Study on compressive strength of concrete at 56 days containing salty materials and curing in seawater

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Abstract. Concrete structures built in coastal area and used local materials will be affected by environment due to corrosion and deterioration in long time. This study evaluated the effect of salty materials in concrete mixtures (not standard materials) and seawater curing on compressive strength and carbonation. The salty materials contained sea water and coastal sand as replacement of fresh water and river sand and clamshell powder as additional material in concrete mixture. The parameters of evaluation were on compressive strength of concrete cube with 15x15x15cm of dimension and carbonation depth at 56 days which were compared to 28 days. In general, this study found that the use of salty materials in concrete mixture resulted various effects. The use of seawater in mixture increased compressive strength at 28 and 56 days but the use of coastal sand reduced it. The addition of clamshell powder in coastal sand mixture might improve the compressive strength. Curing in seawater reduced compressive strength in line with the age of concrete.

Keywords: compressive strength, salty materials, seawater curing

1 Introduction

Concrete made by a mixture of cement, water, sand and coarse aggregate is the most widely materials for many types of construction, not only for terrestrial building but also for coastal infrastructures. Concrete has good physical properties on strength, durability, and versatility [1]. Regarding the corrosion resistance, concrete has better durability than steel in corrosive environments [2]. In other hand, the production of concrete requires a significant number of natural resources, including sand, water, and cement which becomes a growing concern [3]. In addition, the concrete structures built around marine environment (such as breakwaters and port facilities) requires extreme

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durability and corrosion resistance to face corrosion, abrasion, tidal, and marine air exposure continuously [4]. The marine environments might degrade the strength of concrete structures significantly and even causes total failure of construction [5].

People living around coastal area use local materials for making concrete structures, such as sea water, coastal sand, and clam shell powder in concrete production [6], [7] and [8]. These materials are abundant and readily available in coastal regions, making them a sustainable and cost-effective option for concrete production. However, the presence of salt material is the occurrence of carbonation process inside of concrete. Carbonation happens when carbon dioxide from the air infiltrates concrete pores and reacts with calcium hydroxide to form calcium carbonate [9]. 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 [10].

The effect of salty materials use in concrete mixture and marine environment treatments on concrete properties was evaluated in previous study [11] and found that the use of seawater and coastal sand reduced compressive strength at 3, 7, 14 and 28 days. However, the use of clamshell powder slightly improves the compressive strength of concrete containing coastal sand in mixture. This result indicate that coastal sand and clam shell powder have a potential as concrete material in certain condition, for example for concrete structures in rural zone islands. However, the effect of those materials and treatments after 28 days have not been evaluated. Therefore, it is necessary to more explore the properties of concrete after 28 days. This research aims to evaluate the compressive strength and carbonation depth of concrete which used salty materials in mixture and affected by seawater in curing at 56 days.

2 Methods

This study used experimental works in Material and Construction Laboratory of Lampung University which was a part of previous study [11]. Therefore, the result of testing mostly was compared to that reference.

2.1 Materials of concrete

This study used local materials for making a concrete mixture concrete. Cement type was Portland cement composite (PCC), merk of Semen Padang in 50 kg of weight per bag. Fine aggregate was river sand with medium granular, yellowish color, and passing of 4.75 mm sieve. The physical properties of this sand were as follows: 2.5 of specific gravity (SG), 2.04% of absorption, 2.728 of fineness modulus (FM), and 1515 kg/m3 of density. Coastal sand was collected from a beach near Bandar Lampung City and saved in plastic bag without any treatments (no washing or chemical admixture. The physical properties of coastal sand were as follows: 2.26 of SG, 5.02% of absorption, 2.287 of FM, and 1285 kg/m3 of density. The coarse aggregate was andesite type from stone crusher of Tanjungan (South of Lampung) with a maximum size of 20 mm. The physical properties of coarse aggregate were as follows: 2.62 of SG, 2.00% of absorption, 7.367 of FM, and 1579 kg/m3 of density.

Clamshell powder was made by crushing the clamshell of buccinum undatum species manually, passing through a sieve of No. 100 and heating in dry oven at a temperature of 500°C for a duration of 2 hours. The purpose of heating is to activate clamshell powder to be able react with a silica material in concrete mixture. The properties of both aggregates (river sand and coarse aggregate) were accordance to ASTM C-33, while coastal sand was not standard material for concrete materials. However, the coastal sand was used to replace all amount of weight of river sand in concrete mixture in order to evaluate its impact on compressive strength.

2.2 Mixtures Composition and Sample treatments

The composition of concrete mixture was calculated based on physical properties of river sand and coarse aggregate accordance to SNI 03-2834-2000 for compressive strength of 350 kg/m2 based on cube concrete samples. Mixture of normal concrete used standard materials (fresh water, sand river and coarse aggregate). Salty materials were used to replace all amount of river sand and fresh water in mixture. While clamshell powder was used for additional material with the amount of 5% of cement for only concrete mixture using coastal sand. There are two applied treatments on samples, by curing them in fresh water and in seawater. The codes and materials composition of concrete mixtures were presented in Table 1.

Table 1. Codes of composition and number of materials per 1 m3 of concrete (Kg).

Code	Cement	River sand	Coarse agg.	Fresh water	Sea water	Coastal sand	Clamshell powder	Curing
NC-1	444.29	560.90	1156.6	212.21	0	0	0	Freshwater
NC-2	444.29	560.90	1156.6	212.21	0	0	0	Seawater
SWM-1	444.29	560.90	1156.6	0	212.21	0	0	Freshwater
SWM-2	444.29	560.90	1156.6	0	212.21	0	0	Seawater
CSM-1	444.29	0	1156.6	212.21	0	560.90	0	Freshwater
CSM-2	444.29	0	1156.6	212.21	0	560.90	0	Seawater
SPM-1	444.29	0	1156.6	212.21	0	560.90	22.215	Freshwater
SPM-2	444.29	0	1156.6	212.21	0	560.90	22.215	Seawater

2.3 Compression and Carbonation Test

The compression test used concrete cube samples with a dimension of 15x15x15 cm on compression testing machine (CTM) at the age of 56 days after pouring. Loading rate was applied at 0.15 – 0.35 MPa/second, following SNI 1974:2011. The compressive strength was calculated with Equation (1), where f_k = compressive strength (Kg/cm^2); P = maximum load (Kg); and A = surface area (cm2). Then the compressive strength was compared to the ones at 28 days from previous study [11].

$$f_k = \frac{P}{A} \tag{1}$$

The carbonation was tested following to regulation of Indonesian Ministry of Public Works and Public Housing No. 25/SE/M/2015. Method of testing is by applying the phenolphthalein solution to the surface or depth of concrete, then observing the color change. If concrete surface turns to pink or light purple, meaning that carbonation has occurred in concrete due to concrete pH becoming over than 8.2. The depth of carbonation was then measured by distance indicator (ruler or other measuring tools).

3 Results and Discussion

3.1 Effect of salty materials on compressive strength with freshwater curing

The concrete samples were cured in fresh water one day after pouring. Samples were dried at 55 days in temperature room and tested at 56 days. The maximum load was calculated to compressive strength using Equation (1). The compressive strength average of 3 samples was compared with previous study and presented in Table 2 and Fig. 1.

Table 2. The compressive strength of concrete with freshwater curing.

Codes	Compressive strength (kg/cm^2)		Deviation (%)
	Age 28 days*	Age 56 days	
NC-1	355.9	370.9	+4.21
CSM-1	336.1	333.5	-0.77
SWM-1	361.2	378.6	+4.82
SPM-1	347.1	346.6	-0.14

*Helmi et al. (2024)

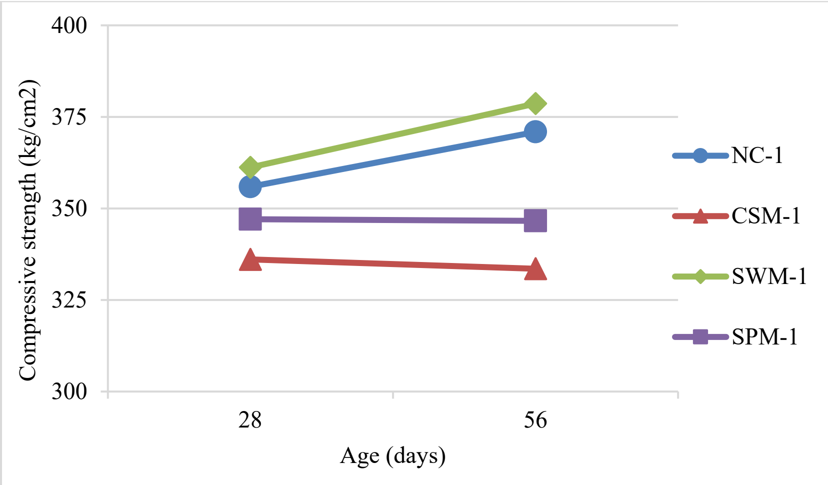


Fig. 1. Trends of compressive strength from 28 to 56 days with freshwater curing.

The previous study results that normal concrete using standard materials and freshwater curing (NC-1) reached the compressive strength of 355.92 kg/cm2 at 28 days. While other mixtures resulted the compressive strength in various, such as 336.08 kg/cm2 for CSM-1, 361.20 kg/cm2 for SWM-1 and 347.05 kg/cm2 for SPM-1. At 56 days, the trends of compressive strength are various for each mixture compared with the ones at 28 days. It was slightly increased in about 4% for NC-1 (370.88 kg/cm2) and SWM-1 378.63 kg/cm2. In other hand, it was decreased in about 1% for CSM-1 (333.53 kg/cm2) and for SPM-1 (346.61 kg/cm2).

This result shows that salty materials affected the compressive strength at 56 days. The use of seawater in concrete mixture (SWM-1) which resulted higher compressive strength than normal concrete at 28 days, also slightly increased at 56 days. The increase trend line of NC-1 was similar with SWM-1 and it might be having a possibility to increase in line with the ages. The compressive strength of CSM-1 in this study was lower than NC-1 due to the chloride, salt content, organic materials, and poor sand gradation [5]. The additional of shell clam powder in concrete mixture with coastal sand might increase the compressive strength at 28 days, however, it could not increase at 56 days. The decrease trend line of SPM-1 was similar with CSM-1. It found that concrete containing coastal sand was possible to be developed by clam shell powder due to calcium oxide role to enhance the bonding between materials [8] and [10].

3.2 Effect of salty materials on compressive strength with seawater curing

The effect of seawater curing on compressive strength was evaluated on all types of concrete mixtures. The concrete samples were cured in seawater one day after pouring and dried at 55 days in temperature room for testing at 56 days. the results of compressive strength are shown in Table 3 and illustrated on Fig. 2.

Table 3. The compressive strength of concrete with seawater curing.

Codes	Compressive strength (kg/cm^2)		Deviation (%)
	Age 28 days*	Age 56 days	
NC-2	331.2	316	-4.59
CSM-2	319.9	303.8	-5.03
SWM-2	341.6	332.9	-2.55
SPM-2	332.2	311.9	-6.11

*Helmi et al. (2024)

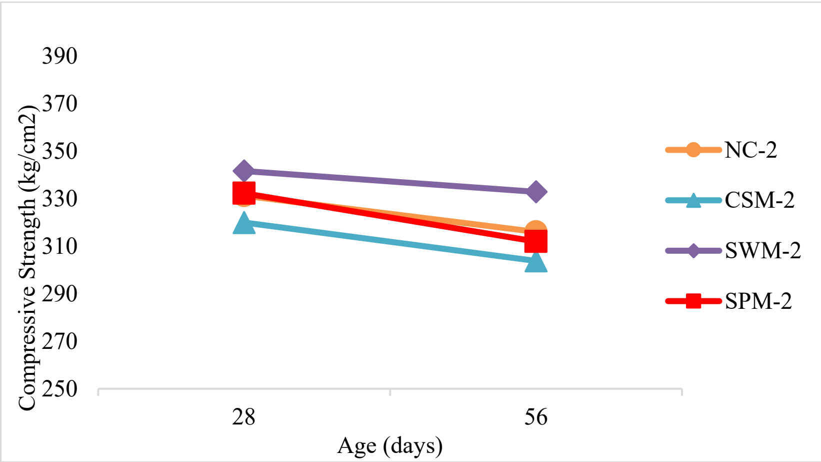


Fig. 2. Trends of compressive strength from 28 to 56 days with seawater curing

Previous study [11] found that curing in seawater reduced compressive strength of all types concrete at 28 days with the value of 331.21 kg/cm2, 319.93 kg/cm2, 341.61 kg/cm2 and 332.23 kg/cm2 for NC-2, CSM-2, SWM-2 and SPM-2 respectively. At 56 days compressive strength became lower than 28 days for all mixtures with a various degree of decrease and the maximum was -6.11%. in SPM-2 mixture. The use of seawater in concrete mixture (SWM-2) also resulted higher compressive strength than normal concrete (NC-2) which was similar with the ones in freshwater curing. However compressive strength decreased at 56 days after curing in seawater. The reason of this phenomenon was similar with previous due to the presence of salt, high chloride content, and the rounded shape of sea sand with poor gradation [8] and [10].

3.3 Effect of curing on compressive strength

The effect of curing was evaluated for all mixture by comparing 2 conditions, curing in freshwater and sea water as shown in Fig. 3 to Fig. 6. They show that normal concrete with freshwater (NC-1) resulted higher compressive strength than the one in seawater conditions (NC-2) for both ages (28 and 56 days). Effect of seawater curing appeared on compressive strength which reduced compressive strength at 7.45% for 28 days and at 28,49% for 56 days, compared by curing in fresh water. Other scholars [12] found that the reduction of compressive strength reached to 15% at 90 days. This fact shows that seawater curing might reduce the compressive strength in line with the ages. According to reference [13], the decrease of compressive strength in seawater curing was due to chemical substances such as chlorides, magnesium, sulphate etc., having role to weak the concrete. In addition, researcher [14] found that the compressive strength might increase at early ages and then it decreased for a long-time age. The decrease of compressive strength was due to the substances of sulphates, chlorides, and magnesium in seawater which can weaken concrete due to breaking-out lime components such as calcium sulphate and calcium hydroxide [15] and [16]. Seawater has bad effect for concrete due to its high levels of chloride ions which can cause the corrosion of steel reinforcement inside concrete structure leading to reduce the concrete strength and structural damage [17].

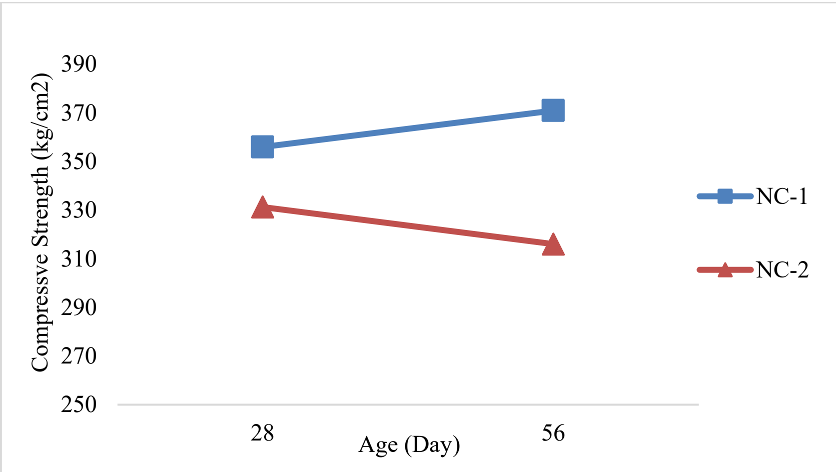


Fig. 3. Compressive strength of NC for both curing

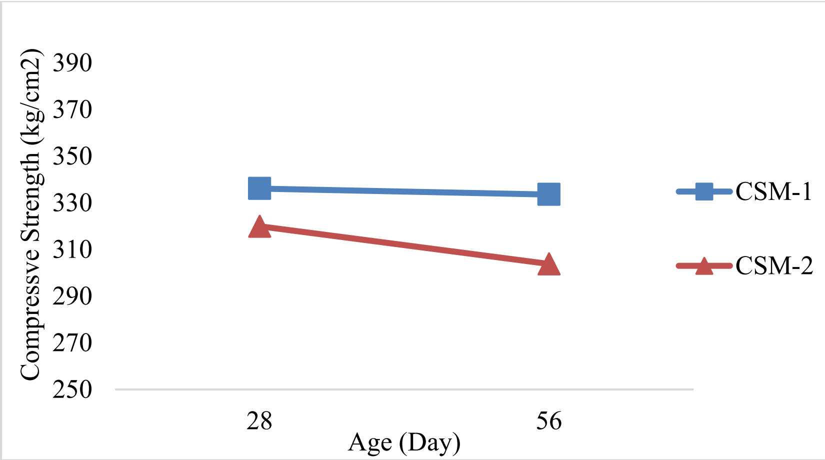


Fig. 4. Compressive strength of CSM for both curing

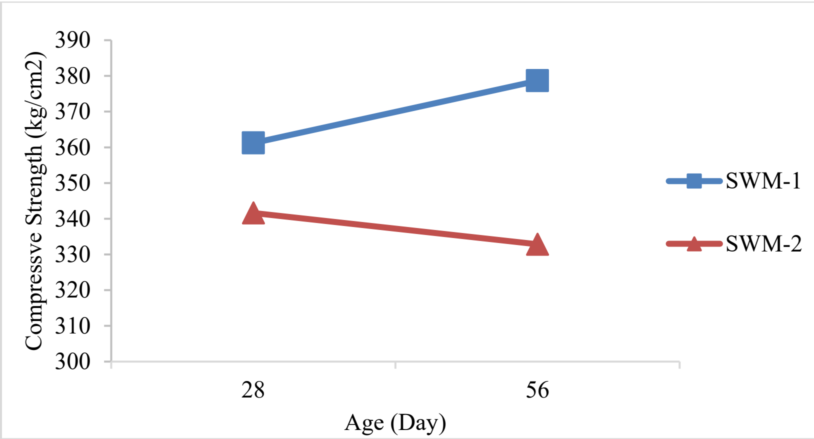


Fig. 5. Compressive strength of SWM for both curing.

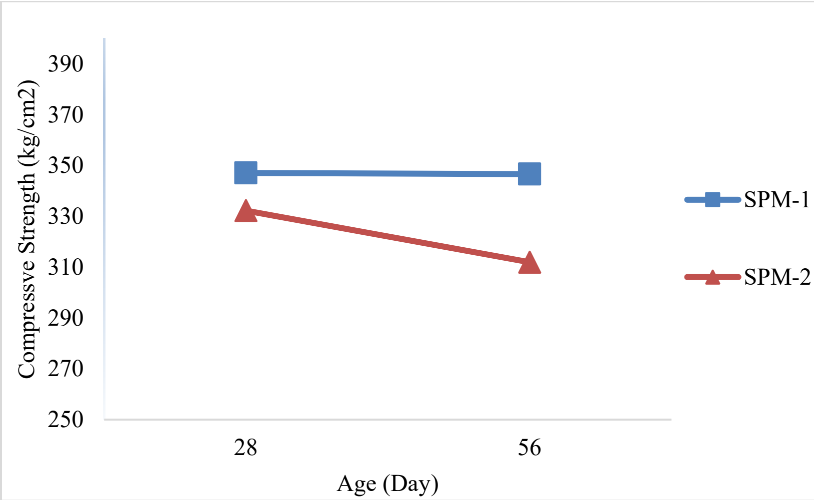


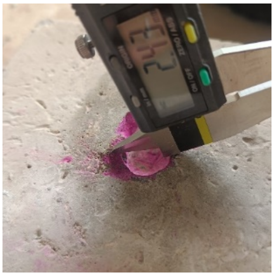
Fig. 6. Compressive strength of SPM for both curing

3.4 Effect of Salty Materials and Curing on Carbonation

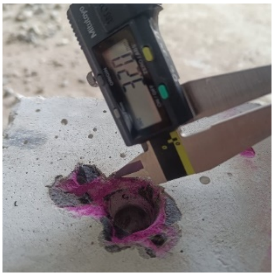
The carbonation test was conducted to evaluate the effect of salty materials and curing in seawater on carbonation of concrete. The carbonation occurs when calcium oxide in the cement paste interacts with air containing carbon dioxide and leads to the formation of calcium carbonate. The measurement depth of carbonation for all mixtures were presented in Table 4 and shown in Fig. 7a to Fig. 7h.

Table 4. Carbonation depth on concrete.

Sample Code	Depth of carbonation (mm)
NC-1	2,46
NC-2	2,71
SWM-1	3,46
SWM-2	3,53
CSM-1	3,49
CSM-2	3,58
SPM-1	3,30
SPM-2	3,44

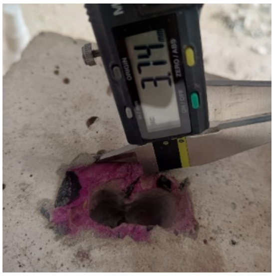



(a) NC-1 (b) NC-2

(c) SWM-1 (d) SWM-2


(e) CSM-1 (f) CSM-2

(g) SPM-1 (h) SPM-2

Fig. 7. Carbonation test for all mixtures.

Table 4 presents that the carbonation appeared in all mixtures with various of depth. The deepest carbonation was found in CSM-2 with 3.58 mm of depth and the lowest was in NC-1 with 2.46 mm of depth. Concrete containing salty material in mixture had deeper carbonation compared to normal concrete. However, the carbonation depth of CSM-1 and CSM-2 can be reduced by clamshell powder addition (see in SPM-1 and SPM-2). In addition, seawater curing also caused the increase of depth carbonation for all mixtures. It suppose due to the role of salts to accelerate carbonation process and gradually reduce pH level inside of concrete [18].

4 Conclusions

This study concludes that salty materials affected the compressive strength significantly. The use of sea water in concrete mixture might increase compressive strength for both ages 28 and 56 days, but of the use of coastal sand in mixture decreased compressive strength. The additional clamshell powder in coastal sand concrete slightly improved the compressive strength. Curing with seawater reduced compressive strength for all mixtures by to 7.45% at 28 days and to 28,49% at 56 days for normal concrete.

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