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Effect of Wood Species on the Mechanical Properties of Wood Plastic Composites

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Abstract

The quality of wood plastic composites (WPCs) is largely influenced by the type and properties of the reinforcing fibres, the manufacturing process, and the composition of the constituent materials. In particular, the choice of wood species used as filler and reinforcement plays a critical role in determining the mechanical performance of the final composite. This study investigated the impact of different wood species on the mechanical properties of WPCs. The selected wood species included *Tectona grandis* (TGS), *Adansonia digitata* (ADA), *Khaya ivorensis* (KHS), *Butyrospermum paradoxum* (BSP), and *Gmelina arborea* (GMA). These were blended with recycled polypropylene at varying filler loadings of 10, 20, 30, 40, and 50 wt%. Mechanical properties such as tensile strength, flexural strength, impact strength, and hardness were evaluated in accordance with ASTM standards. Among the wood species tested, *Khaya ivorensis* (African mahogany) exhibited a notable tensile strength of 20.44 N/m² at 30 wt% and the highest flexural strength (44.47 MPa), followed by *Gmelina arborea* (Parrot Beak) at 39.77 MPa and *Butyrospermum paradoxum* (Shea Butter) at 38.97 MPa. At 50 wt% filler content, *Gmelina arborea* and *Adansonia digitata* (Baobab) demonstrated superior hardness values, with *Gmelina arborea* reaching 59.03 Hv. In terms of impact resistance, African mahogany and baobab recorded the highest values of 0.59 J and 0.55 J, respectively. At 20 wt% filler loading, *Tectona grandis* (Teak), African mahogany, and shea butter exhibited the highest modulus of elasticity, with values of 931.42 MPa, 1004.47 MPa, and 1141.21 MPa, respectively. These findings underscore the significant influence of wood species on the mechanical behavior of WPCs. The selection of suitable wood fibres can therefore be tailored to enhance specific performance attributes of the composite, depending on the intended application.

Keywords

Wood species,
Polymer,
Composite,
Reinforcement agent,
Mechanical properties.

INTRODUCTION

Wood and thermoplastic polymers are combined to create a material known as a wood-plastic composite (WPC). The wood might be sawdust, pulp, or bamboo, and the thermoplastic polymer is typically virgin or recycled polyethylene, polypropylene, polyvinyl chloride and other thermoplastic materials. To develop WPCs, wood residuals, e.g. sawdust, wood shavings, or wood flour, are mixed with a thermoplastic polymer and melt processed (or thermoformed) into their final shape, either as a continuous profile forming through extrusion or as a three-dimensional form through injection molding (Segerholm, 2012). Although studies on the development and application of WPCs are not a new idea, both of its constituent designs could be innovative (Harničárová et al., 2017; Ravivarm.an, et al., 2018).

The use of wood flour in WPC production is increasing as the demand for the WPC continues to soar in the world market. Studies have been carried out on the various plastics and wood species used for the production of WPC. Virgin or recycled thermoplastics including high-density polyethylene (HDPE), low-density polyethylene (LDPE), polyvinyl chloride (PVC), polypropylene (PP), acrylonitrile butadiene styrene (ABS), polystyrene (PS), and polylactic acid (PLA). Oliveros-Gaviria et al. (2024). produced Wood Plastic Composite Based on Recycled High-Density Polyethylene and Wood Waste (Sawdust) and it was discovered that the mechanical analysis revealed that both the strength and Young's modulus of the tensile and flexural properties slightly increased with the addition of sawdust to the composite. Arif et al (2020)

investigated the properties of wood composite plastics made from the predominantly low density poly ethylene plastics and their degradability and asserted that the mechanical properties of these composites also met the Japanese Industrial Standards (JIS) standard, particularly their modulus of elasticity (MOE). Modulus of rupture (MOR) and internal bonding (IB) showed in lower values, depending on the proportion of wood filler they contained. Enayati et.al (2021) studied the Application of Polyvinylchloride (PVC) Waste and Sawdust in Wood-Plastic Composite, the results showed that the mechanical properties of panels were significantly higher when the PVC/Sawdust ratio was 50:50.

Thicknesses swelling after 24 hours as well as long-term holding decreased with the increase in PVC / sawdust ratio. Turkadze et.al (2023) characterize the polypropylene composites reinforced on bio waste from the production of Tung oil, the results shows that the optimal strength properties were observed at a filler content of 40 wt.%, where the compression and bending strength limits were 63.5 and 36.7 MPa, respectively. Köksal and Kelleci (2024) produce and characterize wood polystyrene composites from recycled waste materials, according to the obtained results, it was discovered that there was no significant change in the amount of Thickness Swelling as the fibre filler was increased, but the amount of water uptake has increased. It was also discovered that glass fibre filling swelled less than fibre filler. But water uptake was more than fibre filler. Apart from the addition of 150 % glass fibre, fillers increased the densities. Withdrawal strength resistance

increased with the addition of filler. Li et al (2024) conducted studies on PLA-based Wood-Plastic Composites, the results shows that PLA-based WPC has the advantage of being completely degradable. In order to enhance the performance of PLA-based WPC, in addition to trying different materials blended with PLA, wood fiber treatment, PLA modification treatment, coupling agents and other additives are usually used in the research to enhance the performance of PLA-based WPC.

Kim et al., (2008) reported that WPCs have been manufactured in the Laboratory using a wide variety of wood species, including Osage orange, walnut, yellow poplar, hickory, Utah juniper, salt cedar, and emerald ash borer-infested ash. Previous research has also shown that the WPC produced from hardwood species has better mechanical properties than softwood. Mital'ová (2025) reported that due to the higher cellulose content, samples made from hardwood exhibit higher values of tensile elongation at break and charpy impact strength. Zabihzadeh et al. (2009) conducted a study on the effect of wood species and coupling Agents on the Mechanical Properties of Wood Flour/HDPE Composites, it was concluded that Poplar flour provides an improvement in tensile strength, tensile modulus, tensile energy absorption, and failure strain over pine. Sae-lim and Aht-ong (2013), in one of their works, asserted that the use of hardwood as a filler in HDPE resulted in HDPE composites with higher flexural strength and lower water absorption than softwood.

Wood sawdust and waste plastics are examples of solid wastes which has become a menace in the environment in many countries of the

world especially third-world countries. It is estimated that 1.8 million tonnes of sawdust and 5.2 million tonnes of wood waste are generated annually in Nigeria, with sawmill wastes accounting for about 93 percent. (Oyedepo et al. (2019). These wastes could be re-utilized in the production of certain items such as the WPC which could assist in the mitigation of plastic wastes pollution. This study therefore tends to investigate the development and mechanical properties evaluation of waste PP WPCs from five different wood species: The wood species in this study were *Tectona grandis* (TGS), *Adansonia Digitata* (ADA), *Khaya invorensis* (KHS), *Butyrospermum paradoxum* (BSP), and *Gmelina Arborea* (GMA). with a view in determining their suitability for different applications.

Materials and method

Materials

Waste polypropylene (PP) such as Packaging materials both food and non-food containers, bottles, plastic chairs etc 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, *Tectona grandis* (TGS), *Adansonia Digitata* (ADA), *Khaya invorensis* (KHS), *Butyrospermum paradoxum* (BSP), and *Gmelina Arborea* (GMA).

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 granule 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 from different wood species was sun-dried, milled, and sieved into a uniform particle size of 300 μ m, weighed, and stored at room temperature in an airtight plastic bottle.

Compounding and Compression Moulding

The compounding and compressing of the WPCs from waste PP were carried out at the Polymer Processing Laboratory of the Department of Polymer Technology, Nigerian Institute of Leather Science and Technology. The waste PP was compounded and mixed with the different 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 and mixed for five minutes (5min) to obtain a homogeneous mixture. The same procedure was repeated for all the 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 4 Pascal. Composite sheets were thereafter cut into various dimensions for characterization.

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 (2023) (Notched) standard. 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 (2015). 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

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

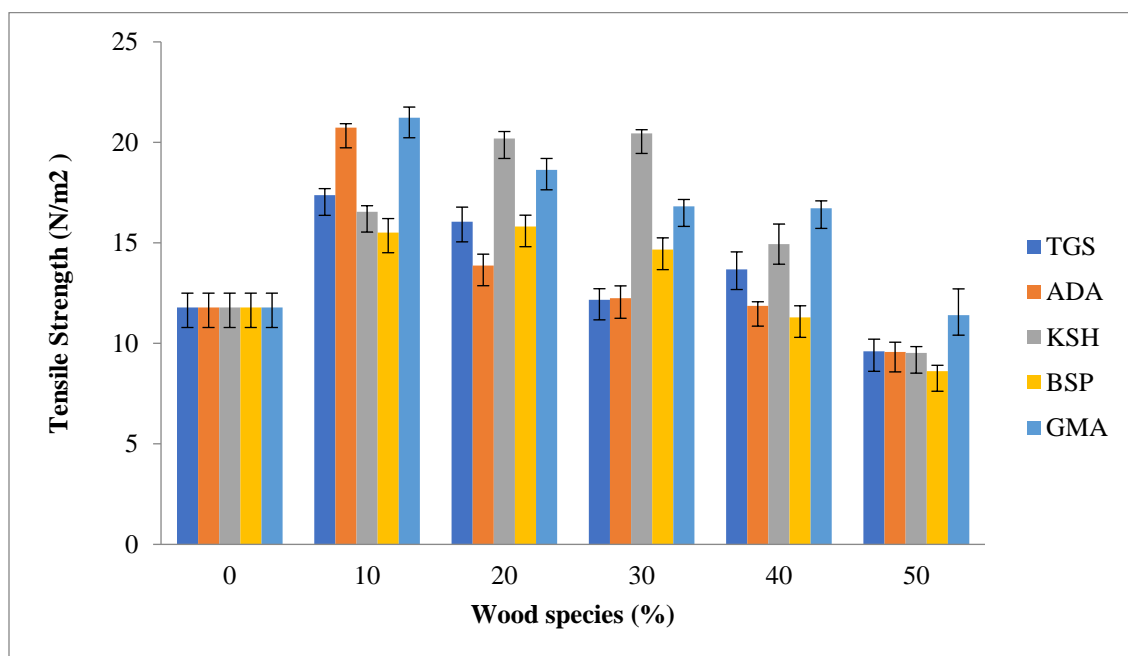


Fig. 1: Effect of different wood species on tensile strength of waste PP composites

GMA and KSH filler displayed a unique trend where tensile strength was observed to be higher at 10% and 30% before declining, indicating enhanced synergy with the matrix at weight percentage of reinforcement. Harder and denser wood species generally produce WPCs with higher tensile strength compared to softer woods; both woods are hardwood with denser structures. These results are in agreement with the work of Dorostkar (2014) who investigated mechanical properties of *Poplar* and *Alder* wood reinforced high density polyethylene composites. The results show that Adler has better tensile properties compared to poplar.

Flexural strength

The result of the flexural strength of the different wood species filled recycled polypropylene composites are presented in Figure 2. The flexural strength of all the wood species used as reinforcements were observed to increase with weight percentage of wood incorporated from 10% - 20% and a decrease at 30% and 40% weight percentage of wood

fibres. KSH fibre was observed to have the highest flexural strength (44.47 MPa), followed by GMA (39.77 MPa) and BSP (38.97 MPa). ADA had the lowest flexural strength (30.38 MPa). This means that KSH is a strong choice for applications requiring high flexural strength, GMA and BSP can also serve as a good alternative to KSH because of its relatively high flexural strength. Factors such as wood density, grain structure, and cellulose content are likely to contribute to these differences in flexural strength.

Jian et al. (2022) obtained similar results which showed that *poplar* wood particles with high cellulose content had higher bending properties when combined with the polymer matrix. Similarly, Adefisan and Mc Donald (2017) asserted that higher density and lower extractives content of mahogany WPCs in comparison with those of other species are probably responsible for its higher flexural properties. The lower values in TGS and ADA suggest that these species may be less suitable for high-load applications.

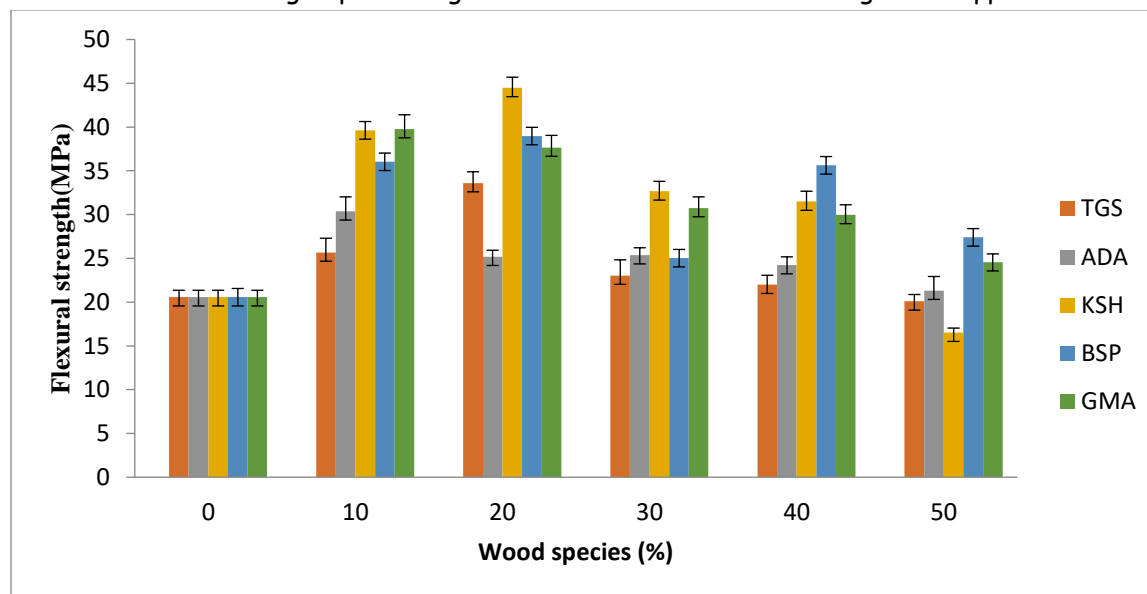


Fig. 2: Effect of different wood species on flexural strength of PP waste composites

Flexural Modulus

Figure 3 presents the result of the flexural modulus of different wood species filled recycled polypropylene composites. The flexural modulus of the composites was shown to increase as the filler wt% increases, TGS, KSH and BSP have the highest modulus at 20 wt% filler loading, with the values of 931.42 MPa, 1004.47 MPa, and 1141.21 MPa respectively, though, statistically it is not

significant. They are hardwood, which has a low void content and might be responsible for having a high flexural strength in the WPC. Gacitua and Wolcott (2009) found that void content is a significant factor affecting the performance of WPCs and the probability of failure under stress, and results from interactions between the anatomical features and the behavior of wood species during processing.

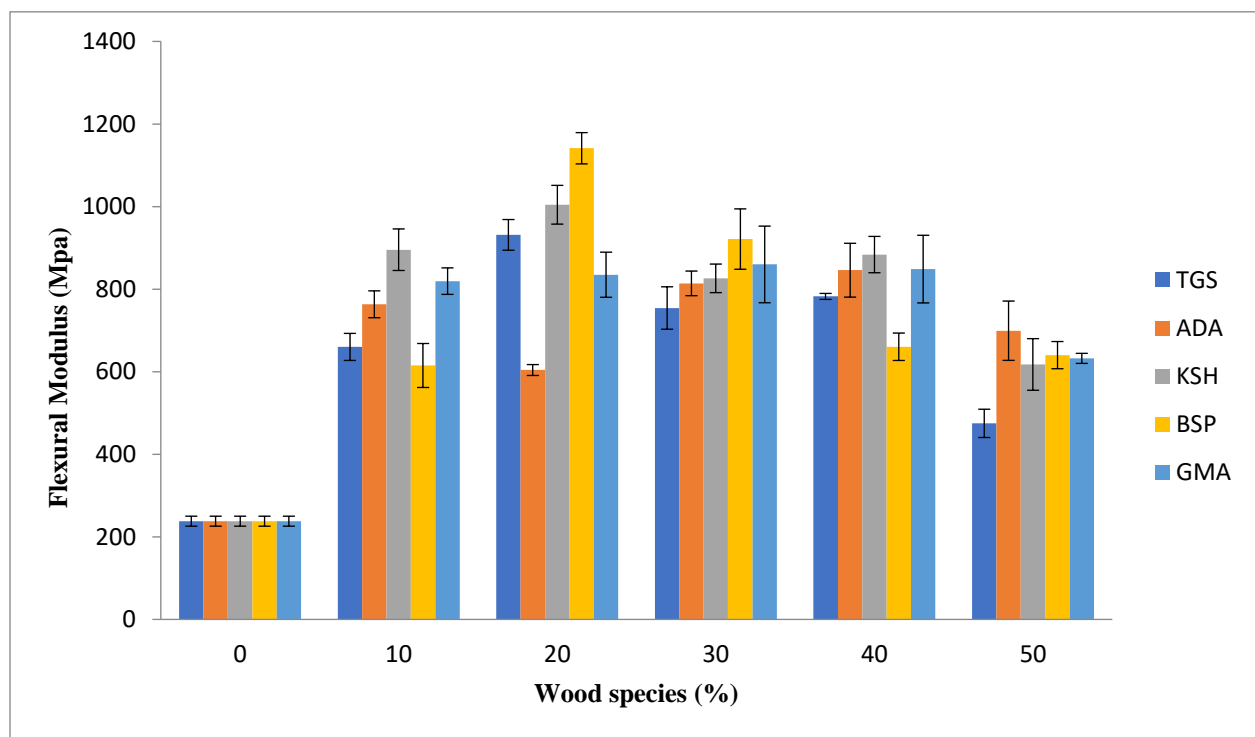


Fig. 3: Effect of different wood species on flexural modulus of composites

Hardness value test

Figure 4 depicts the hardness value of the different wood species filled recycled polypropylene composites. The result shows that, at 50 wt%, *GMA* and *ADA* show the highest hardness values, with *GMA* achieving (59.03Hv), the highest value recorded, and as the wood content increases from 0 wt% to 40

wt%, it leads to an increase in WPCs hardness across all species. However, at higher wood content (50%), a decline in hardness is observed for some species, suggesting an optimal range for wood loading. At 40 wt%, *KSH* presents the highest hardness value (57.33 Hv). The higher hardness observed with *GMA* and *ADA* may be related to their

respective densities and lignocellulosic organization. Huuhilo *et al* (2010) stated that the hardness of WPCs is also a function of the polymer type, porosity of wood species, as well as its density. Parrot beak and Baobab have a diffuse porous structure. Olaniyan S.O (2022) Statistical analysis shows that there is no significant difference in the hardness value at

10-30 wt%, while at 40 wt%, apart from KSH which has a significant difference in hardness value, there is no significant difference between the TGS, ADA, BSP, and GMA. Also, at 50 wt%, ADA, BSP, and GMA, there is statistically, no significant difference in the hardness value.

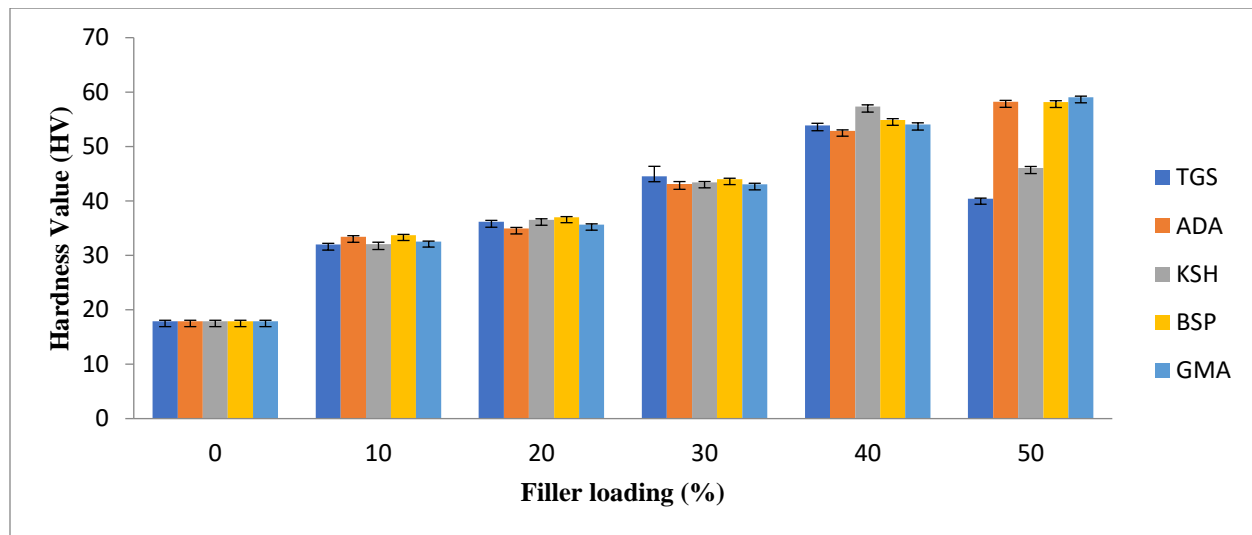


Fig. 4: Effect of different wood species on hardness value of recycled PP composites

Impact strength tests

The results of the Impact strength of different wood species reinforced recycled polypropylene composites are presented in Figure 4. The results show a general trend of decrease in impact strength with weight percentage of wood fibres incorporated across all wood species studied. The impact strength of TGS composites was observed to drop from 0.75 J at 0% (unfilled recycled PP) to 0.25 J at 50% filler loading. Similar trends were

observed for ADA, KSH, BSP, and GMA composites. The highest impact energy recorded was 55J/m² at 10 wt% filler loading of KSH wood. Jumadi *et al.* (2018)., reported that the most common factor which causes the decrement of impact strength with the addition of wood flour in WPC manufacturing is poor interfacial bonding between the reinforcement and the matrix, and also influenced by types of wood, material hardness, and degree of densification.

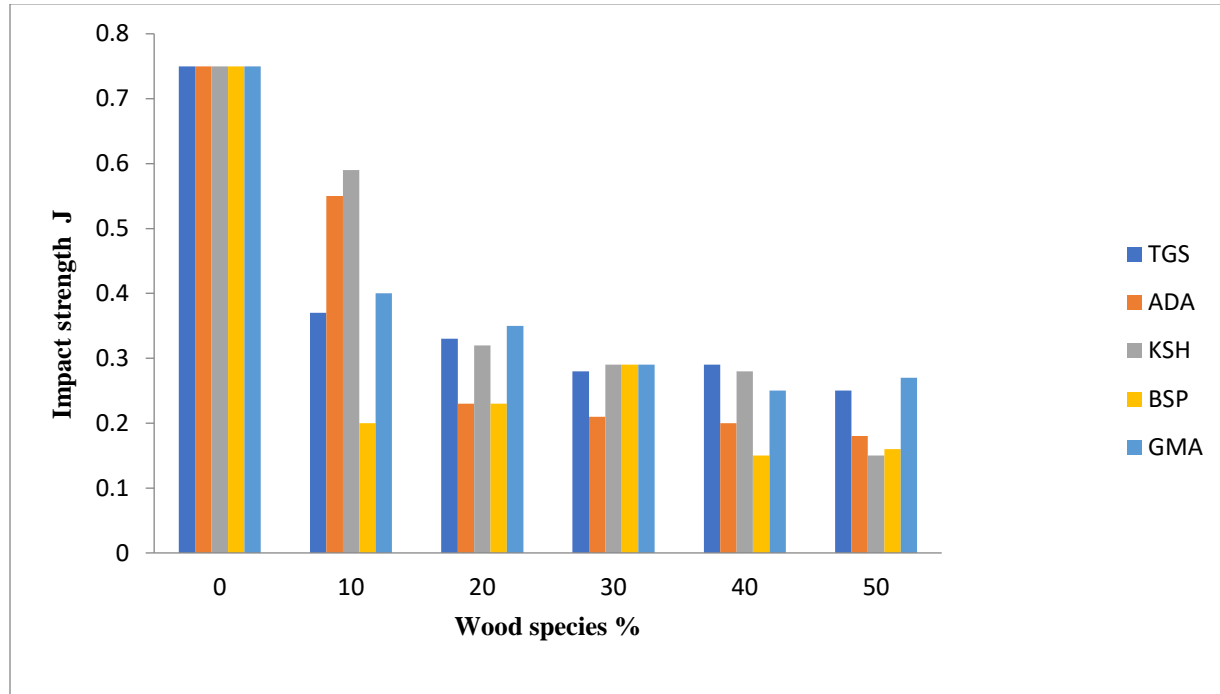


Fig. 5: Effect different wood species on the impact strength of recycled PP composites

Conclusion

The effects of wood species on the mechanical properties of the WPCs were studied. The results obtained indicated that wood species and the percentage of plastics significantly impact the mechanical properties. It was discovered that the WPCs produced from the different hardwood species have better mechanical properties (tensile strength, flexural strength, hardness value, impact strength, and flexural modulus). This may be a result of high densities in their structures, low void contents, and lower extractive contents which have a direct impact on the interphase adhesion between the wood and plastic matrix and thus the resulting composite mechanical properties. KSH has a tensile strength of 20.44N/m² at 30 wt% and has the highest flexural strength (44.47 MPa), followed by

GMA (39.77 MPa) and BSP (38.97 MPa). 50 wt%, GMA, and ADA show the highest hardness values, with GMA achieving (59.03Hv), while KSH and ADA have the highest impact strength of 0.59 and 0.55J respectively. TGS, KSH, and BSP have the highest modulus at 20 wt% filler loading, with values of 931.42 MPa, 1004.47 MPa, and 1141.21 MPa respectively.

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