The Effects of MAPP and OPDC on Physical and Mechanical Properties of OPDC-RPC

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ABSTRACT

Oil palm decanter cake reinforced with polypropylene composite (OPDC-RPC) was developed by varying the percentages of oil palm decanter cake (OPDC) and maleic anhydride polypropylene (MAPP). By adding MAPP, the mechanical properties (tensile, flexural and impact strength) had improved and the optimum mechanical strength was obtained at 30% OPDC due to strong internal bonding of OPDC and polymer. This evidence was captured using SEM where OPDC had a better bonding with MAPP. Water absorption test also confirmed the nature of hydrophilic properties of OPDC. To reduce the water absorption, MAPP was added and able to reduce the void inside OPDC-RPC material, hence reduced water penetration and water absorption rate.

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Introduction

There are many types of reinforced bio-composite developed from agriculture wastes such as abaca, kenaf, jute, coir, flax, empty fruit bunch, and hemp [1]. Currently, there is no report on the study utilising oil palm decanter cake (OPDC) as a reinforcement fibre for composite development. From the previous study, OPDC could be a potential candidate as reinforcement for polypropylene (PP) [2]. However, producing the composite from natural fibre could be a problem simply because the fibre is a polar group (hydrophilic) while polymer is a non-polar material (hydrophobic) [3, 4]. The hydrophilic properties of OPDC are affected by the presence of hydroxyl group (-OH) and it is proven by Fourier Transform Infrared Spectroscopy (FTIR) analysis [5]. The hydrophilic properties not only disturbed the bonding in composite but also in other research works such as enzyme preparation. Other researcher found that the hydrophilic properties may have high retention but they can be removed under severe chemical reaction such as using chemical coupling agent [6]. The major components of OPDC which contain high hydrophilic properties are cellulose and hemicellulose [7,8]. Besides that, OPDC contains a high amount of residual crude palm oil (RCPO) which is 12.5% [9]. However, the RCPO can be removed completely using soxhlet extraction method.

As proposed in the previous study, to improve the bonding, a coupling agent such as maleic anhydride polypropylene (MAPP) can be used [7]. MAPP is used to form a stronger bond between fibre and PP through hydroxyl group of the fibre and the anhydride group of the MAPP which produce efficient interlock [9] and thus, resulted in better composite properties by enhancing its mechanical properties [10].

The composite material properties were also affected by the fibre content where by increasing the fibre content; the composite rigidity and strength were enhanced [11]. However, at certain fibre content depending on the fibre type, the properties of the composite dropped due to weak internal bonding between the fibre and polymer due to the clumping problem. The elasticity of the composite is reduced significantly with the increase of the fibre content due to the increase in its rigidity [12]. The mechanical properties such as flexural strength, tensile strength, and impact strength generally depend on the OPDC-RPC ability to absorb the energy from the load during test. It was reported in several studies that upon application of loads, the energy would be transferred from the polymer to the fibre through shear stress [3, 13]. The fibre would act as energy absorber which absorbs the energy dissipated from the load. Therefore, a good adhesion between the fibre and polymer would provide a better bonding which caused the energy to transfer well within the composite material [14]. So far, there is no reported data for the effect of MAPP towards the properties of composite made from OPDC. Thus, this research was conducted to study the effects of MAPP and OPDC content on the mechanical and physical properties of the developed OPDC composite materials.

Experimental

Material preparation & OPDC pre-treatment

The fresh OPDC was obtained from a Palm Oil Mill located in Perak, Malaysia. The OPDC was dried at 103ºC in an oven (UNB-400 Memmert, USA) to remove the excess moisture until it reached a constant weight as according to American Standard Test Method D1102 test procedure [15]. Then, the sample was grounded to a fine powder using a mill (Retsch, Germany) and sieved to produce a fine powder of less than 250µm. Due to the presence of oil in OPDC, the sample was pre-treated using soxhlet extraction method for 8 hours using n-hexane as an exchange solvent. Lastly, the sample was dried in an oven at temperature of 103ºC and kept dried for further usage.

Oil Palm Decanter Cake-Reinforced Polypropylene Composite (OPDC-RPC) preparations

The dried fine powder OPDC sample was compounded with PP and MAPP using two types of experiments and six different treatments as shown in Table 1. Experiment A was conducted to investigate the effect of different OPDC percentages without MAPP addition on physical and mechanical properties of OPDC-RPC whereas experiment B was conducted with 2% MAPP addition.

Table 1: The percentages of OPDC, PP, and MAPP applied in all the treatments (1-6).

Experiment	Treatment	OPDC (%)	PP (%)	MAPP (%)
A	1	10	90	0
	2	30	70	0
	3	50	50	0
B	4	10	88	2
	5	30	68	2
	6	50	48	2

*% by weight

The OPDC materials were compounded using twin screw extruder (TSE-16 PRISM, USA) at 180ºC. Then, the composite was pressed into 3 mm thick sheets by using hot press mould (Daylight Moulding, China) at 180ºC and 150 kg/m2 pressure.

Testing

Tensile Test

The tensile strength of the OPDC-RPC was determined in accordance to ASTM D638 test method [16]. The testing samples dimensions were 3 mm thick, 19 mm wide and 165 long. The flexural and tensile test was performed using universal testing machine (Instron, UK). The tests were performed in triplicates.

Flexural test

The flexural strength and flexural modulus of OPDC reinforced PP composite (OPDC-RPC) were determined based on the ASTM D790 test method [17]. The testing samples dimensions were 3 mm thick, 12.7 mm wide and 125 mm long. The test was performed using universal testing machine (Instron, UK). The tests were performed in triplicates.

Izod impact test

The izod impact resistant strength of the OPDC-RPC was determined by complying with ASTM D256 test method [18]. The testing samples dimension were 3 mm thick, 12.7 mm wide and 65 mm long. The test was performed using Izod testing machine (Ceast, Italy). The tests were performed in triplicates.

Water absorption test

The water absorption rate of OPDC-RPC was determined in accordance to ASTM D570 test method [19]. The testing samples dimensions were 3 mm thick, 25 mm wide and 50 mm long. The testing was done by submerging the sample in room temperature water.

Field emission scanning electron microscopy

Morphological studies of OPDC-RPC were carried out using a field emission scanning electron microscope (FESEM) (Zeiss Supra 55VP, Germany). The samples were coated with a thin layer of gold to prevent electrostatic charge during imaging process as proposed in the previous study [2].

Statistical analysis

The statistical analysis was carried out using Statistical Package for the Social Sciences (SPSS) to test for any significant differences in the results obtained. The statistical test revealed significant difference among the six types of samples based on flexural strength, flexural modulus, tensile strength, impact resistant strength, and water absorption.

Result and Discussion

Tensile strength

Figure 1 shows the effects of increasing the OPDC content and addition of MAPP to the physical and mechanical properties of OPDC-RPC. The statistical analysis for the MAPP addition indicates that there is no significant difference on the tensile strength of OPDC-RPC with 10% and 30% OPDC content. Meanwhile, for the 50% OPDC content, the results shows a significant difference of the tensile strength, where the calculated p-value is 0.04, which is less than 0.05. The statistical analysis for the different percentage of OPDC content at 0% and 2% MAPP addition indicates that there is a significant difference in both experiments A and B, where by increasing the OPDC percentage to 50% resulted into the calculated p-values of 0.00 and 0.02, respectively which were less than 0.05.

Figure 1 shows that the OPDC-RPC with MAPP addition of 2% has a higher tensile strength compared to the OPDC-RPC without MAPP addition. The graph shows that by adding MAPP, the tensile strength increases slightly.

This study also found that the tensile strength of OPDC-RPC was also affected by the percentage of OPDC fibre used in the composite. It was noted that the tensile strength for both with and without MAPP addition increased with the increasing of OPDC of up to 30% and decreased as the OPDC content was increased to 50%. The reduction of tensile strength when the OPDC content is increased to 50% could be due to the clumping of OPDC with each other.

Thus, the function of OPDC as a force absorber is weakened and the composite cannot withstand higher force exerted. As the result, the tensile strength of the composite dropped.

It was observed that the composite MAPP addition has better tensile strengths compared to the composite prepared without MAPP addition. Other researchers also found similar results that the addition of MAPP has significantly improved the bonding strength between the natural fibre and polymer [4, 10, 20]. Upon application of any load, the natural fibre would absorb the load by dissipating it through the polymer by the shear stress [3]. Poor interfacial bonding between the natural fibre and the polymer could cause micro separation or spaces between the natural fibre and polymer which later could result in the load transfer problem. As a result, the composite would have lower tensile strength as concluded in many studies [20, 21]. Therefore by adding MAPP which serves a role as a coupling agent between the OPDC and PP, it could enhance the composite tensile strength attributed to the strong bonding between OPDC and PP materials as described by Tjong *et. al.* [22].

It was reported that by increasing the tensile strength, it would increase the rigidity property of the composite before it failed at a certain point [12]. Generally, high rigidity of composite allowed it to withstand high load [3]. Test result showed that the tensile strength dropped at 50% OPDC fibre which could be attributed to the decrease in the bonding strength as reported earlier [23]. The amount of PP was insufficient to withstand the load applied during the test. As the amount of PP was insufficient, the OPDC fibre created a huge gap inside the composite, thus affected the tensile strength of composite with 50% OPDC fibre. This result is similar with another study [11]. It was reported that by increasing the tensile strength, it would increase the rigidity of composite which allowed it to withstand high load [3].

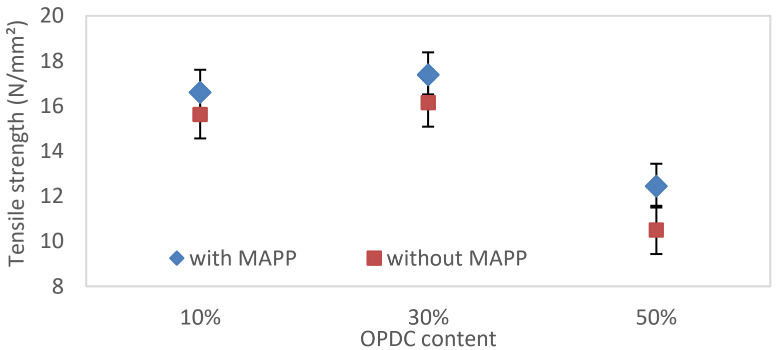

Figure 1: Tensile strength of OPDC-RPC with and without MAPP addition at different OPDC fibre content

Flexural strength

Figure 2 shows the effects of increasing the OPDC content and addition of MAPP to the physical and mechanical of OPDC-RPC. The statistical analysis for the MAPP addition indicates that there is no significant difference on the flexural strength of OPDC-RPC with 10%, 30%, and 50% OPDC content. The statistical analysis for the different percentage of OPDC content at 0% and 2% MAPP addition indicates that there is a significant difference in both experiments A and B, where by increasing the OPDC percentage to 50% resulted the calculated p-values of 0.04 and 0.04, respectively which were less than 0.05.

Figure 2 shows that the OPDC-RPC with MAPP addition of 2% has a higher flexural strength compared to the OPDC-RPC without MAPP addition. The graph shows that by adding MAPP, the flexural strength increases slightly. This study also found that the flexural strength of OPDC-

RPC was also affected by the percentage of OPDC fibre used in the composite. It was noted that the flexural strength for both with and without MAPP addition increased with the increasing of OPDC of up to 30% and decreased as the OPDC content was increased to 50%. The reduction of the flexural strength when the OPDC is increased to 50% was explained previously due to the clumping of OPDC with each other. In both experiments, the trend was similar which could be explained due to the high percentage of OPDC in composite causing the composite properties to weaken.

The trend of result is similar with the behaviour of the tensile strength result where the OPDC-RPC with 30% of OPDC and additional of 2% MAPP has the highest strength. The MAPP function is to enhance the interfacial bonding inside the composite by producing hydrogen bond. The hydrogen bonds are developed between the OPDC hydroxyl groups with the MAPP carboxylic group which dispersed in the PP [24]. Other findings also proved that the addition of MAPP had significantly increased the flexural strength of the composite [22, 25]. The theory of enhanced OPDC-RPC flexural strength is similar with the tensile strength as discussed earlier. When the bonding between the OPDC and PP improves, the flexural strength of the composite will increase. Similar trend was shown from other research [26].

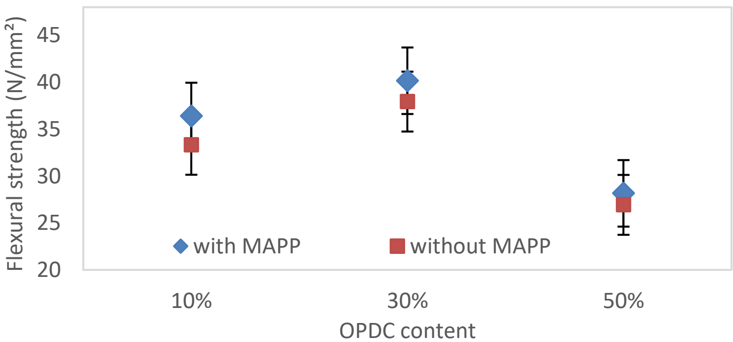

Figure 2: Flexural strength of OPDC-RPC with and without MAPP additional at different OPDC content

Flexural modulus

Figure 3 shows the effects of increasing the OPDC content and addition of MAPP to the physical and mechanical properties of OPDC-RPC. The statistical analysis for the MAPP addition indicates that there is no significant difference on the tensile strength of OPDC-RPC with 10%, 30%, and 50% OPDC content since the p-values are greater than 0.05. The statistical analysis for the different percentage of OPDC content at 0% and 2% MAPP addition indicates that there is no significant difference in experiments A, where by increasing the OPDC percentage up to 50% resulted the calculated p-value of 0.26, respectively which was greater than 0.05. However, there is a significant difference in experiment B in which the calculated p-value is 0.03.

Figure 3 shows that the OPDC-RPC with MAPP addition of 2% has a higher flexural elasticity compared to the OPDC-RPC without MAPP addition. The graph shows that by adding MAPP, the flexural elasticity increases slightly. This study also found that the flexural elasticity of OPDC-RPC was also affected by the percentage of OPDC fibre used in the OPDC-RPC. It clearly shows that the flexural modulus for both with and without MAPP addition decreased with the increasing of OPDC up to 50%. Flexural modulus was defined as the ability to return to its original form before ruptured by flexural load [27].

The decreasing of flexural modulus is caused by the decreasing of polymer content in the composite [25]. The decreasing of PP and the increasing of OPDC affected the rigidity of the composite. The increasing rigidity of the composite restricts the elongation, and limits the stretching of composite [12]. As shown in Figure 2 and Figure 3, the result is inversely proportional. It proved that as the flexural strength increased, the elasticity dropped. However, the composite with 50% OPDC shows poor result for both tests. The amount of PP for the composite is not sufficient for the composite to withstand greater force [26]. The addition of MAPP seems to improve the flexural modulus of the OPDC-RPC compared to OPDC-RPC without MAPP additional. The improvement of the flexural modulus is due to the esterification of the fibre as discussed earlier [25]. The mechanisms of esterification were explained by the reaction of hydroxyl group from the OPDC with the carboxylic group which blended with the PP [24].

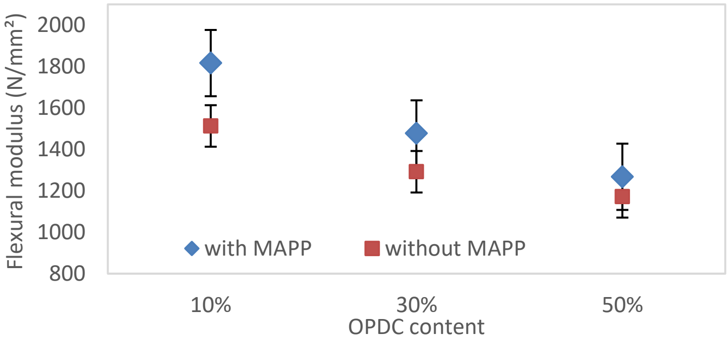

Figure 3: Flexural modulus of OPDC-RPC without and with MAPP additional at different OPDC content

Impact strength

Figure 4 shows the effects of increasing the OPDC content and addition of MAPP to the physical and mechanical properties of OPDC-RPC. The statistical analysis for the MAPP addition indicates that there is no significant difference on the impact strength of OPDC-RPC with 10%, 30%, and 50% OPDC content since the p-values are greater than 0.05. The statistical analysis for the different percentage of OPDC content at 0% and 2% MAPP addition indicates that there is no significant difference in both experiments A and B, where by increasing the OPDC percentage of up to 50% resulted the calculated p-value greater than 0.05.

Figure 4 shows that the OPDC-RPC with MAPP addition of 2% has a higher flexural elasticity compared to the OPDC-RPC without MAPP addition. The graph shows that by adding MAPP, the impact strength increases slightly. This study also found that the impact strength of OPDC-RPC was also affected by the percentage of OPDC fibre used in the composite. It was noted that the tensile strength for both with and without MAPP addition increased with the increasing of OPDC up to 30% and decreased as the OPDC content was increased to 50%.

This result was similar with others researcher’s result where the additional of MAPP increased the impact strength of the composite [25]. In this experiment, the trend was similar to tensile and flexural test which can be explained due to the high percentage of OPDC in composite causing the OPDC to lose its function to absorb the force applied to the composite during the test. The test shows that the impact strength of the composite dropped at 50% OPDC content. The impact strength of the composite was affected by the natural fibre-polymer adhesion. The good adhesion between those two materials increased the shear strength; thus, the composite can resist higher impact [25]. Natural fibres act as energy (impact) absorber for the composite. By improving the bonding between the natural fibre and the polymer, high amount of energy can be absorbed. In others words, the composite impact resistant was increased [3, 20, 28]. The effect of increasing OPDC content to the composite impact strength is shown in Fig. 4. The trend of graph for the impact strength is similar with the trend shown in Figure 1 and Figure 2, where the properties of the composite increased at 10% to 30% OPDC content and dropped at 50% OPDC content.

This common phenomenon occurs because of the addition of natural fibre that enhances the rigidity of the composite [3]. The presence of OPDC functions as load absorber. While the load was applied, it went through the PP and by using the shear stress, the load was transferred to the natural fibre (OPDC). The great amount of load resulted the composite to have high impact strength. However, the presence of too much natural fibre with poor adhesion between the PP and OPDC caused the load not being able to transfer well. As a result, the load cannot be absorbed and the impact strength weakens [23].

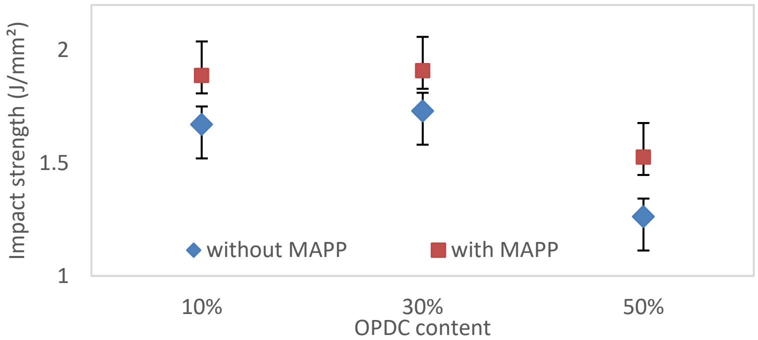

Figure 4: Impact resistant strength of OPDC reinforced polypropylene composites with and without additional of MAPP at different OPDC content

Water absorption

Figure 5 shows the effects of increasing the OPDC content and addition of MAPP to the physical and mechanical of OPDC-RPC. The statistical analysis for the MAPP addition indicates that there is a significant difference on the water absorption rate of OPDC-RPC with 10%, 30%, and 50% OPDC content, where the calculated p-value is 0.00, which is less than 0.05. The statistical analysis for the different percentage of OPDC content at 0% and 2% MAPP addition indicates that there is no significant difference for the composite with 10% OPDC content in both experiments A and B, where the calculated p-value is greater than 0.05. Meanwhile by increasing the OPDC percentage of up to 30% and 50%, the calculated p-values for both experiment A and B are 0.04 and 0.00, respectively which are less than 0.05.

Figure 5 shows that the OPDC-RPC with MAPP addition of 2% has a lower water absorption rate compared to the OPDC-RPC without MAPP addition. The graph shows that by adding MAPP, the water absorption rate slightly decreases. This study also found that the water absorption rate of OPDC-RPC was also affected by the percentage of OPDC fibre used in the composite. It was noted that the water absorption rate for both with and without MAPP addition increased with the increasing of OPDC content. The increasing of water absorption rate could be explained due to the high percentage of OPDC in composite causing the composite hydrophilic ability to increase. As a result, the water absorption rate of the composite increases.

Previous research found that OPDC has low contact angle when contact angle test was done by putting a drop of water on it [3]. The presence of hydroxyl group allowed them to attach the water molecule through hydrogen bond [29]. The high water absorption rate causes the reduction in mechanical properties as their dimension stability becomes low [29,30]. The absorption of water was caused by the presence of pits, cracks, or voids which occurred during the composite production as the PP was non-polar material and OPDC was polar material. The differencet in properties gives a problem during the bonding, thus the defect can occur [31].

It was observed that the MAPP acted to improve the bonding between the OPDC and PP. The improved bonding occurred when the MAPP increased the polarity, which built the hydrogen bonding from the hydroxyl group of the OPDC [10]. As a result, the amount of hydroxyl group which was available to attach the water molecule decreased. Besides that, the improved bonding between fibre and polymer reduced the number of pits, cracks, or voids. As a result, the bonding itself prevented the water from penetrating into the composite [32].

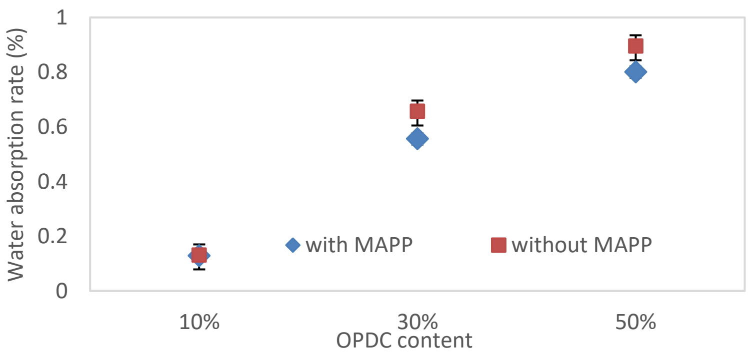

Figure 5: Water absorption percentage of OPDC reinforced polypropylene composites with and without additional of MAPP at different OPDC content

Morphological study of OPDC-RPC

Figure 6 and 7 show the SEM images of the OPDC-RPC with and without MAPP addition, respectively. In Figure 6, a weak interfacial between the OPDC and PP can be clearly seen. This weak interfacial could be caused by poor mechanical and physical properties of the composite as discussed earlier. The weak interfacial caused the composite not being able to withstand the high amount of load due to the poor stress transfer from PP to OPDC. Meanwhile in Figure 7, it clearly shows a strong interfacial between OPDC and PP. The strong interfacial caused the composite to have better mechanical and physical properties as the composite was able to withstand high amount of load. The composite with addition of MAPP has a better load transfer from PP to OPDC which caused it to have higher properties as discussed earlier.

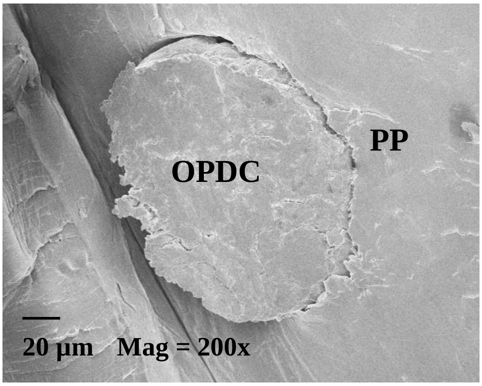

Figure 6: SEM micrograph images of the surface of composite without MAPP addition at 200x magnification

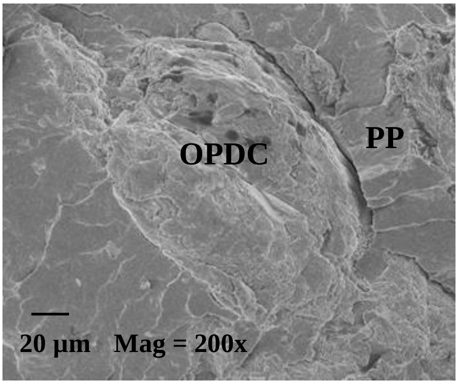

Figure 7: SEM micrograph images of the surface of composite with MAPP addition at 200x magnification

Conclusion

Differences in MAPP content and OPDC content result slightly affect the physical and mechanical of the composite. However, the statistical analysis shows that there is a significant difference and no significant difference by changing the MAPP content and OPDC content, respectively. Increasing OPDC content improved the tensile, flexural, and tensile strength up until 30% OPDC content. The usage of 50% of PP for the matrix seems insufficient binder as composite made from 50% PP shows poor result in all tests even though MAPP is being used. The effect of MAPP is minimal as compared to the effects of OPDC content. The composite made from high OPDC content shows high water uptake since the property of OPDC is hydrophilic. From this study, it clearly shows that the best formulation in order to achieve the optimum results in this study is using 30% OPDC and 2% MAPP.

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