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Compressive Strength and Hydration Process of Self Compacting Concrete (SCC) mixed with Sea Water, Marine Sand and Portland Composite Cement

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Abstract. In order to eliminate the main problems of clean water shortage and fine aggregate in the low land areas and the distant islands, it is purpose to utilized the sea water, marine sand and composite cement to produce the high performance Self Compacting Concrete (SCC), where Portland composite cement containing of fly ash. The evaluation result on the mix design, workability (slump flow, segregation), mechanical properties (compressive strength-static modulus) and hydration process of SCC were discussed.

Introduction

As the world's largest archipelagic state, Indonesia consists of more than 18,000 islands and over 7.9 million square kilometres of sea water. This present study is a part of research work to accelerate the sustainable infrastructure development in the distant islands in addressing the lack of infrastructure and environment issues. The utilization of sea water and marine sand can reduce the consumption of fresh water and river sand, therefore will decrease the price of concrete work in the low land areas and the distant islands those lack of clean water and mountain sand or river sand. The numbers of skilled workers in the construction industry are not enough, especially in the distant islands. Meanwhile, the production of durable concrete structures requires an adequate compaction by the skilled workers. One solution to overcome the shortage of the skilled workers is the application of Self Compacting Concrete (SCC). SCC is a fresh concrete that can flow under its own weight with maintaining its homogeneity to completely fill the mold without vibration or compaction energy [1].

In order to contribute a cleaner environment and to achieve material saving through the recycling of waste materials such as fly ash, then several cement factories produce the blended cement containing of fly ash such as Portland composite cement [2,3]. This paper report for a part of ongoing investigation that focus to achieve an optimum correlation between sea water, marine sand, cement, coarse aggregate, Portland composite cement to produce the high performance SCC. The testing result on the mix design, workability (slump flow, segregation), compressive strength, modulus elasticity and hydration of SCC were discussed.

Materials and Experimental Methods

Portland Composite Cement. The experiments were carried out using Portland composite cement with containing of fly ash and produced by Indonesia cement manufacture. Some component oxide and physical properties of cement used in this research are shown in Table 1 and Table 2, respectively. The component oxides and physical properties meet the requirement of SNI 15-7064-2004 (Indonesia Standard for Portland Composite Cement).

Table 1 Some component oxides of PCC

No	Oxide	SNI 15-7064-2004	Portland Composite cement (PCC)
1	MgO (%)	6.0 max	0.97
2.	SO_3(%)	4.0 max	2.16
3.	Loss of Ignition (%)	5.0 max	1.98

Table 2 Physical properties of PCC

No	Physical properties	SNI 15-7064-2004	Cement used (PCC)
1.	Air content of mortar (%)	12 max	11.5
2.	Fineness/ Blaine meter (m^2/kg)	280 min	382
3.	Expansion, % (max)	0.8 max	-
4.	Compressive strength		
	a. 3 days (kg /cm^2)	125 min	185
	b. 7 days (kg /cm^2)	200 min	263
	c.28 days (kg /cm^2)	250 min	410
5.	Time of setting (Vicat test) :		
	a. Initial set, minutes	45 min	132.5
	b.Final set, minutes	375 max	198
6.	False setting time (minutes)	50 min	-
7.	Heat of hydration 7 days, cal/g		65
8.	Normal consistency (%)		24.15
9.	Specific gravity		3.13

Concrete Mixture. Table 3 and Table 4 show the concrete mixture and some physical properties of aggregates, respectively. Crushed stone (river stone) was used as coarse aggregate. The design slump flow and compressive strength were 650 mm and 42.5 MPa, respectively.

Table 3 Concrete mixture (in 1000 litre)

Sea water (w), kg	Cement (c), kg	Marine Sand, kg	Crushed stone, kg	Superplasticizer, kg	Retarder, kg
204	567.6	760.4	843.6	4.54	1.02

Table 4 Some physical properties of aggregates

Property		Crushed stone (diameter of 10-20 mm)	Marine sand
Specific gravity	Oven dry	2.89	2.43
	Saturated surface dry	2.91	2.47
Water absorption (%)		0.62	1.75

Table 5 Chemical composition of seawater

pH	Chemical Composition (mg/L)					
	Na	Ca	Mg	Cl	SO_4	CO_3
8.5	2085.2	348.4	1973.5	5303.7	134	576.6

Table 6 Chemical composition of marine sand

Chemical Composition (%)						
Mg	Fe	Ca	Al	Cl	SiO_2	MgO
1.1	3.6	1.8	12	0.04	51190	1.95

The hardened of SCC was cured in the sea water until testing days. Table 5 and Table 6 show the chemical composition of sea water and marine sand, respectively.

Testing Methods for Slump Flow and T-500. Slump flow test with T-500 test have been proposed for testing flow ability. Slump flow test was done according to JIS A 1150 (Standard test method for slump flow of concrete).

Testing Methods for Compressive Strength and Static Modulus of Concrete. The compressive strength and static modulus were tested with according to SNI 1974-2011 (Method of test for compressive strength of concrete) and SNI 03-2847 2002 (Method of test for static modulus of concrete), respectively. The diameter and height of cylinder specimen was 15 cm and 30 cm, respectively.

Analysis of Hydration Process. The cement constituents and minerals react with water to form varies hydration products such as C-S-H (calcium silicate hydrate) or torbomorite, portlandite, ettringite, calcium monosulphoaluminate or calcium monocarboaluminate. The increasing and decreasing amounts of ettringite, C-S-H, portlandite and other cement hydrate were observed. X-ray diffraction (XRD) equipment was used to estimate the extent of hydration in 1, 3, 7 and 28 days.

Results and Discussion

Slump flow and T500 Test Result. The observations on slump flow showed that the fresh state of SCC flowed homogenously in all direction, therefore the flow spread was circular and the crushed stones did not remain at the center of the flow spread after removal of Abrams` cone. The time for SCC diameter to reach 500 mm (T500) was 3 seconds. The slump flow or the final diameter of when SCC has stopped flowing after lifting Abrams` cone was 680 mm.

Compressive Strength and Static Modulus Test Result. The visual observation on the cylindrical specimens showed that the surface of hardened concrete was smooth without any honeycomb and large air voids. Table 7 shows the development of compressive strength and elasticity. The compressive strength met the requirement of strength of 42.5 MPa at 28 days. This result showed that SCC flowed under its own weight and completely filled the mould, whilst maintaining homogeneity, without segregation, led to a good achievement of the compressive strength.

Table 7 Development of compressive strength and elasticity

Property	Curing age (day)			
	1	3	7	28
Compressive strength (MPa)	11.32	18.97	31.05	45.77
Static Modulus (MPa)	16325.49	20964.68	26941.55	32647.61

Hydration Process. As shown in Table 8, XRD result test pointed that the C_3A and C_3AF hydrated fast and had been exhausted within 1 day. The observed hydration rate for belite (C_2S) phase hydration was significantly slower than alite (C_3S) phase hydration. The presence of C_3S at the age of 1, 3, 7 and 28 days were 19.38, 16.17, 8.08% and 0.0, respectively. At the age of 1, 3, 7 and 28 days, the presence of C_2S was 35.91, 33.98, 28.72 and 18.89%, respectively.

The bound of chloride in sea water and marine sand with cement hydrates is called Friedelt`s salt [4]. The cement hydrates and content of $SO_4$ in the sea water produced ettringite. As shown in Table 8, the decreased in $Ca(OH)_2$ formation and the increased in ettringite and Friedel`s salt formation at the age of 1 day to 28 days did not interfere with C-S-H development process. Based on the investigation of the hydration process, the compressive strength and static modulus evolve with curing age, reflecting the C-S-H formation process from hydration reaction with time.

Table 8 Chemical hydration process

Chemical compound	Curing ages (days)			
	1	3	7	28
	Content (%)			
Portlandite, $Ca(OH)_2$	9.92	8.10	6.87	5.15
Tobermorite, C-S-H, $3CaO.2SiO_2.3H_2O$	32.93	35.48	46.13	59.36
Friedelt`s salt, $3CaO.Al_2O_3.CaCl_2.10H_2O$	0.71	2.17	4.19	9.18
Ettringite, $3CaO.Al_2O_3.CaSO_4.32H_2O$	1.15	4.1	5.3	7.36
Chloride, Cl	1.98	1.48	0.54	0.10
Tricalcium Silicate, Alite, $3CaO.SiO_2$, (C_3S)	20.7	17.9	10.8	0
Dicalcium Silicate, Belite, $2CaO.SiO_2$, (C_2S)	38.3	38.2	33.2	26.7
Tricalcium Aluminate, (C_3A),$3CaO.Al_2O_3$	0	0	0	0
Tetracalcium Aluminoferrite, (C_4AF), $4CaO.Al_2O_3$. Fe_2O_3	0	0	0	0

Concluding Remarks

1. The fresh state of SCC had a good free deformability and segregation resistance.
2. The good achievement of the compressive strength of 40 MPa was the result of a homogeneous compaction of SCC.
3. The presence of Friedelt`s salt and ettringite within the SCC did not affect its compressive strength and static modulus development at the age of 1 day to 28 days.

4. The interim result showed that marine sand can be used as fine aggregate and sea water can be used as mixing and curing water in the production of SCC.

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Most of the research works were conducted in the Eco Material and Concrete Laboratory, Civil Engineering Department, Hasanuddin University, Makassar-Indonesia.

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