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INFLUENCE OF MAPE COUPLING AGENT TO ENHANCE THE PROPERTIES OF MORUS ALBA FIBER REINFORCED HDPE WOOD POLYMER COMPOSITES

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Abstract :

In recent trends wood polymer composites (WPCs) have gained significant attention due to their sustainability and balanced mechanical performance, where as poor interfacial adhesion, bonding between hydrophilic wood fibers and hydrophobic polymer matrices often limits their properties strength. The coupling agent maleic anhydride grafted polyethylene (MAPE) is used as a compatibilizer to improve interfacial bonding in WPCs. This study examines the effect of MAPE on the physical, mechanical properties of WPCs. Even less percent of MAPE incorporation significantly enhances tensile strength, flexural strength, and impact resistance due to improved stress transfer between the wood fibers and polymer matrix. Scanning electron microscopy reveals reduced fiber pullout and better fiber dispersion in MAPE modified composites. MAPE reduces water absorption by enhancing interfacial compatibility. Hence, the use of MAPE as a coupling agent effectively enhances the properties and durability of WPCs, making them more suitable for structural and various practical applications.

Keywords: MAPE coupling agent, Interfacial bonding, Tensile strength, Flexural strength.

1. Introduction

Wood Polymer Composites (WPCs) are composite materials produced by combining natural wood fibers such as Morus alba with thermoplastic polymers High Density Polyethylene (HDPE). These materials have gained significant attention due to their ecofriendly nature, cost effectiveness and good mechanical performance. WPCs are widely used in various applications indoor and outdoor including decking, furniture, automotive interior panels and construction materials. The incorporation of natural fibers into thermoplastics improves sustainability and utilization of agriculture byproducts [1][2].

One of the major challenges in the development of WPCs is the poor interfacial bonding between the hydrophilic wood fibers and the hydrophobic polymer matrix. Due to this incompatibility, effective stress transfer between the fiber and matrix becomes limited, which negatively affects the mechanical properties, impact resistance and durability of the composite material, and also weak interfacial adhesion can lead to higher water absorption and dimensional instability in WPCs restricting their long term performance in structural applications.

This limitation can change positively by using coupling agents (CA) such as Maleic Anhydride Grafted Polyethylene (MAPE) is used to enhance the compatibility between the Morus alba (silk mulberry) wood fibers and polymer matrix. The coupling agent MAPE acts as a chemical bridge between the hydrophilic fibers and hydrophobic polymer, thereby improving interfacial bonding with adhesion. Even a small quantity only 5% MAPE can significantly enhance fiber matrix interaction promotes efficient stress transfer and reduce the formation of voids within the composite. As a result, the use of MAPE improves the mechanical properties of WPC including tensile and flexural strength, while also reducing water absorption and enhancing dimensional stability [3].

This study aims to investigate the effect of MAPE as a coupling agent in WPCs prepared from Morus alba wood fibers and polymer [4]. The research focuses on understanding how the addition of 5% MAPE, which leads to better stress transfer between the component, fiber matrix interfacial bonding with adhesion and enhances the overall mechanical performance and durability of the composite material [5].

The tensile strength and flexural strength of the composite are increased considerably, this coupling agent reducing poor bonding formation and fibers pull out within the composite structure. thereby improving dimensional stability and impact resistance with this improving the compatibility between hydrophilic wood fibers and the hydrophobic polymer matrix [17].

2. Experimental

2.1 Material preparation

The wood polymer composites (WPCs) were prepared using high density polyethylene (HDPE) of grade HD50MA180 with a melt flow index (MFI) of 13.83 g/10 min at 190 °C. Morus alba (silk mulberry) natural reinforcement wood fibers, maleic anhydride polyethylene (MAPE) (Orevac 18507) as coupling agent in selected formulations, paraffin wax, and coloring pellets were also used to provide a uniform appearance to the composites [10].

Eight WPC formulations were prepared with varying wood fiber content from 200 to 500 g. The first four batch (SMHD1–SMHD4) were produced without the coupling agent. similarly, the remaining four batch (SMHCA1–SMHCA4) contained 50 g of MAPE. In all formulations, the polymer content was adjusted accordingly, and 20 g of paraffin wax was added to maintained at 1 kg. The detailed composition of the prepared WPC samples as shown in Table 1.

Table 1. Formulation for Preparation of WPC

WPC samples	Wood fiber(g)	Polymer(g)	Coupling agent(g)	Wax(g)
SMHD1	200	780	-	20
SMHD2	300	680	-	20
SMHD3	400	580	-	20
SMHD4	500	480	-	20
SMHCA1	200	730	50	20
SMHCA2	300	630	50	20
SMHCA3	400	530	50	20
SMHCA4	500	430	50	20

2.2 FTIR Analysis

The Fourier Transform Infrared (FTIR) spectra of wood, HDPE with coupling agent 5% MAPE, and the composite batches SMHD1, SMHD4, SMHCA1, and SMHCA4 were recorded using PerkinElmer FTIR/FIR Spectrometer Frontier to identify the functional groups and evaluate the interaction between the wood fibers the HDPE and CA matrix.

The wood spectrum exhibits absorption band around 3200-3500 cm^{-1}, which indicate to the O-H stretching vibration of hydroxyl groups present in cellulose, hemicellulose, and lignin. The small peak near 2900 cm^{-1} is attributed to C-H stretching vibrations of aliphatic groups in lignocellulosic structures. Peak observed around 1700-1730 cm^{-1} is corresponds to C=O stretching, which is associated with carbonyl groups in hemicellulose and lignin. a strong band in the region of 1000-1100 cm^{-1} represents C-O vibrations, characteristic of cellulose and other polysaccharide components of wood [11-12]. Whereas HDPE matrix spectrum shows strong characteristic peaks near 2915 cm^{-1} and 2848 cm^{-1}, which correspond to the asymmetric and symmetric C-H stretching vibrations of methylene ($-CH_2$) groups in polyethylene. Another peak around 1470 cm^{-1} is attributed to CH_2 bending vibrations, while the band near 720 cm^{-1} corresponds to CH_2 rocking vibrations, confirming the typical structure of high density polyethylene.

The composite samples SMHD1 and SMHD4 display strong absorption peaks around 2900 cm^{-1}, indicating C-H stretching vibrations [13]. which confirm the presence of the HDPE matrix in the composites. Peaks near 1470 cm^{-1} and 720 cm^{-1} are also observed, corresponding to CH_2 bending and rocking vibrations, which are characteristic of polyethylene. For the SMHCA1 and SMHCA4 samples, similar HDPE characteristic peaks are observed, indicating that the polymer matrix remains structurally intact after modification. However small changes in peak intensity and minor shifts in the C-O and O-H regions suggest improved interaction between wood fibers and the polymer matrix due to the compatibilization CA (Fig (1)).

FTIR analysis confirm the presence of both lignocellulosic functional groups from wood and characteristic polyethylene peaks in all composite samples. The absence of new significant peaks indicates that the interaction between wood and HDPE is primarily physical blending with possible interfacial interactions, not new chemical bonds.

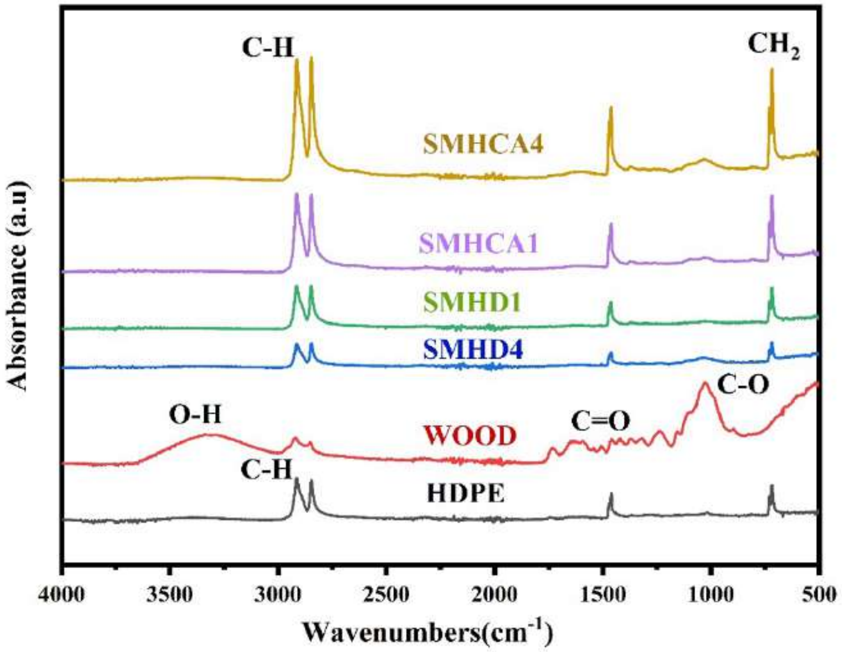

Fig (1). FTIR Analysis of WPC samples

2.3 Mechanical properties

The WPC testing specimens are subjected to mechanical test. Tensile test Flexural test was carried out by using universal testing machine (UTM)(Fig(3)). American Society for Testing and Material ASTM which is for standard of testing the material as per ASTM D638(165x13x3.35 mm dumbbell shape) & ASTM D790(127 mm × 12.7 mm × 6.6 mm rectangular bar) the tensile and flexural test samples are made as per standard (Fig(2), Fig(4)). all SMPP 1 to 4 batch without CA as such with 5% MAPP coupling agent SMPCA 1 to 4 [1-2].

Fig (2)
WPC Testing specimen images

Fig (3)
UTM machine Model AG-I/50N-10kN

Fig (4)
After testing

2.3.1 Tensile strength

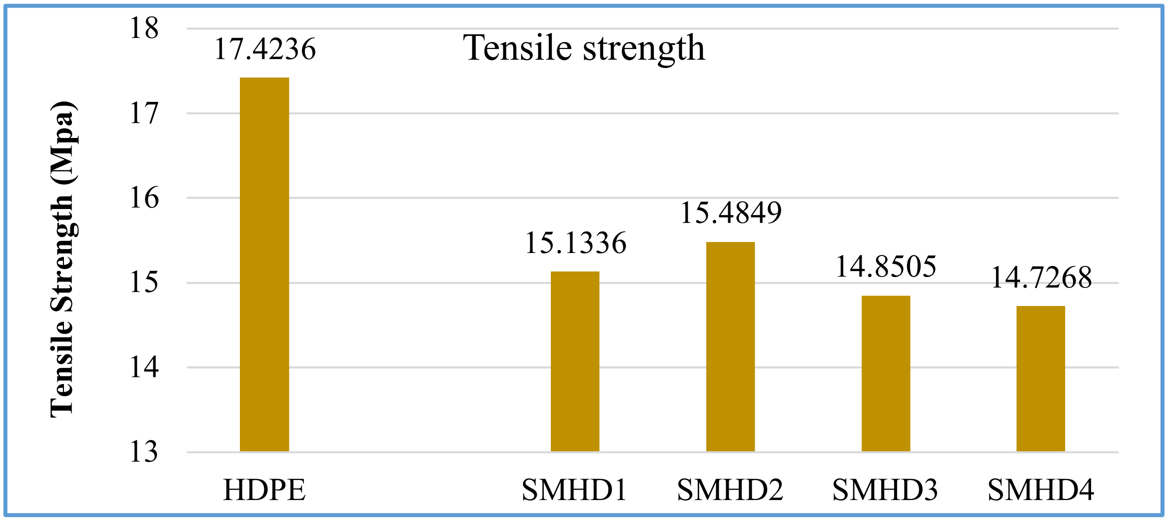

Fig (5). Tensile strength of WPC samples without CA

The Fig (5) explains the tensile strength of pure HDPE and its modified composites (SMHD1, SMHD2, SMHD3, and SMHD4). The HDPE shows the highest tensile strength of 17.4236 MPa, indicating strong resistance to pulling forces. However, after modification, the tensile strength decreases in all composite samples. SMHD1 records a tensile strength of 15.1336 MPa, while SMHD2 shows a slight improvement to 15.4849 MPa. In contrast, SMHD3 and SMHD4 exhibit lower values of 14.8505 MPa and 14.7268 MPa respectively. Hence the results indicate that although the modification may enhance other mechanical properties, the tensile strength of the composites is lower than that of pure HDPE, suggesting that the added filler may reduce the materials ability to withstand tensile loading due to possible changes in interfacial bonding[5-6] .

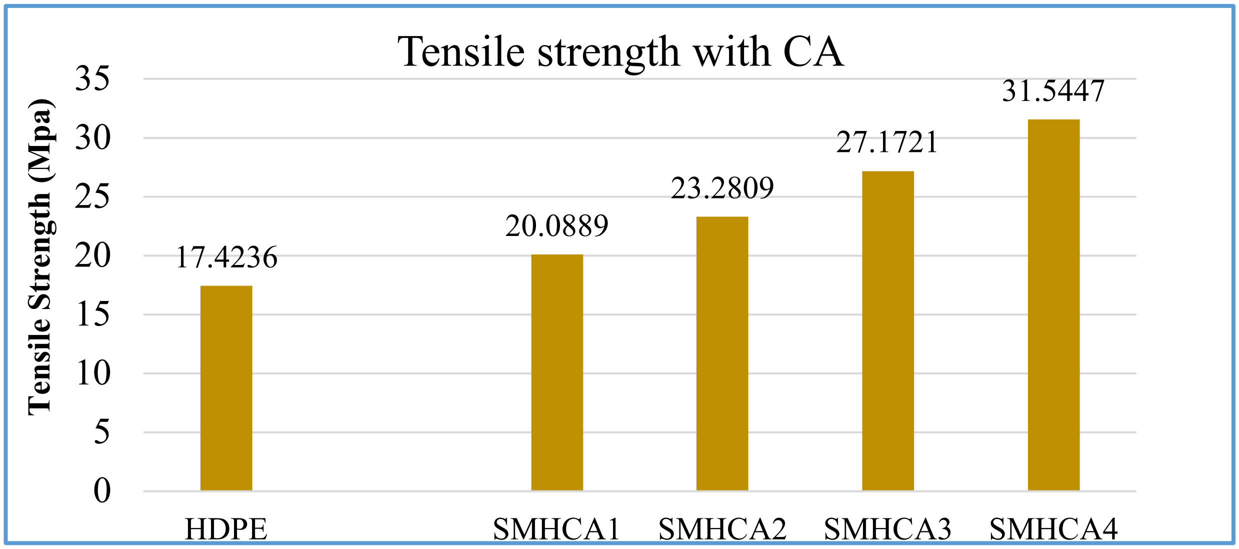

Fig (6). Tensile strength of WPC samples with CA

The Fig (6) clearly shows that, the tensile strength of HDPE and its composites with CA (SMHCA1, SMHCA2, SMHCA3, and SMHCA4). Pure HDPE shows a tensile strength of 17.4236 MPa, which serves as the baseline value. After the addition of CA, a continuous improvement in tensile strength is observed. SMHCA1 exhibits a tensile strength of 20.0889 MPa, the stenght is increased. The strength further increases in SMHCA2 to 23.2809 MPa SMHCA3 with 27.1721 MPa respectively. The highest tensile strength is recorded for SMHCA4 is 31.5447 MPa. The increased value implies that the incorporation of CA significantly enhances the tensile properties of the composite by improving the inter facialbonding between the filler and the polymer, shows better stress transfer and higher resistance to tensile forces. the results said that the only 5% CA has positively influences the tensile strength of the composites.

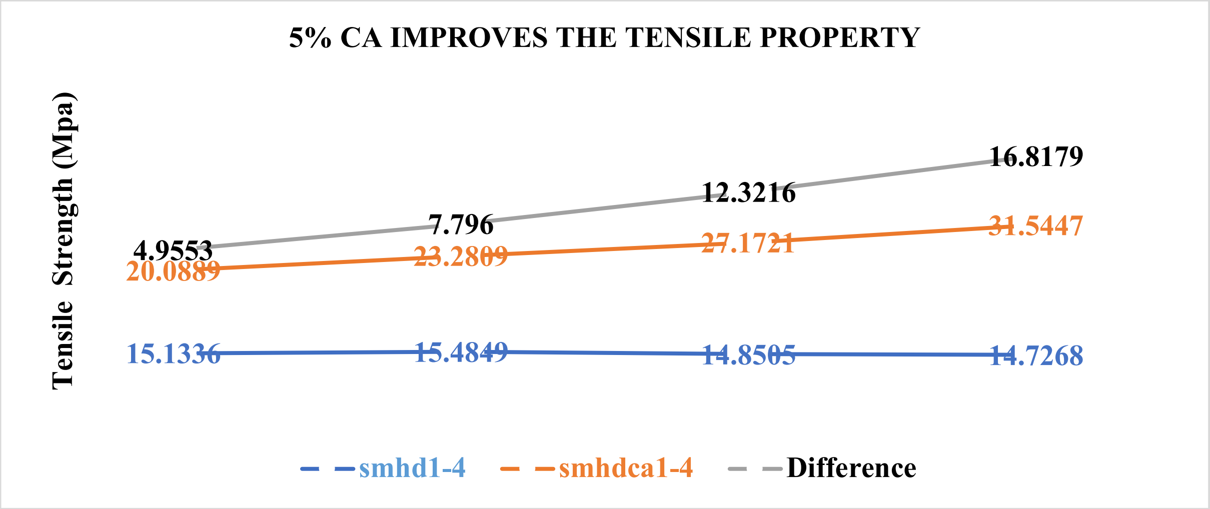

Fig (7). Improved Tensile stength by CA

The Fig (7) briefs the influence of 5% coupling agent (CA) on the tensile strength of HDPE Morus alba fiber composites by comparing untreated samples **(**SMHD1-4**)** with CA-treated samples **(**SMHCA1-4**)**. The blue line represents the tensile strength of untreated composites, the orange line representing CA treated composites shows a clear and steady increase in tensile strength from 20.0889 MPa (SMHCA1) to 31.5447 MPa (SMHCA4). The grey line indicates the difference between treated and untreated samples, which progressively increases from 4.9553 MPa to 16.8179 MPa. This the addition of only 5% CA significantly enhances the tensile properties of the composites [7]. The improvement is mainly attributed to better fiber matrix interfacial adhesion, which made easy more efficient stress transfer from the polymer matrix to the Morus alba fibers.

2.3.2 Flexural strength

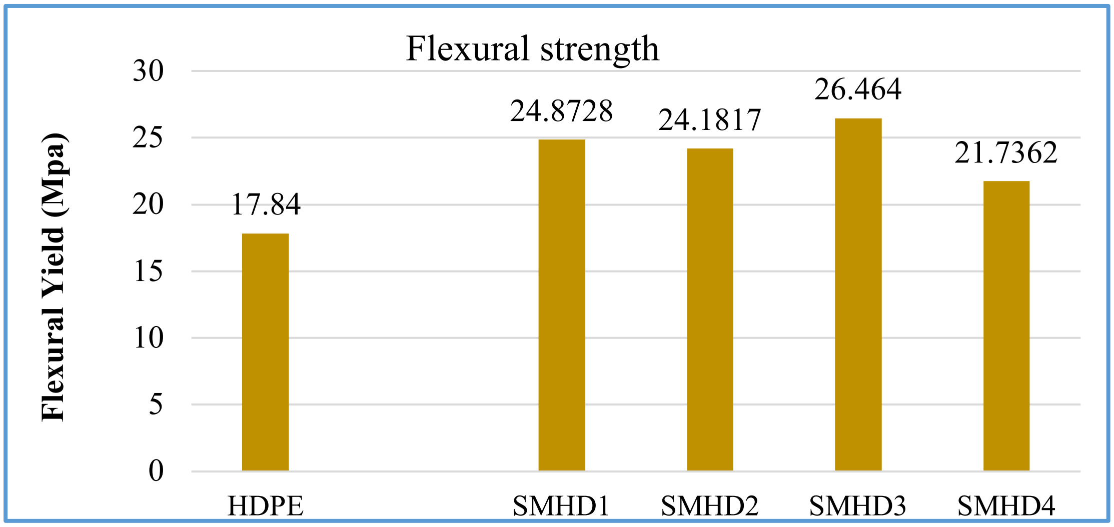

Fig (8). Flexural strength of WPC samples without CA

The Fig (8) flexural strength of pure HDPE polmer and its modified composites (SMHD1, SMHD2, SMHD3, and SMHD4). Pure HDPE exhibits a flexural strength of 17.84 MPa, which is the lowest among all the samples. With the incorporation of 5%CA an improvement in flexural strength is observed. SMHD1is 24.8728 MPa SMHD2 is 24.1817 MPa, though still much higher than pure HDPE. The maximum flexural strength is obtained for SMHD3, reaching 26.464 MPa, indicating the best resistance to bending among the tested composites. However, in SMHD4, the flexural strength decreases to 21.7362 MPa, although it remains higher than the value of HDPE. Hence the result briefs that the modification of polymer significantly improves its flexural properties up to an optimum level (SMHD3)[8].

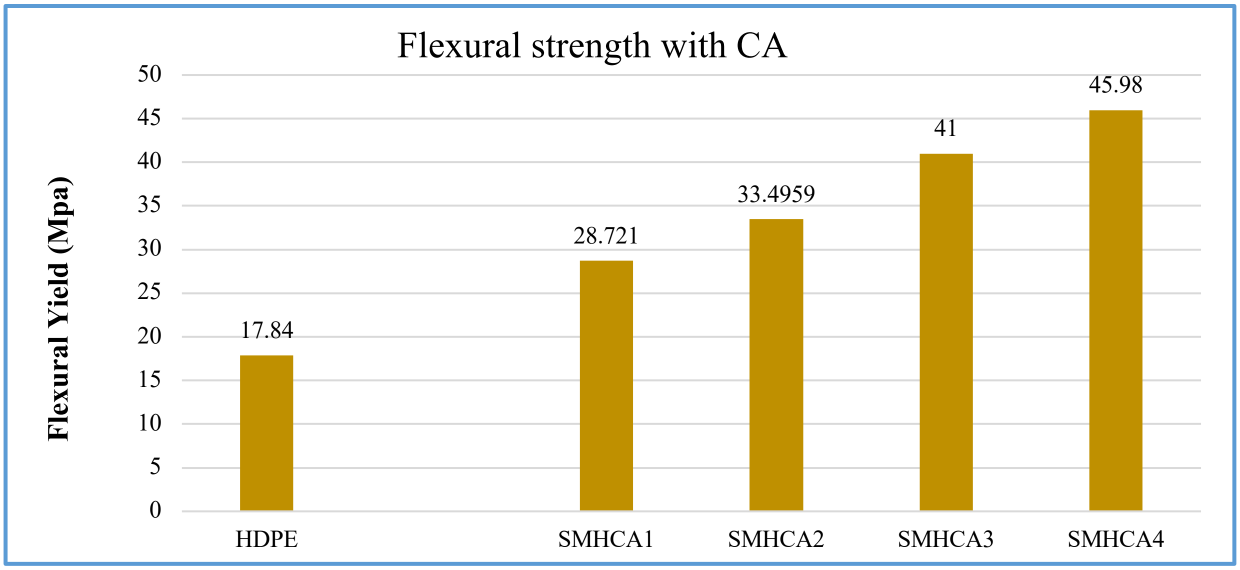

Fig (9). Flexurale strength of WPC samples with CA

The Fig (9) said the flexural strength of polymer HDPE and its composites with CA (SMHCA1, SMHCA2, SMHCA3 and SMHCA4). HDPE polymer exhibits flexural strength of 17.84 MPa. which is the lowest among the tested samples. After the incorporation of CA, continuous enhance in flexural strength is observed. SMHCA1 value of 28.721 MPa. The flexural strength further increases in SMHCA2 is 33.4959 MPa SMHCA3 is 41 MPa. for SMHCA4 is highest value of 45.98 MPa. This indicate the addition of CA greatly improves the bending resistance of the composite material. The improvement is better interfacial bonding and enhanced load transfer between the reinforcement and thepolymer matrix. totally the results indicate that the incorporation of MAPE as CA content significantly improves the flexural properties of the composites[7][9].

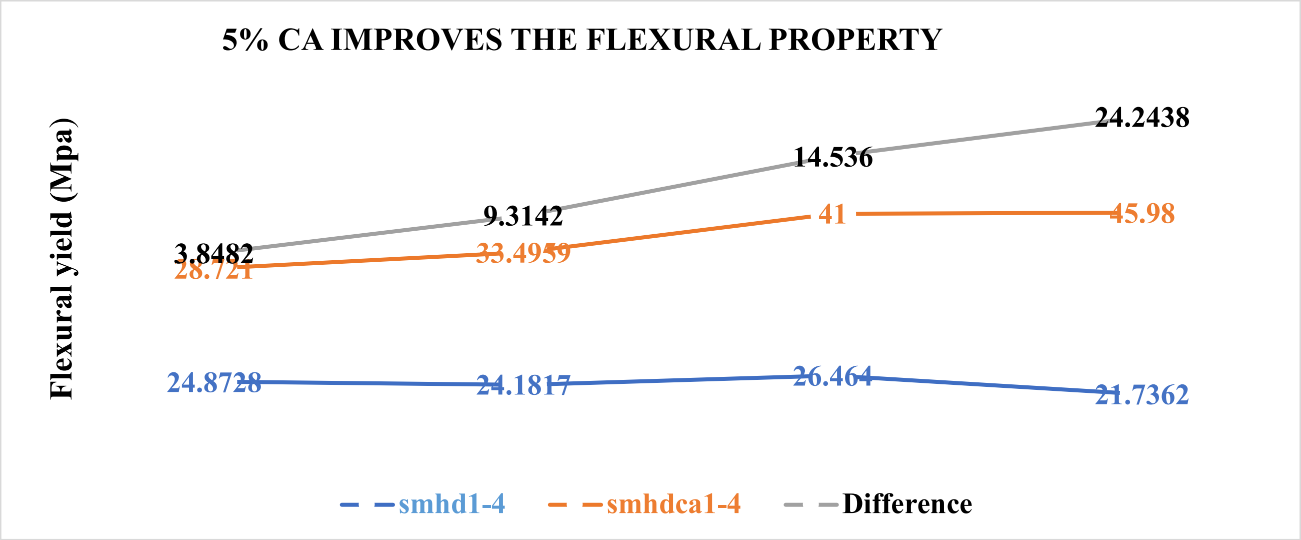

Fig (10). Improved Flexural strenght by CA

The Fig (10) briefs the effect of 5% coupling agent (CA) on the flexural strength of HDPE-Morus alba fiber composites by comparing untreated samples **(**SMHD1-4**)** with CA treated samples **(**SMHCA1-4**)**. The blue line represents the flexural strength of untreated composites, where the values ranging from 24.8728 MPa (SMHD1) to 21.7362 MPa (SMHD4) with a slight peak at 26.464 MPa for SMHD3. Similarly the orange line shows a significant improvement in flexural strength for CA treated composites, increasing steadily from 28.721 MPa (SMHCA1) to 45.98 MPa (SMHCA4). The grey line indicates the difference in flexural strength between treated and untreated samples, which shows increased progressively from 3.8482 MPa to 24.2438 MPa. This is clearly demonstrates that the addition of 5% CA significantly enhances the flexural performance of the composites by improving fiber matrix interfacial bonding and enabling effective stress transfer within the material[14-16]. Hence the results confirm that the coupling agent plays a crucial role in improving the mechanical properties of the composite.

2.4 Morphological interfacial bonding SEM pictures.

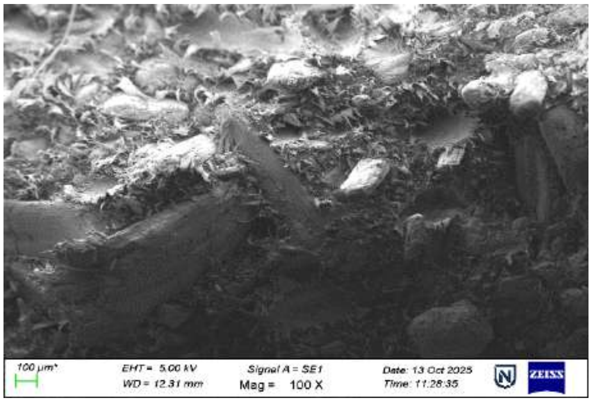

Fig (11). WPC without CA

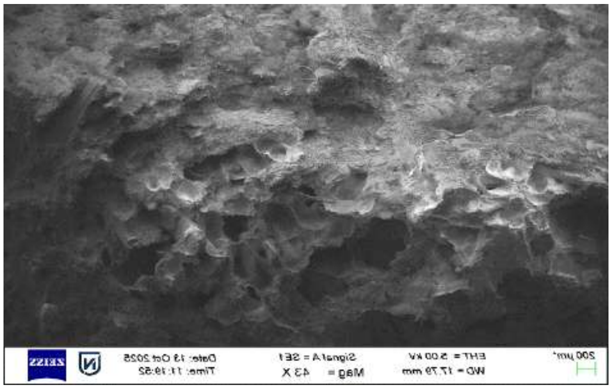

Fig (12). WPC with CA

When observed the above Fig (11) and Fig(12) SEM pictures explains the morphological internal bonding of fibers with polymers is the Fig(11) shows that where the poo internal bonding means it is not up the campact level. it is because there is fibers appeared. where as the Fig(12) clealy shows that the internal bonding between morus alba (silk mulbery) wood fibers and polymer which closely compacted with enhanced compatibility because of MAPE coupling agent, which enhanced the adhesion and improved internal bonding, hence there no fibers apprears in this SEM picture[8][17].

3. Conclusion

The incorporation of 5% MAPE (Maleic Anhydride Grafted Polyethylene) as coupling agent significantly improved the interfacial bonding between Morus alba fiber and the high density polyethylene polymer matrix**.** The presence of MAPE enhanced the adhesion between the fiber and polymer matrix, as a result the better stress transfer within the composite structure. This improved fiber matrix interaction led to an increase in tensile strength as well as enhanced flexural strength and flexural modulus of the material. Which can observe in morphological analysis revealed stronger interfacial compatibility in the MAPE treated composites compared to untreated samples is confirming the effectiveness of the coupling agent. Overall, MAPE acts as an efficient compatibilizer, and significantly improving the mechanical and physical, structural properties of wood polymer composites (WPC).

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