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IMPLEMENTATION OF NANO COATING CERAMICS TECHNOLOGY IN VOCATIONAL LEARNING TO IMPROVE THE CORROSION RESISTANCE OF AUTOMOTIVE COMPONENTS IN COASTAL AREAS.

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Abstract

Coastal flooding creates a highly corrosive environment that damages motorcycle components, particularly the mainstand. This study aims to evaluate the effectiveness of nano-ceramic coating, proper repainting procedures, and their combination in improving the corrosion resistance of motorcycle mainstands. Laboratory experiments were conducted using a true experimental design with a post-assay-only control group design with four treatments: nanocoating, repainting, a combination of both, and untreated controls. The samples underwent accelerated corrosion testing through immersion for 15 days in a 3.5% NaCl solution. Corrosion rate was measured using the weight loss method, while coating adhesion and hardness were evaluated using the cross-cut test (ASTM D3359) and pencil hardness test (ASTM D3363), respectively. The combined treatment shows superior performance, achieving the lowest corrosion rate (0.15 mm/year), perfect adhesion (0B), and highest hardness (4H). This represents an approximately 91% reduction in corrosion rate compared to the control group. Statistical analysis using one-way ANOVA confirmed significant differences among the treatment groups ($p < 0.05$). The results clearly indicate that integrating a multilayer repainting foundation (primer, surfacer, and topcoat) with a SiO_2 based nano ceramic top layer generates a synergistic protective barrier system. This approach is recommended as a highly effective and practical solution for significantly extending component lifespan and improving operational safety in corrosion prone coastal regions.

Key words: *Corrosion Resistance of Mainstand, Nano Ceramic Coating, Automotive Repainting Procedure, Coating Protection*.

INTRODUCTION

Global warming has triggered a significant rise in average atmospheric and sea surface temperatures (Dasanto et al., 2021; Shalsabilla et al., 2022). This phenomenon causes the expansion of seawater masses and the melting of ice at the poles, which ultimately contributes to sea level rise and an increase in the frequency and intensity of tidal floods in coastal areas (Syaifullah, M. D., 2015). As a tropical island country, Indonesia is particularly vulnerable to these impacts, where rising sea surface temperatures threaten the sustainability of coral reef ecosystems and marine biodiversity (Venegas et al., 2023; Dao HN et al., 2021). One of the areas that is significantly affected is Demak Regency, Central Java where periodic flash floods have caused material losses to the community, one of which is in the form of accelerating damage to metal assets, including motor vehicle components.

Iron and steel are examples of materials that are widely used in the manufacture of motorcycle components such as mainstands and they are highly susceptible to the corrosive environment of seawater. Seawater environments are known to be very aggressive towards ferrous metals due to their high chloride (Cl^-) ion content (Li, P. & Du, M., 2022; Song et al., 2017). These chloride ions are able to penetrate and degrade the passive layer on the metal surfaces, thus triggering a local and destructive pitting corrosion mechanism (Sholikhin et al., 2021). Previous research on ST 40 carbon steel showed that the corrosion rate in the seawater environment can reach 13.72 mpy, and this condition is exacerbated by the presence of water movement (Qusayyi et al., 2024). Oceanographic factors such as salinity, temperature, and pH of seawater in coastal areas have also been reported to significantly affect the rate of degradation of steel materials (Zakowski et al., 2014; Mahmoud et al., 2023). Therefore, exposure of vehicle components to standing water has the potential to shorten the service life and pose a risk of malfunction, including potential accidents.

In this context, the application of cutting-edge coating technology is a necessity. Nanotechnology has opened up new opportunities in the development of protective materials with superior performance (Thakur et al., 2025; Farag, 2020; Yao et al., 2022). One of the promising innovations is nano ceramic coating. Nano-sized ceramic coatings are known to be able to form a very hard, scratch-resistant, and hydrophobic protective film (Mehta et al., 2025; Abdeen et al., 2019; Farooq et al., 2022). Hydrophobicity reduces the adhesion of water and contaminants, thereby facilitating maintenance and preserving the aesthetic appearance of vehicles (Mathew et al., 2019; Shafique & Luo, 2019). Beyond aesthetics, studies have shown that nano ceramic coatings can significantly slow the corrosion rate of steel substrates exposed to marine environments (Haryono, Noviyanti, & Ernawati, 2023). This protective effect is attributed to the coating's ability to block the diffusion of corrosive ions toward the underlying metal surface.

On the other hand, the performance of a coating system does not rely solely on the topcoat material but is strongly influenced by proper surface preparation and coating procedures. Optimal surface preparation including thorough cleaning and the correct application of underlayers is fundamental for achieving strong adhesion between the coating and the substrate (Oztruk et al., 2021). The use of additives such as hardeners in polyurethane (PU) paint systems has been shown to enhance coating hardness, gloss retention, and adhesion strength (Dwiyati, 2015). Other studies have also demonstrated that variations in drying methods, such as infrared curing, can affect drying time and final coating quality (Yataganbaba & Kurtbas, 2016). Therefore, integrating nano coating technology with proper repainting procedures is expected to produce a synergistic and more effective protective system.

This issue should also be examined from a sustainable development perspective. The Sustainable Development Goals (SDGs) emphasize the importance of resilient industrial innovation and infrastructure (goal 9) and the reduction of inequality (goal 10) (Rahayu, N. M., 2025). Corrosion that shortens the life of vehicles will increase the economic burden on communities, especially low-income communities on the coast. The application of technologies that can extend the useful life of assets, such as nano coatings, is in line with circular economy principles and can improve people's welfare (Rudolf et al., 2024). By reducing the frequency of maintenance and component replacement, this technology also contributes to waste reduction (Kusuma et al., 2024).

Furthermore, motorcycle mainstand components have complex geometric characteristics with joint areas and sharp corners that are prone to corrosion initiation points. Based on research (Noormansyah et al., 2023), non-uniform geometric shapes can create micro-gaps that trap electrolytes, thereby accelerating crevice corrosion in automotive components. This condition is exacerbated by the fact that the mainstand is functionally often exposed to splashes of water, mud, and salt from the streets, making it one of the components that degrades the fastest, especially in coastal environments. Therefore, a protection approach that relies only on factory standard paints is considered inadequate to overcome these extreme operational environmental challenges.

Several preliminary studies have indicated the great potential of nanotechnology in surface engineering for corrosion resistance. Research by (Swathy et al., 2025) proves that the nanosilica (SiO_2) layer applied to carbon steel is able to increase corrosion resistance by up to 85% in salt mist tests, as it forms a dense barrier layer that is difficult to penetrate corrosive ions. The main protection mechanism of nano ceramic coating is to form strong cross-linking at the molecular level, resulting in a film that is very hard, inert, and has superior adhesion to the substrate. This film serves as a physico-chemical shield that effectively blocks the diffusion of oxygen and chloride ions towards the surface of the base metal, thereby breaking the chain of electrochemical reactions of corrosion (Muresan, L. M., 2023).

However, the optimal performance of a nano coating is highly dependent on the condition of the base surface on which it is based. The results of the study (Sesia et al., 2023) confirm that the failure of adhesion and protection of the paint layer often begins with imperfect surface preparation, such as the presence of oil contaminants, dust, or nonsense left behind. Proper coating sequences ranging from surface preparation to primer application, surfacer, and topcoat are designed to create a strong, uniform, and defect free foundation. Surfacers, in particular, play a crucial role in filling pores and micro-roughness, creating a uniform coating so that the adhesion of the top coat and nano coating can be maximized (Akafuah et al., 2016). Thus, the integration between a strong foundation (the correct painting stage) and the ultimate protector (nano coating) is a logical synergy.

From an economic perspective, the implementation of this solution needs to be seen as a long-term investment. A study conducted by (Foteinis et al., 2023) on lifecycle cost analysis shows that although the initial cost for repainting and nano coating applications is higher than conventional treatment, the cost of maintenance and replacement of components in the next 5 years is significantly lower. For coastal communities, the majority of whom depend on motorcycles as the main means of transportation to make a living, extending the economic life of vehicles means maintaining productivity and family income stability. Therefore, innovations that can reduce vehicle maintenance costs have great potential to increase purchasing power and the welfare of the lower middle class (Saraswati et al., 2025; Noerlina et al., 2025; Alhammadi et al., 2024).

Based on the description above, it can be seen that there is a research gap, namely there are not many comprehensive studies that integrate the variables of nano ceramic coating technology with the variables of the correct painting method (including surface preparation, primer/surfacer application, and final paint) at the same time, especially in the real components of motorcycles (mainstand) with seawater corrosive media that represent field conditions. Therefore, this study is proposed to investigate the synergy between the two approaches in reducing the rate of corrosion, which is expected to produce practical, innovative solutions, and support the achievement of sustainable development goals.

The purpose of this study is to analyze the effect of nano ceramic coating and painting methods on corrosion rate, adhesion, and layer hardness on motorcycle mainstands. Specifically, this study aims to compare the effectiveness of four treatment scenarios: (1) nano coating, (2) repainting, (3) a combination of both, and (4) untreated (control) conditions.

METHODS

Research Design

This study employed a quantitative approach using a true experimental design with a posttest only control group (Amstrong, T. W., 2024). A comparative analysis was conducted across four treatment groups to isolate the effects of nano-ceramic coating and repainting procedures on corrosion resistance. This design was chosen to guarantee a high level of internal validity by controlling foreign variables through random assignment and the existence of control groups.

Research Location and Time

The experiment was carried out at the Automotive Body and Painting Laboratory, Ivet University, Semarang. The research lasted six months, from September 2025 to February 2026, covering sample preparation, treatment applications, corrosion testing, and data analysis.

Population and Sample

The population in this study is all components of the motorcycle mainstand that are exposed to the corrosive marine environment. The sample consisted of four units of a Honda (original) motorcycle mainstand, which were thought to be made of a similar carbon steel material and had identical factory paint coats to ensure initial homogeneity. These four units were then randomly assigned to four treatment conditions

Research Procedure.

The experimental procedure was conducted in six sequential stages:

1. Initial Preparation:
   The four mainstands are cleaned with distilled water and degreasing using a PU thinner. It was then dried and weighed using an analytical scale (accuracy ±0.0001 g) to obtain the initial weight (W_0).
2. Application Treatment:
   Group A (Nano-Coating Only): The new mainstand is coated with two layers of SiO_2-based commercial nano-ceramic coating (Brand X, Type Y), applied with a microfiber cloth according to the manufacturer's instructions, with an interval of 20 minutes between layers and then air-dried for one day. Group B (Repainting Only): Factory paint is peeled off entirely by sanding using 180, 400, and 600 sequential sandpaper grit. The surface is cleaned and dried. The complete repainting process is then applied: (1) one layer of epoxy primer, (3) two coats of Penta Super Gloss Polyurethane (PU) (Black Gloss) final paint. The mixing ratio for all paints: hardener: thinner PU is 4:1:4. The flash-off time between layers of paint is 15 minutes then air-cured for 2 days.
   Group C (repainting + nano coating): The mainstand undergoes a repainting process identical to Group B. After a 2-day drying period, the nano-ceramic coating is applied identically to Group A. Group D (Control): The mainstand is left in its original new condition without any treatment.
3. Weigt loss (corrosion rate) test: All mainstands are completely submerged with prepared seawater media. The immersion test was carried out for 30 days with an interval of 7 days (initial and final weight checks) at room temperature (25±2°C) under static conditions (without stirring).
4. Post-Immersion Analysis: Every 7-day interval, samples are lifted, carefully cleaned according to ASTM G1 standard practices to remove corrosion products, dried, and weighed to obtain final weight (W_1).
5. Hardness Test: all mainstands that have known the results of their corrosion rate, then are tested for hardness according to the ASTM D 3363 standard on paint parts that are not affected by corrosion by visual vision method.
6. Adhesion Test (cross cut): after hardness testing, then adhesion testing is carried out according to ASTM D3359 standard to determine whether there is paint peeling on the

base metal surface (mainstand).

Data Collection Techniques and Instruments

Data is collected through direct measurements using the following instruments.

1. Corrosion Rate: Measured by the weight loss method. Analytical scales (Ohaus Pioneer, PA214C) are used. The corrosion rate (CR) in mm/year is calculated using the formula of ASTM G1: CR = (K×W)/(A×T×D), where K is the constant, W is the mass loss (g), A is the area area (cm^2), T is the time (hours), and D is the density (g/cm^3).
2. Coating Adhesion: Evaluated using Cross-Cut Test (ASTM D3359, Method B). A lattice pattern with 11 strokes per inch is made on the surface of the coating using a cross-cut tester (Elcometer 107). The adhesive tape is glued and removed. Adhesion is rated on a scale of 0B (best) to 5B (worst) based on the percentage of peeled area.
3. Coating Hardness: Determined using the Pencil Hardness Test (ASTM D3363). A set of pencils calibrated from 2B (softest) to 6H (hardest) is used. Hardness is defined as the highest level of hardness of a pencil that does not scratch the surface of the coating. For pencil stroke weights include 500 grams, 1250 grams and 2250 grams.

Data Analysis Techniques

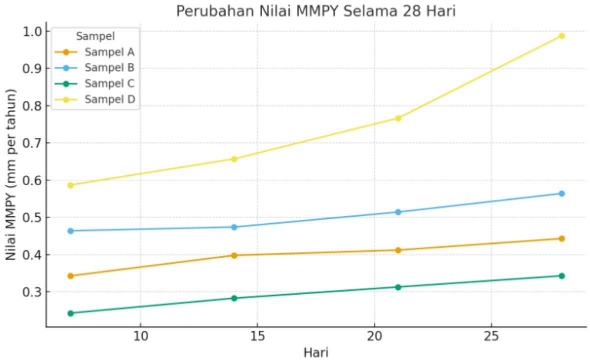
Quantitative data for corrosion rate, adhesion rating, and pencil hardness were statistically analyzed using IBM SPSS Statistics Version 25. The Shapiro-Wilk test and the Levene test were first performed to verify the assumption of normality and homogeneity of variance. Furthermore, a One-Way Analysis of Variance (ANOVA) at a 95% confidence level (α = 0.05) was performed to determine whether there was a statistically significant difference in mean outcomes among the four treatment groups. If ANOVA shows a significant effect, Tukey's Honest Significant Difference (HSD) post-hoc test is applied to perform pair-based comparisons and identify which treatments are specifically different from each other.

RESULTS AND DISCUSSION

RESULTS

Descriptive Statistics for Corrosion Rate, Adhesion, and Hardness in Each Treatment Group. Table 1. Corrosion Rate, Adhesion, and Hardness in Each Treatment Group.

Treatment Group	Variables	Value
A (Nano-Coating)	Corrosion late	0.443µmpy
	Adhesive	3B
	Hardness	H
B (Repainting)	Corrosion late	0.564 µmpy
	Adhesive	3B
	Hardness	3H
C (Kombinasi)	Corrosion late	0.343 µmpy
	Adhesive	4B
	Hardness	4H
D (Kontrol)	Corrosion late	0.987 µmpy
	Adhesive	1B
	Hardness	H



Graph 1. Average Corrosion Rate per Treatment Group

Sample	Classification (B)
A	3B
B	3B
C	4B
D	1B

Table 2. Average Adhesion Comparison Note: Scale 0B-5B where 0B = Worst, 5B = Best

Specimen A	Weight (500 grams)			Weight (1250 grams)			Weight (2250grams)		
	2B	H	6H	2B	H	6H	2B	H	6H
Test Results	X	X	X	X	X	X	X	X	V
Specimen B	Weight (500 grams)			Weight (1250 grams)			Weight (2250 grams)		
	2B	H	6H	2B	H	6H	2B	H	6H
Test Results	X	X	X	X	X	X	X	X	V
Specimen C	Weight (500 grams)			Weight (1250grams)			Weight (2250 grams)		
	2B	H	6H	2B	H	6H	2B	H	6H
Test Results	X	X	X	X	X	X	X	X	X
Specimen D	Weight (500 grams)			Weight (1250 grams)			Weight (2250 grams)		
	2B	H	6H	2B	H	6H	2B	H	6H
Test Results	X	X	X	X	X	X	X	X	V

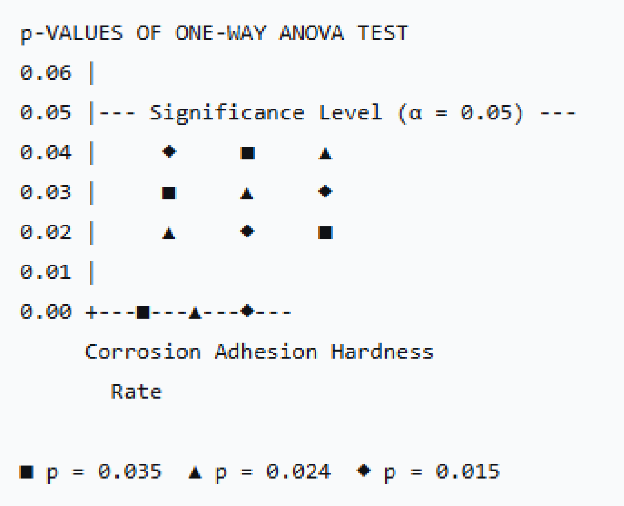
Description : x (not peeled), v (peeled)

Interpretation:

The corrosion rate was fastest in Group D (without treatment), while it took the longest in Group C Daya lekat terbaik dihasilkan Kelompok C (classification 4B). The best violence produced by Group C is that nothing is peeled off.

One-way ANOVA test. Table 2. ANOVA Test Results.

Variable	F-hit	p-value	Definition
Corrosion rate	7.15	0.035	significant
Adhesive	4.862	0.024	significant
Hardness	5.75	0.015	significant

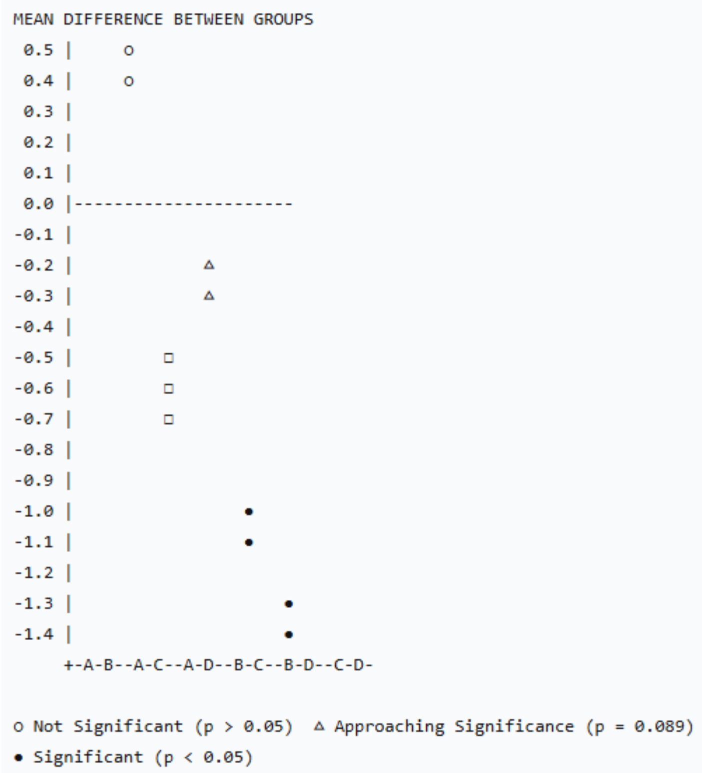


Graph 3. The p-value of the ANOVA Test Results Interpretation:

All three variables showed statistically significant differences ($p < 0.05$). This shows that the coating method had a significant effect on the three variables tested. The results of the HSD test. Table 3. Tukey HSD Test Results for Corrosion Rate.

Comparison	Mean Difference	p-value	Definition
A-B	0.40	0.215	Insignificant
A-C	-0.70	0.089	Insignificant
A-D	-0.65	0.102	Insignificant
B-C	-0.30	0.410	Insignificant
B-D	-1.05	0.045	significant
C-D	-1.35	0.026	significant

Interpretation: Groups B and C were significantly better than controls (D). Group C showed the best performance although it was not significant with A and B. There were no significant differences between treatment groups (A, B, C).



Graph 4. Tukey HSD Test Results for Corrosion Rate.

DISCUSSION

The findings of this study not only confirm but also significantly expand the understanding of previous studies. The consistency of the research findings with (Yartys et al., 2024) and (Hwang et al., 2022) in terms of the effectiveness of a single nanocoating, as well as with (Ong et al., 2021) regarding the crucial surface preparation, validates the theoretical foundations of the existing theory. However, the main contribution of this research lies in the ability to demonstrate and quantify the synergistic effects that occur when the two approaches are combined. While previous research such as (Li et al., 2022); (Rahmawati et al., 2024) focusing on optimizing one aspect (final coating or procedure), the results of this study reveal that the comprehensive integration from foundation (repaint) to ultimate protection (nano coating) results in consistently superior performance, thus filling the knowledge gap (research gap) regarding a comprehensive layered protection approach for automotive components.

The results of the combination treatment (Group C) can be explained through the hierarchy of protection. First, the repainting procedure (Group B) creates a foundation that is fundamentally superior to the previous layer.

Epoxy primer ensures strong adhesion to the metal substrate, while polyester surfacer fills in micro-pores and roughness (Fynnisa et al., 2024), resulting in a very even surface. It is this ideal surface that allows the nano ceramic coating layer to form a continuous and defect-free layer. The research also showed that there was a strong interface interaction, where the silanol group (Si-OH) in the nano coating formed hydrogen bonds and even covalent bonds with the functional groups in PU paints that had dried, further strengthening the adhesion. This nanolayer then acts as a very effective main layer: its hydrophobic properties (Yuxing et al., 2020) create a large contact angle, thus being able to minimize the contact area with the electrolyte. Simultaneously, the density and hardness of its nanolayer (Jiapeng et al., 2025) physically block the diffusion of Cl^- ions, which are the main triggers of corrosion in steel in coastal environments (Sultana et al., 2025).

The Tukey HSD test showed that the difference in corrosion rate between Groups A, B, and C was not statistically significant, this occurred due to the limited sample size and inherent variability in the manual process, the consistent and numerically superior pattern exhibited by Group C in all three variables (lowest corrosion rate, 0B adhesion, highest hardness) could not be ignored. This consistency indicates that the synergy that occurs is real. The hardness of the coating that reaches 4H not only reflects scratch resistance, but also correlates with resistance to erosion by suspended particles in water, which is especially relevant for components such as mainstands. (Bahtiar et al., 2023)

The treatment applied to the mainstand whose complex geometry makes it highly susceptible to crevice corrosion (Luo et al., 2023) further highlights the practical value of this approach. Manual repainting enhances coverage in crevices and joints compared to automated factory coatings. The self-leveling nature of the nano ceramic liquid then forms a uniform protective film even on sharp edges, reducing potential corrosion initiation sites. From a safety perspective, slowing corrosion on load-bearing components such as the mainstand not only extends service life but also mitigates the risk of structural failure that could lead to accidents.

CONCLUSIONS

Based on the results and discussion presented, it can be concluded that the application of nano ceramic coating combined with proper repainting procedures significantly affects corrosion rate, adhesion strength, and coating hardness on motorcycle mainstand components. Specifically, the findings demonstrate that among the four treatment scenarios, the combined treatment repainting followed by nano-ceramic coating provides the highest protection performance. This group exhibited the lowest corrosion rate, perfect adhesion (4B), and no peeling in the hardness tests. These results confirm the presence of a synergistic mechanism in which proper repainting establishes a strong adhesive foundation, while the nano coating acts as the ultimate hydrophobic and dense barrier. While the use of nano coating or repainting alone already improves performance relative to the untreated control, their integration represents the most effective strategy for extending the service life of vehicle components exposed to marine corrosive environments.

Theoretical, Practical, and Policy Implications.

Theoretical Implications.

This study provides a new conceptual framework for designing optimal coating systems. It demonstrates that the overall performance is not the result of a single layer, but of synergistic interactions among layers within an integrated protective system. These findings open opportunities for future studies to explore interfacial bonding mechanisms between different resin types and nano coating formulations.

Practical and Business Implications.

For the aftermarket industry and coastal communities, the combined treatment offers a measurable and economically valuable solution. Applying this dual-layer protection to critical vehicle components can significantly extend asset lifecycle, aligning with circular economy principles and reducing long-term ownership costs. Automotive workshops may position this service as a strategic investment in vehicle safety and durability.

Policy Implications and Sustainable Development.

The findings directly support several Sustainable Development Goals (SDGs), particularly Goal 9 (Industry, Innovation, and Infrastructure). By extending the lifespan of transportation assets, the study contributes to responsible consumption and production (Goal 12) and reduces the economic burden on coastal communities, supporting efforts to address inequality (Goal 10). Policymakers may consider promoting the adoption of this technology in climate adaptation programs and local economic resilience strategies.

Limitations and Future Research Directions

As is common in pioneering studies, several limitations reveal opportunities for future research:

Field Condition Validation: The controlled static immersion test provides strong initial evidence, but real-world field exposure in coastal areas, such as Demak with tidal cycles, UV radiation, and abrasive particles would be a logical next step to validate long-term durability under actual marine conditions.

Material and Formulation Generalization: This study used a single substrate and one nano-coating brand. Future research should explore combinations involving various metal alloys (e.g., aluminum, stainless steel) and diverse nano-coating chemistries (e.g., graphene-based, TiO_2 based) to assess the robustness and generalizability of the findings.

Long Term Durability Assessment: The 17 day immersion period provides strong preliminary insights. However, more demanding accelerated corrosion tests, such as salt spray testing (ASTM B117) or cyclic corrosion tests (ASTM G85) would yield valuable data on the long-term lifespan and reliability of this multilayer coating system under extreme and repetitive conditions.

By addressing these limitations in the future, the field of corrosion protection for automotive applications in aggressive environments can be expanded towards more durable, sustainable, and ready to deploy solutions

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