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OPTIMIZING SEAWATER-EXTRACTED MG(OH)$_2$ COATING AGAINST H$_2$S-INDUCED CONCRETE PIPE DEGRADATION USING DESIRABILITY FUNCTION ANALYSIS

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ABSTRACT: Anaerobic conditions in wastewater environments facilitate the proliferation of sulfate-reducing bacteria (SRB). These bacteria reduce sulfates in the wastewater to sulfide ions, forming hydrogen sulfide (H_2S) and/or sulfuric acid (H_2SO_4) as a by-product. Prolonged exposure to these chemicals can degrade the concrete matrix, undermining its strength and durability. This study investigates seawater-derived magnesium hydroxide ($Mg(OH)_2$) as a sustainable alternative to its commercial counterpart for concrete protective coatings. Six distinct configurations were developed, each containing different proportions of seawater-derived (SW) and commercially available magnesium hydroxide (CA) at 0%, 25%, 50%, 75%, and 100% intervals. The specimens were subjected to a 4M sulfuric acid concentration in a testing chamber for four days. To evaluate the effectiveness of the coatings, weight loss, pH value, compressive strength, and surface roughness were measured for each specimen. Using the experimental results, desirability function analysis (DFA) was conducted to determine the optimum coating ratio based on the four response variables. Results showed that the optimum ratio is 0% SW - 100% CA $Mg(OH)_2$ with 1.099 composite desirability. On the other hand, the 25% SW - 75% CA $Mg(OH)_2$ coating ratio produced a composite desirability of 1.000, indicating that the said ratio, which contains seawater-derived magnesium hydroxide, is still acceptable within the parameters considered in this study. These findings demonstrate that magnesium hydroxide-based coatings can effectively reduce the negative impacts of sulfuric acid-induced corrosion in concrete pipes.

Keywords: Seawater-Derived Magnesium Hydroxide, Hydrogen Sulfide-Induced Corrosion, Magnesium Hydroxide Coating, Concrete Piping

1. INTRODUCTION

Concrete pipes, comprising over 70% of pipe installations in the Philippines, are integral to the nation's wastewater management infrastructure [1]. These pipes are utilized for transporting sewage and wastewater, creating anaerobic environments conducive to the proliferation of sulfate-reducing bacteria (SRB) [2]. These bacteria thrive in conditions where water flow is slow or stagnant, producing hydrogen sulfide (H_2S) [3]. Through metabolic processes, hydrogen sulfide is further converted into sulfur dioxide (SO_2) and sulfur trioxide (SO_3) [3]. When dissolved in water, these sulfur compounds facilitate chemical reactions that produce sulfuric acid (H_2SO_4), which induces corrosive deterioration of concrete surfaces [4].

Current mitigation strategies employ protective coatings such as epoxy tar coal pitch. However, these coatings offer limited protection and pose significant risks due to their toxicity and flammability [5-7]. Additionally, previous studies have explored the incorporation of commercially available magnesium hydroxide ($Mg(OH)_2$) into protective coatings to address the corrosive effects of SRB [8]. Despite its effectiveness, commercial $Mg(OH)_2$ production has been shown to have substantial environmental impacts, as highlighted by the 2011 Reference Life Cycle Data System [9].

In response to these challenges, recent research has proposed the extraction of magnesium hydroxide from seawater as a more sustainable alternative [10]. This method is considered environmentally favorable, as it potentially offsets the environmental burden of the calcination processes used in commercial $Mg(OH)_2$ production [11]. The principle underlying this approach is that extracting $Mg(OH)_2$ from seawater involves fewer detrimental environmental impacts than traditional production methods [11].

The Philippines is an archipelago surrounded by vast bodies of seawater. This abundant resource is underutilized and unexplored, particularly in the construction industry. The high salt content in seawater introduces significant challenges, particularly in reinforced concrete structures, where chlorides accelerate the corrosion of steel reinforcements. This corrosion leads to structural weakening, cracking, and concrete spalling, reducing the lifespan and integrity of buildings and infrastructure. Additionally, sulfates and other aggressive chemicals in seawater can cause chemical attacks on concrete, leading to expansion, cracking, and deterioration over time. These challenges lead to hesitation among engineers and developers in integrating seawater into construction practices.

Several studies [12-17] have investigated the potential of seawater in concrete production, either as a replacement for fresh water in the mixing process or as a curing medium, focusing on its effects on the mechanical properties, durability, and long-term performance of concrete. With the advancements in material science and protective technologies, there is growing interest in exploring solutions such as corrosion-resistant materials, protective coatings, and alternative reinforcement options that could make seawater a viable resource in construction, particularly in coastal and island communities. This study is adapted from [18] and aims to evaluate the efficacy of seawater-derived magnesium hydroxide as a sustainable alternative to commercial magnesium hydroxide for use in concrete protective coatings. The investigation focuses on assessing the properties of concrete specimens coated with varying ratios of seawater-derived and commercially available $Mg(OH)_2$. By examining these coatings' durability and environmental viability, this research seeks to contribute to developing more sustainable solutions for mitigating corrosion in concrete wastewater pipes.

2. RESEARCH SIGNIFICANCE

In the Philippines, concrete pipes are widely used for wastewater transport. The anaerobic conditions in these systems make the concrete susceptible to corrosion from sulfuric acid produced by sulfate-reducing bacteria. Although existing products address this issue, they are environmentally detrimental in several ways, including releasing volatile organic compounds, high energy consumption during production, and non-biodegradability. With these constraints as a framework, this study investigates the potential of seawater-derived magnesium hydroxide ($Mg(OH)_2$) as a sustainable method to enhance the durability of concrete in such environments without compromising environmental sustainability and local adaptability.

3. MATERIALS AND METHODS

3.1 Concrete Specimen Preparation

This study employed concrete specimens with dimensions of 100 mm by 100 mm by 100 mm. A total of 24 specimens, comprising both coated and uncoated samples, were tested across four trials for each configuration. The concrete mix design conformed to the specifications established by the Department of Public Works and Highways (DPWH) for non-reinforced concrete sewers, storm drains, and culvert pipes. The details of the concrete mix are presented in Table 1.

Table 1. Concrete mix design

Material	Amount per 1 m^3 of concrete (kg/m^3)
Water	216.00
Cement	451.88
Coarse Aggregate	984.30
Fine Aggregate	650.25

3.2 Magnesium Hydroxide Coating Design

Stoichiometric calculations were conducted to determine the requisite amount of $Mg(OH)_2$ for application on the concrete specimens, targeting 0.002 g/mm^2 for each face. A 100 mm cubic specimen corresponds to 20 g of $Mg(OH)_2$ per face. Considering that seawater-derived magnesium hydroxide may already be commercially available, this study contextualizes SW magnesium hydroxide as that which was extracted from seawater and calcium oxide, while the CA magnesium hydroxide used in the study was produced using magnesium oxide and water. This is further discussed in the succeeding sections of this paper.

The study investigated five distinct coating ratios: 100% seawater-derived (SW) - 0% commercially available (CA), 75% SW - 25% CA, 50% SW - 50% CA, 25% SW - 75% CA, and 0% SW - 100% CA. Commercially available $Mg(OH)_2$ was obtained by hydrating industrial-grade magnesium oxide (MgO), as represented in Eq. (1).

$$MgO + H_2O \rightarrow Mg(OH)_2 \quad (1)$$

Alternatively, chemical processes can extract $Mg(OH)_2$ from seawater. Previous research has reported that seawater contains approximately 1.29 g/L of magnesium ions (Mg^{2+}) [6], allowing for the extraction of magnesium to produce $Mg(OH)_2$. The process begins with calcium oxide (CaO) hydration, as depicted in Eq. (2).

$$CaO + H_2O \rightarrow Ca(OH)_2 \quad (2)$$

The water-to-quicklime ratio was established based on the Australian standard AS 4489.3.1 for lime testing, which mandates a four-to-one weight ratio of water to quicklime. The resulting calcium oxide (CaO) slurry was then filtered through a 100 µm mesh to eliminate insoluble solids and impurities that could affect the purity of the extracted material. Following purification, the slurry was mixed with seawater to facilitate the production of magnesium hydroxide and dissolved calcium ions, as described in Eq. (3).

$$Ca(OH)_2 + Mg^{2+} \rightarrow Mg(OH)_2 + Ca^{2+} \quad (3)$$

The magnesium precipitate was allowed to settle for 2 hours, after which it was filtered twice. The resulting consistency of the product is shown in Fig. 1.

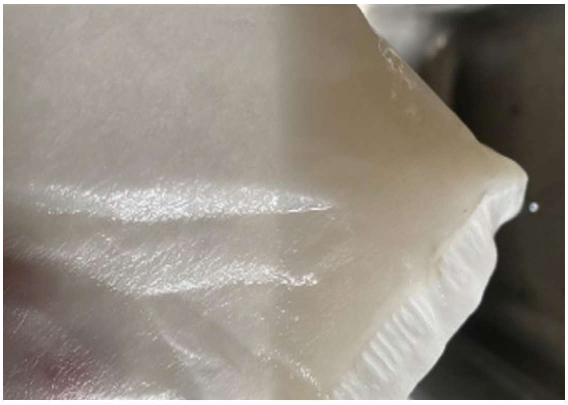

Fig.1 Magnesium coating consistency after filtration [17]

The resulting solids were then oven-dried for 24 hours to obtain magnesium hydroxide in powdered form, as illustrated in Fig. 2.

Fig. 2. Powdered magnesium hydroxide ($Mg(OH)_2$) [17]

A prior study utilized a solid-to-liquid weight ratio of 57.5%, with 42.5% deionized water, for the commercially available magnesium hydroxide coating [10]. This study replicated the same ratio, corresponding to 11.30 g of $Mg(OH)_2$ and 8.5 mL of deionized water per specimen face.

For the coating preparation, 8.5 mL of deionized water was initially heated to 90°C. Then, 0.2 g of methyl-cellulose (MC) was added as an adhesive, and the mixture was stirred continuously until it cooled to ambient temperature. Subsequently, 11.3 g of magnesium hydroxide, including commercially available and seawater-derived $Mg(OH)_2$, was progressively incorporated until the mixture achieved homogeneity. The coating was then applied to the specimen surface using a trowel and spatula and allowed to dry for 24 hours.

3.3 Evaluation of Test Properties

The concrete specimens were exposed to 4M sulfuric acid and placed in an improvised testing chamber. Over four days, each specimen face was manually sprayed with 12.11 mL of sulfuric acid, resulting in a daily total of 290.7 mL of acid applied across all 24 specimens. To assess the effectiveness of the coating ratios, four specimen parameters were tested: weight loss, surface pH, compressive strength, and surface roughness.

Weight loss was determined by measuring the specimen's weight before and after exposure to sulfuric acid. The percentage change in weight was calculated using Eq. (4):

$$\text{Weight loss (\%)} = \frac{\text{Final} - \text{Initial}}{\text{Initial}} \quad (4)$$

Similarly, the surface pH of each specimen was measured before and after the exposure period using a pH meter pen in direct contact with the concrete surface. The compressive strength of the specimens was tested after sulfuric acid exposure using a universal testing machine (UTM) at a load rate of 140 kg/cm². Finally, surface roughness was evaluated using a scanning electron microscope (SEM), with micrographs captured for each coating ratio at a scale of 100 μm. The images were analyzed using ImageJ software to determine surface roughness based on grain size, surface uniformity, and gray value, providing roughness measurements at the 100 μm scale.

3.4 Desirability Function Analysis (DFA)

Desirability Function Analysis (DFA) is an optimization tool that considers multiple response variables simultaneously under multi-objective functions. The multi-objective function of a response variable can be optimized through minimizing, maximizing, or attaining a pre-defined target value. DFA depends on the composite desirability of the individual independent variables being considered [19-20].

Before determining the composite desirability, the individual desirability of each response variable must be obtained first [21-23]. Eq. (5) illustrates the case where the response variable is desired to be maximized:

$$d_i = \begin{cases} 0, y_i \leq y_{min} \\ \left(\frac{y_i - y_{min}}{y_{max} - y_{min}}\right)^r, y_{min} \leq y_i \leq y_{max,}\ r \geq 0 \\ 1,\ y_i \geq y_{min} \end{cases} \quad (5)$$

Where:
d_i is the individual desirability with 1.0 as the ideal value,
y_i is the expected value,
y_{min} and y_{max} are the lower and upper tolerance limits, respectively, and
r is the weight.

In instances where the response variable is desired to be minimized, Eq. (6) is used:

$$d_i = \begin{cases} 1, y_i \leq y_{min} \\ \left(\frac{y_i - y_{max}}{y_{min} - y_{max}}\right)^r, y_{min} \leq y_i \leq y_{max,}\ r \geq 0 \\ 0,\ y_i \geq y_{min} \end{cases} \quad (6)$$

Lastly, if there is a target value for a particular response variable, Eq. (7) is used:

$$d_i = \begin{cases} \left(\frac{y_i - y_{min}}{T - y_{min}}\right)^s, y_{min} \leq y_i \leq T, s \geq 0 \\ \left(\frac{y_i - y_{min}}{T - y_{min}}\right)^t, T \leq y_i \leq y_{max,}\ t \geq 0 \\ 0 \end{cases} \quad (7)$$

Where:
T is the individual target value, and
s and t are the weights.

In this study, the average percent change in weight loss post-exposure to acid in absolute value and the average surface roughness of each mix ratio were desired to be minimized. On the other hand, a target surface pH post-exposure to acid of 9.0 and 24.5 MPa compressive strength was pre-defined as the acceptance values for the said response variables.

Once the individual desirability index of the response variables is obtained, the composite desirability can be calculated using Eq. (8):

$$d_G = \sqrt[w]{(d_1^{w_1})\ (d_2^{w_2}) \ldots (d_i^{w_i})} \quad (8)$$

Where:
d_G is the composite or overall desirability,
d_i and w_i are the individual desirability and weight of the response y_i, respectively, and
w is the sum of the individual weights.

4. RESULTS AND DISCUSSION

4.1 Weight Loss

Table 2 presents the results of the Ryan-Joiner Normality Test and Dixon's Q Test (R10), which were employed to evaluate the data's normality and detect potential outliers for the weight loss parameter, respectively. A significance level of 0.05 was used for both tests.

Table 2. Normality and outlier tests for weight loss

Mix Ratio	Normality Test		Outlier Test	
	Distribution	P-Value	Number of Outliers	P-Value
Control	Normal	p>0.10	0	0.464
100% SW - 0% CA	Normal	p>0.10	0	0.530
75% SW - 25% CA	Normal	p>0.10	0	0.324
50% SW - 50% CA	Normal	p>0.10	0	0.875
25% SW - 75% CA	Normal	p>0.10	0	0.297
0% SW - 100% CA	Normal	p>0.10	0	0.726

As shown in Table 2, all coating ratios yielded p-values greater than the 0.05 significance threshold for the Ryan-Joiner Normality Test and Dixon's Q Test. These results indicate that the data are normally distributed and free from outliers.

Table 3 presents the average percentage change in weight loss, comparing the final day of sulfuric acid exposure with the period preceding the exposure.

Table 3. Weight loss post-exposure to acid

Mix Ratio	Average Percentage Change (%)
Control	-4.83
100% SW - 0% CA	-3.89
75% SW - 25% CA	-3.00
50% SW - 50% CA	-1.97
25% SW - 75% CA	-1.38
0% SW - 100% CA	-0.66

As detailed in Table 3, specimens coated with 0% SW - 100% CA $Mg(OH)_2$ exhibited the lowest weight loss. A trend of increasing weight loss was observed as the proportion of seawater-derived magnesium hydroxide in the coating increased. Nonetheless, all specimens coated with magnesium hydroxide demonstrated less weight loss than the uncoated control specimens, highlighting the effectiveness of the coating in mitigating the effects of sulfuric acid exposure.

4.2 Surface pH

Table 4 shows the results from the Ryan-Joiner Normality Test and Dixon's Q Test (R_{10}) for the surface pH parameter, with 0.05 significance level.

Table 4. Normality and outlier tests for surface pH

Mix Ratio	Normality Test		Outlier Test	
	Distribution	P-Value	Number of Outliers	P-Value
Control	Normal	p>0.10	0	0.535
100% SW - 0% CA	Normal	p>0.10	0	0.500
75% SW - 25% CA	Normal	p>0.10	0	0.192
50% SW - 50% CA	Normal	p>0.10	0	0.500
25% SW - 75% CA	Normal	p>0.10	0	0.797
0% SW - 100% CA	Normal	p>0.10	0	1.000

As indicated in Table 5, the p-values for all coating ratios exceeded the 0.05 significance threshold for both tests, suggesting that the data for this parameter were normally distributed and free from outliers.

Table 5 presents the surface pH values of the specimens following exposure to sulfuric acid. Initially, all concrete specimens exhibited surface pH values ranging from 9.63 to 9.80, indicating an alkaline nature. However, after the testing period, uncoated (control) specimens demonstrated a surface pH of 5.23, placing them in the acidic range. In contrast, all coated specimens maintained surface pH values within the alkaline range, suggesting that the applied coatings effectively protected the concrete from the corrosive effects of sulfuric acid.

Table 5. Surface pH post-exposure to acid

Mix Ratio	Surface pH Before Exposure	Surface pH After Exposure
Control	9.63	5.23
100% SW - 0% CA	9.69	8.86
75% SW - 25% CA	9.68	9.14
50% SW - 50% CA	9.72	9.25
25% SW - 75% CA	9.69	9.37
0% SW - 100% CA	9.80	9.52

Two primary mechanisms contribute to the efficacy of $Mg(OH)_2$ coatings in mitigating the effects of sulfuric acid: the preservation of alkalinity on concrete surfaces and the neutralization of H_2SO_4.

First, the $Mg(OH)_2$ coating is an alkaline reserve. Concrete naturally maintains an alkaline environment, but exposure to sulfuric acid can reduce the surface pH, promoting deterioration. The $Mg(OH)_2$ coating aids in sustaining a high pH level on the concrete surface, which is critical for inhibiting the growth and activity of acidophilic bacteria that thrive in acidic conditions. By preserving alkalinity, the coating prevents the proliferation of these bacteria, thereby reducing their contribution to concrete degradation.

Second, the $Mg(OH)_2$ coating acts as a physical and chemical barrier, neutralizing sulfuric acid. When sulfuric acid interacts with the coating, a neutralization reaction occurs, producing water and magnesium sulfate. This reaction prevents the acid from penetrating the coating and reaching the concrete substrate. Consequently, the concrete remains protected from the corrosive effects of the acid, such as the dissolution of calcium compounds and the weakening of the concrete matrix [10]. In contrast, the lack of $Mg(OH)_2$ coating in the control specimens allowed direct contact between the sulfuric acid and the concrete, which led to a decreased surface pH, and subsequent acid-induced deterioration.

4.3 Compressive Strength

Table 6 presents the results of the Ryan-Joiner Normality Test, and Dixon's Q Test (R_{10}) applied to the surface pH parameter, with a significance level set at 0.05. All coating ratios yielded p-values exceeding the 0.05 significance threshold for both tests, indicating that the data followed a normal distribution and were free of outliers.

Table 6. Normality and outlier tests for compressive strength

Mix Ratio	Normality Test		Outlier Test	
	Distribution	P-Value	Number of Outliers	P-Value
Control	Normal	p>0.10	0	0.732
100% SW - 0% CA	Normal	p>0.10	0	0.530
75% SW - 25% CA	Normal	p>0.10	0	0.324
50% SW - 50% CA	Normal	p>0.10	0	0.253
25% SW - 75% CA	Normal	p>0.10	0	0.100
0% SW - 100% CA	Normal	p>0.10	0	0.622

Table 7 displays the compressive strength results of the concrete specimens following their exposure to sulfuric acid.

Table 7. Compressive strength post-exposure to acid

Mix Ratio	Compressive Strength (MPa)
Control	21.89
100% SW - 0% CA	24.26
75% SW - 25% CA	24.87
50% SW - 50% CA	25.64
25% SW - 75% CA	25.78
0% SW - 100% CA	26.78

A trend emerged wherein compressive strength increased towards the ratio composed entirely of commercially available $Mg(OH)_2$. At the same time, values gradually decreased as the proportion of seawater-derived $Mg(OH)_2$ in the coatings increased. The 0% SW - 100% CA $Mg(OH)_2$ coating exhibited compressive strength values closest to the target strength of the concrete mix design (28 MPa). This observation suggests that coatings composed solely of commercially available $Mg(OH)_2$ were the most effective in preserving compressive strength.

Conversely, the significant reduction in the compressive strength of the control (uncoated) specimens can be attributed to chemical interactions between the concrete's surface components and sulfuric acid. Specifically, calcium hydroxide ($Ca(OH)_2$) and calcium silicate hydrates (C-S-H gel), which are integral to the binding strength and cohesion of concrete, are particularly susceptible to corrosion by H_2SO_4. The degradation of these key components results in a decline in the concrete specimens' strength and durability [24].

4.4 Surface Roughness

Table 8 presents the arithmetic mean deviation values of surface roughness for the concrete specimens following exposure to sulfuric acid.

Table 8. Surface roughness post-exposure to acid

Mix Ratio	Average Surface Roughness (μm)	Change from Control (%)
Control	43.22	-
100% SW - 0% CA	39.28	9.11
75% SW - 25% CA	31.12	27.98
50% SW - 50% CA	28.65	33.70
25% SW - 75% CA	27.86	35.52
0% SW - 100% CA	22.40	48.17

Upon comparing the percentage differences in average surface roughness between the coated specimens and the control sample, it was observed that the 100% SW - 0% CA coating mix resulted in the greatest change, with a value of 48.17%. This indicates the substantial effectiveness of this coating in mitigating hydrogen sulfide-induced corrosion. Conversely, the 100% SW - 0% CA coating mix exhibited the least change, at 9.11%, suggesting that this formulation provided the least resistance to corrosive effects.

In surface coatings, lower mean deviation values indicate improved adhesion and reduced material consumption in the specimens.

4.5 Optimization Using DFA

The individual desirability index of the four response variables, weight loss, surface pH, compressive strength, and surface roughness, were calculated based on the experimental results. The individual desirability index is shown in Table 9.

Table 9. Desirability index of each response variable.

Mix Ratio	Desirability Index			
	Weight Loss	Surface pH	Compressive Strength	Surface Roughness
Control	0.000	0.000	0.000	0.000
100% SW-0% CA	0.689	0.991	0.976	0.660
75% SW-25% CA	0.814	1.009	1.034	0.873
50% SW-50% CA	0.910	1.016	1.095	0.915
25% SW-75% CA	0.954	1.024	1.105	0.927
0% SW-100% CA	1.000	1.033	1.170	1.000

Considering that the surface pH post-exposure to acid and compressive strength had pre-defined targets of 9.0 and 24.5 MPa, respectively, the desirability index of some mix ratios greater than 1.0 indicates that these mix rations exceeded the pre-defined targets. The composite desirability was obtained using the individual desirability index of the four response variables. Table 10 summarizes the composite desirability for each mix ratio and their corresponding rank.

Table 10. Composite index of each response variable.

Mix Ratio	Composite Desirability	Rank
Control	0.000	6
100% SW - 0% CA	0.663	5
75% SW - 25% CA	0.861	4
50% SW - 50% CA	0.962	3
25% SW - 75% CA	1.000	2
0% SW - 100% CA	1.099	1

The results of the DFA showed that the 0% SW - 100% CA $Mg(OH)_2$ coating, with 1.099 desirability, exhibited the optimum performance across all tested parameters. This formulation demonstrated optimum weight loss, retention of surface pH, compressive strength, and surface roughness, thereby indicating its efficacy in protecting concrete specimens from sulfuric acid-induced degradation. Furthermore, the 25% SW - 75% CA $Mg(OH)_2$ coating produced 1.000 desirability, the ideal composite desirability value. This indicates that while the 0% SW - 100% CA $Mg(OH)_2$ ratio ranked first among all mix ratios, 25% SW - 75% CA $Mg(OH)_2$ coating can still be considered an acceptable coating ratio based on the study's parameters.

Moreover, a decline in performance was identified as the proportion of seawater-derived $Mg(OH)_2$ (SW) in the coating was increased. This observation suggests that while seawater-derived $Mg(OH)_2$ contributes positively to the protective properties of the coating, its overall effectiveness diminishes relative to coatings composed entirely of commercially available $Mg(OH)_2$. However, it is essential to note that coatings containing seawater-derived $Mg(OH)_2$, despite exhibiting lower performance than the 0% SW - 100% CA formulation, still outperformed the uncoated control specimens across all evaluated properties.

5. CONCLUSION

The naturally anaerobic conditions found in concrete pipe systems create an environment conducive to the proliferation of sulfate-reducing bacteria (SRB), which pose a significant threat to the integrity of these structures due to hydrogen sulfide-induced corrosion. While traditional protective measures, such as epoxy tar coal pitch and commercially available magnesium hydroxide ($Mg(OH)_2$), have proven effective, their continuous use has raised concerns regarding their environmental impact. Recent studies have highlighted the potential of sourcing magnesium hydroxide from seawater as a more sustainable alternative.

This study explored the viability of seawater-derived $Mg(OH)_2$ as a protective coating for concrete, comparing its performance to commercially available $Mg(OH)_2$. Six different configurations, varying in the ratio of seawater-derived to commercially available $Mg(OH)_2$ (ranging from 0% to 100% seawater-derived content), were prepared, with four replicates for each configuration. The specimens were then exposed to a 4M sulfuric acid concentration for four days in a controlled testing environment. The properties of weight loss, surface pH, compressive strength, and surface roughness were analyzed to assess the effectiveness of each coating mix.

The results demonstrate that specimens coated with commercially available or seawater-derived $Mg(OH)_2$ consistently outperformed uncoated specimens across all parameters. Notably, while coatings with 100% commercially available $Mg(OH)_2$ exhibited the highest performance, coatings containing seawater-derived $Mg(OH)_2$ also showed substantial protective benefits, though with a slight reduction in performance. These findings suggest that integrating seawater-derived $Mg(OH)_2$ into traditional coating formulations could provide a more environmentally sustainable solution without compromising the protective qualities necessary for mitigating hydrogen sulfide-induced corrosion.

Furthermore, upon conducting DFA, it was determined that 0% SW - 100% CA $Mg(OH)_2$ coating is the optimal combination that would produce the least weight loss and surface roughness post-exposure to acid and maximum compressive strength and surface pH. However, a composite desirability of 1.000 was achieved from the coating ratio of 25% SW - 75% CA $Mg(OH)_2$. This indicates that the 25% SW $Mg(OH)_2$ ratio can also be considered acceptable, as it meets the study's performance criteria.

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