

# Hydrophobic Coating Made of Natural Seed Oil and Organic Wax for Wood and Steel

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**Abstract** — *The purpose of the study is to develop a hydrophobic natural solution as an alternative coating material for wood and steel substrates. The study uses Moringa seed oil, Tarap seed oil, and Soy wax to create a natural hydrophobic coating solution that can prevent water infiltration while at the same time being free from harmful chemicals. Using the mixture of Moringa Oil, Tarap Oil, and Soy wax, the wood and steel substrates were dip-coated and cured for seven (7) days. The heat treatment method was then used to determine if there was any improvement to the Water Contact Angle (WCA) of both Wood and Steel substrates. After the series of tests, it has been found that half of the wood samples with salt templating shows sign of hydrophobization, precisely, Wax Coating ( $90.72^\circ \pm 5.12^\circ$ ), Wax-Moringa Coating ( $90.47^\circ \pm 1.42^\circ$ ), Wax-Tarap Coating ( $101.98^\circ \pm 5.18^\circ$ ), Wax-Moringa-Tarap (2:2:1) Coating ( $90.77^\circ \pm 3.53^\circ$ ), and Wax-Moringa-Tarap (2:1:2) Coating ( $91.98^\circ \pm 6.38^\circ$ ). It implies that using salt templating as a surface fabrication effectively increases the WCA of the surface. Also, the wood samples without salt templating (Tarap Coating, Wax-Tarap Coating, and Wax-Moringa-Tarap (2:2:1) Coating) have achieved a hydrophobic level of water contact angle after the heat treatment from  $85.59^\circ$ ,  $85.31^\circ$  and  $82.62^\circ$  to  $90.96^\circ$ ,  $90.35^\circ$ , and  $90.11^\circ$ , respectively. Furthermore, most of the steel samples did not reach a hydrophobic level but still showed a more significant percent increase of WCA after heat treatment of 11.635% than the wood samples of 6.18%, which signifies that the heat treatment is more effective and offers more heat resistance in steel substrates than in wood. Thus, the combination of Moringa seed oil, Tarap seed oil, and Soy wax is effective in creating a hydrophobic bio-based oil product for wood and steel applications.*

**Index Terms**— *Hydrophobic, Salt Templating, Wood and Steel Protection, Natural seed oil, Organic wax*

## I. INTRODUCTION

Through time, wood has been considered the primary material and tool in constructing buildings and houses. Apart from being a readily available material, it has excellent mechanical performance and environmental benefits for society [1]. Another essential material that is commonly used in building construction is steel. Steel is one of the most excellent materials in the construction industry because of its durability and strength [2]. Both wood and steel are in demand in every country; however, these materials also have disadvantages. Wood is highly susceptible to weathering due to moisture changes, temperature, and oxidation that lead to physical and chemical changes [3]. Erosion of the wood surface and undesired changes in the material are caused by the wood's and water's interaction, resulting in hydrophilicity [4]. On the other hand, because of the severe internal and external environmental conditions, steel is highly susceptible to material degradation by corrosion. [5]. About 20% of the world's steel production is lost yearly, with an expenditure of around 2.4 trillion U.S. dollars [2]. Steel corrosion and wood erosion may be inevitable. However, it can still be inhibited by applying coatings to maintain its properties, extending its service life, and reducing maintenance costs [6]. Hence, a coating that can resist water, or what is known as hydrophobic, is needed to minimize damage to wood and steel structures.

Hydrophobic coating studies the possibility of producing coatings on wood and steel applications. Hydrophobicity occurs when a material exhibits a contact angle greater than  $90^\circ$  [7]. Some studies examined the impact of hydrophobic surface coatings from acute and chronic toxic chemicals, such as Zinc Oxide nanoparticles (ZnO-NPs), that are hazardous to the environment, specifically to marine life [8]. This solution is commonly used for commercial applications; however, ZnO-NPs are somehow a threat and can harm humans and animals because of their cytotoxic properties [9]. Hence, non-toxic and natural hydrophobic solutions must be explored. Organic oil and wax are considered effective hydrophobic finishes on wood [4] and rust protection on steel [6]. There is research about organic oil and wax as hydrophobic coatings [4], but there are no studies yet on Marang (Tarap) as hydrophobic coatings. *Artocarpus odoratissimus*, known as Tarap or Marang, is a popular seasonal fruit in the Philippines. The fatty acids in Marang seeds are tetracosanoic acid, octanoic acid, octadecanoic acid, hexadecanoic acid (the most abundant), and hexanoic acid [10]. Each seed contains protein (5.1-6.6%), fat (10.1- 28.1%), and fiber content (3.2-4.7%) [11]. However, the harvest season of Marang in Mindanao is between August and December [10]. On the other hand, *Moringa Oleifera*, also called the drumstick tree, is considered the most useful and cultivated plant because of its medicinal, nutritional, and commercial value [12]. It is widely cultivated because it grows and adapts naturally to climatic conditions and dry soils [13]. The seed contains high monounsaturated/saturated fatty acids (76.73%), linolenic acids (0.46%), and linoleic acid (0.76%) [14]. The other substance is Soybean wax, which is obtained naturally from soybeans and is also abundant in the country [15]. Extracted soybean oil is a potential alternative for paraffin wax because it is renewable, organic, and environmentally friendly [16]. The wax has

triacyl glyceride, which makes the wax hydrophobic [15]. Using plant-oil-based coatings is challenging because they contain triglyceride molecules that are limited in water solubility [17]. Creating a new coating material from inexpensive renewable resources (combinations of organic and natural oil) enhances mechanical, thermal, hydrophobicity, and anti-corrosive performance [18]. Moreover, this coating benefits the structural integrity of the materials used in construction.

Coatings in the construction industry are essential to keep various building surfaces safe and secure from corrosion that may lead to structural failure [2]. It shows that the development of environmentally friendly and cheap hydrophobic coatings is needed [5]. In addition, the mixture of two hydrophobic solutions on surface treatment is limited to a wood substrate and other substrates such as steel.

The main objective of this study is to develop a hydrophobic natural solution as an alternative coating material for wood and steel substrates. The other objective of this study is to determine the heat resistance of the natural solution on both wood and steel substrates. Industries, such as construction, can benefit from this study by considering using cheaper and non-toxic coatings with hydrophobic and anti-deterioration effects on construction materials. In addition, the study is also beneficial to people with a low-cost housing budget without compromising and reducing the service life of the material. Moreover, future researchers can use the study to generate new ideas to develop natural and organic coatings for different construction materials.

Construction materials heavily affect the integrity of the constructed buildings. Without proper surface application and maintenance, structural failure might occur. With that, it is essential to use a coating to protect the material from fast degradation and prevent the loss of material strength.

Demonstrating a simple method of fabrication of hydrophobic coating on wood and steel containing Marang seed oil, Moringa seed oil, and Soy wax may satisfy the problem without the need to use toxic substances, considering its economic worth. Hence, the study is limited to the use of deionized water as a liquid in all contact angle testing. Also, since this study is laboratory scale, we limit the sizes of the substrates to 1''x1''x1/8''.

## II. MATERIALS AND METHODS

### A. Conceptual Framework

The framework describes the process of creating hydrophobic coating from the Moringa Oleifera seed and Marang (Tarap) seed, which involves the extraction of oil from the raw seeds as described in the preparation of materials. The oils are then collected and prepared together with the soy wax for the coating solution procedure. After the coating procedure, the coated substrates are ready for testing.

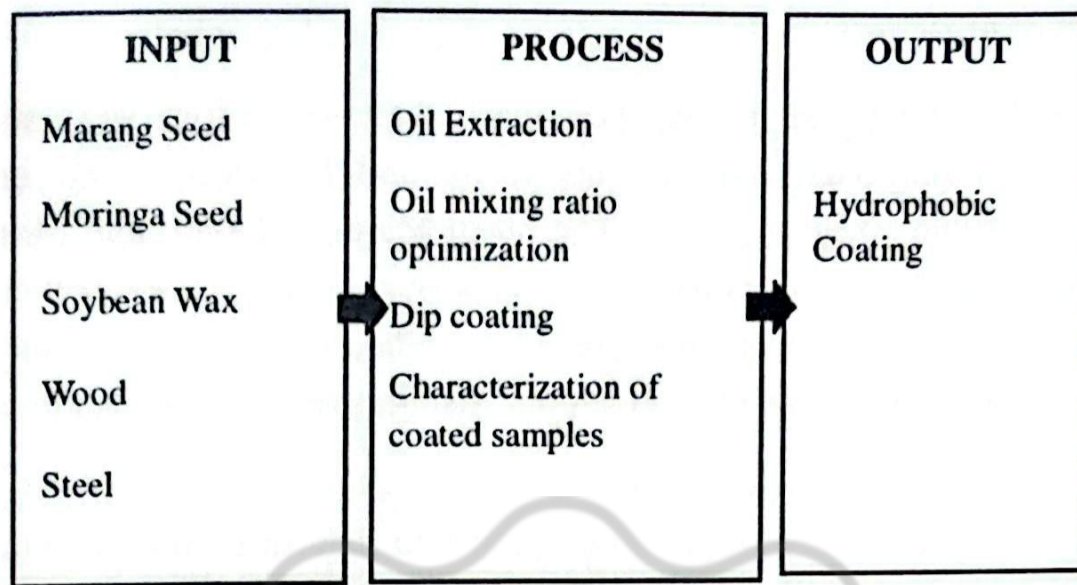


Fig. 1. Conceptual Framework diagram

### B. Materials and Resources

Moringa Oleifera seed oil and Artocarpus Odoratissimus (Marang) seed oil were extracted from Organic Moringa Oleifera seed and Marang (Artocarpus odoratissimus) seed, respectively, and were all obtained from Kerussomarketingcorp.ph (Quezon City, Philippines) and Bankerohan Public Market (Davao City, Philippines). Also, Soy (Glycine Max) Wax from Metro Plus Wax and Candles (Davao City, Philippines) was used as the primary coating material. Other substances include sodium chloride (99.9%, Salinas Foods, Inc.) from (Quezon City, Philippines) which was used for salt templating, ethyl acetate (99.5%, UNIVAR, Ajax Finechem, Auckland N.Z.) used as a solvent in coat mixing, and N-hexane (95%, UNIVAR, Ajax Finechem, Auckland N.Z.) used as a solvent for oil extraction. For the preparation of all substrates, the Marine Plywood was cut in a dimension of 1'' x 1'' x 1/8'' in longitudinal, radial, and tangential directions. Also, the steel plate was cut to 1'' x 1'' x 1/8'' in longitudinal, radial, and tangential directions. The radial surface of the substrate was sanded with 600-grit sandpaper. Lastly, each oil ratio will have five replications of salt-templated and non-salt-templated samples for both wood and steel substrates.

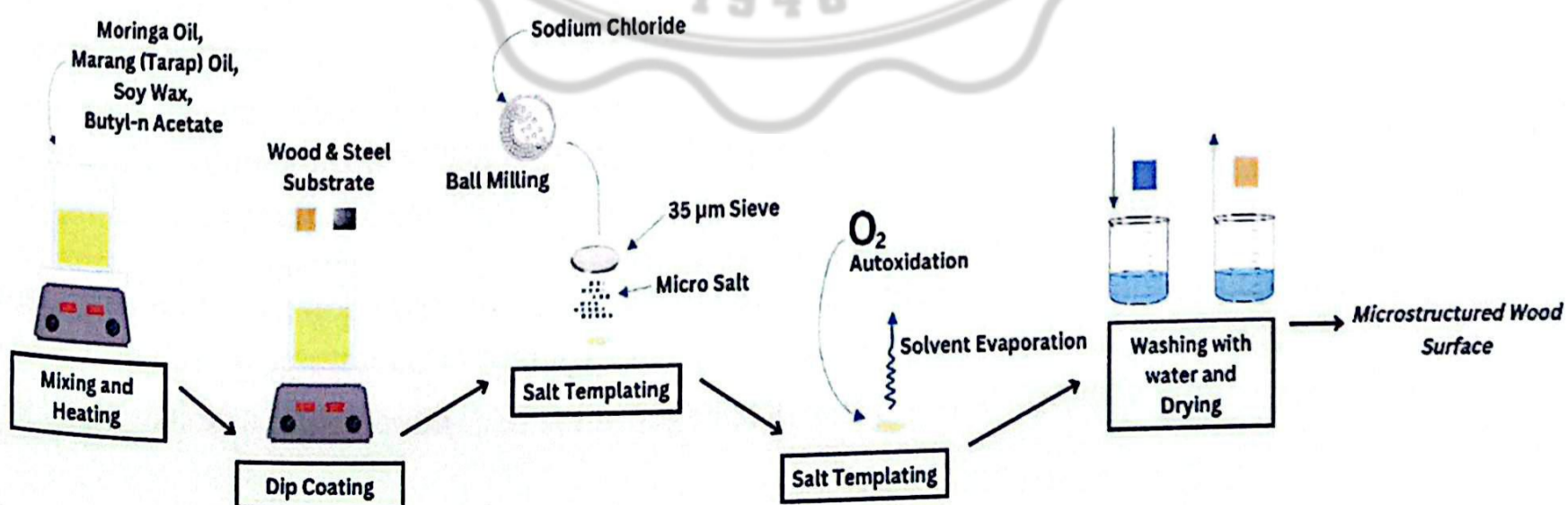


Fig. 2. Graphical representation of producing hydrophobic wood and steel

### C. Preparation of Materials

The collected Marang (Tarap) seeds were washed and dried for five to seven days. The seeds were crushed after drying using a mortar and pestle, and then the crushed seeds were sieved and collected with a particle size of 500  $\mu\text{m}$ . The oil in Marang (Tarap) and Moringa Oleifera seeds was extracted using a thermal Soxhlet apparatus with n-hexane as the solvent. The extracted oil from different seeds is separated and placed in other containers for the coating procedure preparation. Sodium Chloride (20g) was ground using a mortar and pestle at room temperature until it became a fine powder.

Ten (10) ratios of different weights were made to determine the optimum ratio of Moringa seed oil, Tarap seed oil, and Soy wax in creating a hydrophobic coating. The following table describes the weight ratio of Soy Wax (W), Moringa Oil (M), and Marang (Tarap) Oil (T). The samples that received salt templating will be labeled with (S), and the models with no salt templating will be labeled with (N).

Table 1. Salt templated (S) sample ratio of Soywax (W), Moringa (M), and Tarap (T)

LABEL	RATIO	LABEL	RATIO
W1M0T0S	1:0:0	W0M1T1S	0:1:1
W0M1T0S	0:1:0	W1M0T1S	1:0:1
W0M0T1S	0:0:1	W2M2T1S	2:2:1
W1M1T0S	1:1:0	W1M2T2S	1:2:2
W1M1T0S	1:1:0	W2M1T2S	2:1:2

Table 2. Non-salt templated (N) sample ratio of Soywax (W), Moringa (M), and Tarap (T)

LABEL	RATIO	LABEL	RATIO
W1M0TON	1:0:0	W0M1T1N	0:1:1
W0M1TON	0:1:0	W1M0T1N	1:0:1
W0M0T1N	0:0:1	W2M2T1N	2:2:1
W1M1TON	1:1:0	W1M2T2N	1:2:2
W1M1TON	1:1:0	W2M1T2N	2:1:2

### D. Characterization of coating solutions in wood and steel samples

#### Stability of the coating solution

All coating solution variants were heated to 65°C, mixed, and cooled at room temperature to ensure appropriate mixing. Samples were taken at different temperatures: 65°C, 40°C, 30°C, and 25°C to identify changes in its physical properties.

### *Static water angle of coated wood and steel samples*

To measure the static water angle, a software application called Ossila Contact Angle follows ASTM D7334 standard practice for surface wettability of coatings. Water (8 $\mu$ L) was dropped and placed onto the surface of both wood and steel samples with a needle. Five (5) samples of wood and steel substrate were analyzed per ratio. Using the automatic baseline mode and a Young-Laplace fitting model in the software and with the help of the installed camera, the measurements were taken 5 seconds after the deposition.

### *Time stability and heat tolerance of the wetting properties of coated wood and steel*

Each sample of each solution variant with salt and without salt templating procedures was heated in an oven (65°C, 5min.) and cooled down to room temperature to evaluate the possible difference in heat stability of the coating solutions. The stability of the water contact angle was monitored with measurements taken at about 5-second intervals.

### *Microscopic Image Analysis*

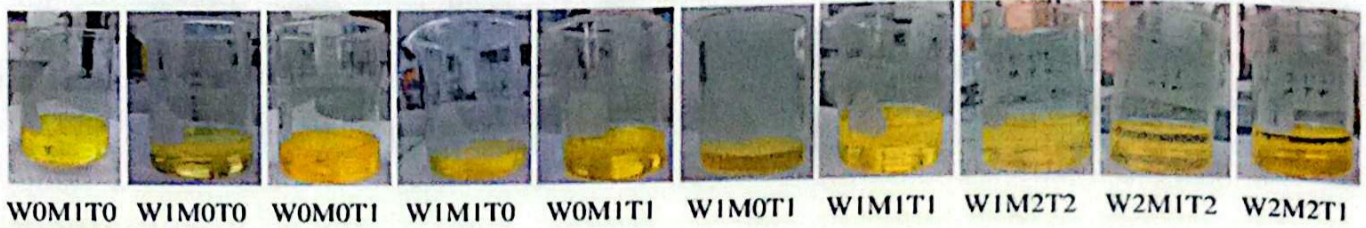
For surface analysis, samples with the highest contact angle were analyzed using Microscopic Image Analysis (MIA). Using the Digital Stereo Microscope with a magnification of 1.5x-3x, it can determine if the coating remains on the surface of the substrate and if there is still the presence of sodium chloride in the given samples that undergo salt templating.

## III. RESULTS AND DISCUSSION

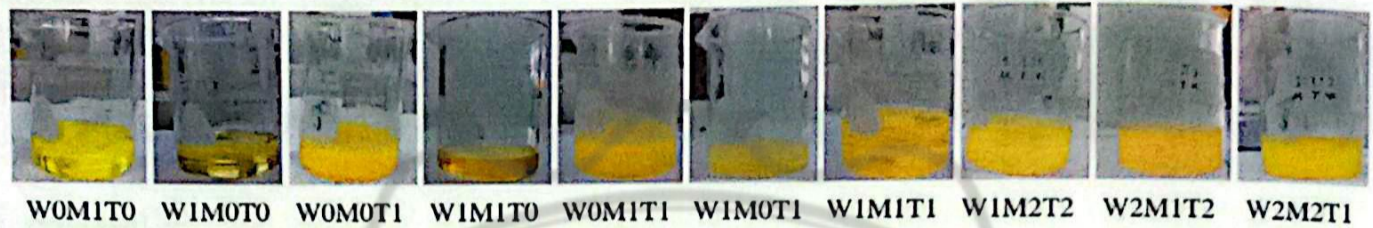
### *A. Stability of the coating*

All coating solutions are in a liquid state at 65°C (Fig.3a). At 40°C, all solutions start to change when it comes to color and texture except W1M0T0, W0M1T0, W1M1T0, and W1M0T1 (Fig.3b). The results show that the ratio and number of oils combined in a solution is the reason for its change in physical properties. As the number of varied oils increases, the more it contributes to the change in the physical property as the temperature drops [4]. As the temperature decreased and reached 30°C, W1M0T0, W1M0T1, and W2M2T1 solidified because of the presence of the soy wax, which quickly hardened as the temperature approached room temperature [20]. At the same time, W0M1T0 and W1M1T0 remained in a liquid state, and the rest were in the viscous state (Fig.3c). At 25°C, all coating solutions had solidified except W0M1T0, which stayed at a liquid state Moringa oil behaves in this manner as it was initially liquid at room temperature [12]. In contrast, soy wax is solid at room temperature [20]. The marang oil was observed to be solid at room temperature and has physical properties similar to waxes. It explains why most of the oil combinations are solid at room temperature. (Fig.3d). From this observation, other oil-wax-based hydrophobic studies show the exact behavior of characteristics in which combined solutions tend to solidify at room temperature [4].

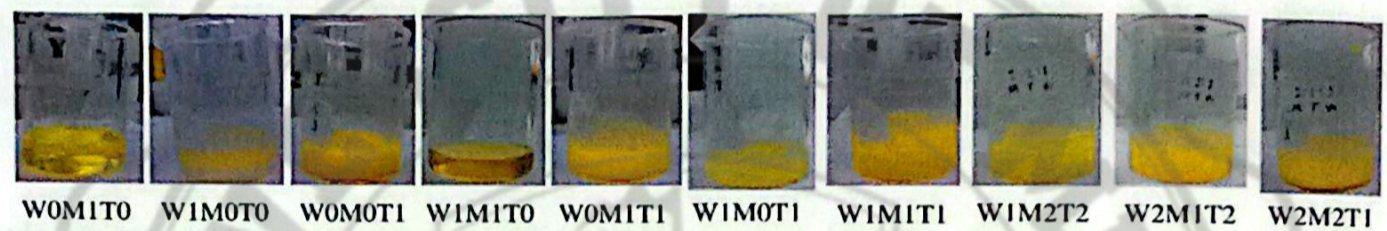
a.) 65°C



b.) 40°C



c.) 30°C



d.) 25°C

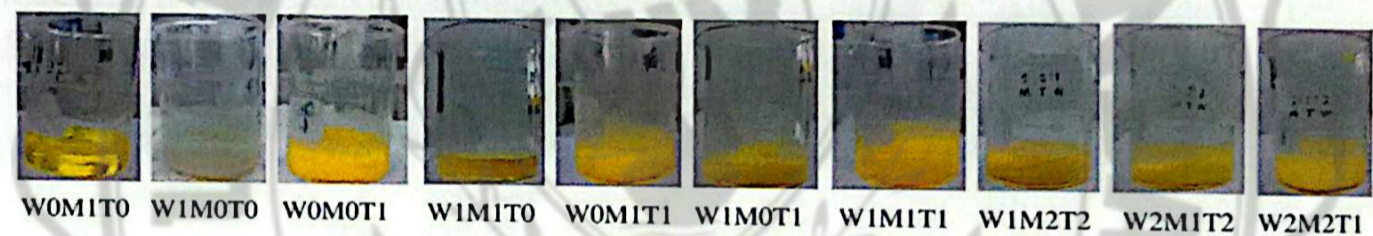


Fig.3. Image of the Ten (10) coating solutions from different mixture of Soywax (W), Moringa (M), and Tarap (T) at different weight ratio (0:1:0, 1:0:0, 0:0:1, 1:1:0, 0:1:1, 1:0:1, 1:1:1, 1:2:2, 2:1:2, 2:2:1) at different temperatures.

#### B. Results of Static water angle of coated wood and steel samples

The static water contact angle on wood and steel samples using mixtures of Moringa oil, Marang (Tarap) oil, and soy wax showed an increase in contact angle with and without salt templating (Fig.4). The water contact angle for uncoated wood is  $45^\circ \pm 9^\circ$  [4] and for uncoated steel is  $47.4^\circ \pm 0.8$  [21].

Only W1M0T0N that contains wax and W1M1T0N that combines resin and Moringa without salt templating showed hydrophobization. Soy wax is already known to reach the hydrophobic level when applied as a coating material [15]. Most likely, the combination of soy wax and moringa oil results in a high contact angle because the oil has penetrated the wood substrate, leaving the soy wax on the surface with a rough structure, with an average value of  $90.64^\circ \pm 4.1^\circ$  and  $97.22^\circ \pm 5.37^\circ$ , respectively. The rest of the wood samples without salt templating did not reach the hydrophobic level, precisely the samples with the Marang seed oil combination. It shows high wettability when applied on a wood surface (Fig.4a), implying more surface hydrophilicity [22].

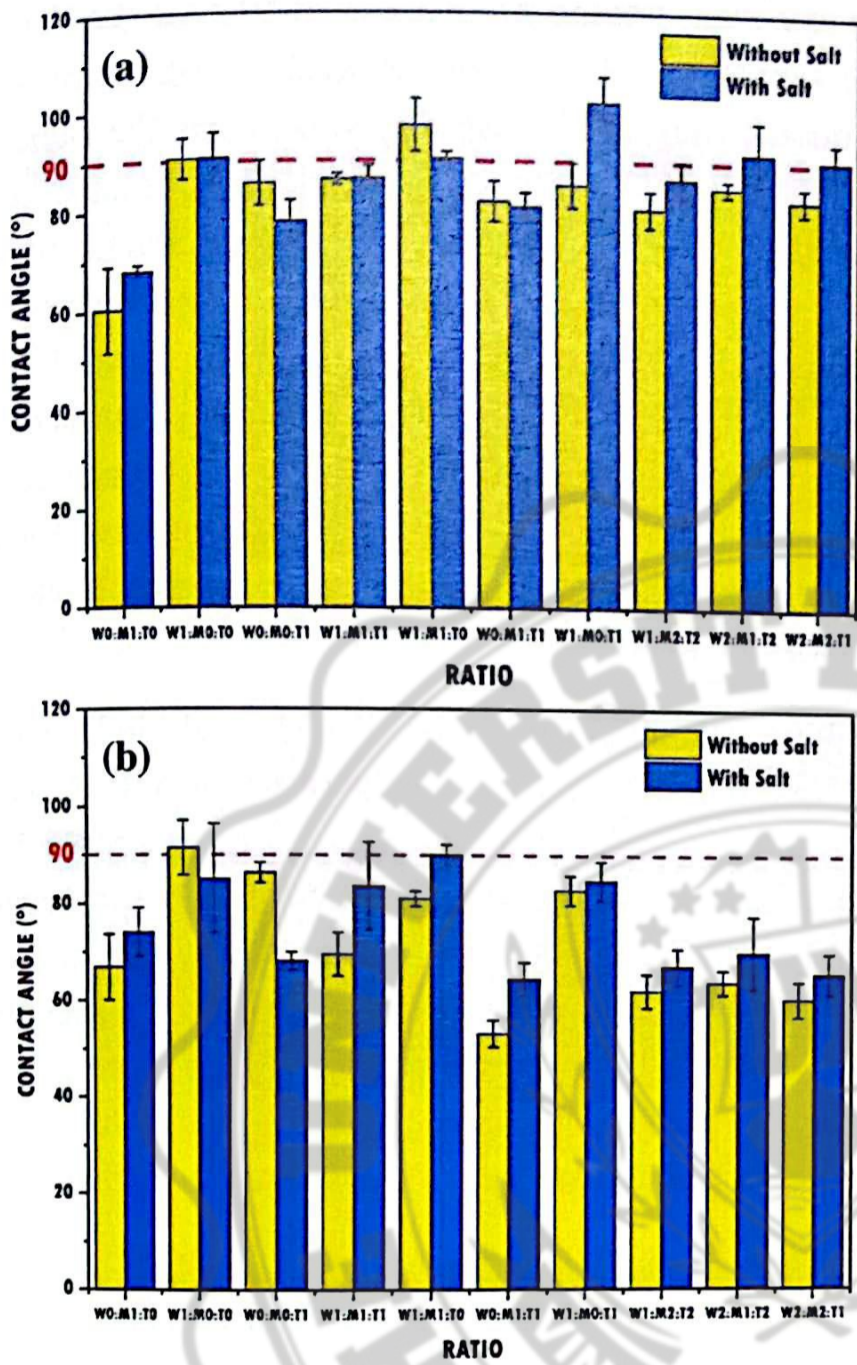


Fig. 4. Average Static Contact Angle of Samples with and without salt templating of Soywax (W), Moringa (M), and Tarap (T); (a) wood samples (b) steel samples

On the other hand, half of the wood samples with salt templating show signs of hydrophobization, which are the following: W1M0T0S ( $90.72^\circ \pm 5.12^\circ$ ), W1M1T0S ( $90.47^\circ \pm 1.42^\circ$ ), W1M0T1S ( $101.98^\circ \pm 5.18^\circ$ ), W2M2T1S ( $90.77^\circ \pm 3.53^\circ$ ), W2M1T2S ( $91.98^\circ \pm 6.38^\circ$ ). The fabrication of the surface structure using salt templating made the samples reach a hydrophobic level [23]. During the curing period, most of the combined samples with salt templating dried, compared to the samples without salt templating, resulting in a rough surface. This rough surface structure helps achieve hydrophobization of the coated sample [24]. Furthermore, most of the samples that reached hydrophobic levels were combined with soy wax, initially hydrophobic because of its wettability properties and surface roughness [15]. While the other half of the samples did not reach a hydrophobic level, they still showed some static water contact angle improvement.

W1M0TON, which solely contains soy wax, having an average of  $91.5^\circ \pm 5.63^\circ$  WCA, reaches the level of hydrophobicity. At the same time, the rest of the steel samples without salt templating show a slight improvement in contact angle (Fig.4b). Soy wax reacts the same way when applied to both wood and steel samples. Its hydrophobicity is achieved because of the coated surface's rough structure [24]. Most of the steel samples with a combination of moringa oil have a low water contact angle. Moringa stays in liquid form even at room temperature, making the combination less viscous or sticky [25]. Also, steel absorbs a maximum of 37% oil, depending on the surface finishing, making most of the oil stay on the substrate surface [26]. Only W1M1T0S shows signs of hydrophobization, having  $90.07^\circ \pm 2.14^\circ$  of average contact angle, and the rest did not. Although most of the steel samples with salt templating have a higher water contact angle than those without salt templating, this signifies that the salt templating method can improve the water contact angle of the coating.

Only a few studies have produced bio-based coatings in wood and steel, and most use waxes to produce hydrophobic coatings [1][2]. Glass was used as a substrate to test the coatings' hydrophobicity [15]. The coating contains soybean wax as well, but in a different approach. By spray method, the authors achieved  $159^\circ \pm 2^\circ$  of water contact angle [15]. Bio-based beeswax and carnauba wax were used to test their hydrophobic angle when applied to the paper surface. It produces a hydrophobic effect on all given ratios and temperatures by conducting a process of emulsification, annealing, and heat treatment [27]. Some may not achieve angles more than  $90^\circ$  because of their low melting point, but having higher heat resistance and better mechanical properties could help produce a hydrophobic effect on the surface of the substrate. Hence, coated samples were heat-treated.

*C. Results of Time stability and heat tolerance of the wetting properties of coated wood and steel*

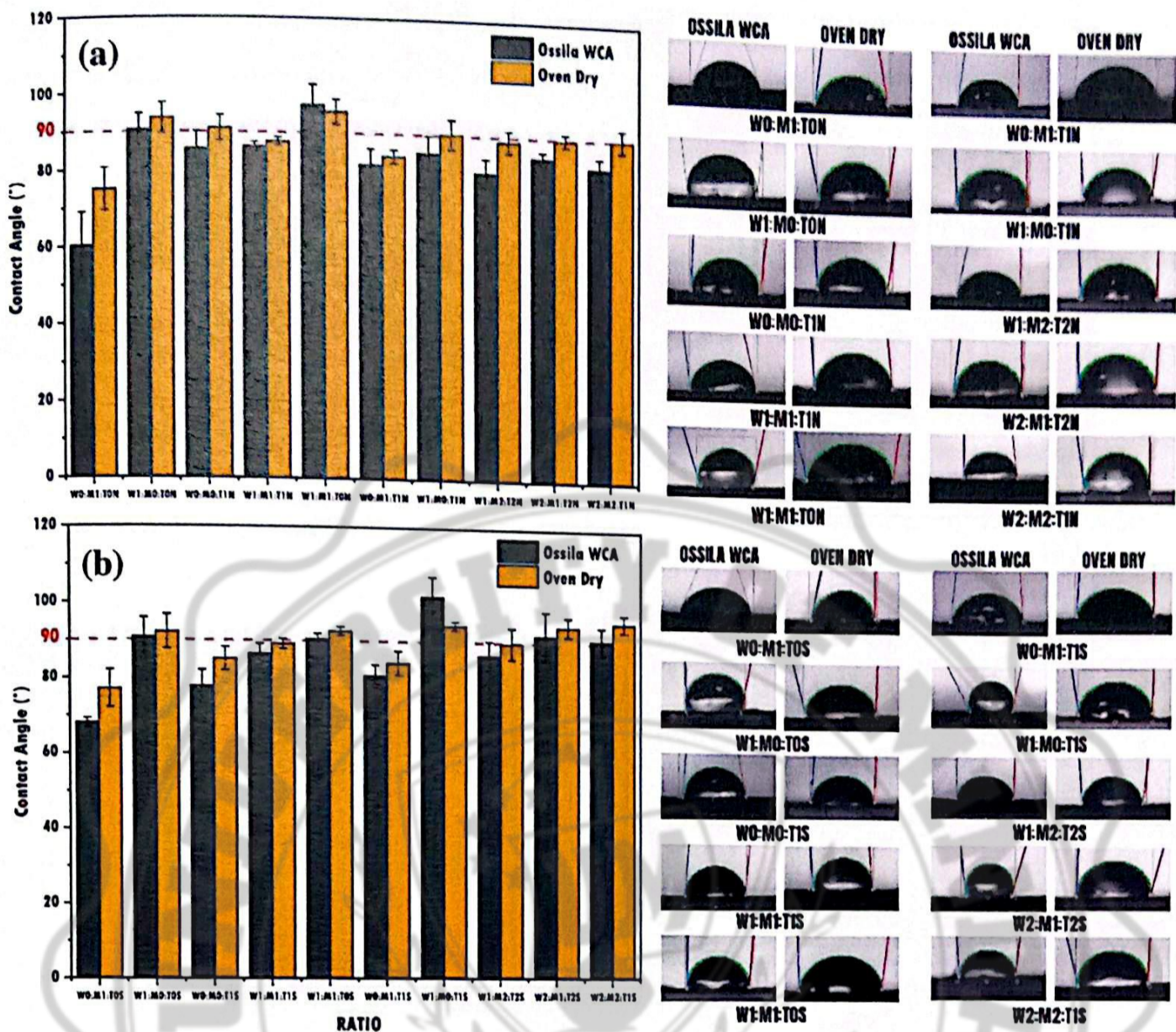


Fig. 5. Comparing WCA of wood substrate before and after oven dry method of Soywax (W), Moringa (M), and Tarap (T): (a) without salt templating (b) with salt templating

After the heat treatment (65°C for 5 min.), some samples showed increased water contact angle value. The samples without salt templating (W0M0T1N, W1M0T1N, and W2M2T1N) have achieved a hydrophobic level of water contact angle after the heat treatment from 85.59°, 85.31° and 82.62° to 90.96°, 90.35°, and 90.11° respectively (Fig.5). While in the samples with salt templating, the samples remained in their respective hydrophobic level. Half of the samples did not reach a hydrophobicity, but most have improved after the heat treatment, with a 6.18% increase in water contact angle. Wood generally absorbs liquid, resulting in a well-structured surface, and the heat treatment has further enhanced it. W0M1T0N showed the most significant increase in water contact angle, reaching 19.66%.

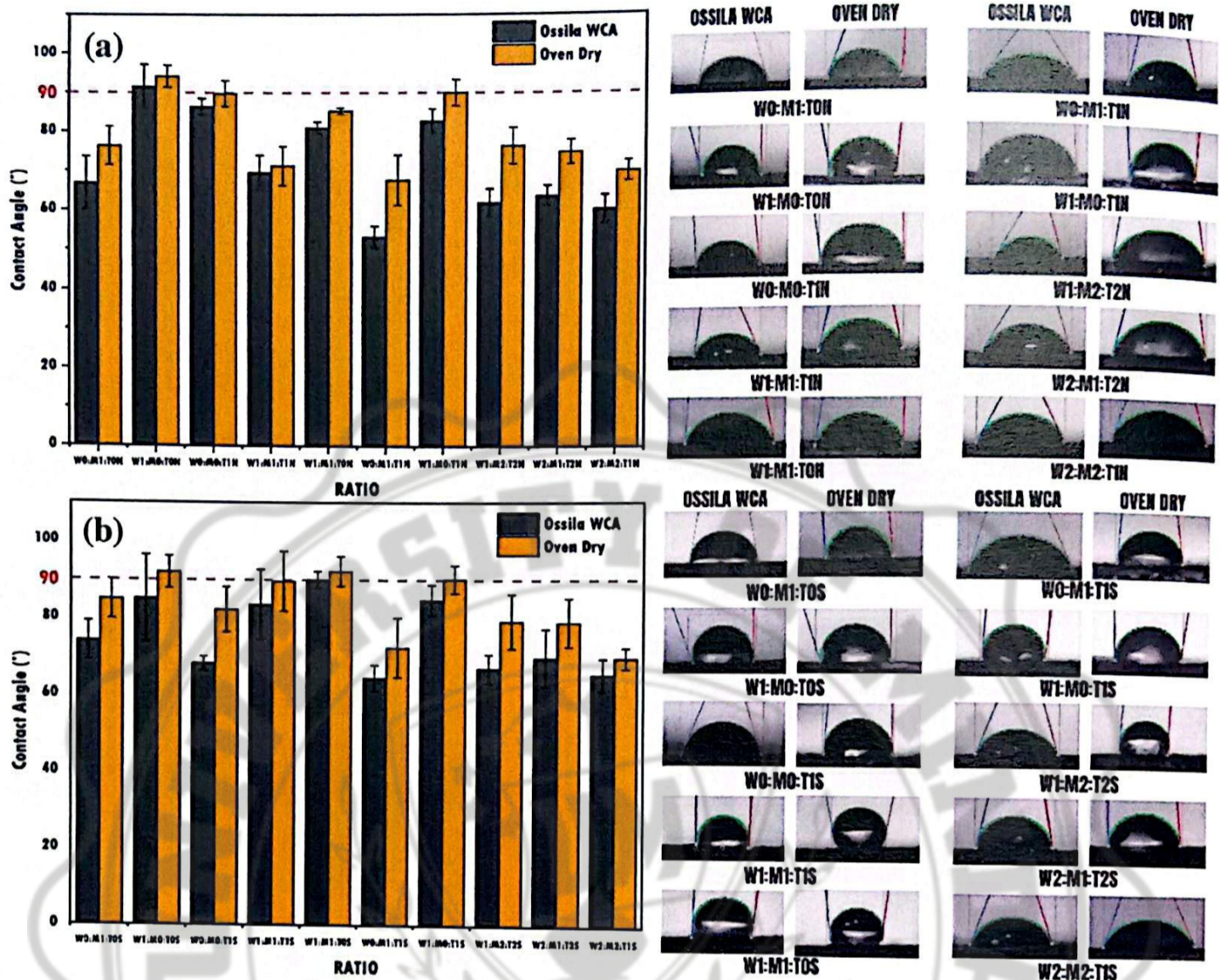


Fig. 6. Comparing WCA of steel substrate before and after oven dry method of Soywax (W), Moringa (M), and Tarap (T): (a) without salt templating (b) with salt templating

W1M0T1N reached the hydrophobic level after the heat treatment from  $82.81^\circ$  to  $90.04^\circ$  WCA. At the same time, the rest remained at their respective level after the treatment (Fig.6). Most samples without salt templating showed an increase in water contact angle after heat treatment. It also indicates that W1M0T0S (WCA =  $91.99^\circ$ ) and W1M0T1S (WCA =  $90.21^\circ$ ) attained hydrophobicity after the heat treatment. Unlike wood, steel absorbs the liquid, causing the surface to moisten. It indicates that steel has high wettability, which contributes to its hydrophilicity. It explains that even with the help of heat treatment, most samples did not reach hydrophobic levels. W1M1T0S remains at a hydrophobic level and slightly increases in water contact angle from  $90.07^\circ$  to  $92.26^\circ$ . At the same time, the other salt-templated samples have not turned into hydrophobic but still showed an 11.64% increase in water contact angle. As the wettability decreased, the surface roughness increased, causing changes in the WCA of all samples [28][29].

#### D. Microscopic Image Analysis

Microscopic Image Analysis was conducted to determine the presence of the coating mixture and sodium chloride on the surface applied in both wood and steel substrates. It also compares the physical aspect of uncoated and coated samples. The analysis started after several processes and tests, such as washing samples and water contact angle tests before and after the oven-dry method. A digital microscope was used to compare samples (Fig. 7 and Fig. 8) morphologically. The uncoated wood sample shows wood strips usually present in marine plywood [1].

In contrast, the coating mixture is visible on the surface in coated wood samples, with and without salt templating. Coating solutions were not evenly distributed to the wood surface because of the wood strips that make the coating cluster in one place and then move to another, except for W0M0T1N and W2M2T1N (Figs. 7 and 8). Also, most of the mixture applied is penetrated directly into wood, making the substrate darker in color, while the rest is concentrated on wood strips. It is observed that there is no phase separation involved as the oil and wax were thoroughly mixed, leaving no room for phase separation.

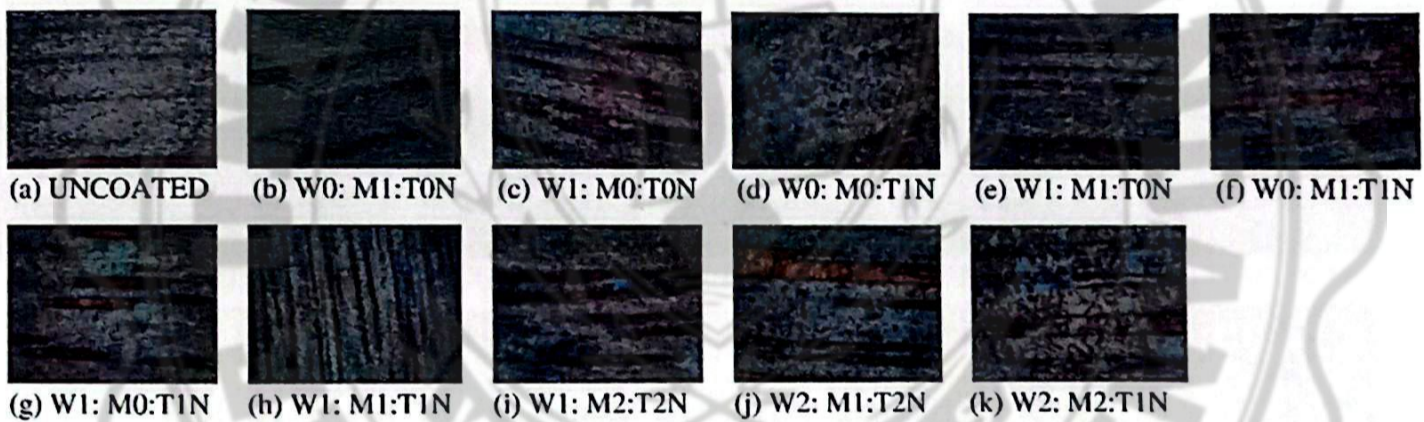


Fig 7. Microscope Image Analysis of Soywax (W), Moringa (M), and Tarap (T) coated wood samples without salt templating (N)

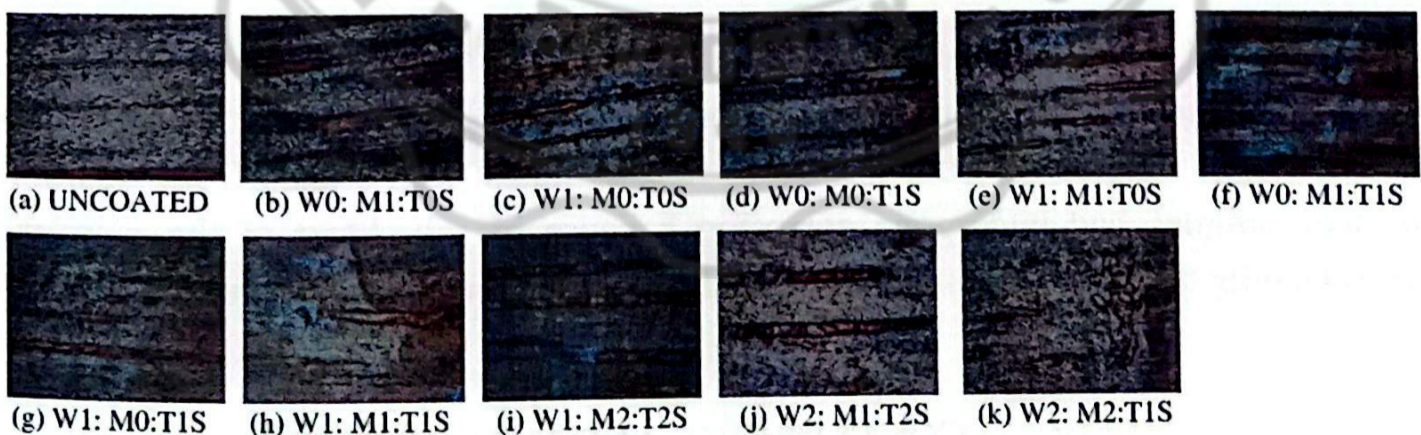


Fig 8. Microscope Image Analysis of Soywax (W), Moringa (M), and Tarap (T) coated wood samples with salt templating (S)

The difference in the surface structure of the steel samples was compared (Fig. 9 and Fig.10). In this figure, uncoated steel forms a grain-like structure that was initially present on steel surfaces [30]. On the other hand, the coating mixture is visible on steel for coated samples, especially for samples with wax in a mixture, both with and without salt templating. Most coated samples are viscous in texture because the solution cannot penetrate well on the substrate. It has been observed that the wetter the surface, the higher its surface energy contributing to its low water contact angle and vice versa.

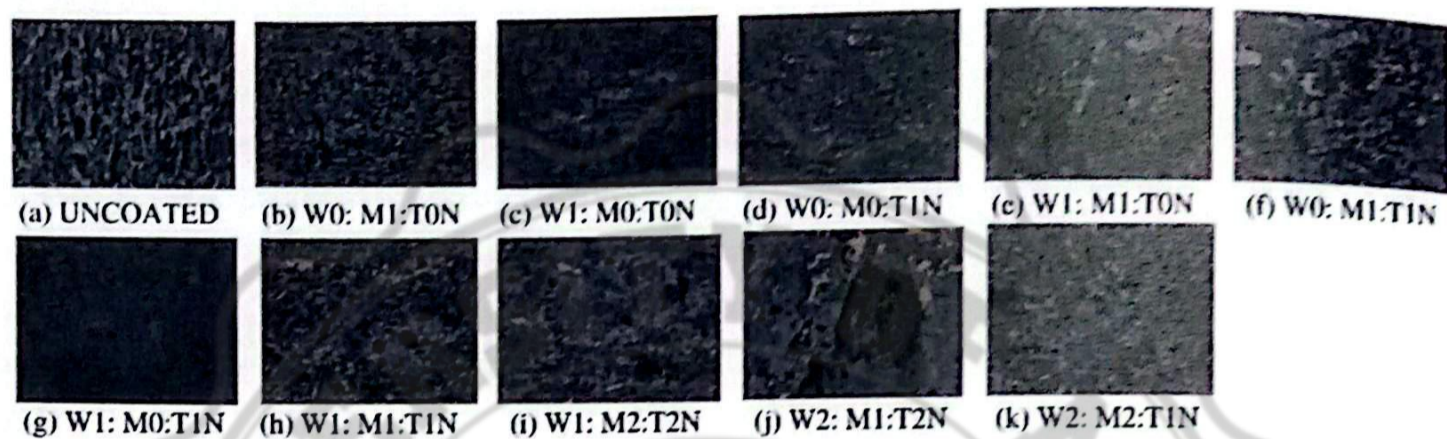


Fig. 9 Microscope Image Analysis of Soywax (W), Moringa (M), and Tarap (T) coated steel samples without salt templating (N)

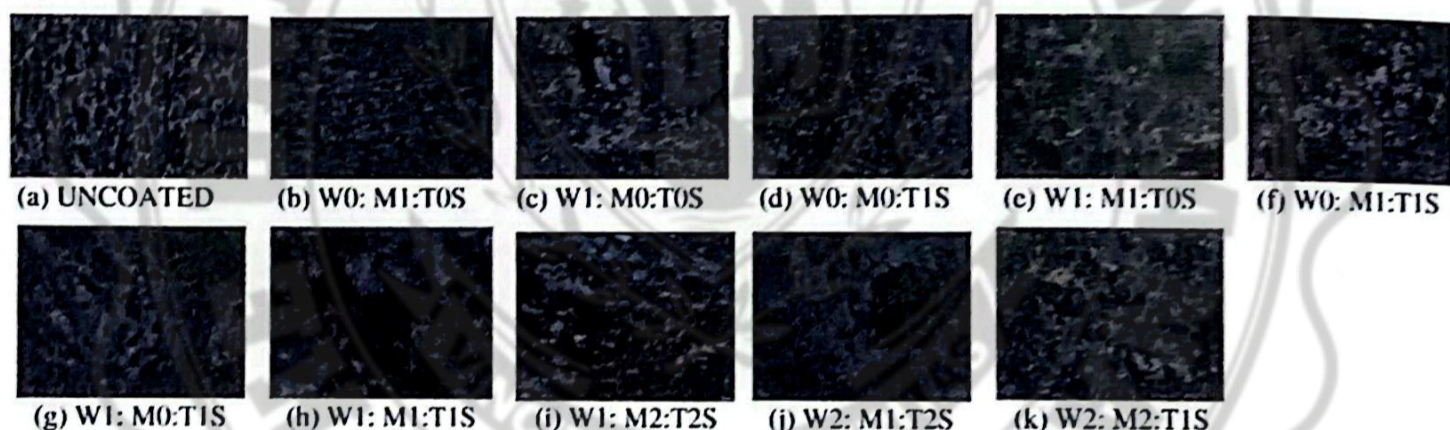


Figure 10. Microscope Image Analysis of Soywax (W), Moringa (M), and Tarap (T) coated steel samples with salt templating (S).

The absence of sodium chloride on every sample's surface signifies the washing procedure's effectiveness for both wood and steel samples (Fig. 8 and 10). It was observed that most steel samples had undergone corrosion because of salt. Most of the samples have wet surfaces leading the salt to solute and mix in the coating solution, which rusts the steel surface.

#### IV. CONCLUSIONS AND FUTURE WORKS

It has been shown that using micro-scaled surface fabrication in bio-based coating effectively increases the coating's hydrophobicity. However, using salt as a component for surface fabrication on steel substrates has a negative effect as it causes rusting on the steel surface. It has also been observed that for the coating containing wax to be workable, especially

on a steel surface, the coating must be heated to 65°C before application. The hydrophobicity of the oil combination, when applied on wood substrates, differs when used on a steel substrate. The pure wax coating is efficient when applied on a steel surface, while the combination of wax and Moringa is effective on a wood surface. The heat treatment also contributes to the increase of hydrophobicity of most oil combinations. Solutions that did not reach hydrophobic levels have reached hydrophobicity after the heat treatment. The percent increase of WCA in a steel substrate (11.635%) is more significant than the percent increase of WCA in a wood substrate (6.18%); this only implies that the heat treatment is more effective in a steel substrate than the wood substrate. Although many oil combinations applied on steel substrate did not reach a hydrophobic level after the heat treatment, it still showed that the heat treatment process is effective for increasing hydrophobicity.

Further study about the properties of Marang oil must be considered. It showed high wettability when coated on a surface. Thus, it contributed to the hydrophilicity of most of the oil combinations. In addition, the ratio's optimization must be thoroughly studied since there might be an increase in hydrophobicity in different oil ratios. Furthermore, the microscopic surface analysis of the sample could be improved using SEM (Scanning Electron Microscopy) or AFM (Atomic Force Microscopy). Also, the test for determining the lifespan of the coating is needed to determine if it can last enough to be used for commercialization. Lastly, for testing the water contact angle, it is preferred to have a high-quality camera when using the Ossila Water Contact angle measurement software for better resolution and precision of the test results.

## REFERENCES

- [1] [1] F. Jiang et al., "Wood-Based Nanotechnologies toward Sustainability," *Advanced Materials*. 2018, doi: 10.1002/adma.201703453.
- [2] A. Fihri, E. Bovero, A. Al-Shahrani, A. Al-Ghamdi, and G. Alabedi, "Recent progress in superhydrophobic coatings used for steel protection: A review," *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. 2017, doi: 10.1016/j.colsurfa.2016.12.057.
- [3] V. Jirouš-Rajković and J. Miklečić, "Heat-Treated Wood as a Substrate for Coatings, Weathering of Heat-Treated Wood, and Coating Performance on Heat-Treated Wood," *Advances in Materials Science and Engineering*. 2019, doi: 10.1155/2019/8621486.
- [4] J. Janesch, B. Armingier, W. Gindl-Altmutter, and C. Hansmann, "Superhydrophobic coatings on wood made of plant oil and natural wax," *Prog. Org. Coatings*, 2020, doi: 10.1016/j.porgcoat.2020.105891.
- [5] A. O. Ijaola, P. K. Farayibi, and E. Asmatulu, "Superhydrophobic coatings for steel pipeline protection in oil and gas industries: A comprehensive review," *Journal of Natural Gas Science and Engineering*. 2020, doi: 10.1016/j.jngse.2020.103544.
- [6] R. E. Melchers and R. Jeffrey, "Modeling of long- term corrosion loss and pitting for chromium-bearing and stainless steels in seawater," *Corrosion*, 2008, doi: 10.5006/1.3280683.
- [7] G. S. Nambafu, N. Kim, and J. Kim, "Hydrophobic coatings prepared using various dipodal silane- functionalized polymer precursors," *Appl. Surf. Sci. Adv.*, 2022, doi: 10.1016/j.apsadv.2021.100207.
- [8] R. W. S. Lai et al., "Hydrophobic Surface Coating Can Reduce Toxicity of Zinc Oxide Nanoparticles to the Marine Copepod *Tigriopus japonicus*," *Environ. Sci. Technol.*, 2021, doi: 10.1021/acs.est.1c01300.
- [9] A. Czyżowska and A. Barbasz, "A review: zinc oxide nanoparticles—friends or enemies?," *International Journal of Environmental Health Research*. 2022, doi: 10.1080/09603123.2020.1805415.
- [10] F. I. Abu Bakar and M. F. Abu Bakar, "Tarap— *Artocarpus odoratissimus*," in *Exotic Fruits*, 2018.
- [11] Y. P. Tang, B. L. L. Linda, and L. W. Franz, "Proximate analysis of *Artocarpus odoratissimus* (Tarap) in Brunei Darussalam," *Int. Food Res. J.*, 2013.
- [12] L. Gopalakrishnan, K. Doriya, and D. S. Kumar, "Moringa oleifera: A review on nutritive importance and its medicinal application," *Food Science and Human Wellness*. 2016, doi: 10.1016/j.fshw.2016.04.001.

- [13] M. A. Mune Mune, C. B. Bakwo Bassogog, E. C. Nyobe, and S. R. René Minka, "Physicochemical and functional properties of *Moringa oleifera* seed and leaf flour," *Cogent Food Agric.*, vol. 2, no. 1, Aug. 2016, doi: 10.1080/23311932.2016.1220352.
- [14] R. Ayerza(h), "Seed characteristics, oil content and fatty acid composition of moringa (*Moringa oleifera* Lam.) seeds from three arid land locations in Ecuador," *Ind. Crops Prod.*, 2019, doi: 10.1016/j.indcrop.2019.111575.
- [15] T. Shen, S. Fan, Y. Li, G. Xu, and W. Fan, "Preparation of Edible Non-wettable Coating with Soybean Wax for Repelling Liquid Foods with Little Residue," *Materials (Basel)*, vol. 13, no. 15, p. 3308, Jul. 2020, doi: 10.3390/ma13153308.
- [16] "Production of Candle from Oil Extract of a Legume - Soybean," *Int. J. Eng. Adv. Technol.*, 2019, doi: 10.35940/ijeat.b2382.129219.
- [17] K. Kingsley, O. Shevchuk, S. Voronov, and A. Voronov, "Effect of highly hydrophobic plant oil- based monomers on micellization of sodium dodecyl sulfate," *Colloids Surfaces A Physicochem. Eng. Asp.*, vol. 568, pp. 157–163, May 2019, doi: 10.1016/j.colsurfa.2019.02.013.
- [18] S. Pathan and S. Ahmad, "Synergistic Effects of Linseed Oil Based Waterborne Alkyd and 3- Isocyanatopropyl Triethoxysilane: Highly Transparent, Mechanically Robust, Thermally Stable, Hydrophobic, Anticorrosive Coatings," *ACS Sustain. Chem. Eng.*, vol. 4, no. 6, pp. 3062–3075, Jun. 2016, doi: 10.1021/acssuschemeng.6b00024.
- [19] N. A. Eman and K. N. S. Muhamad, "Comparison of *Moringa Oleifera* seeds oil characterization produced chemically and mechanically," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 36, p. 012063, Jun. 2016, doi: 10.1088/1755-1315/36/1/012063.
- [20] J. G. Speight, "Hydrocarbons from crude oil," in *Handbook of Industrial Hydrocarbon Processes*, Elsevier, 2020, pp. 95–142.
- [21] N. R. Geraldi et al., "Drag reduction properties of superhydrophobic mesh pipes," *Surf. Topogr. Metrol. Prop.*, vol. 5, no. 3, p. 034001, Jul. 2017, doi: 10.1088/2051-672X/aa793b.
- [22] G. Agrawal, Y. S. Negi, S. Pradhan, M. Dash, and S. K. Samal, "Wettability and contact angle of polymeric biomaterials," in *Characterization of Polymeric Biomaterials*, Elsevier, 2017, pp. 57–81.
- [23] B. W. Chieng, N. A. Ibrahim, N. Ahmad Daud, and Z. A. Talib, "Functionalization of Graphene Oxide via Gamma-Ray Irradiation for Hydrophobic Materials," in *Synthesis, Technology and Applications of Carbon Nanomaterials*, Elsevier, 2019, pp. 177–203.
- [24] X. Wang and Q. Zhang, "Role of surface roughness in the wettability, surface energy and flotation kinetics of calcite," *Powder Technol.*, vol. 371, pp. 55–63, Jun. 2020, doi: 10.1016/j.powtec.2020.05.081.

- [25] A. Leone, A. Spada, A. Battezzati, A. Schiraldi, J. Aristil, and S. Bertoli, "Moringa oleifera Seeds and Oil: Characteristics and Uses for Human Health," *Int. J. Mol. Sci.*, vol. 17, no. 12, p. 2141, Dec. 2016, doi: 10.3390/ijms17122141.
- [26] N. N. Ogarkov, S. I. Platov, E. S. Shemetova, M. N. Samodurova, D. V. Terent'ev, and V. A. Nekit, "Oil Absorption Capacity of the Contact Surfaces in Metal-Forming Processes," *Metallurgist*, vol. 61, no. 1–2, pp. 58–62, May 2017, doi: 10.1007/s11015-017-0454-4.
- [27] Y. Wang, B. He, and L. Zhao, "Fabrication of Hydrophobic Coating on Filter Paper from Self-emulsifying Carnauba Wax-alcohol Emulsions with Nano-TiO<sub>2</sub> Particles for Water/Diesel Separation," *BioResources*, 2017, doi: 10.15376/biores.12.4.7774-7783.
- [28] J. de O. Lopes, R. A. Garcia, and A. M. do Nascimento, "Wettability of the surface of heat-treated juvenile teak wood assessed by drop shape analyzer," *Maderas. Cienc. y Tecnol.*, no. ahead, pp. 0–0, 2018, doi: 10.4067/S0718-221X2018005002801.
- [29] C.-V. Ngo and D.-M. Chun, "Effect of Heat Treatment Temperature on the Wettability Transition from Hydrophilic to Superhydrophobic on Laser-Ablated Metallic Surfaces," *Adv. Eng. Mater.*, vol. 20, no. 7, p. 1701086, Jul. 2018, doi: 10.1002/adem.201701086.
- [30] O. O. Ige, R. Barker, X. Hu, L. E. Umoru, and A. Neville, "Assessing the influence of shear stress and particle impingement on inhibitor efficiency through the application of in-situ electrochemistry in a CO<sub>2</sub>-saturated environment," *Wear*, vol. 304, no. 1–2, pp. 49–59, Jul. 2013, doi: 10.1016/j.wear.2013.04.