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DEVELOPMENT AND PERFORMANCE EVALUATION OF POLYPROPYLENE BASED COMPOSITES REINFORCED WITH RICE HUSK AND MAHOGANY SAWDUST FOR SEDI-ENUGU DISPOSABLE PLASTIC SPOONS

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ABSTRACT

The increasing demand for plastic spoons at weddings and events across Africa and its diaspora has necessitated the development of a sustainable composite material. This study explores the production of composite plastic spoons using virgin polypropylene (PP) blended with rice husk and mahogany sawdust, as well as PP crush. The focus was on evaluating the composites' hardness and mechanical strength. Chemical analysis revealed that a 20% rice husk blend provided optimal percentage strength. The lignin content in rice husk and mahogany sawdust was 20-25% and 20-30%, respectively, with mahogany sawdust showing a higher lignin content of 40-50%. Both materials had cellulose content ranging from 35-40% and hemicellulose from 20-25%. The raw materials were processed into dust, sieved to achieve fine micron sizes, dried, and charred before blending with virgin PP. Weighing of mahogany sawdust samples yielded values between 32.915 grams and 33.868 grams, with adjusted weights ranging from 15.305 grams to 16.258 grams, indicating high consistency. Rice husk samples, weighing between 32.275 grams and 39.047 grams, had adjusted weights ranging from 14.665 grams to 21.437 grams, showing greater variability. A 180-ton injection molding machine was used for production. For PP with mahogany sawdust, the nozzle temperature was set at 220°C, whereas PP with rice husk required a higher temperature of 250°C. The barrel temperature for PP with mahogany sawdust was 200°C, compared to 220°C for PP with rice husk. Processing times varied: injection time for PP with mahogany sawdust was 0.370 seconds, compared to 1 second for PP with rice husk; cooling time was 0.150 seconds for PP with mahogany sawdust, versus 20 seconds for PP with rice husk; and ejection time was 0.110 seconds for PP with mahogany sawdust, compared to 10 seconds for PP with rice husk. The blend of 70% PP, 14% Polymer Crush, 8% mahogany sawdust, and 8% rice husk demonstrated the best tensile strength and hardness. This formulation ensures a robust and durable product suitable for disposable applications, leveraging the high content of PP and Polymer Crush to maximize strength and hardness.

Keywords: Plastic Spoons, Reinforced Mahogany, Rice Husk, Injection Molding, Polypropylene (PP), PP Crush, Composite Materials.

I. INTRODUCTION

Plastics are synthetic materials composed of polymers, which are large molecules made up of repeating structural units known as monomers. Their widespread use across various applications can be attributed to their versatility, lightweight nature, and durability. Plastics can be molded into diverse shapes, making them ideal for a wide range of products, from everyday household items to complex industrial components.

Natural fibers, derived from plants, animals, or minerals, can be spun into filaments, threads, or ropes and subsequently woven or knitted into fabrics. These fibers find applications in textiles, automotive, and construction industries, gaining significant attention due to their sustainability, biodegradability, and lower environmental impact compared to synthetic fibers. Composite materials are created by combining two or more distinct materials to produce properties superior to those of the individual components. In these composites, polymers often act as the matrix material, binding the reinforcement material and distributing loads across the structure. The reinforcement material, which may include fibers, particles, or flakes, enhances specific properties such as strength, stiffness, and thermal stability. The demand for reinforced polymer composites has increased due to their enhanced mechanical properties, including superior tensile strength, stiffness, and durability. Natural fillers, such as wood sawdust and agricultural residues, have emerged as promising reinforcement materials due to their biodegradability, low cost, and renewable nature. The integration of these fillers not only improves the mechanical properties of polymers but also addresses environmental concerns by effectively utilizing waste materials.

This study focuses on crushed Polystyrene (PP), a widely used thermoplastic polymer known for its versatility, ease of processing, and cost-effectiveness. GPPS is characterized by its, rigidity, and brittleness, and can be processed through methods such as injection molding, extrusion, and thermoforming. The molecular formula of polystyrene is $(C_8H_8)_n$, where n represents the number of repeating styrene units in the polymer chain.

Polypropylene (PP) is another versatile thermoplastic polymer, recognized for its excellent chemical resistance, mechanical properties, low density, and relatively high melting point (around 160-170°C). Its molecular formula is $(C_3H_6)_n$, where n indicates the number of repeating units in the polymer chain. Polypropylene is a polymer of propylene (C_3H_6), and its structure comprises repeating units of this monomer.

Natural Fibers (Mahogany Sawdust / Rice Husk)

In this research, two types of natural fibers were utilized: mahogany sawdust and rice husk. Mahogany, a hardwood renowned for its durability, strength, and aesthetic appeal, exhibits a distinctive reddish-brown color. It is extensively used in furniture making, cabinetry, and decorative veneers. Recently, mahogany has garnered interest as a natural fiber for composite materials, particularly for polymer reinforcement. Its use in composites aims to enhance mechanical properties while mitigating environmental impacts compared to traditional composites reinforced with synthetic fibers such as glass or carbon fibers.

Rice husk, the outer shell of rice grains separated during the milling process, is considered an agricultural byproduct despite its status as waste, rice husk has emerged as a valuable natural fiber with potential applications in various fields. Its incorporation into polymer composites not only provides an opportunity to utilize agricultural waste but also contributes to the sustainability and environmental benefits of composite materials.

The inclusion of natural fibers like mahogany and rice husk in polymer matrices is driven by the goal of improving the mechanical properties of the composites while reducing their environmental footprint. This approach reflects a growing trend toward sustainable materials that leverage natural resources for enhanced performance and reduced ecological impact.

Table 1: Chemical Compositions of Mahogany Sawdust and Rice Husk

Material	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Rice husk	35-40	20-25	20-25
Mahogany sawdust	40-50	15-25	20-30

Composition and Properties of Natural Fibers in Polymer Composites

Table 1 presents the compositional analysis of rice husk and mahogany sawdust, which were utilized as natural fibers in this study. Rice husk comprises cellulose (35-40%), hemicellulose (20-25%), and lignin (20-25%). In contrast, mahogany sawdust is composed of cellulose (40-50%), hemicellulose (15-25%), and lignin (20-30%).

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These components significantly contribute to the rigidity, thermal stability, and resistance to biodegradation of the fibers.

The cellulose content in both rice husk and mahogany sawdust imparts structural strength and rigidity to the fibers. Hemicellulose enhances flexibility and bonding characteristics, while lignin contributes to thermal stability and resistance to environmental degradation. These properties make rice husk and mahogany sawdust valuable as reinforcement materials in polymer composites.

In this research, these natural fibers were incorporated into polymer matrices through an injection molding process. The objective was to achieve homogeneity in the composite material and to evaluate its performance. The fibers underwent heat treatment before being introduced into a two-cavity mold to produce a reinforced plastic spoon. This process aimed to enhance the mechanical properties of the composite, including tensile strength, flexural strength, and impact resistance.

The utilization of rice husk and mahogany sawdust as reinforcement materials in polymer composites reflects their potential to improve the mechanical performance of the composites while leveraging natural and sustainable resources. The findings underscore the effectiveness of these natural fibers in enhancing the properties of polymer-based products.

Sixteen (16) Cavities Plastic Spoon Mold

Fig 3: The 16-cavity mold utilized in this study is designed to produce 16 identical plastic parts in a single injection molding cycle. This mold is used with a 180-ton injection molding machine, offering significant advantages in terms of production efficiency and product consistency. The high cavity count of the mold allows for the simultaneous production of multiple parts, which is particularly beneficial for high-demand applications.

The 16-cavity mold is particularly advantageous for manufacturing various plastic products, including executive hangers, bases for measuring cylinders, science and laboratory instruments for educational institutions (primary, secondary, and tertiary), agro-machinery components, plumbing fixtures, and automobile spare parts. The use of this mold ensures consistent quality and precision across all produced parts, meeting the rigorous demands of diverse applications and maintaining high production standards.

The implementation of such a mold not only enhances production efficiency but also supports the scalability of manufacturing processes, making it an essential tool for industries requiring high-volume production with consistent quality control.

Fig 1: SEDI-Enugu 16 cavities spoon mold

Fig 2: SEDI-Enugu: Thicknessing Machine with mahogany shavings

The SEDI-Enugu thicknessing machine is designed to process wood materials with precision, and this study focuses on its application in conjunction with mahogany shavings. Mahogany shavings, a byproduct of mahogany processing, are utilized to enhance the performance and efficiency of the thicknessing machine.

Fig 3: SEDI-Enugu Standard Test Sieve

Fig. 3 Shows the standard test sieve used in this study, which adheres to IS: 460 BSS specifications with a mesh size of 60 (0.80 mm). This sieve was employed in the sieving process of mahogany sawdust and rice husk fillers used in the production of natural fiber-reinforced plastic spoon composites.

The sieve features an aperture size of 0.80 mm, ensuring that only particles smaller than this dimension pass through. Constructed from high-quality brass, the sieve is designed to offer durability and resistance to corrosion. This construction choice enhances the sieve's longevity and maintains its performance over time.

The primary objectives of using this sieve are to achieve consistent quality, ensure uniform particle size distribution, and obtain accurate sieving results. By employing this standard test sieve, the study ensures the reliability of the filler materials, which is critical for the production of high-quality composite materials.

Fig 4: S. Mettler Digital Weighing Balance

Fig. 4 Shows the S. Mettler digital weighing balance utilized in this study. This precision weighing instrument was employed to achieve accurate proportions and reliable measurements of mahogany sawdust and rice husk for the desired blend in the production process of natural fiber-reinforced composites. The digital balance features a clear and intuitive digital display, which facilitates straightforward reading of measurements. This ensures precise control over the weight ratios of the materials being used, which is critical for maintaining consistency and accuracy in the composite production.

The use of the S. Mettler digital weighing balance was integral to ensuring the correct formulation of the composite materials, thereby contributing to the overall quality and reliability of the produced composites.

Fig 5: Disposable spoon produced from polymer blend with Rice husk and mahogany sawdust

Fig 6: Disposable spoon produced from blend with PP and polymer crush

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II. MATERIAL AND METHODS

Equipment: 180 ton injection molding machine, S. Mettler Digital Weighing Balance, SEDI-Enugu: Thicknessing Machine and SEDI-Enugu Standard Test Sieves.

Materials: Mahogany sawdust, Rice Husk, polystyrene crush, Polypropylene

Method: The mahogany was processed into fine particles for uniform blending while the rice husk was cleaned, processed, and ground to a consistent size. The mahogany particles and rice husk were combined in specific ratios to create a composite plastic spoon material designed to optimize mechanical strength and sustainability. A 180-ton injection molding machine was used for the blending with the nozzle temperature set at 220°C, while for PP with rice husk at 250°C, The barrel temperature for PS with mahogany sawdust is 200°C, which is lower compared to 220°C for PP with rice husk. PS with mahogany sawdust has an injection time (0.370 seconds) compared to PP with rice husk (1 second).The cooling time for PS with mahogany sawdust is shorter at (0.150 seconds) compared to PP with rice husk at (20 seconds). Ejection time or PS with mahogany sawdust (0.110 seconds) compared to PP with rice husk at (10 seconds). The composite material was heated to a molten state and injected into spoon molds, ensuring complete cavity fill. The material was cooled within the molds. Solidified spoons were then ejected and subjected to quality control to verify adherence to specifications. The aim was to create a composite material with optimized mechanical strength and sustainability for use in producing plastic spoons.

III. RESULTS AND DISCUSSIONS

The analysis of weights of mahogany sawdust and rice husk used in this study were recorded to evaluate consistency and accuracy in material handling. The measurements were taken for different samples and compared to a standard weight of 17.61 grams for each material. The data are presented as follows:

MAHOGANY SAWDUST MEASUREMENTS

Table 2:

Sample	Weight(g)	Weight after subtraction (g)
A	33.338	15.728
B	33.022	15.412
C	32.966	15.356
D	33.868	16.258
E	32.915	15.305
F	33.237	15.627
G	33.847	16.237

Table 2: The table above shows that the weight measurements of mahogany sawdust were recorded, ranging from 32.915 grams to 33.868 grams. After subtracting a constant weight of 17.61 grams, the adjusted weights of the sawdust samples ranged from 15.305 grams to 16.258 grams. This variation suggests that the samples are relatively uniform, with slight differences observed among them. These variations may be attributed to inherent differences in the sawdust particles or potential measurement precision issues.

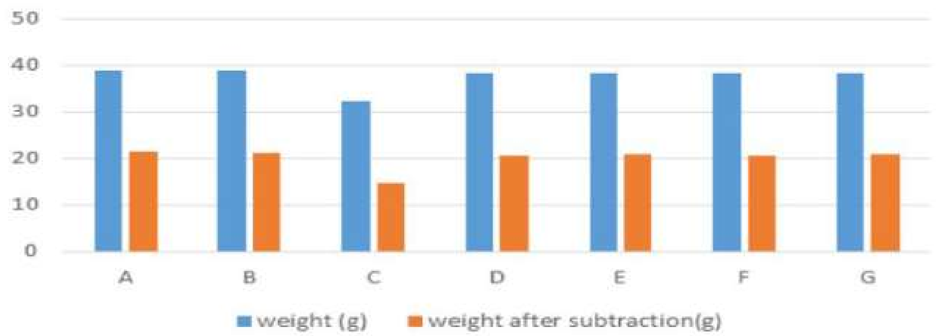

Fig 7:

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Fig 7 shows the weight vs. various samples of polymer blended with Rice Husk before and after subtraction of the weight.

The graph demonstrates the influence of varying rice husk content on the overall weight of the polymer blends. There is weight increments or decrements relative to the percentage of rice husk added. Also there is consistent increase in weight which showed a proportional addition of rice husk to the polymer, while variations could suggest changes in blend composition or processing effects.

RICE HUSK MEASUREMENTS

Table 3:

Sample	Weight(g)	Weight after subtraction (g)
A	39.047	21.437
B	38.875	21.265
C	32.275	14.665
D	38.273	20.663
E	38.404	20.794
F	38.306	20,696
G	38.414	20.804

Table 3: Shows the weight measurements for rice husk range from 32.275 grams to 39.047 grams. After subtracting the constant weight of 17.61 grams, the adjusted weights range from 14.665 grams to 21.437 grams. The broader range in adjusted weights for rice husk compared to mahogany sawdust suggests more variability in the rice husk samples. This variability might be attributed to differences in the size and density of the husk particles or inconsistencies in sample preparation.

Mahogany sawdust samples were weighed, yielding values between 32.915 grams and 33.868 grams. A constant weight of 17.61 grams was subtracted from these measurements to determine the adjusted weights of the samples. The resulting adjusted weights ranged from 15.305 grams to 16.258 grams. The adjusted weights of the mahogany sawdust samples displayed a range from 15.305 grams to 16.258 grams. This narrow range indicates a high degree of consistency among the samples, with only slight variations present.

Rice husk samples were weighed, resulting in measurements ranging from 32.275 grams to 39.047 grams. A constant weight of 17.61 grams was subtracted from these measurements to determine the adjusted weights. The adjusted weights of the rice husk samples ranged from 14.665 grams to 21.437 grams. This broader range indicates a higher degree of variability compared to other materials, such as mahogany sawdust, which displayed a narrower range in adjusted weights.

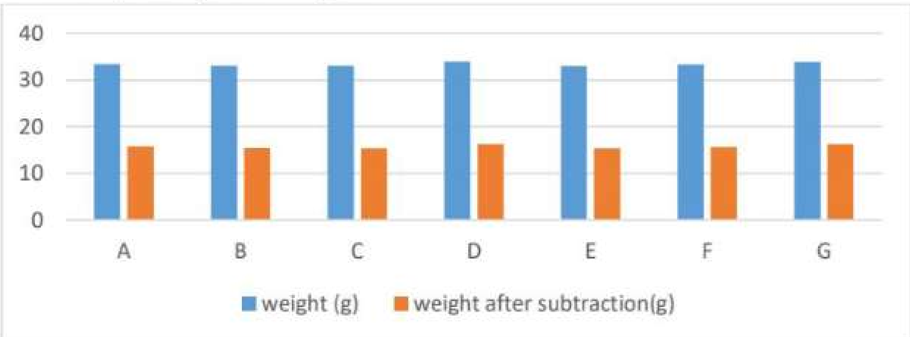

Fig 8:

Fig 8 Shows the weight vs various samples of polymer blended with Mahogany before and after subtraction of the weight. The graph shows the difference between the initial weights and the net weights reveals the amount of Mahogany in each blend in terms of weight reduction. Larger discrepancies suggest a higher Mahogany content and variations in the weight differences can indicate the efficiency of the blending process and the uniformity of Mahogany distribution within the polymer samples.

Table 4: Mechanical Properties of Polymer Blends for plastic spoon

Blend Ratio	Material	Percentage (%)	Tensile Strength (MPa)	Hardness
10:2	PP	70%	32.5	80
10:2	Polymer Crush	14%	32.5	80
10:2	Mahogany sawdust	8%	30.2	76
10:2	Rice husk	8%	30.2	76

The table 4: Shows that for the production of disposable plastic spoons, the blend with 70% PP, 14% Polymer Crush, 8% Mahogany Sawdust, and 8% Rice Husk demonstrates the best tensile strength and hardness. This blend ensures a strong and hard product suitable for disposable applications. The high content of PP and Polymer Crush maximizes both strength and hardness, which is crucial for the durability of disposable spoons.

Table 5: Mechanical Properties of Polymer Blends for plastic spoon

Blend Ratio	Material	Percentage (%)	Tensile Strength (MPa)	Hardness
10:2	PP	65%	31.0	78
10:2	Polymer Crush	13%	31.0	78
10:2	Mahogany sawdust	10%	28.5	74
10:2	Rice husk	12%	28.5	74

The table 5 shows that Polypropylene (PP) and Polymer Crush both exhibit a tensile strength of 31.0 MPa and a hardness of 78, indicating robust mechanical properties. In contrast, the blend containing Mahogany Sawdust shows a reduced tensile strength of 28.5 MPa and a hardness of 74, reflecting a decrease in structural performance

Table 6: Mechanical Properties of Polymer Blends for plastic spoon

Blend Ratio	Material	Percentage (%)	Tensile Strength (MPa)	Hardness
10:2	PP	60%	29.5	75
10:2	Polymer Crush	12%	29.5	75
10:2	Mahogany sawdust	12%	26.8	72
10:2	Rice husk	16%	26.8	72

The tensile strength of the polymer blends remains constant at 29.5 MPa when PP is combined with Polymer Crush. This consistency suggests that Polymer Crush does not significantly alter the tensile properties of the PP matrix. In contrast, the inclusion of natural fillers such as Mahogany Sawdust and Rice Husk results in a reduction in tensile strength to 26.8 MPa. This decrease can be attributed to the inherent differences in the mechanical compatibility and bonding strength between the natural fillers and the polymer matrix compared to the more homogeneous blend of PP and Polymer Crush. Similarly, hardness values decrease from 75 with PP and Polymer Crush to 72 when Mahogany Sawdust or Rice Husk is introduced. This reduction in hardness correlates with the observed drop in tensile strength.

Table 7: Mechanical Properties of Polymer Blends for plastic spoon

Blend Ratio	Material	Percentage (%)	Tensile Strength (MPa)	Hardness
10:2	PP	55%	27.0	73
10:2	Polymer Crush	11%	27.0	73
10:2	Mahogany sawdust	15%	24.5	70

10:2	Rice husk	19%	24.5	70

Table 6: shows that the blends containing PP and Polymer Crush achieve a tensile strength of 27.0 MPa and a hardness of 73. In difference, blends incorporating Mahogany Sawdust and Rice Husk, result in lower tensile strength and hardness, both measuring 24.5 MPa and 70, respectively. This Indicates that PP and Polymer Crush blend maintains higher mechanical performance while the introduction of natural fillers leads to a decrease in both tensile strength and hardness. This suggests that the addition of Mahogany Sawdust and Rice Husk affects the structural integrity and rigidity of the polymer blend, likely due to variations in bonding and compatibility with the PP matrix.

IV. CONCLUSION

This study successfully developed and evaluated composite plastic spoons utilizing virgin polypropylene (PP) blended with rice husk and mahogany sawdust, alongside PP crush, to address the increasing demand for sustainable disposable products. Chemical analyses revealed that both rice husk and mahogany sawdust had high lignin, cellulose, and hemicellulose content, contributing to the overall performance of the composites.

The processing parameters were optimized for the injection molding of these composites, with notable differences in temperature and processing times between blends containing mahogany sawdust and rice husk. Specifically, the formulation of 70% PP, 14% Polymer Crush, 8% mahogany sawdust, and 8% rice husk yielded the best results in terms of tensile strength and hardness. This blend offers a strong and durable alternative suitable for the production of disposable plastic spoons.

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