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Effects of Talc on the Mechanical Properties of Composites Made from Recycled Plastics and Wood Sawdust

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Abstract: This study explores the development of WPCs (wood-plastic composites) using waste LDPE (low-density polyethylene) and ebony wood sawdust to propose a sustainable solution to waste accumulation. The effect of sawdust particle size and the addition of talc as a coupling agent on the mechanical properties of the composites was examined in detail. The results show that increasing the particle size of the sawdust enhances the MOE (modulus of elasticity) and MOR (modulus of rupture) of the composites. The flexural MOE increases by 195% from the PM (plastic matrix) to composites with the coarsest sawdust, the compressive MOE by 72%, and the tensile MOE by 205%. Similarly, the flexural MOR increases by 28%, the tensile MOR by 42%, but the compressive MOR decreases slightly by 7%. The introduction of talc consistently increased the MOE, with an average improvement of 14% in flexion and 10% in tension for the various composite formulations, although it led to a decrease in compression. The MOR was also enhanced by the addition of talc, with an average increase of 16% across all tested loadings. These improvements suggest that talc can effectively serve as a coupling agent, optimizing the mechanical properties of WPCs for better use of recycled materials.

Key words: WPC, talc, wood sawdust, plastic recycling, composite sustainability.

1. Introduction

The global environment continues to suffer the detrimental effects of plastic waste accumulation. Each year, approximately 300 million tons of plastics are produced worldwide, over half of which originates from the packaging sector. According to the *What a Waste 2.0* report by the World Bank, less than 20% of these plastics are recycled, with the remainder being incinerated or discarded in landfills, contributing to enduring environmental pollution [1]. Additionally, the lifespan of plastic bags, for example, is estimated at around 400 years, underscoring the importance of recycling them, especially in the construction sector to aid environmental protection. In the forestry sector, deforestation continues to pose a major issue, with about 80% of deforestation resulting from agricultural expansion and 20% caused by infrastructure development, mining activities, and urbanization, as reported by the FAO (Food and Agriculture Organization) [2]. In Benin, wood residues from sawmills and other wood industries are often burned or discarded, increasing greenhouse gas emissions and exacerbating pollution.

In this context, our study aims to develop an innovative building material by combining recycled plastics and wood residues, contributing to more sustainable development. The WPCs (wood-plastic composites) thus produced can offer a lightweight, cost-effective, and durable alternative for various applications, including in the construction and automotive industries. Previous studies have already demonstrated the viability of such

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composites for various uses [3-8]. The variability of the natural and recycled components significantly influences their performance, particularly in terms of bonding between the matrix and the reinforcement. Our study investigates the use of talc as a coupling agent to optimize these interactions. The addition of talc aims to enhance the adhesion within the composites, which can potentially increase their mechanical strength and prolong their lifespan, making the WPCs more suitable for various structural and environmental applications.

2. Materials and Methods

2.1 Materials

The components of the composite material studied include waste from LDPE (low-density polyethylene) packaging, ebony wood sawdust, and the coupling agent talc.

2.1.1 LDPE

The choice of this type of plastic is explained by the fact that plastic packaging, generally single-use LDPE, constitutes the majority in terms of volume in the wild dumps of cities in Benin. These plastic wastes, collected from the environment, are cleaned and cut for the preparation of the composites (Fig. 1).

2.1.2 Ebony Wood Sawdust

The sawdust is obtained from the sawing and planning operations of ebony wood, known for its hardness and high density, traditionally used in carpentry. It is processed into wood flour with a particle size of less than 1.25 mm (Fig. 2). This flour is then dried at 105 °C and classified into three granular fractions (0.08 mm, 0.16 mm, and 0.315 mm) according to the NF EN 933-1 standard [9].

2.1.3 Talc

Used as a coupling agent, talc is a hydrated magnesium silicate added to improve adhesion between the wood fibers and the Plastic Matrix (Fig.3). Talc is sourced locally due to its low cost and availability. The favorable mechanical properties of talc and its ability to enhance bonding within the composites are well-documented in the scientific literature [10].

Fig. 1 Cut LDPE packaging.

Fig. 2 Ebony wood sawdust.

Fig. 3 Coupling agent (talc).

2.2 Formulation and Manufacturing of WPC

In the industry, WPCs are typically manufactured by injection, extrusion, or compression molding. However, for this study, the fabrication of the WPC was carried out using a craft-based method. This process began with the recycling of plastic waste and wood sawdust. The plastic, heated to a controlled temperature of 170 °C to 190 °C, is transformed into a paste (Fig. 4). This paste is then mixed with wood sawdust, previously dried for 24 h at a temperature of 105 ± 2 °C. The resulting mixture is poured into molds to form the samples (Fig. 5).

Fig. 4 Melted LDPE packaging.

Fig. 5 Wood sawdust-plastic mix during molding.

The chosen formulation for the composites is as follows: 60% plastic, 30% wood sawdust, and 10% talc.

Seven different formulations were prepared as shown in Table 1.

The samples are then cut for testing (Fig. 6). Mechanical tests on the composites include tensile testing in accordance with ASTM D638 [11], compression testing according to ASTM D695 [12], and three-point bending tests to assess the mechanical strength of the different mixes.

3. Results and Discussions

3.1 Effect of Reinforcement and Talc on the Density of WPC

Fig. 7 illustrates the density variations for different WPC formulations. It is noted that the density of the pure PM is generally higher than that of composites enriched with wood sawdust. This observation can be explained by the fact that wood sawdust, being lighter than the PM, reduces the overall density of the composite when it partially replaces the matrix.

Moreover, the particle size variations of the wood sawdust seem to have a negligible impact on the density of the composites. This uniformity indicates that the physical characteristics of the different granular classes used are sufficiently similar not to significantly affect the final density.

Table 1 Formulations and nomenclature of composites.

Formulation	Nomenclature
PM	PM
PMT	PM with talc
WPC-1	WPC at 0.08 mm sieve
WPC-1T	WPC-1 with talc
WPC-2	WPC at 0.16 mm sieve
WPC-2T	WPC-2 with talc
WPC-3	WPC at 0.315 mm sieve
WPC-3T	WPC-3 with talc

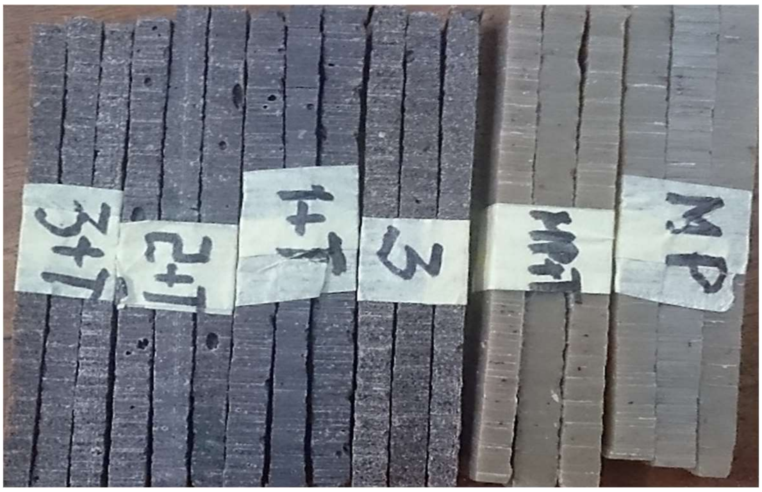

Fig. 6 Flexural test specimens.

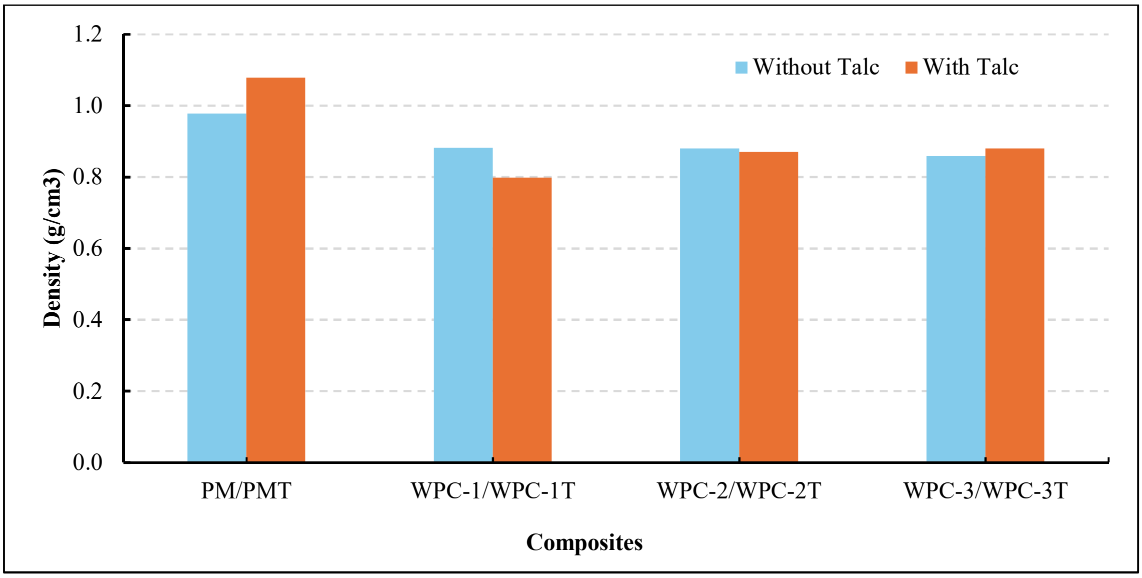

Fig. 7 Density variations of WPC with and without talc addition.

The addition of talc in WPCs modifies their density, as observed in the results. The density of the PM increases when talc is incorporated, which is expected since talc itself has a higher density than the other components of the composite. However, this increase is not as pronounced in the final composites. This could indicate that, although talc increases the intrinsic density of the PM, its effect on the overall density of the composite is moderated. It is possible that talc, by improving the uniformity of the distribution of wood particles in the matrix, does not significantly change the overall density of the composite as much as expected.

Finally, it is important to emphasize that the measured density of the WPCs is lower than the theoretical values anticipated during formulation. This discrepancy may be attributed to the volatilization of some volatile components of the glue during the curing process, resulting in a mass loss not initially considered.

3.2 Effect of Reinforcement on the MOE (Modulus of Elasticity) of WPC

Fig. 8 illustrates the variations in the flexural, compressive, and tensile MOE for different WPC formulations. The analysis reveals that the MOE increases with the progressive addition of wood sawdust of increasing particle size to the PM. This observation is supported by previous research, such as that conducted by Julson et al. [13], which also found that the MOE is a function of the morphology of the reinforcement.

In flexural tests, the flexural MOE significantly increases from the PM (without sawdust) to WPC-3 (sawdust of the highest granularity), from 312.37 MPa to 912.04 MPa. This increase demonstrates the effectiveness of wood sawdust reinforcement in enhancing the material's resistance to flexion.

In compression, the results follow a similar trend, although the increase is less pronounced, from 243.73 MPa for PM to 420 MPa for WPC-3. This indicates that although the reinforcement improves the material's compressibility, the effect is less marked than for flexion.

In tension, the MOE is also enhanced by the addition of sawdust, with a notable increase from 288.15 MPa for PM to 879.56 MPa for WPC-3. The substantial increase in MOE in tension demonstrates that the reinforcement effectively contributes to the composite's resistance to tensile forces.

These results highlight the importance of choosing the particle size of wood sawdust as a key factor in formulating composites to optimize their mechanical properties. The reinforcement by wood sawdust not

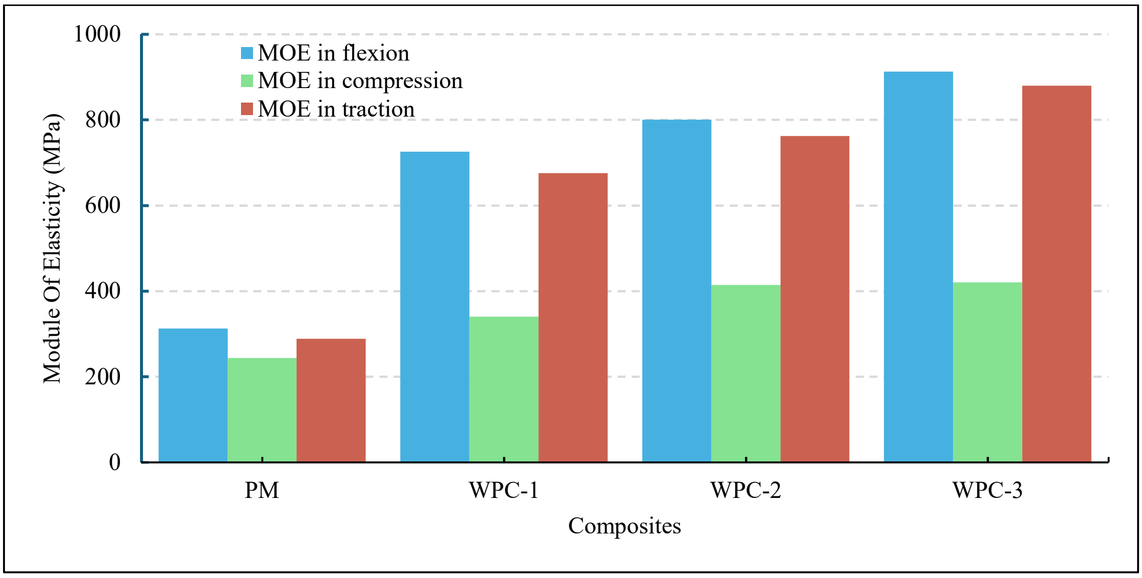

Fig. 8 MOE variations for different WPC formulations.

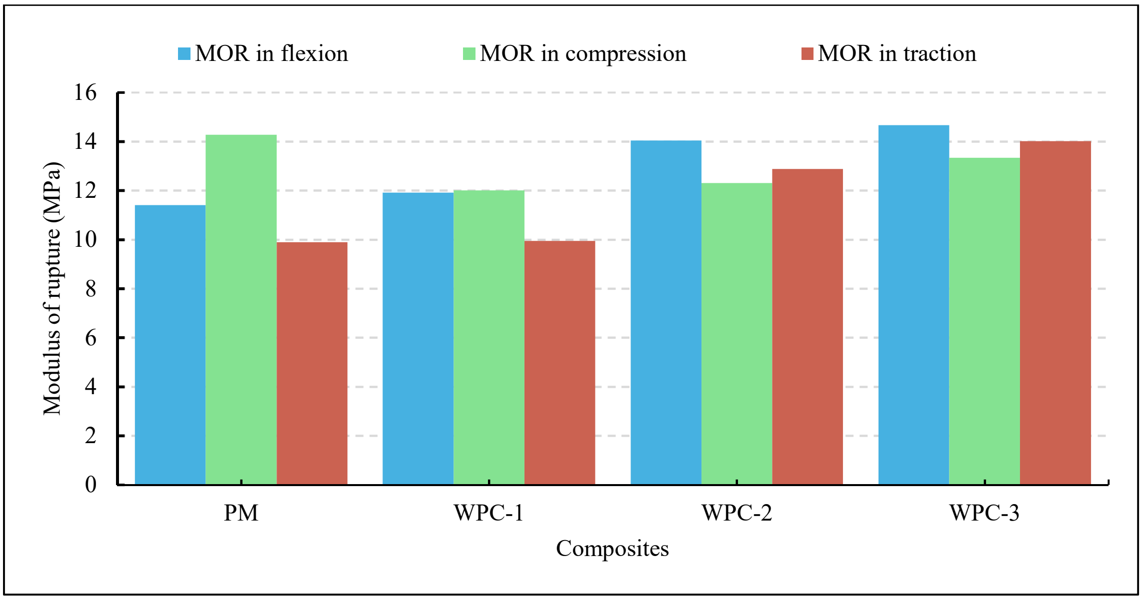

Fig. 9 MOR (modulus of rupture) variations for different WPC formulations.

only improves the material's resilience but also its ability to withstand loads without significant deformation.

3.3 Effect of Reinforcement on the MOR

Fig. 9 illustrates the impact of wood sawdust reinforcement on the flexural, compressive, and tensile MOR of WPC. This visualization highlights the changes in the composites' ability to resist rupture under various mechanical stresses depending on the particle size of the sawdust.

3.3.1 Flexion and Tension

The flexural MOR and tensile MOR of WPC are higher than those of the PM. This is mainly due to the role of wood sawdust reinforcement, which enhances the structural strength of the composites. The wood fibers serve as structural bridges within the matrix, enhancing stress distribution and absorption, which increases the resistance to rupture. Additionally, the larger particle size of the sawdust in WPC-2 and WPC-3 allows for better interfacing between the fibers and the matrix, leading to improved transmission and distribution of loads when forces are applied, thus explaining the increase in MOR with particle size.

3.3.2 Compression

Although the MOR in compression slightly increases from WPC-1 to WPC-3, it remains lower than that of the pure matrix. This phenomenon can be explained by the nature of the load in compression, which tends to compress and eventually compact the material. The wood fibers may introduce discontinuities in the matrix, thus reducing its ability to uniformly resist compressive forces. While the presence of fibers may be advantageous under tension by providing paths of resistance, in compression, these same fibers may create weak points or stress concentrations that were not present in the pure matrix.

3.4 Effect of Talc on the MOE

Fig. 10 illustrates the variations in the flexural MOE for WPCs with and without the addition of talc.

The introduction of talc in the composite formulations consistently resulted in an increase in MOE. For each series of composites (WPC-1, WPC-2, WPC-3), the formulations containing talc (WPC-1T, WPC-2T, WPC-3T) exhibit higher MOE values than their counterparts without talc. This indicates that talc significantly contributes to the stiffness of the material, strengthening the matrix and improving its resistance to deformation under flexural loads. Talc, used as a coupling agent, appears to act by improving the adhesion between the wood fibers and the PM. This enhancement of adhesion could be due to the chemical nature of talc, which promotes better interaction at the fiber-matrix interfaces.

Fig. 11 shows that, similarly to flexion, the introduction of talc in the formulations of WPCs increases the MOE in tension for each series of composites. This observation reinforces the idea that talc, by improving the adhesion between the wood fibers and the PM, contributes not only to better resistance to deformation under flexural loads but also under tensile loads.

As a coupling agent, talc can enhance the adhesion between wood fibers and the PM, which is theoretically beneficial for strengthening the material. However, as shown in Fig. 12, this improvement does not necessarily translate into an increase in MOE in all formulations, particularly in compression where forces act differently compared to tension or flexion. Talc might introduce or accentuate discontinuities within the matrix, especially at higher concentrations or with certain sawdust granularities. These discontinuities can act as weak points under compressive load, reducing the material’s ability to support loads without deforming.

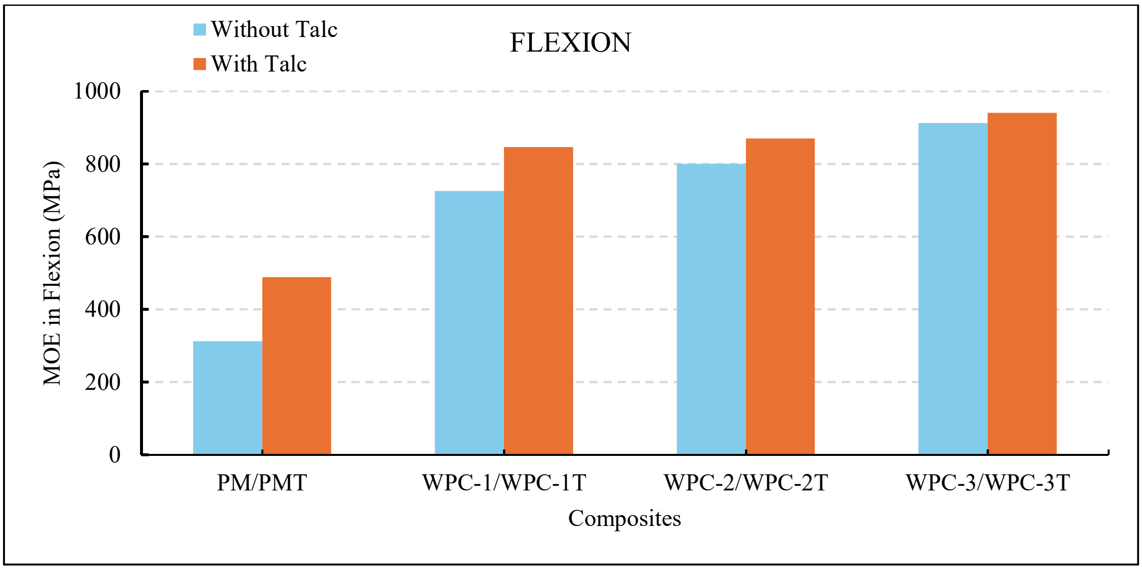

Fig. 10 Influence of talc on the flexural MOE in WPC.

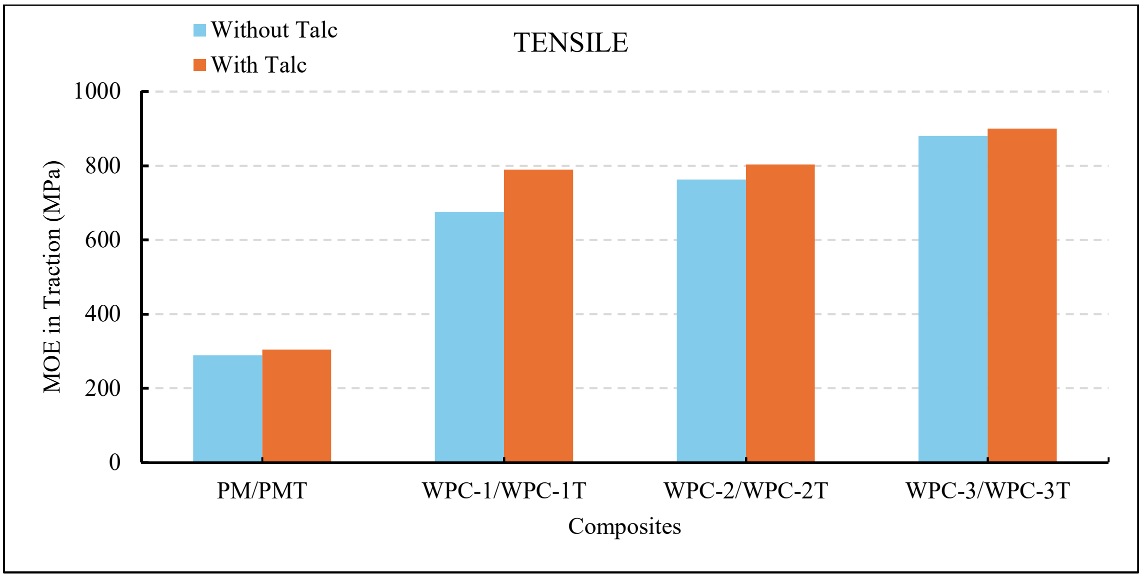

Fig. 11 Influence of talc on the tensile MOE in WPC.

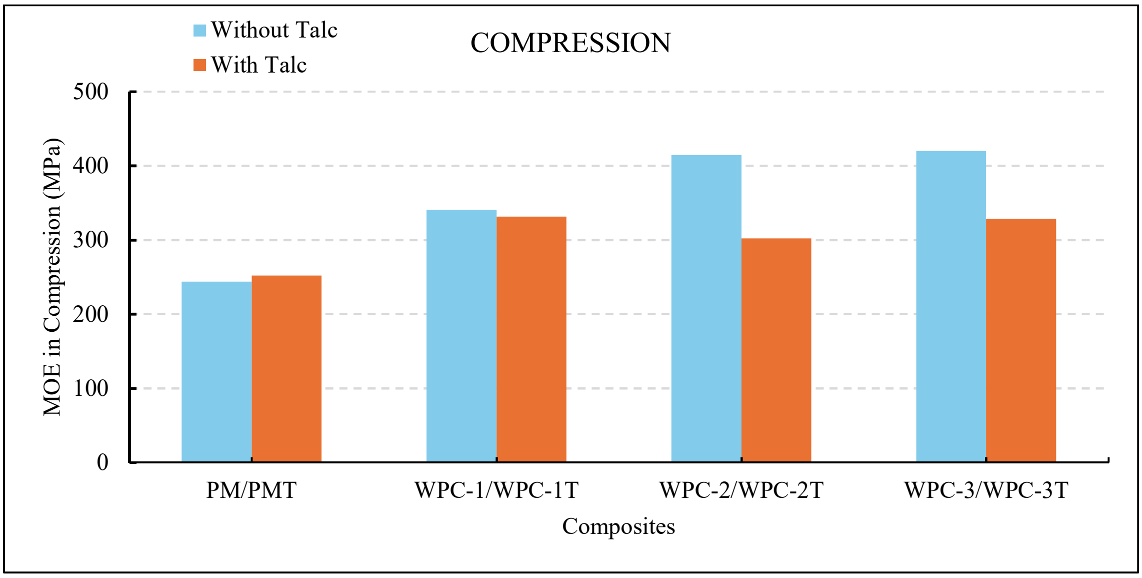

Fig. 12 Influence of talc on the compressive MOE in WPC.

3.5 Effect of Talc on the MOR

Figs. 13-15 show the impact of the addition of talc on the MOR for the PM and WPCs under different mechanical loads. For the PM, a decrease in MOR is observed across all forms of loads when talc is added, which could reflect changes in the composition or internal structure of the matrix when mixed with talc. For the composites, the addition of talc results in an increase in MOR, indicating that talc plays a beneficial role in enhancing the bonding between the wood fibers and the PM. This improvement is due to better integration of fibers into the matrix, thereby facilitating a more effective distribution of loads and strengthening the overall material's resistance to rupture under various types of loads. The results observed here are in line with similar studies like that of Gwon et al. [14], who also reported a 29% improvement in tensile strength of PP/wood fiber composites with the addition of talc.

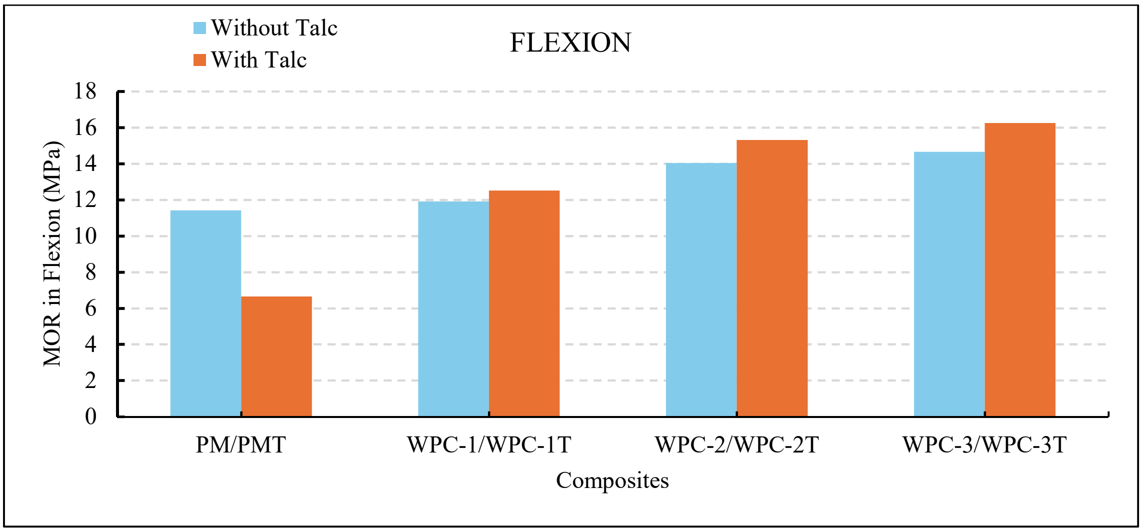

Fig. 13 Influence of talc on the flexural MOR in WPC.

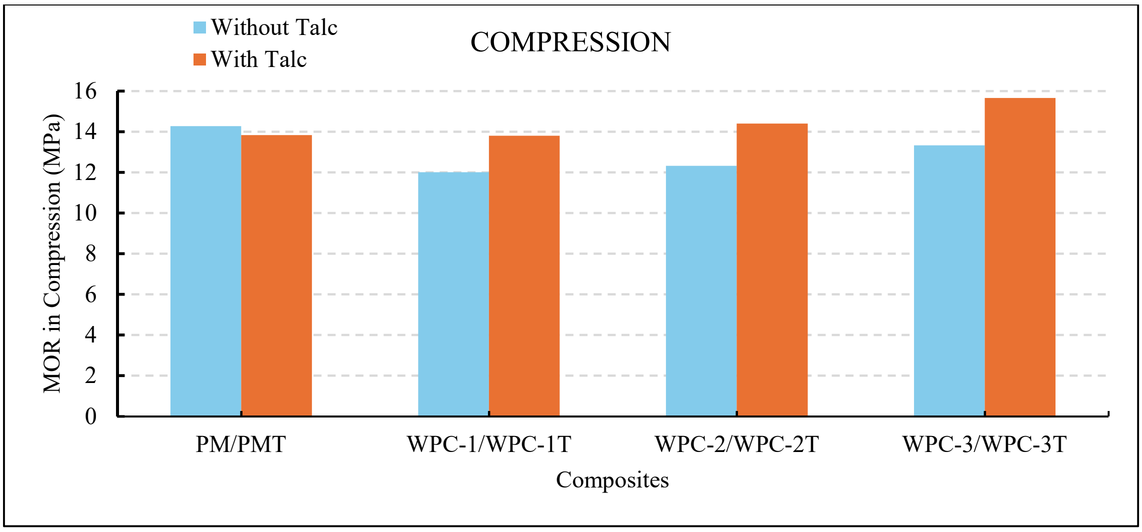

Fig. 14 Influence of talc on the compressive MOR in WPC.

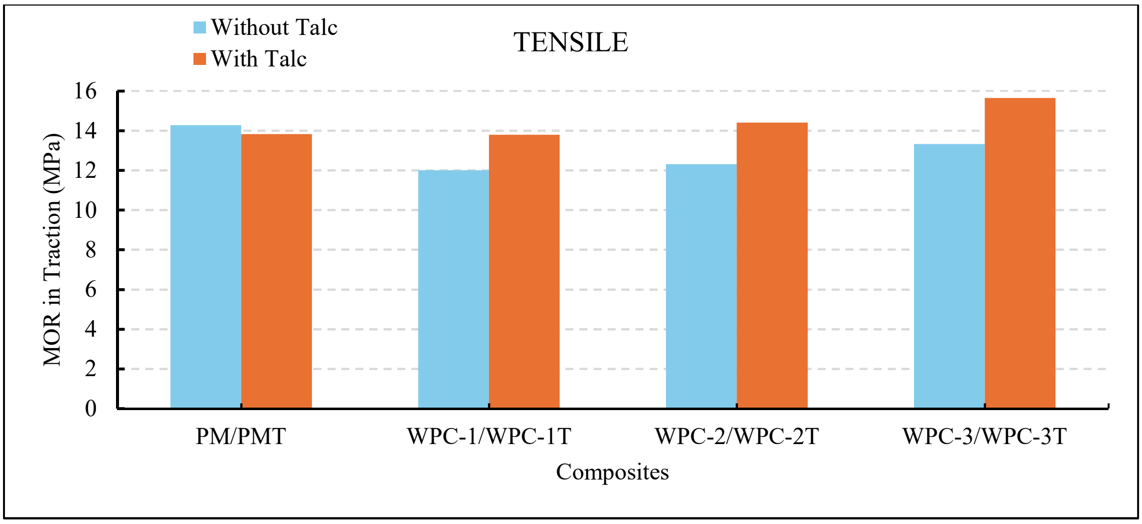

Fig. 15 Influence of talc on the tensile MOR in WPC.

4. Conclusion

This study has explored the development of WPC using waste LDPE and ebony wood sawdust, with a particular focus on the effect of adding talc as a coupling agent. The goal was to create a sustainable building material that contributes to waste management while offering enhanced mechanical performances.

The results confirmed that the addition of talc improves the mechanical properties of the WPCs, particularly the MOR under various loads. The positive effect of talc, which acts by enhancing the adhesion between the wood fibers and the PM, is particularly notable in resistance to flexion, tension, and even compression. It is also important to note that while talc intrinsically increases the density of the PM, this effect is not as pronounced in the final composites, indicating that despite a slight increase in density, the overall impact of talc on the density of the composites is moderated. This observation highlights talc's ability to improve the uniformity of the distribution of wood particles in the matrix without significantly weighing down the material.

Thus, the composites studied offer an interesting alternative for the use of recycled materials in structural applications, supporting the goal of reducing the environmental impact of industrial waste. This study contributes to the existing literature by demonstrating the effectiveness of talc as a coupling agent in wood-plastic composites.

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Author Contributions

Conceptualization and study design: E. Olodo, V. Doko, E. Chabi;

Data collection: M. Salifou, E. Chabi;

Data analysis and interpretation: M. Salifou, V. Doko, E. Chabi, E. Olodo;

Manuscript drafting: M. Salifou, E. Chabi;

Critical manuscript review for intellectual content: M. Salifou, V. Doko, E. Chabi, E. Olodo;

Final manuscript approval: M. Salifou, V. Doko, E. Chabi, E. Olodo.

Conflicts of Interest

The authors declare that there are no conflicts of interest that could inappropriately influence, or be perceived to influence, the work reported in this manuscript.

Data and Code Availability

No additional datasets or code repositories are associated with this research.

Ethical Approval

Ethical approval was not required for this research as it did not involve human or animal subjects.

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