The Influence of Sea Water Content on the Shear Strength of Reinforced Concrete Beams

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Abstract. Reinforced concrete structure has very sensitive behaviour with the impact of seawater content. This work will describe about the effect of seawater content on the shear strength of reinforced concrete beams. Previous research focused on studying effect of seawater content on compression strength, tensile strength, flexure strength, and bond strength in concrete. A review of shear failures conducted by previous researchers without getting an effect on seawater content attacks. Reinforced concrete beam has measure on 1000x200x400 mm. Seawater content attack is given during the treatment process of reinforced concrete beams. Control testing is carry out by treating on fresh water. Stages of testing include testing the basic materials of concrete, immersion in sea water or fresh water, compression strength testing with cylindrical specimens on concrete age 28 and 90 days, as well as shear strength testing. Therefore, the aggressive nature of seawater which can cause micro crack in concrete pores, so that the shear strength that treated using sea water for 90 days has decreased by 10.70% from treatment using fresh water. The decrease in strength that occurs in the shear strength of reinforced concrete beams is not recommended in planning because it can risk to construction.

Keywords: Concrete, Reinforced concrete beam, Seawater content, Shear strength.

1. Introduction
Salt content in sea water consists of components NaCl, MgCl₂ and MgSO₄. Contact of sea water with concrete during curing time is very dangerous because the concrete will experience absorption, so that sea salt will absorb into the concrete as capillary action to fill the pores in the concrete. This compound will trigger an increase in porosity and permeability, loss of strength, and cause concrete cracking and spalling [1].

Control of the influence of sulphate-containing environments on the deterioration of the physical properties of concrete cubes has been observed by Abualgasem. This observation about environmental effects containing sulphate on visual changes, mass loss and beam size. Observations are made periodically using the help of X-ray diffraction and Infrared spectroscopy, so that the damage can be observed both macro and micro. Concrete cubes are treated with the effect of sulphate attack at levels of 6 g/L with variations in the treatment of wet and dry conditions, continuous immersion conditions, and control using ordinary water immersion. Early signs of concrete size change at 84 days, then followed by the appearance of cracks [2].
Investigation on the mechanism of damage caused by sulphate attack on concrete that receives four-point bending loads with varying levels, namely: 20%, 40%, and 60% in wet and dry conditions based on micro and macro observations conducted to determine the effect of action and reactions that occur under these two conditions and determine the impact of crystallization up to 360 days of concrete. The treatment is carried out with a room temperature of about 20 ± 2 ºC to reach a humidity level of 95% carried out on a beam specimen with a size of 100x100x400 mm. The change that occurs visually is the appearance of salt crystallization on the surface of the beam [4].

The effect of the mixture and preservation effect of concrete using seawater on compressive strength, tensile strength, flexural strength, and bond strength on concrete has been done by Wegian. Cube test specimens measuring 150 x 150 x 150 mm³ which will be reviewed for compressive strength are tested at the age of 7, 14, 28 and 90 days, both immersed in sea water or immersed in plain water. Tensile strength with a cylinder measuring 150 x 300 mm², flexural strength in the form of beams measuring 600 x 100 x 100 mm³, and bond strength on concrete using a pull-out test on reinforcement 20 mm in diameter and a cube measuring 150 x 150 x 150 mm³ will be tested on concrete age 28 and 90 days. The cement used uses two types of cement, namely Ordinary Portland Cement (OPC) and

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**Figure 1.** Deterioration of concrete by chemical reactions [3]

**Figure 2.** Mortar cubes under continuous immersion in DS-4 sulfate solution at 5°C [2]

**Figure 3.** Change in mass for binders in continuous immersion [2]
Sulphate-Resisting Cement (SRC). Coarse aggregate used is coarse aggregate in the form of gravel and dolomite. After the age of 90 days the compressive strength of concrete that was immersed using sea water decreased by 3.8% - 14.5%, while the compressive strength of concrete at the age of 7 and 14 days increased by about 3 - 10% and 1-4%. The effect of seawater on the tensile strength is to give a strength increase of 7-26% for 28-day concrete age and 22 - 49% for 90-day concrete age. The result of flexural strength submerged by sea water has decreased by 4% at 28-day concrete age and 4-7% at 90 days. The effect of sea water on adhesion strength does not influence the reduction in adhesion strength [5].

![Figure 4. Visual features: surface crystallization](image1)

![Figure 5. Observations by SEM](image2)

Previous research has focused more on the effect of seawater content on compressive strength, tensile strength, flexural strength, and bond strength in concrete. Shear capacity affects the shear damage of a building which impacts on the sudden collapse of the structure. This condition is undesirable in a building structure planning because it does not provide an opportunity for people in the building to save themselves, so this theme was raised to determine the effect of sea water content on the shear strength of the beam. The assessment of wet and dry conditions was carried out because the realization of conditions in the seawater building field was not free from the influence of wet and dry conditions.

2. Research Methods

The experimental method carried out in the Building Materials Laboratory and Structure Laboratory of the Faculty of Engineering, Gadjah Mada University, Yogyakarta was used to determine the effect of sea water content on the shear strength of reinforced concrete beams. The tests carried out include the basic stages of testing concrete forming materials, designing concrete mixes, making concrete mixes, treating concrete using sea water from the Indian Ocean and fresh water, testing the compressive strength of concrete, and testing the shear strength of beams. Seawater is taken from the Indian Ocean with salinity level of 29/00.

Control testing carried out in this work is the maintenance of test specimens in fresh water. Concrete cylindrical specimens with a diameter of 150 mm and a height of 30 mm were used to determine the compressive strength of reinforced concrete at 28 days and 90 days. The guideline used as a reference in testing concrete compressive strength is SNI 1974: 2011 [6]. Variations of tests carried out in this work include the condition of the surface wet and dry test specimen at the time of the test. The shear strength of reinforced concrete beams is given to a pxftr beam of 1000x200x400 mm$^3$ with the detailed dimensions presented in Figure 6. The specimen is designed with a high beam type with a shear span ratio with an effective height of the slapper ($a/d$) of 1.1 in order to experience shear failure. The concrete used is designed to have a compressive strength of $f'_c =$ 25 MPa assuming the use of low compressive strength in offshore buildings. The design of concrete mixes refers to SNI 03: 2834: 2000 [7]. Shear capacity testing is carried out by a one-point loading system in the centre of the span. Shear testing is carried out at 90 days with varying testing of wet and dry conditions.

| Table 1. Variations of concrete test materials |
| Code   | Amount | Immersed in Seawater | Immersed in Fresh Water | Age Concrete (Day) |
|--------|--------|-----------------------|-------------------------|--------------------|
| SB – B | 3      | 3                     | 28                      |
| SB – K | 3      | 3                     | 28                      |
| SB – B | 3      | 3                     | 90                      |
| SB – K | 3      | 3                     | 90                      |
| BB – B | 3      | 3                     | 90                      |
| BB – K | 3      | 3                     | 90                      |

SB – B : Concrete cylinder in wet condition  
SB – K : Concrete cylinder in dry condition  
BB – B : Reinforced concrete beam in wet condition  
BB – K : Reinforced concrete beam in dry condition

3. Results and Discussion

Before the compressive strength and shear strength of concrete are tested, an examination of the basic ingredients of concrete compilers is carried out at the Laboratory of Building Materials, Faculty of Engineering, Gadjah Mada University by obtaining results that meet ASTM C-33 standards for aggregates [8]. Seawater quality testing is observed to determine the content that
is in the immersion media of the test object. The test was conducted at the Environmental Health Laboratory of Gadjah Mada University.

Table 2. Table of seawater quality testing result

| Number | Parameter | Unit | Sample A | Sample B |
|--------|-----------|------|----------|----------|
| 1      | Salinity  | \(^{0}/00\) | 28.6     | 30.2     |
| 2      | \(pH\)    |       | 8.34     | 8.63     |
| 3      | \(Fe\)    | mg/l | 0.07     | 0.01     |
| 4      | \(CaCO_3\) | mg/l | 7331.97  | 7855.68  |
| 5      | \(Ca\)    | mg/l | 2094.85  | 3665.99  |
| 6      | \(Mg\)    | mg/l | 1256.91  | 1005.53  |
| 7      | \(Cl\)    | mg/l | 14154.95 | 17004.95 |
| 8      | \(KMnO_4\)| mg/l | 70.37    | 76.63    |

Table 3. Table of shear strength reinforced concrete beam with various immersion conditions

| Number | Code    | \(V_{ult}\) (kN) | Average of \(V_{ult}\) (kN) | \(V_{cr}\) (kN) | Average of \(V_{cr}\) (kN) | \(V_{ult} / V_{cr}\) | Average of \(V_{ult} / V_{cr}\) |
|--------|---------|-------------------|-----------------------------|-----------------|-----------------------------|----------------------|-------------------------------|
| 1      | BBA1K   | 465.4             | 231.1                       |                 |                             |                      | 2.0                           |
| 2      | BBA2K   | 492.7             | 233.2                       | 229.1           | 2.1                         | 2.1                  |
| 3      | BBA3K   | 456.7             | 223.0                       |                 |                             |                      | 2.1                           |
| 4      | BBL1K   | 410.7             | 274.9                       |                 |                             |                      | 1.5                           |
| 5      | BBL2K   | 437.7             | 216.6                       | 238.3           | 2.0                         | 1.8                  |
| 6      | BBL3K   | 429.6             | 223.3                       |                 |                             |                      | 1.9                           |
| 7      | BBA1B   | 402.9             | 188.8                       |                 |                             |                      | 2.1                           |
| 8      | BBA2B   | 444.0             | 157.2                       | 180.8           | 2.8                         | 2.4                  |
| 9      | BBA3B   | 420.0             | 196.3                       |                 |                             |                      | 2.1                           |
| 10     | BBL1B   | 446.7             | 166.6                       |                 |                             |                      | 2.7                           |
| 11     | BBL2B   | 426.4             | 153.4                       | 157.9           | 2.8                         | 2.6                  |
| 12     | BBL3B   | 352.0             | 153.7                       |                 |                             |                      | 2.3                           |

*BBA1-3K* : Reinforced concrete beam immersed in freshwater with dry condition
*BBL1-3K* : Reinforced concrete beam immersed in seawater with dry condition
*BBA1-3B* : Reinforced concrete beam immersed in freshwater with wet condition
*BBL1-3B* : Reinforced concrete beam immersed in seawater with wet condition
Figure 8. Graph of difference in load-deflection relations curves in wet conditions

Figure 9. Graph of difference in load-deflection relations curves in dry conditions

Figure 8 and figure 9 shows that immersion in sea water has an influence on the shear strength of reinforced concrete beams. Based on the graph, it can be seen that in dry conditions the strength decrease is 10.70% of reinforced concrete which is treated using fresh water. Whereas in wet conditions, reinforced concrete under sea water has a lower strength of 3.41% compared to reinforced concrete under normal water. The decrease that occurs is due to the micro crack that occurs in the concrete pore by the formation of salt crystallization and the ettringite reaction which gives effect to the compressive strength of concrete. The percentage reduction in strength is smaller in wet conditions than in dry conditions because the force on the pore surface that is forced by crystallization of salt is held by water that fills the concrete pore. During dry conditions the air filling the concrete pore cannot withstand the force on the surface of the concrete pore caused by salt crystallization.
Wet and dry conditions in concrete also have an impact on the shear strength of concrete because wet and dry conditions can affect the durability of concrete. Experimental results show that wet conditions either immersed in seawater or immersed in plain water will produce lower strength than in dry conditions. The decrease that occurred for concrete submerged in seawater was 4.32% and 11.67% for that submerged using plain water.

The percentage reduction that occurs is higher in water-submerged concrete usually because the pores in the beam are submerged by sea water filled by crystallization salt which can play a role when under pressure.

**4. Conclusion**

The formation of salt crystallization which triggers micro cracks in seawater submerged beams can reduce the shear strength of reinforced concrete beams in wet or dry conditions. Micro cracks that occur are the result of physical and chemical reactions between sea water and reinforced concrete. Decrease in wet and dry conditions were 3.41% and 10.70%, respectively. The decrease in strength that occurs in the shear strength of reinforced concrete beams is not recommended in planning because it can pose a
risk to construction. In addition, the wet condition of reinforced concrete beams can also have an influence on the decrease in shear strength. The statement is proven by the strength generated in wet conditions submerged in sea water and fresh water is lower by 11.67% and 4.32%. The results obtained from this test can be used as a material consideration when planning for construction, especially those that are attacked by sea water and are in wet or dry conditions, because these two variables can give effect to the shear strength of reinforced concrete beams.

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