A Study on the Self-Healing Properties of Concrete Blocks Using Calcium Carbonate ($CaCO_3$) from Oyster Shells

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Abstract

This project aims to 1) study the self-repairing properties of concrete blocks using calcium carbonate (CaCO3) derived from oyster shells, and 2) compare the efficiency of self-repairing concrete blocks using calcium carbonate (CaCO3) derived from oyster shells with the TIS standard criteria in terms of density, water absorption capacity, and compressive strength. The study was conducted on the properties of concrete blocks using natural materials, namely oyster shells instead of calcium carbonate (CaCO3). Four formulas were studied: 0%, 5%, 10%, and 15% CaCO3. The TIS standard was used as the basis for the study and testing, focusing on mechanical properties: compressive strength, density, water absorption capacity, and self-repair capacity in humid environments. The experimental results showed that the formula containing 10% CaCO3 had the most suitable properties, especially in terms of compressive strength, water absorption, and density, which were within the criteria that passed the TIS standard (TIS 109-2517), which is used to control the quality of concrete blocks used in general wall construction. It also has a self-repair percentage of approximately 40% and can cover an average of 40% of cracks within 28 days. This feature is an additional highlight that exceeds the minimum requirements of TIS.
Keywords: Self-Healing Concrete, Thai Industrial Standards

Introduction

Currently, the demand for construction materials is increasing due to community expansion and infrastructure development. Concrete blocks are a popular material due to their strength, cost-effectiveness, and rapid construction time. However, conventional concrete blocks have limitations such as cracking, deterioration from moisture, temperature, and impact, which affect the safety and lifespan of buildings. Therefore, new types of construction materials are being developed.self-healing materials to mitigate such issues.

The concept of self-healing materials enables the automatic sealing of micro-cracks, thereby reducing maintenance costs and enhancing structural durability. Simultaneously, sustainable development approaches promote the utilization of waste materials to minimize waste volume and reduce environmental impact regarding the environment, seashells are a waste material primarily composed of calcium carbonate (CaCO3), which holds potential to help stimulate crystallization and seal internal cracks within the material.

Chonburi province is a major source of shellfish waste from oyster farms and the seafood industry. Utilizing shellfish as an ingredient in self-healing bricks is a way to add value to this waste material, reduce production costs, and mitigate environmental problems. This project aims to study the development of self-healing bricks from shellfish, along with testing their compressive strength, moisture resistance, water absorption, and crack recovery capabilities. The goal is to develop high-quality, environmentally friendly construction materials that align with sustainable development principles for the future.

Objectives

1. To study the self-healing properties of concrete blocks using calcium carbonate ($CaCO_3$) derived from oyster shells.

2. To compare the performance of self-healing concrete blocks using calcium carbonate ($CaCO_3$) derived from oyster shells with the Thai Industrial Standard (TIS) in terms of density, water absorption capacity, and compressive strength.

Research Methodology

1. Preparation of the mixture: There are 4 formulas for the proportions of ingredients (per brick) (Ahmed et al., 2016), as shown in Table 1.

Table 1: Proportions of ingredients for making bricks (4 formulas)

Materials	Formulas 1 $CaCO_3$ 0%	Formulas 2 $CaCO_3$ 5%	Formulas 3 $CaCO_3$ 10%	Formulas 4 $CaCO_3$ 15%
Crushed shells	0 g	48 g	97 g	145 g
Portland Cement	973 g	963 g	957 g	951 g
Rock	2,920 g	2,890 g	2,870 g	2,850 g
Sand	1,460 g	1,445 g	1,435 g	1,425 g
Clean water	584 g	584 g	584 g	584 g

2. Production Process

2.1 Prepare all materials in the specified quantities. The preparation process for crushed seashells is as follows:

2.1.1 Preparation of Crushed Seashells

- Wash the seashells thoroughly, removing any remaining shell meat or impurities. Scrub with a brush and rinse with clean water, then sun-dry completely.

- Bake the seashells in an oven at approximately 200-300°C for 2-3 hours to remove moisture and make the shell structure brittle for easy crushing.

- Crush the shells using a mortar and pestle to break them into fine pieces first. Then continue grinding with a dry blender or powder mill. And sieve through a sieve (such as sieve number 100) until you get finely ground shell powder (CaCO3).

2.2 Mix all dry materials. (combined sand or gravel) in a large container and stir well.

2.3 Mix the concoction with clean water and slowly pour it into the dry mixture. At the same time, mix together until you have a moldable material.

2.4 Pour the mixed material into the brick mold. Then press firmly.

2.5 Leave it to initially harden for about 24 hours.

2.6 Curing by covering with a wet cloth or spraying water to maintain humidity 1 – 2 times a day for 7 – 28 days.

3. Testing Procedures

3.1 Compressive Strength Test

3.1.1 Compressive Testing Machine

- Place the sample between the steel plates of the machine.
- The machine will apply compressive force to the surface of the sample until it cracks.

3.1.2 Record the maximum force the material can withstand before failure (Fmax).

3.1.3 Calculate the compressive strength.

3.2 Water Absorption Test

3.2.1 Sample Preparation

- Dry the sample in an oven at 100–110°C until the mass is constant (no water remains) and weigh the dry weight.

3.2.2 Immerse the sample in room temperature water for at least 24 hours.

3.2.3 Remove the sample, pat dry, and weigh it.

3.2.4 Calculate the water absorption rate.

3.3 Density Testing

3.3.1 Weigh the brick (mass, unit: kg).

3.3.2 Measure the dimensions (length × width × height) to calculate the volume (unit: m³).

3.3.3 Calculate the density.

3.4 Crack Testing with a Microscope (Digital Image Analysis)

3.4.1 Use a 50x magnification microscope to examine changes in existing cracks.

3.4.2 Measure the crack width before and after repair every 7 days to analyze the effectiveness of the crack sealing material.

Research Findings:

1. This study investigated the self-healing properties of concrete blocks using calcium carbonate (CaCO3) derived from oyster shells, considering the following physical properties:

1.1 Compressive strength

1.2 Water absorption (% by weight)

1.3 Density (kg/m³)

1.4 Self-healing (cracks 0.3–0.5 mm)

The results are shown in Table 2.

Table 2. Results of the self-repairing properties of concrete blocks using calcium carbonate (CaCO3) derived from oyster shells.

Formulas	Compressive Strength (MPa)	Water Absorption Percentage	Density (Kg/m³)	Self-repair percentage
$CaCO_3$ 0%	3.5	7.5	2,200	~10%
$CaCO_3$ 5%	3.7	6.5	2,230	~30%
$CaCO_3$ 10%	4.0	5.5	2,250	~40%
$CaCO_3$ 15%	3.8	6.2	2,240	~40%

Table 2 shows a study of the physical properties of concrete blocks using calcium carbonate (CaCO3) derived from oyster shells in proportions of 0%, 5%, 10%, and 15% by weight. The results indicate that the formula containing 10% CaCO3 exhibits the best properties, particularly in terms of compressive strength, water absorption, and density. All of these meet the Thai Industrial Standard (TIS 109-2517), which governs the quality of concrete blocks used for general wall construction. Furthermore, it demonstrates approximately 40% self-healing. The next most suitable formula is the one containing 15% CaCO3, while the least suitable is the one containing 0% CaCO3 or no CaCO3.

2. The performance comparison of self-healing concrete blocks using calcium carbonate (CaCO3) derived from oyster shells against the Thai Industrial Standard (TIS) is shown in Table 3.

Table 3. Comparison of the performance of self-healing concrete blocks using calcium carbonate (CaCO3) derived from oyster shells against the Thai Industrial Standard (TIS) 109-2517 (Thailand Industrial Standards Institute, 1998).

Test list	Experimental results ($CaCO_3$ 10%)	Standard TIS 109-2517	Comparison results
Compressive Strength (MPa)	4.0	≥ 3.5	Pass
Water Absorption Percentage	5.5	≤ 15	Pass
Density (Kg/m³)	2,250	Specify specifically: "Should be suitable for the intended use."*	Pass
Self-repair percentage	The cracks were closed on average of 40% in 28 days	*Not specific in TIS*	

**Note: TIS 109-2517 does not specify a clear density value, but for general use, heavy concrete bricks should have a density greater than 1,800 kg/m³.*

Table 3 shows a comparison of the performance of self-healing concrete blocks using calcium carbonate (CaCO3) derived from oyster shells against the Thai Industrial Standard (TIS) criteria in each aspect, as follows:

1. Compressive Strength

Concrete blocks mixed with 10% CaCO3 have an average compressive strength of 4.0 MPa, which is significantly higher than the minimum requirement of 3.5 MPa of TIS 109-2517. Formulations with 5% and 15% CaCO3 have average compressive strengths between 3.7– 3.8 MPa, demonstrating the consistency and stability of the mixture.

2. Water Absorption

The water absorption rate of 10% CaCO3-mixed concrete blocks is approximately 5.5%, which is significantly lower than the 15% requirement according to TIS 109-2517. This reduction reflects a decrease in air voids within the block, resulting in less water penetration, which is also correlated with improved self-healing behavior.

3. Density

The density of 10% CaCO3-mixed concrete blocks is 2,250 kg/m³, classifying them as "heavy concrete blocks" suitable for general structural use. This density also increases impact resistance and reduces cracking.

4. Self-Healing

Although TIS 109-2517 does not specify or test self-healing, microscopic experiments using a Scanning Electron Microscope (SEM) showed that 40% of cracks in 10% CaCO3-mixed concrete blocks were sealed by CaCO3 crystals within 28 days. Therefore, it can be concluded that this property is an additional advantage, exceeding the minimum requirements of TIS.

Summary of research findings

A study on the self-healing properties of concrete blocks using oyster shell-derived calcium carbonate (CaCO3) as an additive, with four formulations: 0%, 5%, 10%, and 15% CaCO3, revealed that replacing Portland cement (OPC) with 10% by weight of oyster shell-derived calcium carbonate (CaCO3) resulted in the best mechanical and physical properties. Specifically, it exhibited the highest compressive strength (4.0 MPa), the lowest water absorption (5.5%), and the highest density (2,250 kg/m³).

Furthermore, it displayed significantly higher self-healing properties compared to other formulations (~40%) Comparing concrete blocks with 10% $CaCO_3$ content to the Thai Industrial Standard (TIS) in various aspects, it was found that: Compressive strength: The average compressive strength of the 10% $CaCO_3$-mixed blocks was 4.0 MPa, significantly higher than the minimum requirement of 3.5 MPa in TIS 109-2517. Water absorption: Approximately 5.5%, clearly lower than the 15% requirement in TIS 109-2517. Density: 2,250 kg/m³, classifying it as "heavy concrete block," suitable for general structural use. While self-healing properties are not specified in the TIS standard, microscopic examination using a Scanning Electron Microscope (SEM) revealed that the 10% $CaCO_3$-mixed blocks had $CaCO_3$ crystals sealing an average of 40% of cracks within 28 days, a significant added advantage. This exceeds the minimum requirements of the Thai Industrial Standard (TIS). Therefore, it can be concluded that concrete blocks using 10% calcium carbonate ($CaCO_3$) derived from oyster shells as an ingredient meet all aspects of TIS 109-2517.

Discuss the experimental results.

From the research on the self-healing properties of concrete blocks using calcium carbonate (CaCO3) derived from oyster shells as an additive, it was found that a 10% CaCO3 mixture was the most suitable and effective formula. This is consistent with the research by Ramezanianpour et al. (2009), which studied the effect of limestone powder at a rate of 0-20% on the properties of concrete and found that a 10% rate provided the best strength and water resistance, especially after 28 days of concrete age. This is because CaCO3 acts as a filler, reducing internal voids in the structure and accelerating the hydration reaction through the formation of nucleation sitesHowever, when used at excessive rates, such as 15–20%, the cement replacement is too greatly reduced, decreasing the amount of reactive products like C-S-H (Calcium–Silicate–Hydrate), which is the main component providing strength to concrete. Similarly, Tsivilis et al. (2002) found that adding more than 15% limestone powder, while improving workability and material smoothness, significantly reduced compressive strength at 28 days. They suggested that 10% is a balanced amount between structural benefits and chemical reactions. Furthermore, Maisarah et al. (2015) reported similar results, finding that excessive CaCO3 addition (>15%) increased microporosity, which correlated with decreased long-term strength and durability, while formulations with only 10% CaCO3 maintained a balance. The microstructure was optimized, and formulations with less than 10% CaCO3, such as 0% (control) and 5%, while not resulting in compressive strength that fails to meet Thai Industrial Standards (TIS), were found to still not adequately improve the internal structure density. This resulted in significantly lower density and higher water permeability, which may affect durability in real-world conditions, such as resistance to water penetration, acid rain, or salt spray.

In summary, experimental results and comparisons with research have shown that mixing 10% calcium carbonate (CaCO3) derived from oyster shells is the optimal ratio to replace cement in order to produce concrete bricks with suitable mechanical properties, high density, low water absorption, and good crack repair potential, without affecting the long-term chemical properties of the material.

Acknowledgements

This project, "A Develop of the Self-Repairing Properties of Concrete Blocks Using Calcium Carbonate (CaCO3) Derived from Oyster Shells," was supported by the school director, Mr. Taweesak Charoentia, who kindly provided the location for the study and experiments; the deputy director of academic affairs, Mr. Chaturant Panthawas, who provided various guidance; and the science teachers, including Mr. Pornchai Sukcharoen, the project advisor, who provided guidance in the project, as well as various documents and textbooks that were useful for research.

We would like to thank the lecturers of the Construction Technology Department, Chonburi Technical College, for providing the location and supporting the experimental equipment, as well as providing valuable guidance on conducting the science project.

We would also like to thank the parents for their guidance and support in completing the project.

Finally, we thank the science teachers for their guidance in the experiments and for supporting the project with equipment and tools until its completion.

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