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Improved Quality of Wood Plastic Composite (WPC) Through the Addition of Maleic Anhydride (MAH)

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Improved Quality of Wood Plastic Composite (WPC) Through the Addition of Maleic Anhydride (MAH)

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Abstract. Due to the hydrophilic nature of wood particles compared to the hydrophobic nature of plastic, Wood Plastic Composite (WPC) has the weakness that it requires the use of a coupling agent to strengthen the bond between its constituent components. The aim of the study was to determine the effect of adding Maleic Anhydride (MAH) on the quality of WPC (P1 0%, P2 4% and P3 8%). The flat pressing process takes 20 minutes at a temperature of 180°C and a press machine pressure of 30 bar, using a plastic to wood particle ratio of 60:40. Data were processed using a completely randomized design (CRD). P3 treatment (8% MAH) gave the best test results (densityof 0.704 g/cm^3, moisturecontentof 2.321%, waterabsorptionof 15.719%, thicknessswellingof 1.733%, modulusofelasticityof 869.029 N/mm^2, modulusofruptureof 6.517 N/mm^2, and internal bondingstrengthof 0.926 N/mm^2). Almost all tests on the physical properties of WPC meet the SNI 8154-2015 standard, but none of the tests on the mechanical properties of WPC meet the standards. This WPC performs well for non-structural use although it is not yet suitable for structural use.

1. Introduction

Making Wood Plastic Composite (WPC) is an effort that is able to manage forestry waste and plastic waste into quality products so that it becomes an alternative to wood while protecting the environment and forests. WPC has the advantages of environmental protection, wood-like characteristics and appearance, and plastic toughness. The use of waste materials such as straw, wood, and other organic waste, low water absorption, resistance to deformation or cracking, and an attractive natural appearance, are some of the other benefits [1].A high-quality WPC board will be produced if the wood particles in the matrix are evenly distributed. However, because wood particles are hydrophilic and plastics are hydrophobic, there is relatively little adhesion between the two materials. In order to strengthen the binding between wood and plastic, a coupling agent is required[2].

To create a link between the filler (wood particles) and the matrix (plastic), a coupling agent (a substance to boost cohesiveness) is used.[3]. Due to higher interfacial bonding, MAH performs better as a coupling agent for WPC board. When tested for mechanical qualities, samples that had MAH added to them performed better in terms of tensile and flexural properties[4].

The use of MAH in making WPC has been carried out by a number of previous studies. In this study, different amounts of MAH were added to a mixture of plastic (polypropylene and polyethylene) and Red Meranti wood particles. It is hoped that this research will be able to present the ideal MAH ratio for improving WPC quality.

This study focused on the effects of using maleic anhydride (MAH) as a coupling agent in the production of a WPC made from plastic (polypropylene and polyethylene) and wood particles.

2. Materials and Method

2.1. Materials and Research Tools

Red Meranti wood particles, polypropylene (PP) and polyethylene (PE) plastic, and maleic anhydride (MAH) are examples of materials. Tools include 16 and 30 mesh sieve, oven, scales, mold, separating stick, aluminum foil, press machine, and Universal Testing Machine (UTM).

2.2. Research Steps

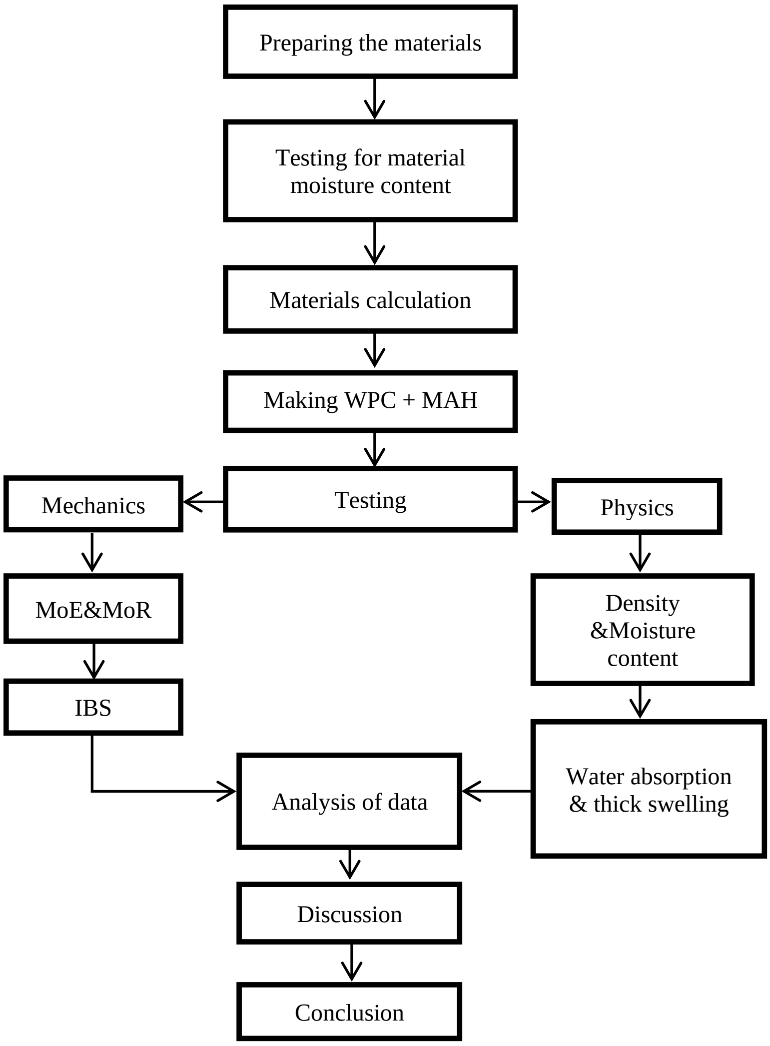

Figure 1. Flow Chart of the Research.

Based on flow chart of the research (Figure 1), the material is dried at 80 °C for 24 hours until it reaches a normal dry condition (wood particle moisture content of 5 percent). This is to ensure the accuracy of material calculations before the ingredients that make up WPC are mixed and pressed. Calculation of the materials needed to make WPC is based on a ratio of plastic polymer (PP and PE) to wood particles of 60:40. Table 1 shows the amount of material used in making WPC.

Table 1. The Quantity of Materials Used to Make WPC.

Treatment	Red Meranti Particles	Plastic		MaleicAnhydride
		Polypropylene	Polyethylene	
P1 (0% MAH)	205.514 g	147.456 g	147.456 g	0
P2 (4% MAH)	205.514 g	137.623 g	137.623 g	19.661 g
P3 (8% MAH)	205.514 g	127.795 g	127.795 g	39.322 g

WPC is made using a flat press machine with a capacity of 30 bar and operating at a temperature of 180 °C for 20 minutes. Ten replications (test samples) were prepared for each treatment. The WPC's sample is conditioned until its weight is stable before tested.

2.3. Physics testing

With reference to the test procedure based on established standards, the following tests were performed to determine the physical properties of the WPC.

2.3.1. Density(ASTM D2395)

$$Density\ (g/m^3) = \frac{m_0}{v_0} \tag{1}$$

v_0 = Normal volume test sample (cm^3)
m_0 = Normal mass test sample (g)

2.3.2.Moisture content (ASTM D4442)

$$Moisture\ content\ (\%) = \frac{(A-B)}{(B)} \times 100\% \tag{2}$$

A = Initial mass test sample (g)
B = Kiln dry mass test sample (g)

2.3.3.Thickness swelling (α) (ASTM D1037)

$$\alpha = \frac{T_2-T_1}{T_1} \times 100\% \tag{3}$$

α = Thick swelling (%)
T_1 = Thickness test sample before soaking (mm)
T_2 = Thickness test sample after soaking (mm)

2.3.4. Water absorption (η)(ASTM D1037)

$$\eta = \frac{M_2-M_1}{M_1} \times 100\% \tag{4}$$

η = Water absorption (%)
M_1 = Mass test sample before soaking (g)
M_2 = Mass test sample after soaking (g)

2.4. Mechanics testing

To determine the mechanical properties of WPC using test methods based on accepted standards, the following tests were carried out.

2.4.1.Modulus of Elasicity (MoE)(ASTM D4761)

$$MoE = \frac{PL^3}{4\delta bd^3} \quad (5)$$

MoE = Modulus of Elasicity (N/mm^2)
P = Load (N)
δ = Deflektion (mm)

2.4.2. Modulus of Rupture (MoR) (ASTM D4761)

$$MoR = \frac{3P_{maks}L}{2bd^2} \quad (6)$$

MoR = Modulus of Rupture (N/mm^2)
P_{maks} = Maximum load (N)
L = Effective span length between supports (mm)
b = Test sample width (mm)
d = Test sample thick (mm)

2.4.3.Internal Bonding Strength (IBS) (ASTM D5651)

$$IBS = \frac{P_{max}}{p \times l} \quad (7)$$

IBS = Internal Bonding Strength (N/mm^2)
P_{max} = Maximum load (N)
p = Test sample length (mm)
l = Test sample width (mm)

2.5. Data analysis
The physical and mechanical test results of WPC were compared to the SNI 8154:2015 standardand analyzed statistically.A completely randomized design (CRD) was employed in the statistical analysis, and there were three treatments (P1, P2, and P3) with ten replications each.
The following is the difference in the amount of MAH added to the WPC.
P1 = 0% MAH
P2 = Addition 4% MAH
P3 = Addition 8% MAH
ANOVA was carried out with 95% and 99% confidence levels to ascertain the impact of the treatment of adding MAH to the WPC on the physical and mechanical properties of the WPC.

3. Results and Discussion
Based on the results of WPC measurements and testing, data for each test was obtained which included physical properties (density, water content, water absorption, and thickness swelling), and mechanical properties (modulus of elasticity, modulus of rupture, and internal bonding strength).

These data were then compared to SNI 8154:2015 standards (Table 2) to ascertain compliance with standard.The WPC can be used for structural purposes if the testing results show that they comply with the SNI 8154:2015 standards; however, if they don't, they can only be used for non-structural uses.
The choosing of this Indonesian standard can be explained by the simple reason that WPC are created there and can adapt to the environment there.

Table 2. Comparison of the WPC's Physical and Mechanical Properties to the SNI 8154:2015 Standard.

Parameters of Physical and Mechanical Properties	WPC	SNI 8154:2015	Remark
Density (gr/cm^3)	0.704	≥0.60	Has fulfilled
Moisture content (%)	2.321	<12	Has fulfilled
Water absorption (%)	15.719	-	No remark
Thickness swelling (%)	1.733	<4	Has fulfilled
Modulus elasticity (MoE) (N/mm^2)	869.029	≥1,961.330	Not fulfilled
Modulus of Rupture (MoR) (N/mm^2)	6.517	≥17.652	Not fulfilled
Internal Bonding Strength (IBS) (N/mm^2)	0.926	-	No remark

The physical properties of WPC (density, water content and thickness expansion) meet the Indonesian standard SNI 8154:2015. Meanwhile, the mechanical properties of WPC (MoE and MoR) do not meet SNI 8154:2015 standard.
Since it is related to the level of load that can be supported by WPC, the mechanical properties of WPC are prioritized for evaluation as structural application requirements. The data above (Table 2) shows that the mechanical properties of WPC do not meet these requirements.

3.1. Physical properties

3.1.1. Density

The WPC density rises with the addition of the MAH ratio (Figure 2). There may have been an esterification reaction between MAH and the OH group of the Meranti Merah particles (*Shorea* sp.), as well as a maleolation reaction between MAH and the plastic, which resulted in a strong bond between the plastic and Meranti Merah particles, achieving WPC compatibility and resulting in a reduction in voids and an increase in WPC density. That a solid link between the wood particles and the plastic is created by the esterification reaction and the maleolation reaction [3].
The addition of MAH to WPC can act as a compatibilizer by repairing physical qualities and enhancing cohesiveness, but it has not been able to enhance the mechanical properties of composite boards [2].
The density value often rises as the plastic composition does as well. As a result, the surface of the wood particles will be practically entirely covered with plastic, leading to a variation in the density of the WPC for each board-mixing ratio [5]. The belief in the properties of MAH which makes the bond between particles and plastic more compact, is further strengthened by the addition of MAH in WPC.

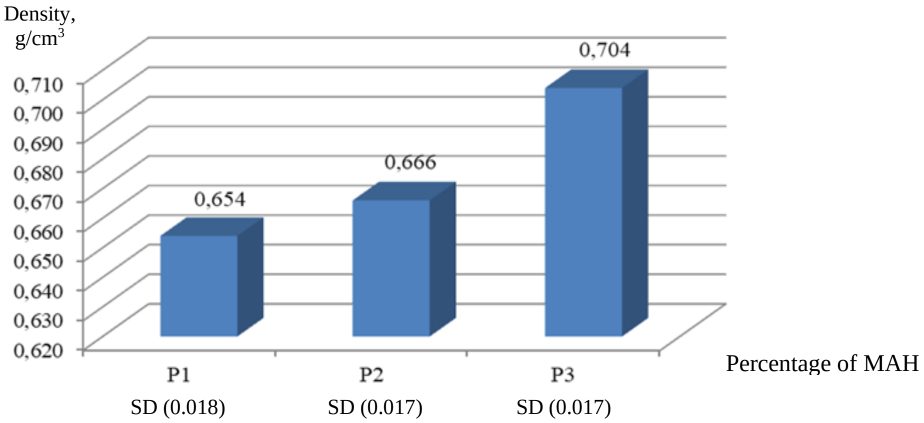

Figure 2. Density of WPC.

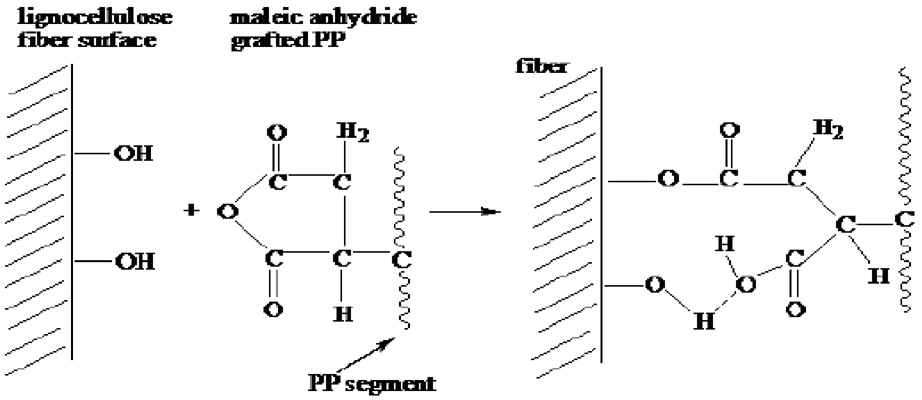

Figure 3. Maleic Anhydride and Wood are Grafted Together as Shown in a Schematic [6].

One method used to strengthen the surface interfacial contact between wood particles and plastic is chemical treatment, in which the addition of functional groups will cause the surface groups of the wood particles to respond. Chemicals with two different functional end groups are coupling agents. While some of the groups are utilized to interact with plastics, others are employed to react with the hydroxyl groups of wood particles (Figure 3). Anhydrides and copolymers modified by anhydrides are two examples of coupling agents. WPC made of wood flour and PP are processed using two maleic anhydride graft polypropylene copolymers (MAPP) with various molecular weights. As a consequence, WPC made of PP and wood flour, which has an intermediate ratio of MAPP and wood flour of 5 to 10%, has the maximum tensile strength. MAPP with a higher molecular weight contributes more to the increase in the strength of the WPC[7].

3.1.2. Moisture content

Achieving WPC compatibility means there are few voids and water vapor cannot easily enter the WPC, this causes the WPC water content to decrease with an increase in the amount of MAH in the WPC (Figure 4). The density of composite boards has an impact on how much moisture they contain because high-density composites have very strong bonds between particle molecules and adhesive molecules, making it difficult for water molecules to fill the cavities in the composite board because they have been filled with adhesive molecules[8].

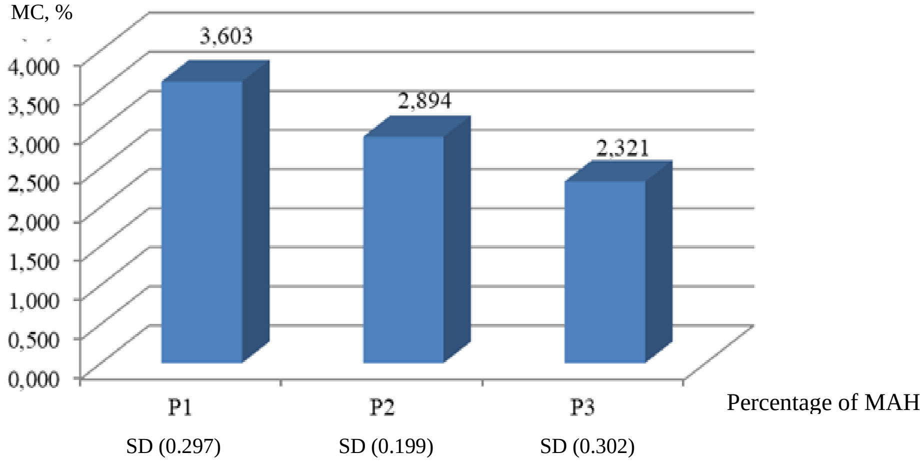

Figure 4. Moisture Content (MC) of WPC.

3.1.3. Water absorption

As with the results of the moisture content test, there was a decline in water absorption on the WPC board as the number of MAH increased (Figure 5). With a higher MAH, the bond between PP and PE plastics and wood particles becomes stronger, allowing for stronger chemical bonding that result in reduced water absorption into the WPC (in this example, the wood particles) when submerged in water.

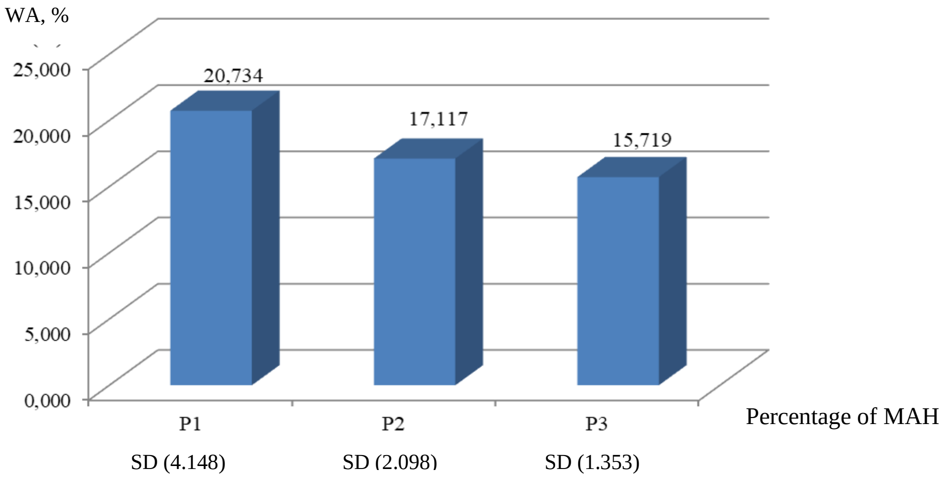

Figure 5. Water Absorption (WA) of WPC.

3.1.4. Thickness swelling

The amount of water absorbed in the WPC decreases resulting in the ability of the wood particles to expand to be reduced or inhibited. As shown in the Figure 6, there was a decrease in thickness expansion due to an increase in the amount of MAH in the WPC which had improved the bond between the PP and PE plastics and the wood particles.

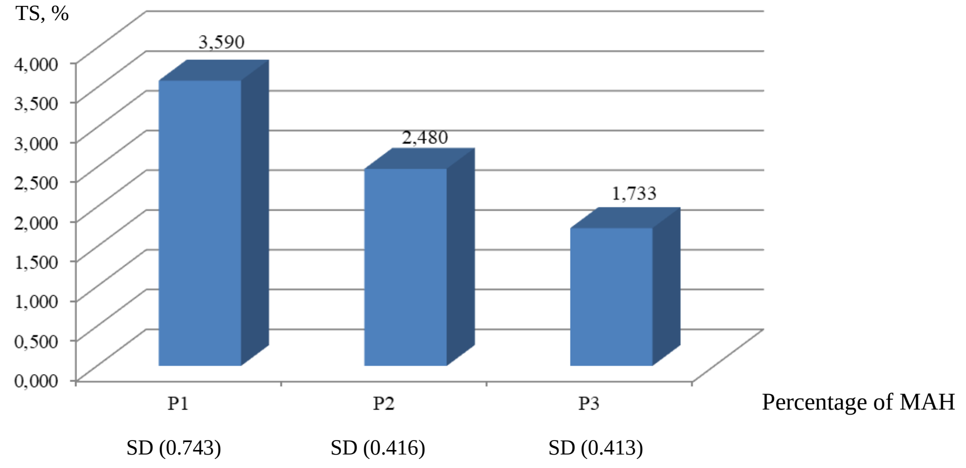

Figure 6. Thickness Swelling (TS) of WPC.

3.2. Mechanical properties

3.2.1. Modulus of Elasticity (MoE)

The amount of MAH added to the WPC causes an increase in the mechanical characteristics of the WPC related to its Modulus of Elasticity (MoE) as shown in Figure 7. Even though the WPC's flexibility is still below the MoE value based on SNI 8154: 2015 requirements, the ability of MAH to begin bonds between PP and PE plastics and wood particles improves bonding and increases flexibility.

The grafting modification increased the tensile and impact strengths of the blends. Infrared spectroscopy and scanning electron microscopy demonstrated that the maleic anhydride could be grafted onto PP and PE chains [9].

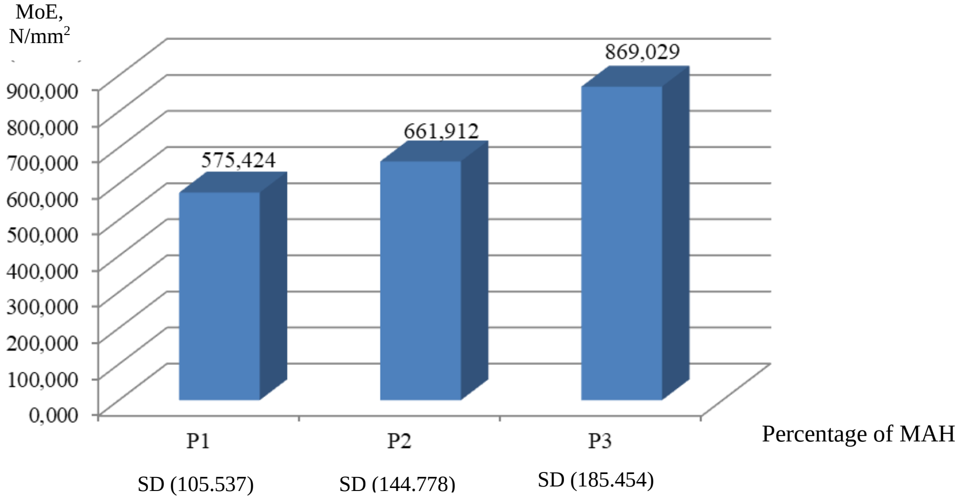

Figure 7. Modulus of Elasticity (MoE) of WPC.

3.2.2. Modulus of Rupture (MoR)

The MoR of the WPC is directly proportional to the capacity to withstand loads up to the maximum limit (fracture), which is indicated by the Modulus of Rupture (MoR). The cause is also the same; more MAH on WPC has made the binding between PP and PE polymers and wood particles stronger, allowing for the support of heavier loads. So that, increasing the number of MAH as well increase the MoR of the WPC (Figure 8).

The increased wood particles and improved interfacial adhesion result in the improved MoR and MoE [7].

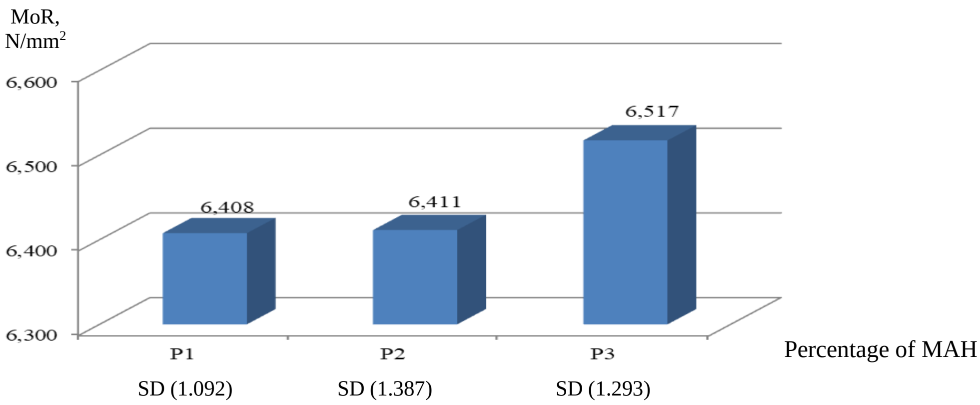

Figure 8. Modulus of rupture (MoR) of WPC.

3.2.3. Internal Bonding Strength (IBS)

Internal Bonding Strength (IBS) measures how well the WPC internal bonds hold together among its constituent parts, and it gets stronger as there are more MAH in the WPC (Figure 9).

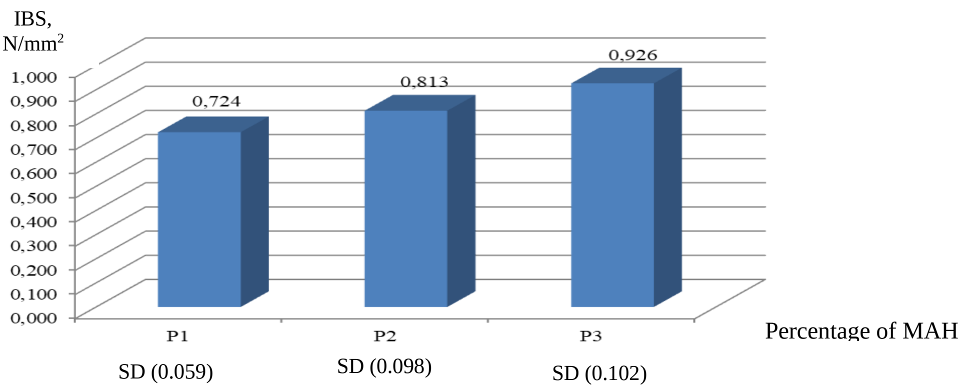

Figure 9. Internal Bonding Strength (IBS) of WPC.

Initial cracks will result from cavities in the specimen because stress concentrations happen when the composite is exposed to a load or force. The number and size of cavities in WPC decreased with the addition of MAH (Figure 10). There is a possibility that as a result, the value of the composite's mechanical strength will decline [10]. With the presence of MAH in the WPC, the problem can be turned back, improving the WPC's strength. The WPC's mechanical strength develops as MAH composition increases.

(0% MAH) (Addition 4% MAH) (Addition 8% MAH)

Figure 10. The Number and Size of Cavities in WPC Decreased with the Addition of MAH.

Table 3. Analysis of Variance Effect of the Addition of MAH on the Results of Physical and Mechanical Testing of WPC.

F-count value for each physical and mechanical test	MAH addition treatment		
	Very significant	Significant	Not significant
Density (23.801)	**		
Moisture Content (57.029)	**		
Water Absorption (8.672)	**		
Thickness Swelling (30.653)	**		
Modulus Elasticity (MoE) (10.271)	**		
Modulus of Rupture (MoR) (0.024)			ns
Internal Bonding Strength (IBS) (12.963)	**		

Value of F-table at confidence levels 95% (3.354) and 99% (5.488)

With the exception of MoR, practically all test values for physical and mechanical properties were significantly affected by the addition of MAH (Table 3). The ability of MAH as a coupling agent, specifically attaching to the surface of wood particles on one side and binding PP and PE plastics on the other, demonstrates that MAH is extremely successful in altering the physical and mechanical properties of WPC in this situation.

The addition of MAH did not significantly change the MoR test results because the ratio of plastic to wood particles (60:40) means that there is more plastic present, making it less likely for WPC to withstand maximum loads before breaking even after the addition of up to 8% MAH.

The low value of the mechanical properties of the WPC does not even meet the SNI 8154:2015 standard, indicating that the addition of 8% MAH is only effective in improving the physical properties of the WPC.

4. Conclusion

The physical properties of WPC meet the minimum requirement of SNI 8154:2015 standard, but this is not the case with the mechanical properties of WPC. The addition of MAH can improve the physical and mechanical properties of WPC but is not yet suitable for structural purposes.

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