The Resistance of High Strength Concrete with Diatomaceous Earth As Cement Replacement to NaCl Attack

Naifah, Muttaqin Hasan’, Taufiq Saidi
Dept. of Civil Engineering, Universitas Syiah Kuala, Banda Aceh, Indonesia

*muttaqin@unsyiah.ac.id

Abstract. High strength concrete (HSC) requires high amount of cement in order to make it more dense and compact. Using diatomaceous earth (DE) is an alternative to reduce the cement content in HSC. In this study the DE was used as cement replacement at the 0%, 5%, 10% and 15% replacement levels. The water to binder ratio was 0.3. The type F superplasticizer at 1.5% of cement weight was added. The DE was first ground, sieved with sieve #200 and calcined at 600°C for 5 hours before it was used as cementitious material. The 50 mm cube specimens were prepared, cured in the water for 28 days, and then immersed in 10% NaCl solution. After 1 and 2 months of immersion period, the surface visual appearance, mass and compressive strength of the specimens were examined and compared with the unimmersed specimens. The surface visual appearance shows that the HSC with 15% has smallest damaged as well as smallest degradation of compressive strength. However, the smallest mass loss was obtained at the HSC with 5% DE content.

1. Introduction

Underground concrete, which is exposed to groundwater and seawater, which usually contains various chemicals, including sulfates and chlorides, can be damaging during its service life [1], [2]. The high concentrations of chloride ions are a big problem for the resistance of concrete because the chloride ion has an element of chlorine which gains electrons or when a compound such a hydrogen chloride is dissolved in water. The chloride ion when it meets steel and other passive materials to react to produce hydrochloric acid [3]. Chloride attack, carbonization, and freeze and thaw cycles can impair the long-term durability of concrete. A Chloride attack is one of the most severe attacks because it can directly corrode steel, cause cracks in concrete, peeling of steel, delamination of the concrete cover, and damage to concrete structures [4], [5]. The solution to reducing the corrosion rate in the presence of attractive cementitious materials such as fly ash, blast furnace slag, and silica fumes, all three of which, when proportioned correctly in the mixture, can significantly reduce the penetrability of concrete and increase its resistivity [6–8].

Diatomaceous earth is natural, has a soft texture, and contains silica, which is easily destroyed so that it can become a fine powder [9, 10]. According to the Department of Mining and Energy of Aceh Province, its deposits in Aceh Besar Regency are high with the weight of 40,353,700 tons [9,10]. The diatomaceous earth can be used as a substitute for cement because it contains 56% silica [10]. Many studies have been conducted on the utilization of diatomaceous earth as cement replacement as well as for lightweight aggregate and brick production [9,11–16]. The previous study has been conducted on the evaluation of the strength of HSC with diatomaceous earth as cement replacement [15,16]. This study, however, was conducted with the aim to evaluate the resistance of HSC with diatomaceous earth as cement replacement against NaCl attack. This research is important to carry out because Indonesia is a maritime country, where infrastructures are building in the coastal areas and offshore
infrastructures are prone to attack by NaCl. The results of this study will give the information on the durability of HSC containing diatomaceous earth against NaCl attack.

2. Materials and Method

2.1. Materials
The aggregate used in this study was stone split with maximum size of 9.52 mm and river sand has a maximum particle size of 2.35 mm. The stone split has a bulk density of 1.6, specific gravity of 2.7, absorption of 0.8% and fineness modulus of 2.4. The river sand has has a bulk density of 1.3, specific gravity of 2.8, absorption of 0.5% and fineness modulus of 5.9. The stone split and river sand in surface saturated condition were used.

For binder materials ordinary cement Portland and diatomaceous earth were used. The diatomaceous earth was used as cement replacement. The diatomaceous earth originally from Beureunut Village, Seulimum Sub District, Aceh Besar Regency was ground, sieved with sieve #200 and calcined at 600°C in a furnace for 5 hours before it was used as binder material. Superplasticizer of Viscocrete-1003 was also used for workability control.

2.2. Method
The mix proportion of the materials was determined in accordance with ACI 211.4 R-93 [17]. The initial mix determined the ingredient proportion of HSC mixture without diatomae powder. There were 4 cement replacement rates of 0%, 5%, 10% and 15% (w/w) by diatomaceous earth while other ingredients remained constant, so that 4 different mixtures were planned. The water to binder ratio used was 0.30. The proportions of the mixture are shown in Table 1.

After all the ingredients are ready, they were mixed in a concrete mixer. The workability of fresh concrete was determined by a flow test. Cubes with sides of 50 mm were printed, for each mixture of nine specimens. After one day since casting, the concrete mold is opened. When the 28 day old specimen the compressive strength test of the specimens was carried out in accordance with ASTM C39/C39M-2003 [18]. Besides that, the mass of all the specimens was also measured. Then the remaining specimens were immersed in 10% NaCl solution for 1 and 2 months, for further visual observation, mass measurement and compressive strength testing were carried out. The results were compared with the test specimens that were not immersed (control specimens).

| Mixtures | DE (%) | Water (kg) | Cement (kg) | DE (kg) | Sand (kg) | Stone split (kg) | Superplasticizer |
|----------|--------|------------|-------------|--------|-----------|-----------------|-----------------|
| DE0      | 0      | 184        | 613         | 0      | 924       | 697             | 9.2             |
| DE5      | 5      | 184        | 583         | 31     | 924       | 697             | 9.2             |
| DE10     | 10     | 184        | 552         | 61     | 924       | 697             | 9.2             |
| DE15     | 15     | 184        | 521         | 92     | 924       | 697             | 9.2             |

3. Results and Discussion

3.1. Visual Appearance
Visual observations were made after high strength concrete (HSC) specimens were immersed in NaCl solution for 1 and 2 month, then compared with the concrete specimens before soaking. The minimum visible damage was seen in HSC specimens with 15% cement replacement. The visual appearances of all specimens are shown in Figures 1-4.
Figure 1. Visual appearance of concrete specimens DE0 after immersion: (a) 0; (b) 1; (c) 2 months

Figure 2. Visual appearance of concrete specimens DE5 after immersion: (a) 0; (b) 1; (c) 2 months

Figure 3. Visual appearance of concrete specimens DE0 after immersion: (a) 0; (b) 1; (c) 2 months

Figure 4. Visual appearance of concrete specimens DE0 after immersion: (a) 0; (b) 1; (c) 2 months
3.2. Mass Change

The change in the mass of the specimens was measured after immersing the concrete specimens in NaCl solution for 1 and 2 months and compared with the mass of the specimens before immersion. The results of the mass change of the specimens are shown in Table 2.

Table 2. Mass loss of concrete specimens due to NaCl attack

| Immersion time | DE content | Average mass before immersion (gr) | Average mass after immersion (gr) | Average mass loss (%) |
|----------------|------------|-----------------------------------|----------------------------------|-----------------------|
| 1 month        | 0%         | 335.33                            | 334.77                           | 0.17                  |
|                | 5%         | 341.67                            | 341.13                           | 0.16                  |
|                | 10%        | 337.33                            | 336.80                           | 0.16                  |
|                | 15%        | 334.33                            | 333.97                           | 0.11                  |
| 2 months       | 0%         | 319.33                            | 318.73                           | 0.19                  |
|                | 5%         | 350.67                            | 350.10                           | 0.16                  |
|                | 10%        | 338.00                            | 337.43                           | 0.16                  |
|                | 15%        | 342.00                            | 341.53                           | 0.14                  |

![Figure 5. Avarage Mass loss of concrete specimens due to NaCl attack](image)

3.3. Compressive Strength

The compressive strength test was carried out after the concrete was immersed in NaCl solution for 1 and 2 months, then compared to the non-immersed concrete as a control specimens. The results of the compressive strength test are shown in Table 3.

Table 3. Change in compressive strength

| Immersion time | DE content | Average compressive strength (MPa) | Ratio of compressive strength after being immersed to that without immersion (%) |
|----------------|------------|------------------------------------|---------------------------------------------------------------------------------|
| No immersion   | 0%         | 91.43                              | 100                                                                             |
|                | 5%         | 82.66                              | 100                                                                             |
|                | 10%        | 78.48                              | 100                                                                             |
|                | 15%        | 75.46                              | 100                                                                             |
| 1 month        | 0%         | 77.35                              | 84.60                                                                           |
|                | 5%         | 76.24                              | 92.22                                                                           |
|                | 10%        | 72.93                              | 92.94                                                                           |
|                | 15%        | 75.42                              | 99.95                                                                           |
| 2 months       | 0%         | 68.07                              | 74.45                                                                           |
|                | 5%         | 68.05                              | 82.32                                                                           |
|                | 10%        | 64.87                              | 82.67                                                                           |
|                | 15%        | 69.70                              | 92.37                                                                           |
4. Conclusions

From the results obtained in the research, the following conclusions were drawn.

a. High strength concrete (HSC) immersed in NaCl solution experienced visual damage only on the edges of the concrete which were no longer smooth at the immersion age of 1 month. However, at the age of 2 months of immersion, the pores in the concrete were enlarged. The smallest damage was observed on HSC specimens with 15% diatomaceous earth.

b. The smallest mass loss to NaCl attack after 1 and 2 months of immersion occurred at the specimens with 15% diatomaceous earth which were 0.11% and 0.14% of the initial mass, respectively.

c. The compressive strength of HSC due to NaCl attack after 1 and 2 months immersion has the smallest decrease in the specimens with 15% diatomaceous earth with remaining compressive strength of 99.95% and 92.37% of the initial compressive strength, respectively.

d. The use of diatomaceous earth up to 15% of the cement weight can strengthen the bond between the concrete particles so that the resistance of HSC to NaCl attack increases.

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Figure 6. Reduction of compressive strength of concrete specimens due to NaCl attack
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