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Effectiveness of Asian Green Mussel (Perna Viridis) Shells as Partial Replacement for Portland Pozzolana Cement (Ppc) On Magnesium Sulfate Resistance in Concrete

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ABSTRACT

This study evaluated the effectiveness of Asian Green Mussel Shells (Perna Viridis) as a partial replacement for Portland Pozzolana Cement (PPC) in marine concrete, focusing on compressive strength and resistance to magnesium sulfate attack. Concrete mixtures containing 0%, 4%, 8%, 12%, 16%, and 20% GMS powder were prepared and subjected to 28-day water curing and exposure to a 5% magnesium sulfate solution. The concrete mix proportion was established at 1:2.86:3.43 using the ACI method. Compressive strength was determined in accordance with ASTM C39, while resistance to chemical exposure was evaluated using the Strength Retention Index (SRI). Results showed that compressive strength increased from 19.39–20.06 MPa (0% GMS) to 23.062 MPa at 12% replacement under normal curing, and from 16.953–18.371 MPa to 21.882 MPa under magnesium sulfate exposure. However, higher replacement levels (16%– 20%) resulted in reduced strength, ranging from 15.098 to 18.139 MPa. These findings indicate that GMS powder acts primarily as a micro-filler, improving particle packing and contributing to higher compressive strength and better resistance under early exposure conditions at an optimal replacement level of 12%. Beyond this level, performance decreases due to the dilution of cementitious material.

Keywords: Asian Green Mussel Shell, Perna viridis, Portland Pozzolana Cement, magnesium sulfate attack, concrete durability, partial cement replacement, Strength Retention Index, sustainable concrete

INTRODUCTION

Marine and coastal concrete structures are continuously exposed to aggressive environmental conditions. Sulfate and magnesium ions present in seawater can penetrate the concrete matrix and contribute to cracking, deterioration, and loss of mechanical performance. Sulfate attack may produce expansion and cracking, while magnesium attack can adversely affect the calcium silicate hydrate (C–S–H) system responsible for concrete strength and cohesion. The deterioration of concrete in marine environments consequently affects the service life, safety, maintenance requirements, and rehabilitation costs of infrastructure.

The search for sustainable cement-replacement materials has intensified because conventional cement production consumes natural resources and contributes to environmental pollution. Waste materials containing calcium carbonate have received particular attention because of their potential application as fillers or partial cement replacements.

Asian Green Mussel (Perna viridis), locally known as "tahong," is abundant in the Philippines and produces considerable quantities of shell waste. Green Mussel Shells contain high levels of calcium carbonate ($CaCO_3$), making them potentially suitable for use as a fine filler in cement-based materials. Previous studies reviewed in the source paper indicate that finely processed mussel shell materials can improve concrete properties at appropriate replacement levels, while excessive replacement can reduce performance because of cementitious-material dilution.

The environmental significance of shell waste is also considerable. Improperly discarded shells can contribute

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to waste accumulation, water pollution, eutrophication, and other environmental problems. Recycling shell waste into construction materials therefore provides an opportunity to integrate waste management with sustainable construction practices. The use of shell-derived material in concrete is consistent with the circular economy approach because a waste stream is converted into a potentially useful construction resource.

Portland Pozzolana Cement (PPC) was selected as the base cementitious material because of its established durability characteristics under aggressive environmental exposure. The source study identifies a research gap concerning the combined use of GMS-derived calcium carbonate and PPC under sulfate and magnesium exposure. The study therefore investigates whether GMS can function as a partial PPC replacement while maintaining or improving concrete strength and resistance to magnesium sulfate attack.

General Objective

This study evaluated the effectiveness of Asian Green Mussel Shells (GMS) as a partial replacement for Portland Pozzolana Cement (PPC) in improving the durability performance of concrete under magnesium sulfate exposure, which represents combined sulfate and magnesium attack.

Specific Objectives

To determine the fineness, specific gravity and moisture content of Asian Green Mussel Shells (GMSs).

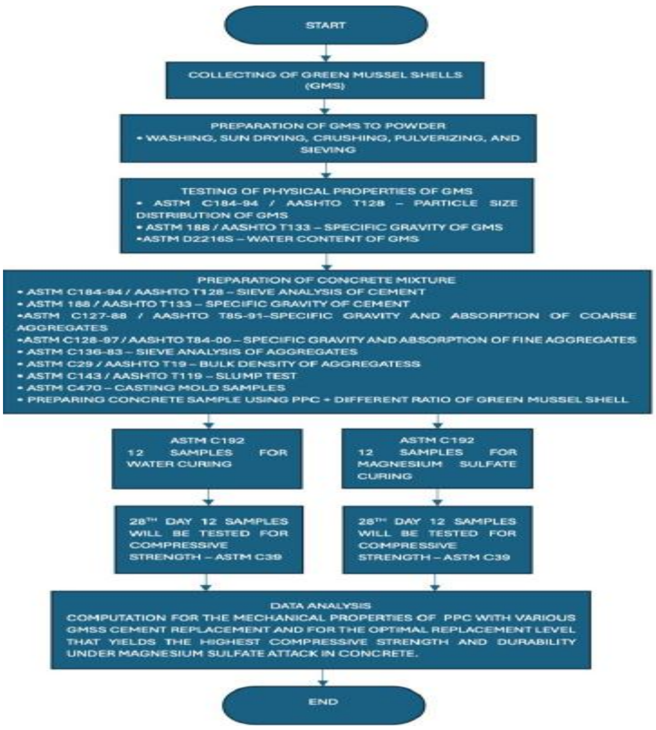
To determine the optimal partial replacement level of GMSs (at 0%, 4%, 8%, 12%, 16%, and 20%) as a partial replacement for PPC that yields the highest compressive strength and the greatest durability under magnesium sulfate solution exposure

To determine the compressive strength of PPC with various levels of GMSs replacement.

METHODOLOGY

Research Design

Figure 1



This study used a quantitative method, which focused on gathering and analyzing numerical data to understand, predict, or measure specific variables (Sreekumar, 2024). This method allowed researchers to draw conclusions that could be generalized to larger populations by using numbers and statistical techniques. Quantitative research typically involved structured tools such as experiments or surveys to collect precise and measurable data, enabling the identification of patterns, trends, and potential causal relationships (Fleetwood, 2024).

This study employed a quantitative and experimental research design focused on the development and testing of concrete mixtures incorporating GMSs as a partial replacement for PPC. Quantitative data were collected through controlled laboratory experiments to measure the effects of varying GMSs replacement levels on the compressive strength and magnesium sulfate resistance of marine concrete. An experimental design was implemented within a controlled environment, where specimen preparation and testing followed standardized procedures under ASTM, AAHSTO, ACI, and DPWH protocols to ensure reliability of results. *Figure 1* outline the three main objectives of this research. The first experiment was conducted using ASTM 184-94 / AASHTO T128 to determine the particle size distribution of GMS, and ASTM C188 / AASHTO T133 to determine the specific gravity of GMS. Then, the next phase was conducted in accordance with ASTM C39 and aimed to determine the effect of partially replacing PPC with GMSs on the compressive strength and residual compressive strength of concrete. The optimal replacement level was established based on the compressive strength of the resulting concrete when cured to magnesium sulfate solution. These durability assessments imitated chemical attack conditions to evaluate the performance of the modified concrete at 28 days. All experimental procedures were conducted within a controlled laboratory environment to eliminate external variables that may influence strength and durability outcomes.

Data Collection

This study utilized five main locations for different stages of the research process. The Asian Green Mussel Shells (GMS), which served as the primary raw material, were collected from the Navotas Fishport Complex at North Bay Boulevard, Navotas City, Metro Manila, Philippines.

This site is recognized as the largest fish trading center in the country and provides a continuous supply of discarded mussel shells. The pre-treatment of the shells, including cleaning, soaking, and boiling was conducted at a facility located along North Bay Boulevard, Navotas City, near the Navotas Fishport Complex and Cuatro de Julio, Quezon City.

The grinding and sieving of the shells were carried out at the Civil Engineering Laboratory of Pamantasan ng Lungsod ng Maynila (PLM). This stage involved processing the shells into fine powder suitable for use as a micro-filler material in concrete mixtures.

Sampling

An experimental laboratory approach was used to evaluate the effectiveness of Asian Green Mussel Shells (GMSs) as a partial replacement for Portland Pozzolana Cement (PPC). GMS, typically discarded as waste after meat extraction, were collected from the Navotas Fishport Complex in Navotas City. The shells underwent washing, oven-drying, grinding into fine powder, and sieving in a no. 200 sieve to achieve uniform particle size.

Data Gathering Procedure

Approximately 6kg of Green Mussel Shells, serving as the raw material, were collected directly from Navotas Fish Port Complex in North Bay Boulevard, Navotas City, Philippines.

Figure 2. Navotas FishPort Complex (Source: Choy Rosales Photography)

PHASE 1: Preparation of Green Mussel Shells as Partial Replacement

The shell preparation began with cleaning to eliminate impurities, organic matter, and residual salts. Green Mussel Shells (GMSs) were scrubbed with soap and a brush, and rinsed with tap water, followed by a final wash (Hasan et al., 2021; Tayeh et al., 2020). The GMSs underwent sun-drying for 3 days to remove the water content (Maglad et al., 2023; He et al., 2023). The GMS material was then manually crushed into coarse particles measuring 5 to 10 mm using a mortar and pestle in preparation for further grinding (He et al., 2023).The crushed green mussel shells underwent additional pulverization using a laboratory blender and a laboratory grinder to obtain a finer and more uniform consistency (Binag, 2016). Lastly, the pulverized green mussel shell powder was sieved using a standard 200-mesh laboratory sieve to ensure uniform particle size, as established in previous research (Binag, 2016).

PHASE 2: Testing of Physical Properties of Green Mussel Shell Powder

The physical characteristics of green mussel shells (GMS) were evaluated through a series of tests at the PLM Civil Engineering laboratory. First, pulverized GMS samples were analyzed for particle size distribution in accordance with ASTM C184-94/AASHTO T128 standards. A sieve analysis was conducted using the specified sieves.After assessing the fineness of the Green Mussel Shell Powder, the next step involved conducting a specific gravity test of the GMS powder. This process adhered to established standards set by ASTM C188/AASHTO T133. The test was carried out using a Le Chatelier flask apparatus. A clean and dry Le Chatelier flask was first prepared and filled with kerosene up to the initial graduation mark, ensuring the fluid did not react with the GMSs. The temperature of the liquid was recorded. A carefully weighed amount of GMSs powder, typically 64 grams, was introduced gradually into the flask using a small funnel, allowing the powder to settle slowly into the liquid without sticking to the neck. The flask was then gently rolled, tilted, and rotated to release any trapped air bubbles. Once all the GMSs powder had settled and no more bubbles were observed, the final liquid level was read at the meniscus. The moisture content of green mussel shell powder was determined in accordance with ASTM D2216 by oven-drying a weighed sample at 110 ± 5 °C to a constant mass.

PHASE 3: Preparation of Concrete Mixture

Concrete preparation began with sieve analysis, conducted in accordance with ASTM C184-94/AASHTO T128, using sieves to assess the fineness of Pozzolanic Portland Cement, and Green Mussel Shell Powder. This process ensured a uniform particle size distribution, which facilitated control over the hydration rate and the subsequent strength of development of the concrete.The particle size distribution, or gradation, is determined using ASTM C136-83. Proper gradation is essential for achieving optimal particle packing, which reduced paste requirements and improved both workability and ultimate strength of the concrete.The specific gravity and water absorption characteristics are determined separately for coarse aggregates using ASTM C127-88 / AASHTO T19 and fine aggregates using ASTM C128-97 / AASHTO T84- 00. Specific gravity is used to convert aggregate volume to mass during batching, while absorption capacity indicates the amount of water the aggregates was absorb.The water-to-cement ratio is added gradually. Workability is verified using the Slump Test, as specified in ASTM C143/AASHTO T119. The slump test must be in the range of 50 – 100 mm based on the specification of DPWH Structural Concrete. Finally, the casting and curing phase produced standardized test specimens. The casting procedure follows ASTM C192, using 102mm x 203mm or 4” x 8” cylindrical molds that comply with ASTM C470. The molds are filled in layers, with each layer consolidated using 25 strokes of a tamping rod to remove air voids.

Data Analysis

All data obtained from the ASTM C39 compressive strength tests and the residual compressive strength measurements after exposure to magnesium sulfate solution were analyzed using descriptive and comparative statistical methods. The initial mass of each specimen was recorded before immersion, and after exposure using a digital weighing scale. These values were compiled in a table to compare mass changes as the duration of magnesium and sulfate exposure increases. This comparison helped assess potential deterioration or material loss due to chemical attacks. The compressive strength of each specimen was calculated in accordance with ASTM C39. The Strength Retention Index (SRI) was computed. The residual compressive strengths of the experimental group are compared with the control group to evaluate the performance of each replacement ratio on day 28. The percentage loss in strength was determined by subtracting the computed SRI value from 100. All percentage loss values were compiled to compare the effects of each mix ratio. The optimal replacement ratio was identified as the one that achieves the highest compressive strength and the lowest percentage loss after magnesium sulfate exposure.

ANALYSIS OF RESULTS

Green Mussel Shell Physical Properties

A 1,500 g sample of processed Asian Green Mussel Shell (GMS) powder was subjected to sieve analysis using a No. 200 (75 μm) sieve in accordance with ASTM C184. The mass of material passing the sieve was recorded as 1,499.763 g. The result indicated that 99.984% of the GMS powder passed through the No. 200 sieve, confirming that the material was extremely fine and falls within the micro-filler particle size range. The specific gravity of the GMS powder was determined using the Le Chatelier flask in accordance with ASTM C188. Three (3) trials were conducted to ensure consistency and reliability of the results. The individual test results obtained were 2.723, 2.667, and 2.774, yielding an average specific gravity of 2.72133. The computed value of 2.72133 is lower than that of PPC, which has a specific gravity of 2.98411. This indicates that the GMS powder is less dense compared to cement. Furthermore, the relatively lower density of the GMS powder implies that when used as a partial replacement by weight, it occupies a greater volume within the concrete mixture. This contributes to improved particle packing and microstructure densification, which are essential in enhancing the overall compactness of the concrete matrix. In terms of moisture content, a 74 g sample of GMS powder was tested to determine its water retention after processing. The initial mass was recorded at 100 g with container, while the final oven-dried mass with container was measured at 99 g. Moisture content were computed to be 1.37%. This low moisture content suggests that the material is relatively dry and stable, making it suitable for use as a cement replacement without affecting the water demand of the concrete mix.

Aggregate Physical Properties

Table 1 presents the coarse aggregate properties, including a dry rodded mass of 1592.096 grams, which indicates good compaction for mix proportioning. The bulk specific gravity of 2.85 falls within the typical range for normal-weight aggregates (2.5–3.0), suggesting adequate density and strength potential. Its low water absorption of 0.66% reflected low porosity, meaning minimal water uptake during mixing. The sieve analysis conducted on the 3/4-inch coarse aggregate yielded a fineness modulus of 6.93, indicating a relatively coarse and well-graded particle size distribution. This value falls within the expected range for coarse aggregates and suggests that the material contains a good proportion of larger particles.

Table 1. Coarse Aggregates Test Result

COARSE AGGREGATES DATA	
Dry Rodded Mass	1592.096 grams
Bulk Specifc Gravity	2.85
Water Absorption	0.66%

Table 2 summarizes the fine aggregate results, with a dry rodded mass of 1525.8099 grams, also indicating proper compaction. The bulk specific gravity of 2.6477 is within the standard range for fine aggregates. However, the water absorption of 6.87% is relatively high, implying higher porosity and the need to adjust mixing water to maintain workability. The fine aggregate exhibited a fineness modulus of 2.57, classifying it as medium sand suitable for concrete production. This grading indicates a balanced distribution of particle sizes, allowing the material to effectively fill the voids between coarse aggregate particles.

Table 2. Fine Aggregates Test Result

FINE AGGREGATES DATA	
Dry Rodded Mass	1525.8099 grams
Bulk Specific Gravity	2.6477
Water Absorption	6.87%
Fineness Modulus	2.57016

Portland Pozzolana Cement Properties

A representative 500 g sample of cement was subjected to sieve analysis using a No. 200 (75 µm) sieve in accordance with ASTM C184-94 procedures for fineness determination of hydraulic cement. Results indicate that no cement particles were retained on the No. 200 sieve, corresponding to a 0 g retained mass. This implies that 100% of the cement sample passed through the sieve, confirming that the material is sufficiently fine for use in concrete production. The results in *Table 3* for specific gravity indicate that all three trials yielded values that are closely related, showing consistency in the experimental procedure. The slight variation among the values may be attributed to minor experimental factors such as air entrapment, temperature variation, or reading inaccuracies during the test. The computed average specific gravity was 2.98411, which falls within the typical range of 2.90 to 3.05 for Portland Pozzolana Cement. This indicates that the cement used in the study possesses normal density characteristics and is suitable for concrete production.

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Table 3. Specific Gravity Test for Portland Pozzolana Cement

SPECIFIC GRAVITY	TRIAL 1	TRIAL 2	TRIAL 3
a. Weight of Le Chatelier Flask & Kerosene, g	366.96	361.09	361.34
b. Initial Volume Reading, mL	0.9	0.9	0.9
c. Bath Temperature at Initial Volume Recording,	25°C	25°C	25°C
d. Weight of La Chatelier Flask, Kerosene & Sample, g	430.1	424.86	425.1
e. Final Volume Reading, mL	22.2	22.1	22.3
f. Bath Temperature at Final Volume Recording	25°C	25°C	25°C
g. Specific Gravity (d-a)/e-b	2.96431	3.00802	2.98

Concrete Mix Design (ACI Method)

Using American Concrete Institute (ACI), results for estimated batch masses for cubic meter of concrete, concrete ratio and proportion were calculated. The estimated batch masses for one cubic meter of concrete consist of 199 kg of water, 303 kg of cement, 1040 kg of coarse aggregate, and 868 kg of fine aggregate, resulting in a total batch mass of 2410 kg per cubic meter.

This mix design establishes the standard composition used as the basis for all experimental specimens. The mix design was scaled down for 4" x 8" cylindrical molds to ensure uniformity across all samples. The required quantities per cylinder are 0.33 kg of water, 0.50 kg of cement, 1.71 kg of coarse aggregate, and 1.43 kg of fine aggregate.

Table 4. Weight of Aggregate, Cement, and GMS Powder per Ratio

Ratio per Specimen	0% GMS	4% GMS	8% GMS	12% GMS	16% GMS	20% GMS	Total
Cement (kg)	2.12	2.0352	1.9504	1.8656	1.7808	1.696	11.448
Tahong (kg)	0	0.0848	0.1696	0.2544	0.3392	0.424	1.272
Coarse (kg)	7.28	7.28	7.28	7.28	7.28	7.28	43.68
Fine (kg)	6.08	6.08	6.08	6.08	6.08	6.08	36.48
Water (kg)	1.4	1.4	1.4	1.4	1.4	1.4	8.4

Data Gathering for Concrete Specimens

Visual Physical Characterization

The physical dimensions such as weight, length, and diameter of the 24 concrete cylindrical specimens were measured before and after the 28-day curing period. Generally, *Tables 5 and 6* showed slight variations in mass and dimensions, which are common during the concrete hydration and curing process.

Most samples in both groups showed a slight increase in weight after curing, which is expected as concrete gains mass through continued hydration and the absorption of curing fluids.

Table 4. Physical Characteristics of Control Group

CONTROL DATA (BEFORE CURING)				CONTROL DATA (AFTER CURING)			
Sample ID	Weight	Length	Diameter	Sample ID	Weight	Length	Diameter
A1	3957g	205	102	A1	3928g	204.22	102.5
A2	3992g	203	101	A2	3985g	204.65	102.33
A3	3851g	205	102	A3	3879g	208.73	101.56
A4	3829g	202	101	A4	3862g	200.63	102.22
A5	3902g	205	100	A5	3920g	205.77	102.09
A6	3861g	203	100	A6	3896g	205.19	101.98
A7	3839g	204	101	A7	3856g	204.22	102.42
A8	3817g	203	101	A8	3836g	202.75	101.63
A9	3752g	202	102	A9	3771g	200.21	102.32
A10	3841g	203	101	A10	3867g	201.14	102.44
A11	3871g	202	101	A11	3924g	201.31	102.340
A12	3943g	203	100	A12	3967g	201.45	101.290

Table 5. Physical Characteristics of Magnesium Sulfate Group

MAGNESIUM SULFATE DATA (BEFORE CURING)				MAGNESIUM SULFATE DATA (AFTER CURING)			
Sample ID	Weight	Length	Diameter	Sample ID	Weight	Length	Diameter
B1	3950g	205	103	B1	3870g	203.12	102.54
B2	3931g	202	102	B2	3952g	202.18	101.96
B3	3845g	202	101	B3	3894g	202.95	102.5
B4	3791g	202	101	B4	3830g	199.73	102.55
B5	3882g	205	102	B5	3911g	205.77	103.25
B6	3841g	206	100	B6	3892g	205.93	102.42
B7	3810g	203	101	B7	3846g	203.03	102.13
B8	3790g	203	103	B8	3820g	203.37	102.34
B9	3825g	200	102	B9	3855g	202.52	102.7
B10	3757g	202	102	B10	3783g	201.03	102.61
B11	3897g	201	102	B11	3913g	201.68	102.56
B12	3884g	202	102	B12	3924g	203.34	102.67

Mechanical Properties of Concrete

Table 6 presents the compressive strength results of the control concrete specimens at different replacement ratios after 28 days of curing. The untreated specimen (0% ratio) recorded compressive strength values ranging from 19.39 MPa to 20.063 MPa, which serves as the baseline strength of the conventional concrete mix. At 4% and 8% replacement ratios, there is a noticeable improvement in compressive strength, reaching up to 20.985 MPa and 22.600 MPa, respectively, indicating that moderate replacement levels enhance the load-bearing capacity of the concrete. The highest compressive strength was observed at the 12% replacement ratio, with a peak value of 23.062 MPa, suggesting that this is the optimum proportion for achieving maximum strength performance. However, beyond this level, a decline in compressive strength is evident at 16% and 20% ratios, where values drop to around 17.593 MPa to 20.067 MPa. This decrease indicates that excessive replacement disrupts the concrete matrix and weakens its internal bonding structure, resulting in reduced compressive performance.

Table 6. 28-Day Compressive Strength Results for Control Group

CONTROL							
Sample ID	Ratio	Age (days)	Diameter (mm)	Cross Sectional Area (sq.mm)	Max Load (kN)	Compressive Strength (MPa)	
A1	0%	28	102.5	8251.589	160	19.390	
A2	0%	28	102.330	8224.241	165	20.063	✓
A3	4%	28	101.560	8100.937	170	20.985	✓
A4	4%	28	102.220	8206.569	150	18.278	
A5	8%	28	102.090	8185.709	185	22.600	✓
A6	8%	28	101.980	8168.078	170	20.813	
A7	12%	28	102.420	8238.714	190	23.062	✓
A8	12%	28	101.630	8112.108	180	22.189	
A9	16%	28	102.320	8222.634	165	20.067	✓
A10	16%	28	102.440	8241.932	145	17.593	
A11	20%	28	102.340	8225.849	115	13.980	
A12	20%	28	101.290	8057.921	145	17.995	✓

The *Table 7* presented the compressive strength results of concrete specimens exposed to magnesium sulfate solution at 28 days of curing. The specimen with 0% ratio of GMSs recorded compressive strength values ranging from 16.953 MPa to 18.371 MPa, which is relatively lower compared to the control group, indicating the initial weakening effect of magnesium sulfate exposure on concrete. At 4% and 8% replacement ratios, the compressive strength gradually increases, reaching up to 19.390 MPa and 20.901 MPa, respectively, showing that moderate replacement levels still improve strength performance even under magnesium sulfate conditions. The peak compressive strength is observed at the 12% replacement ratio, with a maximum value of 21.882 MPa, suggesting that this is the optimal proportion for magnesium sulfate-exposed concrete as well. However, beyond this level, a decline in strength is observed at 16% and 20% ratios, where values drop to around 15.098 MPa to 18.139 MPa. This reduction indicates that higher replacement levels, combined with magnesium sulfate exposure, weaken the concrete's internal structure and bonding, leading to reduced resistance against compressive loads and suggesting the harmful effect of excessive replacement under aggressive magnesium sulfate environments.

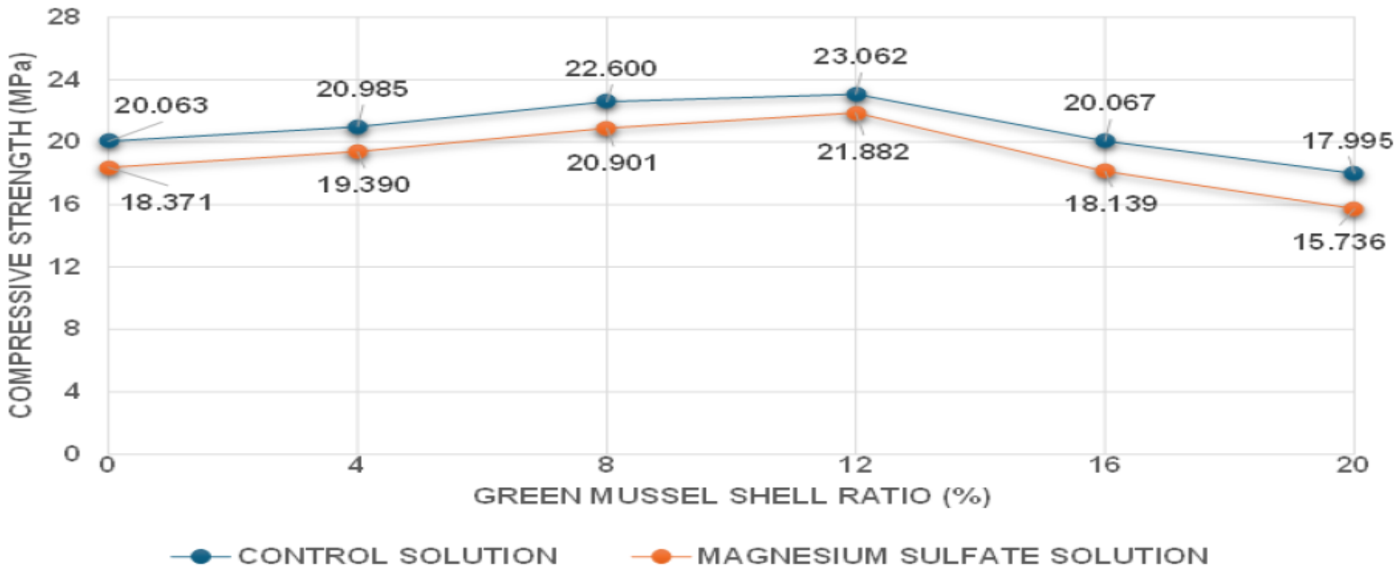
Table 7. *28*-Day Compressive Strength Results for Magnesium Sulfate Group

MAGNESIUM SULFATE							
Sample ID	Ratio	Age (days)	Diameter (mm)	Cross Sectional Area (sq.mm)	Max Load (kN)	Compressive Strength (MPa)	
B1	0%	28	102.540	8258.031	140	16.953	
B2	0%	28	101.960	8164.875	150	18.371	✓
B3	4%	28	102.500	8251.589	160	19.390	✓
B4	4%	28	102.550	8259.642	160	19.371	
B5	8%	28	103.250	8372.786	175	20.901	✓
B6	8%	28	102.420	8238.714	170	20.634	
B7	12%	28	102.130	8192.125	170	20.752	
B8	12%	28	102.340	8225.849	180	21.882	✓
B9	16%	28	102.700	8283.822	140	16.900	
B10	16%	28	102.610	8269.310	150	18.139	✓
B11	20%	28	102.56	8261.253	130	15.736	✓
B12	20%	28	102.67	8278.983	125	15.098	

Figure 3 summarizes the compressive strength results of both the control and magnesium sulfate–exposed concrete specimens at varying green mussel shell ratios (0%, 4%, 8%, 12%, 16%, and 20%) after 28 days of curing. It illustrated that both mixtures exhibited a similar trend, where compressive strength increases with the addition of green mussel shell powder up to an optimum level, then gradually decreases beyond this point. It highlights that the optimum green mussel shell replacement ratio for maximum compressive strength is 12%. It also suggests that magnesium sulfate exposure consistently results in lower compressive strength compared to

the control, indicating a weakening effect on concrete performance under magnesium sulfate conditions. The increase in compressive strength at 12% replacement is attributed to the filler effect of fine GMS particles, which improves particle packing and reduces voids in the concrete matrix.

Figure 3.Comparison of Compressive Strength Between Control and Magnesium Sulfate – Exposed Specimens



Residual Compressive Strength

The data in *Figure 4* illustrated the relationship between the Green Mussel Shell (GMS) ratio and the resulting percentage loss in the strength of the concrete samples. A clear downward trend is observed as the GMS ratio increases from 0% (control) to 12%, where the percentage loss reaches its minimum value of 5.115%, representing the highest level of resistance to deterioration, indicating improved magnesium sulfate resistance at moderate replacement levels. However, at higher contents (16%–20%), SRI declines to 90.396% and 87.449%, with increasing losses up to 12.551%, showing reduced durability. Overall, 12% GMS is identified as the optimum level for maximum strength retention.

Figure 4.Correlation between Green Mussel Shell Ration and Strength Retention

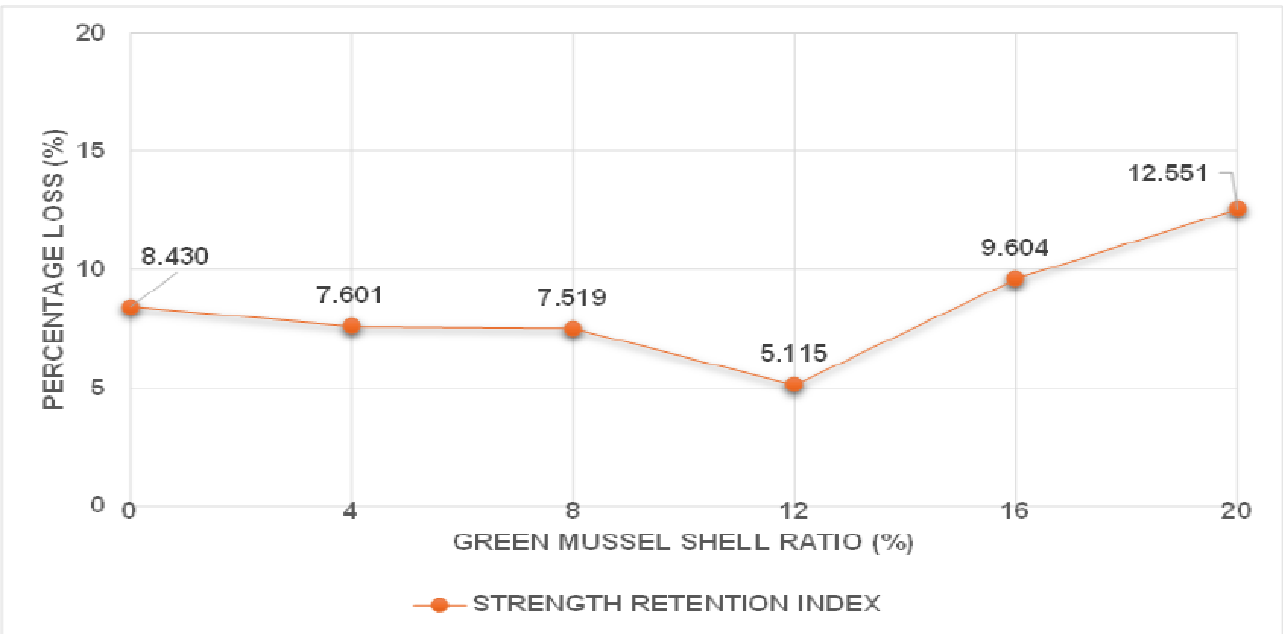


Table 7. Computed Percentage Loss and SRI across Variable GMS Ratio

PERCENT OF GMS (%)	RESIDUAL STRENGTH (MPa)	CONTROL STRENGTH (MPa)	SRI (%)	PERCENTAGE LOSS (%)
0	18.371	20.063	91.570	8.430
4	19.390	20.985	92.399	7.601
8	20.901	22.600	92.481	7.519
12	21.882	23.062	94.885	5.115
16	18.139	20.067	90.396	9.604
20	15.736	17.995	87.449	12.551

The data demonstrates that while GMS serves as an effective micro-filler up to a 12% replacement level, further replacement leads to a decline in both mechanical strength and durability. This trend is likely due to the dilution effect, where the reduction in reactive cementitious material (PPC) is no longer compensated for by the physical filling effect of the GMS. The overall results of the study indicate that the incorporation of GMS as a partial replacement for PPC has a positive effect on both compressive strength and early resistance to magnesium sulfate exposure, particularly at an optimal replacement level of 12%. The improvement in performance is primarily due to the physical filler effect of GMS particles, which enhances particle packing, reduces voids, and improves the density of the concrete matrix. This leads to better mechanical performance, which is critical in resisting chemical ingress.

CONCLUSION

This study evaluated the effectiveness of Asian Green Mussel Shells (GMS) as a partial replacement for Portland Pozzolana Cement (PPC) in marine concrete, with a specific focus on its performance against sulfate and magnesium attacks. Based on the findings from the experimental testing of various replacement ratios, it suggested that pulverized GMS powder serves as a functional micro-filler that contributes to the improvement of both the mechanical properties and the durability of concrete specimens. The concrete mix was designed using ACI method to achieve 20.86 MPa with a mix proportion of 1: 2.86: 3.43. Notably, some GMS-modified specimens even exceeded the target strength, suggesting that the addition of GMS contributed positively to concrete performance. One of the key findings from the study is that the effectiveness of GMS depends on the replacement level used. Among the tested proportions (4%, 8%, 12%, 16%, and 20%), following a 28-day curing period, it was observed that the 12% replacement ratio yielded the most favorable results in terms of compressive strength and resistance to chemical attack. This indicates that an optimal balance between cement content and filler material is necessary to achieve improved performance, as it results in a denser and more stable internal structure. Strength Retention Index (SRI) following exposure to a 5% magnesium sulfate solution. The study showed a difference in how the specimens maintained their structural integrity depending on the presence of the shell powder. Specifically, the 12% replacement level achieved a superior SRI of 94.885%, losing only a minimal percentage of its strength compared to the control samples. This finding suggests that the inclusion of finely ground GMS helps reduce permeability and limits the ingress of harmful sulfate and magnesium ions, thereby improving resistance to chemical deterioration.

Conversely, the study also revealed that exceeding the 12% replacement threshold led to a gradual decrease in performance. At replacement levels of 16% and 20%, the specimens exhibited lower compressive strengths and visible signs of salt crystallization. This indicates a dilution effect, where the reduction of reactive cement outweighed the physical filling benefits of the GMS. These observations serve as an important indicator that precise dosing is essential for maintaining the structural integrity of the concrete when using alternative waste materials.

RECOMMENDATIONS

To enhance the validity and applicability of the findings, future research should consider expanding both the experimental and sampling scope based on the 3pcs per sample. First, it is recommended to test a wider range of Asian Green Mussel Shell (GMS) replacement levels with greater precision. While this study identified 12% as the optimal ratio, using more incremental variations such as 10%, 11%, 13%, and 14%, could help pinpoint the ideal amount for optimal performance. This would allow for more accurate and refined recommendations for industrial concrete mixing and real-world construction applications. Second, extending the duration of the sulfate exposure process is essential for determining the long-term durability of the GMS-modified concrete. Future studies should consider testing specimens at longer intervals, such as 90, 180, or 365 days, to observe how the material behaves under prolonged chemical attack. A longer exposure period would provide a more comprehensive understanding of the concrete's ability to maintain structural integrity in marine settings over several years. It would also be beneficial to move beyond controlled laboratory simulations and conduct testing in actual marine conditions. Future research could involve exposing specimens to natural seawater and real-world coastal environments, where variables such as tidal fluctuations, wave action, and cycles of wetting and drying are present. Testing the performance of GMS-modified concrete in these maritime settings would provide more realistic insights into its resilience and help determine if its effectiveness remains consistent across different locations and coastal conditions. Furthermore, future research should incorporate microstructural and chemical analyses, such as Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray (EDX) spectroscopy. These advanced techniques would help to further confirm the physical filling effects and chemical interactions occurring within the concrete matrix at a microscopic level. Researchers can better explain the underlying mechanisms that lead to improved density and reduced permeability by visualizing the pore refinement and the bond between the GMS powder and the cement paste. Expanding the testing parameters to include other mechanical properties, such as flexural strength, splitting tensile strength, and bond strength with steel reinforcement, would provide a more holistic evaluation of the material. Investigating how the inclusion of GMS influences the bond between concrete and steel, as well as its potential to protect reinforcement from corrosion, would be particularly beneficial given that marine infrastructure is predominantly reinforced.

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