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Geotechnical Engineering

INFLUENCE OF SULFATE ATTACK TO REACTIVE POWDER CONCRETE

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ABSTRACT

Sulfates are often present in groundwaters, particularly when high proportions of clay are present in the soil, and sea water has sulfates as a major constituent. Sulfate attack on concrete is actually a rather complex process which may involve a number of secondery processes. This is accompained by a very large increase in solid volume, which cause a volume expansion within the paste and which generates accompanying internal stress and ultimately leads to cracking.

The use of special concrete such as reactive powder concrete can improve sulfate resistance. Ordinary portland cemen (OPC) or portland compocite cement (PCC) can be used instead of a type II cement, type II of cement that have the best performace from sulfate attack on reactive powder concrete.

KEYWORDS: concrete, sulfate, cement, resistance, cracking.

1. INTODUCTION

The most widespread and common form of chemical attack is the action of sulfates on concrete. Groundwaters may have local concentrations of sulfates in the vicinity of industrial wastes such as mine tailings, slag heaps, and rubble fills. Sulfates present in rainwater from air pollution, or produced by growths, may coause slow deterioration even in concrete above ground (Mindess and Young, 1981).

External sulfate attack is the more common type and typically ocurs where water containing dissolved sulfate penetrates the concrete. A fairly well-defined reaction front can often be seen in polished sections; ahead of the front the concrete is normal, or near-normal. Behind the reaction front, the composition and microstructure of the concrete will have changed. these changes may vary in type or severity but commonly include extensive cracking, expansion, loss of bond between the cement paste and agregate. The effect of these changers is an overall loss of concrete strength (Winter, 2012).

Reactive Powder Concrete (RPC) are well-known for their high strength resistance. Their very low porosity gives them important durability and transport properties and makes them potentially a suitable material for the agressive inveroment such as ground water and seawater (Matte and Moranville, 1999).

This paper describes a study which was carried out to better understand the behaviour of the RPC especialy compressive strength and flexture strength to the influence of sulfate attack.

2. REACTIVE POWDER CONCRETE

RPC composed by cement, sand, quartz powder, silica fume, 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. Convensional concrete aggregates form a set of rigid inclusions. On application of a compression force shear and tensile stresses appearing at the paste/aggregate interface generate cracks in paste. The size of these cracks is related to extent of the zone under tensile or shear stress. For RPC, with eliminated coarse aggregat a major reduction is obtained in the size of microcraks of the following origins: external load, autogenous shringkage and differential expansion between paste and aggregate under effect of heat treatment (Richard and Cheyrezy, 1995).

Elimination of coarse aggregates combined to optimization of granular mixture allows the obtention of an homogeneous and dense cementitious matrix that exhibits high mechanical performances (Kushartomo et al, 2013).

3. SULFATE ATTACK

Sulfate attack on concrete is actually a rather complex process which may involve a number of secondery processes. however, laboratory and field experiences have definitely established a correlation between the C3A content of a portland cement and its susceptibility to sulfate attack. The major cause is soulfoaluminate corrosion, in withc ettringite is formed from monosulfoaluminate (Mindes and Young, 1981):

$$C_4A\overline{S}H_{12} + 2C\overline{S}H_2 + 16\,H \longrightarrow C_6A\overline{S}H_{32}$$

This is accpmpained by a very large increase in solid volume, which cause a volume expansion within the paste and which generates accompanying internal stress and ultimately leads to cracking.

Mindess and Young (1981) describes the sulfate attack into 3 processes:

1. Penetration 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:

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

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.

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

Calcium Aluminate Hydrate + *Gypsum* + Water → Ettringite

4. RESEARCH METHODE

The RPC used in this study was prepared from the following cpmponents, quartz sand with maximum size 0,6 mm was used as a fine aggregate. The specific gravity of quartz sand is 2,65 g/cm^3. polycarboxylate based superplasticizer (SP) is conformity with ASTM C 494-81, type F was used in this study. The physical, chemical and mechanical properties of cement (type 1, type II and PCC), properties of silica fume and quartz powder are presented in Table 1. Furthermore, to accelerated chemical reaction the highest magnisium sulfat (MgSO4) concentration was used. Various mixture designs (mass ratio with respect to cement) silica fume, quartz as fine aggregate, quartz powder and superplasticizer are presented in Table 2.

Table 1. Physical and mechanical properties of cement, silica fume, and quartz powder

	Type I	Type II	PCC	Silica Fume	Quartz powder
Chemical composition (%)					
SiO_2	20.15	22,6	22,5	98,0	98,6
Al_2O_3	5,65	3,4	6,0	0,29	0,7
Fe_2O_3	2,15	4,2	3,5	0,03	0,03
CaO	62,92	64,9	60,0	0,2	
MgO	1,14	0,90	2,25	0,09	
$Na_2O + K_2O$	1,15	0,05	0,45	0,23	
SO_3	2,52	2,2	2,25	0,08	
Cl^-	0,001	0,01	0,015	0,01	
F.CaO (%)	0,52	1,0	1,0		
Physical properties					
Specific gravity	3,13	3,15	3,05	2,20	2,65
Initial setting (min)	130	130	130		
Final seting (min)	210	280	305		
Surface area (cm^2/g)	380	380	385		
Compressive strength (MPa)					
3 days	29,2		23,0		
7 days	43,2		30,0		
28 days	51,9		41,0		

Table 2. Composition of the mixture investigation

Materials	Type I	Type II	PCC	Type I	Type II	PCC
Cemen (kg)	757,8	759,0	753,0	730,1	731,2	725,7
Water (kg)	151,6	151,8	150,6	182,5	182,8	181,4
Silica fume (kg)	189,5	189,7	188,3	182,5	182,8	181,4
Quartz powder (kg)	189,5	189,7	188,3	182,5	182,8	181,4
Fine aggregate (kg)	1136,7	1138,5	1129,5	1095,2	1096,8	1088,6
Superplasticizer (kg)	22,7	22,8	22,6	21,9	21,9	21,8
Water/cement	0,20	0,20	0,20	0,25	0,25	0,25
Silica fume/cement	0,25	0,25	0,25	0,25	0,25	0,25
Quartz powder/cement	0,25	0,25	0,25	0,25	0,25	0,25
Fine aggregate/cement	1,50	1,50	1,50	1,50	1,50	1,50
Superplasticizer/cement	0,03	0,03	0,03	0,03	0,03	0,03

The concrete was mixed, cast, and vibrated like conventional concrete. Dry concrete powder components are mixed for 3 to 5 minutes, water is added with half on the volume superplasticozer and mixed for 3 minutes, and the second half of the volume of the superplasticizer is added and mixed for 5 minutes. The cylindrical samples were 750 mm in diameter and 150 mm long. The following curing treatment was applied to stabilize the mechanical and physical properties of speciment:in steam at 90°C for 12 hours. The Sulfate attack test simulates the worst attack on the cylindrical samples used saturated solution of MgSO4. In this severe test, the samples are immersed in sulfate solution bath maintained 24 hours, washing with hot water, 24 hours drying oven at 105 °C, immersed again continously for 7 times. Specimen will be tested when it's already 28 days.

5. RESULT AND ANALYSIS

These chemical reactions can lead to expansion and cracking of concrete, and/or the loss of strength and elastic properties of concrete is given in Fig. 1 dan Fig. 2, its represents comprssive strength of RPC containing different treatment. The form and extent of damage to concrete will depend on the sulfate concentration, the type of cations (eg sodium or magnesium) in the sulfate solution, the pH of the solution and the microstructure of the hardened cement matrix (Sarkar et al, 2010).

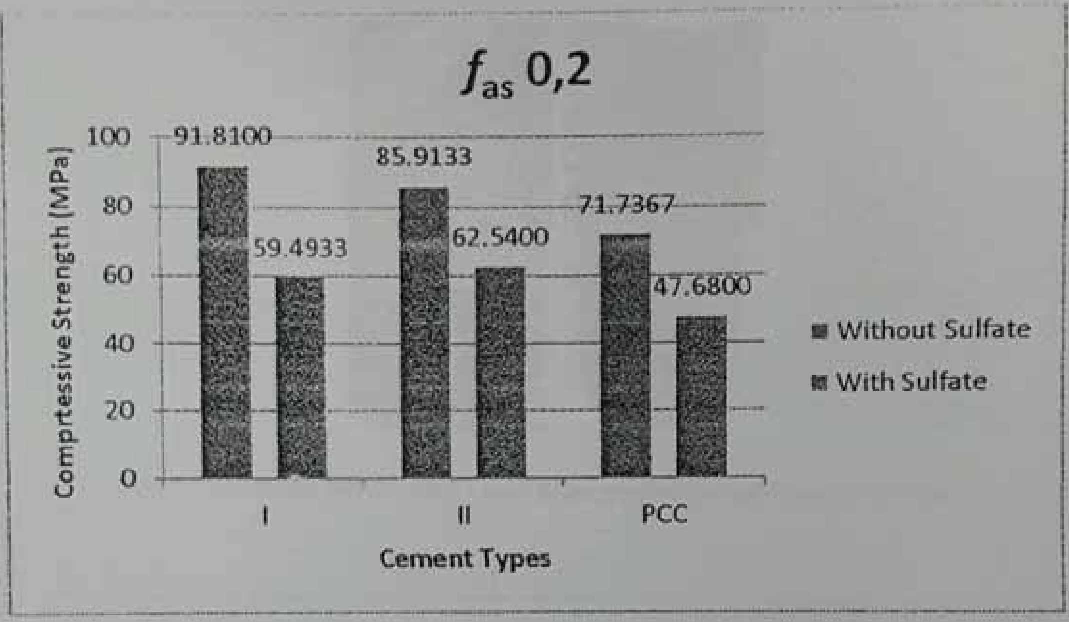

Figure 1. Compressive Strength with f_{as} 0,2 diagram

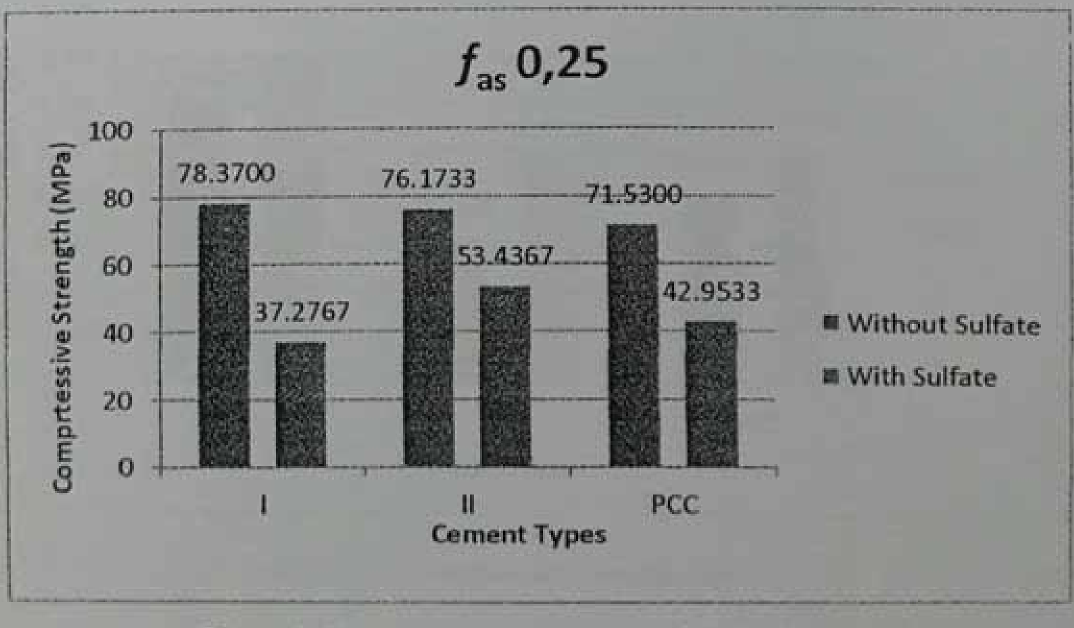

Figure 2. Compressive Strength with f_{as} 0,25 diagram

Figure 3 represent mass reduction indicated of sulfate attack. It can be seen face differences of RPC samples. There are no holes are formed for normal sample and any holes for sample immersed in sulfate solution, it caused reduces mass of RPC sample as given on Fig.4. Holes due to the formation of ettringite compounds that are expanding. Some cements are more susceptible to magnesium sulfate than sodium sulfate, the key mechanism is the replacement of calcium in calcium silicate hydrates that form much of the cement matrix. This leads to a loss of the binding properties. Formation of brucite ($Mg(OH)_2$) and magnesium silicate hydrates is an indication of such attack.

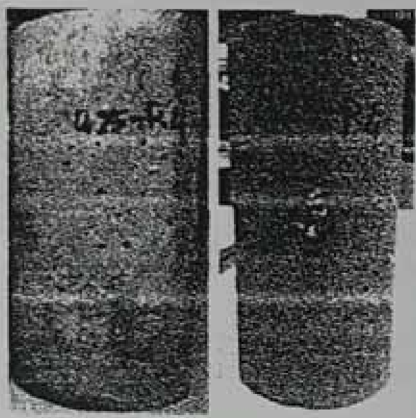

Figure 3. Specimen before (left) and after (right) immersion in sulfate

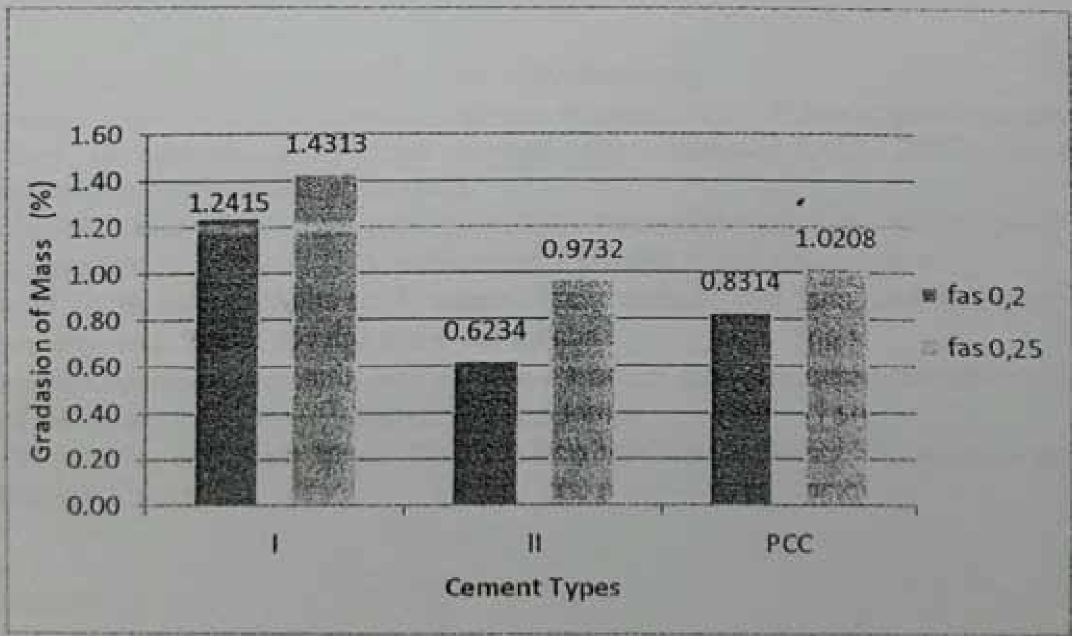

Figure 4. Gradation of mass diagram

In the composition of the cement, C_3A compound is a compound that was attacked by sulfate. Composition of C_3A in type II cement is the least as much as 6%, so the cement Type II said to be good for sulfate attack. If C_3A met with gypsum, it form ettringite that cause the crack expands and causes the compressive strength of concrete decreased.

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.

C_3A in the cement compounds also affect the sulfate reaction which affected by gypsum. The main initial reaction of C_3A and gypsum reacts with water to form trisulfoaluminat / ettringite. If the sulfate is all consumed before C_3A completely hydrate, then ettringite transform to another calcium sulfoaluminate hydrate containing less sulfate called monosulfoaluminate.

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

$$C_3A + 3C\bar{S}H_2 + 26H \rightarrow C_6A\bar{S}_3H_{32}$$

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

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 (Mindes and Young, 1981):

$$C_3S_2H_3 + 3M\bar{S} \rightarrow 3C\bar{S}H_2 + 3MH + 2SH_x$$

$$C_4A\bar{S}H_{12} + 3M\bar{S} \rightarrow 4C\bar{S}H_2 + 3MH + AH_3$$

6. 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.

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