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Andrea Joy D. Abergas
De La Salle University

Jozette Nicole R. Ardiente
De La Salle University

Ahmed Mujahib D. Ramos
De La Salle University

Aaron Johann L. Tan
De La Salle University

他

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Andrea Joy D. Abergas[1], Jozette Nicole R. Ardiente[2], Ahmed Mujahib D. Ramos[3], Aaron Johann L. Tan[4], Kenneth Jae T. Elevado[5], Nicanor R. Roxas Jr.[6], Cheryl Lyne C. Roxas[7]
[1, 2, 3, 4, 5, 6, 7]De La Salle University, 2401 Taft Avenue Manila, 1004, Philippines.
andrea_abergas@dlsu.edu.ph[1], jozette_ardiente@dlsu.edu.ph[2], ahmed_ramos@dlsu.edu.ph[3], aaron_johann_tan@dlsu.edu.ph[4], kenneth.elevado@dlsu.edu.ph[5], nicanor.roxas@dlsu.edu.ph, cheryl.capiz@dlsu.edu.ph[6]

Abstract: *This study explores the use of magnesium hydroxide ($Mg(OH)_2$) coatings derived from natural seawater as a sustainable solution for mitigating biogenic sulfuric acid (BSA) corrosion in concrete wastewater pipes. $Mg(OH)_2$ was extracted from seawater through a precipitation process and compared with commercially available $Mg(OH)_2$. Concrete specimens were coated using varying ratios of both sources and subjected to acid spraying for four days to simulate corrosive sewer conditions. Compressive strength tests revealed that all coated specimens exceeded the ASTM minimum threshold of 24.5 MPa, with the 100% seawater-derived coating achieving the highest strength at 41.893 MPa. Surface degradation patterns confirmed acid attack, validating the need for protective coatings. The results suggest that seawater-derived $Mg(OH)_2$ not only offers effective corrosion resistance but also presents an environmentally sustainable alternative to mined materials, supporting its potential for improving the durability and resilience of sewer infrastructure.*

Keywords: corrosion; sulfuric acid; magnesium hydroxide; anti-corrosion coating, seawater

1. INTRODUCTION

Sewer systems are crucial in a community because they ensure sanitation and safety by transporting wastewater to designated locations. Wastewater comes from domestic and industrial sources, comprising microorganisms, chemicals, heavy metals, and organic and inorganic matter [1]. The composition of wastewater exhibits a corrosive environment for the concrete pipes of the sewer system.

Corrosion in concrete pipes involves chemical, microbiological, and mechanical interactions, but the most damaging would be microbiological interactions, specifically referred to as biogenic sulfuric acid (BSA) corrosion [2]. Anwar et al. [2] and Merachtsaki et al. [3] stated that biogenic sulfuric acid (BSA) corrosion—also known as microbiologically induced corrosion (MIC), microbiologically induced deterioration (MID), biodegradation, and hydrogen sulfide corrosion—starts with the interaction between anaerobic bacteria, specifically the sulfate reducing bacteria (SRB), and the sulfates (SO_4^{2-}) present in the wastewater [4]. This interaction produces hydrogen sulfide (H_2S) in aqueous form. Over time, the pH of the wastewater would drop below 7, wherein the H_2S would turn from aqueous to gaseous form. As a gaseous form, the H_2S would rise to the top of the concrete pipe and condense as a thin moisture film, resulting in the H_2S dissolving the concrete surface and lowering its pH level. When the pH level drops low enough, aerobic bacteria such as the acidophilic sulfur-oxidizing bacteria (ASOB) and neutrophilic sulfur-oxidizing bacteria (NSOB) start to thrive and produce sulfuric acid (H_2SO_4), which further corrodes the concrete surface. This can be seen in Figure 1, where H_2S decreases the pH on the top of the concrete pipe, which results in H_2SO_4 formation and further corrosion. When this occurs, gypsum, ettringite, and iron rust will form on the concrete surface, contributing to corrosion. As corrosion progresses, it would eventually fail due to cracking [5] and spalling, which can have adverse social, economic, and environmental impacts.

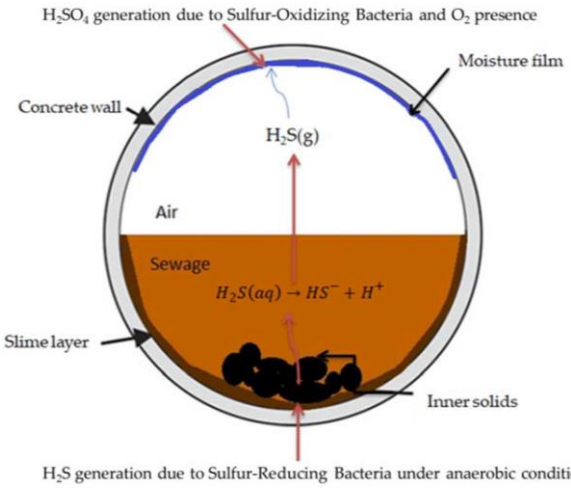

Fig. 1. Biogenic Sulfuric Acid (BSA) Corrosion [3]

Currently, there are several measures to prevent BSA corrosion, such as polymer-based coatings [6]. Existing preventive measures have discernible environmental impacts [7-8]. As such, this paper explores a possible alternative that produces fewer environmental impacts by taking advantage of abundant resources, particularly natural seawater, as opposed to Moa et al. [7-8], which utilized artificial seawater.

Seawater contains a key component that can be used to develop an anti-corrosion coating: magnesium [7-8]. Magnesium is one of the six major ions found in seawater [9]. Typically, the amount of magnesium found in seawater is 1.29 g/L. With this, the magnesium ions in seawater can be used in a precipitation reaction to get

magnesium hydroxide $Mg(OH)_2$, which is subsequently used to create the anti-corrosion coating.

Therefore, this study explores the use of natural seawater in extracting $Mg(OH)_2$ and how $Mg(OH)_2$ can be used to develop an anti-corrosion coating. To evaluate the feasibility of the developed coating, acid spraying was applied to simulate BSA corrosion. Concrete specimens were subjected afterwards to compressive strength test. The concrete specimens tested included uncoated samples, those coated with seawater-derived (SW) coating, those with a commercially available (CA) coating, and those treated with a combination of SW and CA coatings in varying ratios for comparative analysis.

2. MATERIALS AND METHODOLOGY

Figure 2 illustrates the methodology of the study. It employed a quantitative research design to evaluate the effectiveness of the derived $Mg(OH)_2$ from natural seawater collected in Pinamucan, Batangas City, Philippines.

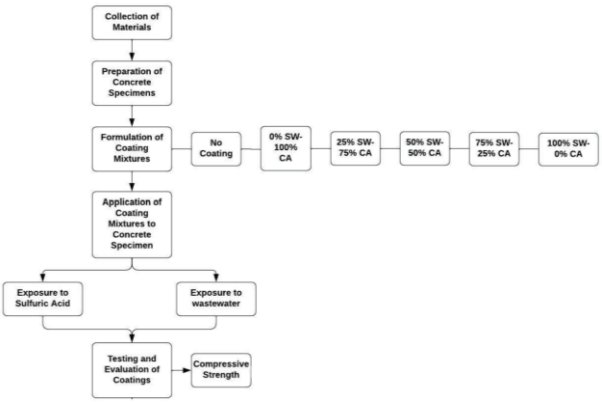

Fig. 2. Methodology of the Study

2.1 Preparation of Concrete Specimens

A total of 18 concrete samples were prepared, each measuring 100mm x 100mm x 100mm, according to the mix design in Table 1. The mix design adhered to relevant ASTM standards for the material properties of concrete constituents.

Table 1. Concrete Mix Design

Materials	Batch Weight per cubic meter
Portland-Pozzolan Cement (Type 1P), kg/m^3	364.00
Coarse Aggregates, kg/m^3	1100.09
Fine Aggregates, kg/m^3	667.70
Water, kg/m^3	205.00

The concrete mix was cured for 28 days, as presented in Figure 2, with a target compressive strength (f'c) of 28 MPa.

Fig.2. Curing of Concrete Specimens

2.2 Obtaining Natural Seawater-derived Mg (OH)$_2$

Following the methodology of Moa et al. [7-8], $Mg(OH)_2$ was extracted from natural seawater. The chemical reactions outlined in Equations (1) and (2) were used as a basis for $Mg(OH)_2$ extraction procedures.

$$\boldsymbol{CaO + H_2O \rightarrow Ca(OH)_2} \quad (1)$$

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

First, lime slaking was performed by hydrating quicklime (CaO) with water to form Calcium Hydroxide ($Ca(OH)_2$). The seawater sample was also aerated for 20 minutes using a venturi aerator. A 1:4 ratio of CaO to water was used, wherein 10.87 grams of CaO were combined with 43.48 grams of water, and the mixture was continuously stirred at a rate of 400 rpm as presented in Figure 3.

Fig.3. CaO and Water mixture

The resulting calcium hydroxide slurry underwent wet screening at 100 µm-sized sieves. The process refined the magnesium hydroxide, ensuring higher purity for the reaction outlined in Equation 2. After the reaction, the magnesium hydroxide precipitate was allowed to form and settle, then filtered to minimize residual soils. Finally, the samples were over-dried for 24 hours to achieve the desired powdered form of magnesium hydroxide, as illustrated in Figure 4.

Fig.4. Mg $(OH)_2$ derived from Natural Seawater

2.3 Obtaining Commercially Available Mg $(OH)_2$

While existing coatings already utilize magnesium hydroxide ($Mg(OH)_2$), the key distinction in this research is that the $Mg(OH)_2$ was derived from seawater, as opposed to the commercially available sources typically used. Commercially available magnesium hydroxide (CA $Mg(OH)_2$) comes from minerals (e.g., from serpentinite rock via the Magnifin process) that are mined in mountains or underground [10]. Commercially available (CA) $Mg(OH)_2$ was used in this research to enable comparison with seawater-derived $Mg(OH)_2$.

Since commercially available (CA) $Mg(OH)_2$ was difficult to obtain directly, this research instead acquired magnesium oxide (MgO) and hydrated it to produce magnesium hydroxide ($Mg(OH)_2$), as illustrated in the chemical Equation (3) and Figure 5.

$$\boldsymbol{MgO + H_2O \rightarrow Mg(OH)_2} \quad (3)$$

Fig.5. Commercially Available Mg $(OH)_2$

2.4 Making the Mg $(OH)_2$ Coating

Table 2 shows the required amount of reactants to formulate a slurry for one face of a specimen [7-8].

Table 2. Required Input Quantities

Substance	Amount needed for 20g
Quicklime (CaO)	10.87 g
Seawater (Mg^{2+})	3.65L

Following the methodologies outlined by Moa et al. [7-8] and Merachtsaki et al. [6], methylcellulose was mixed with deionized water and powdered $Mg(OH)_2$ to create a homogeneous slurry for coating the concrete specimens (Figure 6). The methylcellulose was a binding agent for the coating, enhancing adhesion, as $Mg(OH)_2$ alone exhibits limited adhesion to concrete [6].

Fig.6. Coating slurry

Several concrete specimens were prepared and coated with different proportions of seawater-derived $Mg(OH)_2$ and commercially available $Mg(OH)_2$. A total of 18 concrete specimens were produced and systematically divided into six distinct groups based on the coating ratios, following the approach used by Moa et al. [7-8]. The distribution of specimens for each coating ratio is detailed in Table 3.

Table 3. Number of concrete specimens

Coating Ratio	Number of Concrete Specimens
Control Group (*No Coating*)	3
100% CA- 0% SW	3
75% CA- 25% SW	3
50% CA- 50% SW	3
25% CA- 75% SW	3
0% CA- 100% SW	3

2.5 Applying the Mg $(OH)_2$ Coating

After extraction, the $Mg(OH)_2$ was applied as a coating on the prepared 100 mm cubical concrete specimens as presented in Figure 7.

Fig.7. Application of Coating to Concrete Specimens

The application was executed using a trowel and spatula to ensure a uniform layer across the surface of each specimen. To ensure consistency, a predetermined amount of $Mg(OH)_2$ was measured for each specimen before application to achieve the desired coating thickness of 0.18–0.20 g/cm², as prescribed in the studies conducted by Merachtsaki et al. [5]. However, direct coating thickness measurement posed a challenge due to the limitations associated with measuring very small

thickness values. To address this, the amount of coating applied to each specimen was standardized at 20 grams. The coating thickness was kept consistent by predetermining a specific application height and measuring multiple points on each specimen to ensure uniformity, as illustrated in Figure 8. This approach helped prevent excessive or insufficient coverage.

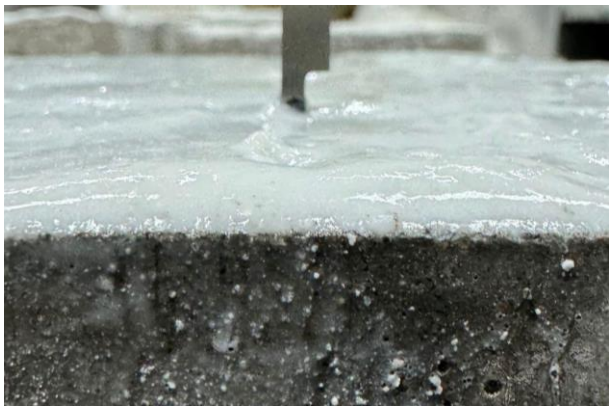

Fig.8. Verification of Coating Thickness on Concrete Specimens

Moreover, the application occurred in a controlled environment to minimize variables affecting adhesion and coating integrity. After application, the coated specimen was cured for 24 hours, promoting proper adhesion of the $Mg(OH)_2$ before exposure to corrosive conditions.

2.6 Acid Spraying

After the coating application, the concrete specimens were exposed to sulfuric acid using an automated spray system for 4 days. The testing procedures used to assess the performance of these coatings were based on the specimens' compressive strength, measured at the specified 4-day interval. This allowed for observing changes in the mechanical properties of the concrete specimens over time under aggressive chemical and real-world wastewater conditions.

2.7 Compressive Strength Test

The compressive strengths of the concrete specimens were evaluated using a universal testing machine (UTM) as shown in Figure 9.

Fig.9. Compressive Strength Test using UTM

Following the approach of Moa et al. [7-8], the study aimed for a target compressive strength (f'c) of 28 MPa for all specimens, with an acceptance threshold set at 24.5 MPa after exposure to corrosive environments. This threshold was based on the criteria in ASTM 318, which specifies that no individual test result should fall more than 3.5 MPa (or 500 psi) below the target strength when the specified f 'c is less than 35 MPa.

3. RESULTS AND DISCUSSION

The average compressive strength results for all specimens subjected to different coating ratios are summarized and presented in Table 4.

Table 4. Compressive Strength Test Data

Coating Ratio	Compressive Strength, MPa
Control Group (*No Coating*)	36.070
100% CA- 0% SW	32.083
75% CA- 25% SW	25.290
50% CA- 50% SW	24.827
25% CA- 75% SW	30.173
0% CA- 100% SW	41.893

Based on the acceptance threshold of 24.5 MPa, all coating ratios satisfied the acceptance criterion. A graphical representation of the deviation of the compressive strength values from the acceptance threshold is seen in Figure 10.

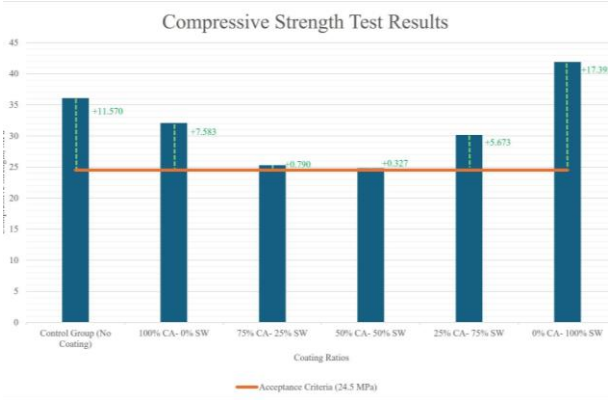

Fig.10. Compressive Strength Results

Although all coated specimens exhibited increased compressive strength, the 50% CA- 50% SW coating ratio showcased the smallest increase from the acceptance criteria values. In contrast, the 100% SW- 0% CA coating yielded the highest compressive strength among all coating ratios, highlighting its effectiveness against degradation of compressive strength.

In comparison with Moa et al. [7-8] 's findings, where the highest compressive strength increase was observed at a 100% CA–0% SW coating ratio, the present study initially followed a similar trend. Higher concentrations of CA in the coating corresponded to greater compressive strength, with the 100% CA coating resulting in an increase of 7.583 MPa.

However, a decline in the compressive strength values was observed with SW percentages in the coating ratio until the 50% proportions, resulting in a 0.327 MPa increase from the acceptance threshold.

Notably, the trend of the decreasing compressive strength with an increase in the proportion of SW in the coating was reversed, resulting in the highest compressive strength value observed at 100% SW coating ratio.

With the difference in observed results from Moa et al. [7-8], the effectiveness of the SW coating may be attributed to its mineral composition and subsequent interaction with the concrete specimens, enhancing its overall resistance to exposure to sulfuric acid.

Fig. 11. Concrete Cubes After 4 Days of Sulfuric Acid Exposure

After four days of exposure to a 4M sulfuric acid solution, the concrete specimens exhibited significant signs of chemical attack, highlighting the aggressive nature of the environment. As observed in Figure 11, the specimens developed pronounced surface degradation characterized by distinct yellowish-brown staining. These visual indicators are consistent with the formation of gypsum, which forms as a reaction product between sulfuric acid and calcium hydroxide. The formation of gypsum leads to the replacement of cementitious compounds with expansive secondary minerals, resulting in surface softening and eventual strength loss.

These findings are consistent with the literature on sulfuric acid attack in cement-based materials. Moa et al. [7-8] and Merachtsaki et al. [6] described gypsum as one of the earliest products to form during sulfuric acid exposure, leading to the initial softening and expansion of the surface layer. The early and aggressive attack observed here demonstrates the importance of immediate protective strategies in acidic environments.

Overall, this study suggests that seawater-based coatings may offer an effective and sustainable means of improving concrete's acid resistance. By limiting the penetration of aggressive ions and slowing the formation of expansive secondary products like gypsum, such coatings can extend the service life of concrete structures in wastewater treatment plants and sewer systems.

4. CONCLUSION

This study evaluated the effectiveness of seawater-derived magnesium hydroxide ($Mg(OH)_2$) as a sustainable coating for protecting concrete against biogenic sulfuric acid (BSA) corrosion. Concrete specimens were exposed to a 4M sulfuric acid solution via an automated spraying system for four days to simulate aggressive sewer conditions.

All coated specimens exceeded the compressive strength threshold of 24.5 MPa, with the 100% seawater-based coating performing best at 41.893 MPa. Surface observations revealed yellowish-brown discoloration (Figure 6), indicative of gypsum formation—a reaction product of sulfuric acid and calcium hydroxide known to weaken concrete, as supported by Moa et al. [7-8] and Merachtsaki et al. [6].

The early signs of degradation emphasize the corrosive nature of such environments and the need for immediate protection. Seawater-derived $Mg(OH)_2$ proved effective in enhancing acid resistance and presents a sustainable alternative to commercially mined materials, making it a promising solution for improving the durability of concrete in wastewater infrastructure.

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