JOURNAL OF STRUCTURAL MONITORING AND BUILT ENVIRONMENT
e-ISSN: 2821-3432

Vol. 4 No. 1 (2024) 49-55
https://publisher.uthm.edu.my/ojs/index.php/jsmbe

JSMBE

Comparison between Conventional Method and Cradle-to-Cradle Method of Waste Management Method

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DOI: https://doi.org/10.30880/jsmbe.2024.04.01.007

Article Info

Received: 20 February 2024
Accepted: 27 May 2024
Available online: 30 June 2024

Keywords

Rice husk ash, coal botton ash, e long-term performance, seawater concrete

Abstract

Concrete is a widely used material in the construction industry. Rice husk ash and coal bottom ash are by-product materials chosen to alternate the use of cement and sand in concrete production. Concerns about the long-term performance of seawater concrete structures incorporated with RHA-CBA have been obstacles to the developing uses of sustainable concrete due to the scarcity of knowledge and test data. Thus, the long-term performance of seawater concrete consisting of RHA as cement replacement and CBA as sand replacement on compressive strength and carbonation was evaluated in this study. To accomplish the study's goal, existing specimens aged 1 year and 4 months, and 2 years with different mixture series were used. In the mixture, seawater was utilized to fully replace freshwater, along with 10% RHA used to replace cement. Additionally, 10% to 100% CBA replaced the sand with a 10% increment. The specimens consisted of 68 cylindrical concretes in 100 × 100 mm and 100 × 200 mm exposed to indoor environmental conditions. Compressive strength and carbonation tests were performed to assess the strength and durability of the concrete. The results indicate that the concretes' strength grows insignificantly in the atmospheric environment within exposure age. After a prolonged period, the specimen's strength development reduces as the amount of CBA in the concrete mixture increases. Meanwhile, test results revealed that RHA-seawater concrete containing CBA exhibited minimal carbonation after 2 years of aging. Higher incorporation of CBA in the concrete mixture leads to a greater carbonation rate, reducing the concrete's alkalinity. The findings of this study contribute to the understanding and advancement of long-term performances of sustainable concrete materials for construction practices.

1. Introduction

One of the most important man-made building materials in Malaysia is concrete. Recently, concrete production has been the largest consumer of limited natural resources due to high demand in the construction industry. Using natural sources as the main elements in concrete mixing is ideal. However, this condition indirectly causes a negative environmental impact, resulting in water scarcity and global warming by emitting tons of carbon dioxide. Several sustainable materials such as waste and byproducts were introduced for normal concrete materials replacement. Sustainable concrete retains its performance and strength while emitting much fewer greenhouse gases than conventional concrete [1]. Thus, this study is continuous with a previous study done by Rabiatul Adawiyah in 2021 about the strength and durability performance of seawater concrete containing RHA and CBA.

Based on the existing specimens, seawater was fully utilized to replace the freshwater in concrete mixing. Meanwhile, rice husk ash and coal bottom ash are by-products materials chosen to alternate the use of cement and sand, respectively.

The influence of seawater on concrete mixing can have a considerable impact on the concrete's long-term strength. The addition of seawater to the concrete mixing proportion enhanced the resistance to chloride permeation and compressive strength of concrete [2]. After 365 days of aging, seawater's effect on the concrete's long-term strength can become more pronounced. Seawater may have a cumulative impact on concrete, causing it to deteriorate faster over time and reducing its overall durability and structural integrity. Therefore, this study will observe the effect of using seawater in concrete production in terms of compressive strength for long-term performance.

To enhance the performance of concrete, additional cementitious materials can be used and combined with ordinary Portland cement in both fresh and hardened states [3]. An alternative way is by substitution or addition of waste materials such as rice husk ash. Rice husk ash as sustainable material allows the concrete manufacturer to adjust the concrete mix to enhance the workability, strength, and durability of concrete. RHA has been proposed by researchers as an alternate element that could improve concrete quality and lower the cost of concrete structures [4]. Subsequently, coal bottom ash, a waste product from coal-fired power plants, is one of the constituent materials that can replace fine aggregate in the concrete mixture. The employment of coal bottom ash in concrete mixes is with varying percentages starting from 10% to 100% of CBA content, by weight. The physical and chemical properties of CBA differ from location to location depending on the type of raw materials [5].

2. Materials and Methods

2.1 Materials

Existing concrete specimens were prepared and designed by Rabiatul Adawiyah at the end of 2021. The main materials used in producing the concrete were seawater, coal bottom ash, rice husk ash, and cement. Seawater was collected from Pantai Minyak Beku, Batu Pahat, which utilized 100% as mixing water. Raw coal bottom ash used had been collected from Tanjung Bin Power Plant, Pontian, which passed through 5 mm sieving. Meanwhile, rice husk ash was collected from Nibong Tebal, Pulau Pinang which underwent an incineration process at 600°C and passed a 75-micron sieve [6]. The type of cement used is according to type 1 of ASTM C 150-07, known as ordinary Portland cement [7].

2.2 Mix Proportion

There were 12 different series of concrete mixtures with diverse mix proportions. There was a control specimen which consisted of 100% freshwater added with 100% ordinary Portland cement. Seawater was utilized 100% to alternate the use of freshwater in concrete mixing. Meanwhile, 10% rice husk ash was utilized in place of cement. 10% to 100% coal bottom ash was used to replace the sand, with a 10% increment. The categories of all mixing proportions were presented in Table 1.

Table 1 *Categories of mixture series with different mix proportions*

Series	Label
Freshwater + 100 OPC	Control-FW
Seawater + 100 CBA	0RHA-100CBA
Seawater + 90 OPC + 10 RHA + 10 CBA	10RHA-10CBA
Seawater + 90 OPC + 10 RHA + 20 CBA	10RHA-20CBA
Seawater + 90 OPC + 10 RHA + 30 CBA	10RHA-30CBA
Seawater + 90 OPC + 10 RHA + 40 CBA	10RHA-40CBA
Seawater + 90 OPC + 10 RHA + 50 CBA	10RHA-50CBA
Seawater + 90 OPC + 10 RHA + 60 CBA	10RHA-60CBA
Seawater + 90 OPC + 10 RHA + 70 CBA	10RHA-70CBA
Seawater + 90 OPC + 10 RHA + 80 CBA	10RHA-80CBA
Seawater + 90 OPC + 10 RHA + 90 CBA	10RHA-90CBA
Seawater + 90 OPC + 10 RHA + 100 CBA	10RHA-100CBA

2.3 Specimens Preparation

The specimens used were cast from a previous study done by Adawiyah. There were 34-cylinder specimens cast in dimensions 100 × 200 mm, which specifically tested for compressive strength test in this study. Meanwhile, another 34-cylinder specimen cast in size 100 × 100 mm which used for the carbonation test. Subsequently, there were 3 specimens for each different series of mixtures. Thus, there were 68 total specimens for the compressive strength test and carbonation test evaluated in this study.

Fig. 1 *All specimens with different series of mixtures from previous research*

2.4 Testing

In this study, the long-term performance of concrete aged 1 year and 4 months, and 2 years was evaluated based on compressive strength and carbonation. Before conducting the compressive strength test, the density of the concrete was taken to compare the density between current works and previous studies. The compressive strength test was performed in accordance with BS EN 12390-3:2009. The compressive strength test was performed in accordance with BS EN 12390-3:2009. Concrete's compressive strength is defined as the highest load that it can sustain without failing [8]. In this study, specimens in size 100 × 200 mm aged 1 year and 4 months exposed to indoor environmental conditions were evaluated for the compressive strength test. The purpose of this test was to assess the quality and workability of long-term aged seawater concrete specimens containing RHA and CBA. Gypsum capping was done for all specimens' top and bottom surfaces to achieve surface planeness. According to ASTM C617, gypsum capping on hardened cylinder concrete is used to obtain an efficient compressive strength measurement. Meanwhile, the specimens cast in cylindrical concrete size 100 × 100 mm and exposed to indoor environmental conditions aged 2 years were used for carbonation test. The measurement of carbonation depth was carried out by using the phenolphthalein indicator solution, which was sprayed on the split surface of the concrete specimen. The carbonated regions of the specimen remained colorless, whereas the non-carbonated parts of the specimen turned purple in color [9]

3. Results and Discussion

3.1 Density

The density data of concrete was used to evaluate its long-term performance and durability. Figure 2 represents the density between the current works and data for 7 and 28 days by Adawiyah in 2022. The results indicated that the density of seawater concrete incorporated with RHA and CBA after reaching 1 year and 4 months of age were lower than the hardened density at 7 and 28 days.

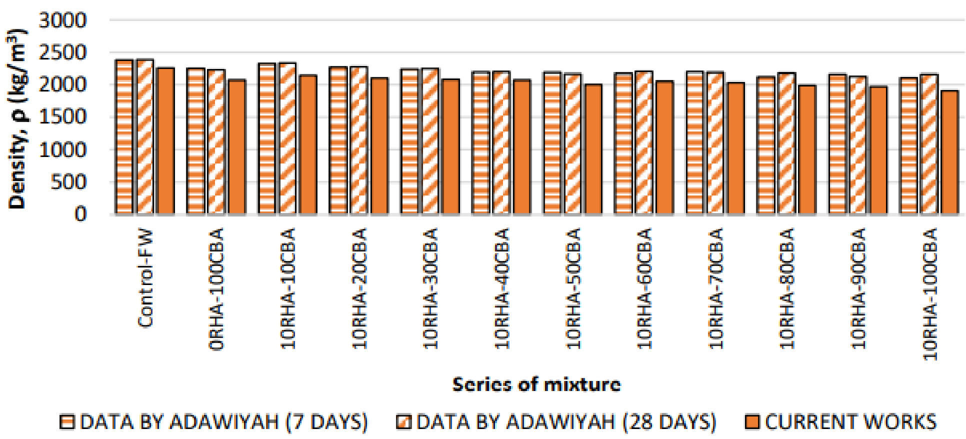

Fig. 2 *Density between current works and 7 and 28 days by Adawiyah in 2022*

The data recorded on the concrete specimens' density shows a significantly decreased due to added percentages of CBA content. As 1 year and 4 months go by, the density of concrete becomes weaker. Environmental factors such as exposure to moisture and temperature fluctuation might affect the results which can degrade the concrete and reduce its density.

3.2 Compressive Strength

Table 2 displays the compressive strength test results for specimens at 1 year and 4 months. The compressive strength of the control specimen was the highest among other mixture series which was 40.5 MPa. From Table 2, it can be observed that the addition of CBA as sand replacement along with an optimum value of 10% of RHA reduced the concrete's strength after reaching 1 year and 4 months.

Table 2 *Compressive strength of specimens at 1 year and 4 months*

Label	Compression Test Load (kN)	Compressive Strength (MPa)
Control-FW	318.10	40.5
10RHA-SW	224.60	22.4
0RHA-100CBA	118.48	15.1
10RHA-10CBA	310.64	39.6
10RHA-20CBA	314.50	40.0
10RHA-30CBA	224.54	28.6
10RHA-40CBA	268.92	34.3
10RHA-50CBA	250.26	37.8
10RHA-60CBA	250.34	31.9
10RHA-70CBA	204.61	26.1
10RHA-80CBA	178.28	22.7
10RHA-90CBA	226.88	28.9
10RHA-100CBA	214.77	27.4

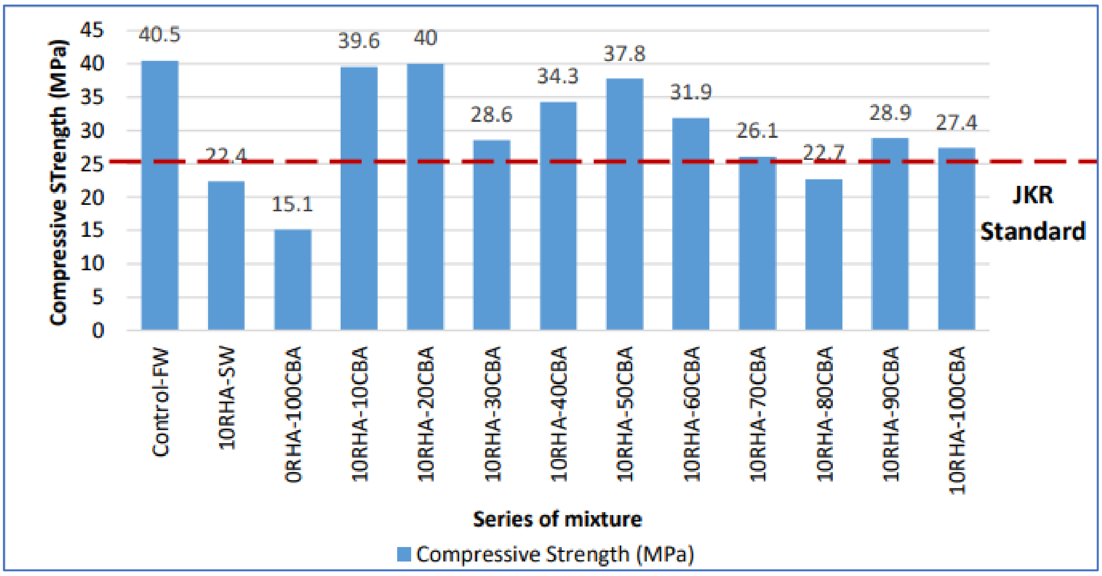

Fig. 3 *Compressive strength of concrete containing RHA and CBA after 1 year and 4 months*

Generally, the compressive strength trend is fluctuating which indicates inconsistencies in the concrete strength. As a result of the combination containing 10% RHA and a larger amount of CBA, the compressive strength of concrete is reduced. Control-FW specimens have the highest strength with 40.5 MPa. However, the 10RHA-20CBA (40.0 MPa) is slightly lower compared to control-FW (40.5 MPa) with a 1.24% difference. Specimen with 0% RHA and 100% CBA experienced the lowest strength (15.1 MPa) compared to 10% RHA and 100% CBA (27.4 MPa). 10% RHA is the optimum value to increase the compressive strength of the concrete [10]. The 10RHA-100CBA achieved the minimum structural strength as stated in the JKR standard requirement [1]. This study shows that the strength development fluctuates and most of the strength specimens are decreased compared to previous research. The compressive strength value decreases as the increasing coal bottom ash content in the concrete series mixture. These factors could include variations in the concrete mix proportions such as the presence of RHA and CBA as pozzolanic materials.

3.3 Carbonation

This study evaluated the carbonation test by measuring the depth of the carbonated area on the specimens' surfaces. Measuring carbonation depth is to assess the extent to which carbon dioxide (CO2) from the atmosphere has been penetrated concrete structures. Table 3 represents the results of the specimens' average carbonation depth with different mixtures series.

Table 2 *Compressive strength of specimens at 1 year and 4 months*

Label	Compressive Strength (MPa)
10RHA-SW	1.58
0RHA-100CBA	4.78
10RHA-10CBA	2.17
10RHA-20CBA	3.51
10RHA-30CBA	2.75
10RHA-40CBA	3.16
10RHA-50CBA	3.25
10RHA-60CBA	4.32
10RHA-70CBA	4.68
10RHA-80CBA	4.29
10RHA-90CBA	4.77
10RHA-100CBA	4.44

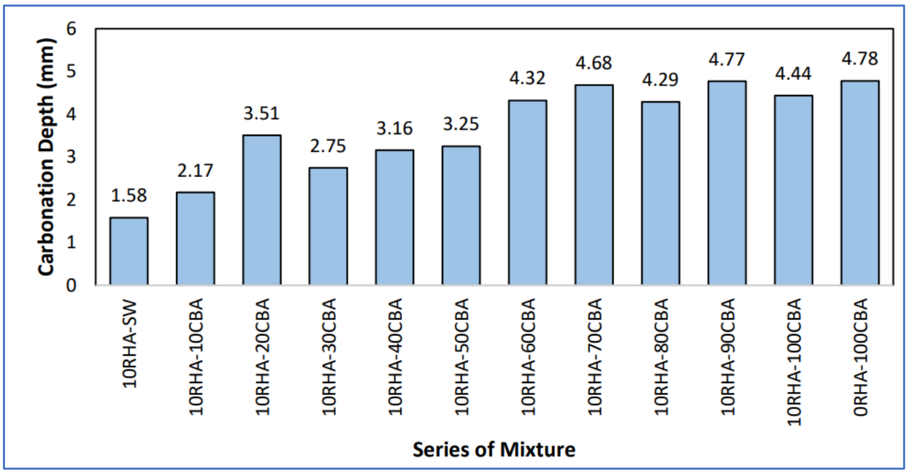

Fig. 4 *Average carbonation depth of specimens aged 2 years and 1 month exposed to an indoor environment*

Generally, the carbonation depth trend is fluctuating but roughly inconsistently increasing. Specimens with 0% RHA and 100% CBA content exhibit the highest carbonation depth with an average of 4.78 mm. Conversely, the lowest carbonation depth measured is from the specimens' mixture with seawater and 10% RHA with an average of 1.58 mm. Approximately, from the carbonation test results, as the percentage of CBA content is rising, the carbonation depth measured is increasing.

4. Conclusion

As a result, this study shows that incorporating RHA and CBA into seawater concrete may influence long-term compressive strength and carbonation rate. The first objective referred to the investigation of the compressive strength of RHA-seawater concrete containing CBA as a sand replacement after 1 year and 4 months. The strength development of specimens is inconsistent as the trend is fluctuating and tends to decrease along with the increasing content of coal bottom ash. Adding more CBA content up to 100% in the mixture can diminish the strength development of the concrete. At 10RHA-100CBA, the strength of the specimen at aged 1 year and 4 months is still above the minimum specification requirement of JKR for the structural strength of concrete. Current works exhibit higher compressive strength, while others show lower strength, compared to previous research consisting of specimens aged 7 and 28 days.

The second goal of this research is to investigate the carbonation activities of RHA-seawater concrete using coal bottom ash as a sand substitute after 2 years. The results indicated that the carbonation depth trend fluctuates but generally increases as the CBA content increase. With a 0.21% difference, 0RHA-100CBA has the highest carbonation depth with an average of 4.78 mm, followed by 10RHA-90CBA with an average of 4.77 mm. These specimens have the most carbonated area, which exposed the concrete to a lower pH and reduced the alkalinity. Overall, the carbonation activities observed on the RHA-seawater concrete containing CBA after 2 years reveal that with 10% RHA and a larger percentage of CBA content, the greater the carbonation depth.

Acknowledgement

This research was made possible by guidance and knowledge from all parties involves. The authors would also like to express their gratitude to the Faculty of Civil Engineering and Built Environment at Universiti Tun Hussein Onn Malaysia for their assistance.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

All authors reviewed the results and approved the final version of the manuscript.

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