite (OMMT) on Chinese fir (*Cunninghamia lanceolata*) waste and low-density polyethylene as a compatibiliser, the result shows a significant increase in tensile strength of about 41.46 % the impact strength by 26.89 % above the neat sample. Thus, the utilization of both compatibilizers offers an efficient route to improve the interaction and mechanical properties of WPC. Sawdust from five different types of wood and recycle polypropylene was used for this research using maleic anhydride (MA) as a compatibiliser.

Different research work has been carried out on the effect of filler on the properties of WPC, but no major work has been done in comparing the same filler sizes using different types of wood.

Onuegbu (2021) uses periwinkle shell powder as a filler, and discovered that there is improvement in the mechanical properties of recycled polypropylene (PP) composites, with optimal filler loadings around 15-20 wt%. While tensile strength and flexural strength increase with increasing filler loading, elongation at break decreases. Mark et al., (2019) uses coconut shell as a filler and confirm that the increase in filler loading at improve the mechanical properties of the WPC at optimal of 48%, while the elongation at break and modulus of resilience of the prepared polypropylene/carbonized coconut shell particles composites were observed to decline with an increase in the filler loading compared with the neat polypropylene. Sabarinathan et al., (2021) uses recovered brown alumina (RBA) particles as a filler in epoxy glass fibre composites, it was observed that maximum mechanical properties and thermal stability was observed at 20% filled RBA polymer composites

### Materials and method

#### Materials

Waste polypropylene (PP) was collected at different spots in Ilorin, Kwara state. Nigeria. Saw dust of the following woods samples were collected from Offa Garage sawmill in Ilorin South Local Government Area of Kwara State, North Central Nigeria, Teak (*Tectona grandis*), Baobab (*Adansonia Digitata*), African Mahogany (*Khaya invorensis*), Shea Butter (*Butyrospermum paradoxum*) and Parrot Beak (*Gmelina Arborea*).

Maleic anhydride (MA) as a compatibiliser

### Methods

#### Preparation of polypropylene plastic wastes

The waste collected was fed into an agglomerator machine in order to agglomerate and blend the input product and also reduce the volume since most of the wastes are polymer films. The machine is made up of high-speed energy blades which shreds the materials and press it under the rotor. The friction generates heat to make the material viscous; it was cooled through contact with water and become plastic crumbs.

The crumbs were fed into the crusher through the hopper and undergo crushing between rotor, the rotor is driven by electric motor to produce a plastic granules good enough for the pelletize machine. The granules were feed into pellet machine through the hopper, the polymer melt having passed through the extruder, is divided into a ring of strands that flows through an annular die into a cutting chamber flooded with water. A rotating cutting head in the water streams cuts the polymer strands into pellets.

#### Preparation of wood

The sawdust was sun-dried, milled, and sieved into a uniform particle size of 300um, weighed, and stored at room temperature in an airtight plastic bottle.

#### Compounding and Compression Moulding

The compounding and pressing were carried out in the polymer processing laboratory of the

Department of Polymer Technology (Nigerian Institute of Leather Science and Technology).

The waste polymer (PP) was compounded and mixed with individual wood flour in a two-roll mill machine in accordance with ASTM D 15-627 by introducing the polypropylene matrix into the heated rollers at 210°C at which it melted and flowed then the wood was introduced to it and mixed for five minutes (5min) which was enough to obtain a homogeneous mixture. The same

procedure was repeated for all five wood samples. The mixtures were collected and subsequently placed in a metal mould 150 x 150 x 5 (mm) in length, width, and thickness respectively, and then pressed on a compression moulding machine at 160°C for five minutes (5min) and thereafter cold pressed at room temperature for three minutes (3min) and pressure of 4Pa. Composite sheets were thereafter cut into various dimensions for characterization.

Table 1: Formulation table

| S/no | wPP (%) | Wood (%) | Coupling agents (%) |
|------|---------|----------|---------------------|
| 1    | 88      | 10       | 2                   |
| 2    | 78      | 20       | 2                   |
| 3    | 68      | 30       | 2                   |
| 4    | 58      | 40       | 2                   |
| 5    | 48      | 50       | 2                   |

### **Tensile Test (ASTM D638)**

The tensile test was carried out using a tensile properties tester (YG026D Multifunctional Electronic Fabric Strength Machine) according to ASTM D638 (2014) with a maximum force of 10 KN. The sample's dimensions were 100 x 15 x 5 (mm) in length, width, and thickness respectively. A cross-head speed of 2 mm/min was used. The test specimens were held in the grips of the testing machine and tightened evenly and firmly to prevent any slippage as the test commenced. The resistance and elongation of the specimens were detected and recorded by the

load cell until a failure or rupture occurred. From the tensile test, tensile parameters (tensile strength (breaking point), elongation at break, and tensile modulus) were determined and recorded. The same method was used by AbouelNour et al., (2024)

### **Flexural Test (ASTM D 790)**

The flexural or 3-point bending test was carried out on Enerpac universal material testing machine (Universal material testing machine Cat Nr. Model: 26) with a maximum load of 100 KN and a crosshead speed of 5 mm/min. The test was carried out according to ASTM D790 (2017). The

dimensions of the sample were 100 x 30 x 5 mm in length, width, and thickness respectively. The specimens were positioned horizontally on the sample compartment of the machine and then the test started. The flexural strength and modulus were determined and recorded. The same method was used by Kamalakannan and Bhaskar. (2020)

#### **Impact Strength Test (ASTM E 23)**

The impact strength of the composite samples was carried out using the Charpy impact tester (Model no. 6957, capacity of 15 joules) according to ASTM E23 (Notched) standard (2023). Samples were tested at room temperature by a single swing of the pendulum hammer using Norwood. The specimen size was 100 x 11 x 5 (mm). Each sample was placed on the vice and clamped firmly. The pendulum hammer was raised to the required height and then released and struck the sample once. Then, the impact energy absorbed by the specimen was recorded. The impact strength of the samples in joules per

square metre was recorded. Similar method was used by Lucon (2025)

#### **Hardness Test (ASTM D 2240)**

The sample hardness was measured using (Vickers Hardness Tester MV1-PC, Mh-v CM. 07/2012-1329) with a maximum capacity of 0.1 Kgf (150 HV) in accordance with ASTM D2240 (2025). The test was carried out at temperature ( $23 \pm 2^{\circ}\text{C}$ ). The specimen dimension was 30 x 10 x 5 (mm). The specimen was mounted on a specimen compartment and then the indentation point was focused thereafter five different points were indented on each specimen and the hardness values were recorded. The average of the five readings was calculated and recorded. Azzeddine et al., (2022) employed the same method.

#### **Results and Discussion**

##### **Tensile Strength tests**

The result of the tensile strength of wood fillers and recycled polypropylene composites is presented in Figure 1

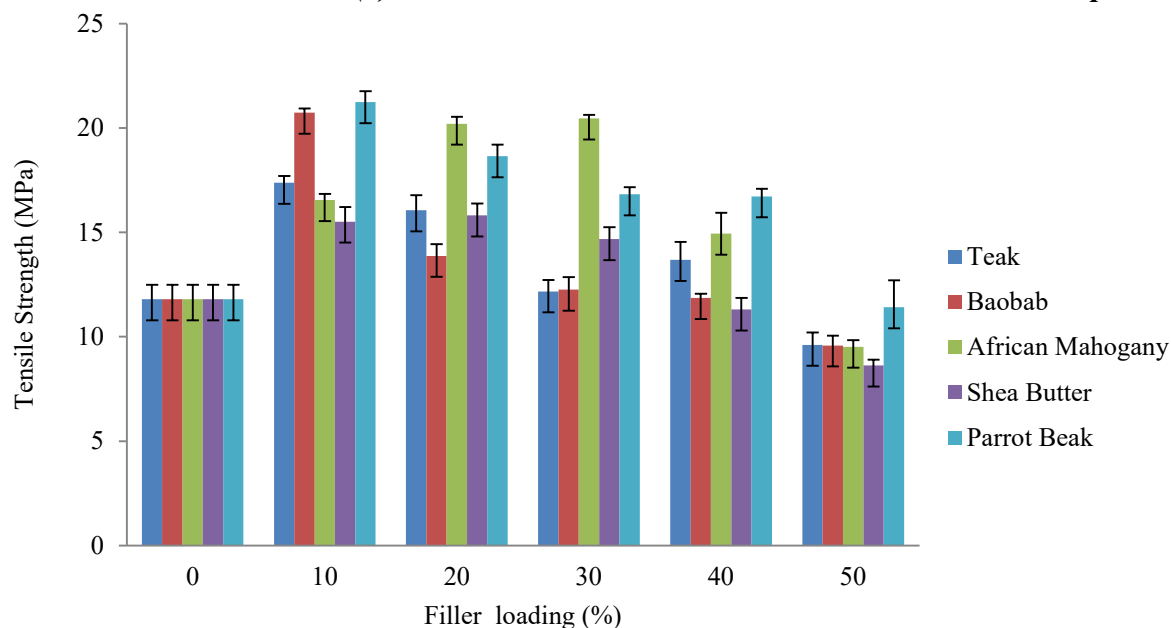


Fig.1: Effect of Filler Loading on Tensile Strength of waste PP Composites

The effect of filler loading on the tensile strength of the composites as presented in Figure 1 was generally observed as the tensile strengths of the 10 wt% - 40 wt% filled polypropylene were generally higher than that of the neat polymer, an indication that the fillers were dispersed more uniformly through the polymer matrix at low concentrations to increase the surface attraction between the filler and the polymer matrix. At 10 wt%, the baobab and the parrot beak had the highest tensile strength of 20.73MPa and 21.23MPa respectively. Above 10%, teak, baobab, and parrot beak experienced a reduction in tensile strength which might be due to poor adhesion between the filler and the polymer matrix.

At 20 wt%, African mahogany and Shea butter have an increase in the tensile strength of 20.2 MPa and 15.81MPa which is due to good interaction between the polymer and filler matrix, however, this is the optimum loading for Shea butter as the tensile strength decreases at 30 wt%. The highest tensile strength of African mahogany is 20.45MPa at 30 wt%, above this, there is a decrease at 40 wt% and 50 wt% filler loading. The highest tensile strength of all the filler is 21.23MPa at 10 wt% baobab, while the lowest is at 8.62MPa at 50 wt% Shea butter.

As the teak filler load increases from 10 wt% to 30 wt%, there is a decrease in the tensile strength of the composites, there are slight increases at 40 wt% and decreases at 50 wt% filler loading. The decrease may be a result of a lack of interfacial

adhesion between recycled polypropylene and filler due to large surface differences and hence the reduction in the tensile strength. The increase at 40 wt% filler loading supports the observation made by Mahdi and Dean (2020) that the incorporation of filler into a polymer matrix may increase or decrease the tensile strength of the resulting composite.

As the baobab filler load increases from 10 wt% to 50 wt%, there is a decrease in the tensile strength of the composites, baobab wood is fibrous and spongy and does not have distinct growth rings typical of hardwood trees, and this may lead to poor adhesion between the wood particles and recycled polypropylene. This is in agreement with Uzochukwu et al. (2020), which concluded that the sample with 10 wt% filler had the highest tensile strength of 48 MPa; while a

sample with 50 wt% of filler had the least tensile strength of 20.9 MPa.

### Flexural strength

The result of the flexural strength of wood fillers and recycled polypropylene composites is presented in Figure 2. The effects of filler loading on flexural strength of the composites as presented in figure 2 shows that, at 10 wt%, all fillers demonstrated improved flexural strength compared to the neat recycled polypropylene (0 wt %). This increase is expected due to enhanced adhesion between the components in the blends. Baobab and parrot beak reached their optimum performance. African mahogany peaked at 20 wt% with a flexural strength of 44.47 MPa, after which a noticeable decline was observed at 50 wt%.

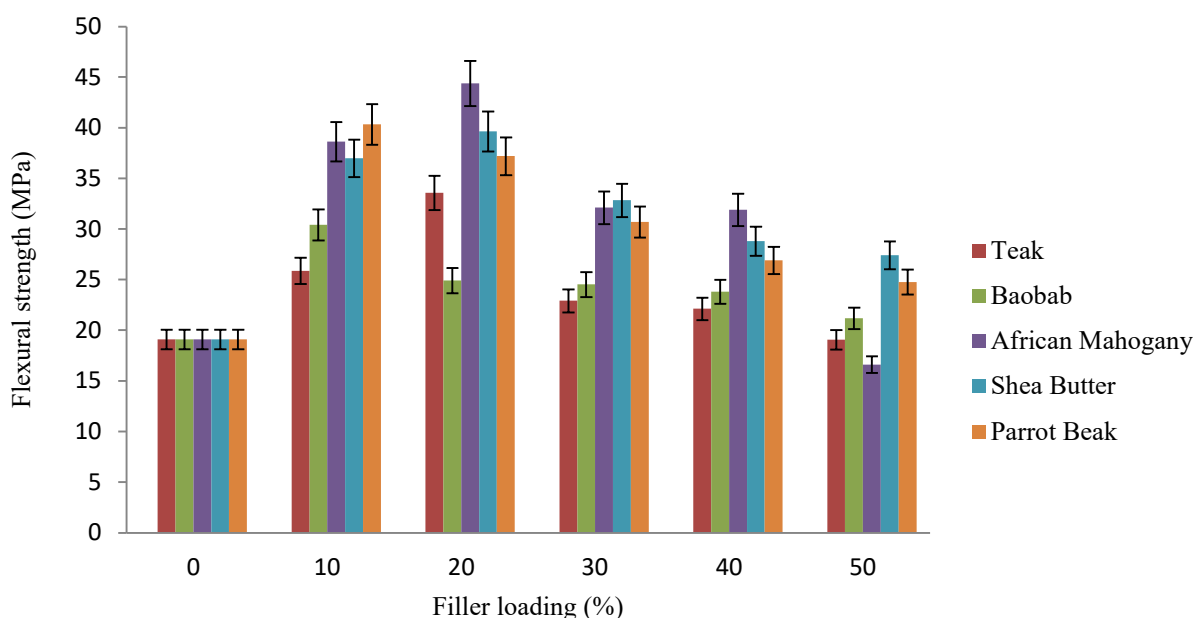


Fig. 2: Effect of Filler Loading on Flexural Strength of waste PP Composites

The Teak sample exhibited a consistent drop in strength beyond 20 wt%, likely indicating poor filler dispersion within the polymer matrix due to the reduction of interface bond between the fiber and matrix. In contrast, Shea Butter demonstrated resilience at 40 wt%, with strength of 35.63 MPa, before declining at 50 wt%. Bal (2023) reported that the reduction in flexural strength was due to the poor compatibility between the polar wood flour and non polar polymer, which forms a weak interfacial region.

### Hardness

The result of Hardness of wood filler and recycled polypropylene composites presented in Figure 3. The effects of filler loading on the hardness value of the composites as presented in figure 3 shows that, at 10 – 40 wt% filler loading, it was observed that the hardness of the composites increases with the increase in filler

loading, illustrating a positive correlation between filler content and the polymer matrix, this was supported by Onuoha et.al (2017) which stated that increasing fiber load improves the strength and stiffness of the composite but decreases elongation and energy to break. However, teak and African mahogany recorded a drop at 50 wt% which might be a result of a change in composite structure due to excess filler. At 50 wt%, baobab and Parrot Beak and baobab had an impressive hardness of 58.2 HV and 59.03 HV respectively with no significant difference since the error bar overlapped, the hardness suggesting its viability as a filler material for applications that require high hardness. This increase in hardness can be attributed to the fact that the additions of fillers in recycled polypropylene imparted stiffness, thus making the composites rigid and hard and restricting the mobility of polymeric chains.

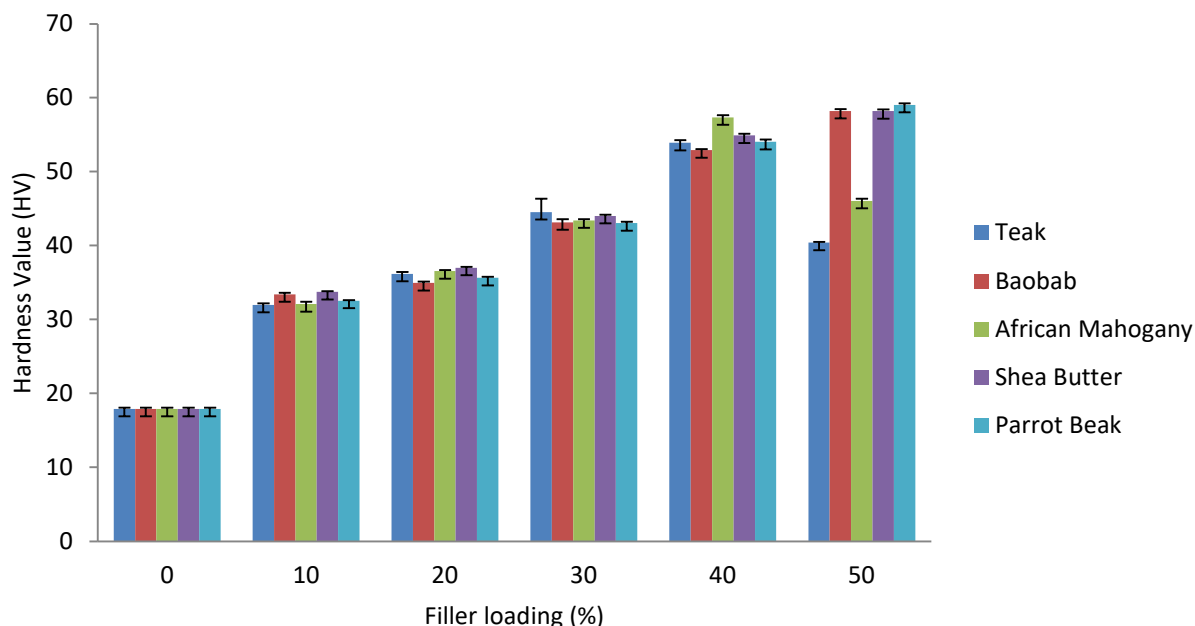


Fig. 3: Effect of Filler Loading on Hardness Value of waste PP Composites

Statistical analysis shows that there is no significant difference in the hardness value at 10-30 wt% as the error bars overlap each other. While at 40 wt%, apart from African mahogany that has a significant difference in hardness value, there is no significant difference between the teak, baobab, shea butter and parrot beak. Also at 50 wt%, baobab, shea butter and parrot beak, there is statistically, no significant difference in the hardness value. This is in support of the findings by Yeshiwas et al. (2024) that there is a correlation between hardness and specimen types, at 40 wt % and above wood content, the composites is harder than neat HDPE.

### Impact strength

The result of Impact strength of wood filler and recycled polypropylene composites is presented in Figure 4. The effects of filler loading on the impact strength of the composites as presented in figure 4 indicate a general trend where an increase in filler loading correlates with a decrease in impact strength across all composite types studied. For instance, the impact strength of Teak composites dropped from 0.75 J at 0% filler loading to 0.25 J at 50% filler loading. Similar trends were observed for Baobab, African mahogany, Shea Butter, and Parrot Beak composites.

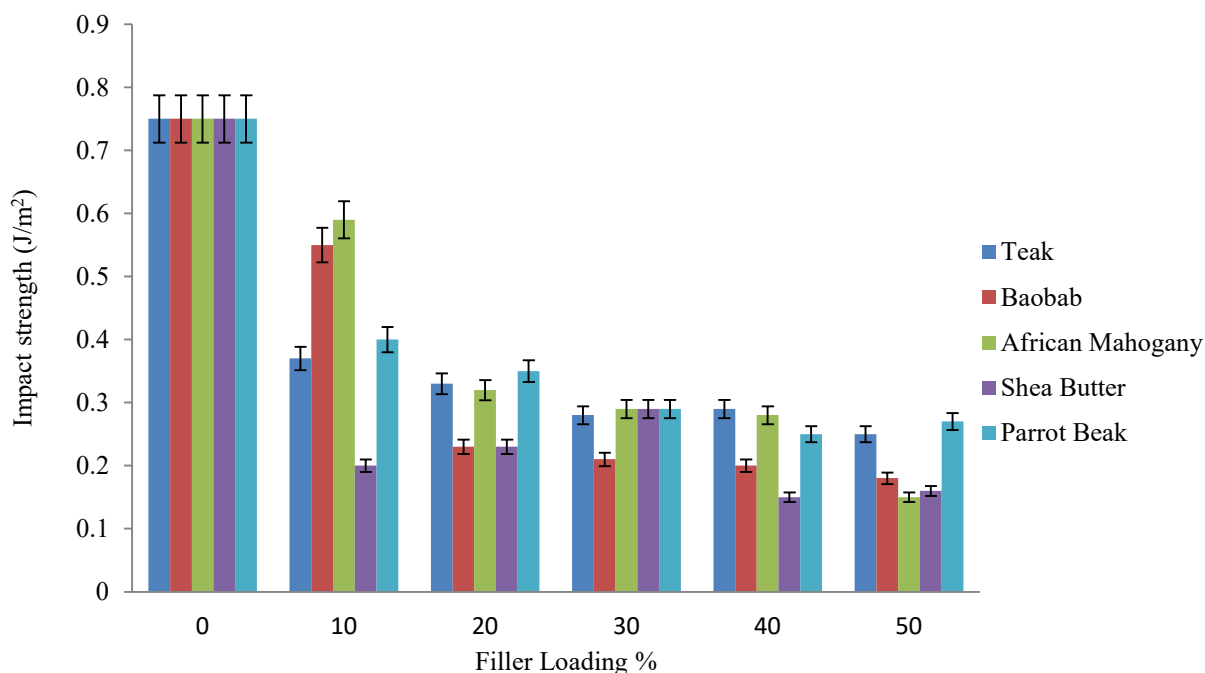


Fig 4: Effect of Filler Loading on Impact strength of waste PP Composites

This decline in impact strength can be attributed to several factors, including increased brittleness with higher filler contents and the inadequate bonding between the fibers and the matrix material at elevated loadings. Meekum and Khongrit (2018) obtained a similar result that the impact strength of the wood plastic composites becomes weak at high loading as a result of reduction in cross link/bonding reaction between the fibre and polymer. The highest impact energy recorded was 55J/m<sup>2</sup> at 10 wt% filler loading in baobab, while the lowest impact energy of 14J/m<sup>2</sup> was obtained in shea butter.

### Flexural Modulus

The result of Flexural Modulus of wood filler and recycled polypropylene composites

presented in Figure 5. The effects of filler loading on the flexural modulus of the composites as presented in figure 5 shows that the flexural modulus of the composites increases as the filler wt% increases. Teak, African mahogany and shea butter have the highest modulus at 20 wt% filler loading, with the values of 931.42 MPa, 1004.47 MPa, and 1141.21 MPa, respectively, suggesting optimal filler loading supports better load transfer until a certain threshold. The increase could be attributed to the fair distribution of the filler in the matrix, which efficiently hinders chain movement during deformation.

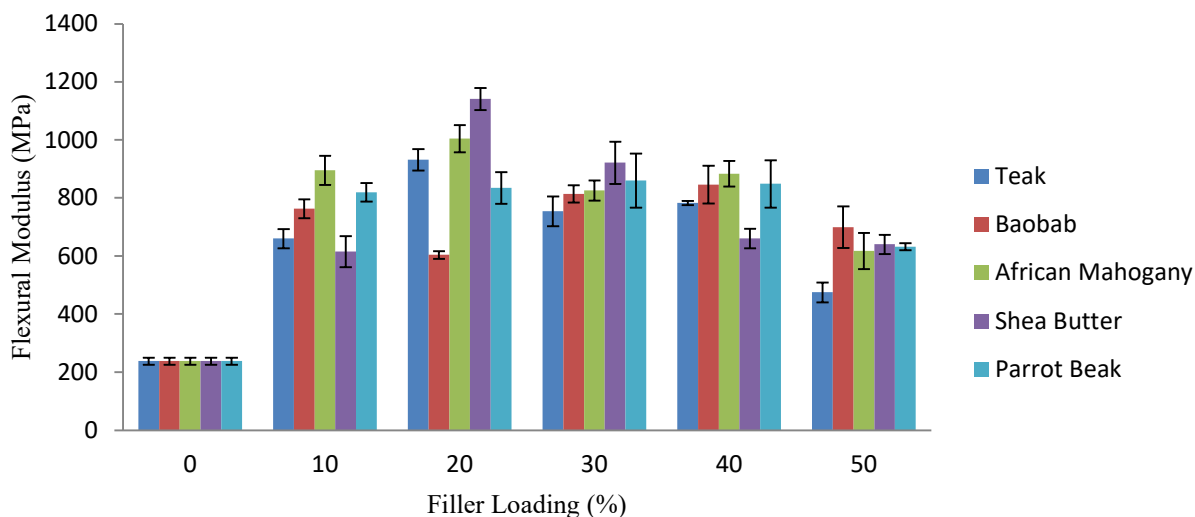


Fig. 5: Effect of Filler Loading on Flexural Modulus of waste PP Composites

Tensile modulus is an indication of the stiffness of a material, the incorporation of fillers into the polymer matrix improves the stiffness of the composites. Swasono et.al (2019) attributed the decrease in flexural modulus is due to insufficient amount of polymer matrix to wrap the surface of the saw dust that tend to be agglomerated leading to weak interfacial adhesion.

## Conclusion

The effects of filler loading on the mechanical properties of wood plastic composites were studied. The results obtained indicated that filler loading significantly impacts the mechanical properties. Teak, African mahogany and Shea butter trees have the highest modulus at 20 wt% filler loading, with values of 931.42 MPa, 1004.47 MPa, and 1141.21 MPa, respectively. The flexural strength of teak, African mahogany,

shea butter tree, and parrot beak peaked at 20 wt% filler loading at 33.6 Mpa, 44.7 Mpa, 38.97 Mpa and 37.66 Mpa respectively and at 20 wt%, African mahogany and Shea butter has an increase in the tensile strength of 20.2 MPa and 15.81MPa respectively. At 10 – 40 wt% filler loading, it was observed that the hardness of the composites increases with the increase in filler loading, illustrating a positive correlation between filler content and the polymer matrix. However, the impact strength decreases with the addition of fiber loading, which may be as a result of increased brittleness with higher filler contents and inadequate bonding between the fibers and the matrix material.

Based on the findings, it can be concluded that the optimum fiber loading for this composite material is 20%, which results in the optimal balance of tensile strength, optimum balance for flexural

strength, hardness test, and flexural modulus. Though there is no universal "best" percentage, the optimal filler loading depends on factors like the specific filler material, the type of plastic matrix, and the desired properties of the WPC. Some studies show increased mechanical properties (like tensile modulus or flexural strength) at 20% loading.

Wood-plastic composite (WPC) with a high plastic content can be useful in industrial applications like automotive parts, building materials, and consumer goods, leveraging its blend of wood's strength and plastics' durability and resistance. It can also be useful in applications requiring weather resistance and chemical inertness, because of its high plastic ratio, such as outdoor decking, fences, car door panels, and furniture, as well as insulation panels and various structural components in construction.

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