Journal of Coastal Development ISSN: 1410-5217
Volume 8, Number 2, February 2005: 89-95 Accredited: 23a/DIKTI/Kep/2004

Original paper

THE PERFORMANCE OF EARLY-AGE CONCRETE WITH SEAWATER CURING

*M.I Retno Susilorini [1, 3 *], Kristina Retno Dewi W [2], Tri Wibowo [2]*

[1)] Civil Engineering Department, Faculty of Engineering, Soegijapranata Catholic University, Semarang, Indonesia
[2)] Alumnus, Civil Engineering Department, Faculty of Engineering, Soegijapranata Catholic University, Semarang, Indonesia
[3)] Center of Eco-Settlement Study, Research Institute, Soegijapranata Catholic University, Semarang Indonesia

Received: January, 2, 2005 ; Accepted: January, 20, 2005

ABSTRACT

It is well known that concrete has been implemented for marine structures. Marine environment causes physical and chemical deterioration of concrete structures, thus, there is no doubt that the durability takes an important role in concrete performance. Learning about the performance of early-age concrete is to study the maturity of concrete, which is a key of concrete durability where "Maturity Concept" attempts to predict the development of concrete properties as a function of time and temperature of curing and becomes an excellent indicator of in-place strength development and quality from fresh to hardened concrete. It is a hypothesis for this research that the compressive strength of early-age concrete cured by seawater is higher than the one cured by plain water.

This research was conducted by using two methods, experimental method and analytical method. The experimental method investigated the compressive strength of concrete cylinders, with 7 days and 14 days seawater curing and plain water curing. Concrete compressive strength design, f'_c, is 22.5 MPa, and varies with water-cement ratio: 0.4, 0.5, and 0.6. After 7 days and 14 days of curing, the concrete cylinders were tested by compressive testing machine.

The experimental results of this research showed that the compressive strength of 7 days and 14 days concrete specimens with seawater curing is higher than those cured by plain-water, about 2.56-5.25% for 7 days old specimens and 3.39-11.87% for 14 days old specimens. The result also showed that the lower water-cement ratio, the higher concrete compressive strength would be. The analytical calculation also gave higher compressive strength to specimens cured by seawater, about 0.06-0.39% for 7 days old specimens and 0.11-0.33% for 14 days old specimens. The higher strength compressive of concrete specimens with seawater curing is provided by the existence of calcium chloride in seawater and by high temperature of seawater. The analytical result of the "Maturity Concept" has given a good performance in predicting the compressive strength of concrete very well veryfying the experimental results. The hypothesis of this research is proven, that both experimentally and analytically, the compressive strength of 7 days and 14 days old concrete specimens cured by seawater are higher than those cured by plain water.

Key words: Concrete, early-age, maturity, seawater, curing, compressive strength

*** Correspondence**: Phone 024-8416052, 024-8441555 ext. 218, Fax. 024-8416052,
E-mail: susilorini@unika.ac.id

INTRODUCTION

It is well known that concrete has been implemented for marine structures, on-shore and offshore, more than steel or timber materials. The wide structural application of concrete that is exposed to seawater needs special attention. Marine environment causes physical and chemical deterioration processes of concrete structures, thus, there is no doubt that durability of concrete takes an important role in concrete performance. The durability of concrete is defined as long service life of concrete (Mehta and Monteiro, 1993), therefore the early-age concrete performance will determine its long service life performance. The deterioration of structural concrete may give some economic consequences that should be paid for. According Gerwick (1994), the cost of maintenance and repair, including provision of access on operating structures, plus the cost of interruption to service during repairs, are more serious than commonly appreciated.

According to Mehta and Monteiro (1993), generally the chemical composition of seawater is uniform, about 3% of soluble salt and high ionic concentrations that are represented by Na^{+} and Cl^{-}, typically 11,000 and 20,000 mg/liter. There are also sufficient amounts of Mg^{2+} and SO_4^{2-} present, about 1400 and 2700 mg/liter, which generate aggressive action to cement hydration products. The deterioration of concrete caused by the presence of sulfate ionic will make expansion and loss of concrete mass, beside the crystallization of natrium chloride that causes concrete cracks and steel corrosion. Mehta (1991) said that temperature of seawater varies from -2^{o}C to 30^{o}C in tropical area. The deeper seawater surface, the lower temperature of seawater, even reaches 2^{o}-5^{o}C at 100-1000 m depth. It should be noted that there is chemical reaction increasing, twice for every 10^{o}C temperature increasing (Mehta, 1991).

Many researches have conducted, even there were two 150-200 years old reports (Mehta, 1991), on topics of the durability of concrete structures to seawater. One early research was a study of cement and concrete on the Passamaquoddy Tidal Power Project 9, in Maine, USA, on 1935 (Casey, 1937), was one that considered the durability of concrete to freezing and thawing. Mehta and Haynes, in 1905, exposed some unreinforced concrete blocks in seawater at San Pedro harbor for 67 years that were examined in 1972 (Mehta, 1991). According to Mehta (1991), a survey of 20-50 years old of four hundred coastal structures conducted in Denmark by Idorn, was followed by a survey of Norwegian seaboard over seven hundred concrete structures by Gjørv during 1962-1964. There was an inspection of coastal marine structures in the Gulf area in period 1974-1986 by Normand, and also an investigation of 60 years old pier by Gjørv and Kashino in 1986 (Mehta, 1991). Recently, a study of microstructure and interface in concrete was conducted to investigate the concrete durability after 15 years of exposure in tidal environment (Mohammed, et. al, 2002). According to Mehta (2001), it is clear enough that to build environmentally sustainable concrete structures, instead of strength, the 21st century concrete practice must be driven by consideration of durability.

Learning about the performance of early-age concrete is to study performance of concrete as well as concrete maturity, which is a key of concrete durability. The performance of early-age concrete is represented by compressive strength of concrete. Mehta and Monteiro noted that water-cement ratio (w/c) becomes an important factor in determining the strength of concrete because it affects the porosity of cement paste and the performance of transition zone between the matrix and the coarse aggregate. It can be said that at a certain degree of cement hydration, the higher water-cement ratio, the lower compressive strength will be. Another important factor is maturity, referred as "Maturity Concept", which attempts to predict the development of concrete properties as a function of time and temperature of curing (Pinto and Hover, 1999). It can be said that maturity becomes an excellent indicator of in-place strength development and quality from fresh to hardened concrete (Kehl, et. al, 1998). Since maturity approach implemented to classical maturity function (Mehta and Monteiro, 1993), there are many development in theoretical (Shetty, 1982; Chen, et. al, 1996) and practical use (Kehl, et. al, 1998; Pinto and Hover, 1999).

Considering the durability and maturity approach mentioned above, it is important to know the performance of early-age concrete with seawater curing. Based on Banthia and Foy (1988), the steel fiber composite specimen that is cured by seawater generally showed higher initial (less than 28 days) pull-out strengths and energies because of the existence of calcium chloride in seawater. The calcium chloride is well known as an accelerator (Mehta and Monteiro, 1993) that will promote early high strength of concrete (Banthia and Foy, 1988). It is a hypothesis for this research that the compressive strength of early-age concrete cured by seawater is higher than the one cured by plain water.

MATERIALS AND METHODS

This research was conducted by using two methods, these are experimental method and analytical method. The analytical calculation will verify the experimental result.

The experimental method inves-tigated the compressive strength of concrete cylinders, with 7 days and 14 days seawater curing and plain water curing. The concrete cylinders are 15 cm in diameter and 30 cm height. Concrete compressive strength design, f'_c, is 22.5 MPa, and varies with water-cement ratio: 0.4, 0.5, and 0.6. After 7 days and 14 days of curing, the concrete cylinders were tested by compressive testing machine.

The analytical method purpose is calculating the compressive strength by implementing "Maturity Concept" with Plowman constants. Plowman determined the initial temperature of -11°C and expressed by equation (Shetty, 1982):

$$M = \Sigma\left(time\ x\ temperature - \left(-11\right)\right) \quad (1)$$

The concrete compressive strength can be derived by equation (Shetty, 1982; Chen, et. al, 1996):

$$\frac{S_e}{S_{28}} = A + B\log\left[\frac{M}{1000}\right] \quad (2)$$

where S_e = compressive strength of concrete corresponding to maturity index, M (kg/cm^2); S_{28} = compressive strength of concrete at 28 days (kg/cm^2); A and B are Plowman constants (see **Table 2**); M = Maturity (°CH); with time and temperature recorded during the curing period.

Table 1

Strength after 28 days at 18°C-38°C (Maturity 19800°CH) (kg/cm^2)	Constant	
	A	B
less than 175	10	68
175 - 350	21	61
350 - 525	32	54
525 - 700	42	46.5

ISSN: 1410-5217
Accredited: 23a/DIKTI/Kep/2004

RESULTS AND DISSCUSSION

The experimental primary data (**Table 2**) were collected from concrete compressive test. The analytical calculation (**Table 3**) were implemented by deriving the Maturity from equation (1) and then calculating the compressive strength from equation (2), where the equation (1) was supported by primary data recording of time and temperature during the curing period. It should be noted that the unit of compressive strength of equation (2) is converted from kg/cm^2 to MPa.

Table 2

Specimen Code	w/c	compressive strength f'_c (MPa)				average compressive strength f'_c (MPa)			
		curing				curing			
		plain water		seawater		plain water		seawater	
		7-d	14-d	7-d	14-d	7-d	14-d	7-d	14-d
A-1	0.4	20.94	26.60	22.64	27.73				
B-1	0.4	22.07	26.60	22.64	27.16	21.69	26.79	22.26	27.73
C-1	0.4	22.07	27.16	21.50	28.29				
A-2	0.5	16.98	21.50	18.11	24.33				
B-2	0.5	16.41	20.37	16.98	24.90	16.98	21.31	17.92	24.18
C-2	0.5	17.54	22.07	18.67	23.20				
A-3	0.6	14.15	20.94	15.28	20.94				
B-3	0.6	15.84	18.67	14.71	33.64	14.90	19.81	15.46	21.32
C-3	0.6	14.71	19.81	16.41	20.37				

Table 3

Specimen Code	w/c	compressive strength f'c (MPa)							
		plain water curing				seawater curing			
		M (^{o}CH)	7 days	M (^{o}CH)	14 days	M (^{o}CH)	7 days	M (^{o}CH)	14 days
SA	0.4	6600.5	15.973	13212.5	20.110	6610	15.982	13260.5	20.132
SB	0.5	6537	15.916	13059.5	20.041	6605.5	15.978	13175.5	20.094
SC	0.6	6516	15.897	13021.0	20.023	6537	15.916	13164.0	20.088

Generally, the experimental results (primary data of Dewi W and Wibowo, 2002) of this research showed that the compressive strength of 7 days and 14 days concrete specimens with seawater curing are higher than those cured by plain-water. The values are in range about 2.56-5.25% for 7 days old specimens and 3.39-11.87% for 14 days old specimens. The result showed that the lower water-cement ratio, the higher concrete compressive strength would be. Thus, the water-cement ratio of 0.4 produced the highest concrete compressive strength. The most concrete specimens, especially all that were cured by seawater, showed that they had greater compressive strength (average values in range about 21.69-22.26) than the design compressive strength (22.5 MPa). It happened because of the proper curing by maintaining the cement hydration process which was running well and then the hardening of concrete gave a good performance. The seawater curing also affected the chemical process of concrete hardening by the existence of calcium chloride and the higher temperature of seawater.

The temperature data recorded during curing period of 7 days and 14 days (primary data of Dewi W and Wibowo, 2002) showed that the temperature of seawater curing is higher than plain water curing. It has provided the higher value of Maturity to the specimens cured by seawater. Therefore, the verification implemented by analytical calculation (Dewi W and Wibowo, 2002) has given a higher compressive strength to specimens cured by seawater. The values are in range about 0.06-0.39% for 7 days old specimens and 0.11-0.33% for 14 days old specimens. The results of analytical calculation of compressive strength showed a little difference (about 1.06-16.9%) for specimens with water-cement ratio of 0.5 and 0.6 compared to experimental results, but there is a bigger difference (about 24.93-28.25%) for specimens with water-cement ratio of 0.4.

The comparisons of experimental and analytical results are shown by **Fig 1** (Dewi W and Wibowo, 2002). It shows that in one side, the higher strength compressive of concrete specimens with seawater curing is provided by the existence of calcium chloride in seawater that accelerate the hardening concrete process, as resulted in Banthia and Foy (1988) research. In the other side, as noted by Mehta (1991), the high temperature of seawater also gave contribution to the chemical reaction accelerated, thus the concrete being mature faster.

The analytical result of the "Maturity Concept" is optimum for specimens with water-cement ratio of 0.5 and 0.6, but in general, the analytical calculation is coming close to experimental result. It can be said that the "Maturity Concept" has proven a good performance in predicting the compressive strength of concrete very well verifying the experimental results.

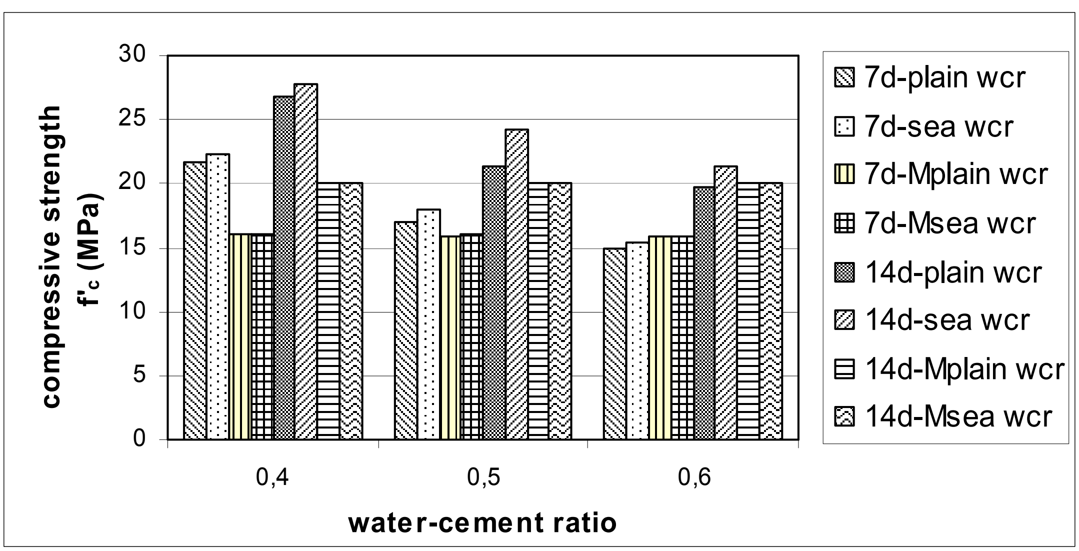

Fig. 1

CONCLUSION

The hypothesis of this research is proven, that both experimentally and analytically, the compressive strength of 7 days and 14 days old concrete specimens that are cured by seawater is higher those cured by plain water. Without neglecting the deterioration that happens in concrete structural elements in marine environment, we should take the benefits of seawater curing for accelerating the compressive strength of early-age concrete. The deterioration of concrete in marine environment, however, must always be paid attention by any efforts such as proper mix-design, admixture, and structural design, as well as modeling the material properties.

REFERENCES

Banthia, N, and Foy, C. 1988. "Marine Curing of Steel Fiber Composites", *J. Mat. Civil Eng.*, ASCE, 1:86-96.

Casey, HJ. 1937. "Cement and Concrete Studies on Passamaquoddy Tidal Power Project", Proceeding of American Concrete Institute, J. American Concrete Institute, Appendix E, January-February, 3:279-302.

Chen, HJ, Yen, T, and Chiu, JD. 1996. "Strength Development of High Performance Concrete at Early Ages", Proceeding of Fourth International Symposium on the Utilization of High Strength/High Performance Concrete, Paris, France, 2:719-724.

Dewi W, Kristina Retno, and Wibowo, Tri. 2002. "Analisa Pengaruh Perawatan dengan Air Laut dan Variasi f.a.s pada Kuat Tekan Beton Umur Muda terhadap Konsep Maturity", Tugas Akhir, Jurusan Teknik Sipil, Fakultas Teknik, Universitas Katolik Soegijapranata. (Indonesian)

Gerwick, BC. Jr. 1994. "The Economic aspect of Durability – How Much Added Expense Can Be Justified?", Proc. PK. Mehta Symposium on Durability of Concrete, Nice, France, May, pp.1-19.

Kehl, RJ, Constantino, RA, and Carrasquillo, R. 1998. "Math-Cure and Maturity: Taking Concrete Strength Testing to Higher Level", Project Summary Reports 1714S, Center of Transportation Research, The University of Texas, Austin, pp. 1-3.

Mehta, PK. 1991. Concrete in the Marine Environment, Elsevier Applied Science, London, New York.

Mehta, PK, and Burrows, RW. 2001. "Building the Durable Structures in 21st Century", *Indi. Concr. J*, pp. 437-443.

Mehta, PK, and Monteiro, PJM. 1993. Concrete - Structure, Properties, and Materials, Second Edition, Prentice Hall, New Jersey.

Mohammed, TU, Yamaji, T, and Hamada, H. 2002. "Microstructures and Interfaces in Concrete After 15 Years of Exposure in Tidal Environment", *ACI Mat. J*, 99: 352-360.

Pinto, RCA, and Hover, KC. 1999. "Application of Maturity Approach to Setting Times", *ACI Mat. J*, 96: 676-691.

Shetty, MS. 1982. Concrete Technology – Theory and Practice, S. Chand & Company, Ltd, New Delhi.