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EFFECT OF SEA WATER, COASTAL SAND, AND CLAM SHELL POWDER ON COMPRESSIVE STRENGTH OF NORMAL CONCRETE

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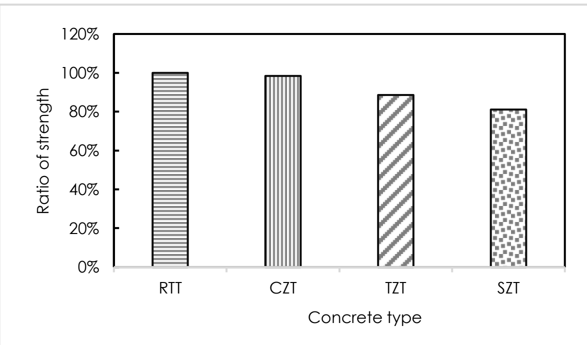
Graphical abstract



Abstract

Durability and resilience are essential factors of reinforced concrete structures in maritime environment which are subjected by stress, abrasion, and tidal exposure continuously. The research aims to analyze the effect of marine materials and its environment on the compressive strength of concrete cube (15x15x15 cm) at various days such as 7, 14, 28, and 56 days. The marine materials were used such as seawater, coastal sand, and clamshell powder as part of the concrete mixture. In addition, the effect of seawater on curing period, also were investigated. Treatment of marine environment were conducted by placing the samples after 28 days of age in tidal zone, submerged, and coastal atmospheric area. The results show the marine environment decreased the compressive strength about of 2%, 11% and 19% for coastal atmosphere, tidal and submerged treatments respectively which correlated to carbonation depth. The use of coastal sand in concrete mixture decreased compressive strength of concrete while the presence of clamshell powder slightly increased compressive strength for both curing treatments in fresh water and seawater. The curing process in seawater until the 28-days had a similar of compressive strength rate with the ones in freshwater.

Keywords: Compressive strength, curing, marinel environment, seawater, carbonation

1.0 INTRODUCTION

In the era of globalization, concrete has become an essential component in construction, playing an important role for infrastructure construction [1]. The exponential growth of the world's population has led to an increasing demand for infrastructure, including skyscrapers, iconic bridges, port facilities, and other complexes. However, the dominance of concrete usage for infrastucture also brings about serious ecological consequences. The substantial consumption of raw materials, particularly freshwater and river sand, in concrete production has raised concerns about significant environmental impacts [2]. This concern is not limited to terrestrial contexts, as concrete has also played a central role in constructing structures in marine environments which require extreme durability and resilience. Projects such as breakwaters, seawalls, and port facilities are tangible examples of concrete addressing complex marine environmental challenges. One of the most prominent advantages of concrete is its resistance to corrosion, making it a superior choice compared to other materials like steel in corrosive environments [3]. Concrete structures in marine environtment which face abrasion and erosion countinously need extraordinary strength and durability [4].

However, the sustainability of using concrete structure for infrastructure in marine environments with challenging environmental conditions cannot be ignored. Water, as a fundamental element in concrete mixtures, faces constraints in terms of its availability. It is estimated that more than 50% of the global population will experience freshwater scarcity for daily needs by 2050. Moreover, concrete production confronts a shortage of river sand due to excessive extraction, posing a threat to the sustainability of river ecosystems and related infrastructure [5]. Many researchers are seeking alternatives, such as using seawater as a substitute for fresh water in concrete production and employing coastal sand as a replacement for river sand in concrete mixtures as measures to address this resource crisis [6, 7, 8].

In addition, the presence of chloride ions in seawater poses a serious risk to the integrity of concrete. Challenging marine environments can significantly degrade concrete structures, and in extreme scenarios, these influences can even trigger total structural failure, resulting in severe disaster impacts [9]. One negative consequence of the presence of sea salt is the occurrence of carbonation in concrete. Carbonation happens when carbon dioxide from the air infiltrates concrete pores and reacts with calcium hydroxide to form calcium carbonate [10]. While this reaction can enhance concrete strength, the lower pH results in the deterioration of the protective layer on reinforcement steel, which can lead to corrosion. Major salt ions in the marine environment, including Na+, Mg2+, Cl-, and SO42+, have the potential to significantly impact concrete performance [11].

Regarding these negative effects, some appropriate initiatives need to be taken to mitigate by using seawater, coastal sand and clam shell powder in concrete production. The potential use of clam shell powder, derived from the fishing and restaurant industries, as an additive can enhance the concrete strength significantly due to minerals content [12]. When clam shell powder was activated with a treatment, it produces a high calcium carbonate (CaCO3) which makes an attractive option for an additive in cement production [13, 14, 15, 16, 17, 18, 19, 20]. Therefore it needs some research to find sustainable alternatives materials for concrete structure in marine environtments.

The objective of this research is to analyze the effects of the marine materials and its environment on compressive strength and carbonation depth of concrete. This study used seawater as freshwater subtitution in curing process and concrete mixture, costal sand to subtitute river sand, and clam shell powder as cement addition which were correlated with compressive strength. The results of research migth contribute to knowledge development of concrete strength affected by marine environments. . In addition, the use of waste-derived materials in concrete production, contributing to both environmental conservation and the sustainable practices of the construction materials.

2.0 METHODOLOGY

2.1 Materials

The research used cement type of Portland Cement Composite (PCC) with a brand of Semen Padang which was found from local market and packaging in 50 kg of weight per bag. The reason to choose this type of cement was due to availability in local market and produced by known established industry in Indonesia. This cement was mixed with other materials to make concrete samples.

Other materials used in this study were fine aggregate, coarse aggregate, coastal sand and clamshell powder. The fine aggregate was river sand with a color of yellow to brownish color and passing of sieve 4.75 mm of diameter. Coastal sand was from *Puri Gading* Beach area with color of whitish. The physical properties both sands were shown in Table 1 and Figure 1.

Table 1 Physical Properties of River Sand

Testing Type	River Sand	Coastal sand	ASTM Standard
Moisture Content (%)	0,59	0,96	0 – 1
Specific Gravity	2,50	2,26	2,0 – 2,9
Absorption (%)	2,04	5,02	1 – 3 %
Fineness Modulus	2,728	2,287	2,3 – 3,1
Density (kg/m^3)	1515	1285	-
Mud Content (%)	2	-	< 5
Organic Content	No. 1	No. 1	< No. 3

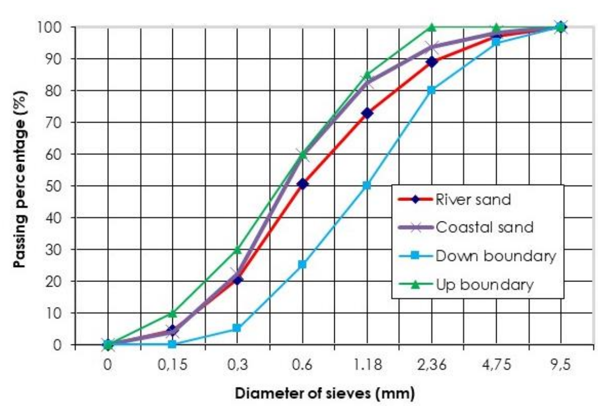


Figure 1 Gradation of river sand and coastal sand

The coarse aggregate was crushed stone (maximum size of 20 mm) with color of black-grayish and properties as shown in Table 2 and Figure 2.

Table 2 Physical properties of coarse aggregate

Testing Type	Test Result	ASTM Standard
Moisture Content	2,09%	0 – 3 %
Specific gravity	2,62	2,5 – 2,9
Absorption	2,00%	1 – 3 %
Fineness Modulus	7,3667	6 – 8
Density	1519,4 kg/m³	-

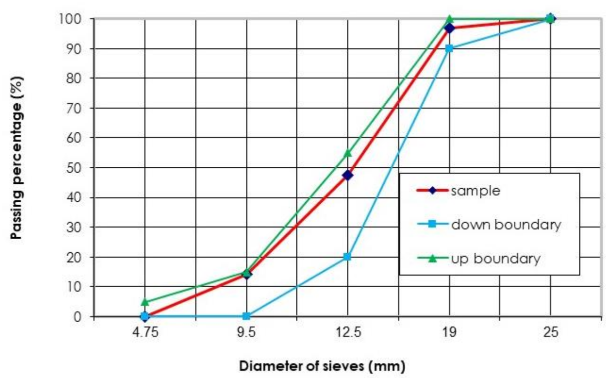


Figure 2 Gradation of coastal aggregate

In general, the physical properties of sand river and coarse aggregate materials accord to the ASTM requirements, therefore, those materials can be used as concrete materials.

Furthermore, clamshell powder was derived from fishery waste with the species of *buccinum undatum* with process as follows: crushing dry clamshell to become powder, sieving on a sieve No. 100, and burning the powder in oven at temperature of 500°C for 60 minutes, and lastly saving the activated powder in a metal can.

2.2 Composition of Materials

The composition of concrete was calculated based on the properties of materials with Indonesian Standard procedure (SNI 03-2834-2000) to result slump value of 10 ± 2 cm and compressive strength of concrete cube about 350 kg/cm². The summary of materials composition for 1 m³ of normal concrete is presented in Table 3. The composition of another concrete types were similar to normal concrete, by replacing the equal amount of fresh water with seawater or river sand with coastal sand. While clamshell powder was used as additional materials with amount of 5% of cement weight.

Table 3 Composition of materials of concrete

Material	Concrete
Cement	444,29 kg
Fine aggregate	560,90 kg
Coarse aggregate	1156,6 kg
Water	212,21 Liter

2.3 Preparation of Samples

The samples of concrete were made in Laboratory of Materials and Construction, University of Lampung in a cube form with dimension of 15x15x15 cm and then treated in various conditions to evaluate their effects on compressive strength and carbonation. The total number of samples made were 84 for evaluating the effect of material content, marine environment and curing process. Those samples were tested at 7, 14, 28, and 56 days after casting and named with different code as shown in Table 4.

Table 4 Code and number of samples

Sample code	Samples age and number				Total
	7	14	28	56	
NC-1	3	3	3		9
NC-2	3	3	3		9
RTT-1	-	-	-	3	3
CZT-1	-	-	-	3	3
TZT-1	-	-	-	3	3
SZT-1	-	-	-	3	3
SWM-1	3	3	3		9
SWM-2	3	3	3		9
CSM-1	3	3	3		9
CSM-2	3	3	3		9
SPM-1	3	3	3		9
SPM-2	3	3	3		9
Total					**84**

Note:
-1 = cured in freshwater
-2 = cured in seawater
NC = normal concrete
RTT = room temperature treatment
CZT = coastal atmosphere zone treatment
TZT = tidal zone treatment
SZT = submerged zone treatment
SWM = seawater material for replacement of 100% fresh water in concrete mixture
CSM = coastal sand material for replacement of 100% river sand in concrete mixture
SPM = CSM + clamshell powder material for additional 5% of cement weight.

2.4 Treatments of Samples

The normal concrete samples (NC) and the ones with materials replacement (SWM, CSM and CSM) were released from steel mould after one day of casting and treated with different condition by curing in fresh water (code of -1) and in seawater (code of -2) for 7, 14, and 28 days to analyze the effect of seawater on rate of compressive strength as shown in Figure 3.

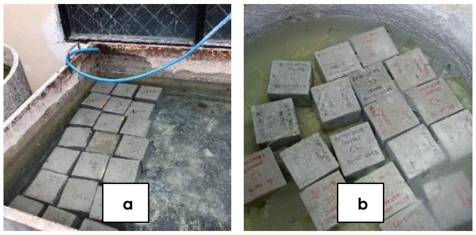


Figure 3 Curing process: (a) in fresh water and (b) in seawater

Other treatments were implemented on samples after cured in fresh water for 28 days by 3 conditions of marine environment exposure (Figure 4), such as: (a) placing on dry area affected by coastal atmosphere (CZT), (b) submerged in seawater (SZT), and (c) placing on tidal zone (TZT). These treatments were implemented in order to approach closely the natural impact of marine environment on concrete.

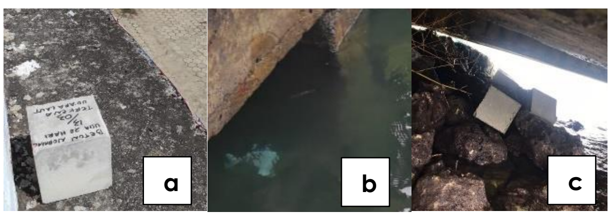


Figure 4 Marine environment treatments: (a) CZT, (b) SZT, and (c) TZT

2.5 Compressive Strength Test

Samples were tested by a compression testing machine (CTM) with a capacity of 150 tons and a loading rate of 0.15 – 0.35 MPa/second, conforming to Indonesian Standar (SNI 1974:2011). The compressive strength was obtained from average of three samples with a formula as follows:

$$f'_c = \frac{P}{A} \qquad (1)$$

Note:

f'_c = Compressive strength of concrete (Kg/cm^2)

P = Maximum load (Kgf)

A = Surface area of cube (cm^2)

2.6 Carbonation Test

Carbonation test which describes a level of reducing the alkalinity of hydrated cement due to marine environment effect was observed on freshly cut surface of concrete by spraying phenolphthalein ($C_{20}H_{14}O_4$) liquid [21], following the PN-EN 14630:2007 standard.

If the carbonation of concrete has happened, then sprayed area remains colorless (no color change) which indicates the pH of concrete is lower than 8.5. In noncarbonated condition, the concrete indicates color different, turning to red or purple (as shown in Figure 5). The testing measures the dept of carbonation from surface of concrete cube to inside or center.

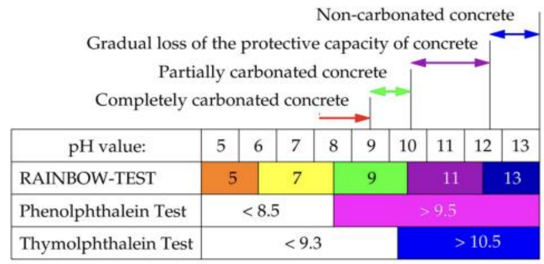


Figure 5 Colours indicate pH values [21]

3.0 RESULTS AND DISCUSSION

3.1 Appearance of Concrete after Treatments

The effect of treatments on concrete surface were observed after 28 days and documented by visual camera. Through direct visual observations, the appearance on concrete surface was then identified, such as color changes, cracks, pores, or other alterations.

Regarding curing process, normal concrete cured in fresh water (NC-1) results different picture with the ones in sea water (NC-2) as shown in Figure 6. NC-1 had no change of color and its surface still plain without any cracks. While NC-2 shows that the color on concrete surface turned to light gray and appeared efflorescence formation on concrete surface. Efflorescence is the deposition or crystallization of salts which frequently occurs due to evaporation of water within the concrete and leaving salts on the concrete surfaces as shown in Figure 7.

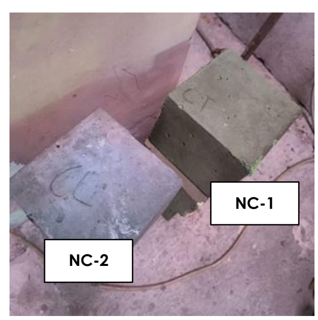


Figure 6 Effect of curing on sampel surface

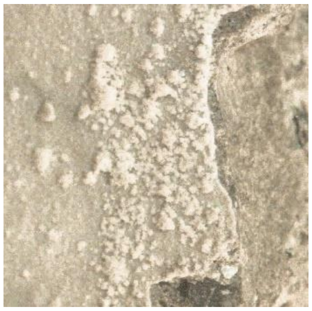


Figure 7 Efflorescence appearance on surface

Seawater containing minerals (such as salt of magnesium, sulfate, or calcium) can interact with concrete and potentially change the color of concrete surface. It supposes those minerals' role changed a gray color of concrete to a lighter appearance on sample surface. However, curing treatment using seawater in laboratory did not cause cracks or pore appearance on concrete surface.

Concrete samples treated with marine environment for 28 days showed various effects on the surface of samples (see in Figure 8). Coastal atmosphere zone treatment (CZT) appeared greyish color on the surface of sample which was lighter than the ones in temperature room of laboratory. The color appearance is different in samples of TZT and SZT. In TZT sample, the treatment changed concrete appearance, the color becoming greyish and brownish with many pores on the surface. In other hand, submerged treatment caused color change becoming brownish-green hue and appearance biological deterioration on concrete due to the growth of marine organisms, including algae on the surface. In addition there was crustaceans or barnacles on the surface which drilled holes into the concrete and could reduce the strength of concrete structure [22].

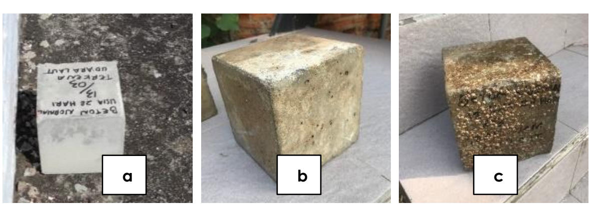


Figure 8 Samples appearance (a) CZT, (b) TZT, (c) SZT

3.2 Compressive Strength of Concrete

3.2.1 Effect of Curing Treatment on Strength

Compressive strength is the most important mechanical properties of concrete which influence the ability and durability of concrete structures to hold the loads and environments effects. Therefore, the effect of curing on compressive strength of concrete whether in fresh water or in seawater were also investigated in this study. The result of compressive strength of both treatments is presented in Table 5 and illustrated in Figure 9. Table 5 shows that curing treatment in seawater reduced the compressive strength for all period testing in about 7%-9% compared to the ones in fresh water. While compressive strength at 7 and 14 days were compared to 28 days (as seen in Figure 9), both treatments showed a similar trend of compressive strength rate in 83-84% and 91-93% for 7 and 14 days respectively. It is believed that the seawater decreased compressive strength in curing period due to the presence of sodium chloride and salt impurities into concrete [23, 24].

Table 5 Compressive strength of concrete affected by curing treatment

Code	Compressive strength (kg/cm²)		
	7 days	14 days	28 days
NC-1	300,36	332,32	355,92
NC-2	273,53	302,23	331,21

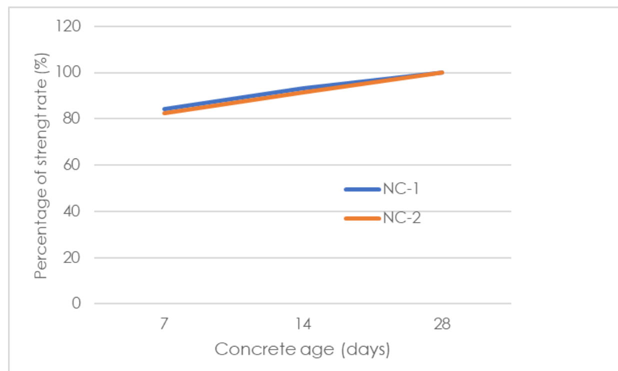


Figure 9 Rate of compressive strength due to curing condition

3.2.2 Effect of Marine Environment on Strength

After applying marine environment treatments for 28 days, samples were brought to laboratory to conduct the compression test directly in humid condition. In general, the compressive strength of concrete treated with marine environment were lower than the ones in laboratory as seen in Table 7 and illustrated in Figure 10.

Table 7 Compressive strength of concrete after marine environment treatments

Sample code	Compressive strength (kg/cm²)
RTT	433,56
CZT	426,63
TZT	384,09
SZT	351,60

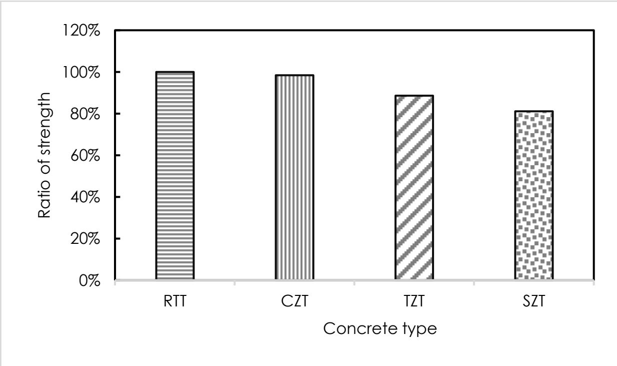


Figure 10 Reduction of compressive strength due to environment effects

Comparing by samples with room temperature treatment, all marine environment treatments reduced the compressive strength of concrete and its reduction was depending on exposure zone. The most significant effect on compressive strength was caused by submerged in seawater, reaching 19% of reduction. While coastal atmosphere treatment reduced a less compressive strength in about 2%. In other hand, submerging concrete in seawater accelerated the degradation of compressive strength faster than 2 other treatments. These results describe that directly contact between seawater and concrete reduced the concrete strength more significant than by coastal atmosphere. It supposes due to sodium chloride and salt impurities into concrete and erosion process by marine wave [25].

In submerged condition (SZT), the pores formed by marine organism also was believed as main reason of this worst degradation. In addition, submerging concrete in seawater limited hydration process due to low oxygen environment and even reduced the strength [26]. In other hand, concrete in tidal zone treatment (TZT) which experience wet-dry cycles (due to ebb and flow of seawater) showed slightly better strength than in submerged condition. It perhaps due to condition of seawater exposure on concrete not continuous, therefore the concrete has a chance to recover itself before being exposed again by seawater [27]. In addition, cyclic exposure between air and water, might improve concrete preservation and hydration, leading to higher compressive strength [22]. However, Mechanisms of diffusion, absorption, capillary action, and permeation repeatedly might grow some aggressive species on concrete. The mechanical action of waves could also cause physical damage such as abrasion, erosion and salt crystallization [28]. Concrete treated by coastal atmosphere had less effect on compressive strength. Though atmosphere containing chloride and moisture, however, this chloride is lower concentrations and considered less aggressive than chloride in seawater [29].

In general, these results shows that the decrease of compressive strength was characterized by the presence of humidity, chloride ions, and marine organism which then caused many pore appearance and reduce the strength.

3.2.3 Effect of Salty Materials on Strength

This study also used salty materials (coastal sand, sea water and clam shell powder) as part of mixtures which then cured by both conditions and tested in compression at 7, 14 and 28 days. The compressive strength for all type mixtures is presented in Table 8 (curing in fresh water) and Table 9 (curing in seawater).

Table 8 Compressive strength of concrete using non-standard materials and cured in freshwater

Sample Code	Compressive Strength (kg/cm²)		
	Age 7	Age 14	Age 28
NC-1	300,36	332,32	355,92
CSM-1	289,39	320,69	336,08
SWM-1	300,72	348,81	361,20
SPM-1	304,91	330,12	347,05

Table 9 Compressive strength of concrete using non-standard materials and cured in seawater

Sample Code	Compressive Strength (kg/cm²)		
	Age 7	Age 14	Age 28
NC-2	273,53	302,23	331,21
CSM-2	278,65	306,56	319,93
SWM-2	297,02	327,13	341,61
SPM-2	294,48	316,76	332,23

Table 8 and Table 9 show that the compressive strength generally increased in line with the age of concrete, whether cured in fresh water or in sea water. The use of coastal sand replacing all sand river in normal concrete mixture reduced compressive strength for all ages of testing in about 6% lower than normal concrete at 7, 14 and 28 days. The use of sea water as fresh water replacement in mixture almost had no effect on compressive strength at 7 days, but slightly increase at 14 and 28 days. When concrete CSM was added by clam shell powder, the compressive strength was almost similar within normal concrete at 7 and 14 days but slightly decreased at 28 days. These phenomena mostly happened on both curing in fresh water and in sea water.

These results describe that the use of coastal sand in a mixture can deteriorate concrete due to chloride and salt contents, organic matter poor sand gradation, leading to poor quality of concrete [30]. In other hand, the addition of activated clamshell powder can improve the concrete strength due to calcium oxide (CaO) content helps the concrete's components adhere better [31, 32, 33]. Although the use of seawater increased the compressive strength, however, it has a negative impact on reinforced concrete structure due to leading to corrosion of steel inside of concrete.

3.3 Effect of Marine Environment to Carbonation Depth of Concrete

Carbonation in concrete occurs when calcium oxide in the cement paste interacts with air containing carbon dioxide. This interaction leads to the formation of calcium carbonate, ultimately resulting in a decrease in the pH within the core of the concrete. This research also was measured the carbonation dept on concrete treated by marine environment at 56 days. The result is presented in Table 10.

Table 10 Carbonation depth of concrete treated by marine environment

Sample code	Depth (mm)	Description
RTT	0	Uncarbonated
CZT	0	Uncarbonated
TZT	4,4	Carbonated
SZT	7,4	Carbonated

Table 10 shows that concrete placed in laboratory room and coastal atmosphere did not carbonate. In contrast, carbonation occurred in concrete having contact with seawater directly by placing in submerged and tidal zones. The depth of carbonation for both were 4.4 mm and 7.4 mm for tidal and submerged zone respectively. In the case of concrete samples placed in the tidal zone, carbonation occurred to a depth of 4.4 mm, and for samples placed in the submerged zone; carbonation reached a depth of 7.4 mm.

Figure 11 shows the color of concrete after spraying by Phenolphthalein solution. Concrete submerged in seawater (SZT) experiences the deepest carbonation due to the presence of dissolved carbon dioxide in seawater. This carbon dioxide can react with the calcium hydroxide in the concrete, leading to the formation of calcium carbonate [34]. Moreover, seawater has the capability to leach calcium hydroxide from concrete, increasing its porosity and rendering it more susceptible to carbonation [35]. Elevated moisture levels in concrete further facilitate the penetration of carbon dioxide into the material, thereby accelerating the carbonation process [36].

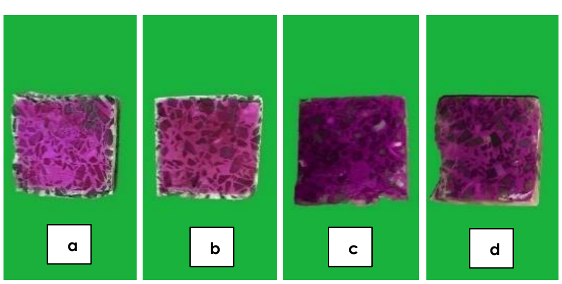


Figure 11 Carbonation in concrete: (a) SZT, (b) TZT, (c) RTT, (d) CZT

The carbonation in the TZT concrete was less dept than ones in the SZT concrete. This difference arises correlating to the tidal zone condition that the concrete was not continuously exposed by seawater, resulting in lower moisture content inside which might impede the penetration of CO2 into the concrete sample [37]. Besides that, the carbonation process was also influenced by various environmental parameters, including temperature, humidity, and carbon dioxide concentration [38]. The carbonation rate was indeed closely related to the microstructure of cement-based materials. In addition, factors within the mix proportions, such as the water-to-cement ratio and sand binder ratio, influence the carbonation process by shaping the microstructure of the material. On a micro scale, CO_2 in the surrounding air diffuses into the material through the pore network, indicating that CO_2 diffusion depends on the pore structure [4].

From an environmental perspective, concrete facilities built on the seaside or partially submerged in the sea, the most critical point to avoid corrosion is at the boundary between air and water, which is the sea surface. Thus, the concrete pores might be filled with a combination of gases and liquids. From an interior standpoint, cement hydration and other chemical reactions continue to occur, allowing water to be use or released during the reactions [38].

The carbonation process and chloride transport processes is often considered together [28]. Regarding the influence of carbonation on chloride transport, it can reduce the porosity of concrete or disrupt the binding process. Meanwhile, the influence of chloride transport on carbonation primarily demonstrates that chloride salt crystals can form near the surface of intrusion, which can increase the concentration of carbon dioxide ingress. This interplay between carbonation and chloride transport is an important consideration for the durability and corrosion resistance of concrete structures in marine environments [38].

Concrete placed laboratory and coastal atmosphere typically does not experience chloride which then induce corrosion and lead to carbonation [37]. Concrete putting in laboratory room or air environments generally have lower humidity levels compared to concrete having contact directly with seawater. This condition might reduce carbonation in the concrete [30, 31]. The concentration of carbon dioxide in the air is significantly lower than in seawater.

4.0 CONCLUSION

The use of sea water, coastal sand, and clam shell for curing and mixing materials affected the compressive strength of concrete. Curing of concrete in seawater reduced the compressive strength in about 9% of ones cured in fresh water at 28 days. Marine environment affected the compressive strength in various level. The highest reduction was 19% by submerging concrete in sea water and the least impact was 2% by coastal environment. The use of coastal sand in concrete mixture slightly reduced the compressive strength of concrete while additional of clamshell powder in concrete mixture containing coastal sand can improve the strength of concrete. Carbonation process happened in concrete having contact with seawater directly and continuously due to the presence of dissolved carbon dioxide in seawater and stimulate pores appearance.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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