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Durability of Reactive Powder Concrete

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Durability of Reactive Powder Concrete

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Abstract. Concrete is a generally used material in building construction. The construction will be built on the ground and could also be in places exposed to sea water. Sulfate contained in ground water and sea water could cause sulfate aggression to concrete itself. Therefore, the research used Reactive Powder Concrete which is one of the concretes that is currently popular and has a high durability. The research was done by doing a constant repetition of saturated sulfate submersion and specimen abstersion. The varieties of specimen used along with the research such as Type I, Type II, and PCC variations of cements, also varieties fas 0.2 and fas 0.25. Research shown that Reactive Powder Concrete which is contained type II cement has the best resistance because the compressive strength does not reduced to 30% and the reduced weight is less than 1% when exposed to high concentration of sulfate.

1. Introduction

Concrete is a material that's mostly used in buildings. Construction will be build in direct contact with soil that contain groundwater. The construction that's built close to the sea can led the construction be in contact with sea water. Ground water and sea water contained substances - chemicals that are reactive to the elements contained in concrete and can eventually lead to the disintegration of the concrete [1]. One of these chemicals is sulfate. Therefore, the concrete should have a high durability in order to minimized the sulfate attack.

One type of concrete that can meet the need for high durability is Reactive Powder Concrete (RPC). Reactive Powder Concrete is an ultra high-strength and high ductility by optimizing the aggregate with the micro size and proper gradation of all the particles contained in the concrete mix to produce the maximum density [2].

RPC is composed of very fine powders (cement, sand, quartz powder and silicafume), steel fiber (optional) and superplasticizer**.** The superplasticizer, used at its optimal dosage, decreases the water to cement ratio (w/c) while improving the workability of the concrete**.** . A very dense matrix is achieved by optimizing the granular packing of the dry fine powders. This compactness gives RPC ultra-high strength and durability. [3]

Microstructure enhancement of RPC is done by heat curing. Heat curing is performed by simply heating (normally at 90°C) the concrete at normal pressure after it has set properly.

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This considerably accelerates the pozzolanic reaction, while modifying the microstructure of the hydrates that have formed [1].

The most common concrete attack is the sulfate attack on concrete. Murdock (1999) mentions the chemical sulfate attack on concrete will cause damage on concrete and can cause cracks on concrete itself [4]. According to Masruri (1993), sodium sulfate and magnesium sulfate have more detrimental effect than the loss caused by gypsum (calcium sulfate), because these salts are not only more soluble, but also resulted in a greater concentration of sulfate in groundwater and minerals react with cement, thus causing total damage to the cement paste [5].

The combination of water with cement will form a cement paste by the hydration process. The cement paste are combines aggregate, fill the empty space, and free flowing. Sulfate attack occurs by attacking calcium hydroxide which is formed from the cement hydration process. Cement hydration process can be seen as follows:

$$C_3S + H \rightarrow C\text{-}S\text{-}H + CH$$

Tricalcium silicate + Air → Calcium silicate hydrate + Calcium hydroxide

$$C_2S + H \rightarrow C\text{-}S\text{-}H + CH$$

Dicalcium silicate + Air → Calcium silicate hydrate + Calcium hydroxide

Mindess and Young (1981) describes the sulfate attack into 3 stages [6]:

1. Penetration of sulfate ion
   The first process is the diffusion sulfate ions into the pores of the concrete, whice is controlled by the permeability coefficient and the diffusion coefficient of the sulfate ions.

2. Gypsum corrosion
   In its initial stages, gypsum corrosion may actually be beneficial, since gypsum is more soluble than calcium hydroxide and the dissolution-crystallization reaction will allow gypsum to crystallize without expansion. Equation of gypsum corrosion is as follows:

$$CH + SO_4^{2-} + 2H_2O \rightarrow C\bar{S}H_2 + 2OH^-$$

Calcium hydroxide + Sulfate + Water → Gypsum + Hydroxide

3. Sulfoaluminate corrosion
   As sulfoaluminate corrosion causes internal cracking, the diffusion coefficient of the concrete will be increased, thereby accelerating further sulfate attack. Ettringite in this case is formed from monosulfoaluminate can be seen below.

$$C_4A\bar{S}H_{12} + 2C\bar{S}H_2 + 16H \rightarrow C_6A\bar{S}_3H_{32}$$

Calcium Aluminate Hydrate + *Gypsum* + Water → Ettringite

C3A in the cement compounds also affect the sulfate reaction which affected by gypsum. The main initial reaction of C3A and gypsum reacts with water to form trisulfoaluminat / ettringite. If the sulfate is all consumed before C3A completely hydrate, then ettringite transform to another calcium sulfoaluminate hydrate containing less sulfate called monosulfoaluminate.

$$C_3A + 3C\overline{S}H_2 + 26H \rightarrow C_3A.3C\overline{S}_3.32H$$

$$C_3A + 3C\overline{S}H_2 + 26H \rightarrow C6A\overline{S}_3H_{32}$$

$$2C_3A + C_6A\overline{S}_3H_{32} + 4H \rightarrow 3C_4A\overline{S}H_{12}$$

At higher concentrations of sulfate, gypsum corrosion can contribute greater. Magnesium Sulfate can be even more aggressive because of the possibility of additional corrosive reaction due to the presence of magnesium ions, which can decompose both C-S-H and the calcium sulfoaluminates [6]:

$$C_3S_2H_3 + 3M\overline{S} \rightarrow 3C\overline{S}H_2 + 3MH + 2SH_x$$
$$C4A\overline{S}H_{12} + 3M\overline{S} \rightarrow 4C\overline{S}H_2 + 3MH + AH_3$$

This study aims to determine the force and weight of concrete due to sulfate attack in aggressive environments. The problems of this study was to determine the strength of concrete due to sulfate attack in aggressive environments and to determine the value of the weight of concrete due to sulfate attack in aggressive environments.

2. Research method

Materials that used in this research are 1. Water. 2. Sand with a maximum grain size of 0.6 mm. 3. There are 3 types of cement that being used: Type I cement, Type II cement, and PCC.
4. Silcafume with a grain size of 40 µm. 5. Quartz powder with 1200 mesh. 6. Superplasticizer used is Sika Viscocrete-10. 7. MgSO4 salt.

By using the material of No. 1-6, the mix design can be made. In this study, there are two types of mix design. The design are as follows:

- Water cement ratio (f_{as}) = 0,2 and 0,25
- Fine aggregate = 1,5 mass of cement
- *Silicafume* = 25% mass of cement
- *Super plasticizer* = 3% mass of cement
- *Quartz powder* = 25% mass of cement

The study begins with an examination of fine aggregate [7] based on standards that have been determined. After all the examination of fine aggregate finish, then make cylinders concrete specimen with a diameter of 75 mm and a height of 150 mm in accordance with the mix design that has been determined in advance. The slump test for this study is inverted slump test. After the concrete mixture is ready, then pour it into the mold. For the curing, its use steam curing method. For sulfate treatment, treatment used is based soundness test, ASTM C88 [8]. In this study sulfate used was a saturated solution of sulfate. MgSO4 salts dissolved in water until the salt can't dissolve anymore. Specimen will be tested when it's already 28 days.

3. Result and analysis

Based on the research, the compressive strength of concrete exposed to sulfate is lower than the concrete not exposed to sulfate. The results of compressive strength of concrete with and without immerse in sulfate can be seen in Table 1, Figure 2 and Figure 3.

Table 1. Concrete Test Result.

f_{as}	Cement Types	Compersive Strength			Mass
		Without Sulfate (MPa)	With Sulfate (MPa)	Difference (%)	Difference (%)
0,2	I	91,8100	59,4933	35,1995	1,2415
	II	85,9133	62,5400	27,2057	0,6234
	PCC	71,7367	47,6800	33,5347	0,8314
0,25	I	78,3700	37,2767	52,4350	1,4313
	II	76,1733	53,4367	29,8486	0,9732
	PCC	71,5300	42,9533	39,9506	1,0208

Concrete with immersion in sulfate mass reduction will occur as can be seen in Table 1. The mass reduction can also be seen in the specimen image. In Figure 1 it can be seen that there is still no holes are formed due to sulfate attack. Holes due to the formation of ettringite compounds that are expanding can be seen in Figure 1.

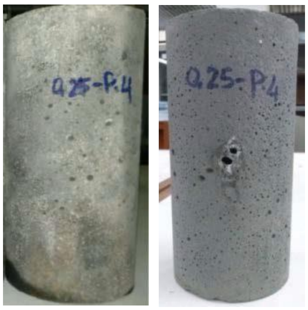

Figure 1. Specimen before (left) and after (right) immersion in sulfate.

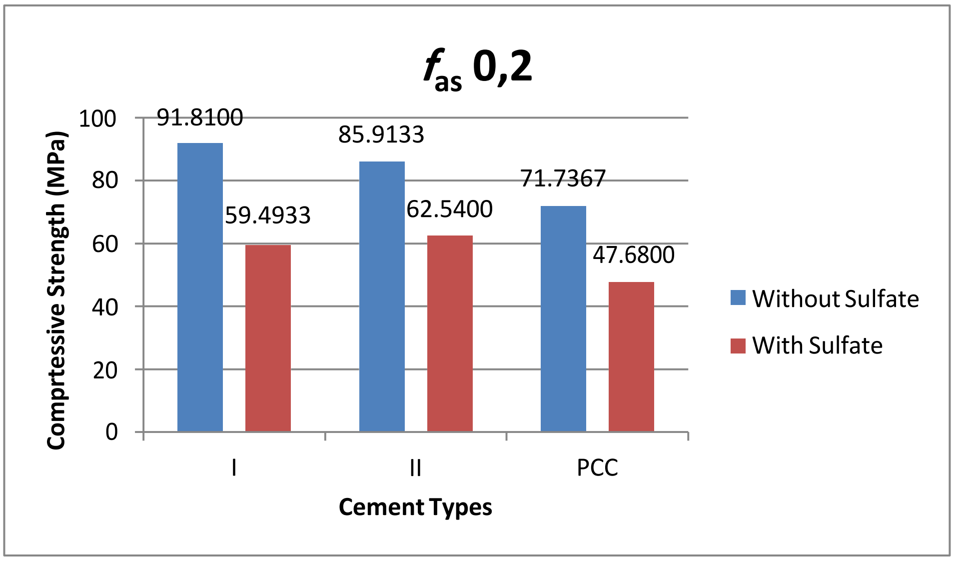

Figure 2. Compressive Strength with f_{as} 0,2 diagram.

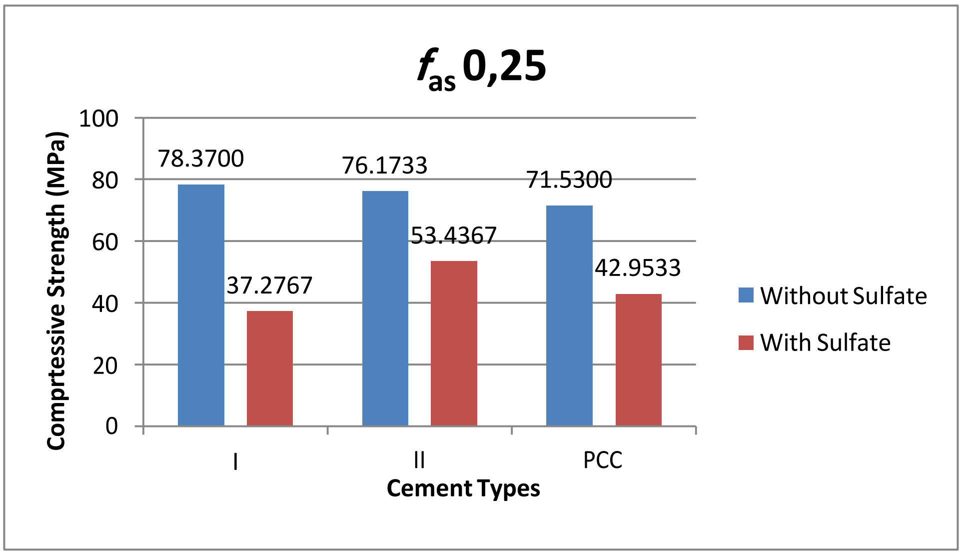

Figure 3. Compressive Strength with f_{as} 0,25 diagram.

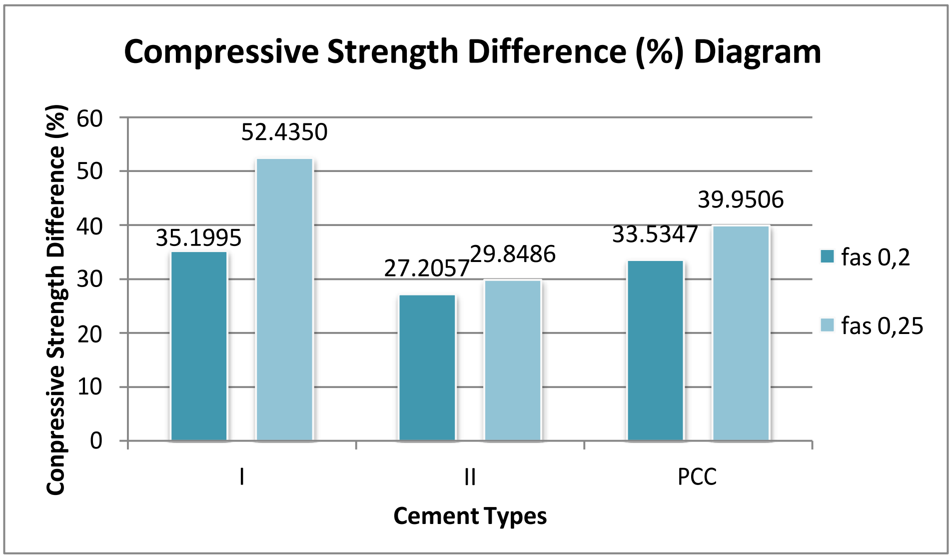

Figure 4. Compressive strength difference (%) diagram.

From Figure 4, if its sorted from the largest to the smallest compressive strength difference, that are specimen with cement type I, cement PCC and cement type II. This applies to specimen with f_{as} 0,2 as well as f_{as} 0,25.

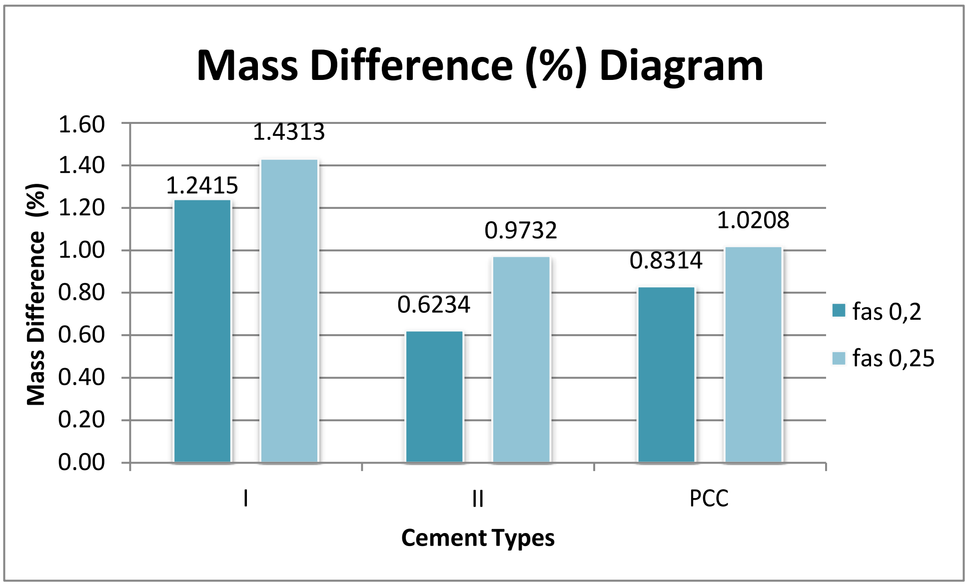

Figure 5. Mass Difference (%) diagram.

The less percentage difference in mass means the less mass from the specimen are missing. Based on Figure 5. the specimen with the least reduction in specimen mass is the specimen with Type II cement.

In the composition of the cement, C3A compound is a compound that was attacked by sulfate. Composition of C3A in type II cement is the least as much as 6%, so the cement Type II said to be good for sulfate attack. If C3A met with gypsum, it form ettringite that cause the crack expands and causes the compressive strength of concrete decreased.

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It can be seen from the results of compressive strength test, specimens with Type II cement mixture produces % reduction in compressive strength at least compared to cement Type I and PCC. So it can be said that the Type II cement is the cement that has good resistance to sulfate compared with Type I cement and cement PCC.

4. Conclusion

Based on the research, we can conclude some of the following:

- Reactive Powder Concrete with a mixture of cement type II has a good resistance against sulfate, because the compressive strength only decreased by 27.2057% on the highly concentrated (saturated) sulfate attack.
- Reactive Powder Concrete is good for resistance to sulfate attack due to the weight loss of the test specimen is not up 1.5% to sulfate attack that has a high concentration.
- Based on this research, Type II cement is the cement that has good resistance to sulfate compared with Type I cement and cement PCC.
- Reactive Powder Concrete is best used on structures that are directly related to ground water and sea water, for examples foundation and harbor.
- In responding to sulfate attack, Reactive Powder Concrete with PCC cement more efficient than type II cement.

References

[1] Putra Dharma 2006 Penambahan Abu Sekam Pada Beton Dalam Mengantisipasi Kerusakan Akibat Magnesium Sulfat Pada Air Laut *Jurnal Ilmiah Teknik Sipil* **10**
[2] Richard P and Cheyrezy M 1995 Composition of Reactive Powder Concrete *Cement and Concrete Research* **25** p 1501
[3] Bonneau O, Vernet C, Moranville M and Aitcin P C 2000 Characterization of the granular packing and percolation threshold of reactive powder concrete *Cement and Concrete Research* **30** p 1861
[4] Murdock L J 1999 *Bahan dan Praktek Beton* (Ciracas: Erlangga)
[5] Masruri N 1993 Pengaruh Garam Sulfat terhadap Beton dan Cara Pencegahannya *Jurnal Pemukiman* **9** pp 11
[6] Mindess, Sidney and Young J F 1981 *Concrete* (America: Prentice-Hall)
[7] Laboratorium Konstruksi dan Teknologi Beton 1997 *Buku Petunjuk Praktikum Konstruksi dan Teknologi Beton* (Jakarta: Universitas Tarumanagara)
[8] American Society for Testing and Materials 1999 *Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate* (Philadelphia: ASTM)