

Bond between Steel Reinforcement Bars and Seawater Concrete

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Abstract

In order to promote sustainable development in the remote islands this present research attempted to study the suitability of seawater, that available abundantly surrounding the remote islands with Portland composite cement (PCC) and crushed river stones to produce concrete. This research aims to utilize seawater, and Portland composite cement (PCC) to produce high-performance concrete in order to eliminate the main problems of clean water shortage in the low land areas and the remote islands. Infrastructure development can be sustained through the effective use of natural available local materials on the remote islands. The method used in this research is an experimental method in the laboratory. Two variations of concrete were made using freshwater and seawater, respectively as a mixing material with a water to cement ratio (w/c) of 0.55. The evaluation result on concrete compressive strength and bond strength of seawater concrete were discussed. Experimental results showed the compressive strength of the seawater concrete is lower by 6.26% as compared to the normal concrete at water-cement ratio (w/c) of 0.55. In addition, the bonding strength of steel bar embedded in seawater concrete is lower by 4.34% as compared to the bonding strength of steel bar embedded in normal concrete at water-cement ratio (w/c) of 0.55.

Keywords: Seawater Concrete; Normal Concrete; Portland Composite Cement; Compressive Strength; Bond Strength.

1. Introduction

Indonesia is an archipelagic country in the sense that at every location, there are buildings located on the coastal areas and remote islands. Hence the process of constructing buildings on the coastal areas and remote islands, have the high tendency to contact with seawater which is inevitable, coupled with the limited supply of freshwater to the construction site, therefore making use of seawater for concrete work is an interesting innovation. One important aspect of reinforced concrete is the compressive strength of concrete, the bonding strength of steel reinforcement to concrete, and the water cement ratio in concrete structures exposed in coastal areas.

Portland composite cement is one of the newest blended cement types that contain fly ash. Currently, Portland composite cement has been widely used in concrete construction in Indonesia. Several studies revealed that seawater and Portland composite cement can be used to produce high performance concrete [1-4].

A previous study on the bond strength of steel reinforcement to concrete with regard to cement water factors was conducted by Hwan and Kim (2007) [5], with purpose to propose a realistic model for bond tension-slip relationships. Another research based on bonding strength was conducted by Yalciner et al. (2012) [6], where the bond strength due to the un-corroded influence and the corrosive influence between reinforcement and concrete were studied in an experimental series. The purpose of the research conducted by Diab et al. (2014) [7] was to assess bond tension of the

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low-strength concrete and high-strength concrete. Another research based on bonding strength conducted by Mostofinejad and Mohammadi (2020) [8] was the externally bonded reinforcement-strengthened specimens experienced a 3 and 9% decrease in their bond strength, and the externally bonded reinforcement on grooves-strengthened specimens experienced no decrease in bond strength and increases in the range of 7-19%. Mousavi et al. (2020) [9] Indicate that as the crack width corresponding to the low confinement increases, rib sliding is expected to occur as an illustration of weak interfacial strength. McIsaac et al. (2019) [10] investigated the bond strength between concrete and fiber-reinforced polymer (FRP) wet lay-up systems using resins with biobased content of various proportions as a partial replacement of epoxy, which is well known to be an unsustainable product derived from petroleum. Moghaddas and Mostofinejad (2019) [11] Debonding failure is observed to occur in all of the specimens, the results obtained confirm the superiority of the externally bonded reinforcement on grooves over the externally bonded reinforcement specimens, as evidenced by an average enhancement of 31% achieved in bond strength and the postponed debonding. Experimental results in Mohammadi et al. (2017) [12] study showed that the specimens strengthened by the externally bonded reinforcement on grooves method and subjected to the adverse conditions of an alkaline environment resisted higher bond loads by up to 50% their ultimate bond loads compared to those strengthened via the externally bonded reinforcement method. Most of the previous studies mainly focus on the bond strength between reinforcement bar with normal concrete. Little studies have been conducted on comparing the seawater, and freshwater concretes, especially on microstructure analysis Mansyur and Permana (2020) [13]. The objective of this study was to reveal the compressive strength, elasticity, and microstructure of concrete using seawater and freshwater as the mixing water. However there are very limited information with regard to bond strength between reinforcement bars with seawater concrete. Based on aforementioned backgrounds, this research aimed to analyze the bonding strength of steel reinforcement bar embedded in the seawater concrete.

2. Bonding Strength

Bonding strength between reinforcement bar and concrete have been categorized in three classification according to ACI 408R-03 [14]: 1) the chemical adhesion between the reinforcement bar and surrounding concrete; 2) frictional forces caused by roughness between reinforcement bar and concrete; and 3) bearing forces on the concrete from the bar deformations. Bond strength is the ability of reinforcing steel and concrete covering it in resisting forces from the outside or other factors that can cause the detachment of bonding between reinforcing steel and concrete. Hence the bonding strength between reinforcing steel with concrete can be calculated by the Equation 1 [15].

$$\tau_{max} = \frac{P_{max}}{\pi \cdot D \cdot l} \quad (1)$$

Where:

τ_{max} : Bond strength of reinforcement steel in concrete (N/mm²),

P_{max} : Maximum load (N),

D: Reinforcement steel diameter (mm),

l: Embedded length (mm).

3. Materials and Methods

3.1. Materials

Concrete is generally composed of three main constituent materials, namely cement, aggregate, and water. In general, concrete contains about 1-2% air content, cement paste (cement and water) around 25-40%, and aggregates (fine aggregate and coarse aggregate) around 60-75%, respectively. Table 1 shows the physical properties of PCC used to make normal concrete and sea water concrete in this study. The PCC used is a production from a national cement factory and available in the market. Tables 2 and 3 show the physical properties of coarse and fine aggregates respectively, that was used to make normal concrete and sea water concrete in this study. Coarse aggregate obtained from the crushed river stone and sand used as fine aggregate obtained from the Jeneberangriver, South Sulawesi Province. Sea water was collected from Barombong beach, South Sulawesi Province. Table 4 shows mix design of the concrete in 1 m³. Freshwater was used for making normal concrete and seawater was used to make sea water concrete. Normal concrete and seawater concrete were produced in the laboratory. After the fresh concrete is put into the compressive test mold and bonding strength test, the specimen is left for 24 hours in a room temperature of 27°C and a humidity of 65% RH. The test objects was then removed from the mold later. The test samples for compressive strength was cured in freshwater for normal concrete and seawater for seawater concrete.

Table 1. Physical properties of PCC cement

Physical property	Fineness	Compressive strength (N/mm ²)			Specific gravity	Normal consistency (%)
		3 days	7 days	28 days		
Value	382	18.86	26.81	41.79	3.03	25.15

Table 2. Properties of coarse aggregate

Property	Value
Maximum size	19 mm
Water absorption	2.10 %
Bulk specific gravity	2.63
Saturated surface dry specific gravity	2.68
Apparent specific gravity	2.78
Flakiness index	9.40 %
Abrasion aggregate	24.40 %

Table 3. Properties of fine aggregate

Property	Value
Water Absorption,	2.79 %
Bulk specific gravity	2.45
Saturated surface dry specific gravity	2.52
Apparent specific gravity	2.63
Sand Equivalent	89.70 %

Table 4. Mix design of normal concrete and seawater concrete (w/c = 0.55)

Material	Weight in 1 m ³ concrete (kg)	Ratio to the amount of cement
Water	204.12	0.55
Cement (PCC)	371.13	1.00
Sand	590.39	1.59
Coarse aggregate	1099.29	2.96

3.2. Research Design

Figure 1 shows the research design. This research uses freshwater and seawater as a mixing material of concrete with w/c = 0.55. After the age of the specimen is 28 days, the compressive strength and pull out tests are carried out to determine the value of the bond strength value between freshwater concrete and seawater concrete.

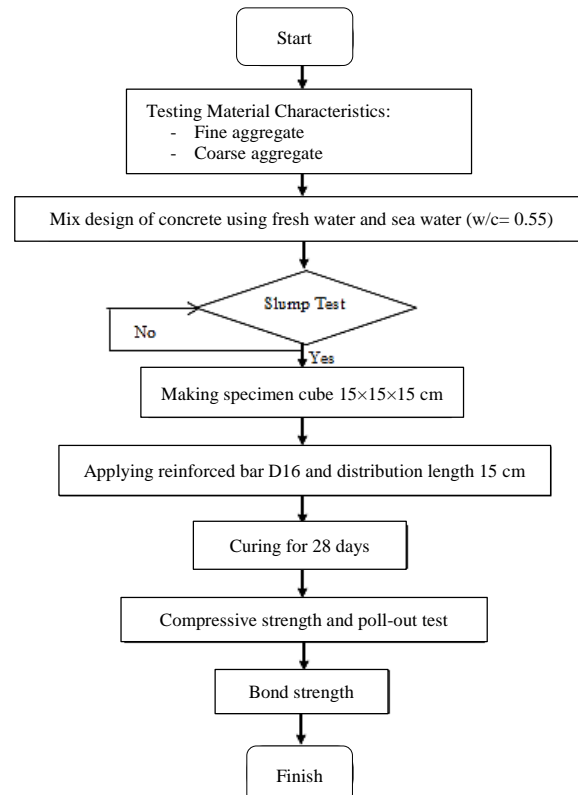


Figure 1. Flowchart of the research methodology

3.3. Pull-out Test

In the test of bonding between concrete and reinforcement was carried out with reference to RILEM [16]. In this test, the specimen was placed on a flat plate of confinement cage and the reinforcement was subject to tensile loads. Such a method can cause compressive stress on the concrete on one side and tensile stress on the reinforcement on the other side. The selection of test specimens in this study was planned so that the stresses that occur can typify the stress conditions in reinforced concrete structures.

The pull out test set up to measure the bonding strength between the deformed steel bar and the concrete is shown in Figure 2. Based on the above considerations, this study determined a cube-shaped specimen with dimensions of 150×150×150 mm employed in the pull out test. Deformed steel bar with a diameter of 16 mm was embedded 5 times of its diameter (the bonded section length was 80 mm). The pull-out load was gradually employed until attaining the ultimate bonding stress.

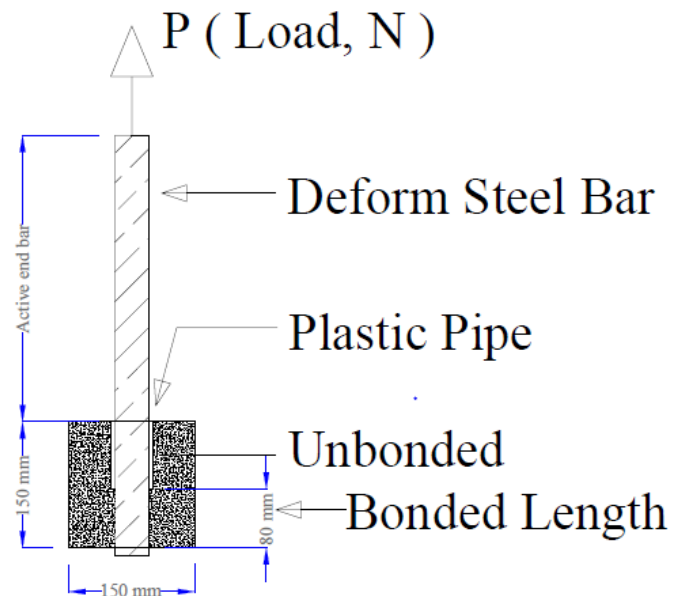


Figure 2. Set up of pull-out test

3.4. Compressive Strength Test

The compressive strength test is shown in Figure 3. The compressive strength test were carried out in three cubes specimens of dimensions 150×150×150 mm. The specimens were tested with UTM machine at rate of compression loading of 0.3 mm/sec.



Figure 3. Compressive strength test (specimen cube 15×15×15 cm)

4. Results and Discussion

4.1. Compressive Strength Test

The results of the compressive strength test at 28 days are shown in Table 4. At water-cement ratio (w/c) of 0.55, the compressive strength of normal concrete is 23.00 N/mm², while seawater concrete has a compressive strength of 21.56 N/mm². These results indicate that the compressive strength of seawater concrete is 6.26% lower than that of normal concrete.

Table 5. The test results of the compressive strength

No.	Age (days)	Area (mm ²)	Maximum load (kN)	Compressive strength (N/mm ²)	Average Compressive strength (N/mm ²)	Types of concrete
1	28	22500	537.21	23.88	23.00	Normal w/c 0.55
2			511.61	22.74		
3			503.69	22.39		
1	28	22500	495.81	22.04	21.56	Seawater w/c 0.55
2			486.65	21.63		
3			472.93	21.02		

4.2. Bonding Strength

In the pull-out test of steel reinforcement in normal concrete with a water cement ratio (w/c) of 0.55, the test specimens were treated with water curing for 28 days without acceleration (normally there was no rust) as shown in Figure 4.



Figure 4. Pull-out test (specimen cube 15×15×15 cm)

Provide a grading curve for the used freshwater and seawater as a mixing materials of concrete with w/c = 0.55 shows the research mix design (Figure 5).

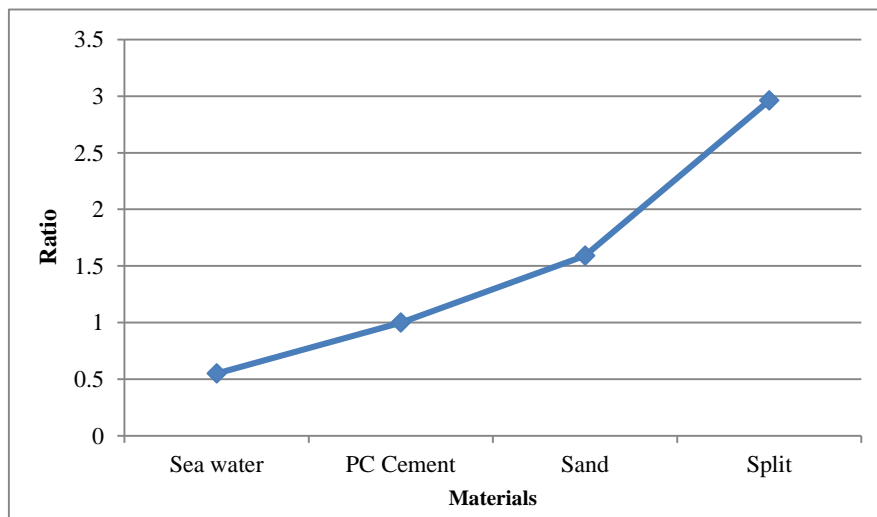


Figure 5. Curve for the used materials sea water concrete w/c 0.55

Figures 6 and 7 are shown the relationship between tensile load and displacement.

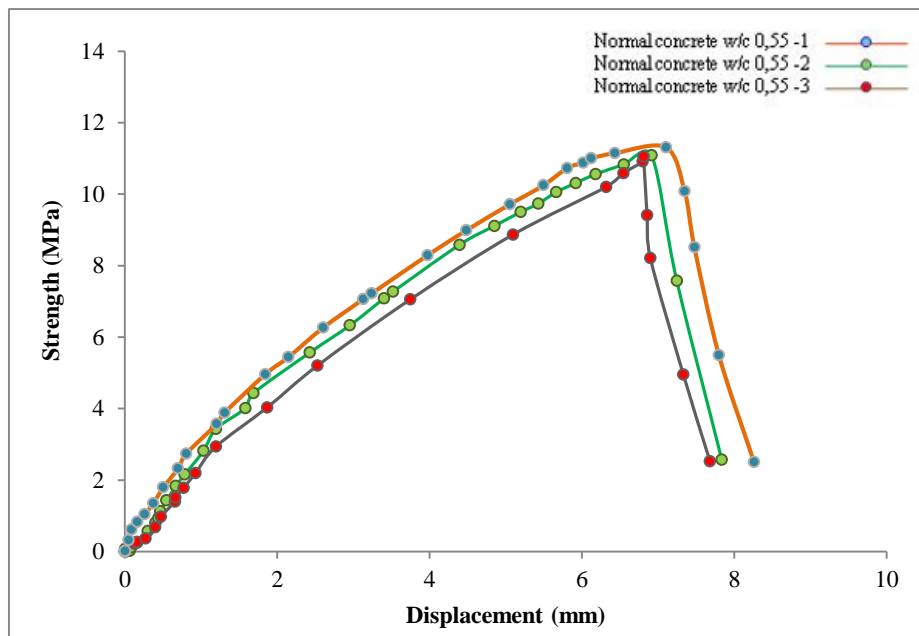


Figure 6. Relationship load to displacement w/c 0.55 (the sample normal concrete)

The maximum sample load for normal concrete specimens with a water cement ratio ($w/c=0.55$) in Figure 6, without acceleration (normal rust does not occur) on specimens 1, 2 and 3 are 44.548, 44.436 and 45.460 kN respectively. The bonding strength values were 11.084, 11.056 and 11.311 MPa, respectively, with displacement of 6.916, 6.810 and 7.104 mm, respectively.

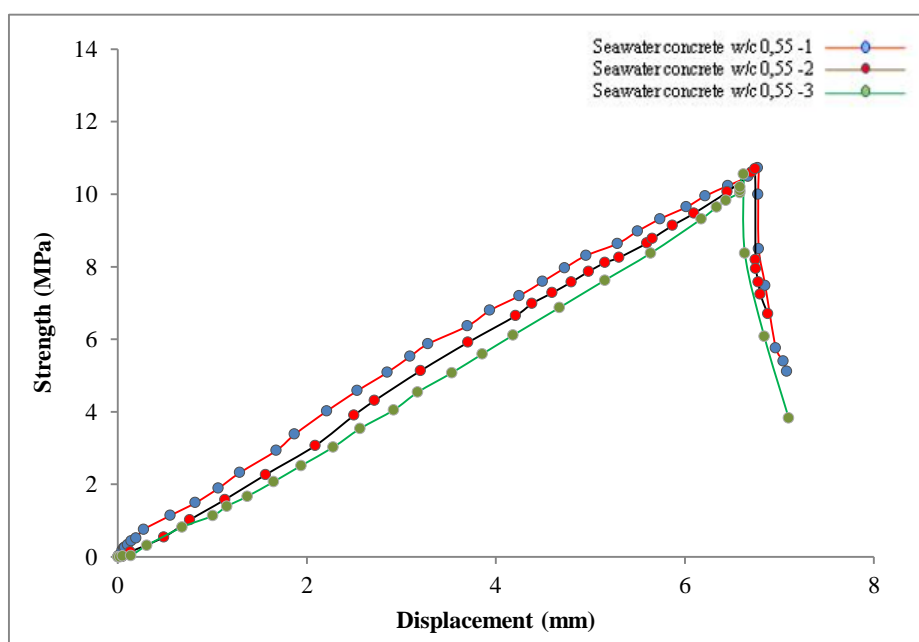


Figure 7. Relationship load to displacement w/c 0.55 (the sample sea water concrete)

The maximum sample load for sea water concrete specimens with a water cement ratio ($w/c=0.55$) in Figure 7, without acceleration (normally no rust occurs) on specimens 1, 2 and 3 are 43.128, 43.017 and 42.444 kN respectively. The bonding strength values were 10.730, 10.703 and 10.560 MPa, respectively, with displacement of 6.772, 6.744 and 6.622 mm, respectively.

Bonding strength of steel reinforcement embedded in concrete cube can be seen in Table 6. At water-cement ratio (w/c) of 0.55, the bonding strength of normal concrete is 11.15 N/mm², while seawater concrete has a bonding strength of 10.66 N/mm². These results indicate that the bonding strength of seawater concrete is 4.34% lower than that of normal concrete.

Table 6. Bonding strength and slip of steel reinforcement in concrete cube

No.	Concrete	Reinforcement diameter (mm)	Embedded length (mm)	Load Max (kN)	Bond strength (N/mm ²)	Average Bond strength (N/mm ²)
		D	l	Pmax	τ_{max}	
1	Normal concrete	16	80	44.55	11.08	11.15
2				44.44	11.06	
3				45.46	11.31	
1	Sea water concrete	16	80	43.13	10.73	10.66
2				43.02	10.70	
3				42.44	10.56	

5. Conclusions

The results of the experiments and analyzes carried out in this study can be concluded that the water cement ratio (w/c) affects the compressive strength of concrete and the bonding strength of concrete. From the experiment, the compressive strength and bonding strength of sea water concrete to normal concrete with a water cement ratio is, the results of the analysis of the average compressive strength of sea water concrete with a water cement ratio w/c 0.55 of 21.561 MPa against normal concrete compressive strength of 23,000 MPa. The results of the analysis show a less pronounced decrease in compressive strength of 6.26% against the compressive strength of normal concrete.

The result of the analysis of the average bonding strength of the test specimens sea water concrete with a water cement ratio of w/c 0.55 is 10.730 MPa to normal concrete of 11.311 MPa. The results of the analysis of the bonding strength of sea water concrete showed a less pronounced decrease in bonding strength of 5.14% w/c 0.55 to the bonding strength of normal concrete. Failure of the bond strength test specimen does not occur due to leaking of reinforcement and breaking of the concrete cover. The crack width of sea water concrete against normal concrete with a water cement ratio of 0.55 w/c seawater concrete is 0.15 mm against normal concrete is 0.10 mm, the average difference is 0.05 mm.

The results of the compressive strength analysis, the bonding strength of sea water concrete to normal concrete shows a subtle difference in the results of the analysis, so that the use of sea water together with Portland Composite Cement (PCC) as a material for concrete mixture is possible, especially for areas lacking clean water and isolated islands. The failure of the bond strength test object in the pull-out test did not occur in the form of cracking of the concrete cover and breaking of the reinforcement in the test object, to produce the expected pull-out test.

Based on this limited study of the bonding strength of steel bar in the normal concrete and the seawater concrete, the following findings were made:

- Normal and seawater concrete had compressive strength of 23.00 and 21.56 N/mm², respectively.
- Normal and seawater concrete had bonding strength of 11.15 and 10.66 N/mm², respectively.

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7. Conflicts of Interest

The authors declare no conflict of interest.

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