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The Effect of Different Percentage of Dammar Gum on Water Absorption Performance of Palm Oil Frond Fiber Reinforced Tapioca Starch Composite

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Abstract

The demand for wood and wood-based composites is increasing rapidly due to global economic growth and population rise. This has led to deforestation and global warming, raising sustainability concerns. A major drawback in fiberboard manufacturing is poor water resistance, particularly among coupling agents. Another issue is determining the optimum composition of dammar gum to achieve the best water resistance. This study investigates the effect of varying dammar gum percentages on the water absorption performance of oil palm frond fiber reinforced with tapioca starch. Materials used include oil palm fronds, tapioca starch, and dammar gum in 2%, 4%, 6%, and 8% weight ratios. The process involved crushing, sieving into two fiber size groups, drying, mixing, compression molding, and laser cutting. Water absorption and thickness swelling tests were conducted. DG 6% performed best with the lowest thickness swelling (3% at 5 hours, 20% at 24 hours) and relatively low water absorption (80% at 5 hours, 83% at 24 hours). The control sample, DG 0%, showed the worst performance with thickness swelling up to 74% and water absorption up to 68%. DG 8% showed the best long-term resistance with 31% water absorption and 11% swelling at 504 hours. In conclusion, dammar gum is effective in reducing water absorption, but excessive amounts can cause agglomerates, reducing performance.

1. Introduction

The wood-based panel industry includes multiple specialized sectors that manufacture different types of engineered wood products, such as fiberboard, particleboard (PB), plywood, oriented strand board (OSB), and more. The furniture and building industries are the primary drivers of the wood-based panel industry's recent explosive growth [1]. According to the Food and Agriculture Organization (FAO), medium-density fiberboard (MDF) is the world's most widely used wood-based panel, with global production hitting around 111 million cubic meters in 2021 (Lao & Chang, 2023).

Major drawback of a fiberboard in a manufacturing is poor resistance to the water among coupling agent. Dammar Gum is a potential green coupling agent to be used in these combinations. A lot of study were conducted to improve the water resistance of fiberboard.

In previous studies, water absorption performance has been investigated in fiberboard composites. One study on wood-polypropylene composites showed a variation in water absorption with different wood powder contents, where higher wood content resulted in greater water uptake. This was particularly evident when the composite samples were soaked in water for a specified period (Wang et al., 2020).

The major problem of this approach, the optimum composition of the dammar gum in producing best water resistance performance. Therefore, this research was conducted to determine the optimum dammar gum percentage for oil palm frond fiber - tapioca starch composite.

This study was conducted to investigate the effect of different percentages of dammar gum on the water absorption performance of oil palm frond fiber-reinforced tapioca starch composites. Specifically, the objectives of this research are to evaluate the influence of varying dammar gum content on water absorption, to examine the failure behavior of the composite material under different dammar gum concentrations, and to determine the optimum percentage of dammar gum for enhancing the performance of oil palm frond fiber-tapioca starch composites.

Natural fibers such as oil palm frond (OPF) require surface treatments to enhance the performance of natural fibers fibers [4]. While it improves adhesion between fibers and the matrix, the intrinsic properties of the materials themselves also heavily influence the composite's performance. This alkali treatment offers several advantages that enhance the mechanical performance of natural fiber-reinforced composites (NFRCs). These benefits include: (1) an increase in cellulose content and crystallinity, contributing to greater fiber strength and stiffness; (2) improved surface roughness, which promotes stronger mechanical interlocking with the matrix; (3) greater exposure of cellulose, providing more bonding and reaction sites on the fiber surface; and (4) elevated surface energy, which enhances wetting and compatibility with the matrix material [5]. Alkali treatment on OPF is preferred for improving the fiber–matrix adhesion compared to other treatments. These surface treatments are non-organic and researcher are looking for organic coupling agent. Dammar gum is an alternative for making surface treatments.

Dammar Gum is a substance that does not dissolve in water and is widely used in the food industry as a stabilizer, thickener, and emulsifier. It is also used in the pharmaceutical industry as a binder and coating agent for tablets and capsules. The purified resin is dried and ground into a fine powder for various applications. Because of its adhesive qualities, DG is anticipated to improve the interfacial addition between fiber and matrix in natural fiber composites. The impact of natural binders, such as DG, on the mechanical and thermal performance of natural fiber-polypropylene composites has been investigated. The research indicates that adding natural binders can improve the interface strength between the natural fibers and the polymer matrix [6].

2. Materials and Methods

This chapter explained how the preparation was carried out before the following process began. The materials used in the study were oil palm frond (OPF) and dammar gum (DG).

2.1 Materials

2.1.1 Oil Palm Frond

Fresh OPF petioles were obtained from Parit Sulong oil palm plantation, Batu Pahat Johor Malaysia. The oil palm frond is approximately 2-3 meters longand weighs about 10kg (wet weight). It consists of the petiole (the stem) and many long leaflets on either side of the stem as shown in Figure 1

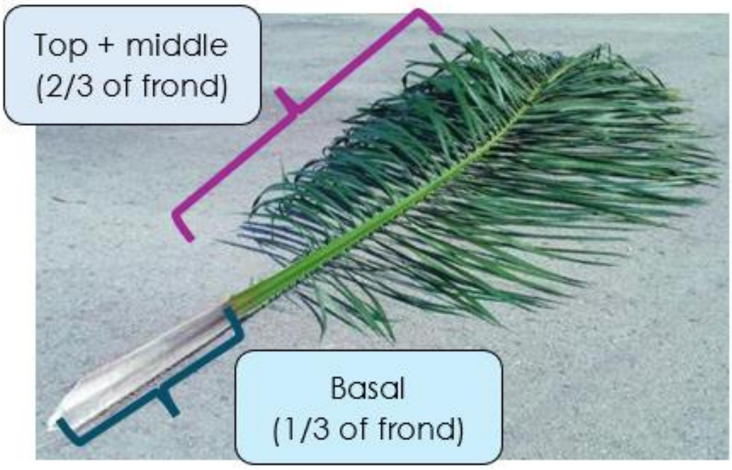

Fig. 1 *Oil Palm Frond Length*

2.1.2 Dammar Gum (DG)

Figure 2 shows the DG as a natural binder utilized in this study and additional material improve the thermal conductivity and thermal performance on the preparation of composite phase change material [7], purchased from Kalimantan, Indonesia. The density of DG varies from 1,040 to 1,120 kg/m^3 with a melting point of 150 °C and a degradation point of 200 °C.

Fig. 2 *Dammar Gum (DG) Powder*

2.2 Compounding

Initially, four different percentages of Dammar Gum (DG), specifically 2%, 4%, 6%, and 8% were added to the OPF-TS mixture with fiber size less than 0.5mm and between 0.5mm-1.2mm. Five samples are prepared with different percentages of DG added to the specified fibre lengths to analyse the suitable combination of composition.

Table 1 *Present the detail composition of OPF-DG sample in this research*

	Fiber (g)	Matrix (g)	Coupling Agent %
DG 0	50	50	-
DG 2	50	48	2
DG 4	50	46	4
DG 6	50	44	6
DG 8	50	42	8

2.3 Water Absorption

Figure 3 shows a water absorption test conducted according to ASTM D570. Each sample was soaked in distilled water for 21 days at room temperature. Weight measurements were taken using a Mettler Toledo Al54 Laboratory Scale.

(a)

(b)

Fig. 3 *(a) Water Absorption test samples immersed in distilled water; (b) Mettler Toledo A154*

Before testing, the weight of each specimen was measured and recorded (W1). To measure the Water Absorption (WA), specimens were removed from distilled water and were wiped off to remove surface water, and then the specimens were weighed after absorbing water (W2). WA is stated as the weight gain in percentage and calculated according to Eq. (1) [8]:

$$\mathrm{WA} = \frac{W_2 - W_1}{W_1} \times 100 \tag{1}$$

where, W2 is the weight after immersion, and W1 is the original weight of the composite.

2.4 Thickness Swelling

The purpose of the thickness swelling test is to determine how much the specimens thickness changes as a result of absorbing water during the duration of their immersion. Both the water absorption and thickness swelling tests run simultaneously to obtain as many accurate results as possible. The thickness change of the specimens was measured using a digital Vernier calliper capable of giving accuracy up to 2 decimal places. The percentage of thickness swelling Ts was calculated using Eq. (2) [8]:

$$\mathrm{T}_s = \frac{T_2 - T_1}{T_1} \times 100 \tag{2}$$

where, T2 is thickness after immersion, and T1 is the original thickness of the composite

3. Results and Discussion

The findings could demonstrate the feasibility of using dammar gum as an eco-friendly alternative to synthetic coupling agents in biocomposite fabrication, advancing the development of sustainable materials.

3.1 Influence of Dammar Gum on Physical Properties

3.1.1 Water Absorption

Figure 4.1 presents the water absorption results for DG 0, DG 2, DG 4, DG 6, and DG 8. The graph demonstrates the correlation between the percentage of water absorption and the duration of immersion, which ranges from 0 to 504 hours, equivalent to 21 days. The water absorption rate varied and depended on the time submerged

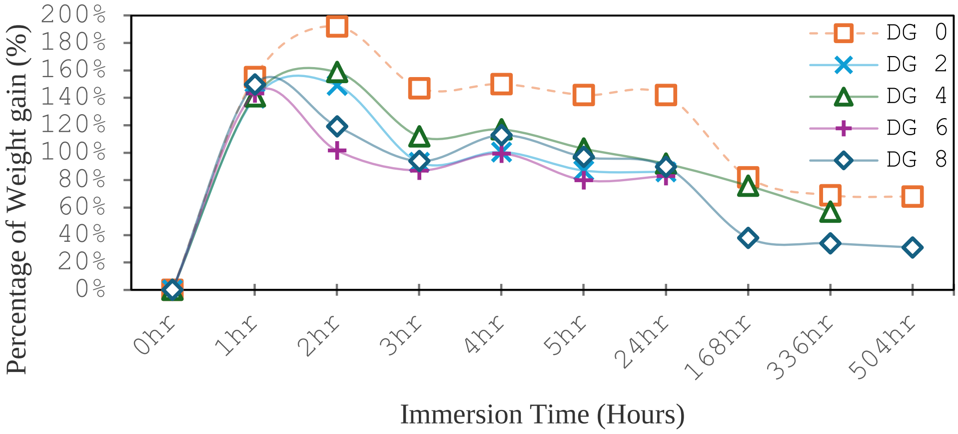

Fig. 5 : *Percentages of weight gain for OPF-TS composites with varying dammar gum content over immersion time.*

At the 1hour mark, the results presented in Figure 4.2 demonstrate that sample without dammar gum (DG 0) shows the highest water absorption at 155% which suggests that the composite without any dammar gum has the least resistance to water absorption. The addition of dammar gum (DG 2) results in a reduction of water absorption to 140% indicating a slight improvement in water resistance. The water absorption of DG 4 at 141% is almost identical of DG 2 suggesting that the addition of 4% dammar gum provides minimal improvement over 2%. DG 6 and DG 8 with higher concentrations of dammar gum show water absorption rates of 143% and 150% respectively.

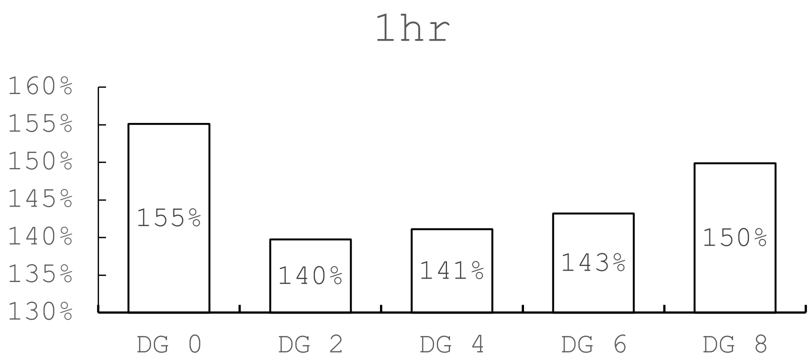

Fig. 6 *: Graph Bar of OPF-TS-DG Samples and Water Absorption Percentage After 1 hour of immersion*

This suggests that increasing the dammar gum concentration does not lead to significant reduction in water absorption at early stage.

After 2 hours, DG 0 still shows the highest water absorption at 192% indicating that it continues to absorb more water than the dammar gum containing samples. DG 2 shows a marked reduction in absorption down to 149% highlighting the positive effect of dammar gum in slowing water uptake. DG 4 absorbs 159% showing a slight improvement compared to DG 0, but still more than DG 2. The most significant improvement occurs with DG 6 which has a water absorption of 102%. This suggests that a 6% concentration of dammar gum offers superior resistance to water absorption compared to both lower and higher concentrations. DG 8 absorbs 119% which is better than DG 0 but not as effective as DG 6.

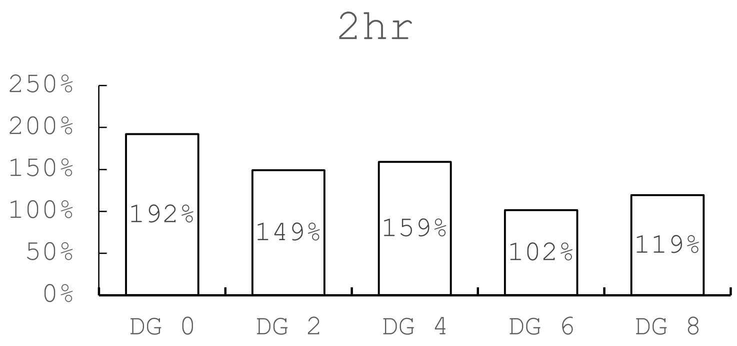

Fig. 7 : *Graph Bar of OPF-TS-DG Samples and Water Absorption Percentage After 2 hour of immersion*

The graph indicates that 6% dammar gum provides the most effective balance of water resistance after 2 hours of absorption.

At the 3 hour, the water absorption rate of DG 0 decreases to 147% but it is still the highest among all the samples. DG 2 shows a futher reduction in absorption, now at 93% indicating that the presence of dammar gum significantly improves water resistance over time. DG 4 absorbs 112% which is still an improvement over DG 0 but not as effective as DG 2. The best performance is observed with DG 6 which absorbs only 87% suggesting that a 6% dammar gum concentration provides the best water absorption resistance at this stage.

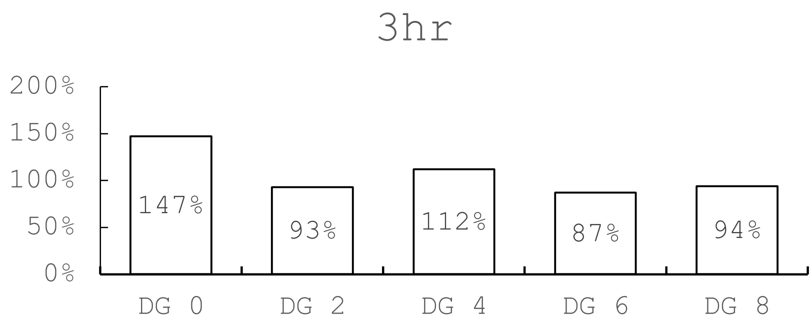

Fig. 8 : *Graph Bar of OPF-TS-DG Samples and Water Absorption Percentage After 3 hour of immersion*

DG 8 absorbs 94% which is slightly higher than DG 6, indicating that further increases in dammar gum concentration beyond 6% do not result in a significant improvement in water resistance at this point.

After 4 hours, DG 0 has absorbed 150% of its initial weight indicating that its water absorption of 101% which suggests that dammar gum continues to reduce water absorption over time. DG 4 absorbs 117% showing a small improvement compared to DG 2 but not as significant as the reduction seen with DG 2. DG 6 continues to show the best performance with water absorption reduced to 99%. The results indicate that the 6% dammar gum concentration remains the most effective at this stage.

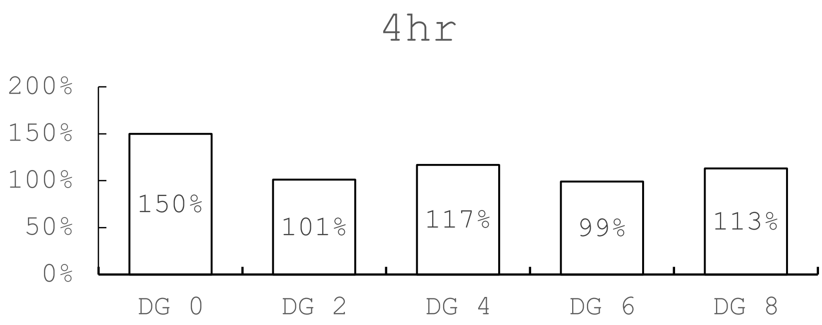

Fig. 9 : *Graph Bar of OPF-TS-DG Samples and Water Absorption Percentage After 4 hour of immersion*

DG 8 absorbs 113% demonstrating that increasing the concentration of dammar gum above 6% does not improve water resistance.

DG 0 has stabilized at 142% water absorption after 5 hours. Although it is now consistent, the control sample rate is still highest of all the samples. With an 87% water absorption rate, DG 2 exhibits a notable improvement. This decrease demonstrates how well dammar gum works to improve the composite resistance to the water. DG 4 absorbs 103% and while still better than DG 0 it does not show as much improvement as DG 2.

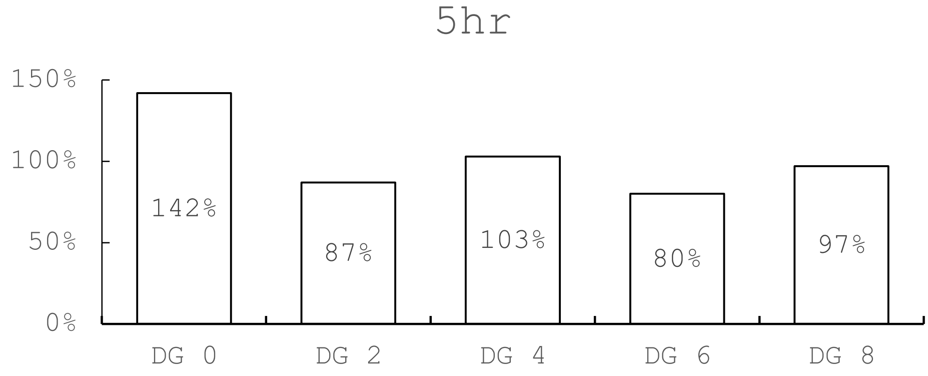

Fig. 10 : *Graph Bar of OPF-TS-DG Samples and Water Absorption Percentage After 5 hour of immersion*

The optimum performance is maintained by DG 6 absorbs 80%. While DG 8 absorbs 97% indicates that raising the dammar gum content over 6% currently offers little additional benefit.

The control sample has attained its highest absorption capability as evidenced by DG 0 continuous water absorption of 142% after 24 hours. With an absorption rate of 86%, DG 2 keeps proving dammar gum beneficial effects on water resistance over time. Although DG 4 with absorption rates is 92% of water indicates a slight decrease from DG 2. It is still not superior to DG 6 with absorption rates 83%. DG 6 continues to perform the best showing water resistance.

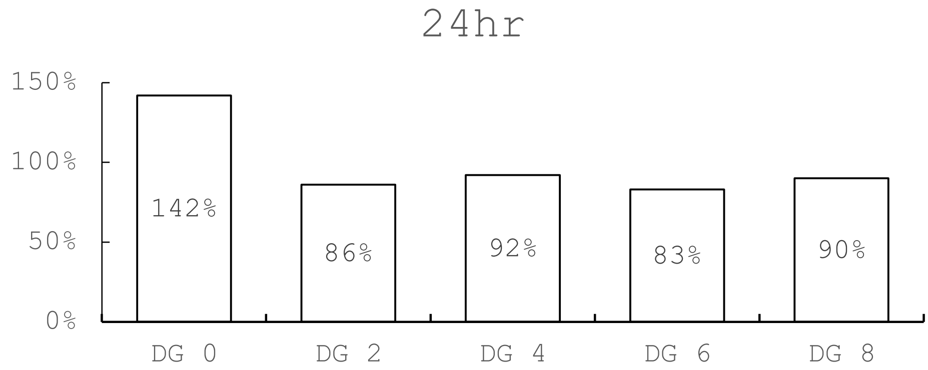

Fig. 11 : *Graph Bar of OPF-TS-DG Samples and Water Absorption Percentage After 24 hour of immersion*

With a 90% water absorption rate, DG 8 demonstrates that after 24 hours further increases in dammar gum concentration do not provide much more benefit.

By 168 hours, DG 0 stabilizes at 82% showing that water absorption for the control sample has leveled off. However, both DG 2 and DG 6 do not have data available for this time point due to fracture issues which means we cannot make a direct comparison for their performance. The 4% dammar gum concentration provides considerable water resistance but is less effective than DG 2 or DG 6 as seen by DG 4 with 76% absorption.

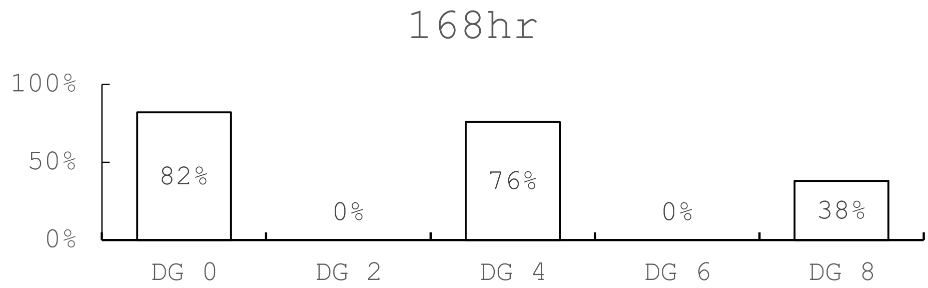

Fig. 12 : *Graph Bar of OPF-TS-DG Samples and Water Absorption Percentage After 168 hour of immersion*

Although DG 8 performs the best among the samples at this stage with an absorption rate of 57%, it is still less effective than DG 6 or DG 2 in the early hours.

DG 0 reaches 69% showing a continued decrease in water absorption but still the highest among the samples. Once more, DG 2 and DG 6 cannot be compared since they lack data because of fractures.

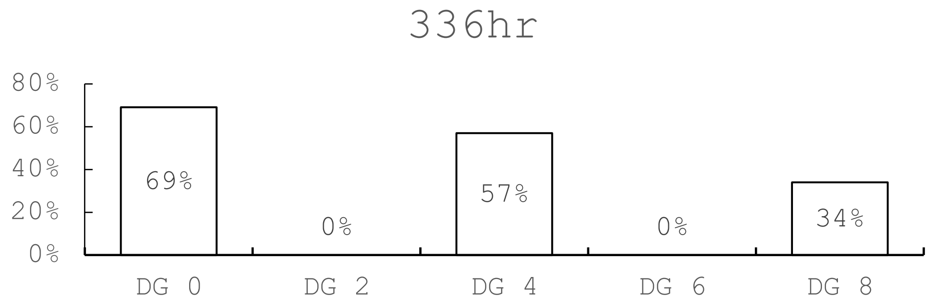

Fig. 13 : *Graph Bar of OPF-TS-DG Samples and Water Absorption Percentage After 336 hour of immersion*

Although DG 4 absorption rate of 57% is slightly improved than that of 168 hours it still falls short of DG 8 with 34% absorption rate which at this point indicates superior water resistance.

At final time point, DG 0 absorbs 68% indicating that the control sample water absorption. It is challenging to evaluate DG 2, DG 4 and DG 6 long term performance because they are once more missing data because to fracture. DG 8 absorbs 31% which is a comparatively low amount of water absorption as compared to previous measurement.

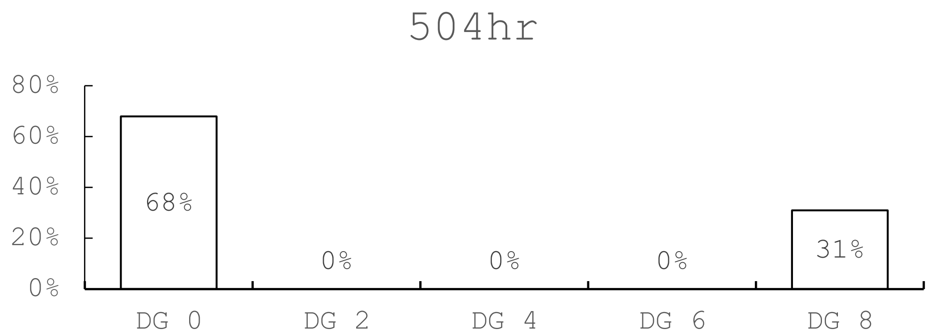

Fig. 14 : *Graph Bar of OPF-TS-DG Samples and Water Absorption Percentage After 504 hour of immersion*

From this graph, we can conclude that DG 6 (6% dammar gum) provides the best balance of water absorption resistance at short term, while DG 8 offers promising long term resistance. This could be because the higher resin percentage created more linkages between fibers, preventing water absorption [9]. The control sample (DG 0) has the highest water absorption because poorly dispersed fiber may form into clumps in which many of the fibers are only in partial contact with the matrix [10] and the addition of dammar gum helps significantly reduce water uptake. DG 6 is particularly effective between 2 and 24 hours providing the best balance of water resistance without significant diminishing returs seen with higher concentrations (DG 8).

3.1.2 Thickness Swelling

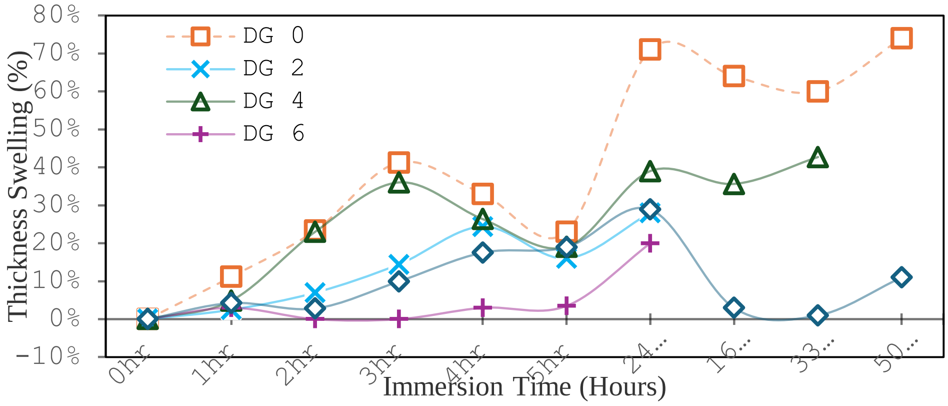

Fig. 15 : *Percentages of Thickness Swelling for OPF-TS composites with varying dammar gum content over immersion time.*

Based on the graph, The sample without dammar gum (DG 0) showed the highest thickness swelling, starting at 11% after 1 hour and rising to 74% at 504 hours. The thickness swelling of the specimen was mainly due to the high water attraction nature of the hemicellulose part and the presence of the hydroxyl group in the cellulose structure of the natural fibres. The aforementioned factors and the capillary action might have caused the composite specimen to absorb more moisture when immersed in water, hence increasing thickness [11]. In contrast, DG 2 which contained 2% dammar gum showed only 2% of thickness swelling at 1 hour and 7% at 2 hours increasing moderately to 28% at 24 hours. While long term data after 24 hours for DG 2 is unavailable due to the fracture. DG 4 presented moderate behavior, beginning with 5% swelling at 1 hour. Peaking at 36% by 3 hours.

The 24 hour mark revealed significant differences in sample performance. DG 0 continued to show the highest swelling at 71%, indicating poor dimensional stability under prolonged moisture exposure. DG 4 maintained moderate swelling at 39% while DG 2 and DG 8 showed similar swelling values of 28% and 29% respectively. DG 6 continued to demonstrate exceptional performance with only 20% swelling at 24 hours, significantly outperforming all other samples.

DG 0 showed poor performance throughout reaching 74% swelling at 504 hours. DG 4 demonstrated moderate but gradually declining performance, from 39% to 36% and then increased from 36% to 43% swelling. DG 8 showed dropping to 1% at 336 hours before increasing to 11% at 504 hours. However, DG 2 moderate swelling around 28%.

DG 6 demonstrated superior moisture resistance with consistenly low swelling value (maximum 20% at 24 hours), establishing it as the best performing sample. DG 0 showed poor dimensional stability with the highest swelling throughout testing. Reaching 74% for 504 hours.

Based on the thickness swelling analysis, DG 6 is identified as the best performing sample, demonstrating superior moisture resistance and dimensional stability throughout the testing period. The sample maintained consistently low swelling values, making it the most suitable choice for applications requiring minimal dimensional changes under moisture exposure. DG 0 showed the poorest interaction between fibre/matrix and distribution of fibres affects thickness swelling and dimensional stability composite [12], [13].

4. Conclusion

In conclusion, dammar gum serving as a coupling agent has proven effective in reducing water absorption in the composite. However, its effectiveness is highly dependent on the applied concentration. The excessive use of dammar gum may result in negative impacts like increased water absorption because of agglomerates that form inside the composite structure.

Under ideal conditions (DG 0), the fibreboard surface contains no exposed pores or voids. The addition of dammar gum helps to fill and seal these surface imperfections, effectively reducing the pathways for water penetration and thereby enhancing the composite's resistance to moisture absorption.

DG 0 shows higher water absorption compared to DG 6. In this case during the two hours, DG 6 demonstrates good water resistance. Among all the compositions tested, DG 6 is considered the most optimum. The other formulations still have potential for improvement over longer durations. Excessive amounts of dammar gum may lead to higher water absorption due to the formation of agglomerates, which negatively affect the performance. Therefore, dammar gum can improve water absorption performance. However, the utilization of dammar gum beyond the optimum concentration may result in drawbacks.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

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