Mechanical Characterization of Waste Wood Polymer Composites: Exploring Sustainable and Eco-Friendly Alternative

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***Abstract*—In this research, the aim is to transform, waste wood powders and dry leaves into eco-friendly wood polymer composites, prioritizing the reinforcement of waste wood with MDI polymer matrix. The mechanical tests including tensile, compressive, and flexural strength assessments conducted according to ASTM standards, were used to optimize composition. By varying wood reinforcement from 30-50 wt%, the study found a significant enhancement in composite properties as particle weight percentage increased relative to the matrix material. Hence, the study proposes that cost-effective reinforcement from waste wood powders and dry leaves and MDI-based polymer composites could effectively substitute traditional wood and metal materials. This is especially relevant in sectors such as packaging industries, providing solutions that are both lightweight and high in strength**

Keywords: Waste wood powder, dry leaves, MDI matrix, wood polymer composites, Mechanical Properties

I. INTRODUCTION

Wood polymer composites (WPCs) are a promising eco-friendly alternative to traditional disposal methods for waste wood powders, reducing landfill burden and environmental impact [1]. WPCs are largely sustainable because the used wood waste keeps the trees' carbon sequestration and doesn't contribute to more deforestation. Both virgin and waste materials have been used as matrix and fillers in WPCs [2]. WPCs are renewable and sustainable materials that are composed of natural fibers as fillers and a thermoplastic polymer matrix [3].

Proper management of wood waste (WW) from the furniture industry has become a significant concern, with life-cycle assessment (LCA) being a widely used tool in understanding wood waste management systems [4]. Recent studies propose guidelines for consistent and standardized LCAs of wood waste management systems, emphasizing the need for sustainable practices in the industry [5]. Wood waste utilization is crucial for environmental and economic outcomes, driving the development of proper methods to maximize its potential [6]. Innovative approaches, such as those discussed in sustainable materials and technologies, offer novel ways to utilize wood waste, reducing the consumption of raw wood resources [7]. The detailed understanding of waste wood supply chains, as explored in Germany, provides insights into strategic decision-making for effective waste wood management. Additionally, assessments of wood waste management practices in small and medium-scale enterprises offer valuable insights into collection, recycling, and disposal methods. Moreover, literature exploring wood waste applications in various fields, such as construction and renewable energy, highlights its versatile potential [8].

Wood Polymer Composites (WPCs) are transforming the materials industry by combining natural wood fibers or particles with polymers. The result is a versatile, durable, and eco-friendly product that offers numerous benefits [9] WPCs address environmental challenges by reducing the demand for virgin polymers, utilizing wood waste and recycled materials instead. This approach promotes sustainability, curbs deforestation, and reduces the amount of wood waste in landfills, aligning with the principles of a circular economy. Another significant advantage of WPCs is their ability to effectively utilize waste wood. By incorporating wood residues, sawdust, or fibers, manufacturers create valuable products while minimizing environmental impact [10]. This not only supports the eco-friendly nature of WPCs but also contributes to resource efficiency, an essential aspect of sustainable development. Ongoing research is focused on enhancing the mechanical properties, durability, and fire resistance of WPCs. Scientists are striving to find the optimal balance between wood content and polymer matrix, as well as exploring innovative additives and treatments [11]. An exciting area of study is the integration of MDI (Methylene Diphenyl Diisocyanate) polymer matrices, a form of polyurethane, into WPCs. The understanding of how MDI matrices interact with wood fibers is driving innovation and leading to the development of high-performance WPCs. The field of Wood Polymer Composites continues to evolve, offering sustainable solutions and promoting a greener future [12,13].

II FABRICATION OF COMPOSITE

To create the wood composite material, a compression method is utilized. It begins by crushing dry leaves fallen from trees due to climate change into fine particles. Additionally, wood powder obtained from sawmills is incorporated into the mixture. The wood powder and leaf powder are combined in a 1:1 ratio. Subsequently, a mixture of MDI (methylene diphenyl diisocyanate) and polyol is prepared in a 1:2 ratio, forming polymeric MDI. The blend of wood powder and leaf powder is thoroughly mixed, and the resulting mixture is placed in a molding cavity with metal sheets to prepare the mold. Polymeric MDI is then poured onto the mixture and compacted.

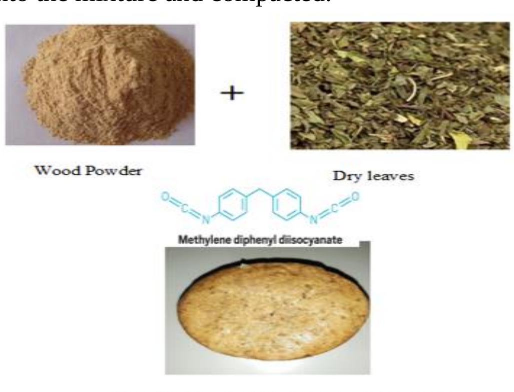

Figure1: Fabrication of waste wood MDI composites.

The molding cavity is sealed and allowed to settle. Prior to settling for 24 hours, the mixture is lightly rammed to ensure proper air circulation. This process leads to the production of genuine wood composite material is shown in fig.1. In this process, three different compositions of wood powder epoxy resins are employed: 30% dry leaves and wood powder + 70% MDI, 40% dry leaves and wood powder + 60% MDI, and 50% dry leaves and wood powder + 50% MDI. The present method offers an eco-friendly alternative to traditional wood materials, helping to reduce waste and promote sustainability.

III TESTING METHODS

3.1 Tensile testing

Tensile tests for wood polymer composites were conducted to measure the strength in accordance with ASTM D- 638 standards. Test specimens for the evaluation of tensile properties were molded in a mold. The dimensions are as follows; W=13.0 ± 0.03 mm, L=57.0±0.08mm, G=50.0±0.02 mm, T=3.0±0.08 mm, where W= width of narrow section l= length of narrow section, G= gauge length and T= thickness of narrow section. The tests were conducted using universal testing machine at a speed of 10 mm/min. Each test was repeated five times.

3.2 Compression testing

Compression test for wood polymer composites were conducted to measure the strength in accordance with ASTM D-695 standards. Test specimens for the evaluation of compressive properties in a mold. The dimensions are as follows; D=12.7± 0.03 mm, L=25.4± 0.02 mm bar with 191*10*10 mm. where D= Diameter of the specimen, L=Length of the specimen. The tests were conducted using Universal testing machine at a speed of 1.30 mm/min. Each test was repeated five times.

3.3 Flexural testing

A three-point bending arrangement has been employed to carry out the flexural test. In this system, a center loading is utilized on a simply supported beam. Test specimens were according to the ASTM standards (ASTM D790M). It is a rectangular cross-section. bar with 191*10*10 mm.

IV RESULTS AND DISCUSSION

4.1 Tensile properties

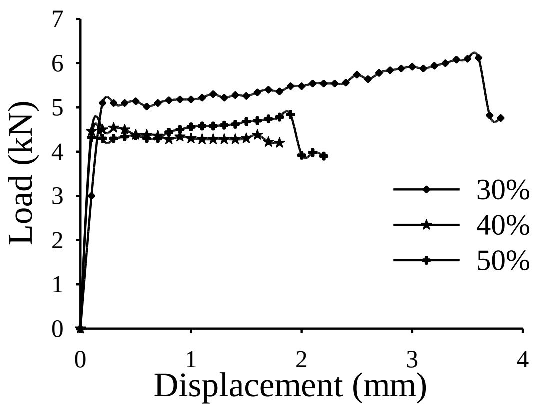

Fig.2 Tensile curves of waste wood powder and dry leaves reinforced MDI composites

The graph illustrates the influence of the MDI (Methylene Diphenyl Diisocyanate) polymer matrix on the tensile behavior of waste wood powder and dry leaves-MDI composites shown in fig. 2. Increasing MDI content enhances stiffness, yield stress, tensile modulus, and strength, while reducing material ductility. In 30 wt% waste wood powder and dry leaves-reinforced composites, poor waste wood powder and dry leaves-MDI bonding create micro-voids, limiting stress transfer. Despite this, the 30 wt% waste wood powder and dry leaves reinforcement withstands a peak load of 6.06.

Fig. 3. Tensile strength of waste wood powder and dry leaves reinforced MDI composites

Fig. 3 illustrates the average tensile strength of waste wood powder and dry leaves MDI polymer composites. The study found that composites containing 30 wt% of waste wood powder and dry leaves reinforcement achieved the highest tensile strength at 53 MPa. Composites with 50 wt% of waste wood powder and dry leaves composition exhibited the lowest tensile strength at 42 MPa. The composite with 40 wt% of waste wood powder and dry leaves reinforcements displayed a tensile strength of 48 MPa. Researchers attributed the decrease in tensile strength and stiffness to the weak bonding between the waste wood powder, dry leaves, and the MDI polymer matrix, especially as the waste wood powder and dry leaves reinforcement content increased.

4.2 Compressive properties

In wood polymer composites, compression yield stress significantly differs (compression, 53 MPa under tension) at 30% waste wood powder and dry leaves reinforcement. This stress increases with higher waste wood powder and dry leaves content, enhancing yield stress and ductility is shown in fig.3.. Buckling, attributed to cellulose-lignin interaction, characterizes the compressive failure mode. As waste wood powder and dry leaves content decreases, compressive strength rises; the composite with 30% waste wood powder and dry leaves achieves 68 MPa, whereas the 50% content composite records 57 MPa. The behavior is due to the presence of Methylene Diphenyl [illegible]

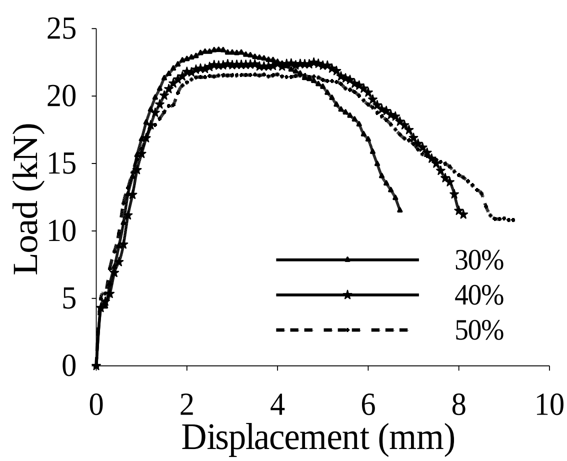

Fig.4 Compressive curves of waste wood powder and dry leaves reinforced MDI composites

Fig.4 Compressive curves of waste wood powder and dry leaves reinforced MDI composites and Fig. 4 Compressive strength of waste wood powder and dry leaves reinforced MDI composites with increasing levels of wood reinforcement

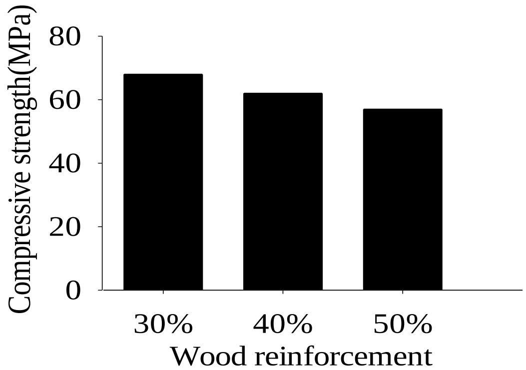

Fig. 5 Compressive strength of waste wood powder and dry leaves reinforced MDI composites

Methylene diphenyl diisocyanate (MDI) composites exhibit higher load-bearing capacities under compression loads than tensile loads. The composite with 30% wood reinforcement reaches a peak load of 23.48 kN, while the 50% wood reinforcement composite shows a minimum peak load of 21.24 kN. Additionally, the 50% wood reinforcement composite experiences higher deflection at 8.80 mm, compared to 6.70 mm for the 30% wood reinforcement composite.

4.3 Flexural properties

The Fig.6 Flexural curves of waste wood powder and dry leaves reinforced MDI composites. Results clearly demonstrate that the incorporation of waste wood powder and dry leaves into MDI (methylene diphenyl diisocyanate) matrix composites has substantially enhanced their flexural properties. Regarding load-bearing capacity

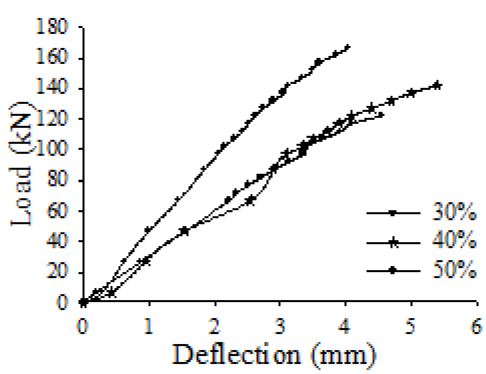

Fig.6 Flexural curves of waste wood powder and dry leaves reinforced MDI composites

the 40 wt% waste wood powder and dry leaves-reinforced MDI matrix composite stood out with a remarkable value of 1481 MPa, closely followed by the 50 wt% composite, which demonstrated an impressive load-bearing capacity of 2140 MPa. Notably, the 50 wt% composite could withstand a maximum load of 167 kN, while the 30 wt% composite had a minimum load-bearing capacity of 122 kN. Furthermore, the 40 wt% composite displayed a maximum deflection of 5.8 mm. As the percentage of waste wood powder and dry leaves increased, there was a corresponding rise in flexural strength. Specifically, the 50 wt% waste wood powder and dry leaves-reinforced MDI matrix composite showcased the highest flexural strength at 28 MPa, whereas the 30 wt% counterpart exhibited a strength of 21.11 MPa (Fig.7). In summary, the data underscores a significant trend: augmenting the proportion of waste wood powder and dry leaves in MDI matrix composites leads to substantial enhancements in both flexural strength and stiffness. These improved mechanical properties hold promising potential for applications where superior strength and stiffness are essential requirements.

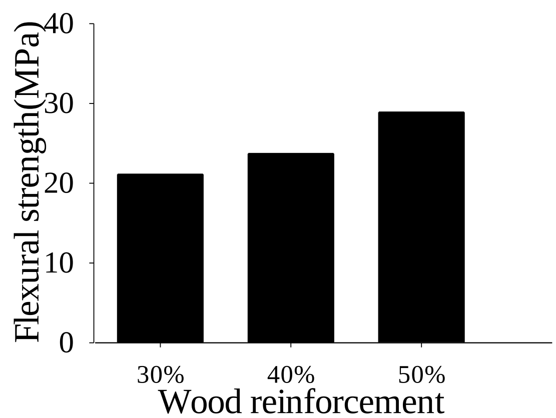

Fig. 7 Flexural strength of waste wood powder and dry leaves reinforced MDI composites

V CONCLUSION

In summary, the research showcases the transformation of waste wood powder and dry leaves into eco-friendly wood polymer composites, reinforcing them with MDI polymer matrix. Rigorous mechanical tests revealed enhanced flexural strength and stiffness with increasing waste wood content, reaching 28 MPa at 50 wt%. Compressive yield stress peaked at 68 MPa with 30% waste wood content, showcasing increased strength and ductility. The presence of MDI acted as a strengthening agent in compression, positively impacting the composite's properties. Tensile tests indicated optimal performance at 30 wt%, achieving a tensile strength of 53 MPa, while weak bonding at higher content led to reduced strength. These findings highlight the composites' potential in sectors like packaging, offering lightweight, high-strength solutions. The study emphasizes the feasibility of waste wood and MDI composites as sustainable alternatives to traditional materials.

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