

The 5th International Conference of Euro Asia Civil Engineering Forum (EACEF-5)

Porosity, pore size and compressive strength of self compacting concrete using sea water

Erniati^{a,*}, M. Wihadi Tjaronge^b, Zulharnah^a, Ulva Ria Irfan^c

^aDepartment of Civil Engineering, Engineering Faculty, Fajar University, Makassar, Indonesia

^bDepartment of Civil Engineering, Engineering Faculty, Hasanuddin University, Makassar, Indonesia

^cDepartment of Geological Engineering, Engineering Faculty, Hasanuddin University, Makassar, Indonesia

Abstract

Indonesia is the largest archipelago in the world, so it has much territory that the quality of the source water is not qualified as mixing water in construction. Besides, construction of concrete in areas that are likely quantity of water or fresh water is very minimal or even nothing then the sea water cannot be avoided in mixing concrete. This research was an experimental study, the samples for compressive strength test are cylindrical premises size of 10 mm×20 mm. The porosity relation, compressive power, age and model of porosity relationship with SCC concrete compressive strength which using sea water is discussed in this paper. Compressive strength testing is following the standard ASTM 39/C 39-99. Universal Testing Machine (UTM) was used in the testing of compressive strength. Test specimen for porosity created by taking part of the cylinder and then slashed with a size of approximately 2 cm×3 cm with a 0.003 mm thick. The type and pore size and porosity were analyzed by using a polarizing petrography microscope Olympus BX 51-P. The result of research was increased the compressive strength and density of microstructures in line with the decrease in porosity and pore size of concrete and concrete age. Compressive strength relations (σ_{ss}) and porosity (p_{ss}) the SCC used sea water can be approximated equation $\sigma_{ss} = \sigma_o (1-p)K$, with $\sigma_o = 119.6$ and $K = 7.502$.

© 2015 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license

(<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review under responsibility of organizing committee of The 5th International Conference of Euro Asia Civil Engineering Forum (EACEF-5)

Keywords: self compacting concrete; sea water; porosity; compressive strength.

* Corresponding author. Tel.: +6285340570417/+6281354937610; fax: -.

E-mail address: emi_nurzaman@yahoo.com

1. Introduction

The largest archipelagic state of world is Indonesia which has an area of 1,904,569 km² with a number of islands as much as 17,508. Indonesia is an archipelago, so it's many areas with the quality of water resources is not qualified as mixing water in construction. Construction of concrete construction in areas that are likely quantity of fresh water is very minimal or nothing, then the sea water cannot be avoided in the concrete mixing and maintenance.

The United Nations estimates that in 2050 the world will get an additional population of about 3.5 billion, with the largest growth in developing countries that have experienced in a water crisis. In addition, more than half of the world population will not be able to get enough drinking water. Increasing infrastructure development is in line with the needs of clean water more and more. In the concrete industry, several billion tons of water used in mixing the earth as water, curing and cleaning water every year, where sea water has not been used for such things. For that reason, study of freshwater savings is very seriously needed. The use of sea water, the percentage is 97% from the total water on Earth, is absolutely necessary. In the near future, water will be very difficult to obtained and limited and also he revealed that today, there are some areas where sea water or sand containing chloride is used as a water / material mixing with or without intention [1,2]. Previous research regarding use of sea water as the mixing water in concrete, the mixing of sea water on concrete using Blast-Furnace Slag Cement (BFS) produce the Friedel's salt and the total pore volume decreased and the strength increased compared to freshwater [1–3]. The presences of chloride accelerate the development of early age strength of concrete with slag until about 7-14 days [4]. After this age, there is a distinct disadvantage on the strength of concrete with chlorides but the reduction of the strength was not significant. The presence of super plasticizer on Self Compacting Concrete (SCC) showed of the microstructure was denser and microcrystalline calcium silicate hydrate (CSH) as the main product of hydration with sheets of calcium hydroxide (CH) [5]. Sea water and sea sand as a material in concrete SCC does not decimate the strength of concrete [6]. Research of SCC using seawater, sea water does not reduce the strength of the SCC up to the age of 90 days but seawater will accelerate the increase in the strength of concrete at early age. Then, the use of sea water as the mixing water in concrete was qualified as workability SCC and the higher mechanical properties compared to fresh water, especially at ie early age of 1 and 3 days [7,8]. A decrease the porosity in line with the improved quality of the microstructure phase tobermorite (CSH), portlandite (CH), Friedel's salt and ettringite [9]

Porosity is a measure of the spaces between the material and a fraction of the volume of empty space of the total volume, which it is a value between 0 and 1, or as a percentage between 0–100%. Porosity depends on the type of material, material size, pore distribution, and composition. In general, that the decrease in porosity in line with the increase in the strength of the solid materials.

Assessment of existing models on the relationship between the compressive strength and porosity of the cement material is a linear equation $\sigma = \sigma_0 - Kp$, the power exponential equation $\sigma = \sigma_0(1 - p)^K$, the exponential equations $\sigma = \sigma_0 e^{-Kp}$, logarithmic equation $\sigma = K \ln(\sigma_0/p)^m$, with σ is the compressive strength on the porosity p , σ_0 is the compressive strength at zero porosity, m and K are empirical constants [10].

This paper discusses the relationship of the porosity, compressive strength and age and model relationship of porosity and compressive strength of SCC using sea water.

2. Material and experiment methods

The material used in the study were Portland composite cement (PCC), sea water, crushed stone, sand and super plasticizer. SCC using sea water used the methods of the European Federation of Specialist Chemicals and Concrete Constructions Systems (EFNARC [11,12]). The design used water-cement ratio was 0.35. The mixture composition of SCC using sea water can be seen in Table 1.

Samples for compressive strength were test cylinder measuring 10 mm×20 mm. Compressive strength testing was following the standard ASTM test standard 39 / C 39M – 99 [13]. The tool used in the testing of compressive strength is Universal Testing Machine (UTM). Test specimen for porosity was created by taking part of the cylinder and then slashed with a size of approximately 2 cm×3 cm with a thickness of 0.003 mm. Pores types and pore size of porosity were analyzed by using the tool petrography polarizing microscope Olympus BX 51-P.

Table 1. The composition of the SCC/m³

Materials	weight, kg
Sea Water	206
Cement	601
Sand	770
Crushed stone	785
Superplasticizer	6

3. Result and Discussion

The test results of pore size, porosity and photo micrographs using petrography tool can be seen in Table 2 and Fig. 1.

Table 2. Results of testing pore size and porosity of the SCC using sea water.

Age (day)	Porosity (%)	Pore size (μm)	
		Isl-p	Intr-p
1	24.30	119.8-666.6	6.4-18.6
7	13.60	90.2-332.4	5.0-19.5
28	10.62	79.5-233.4	3.9-15.1
90	10.50	50.5-233.1	1.9-12.0

Explanation :Isl-p : isolated pore, Intr-p : Intergranular pore

Analysis on thinly slice of the SCC using sea water, there are two kinds of pores were observed i.e. inter granular pore and pore isolated as can be seen in Fig. 1. The two types of isolated pore size and inter granular pore of SCC were getting smaller with increasing age. Inter granular pore is pores between the grains making up the concrete and has smaller size than the isolated pore. Isolated pore is a pore that is formed from the initial formation of the sample.

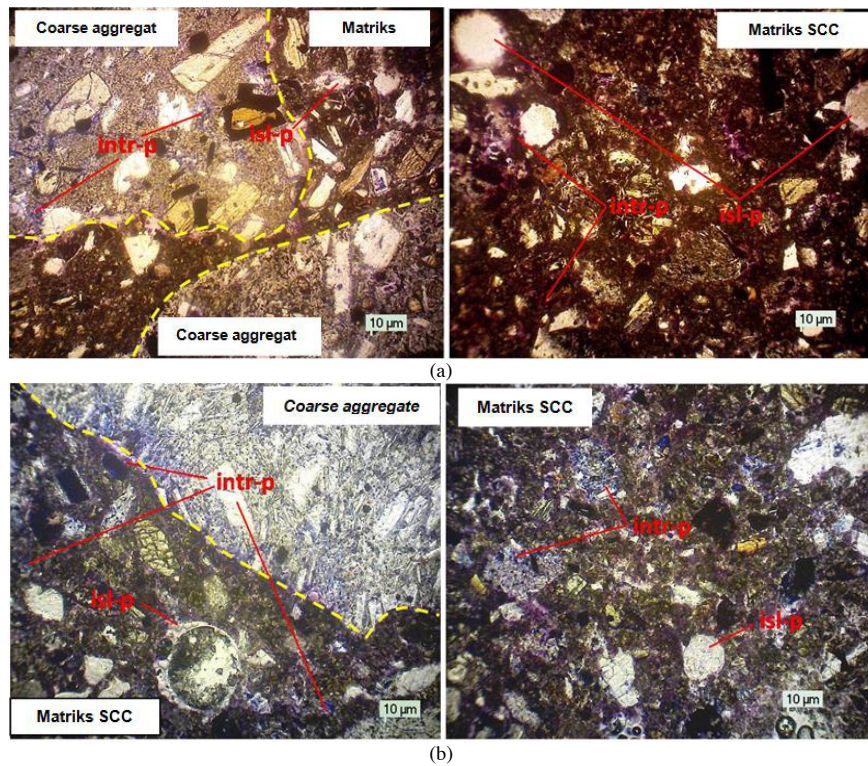
Fig. 1(a) showed photo micrographs of the SCC using sea water as the mixing water at the age of 1 day and Fig. 1(b) showed the micrograph photo at SCC that uses sea water as the mixing water at 28 days had a good bond between the matrixes with coarse aggregate. The SCC using sea water aged 1 day had of inter granular pore size of 6.4 to 18.6 μm and isolated pore with a size of 119.8 to 666.6 μm . Pore size at age 7, 28 and 90 days can be seen in Table 2. Decrease of pore size was in line with porosity. Decrease of pore size and the porosity was in line with increasing age of the SCC. Thus, increasingly of dense microstructure density was in line with decreasing of pore size, porosity and increasing age of SCC concrete.

The results and discussion of the compressive strength of SCC using sea water has been described previously, that increasing compressive strength of SCC was in line with age, In addition, sea water gives increasing effect of SCC compressive strength at an earlier age if it was compared with SCC that using fresh water [7,8].

Fig. 2 showed curve of the relationship between porosity, compressive strength and age which SCC using sea water had decreasing pore size in line with the increasing age. Otherwise SCC uses sea water had a compressive strength is increasing in line with age. Besides, microstructure and porosity had also been discussed by researchers previously that the density of increasingly dense microstructure in line with the decreasing of porosity. Sea water did not inhibit the formation of tobermorite (CSH), but accelerated the formation of tobermorite was at early age. Seawater as mixing water of SCC had been formed by friedel's salt crystal [9].

With the regression analysis, curve relationship between the porosity and age of SCC tended shaping curve of power exponential. The equation of porosity relationship p_{ss} (%) and age $t(\text{day})$ of SCC using sea water obtained from the analysis can be seen in equation 1.

$$p = 22.21t^{-0.19} \quad (1)$$



Isl-p: Isolated pore; Intr-p: Inter granuler pore

Fig. 1 Photo micrographs of SCC using sea water

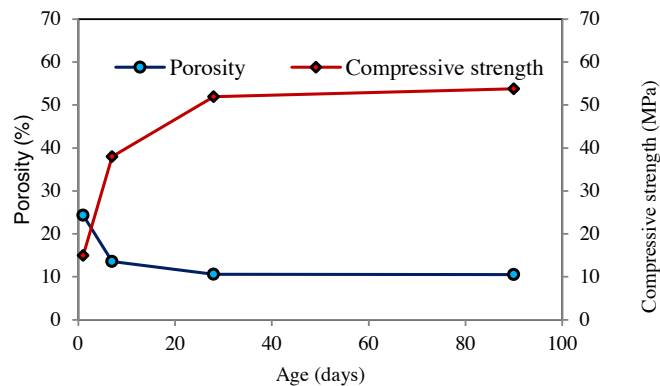


Fig. 2. Relationship of porosity and compressive strength with age of the SCC using sea water.

The increasing quantity of CSH as the main compounds was greatly influence the development of the concrete properties, so that the resulting bond between the matrixes with aggregate getting stronger. Pore or empty space that was originally occupied by water and cement particles dissolve so that the CSH replaced with concrete porosity was reduced. That reaction gave a major contribution to the increase in compressive strength and density of microstructures in line with the decrease in the porosity and pore size well as increasing age of the SCC. As previous studies on the relationship with the phase microstructure porosity, that increasing age with adequate care conditions, so that the quantity of hydration products mainly tobermorite (CSH) resulting from the reaction of three calcium silicate (C_3S)

and two calcium silicate (C_2S) with water (H_2O) more increased. Thus increasing quantities of tobermorite (CSH) in line with the increase in compressive strength, density of the microstructure and decrease in porosity of SCC using sea water [9].

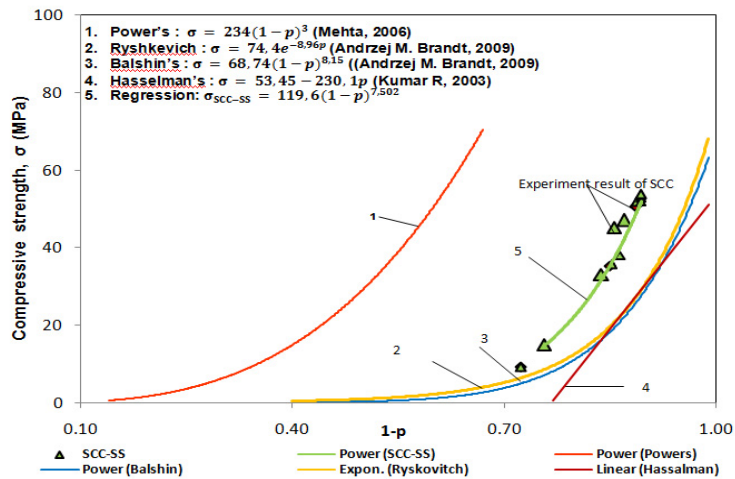


Fig. 3. Curve relationship of compressive strength and porosity of cement based material

Fig. 3 showed curve of the relationship between the compressive strength and the porosity solid materials cement-based materials. The experimental results with previous studies had the same predisposition, decreased compressive strength was in line with the increasing of porosity. According by Power's ($\sigma = 234(1-p)^3$) that value porosity was different with the results research of SCC using sea water ($\sigma_{SS} = 119,6(1-p)^{7,502}$), Riskewitch ($\sigma = 74,4e^{-8,96p}$), Balshin's ($\sigma = 68,74(1-p)^{8,15}$) and Hasselman's ($\sigma = 53,45 - 23,1p$). Power Curve models appear to have the porosity greater than the research results of SCC using sea water, models Riskewitch, Balshin and Hasselman.

Results of this research approach the Balshin models, Riskewitch and Hasselman. This happens because of the resulting model was a model from various different material, in other words that the hydration process and microstructure results of different pore sizes would produce the relationship of compressive strength and different porosity. Power's model find the equation of the results of research on the compressive strength and porosity of mortar [14], Balshin and Riskewitch find models of studies compressive strength and porosity in the ceramic metal [15] and Hasselman proposed equation model compressive strength and the porosity of fire-resistant material [16].

From the analysis of the results of the research, the relationship between the porosity and compressive strength tended to follow the model of Power's and Balshin, for that curve of compressive strength and porosity following the model $\sigma = \sigma_0(1-p)^m$ as in Fig. 3, the next relationship between the compressive strength σ_{SS} (MPa) and the porosity SCC using sea water p (%) can be approximated by the equation 2.

$$\sigma_{SS} = 119,6(1-p)^{7,502} \quad (2)$$

4. Conclusions

CSH compound is the main compounds which greatly influence to the development of the physical properties and microstructure. The increasing of CSH quantity gave effect to matrix bond with the stronger aggregate and SCC concrete porosity is getting smaller. The improved compressive strength and density of microstructures were in line with the decreasing porosity and pore size of the concrete. Compressive strength relationship and porosity at SCC using sea water can be approximated equation $\sigma_{SS} = \sigma_0(1-p)^K$ with $\sigma_0 = 119,6$ dan $K = 7,502$.

Acknowledgements

Gratitude and appreciation to the Ministry of Research and Higher Education on funding research with competitive grants scheme.

References

- [1] Otsuki, N., Furuya, D., Saito, T. And Tadokoro, Y. 2011. *Possibility of Sea Water as Mixing Water in Concrete*, 36th Conference on Our world in Concrete & Structures, Singapore.
- [2] Otsuki, N., Saito, T. and Tadokoro, Y. (2012), Possibility of Sea Water as Mixing Water in Concrete, *Journal of Civil Engineering and Architecture*, ISSN 1934-7359, Vol. 6, No. 10 (Serial No. 59), pp. 1273–1279, USA.
- [3] Furuya, D., Otsuki, N., Saito, T., Lee Yun. 2009. *A Study On The Effects Of Seawater as Mixing Water on The Hydration Characteristics of Blast-Furnace Slag Cement*, 34th Conference on Our World In Concrete & Structure: 16 - 18 August 2009, Singapore.
- [4] Aburawy, M.M. and Swamy, R. N. 2008. Influence Of Salt Weathering On The Properties Of Concrete”, *The Arabian Journal for Science and Engineering*, Vol. 33, Number 1B
- [5] Heikal, M., Zohdy, K.M. and Abdelkreem, M. 2012. Mechanical, Microstructure and Rheological Characteristics of High Performance Self-Compacting Cement Pastes and Concrete Containing Ground Clay Bricks, *Construction and Building Materials*, 38: 101-109.
- [6] M.W. Tjaronge, M.W. Rita Irmawaty, R.A. Adisasmita, A. Amiruddin. Compressive Strength and Hydration Process of Self Compacting Concrete (SCC) Mixed with Sea Water, Marine Sand and Portland Composite Cement, *Advanced Materials Research* Vol. 935 pp 242-246 (2014)
- [7] Erniati, M.W.Tjaronge, Rudy Djamaluddin, Victor Sampebulu, *Microstructure Characteristics of Self Compacting Concrete using Sea Water*, *International journal of Applied Engineering Research: Vol 9. Number 22 (2014) pp 18087-18095*
- [8] Erniati, M.W.Tjaronge, Rudy Djamaluddin, Victor Sampebulu, Compressive Strength and Slump Flow of Self Compactig Concrete Uses Fresh Water and Sea Water, *ARNP Journal of Engineering and Applied Sciences: Vol 10. Number 6(2015) pp 2373-2377*.
- [9] Erniati, M.W.Tjaronge, Rudy Djamaluddin, Victor Sampebulu, Porosity and Microstructure Phase of Self Compacting Concrete Using Sea Water as Mixing Water and Curing, submitted on International Conference on Key Engineering Materials (ICKEM 2015) March 21-23, 2015, it will be published on *Advanced Material Research*, vol 1119.
- [10] Kumar, R. and B. Bhattacharjee (2003). Porosity, pore size distribution and I situ strength of concrete, *Cement and Concrete Research* 33, 155-164, Pergamon.
- [11] EFNARC, “The European Guidelines for Self compacting Concrete”, Efnarc, UK (www.efnarc.org), February, 2002
- [12] EFNARC, “The European Guidelines for Self-Compacting Concrete: Specification, Production and Use”, UK (www.efnarc.org), May, 2005
- [13] *ASTM C39/C39M – 12a*, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, October 2012.
- [14] Mehta, P.K and Monteiro, P.J.M (2006). *Concrete: Microstructure, Properties and Materials*, 3rd Ed, McGraw-hill_Professional
- [15] Andrzej M. Barandt. (2009). *Cement- Based Composite*, Second edition, Taylor & Francis e-Library, USA and Canada.
- [16] X. Chen, Shengxing Wu, Jikai Zhou. (2013), Influence of Porosity on Compressive and Tensile Strength of Cement Mortar, *Construction and Building Materials* Vol. 40: 869-874.