THE IMPLEMENTATION OF "MATURITY CONCEPT" TO EVALUATE THE EARLY-AGE CONCRETE PERFORMANCE AFTER 500°C HEATING

M. I. Retno Susilorini, Noni Rumania, and Nina Rumania
Email: susilorini@unika.ac.id
Department of Civil Engineering
Soegijapranata Catholic University
Jl. Pawiyatan Luhur IV/1, Bendan Dhuwur, Semarang 50234

ABSTRAK: Keawetan beton dipengaruhi oleh factor-faktor internal dan eksternal. Pada kasus tertentu, keawetan beton berhubungan dengan ketahanan terhadap panas dan semestinya memperlihatkan ketahanan yang baik terhadap lingkungan yang bersuhu tinggi. Tujuan dari penelitian ini adalah mengimplementasikan "*Maturity Concept*" dalam mengevaluasi kinerja beton umur muda, yang dinyatakan dengan kuat tekan, setelah pemanasan 500°C. Penelitian ini dilaksanakan dengan metode eksperimental dan analitis. Metode eksperimental bertujuan menyelidiki kuat tekan silinder beton berumur 7 hari dan 14 hari, tanpa dan dengan pemanasan 500°C. Benda uji beton memiliki variasi faktor air-semen 0.4, 0.5, dan 0.6. Setelah perawatan 7 hari dan 14 hari, benda uji dengan maupun tanpa pemanasan diuji kuat tekannya. Pada metode analitis, dilakukan perhitungan kuat tekan dengan mengimplementasikan "*Maturity Concept*" dengan konstanta Plowman. Perhitungan analitis didukung oleh data primer berupa rekaman waktu dan suhu selama masa perawatan. Perbedaan kuat tekan antara spesimen tanpa dan dengan pemanasan untuk faktor air-semen 0.4, 0.5, dan 0.6 adalah sebesar 4.763%, 15.556%, dan 48.719% (untuk spesimen berumur 7 hari); 11.113%, 26.494%, dan 57.210% (untuk spesimen berumur 14 hari). Secara fisik, benda uji yang dipanasi kerusakan dan retak-retak permukaan. "*Maturity Concept*" telah memperlihatkan hasil yang baik dengan perbedaan nilai kuat tekan yang relatif kecil (2.490%-2.984% untuk spesimen berumur 7 hari; 1.018%-1.539% untuk spesimen berumur 14 hari) antara hasil perhitungan analitis dan hasil uji eksperimental. Hasil perhitungan analitis menunjukkan bahwa nilai optimal kuat tekan dicapai oleh benda uji dengan faktor air-semen 0.5. Perlu diingat bahwa "*Maturity Concept*" perlu diterapkan secara hati-hati dalam mengevaluasi kuat tekan beton yang mengalami pemanasan suhu tinggi.

KATA KUNCI: *maturity*, beton umur muda, pemanasan, kuat tekan, faktor air-semen

ABSTRACT: Concrete durability affected by internal and external factors. In certain case, it also related to thermal resistance that concrete should have a good resistance to high temperature environment. The research purpose is to implement the "Maturity Concept" in evaluating the early-age concrete performance, represented by compressive strength value, after 500°C heating. This research conducted by experimental method and analytical method. The experimental method investigated the 7 days and 14 days old compressive strength of concrete cylinders, unheated and heated by 500°C temperature. Concrete specimens varies with water-cement ratio: 0.4, 0.5, and 0.6. After 7 days and 14 days curing, the concrete cylinders those were unheated and heated then tested to measure their compressive strength. The analytical method purpose is calculating the compressive strength by implementing "Maturity Concept" with Plowman constants. The analytical calculation was supported by primary data of time and temperature recorded during the curing period. The compressive strength difference between unheated and heated specimens for water-cement ratio 0.4, 0.5, and 0.6 are 4.763%, 15.556%, and 48.719% (for 7 days old specimens); 11.113%, 26.494%, and 57.210% (for 14 days old specimens). Physically, the heated specimens suffered damages and cracks over the surface of specimens. The "Maturity Concept" promotes good results with relative small difference of compressive strength value (2.490%-

2.984% for 7 days old specimens; 1.018%-1.539% for 14 days old specimens) of analytical result compared to experimental unheated result. The analytical result noted that the compressive strength of heated specimens with water-cement ratio 0.5 is the most optimum value. It must be paid attention, that "Maturity Concept" should be carefully applied in evaluating the compressive strength of concrete that is heated by high temperature.

KEYWORDS: maturity, early-age concrete, heating, compressive strength, water-cement ratio

INTRODUCTION

The long-term performance of concrete is determined by its early-age performance. It is known that the "young-immature" concrete performance such as workability, loss of slump, segregation, bleeding, plastic shrinkage, setting time, and curing temperature, takes an important role in building the concrete strength development and durability. Significantly, the concrete strength will decrease when it is heated in high temperature (beyond 300°C) that would not recover after the heating is stopped (Soemardi and Munaf, 1998). Thus, the evaluation of early-age concrete after high temperature heating is very important.

Evaluating the performance of early-age concrete is learning the performance of concrete as well as the maturity of concrete, which is a key of concrete durability. The compressive strength of concrete becomes an indicator to determine the performance of early-age concrete performance. It is noted by Mehta and Monteiro (1993) that the water-cement (w/c) ratio affects the porosity of cement paste matrix and the 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.

Concrete durability affected by internal and external factors. In certain case, it also related to thermal resistance that concrete should have a good resistance to high temperature environment. The high temperature influences the porosity and mineralogy of aggregates (Mehta and Monteiro, 1993). Basically, concrete cannot resist the heat beyond 250°C (Tjokrodimuljo, 2000). Shetty (1982) noted that the concrete strength degradation is not so significant up to 300°C of heating. The serious concrete strength degradation happens beyond 500°C of heating, as shown by Figure 1.

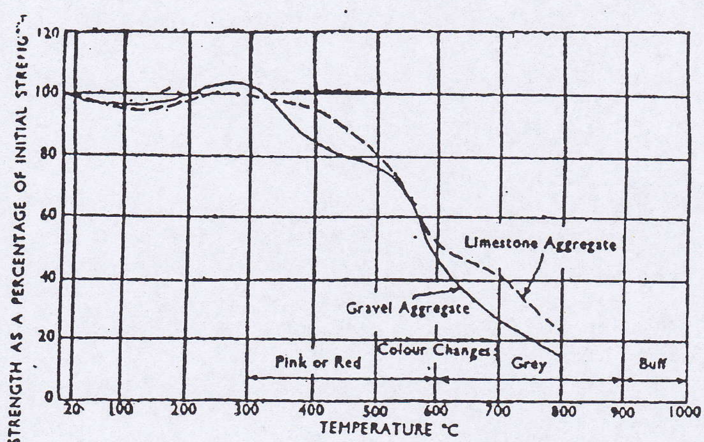

Figure 1. Compressive strength of concrete after high temperature of heating (Shetty, 1982)

The heat will change the chemical composition of concrete, generate crack and spalling, and finally reach the stage of concrete strength loosing. According to Sumardi (2000), when the concrete receives heat, the concrete surface temperature is greater than inside. The heat transferred from the concrete surface to the inside parts of concrete. After the heating process, the concrete becomes very porous. It causes the strength degradation of concrete. In case of very high temperature of heating, the decomposition reaction phenomenon of hydrate cement mass will emerged. The decomposition results calcium (CaO) and the concrete expansion that generates cracks. Usually, decomposition will happen at 400°C heating. Table 1 shows the chemical process during the concrete heating. The field observation also gives a view of physical change of concrete after high temperature of heating as described by Table 2.

Table 1. The chemical process during the concrete heating (Sumardi, 2000)

No.	Temperature	Process
1	100°C - 500°C	Water evaporates from the concrete pores
2	400°C - 600°C	Dehidration of Portlandite, $Ca(OH)_2$ change to CaO
3	600°C - 900°C	Decomposition of C-S-H (cement hydrat compound) to become its oxides
4	≥ 900°C	Decomposition of cement hydrat compound and minerals that will form a new ceramic chain

Table 2. The physical change of concrete after high temperature of heating (Soemardi and Munaf, 1998)

No.	Temperature	Physical Change
1	≤ 300°C	Water content reduction
2	300°C - 600°C	Concrete colour change to pink, strength decreases, and spalling emerges
3	600°C - 900°C	Concrete colour change to grey-whitish, strength decreases, concrete becomes weak and fragile
4	≥ 900°C	Concrete colour change to dark-vague, concrete becomes weak and fragile

However, "time" is not only an appropriate measurer to determine how "old" the concrete is. The cement hydration rate will also affects the development of concrete hardening that means the temperature, which influences the hydration, becomes another measurer in concrete strength development. Pinto and Hover (1999) experienced that the "setting" of concrete is a transition phase from liquid to solid form. After setting, concrete will get its strength which develops during the hardening period. It is clear that setting time of concrete takes an important role in determining time period of placement, consolidation, finishing, and casting-removal.

The existence of "Maturity Concept" in evaluating the concrete performance should be taken account. The "Maturity Concept" attempts to predict the development of concrete properties as a function of time and curing temperature (Pinto and Hover, 1999). It also becomes an excellent indicator of in-place strength development and quality from fresh to hardened concrete (Kehl, et al., 1998). It should be noted that maturity approach has implemented to classical maturity function (Mehta and Monteiro, 1993), with many development in theoretical (Shetty, 1982; Chen, et al., 1996) and practical use (Kehl, et al., 1998; Pinto and Hover, 1999). Shetty (1982) emphazised that the strength of concrete will be hardly influenced by the maturity of concrete as shown by Figure 2. The figure describes that the linear relationship between compressive strength and maturity.

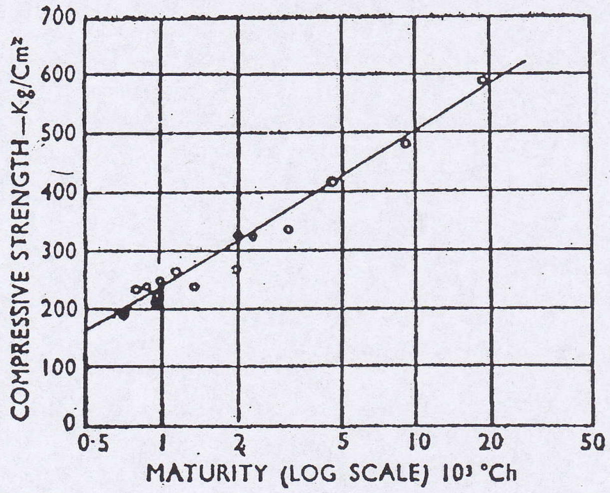

Figure 2. The linear relationship between compressive strength and maturity (Shetty, 1982)

According to the description mentioned above, this research conducted in purpose to implement the "Maturity Concept" in evaluating the early-age concrete performance, represented by compressive strength value, after 500° C heating.

METHODOLOGY

This research conducted by experimental method and analytical method. The analytical calculation will verify the experimental result.

The experimental method investigated the compressive strength of concrete cylinders; with 7 days and 14 days ordinary curing then half of the specimens were heated by 500°C temperature in huge burning stove of crematorium for around 60 minutes. 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 curing, the concrete cylinders those were unheated and heated then tested by compressive testing machine to measure their compressive strength.

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 1 (Shetty, 1982):

$$Maturity = M = \Sigma(time \times temperature - (-11)) \qquad (1)$$

The concrete compressive strength can be derived by equation 2 (Shetty, 1982; Chern, et. al, 1996):

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

where:
S_e = concrete compressive strength corresponding to maturity index, M (kg/cm^2)
S_{28} = concrete compressive strength at 28 days (kg/cm^2)
A and B = Plowman constants (see Table 3)
M = Maturity (°CH); with time and temperature recorded during the curing period

Table 3. Plowman constants (Shetty, 1982)

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

RESULTS AND DISSCUSSION

The experimental primary data (Table 4) recorded and analyzed from concrete compressive test. The analytical calculation (Table 5) implemented by derived the Maturity from equation (1) and then calculate the compressive strength from equation (2), where equation (1) was supported by primary data of time and temperature that was recorded every hour 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 4. Concrete compressive strength of experimental results (Rumania and Rumania, 2002)

Specimen code	w/c ratio	compressive strength f'c (MPa)				average compressive strength f'c (MPa)			
		unheated		heated 500°C		unheated		heated 500°C	
		7-d	14-d	7-d	14-d	7-d	14-d	7-d	14-d
A-1	0.4	24.899	29.992	22.635	24.899				
B-1	0.4	20.938	29.992	22.069	29.426	23.767	30.558	22.635	27.162
C-1	0.4	25.456	31.690	23.201	27.162				
A-2	0.5	15.845	22.069	15.845	11.884				
B-2	0.5	18.108	21.504	13.015	17.542	16.977	22.069	14.336	16.222
C-2	0.5	16.977	22.635	14.147	19.240				
A-3	0.6	15.845	18.108	5.659	11.844				
B-3	0.6	13.581	21.504	8.488	7.356	14.71	19.806	7.545	8.475
C-3	0.6	14.713	19.806	8.488	6.225				

The experimental results (Table 4) showed that compressive strength of unheated 7 days old specimens ranged by 13.581-25.456 MPa; 14 days old specimens ranged by 19.806-31.690 MPa. The compressive strength of heated 7 days old specimens ranged by 8.488-23.201 MPa; 14 days old specimens ranged by 6.225-29.426 MPa. The compressive strength increasing of concrete specimens proves that concrete specimens became "mature" during the time curing period. There was a strength reduction after the specimens were heated at 500°C. The compressive strength difference between unheated and heated specimens for w/c ratio 0.4, 0.5, and 0.6 are 4.763%, 15.556%, and 48.719% (for 7 days old specimens); 11.113%, 26.494%, and 57.210% (for 14 days old specimens). Physically, the heated specimens suffered damages and cracks over the surface of specimens. The concrete colour change to brownish (for w/c ratio 0.4), grey-brownish (for w/c ratio 0.5), and grey-whitish (for w/c ratio 0.6). However, a greater w/c ratio adds more water content that reduces the concrete strength because it more porous. During the heating process, the loss of water content in greater w/c ratio will be greater too.

The analytical results (Table 5) noted that there was significant compressive strength increasing because of the higher value of M (Maturity) caused by 500°C heating. It can be understood that this high temperature heating gave great contribution to Maturity value that is time and temperature dependent.

Table 5. Maturity and concrete compressive strength of analytical calculation (Rumania and Rumania, 2002)

Specimen Code	w/c ratio	Maturity M (°CH)				compressive strength f'c (MPa)			
		unheated		heated 500°C		unheated		heated 500°C	
		7 days	14 days	7 days	14 days	7 days	14 days	7 days	14 days
SA	0.4	6563.5	13056.5	7073.5	13721	15.940	20.040	16.386	20.336
SB	0.5	6516	13021	7073.5	13721	15.897	20.023	16.386	20.336
SC	0.6	6605.5	13254	7073.5	13721	15.978	20.129	16.386	20.336

In general, Figure 3 shows that the "Maturity Concept" promotes good results with relative small difference of compressive strength value (2.490%-2.984% for 7 days old specimens; 1.018%-1.539% for 14 days old specimens) of analytical result compared to experimental unheated result. It was also found a higher compressive strength of unheated specimen, analytically and experimentally, compared to heated specimen. The compressive strength of heated specimens with w/c ratio 0.5 is the most optimum value that analytically contributed by "Maturity Concept" has 20.230% higher value compared to unheated specimens. It must be paid attention, that "Maturity Concept" should be carefully applied in evaluating the compressive strength of concrete that is heated by high temperature.

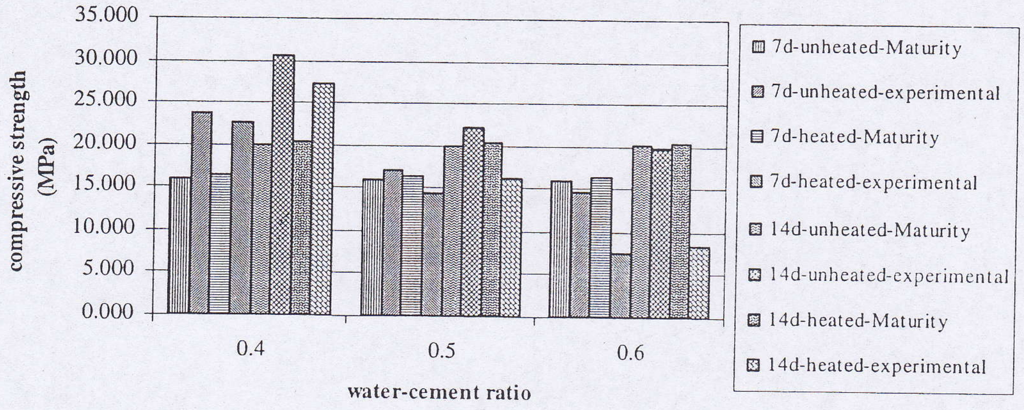

Figure 3. Comparison of experimental results and analytical calculation (Rumania and Rumania, 2002)

CONCLUSIONS

Some conclusions can be derived from the research:

1. The compressive strength increasing of concrete specimens proves that concrete specimens became "mature" during the time curing period.
2. After the specimens were heated at 500°C, the specimens suffered strength reduction. The compressive strength difference between unheated and heated specimens for w/c ratio 0.4, 0.5, and 0.6 are 4.763%, 15.556%, and 48.719% (for 7 days old specimens); 11.113%, 26.494%, and 57.210% (for 14 days old specimens).
3. From physical observation, the concrete colour change to brownish (for w/c ratio 0.4), grey-brownish (for w/c ratio 0.5), and grey-whitish (for w/c ratio 0.6).
4. It is found that during the heating process, the loss of water content in greater w/c ratio will be greater too that causes the reduction of compressive strength.
5. In general, the "Maturity Concept" promotes good results with relative small difference of compressive strength value (2.490%-2.984% for 7 days old specimens; 1.018%-1.539% for 14 days old specimens) of analytical result compared to experimental unheated result. The compressive strength of heated specimens with w/c ratio 0.5 is the most optimum value that

analytically contributed by "Maturity Concept" has 20.230% higher value compared to unheated specimens.

6. The "Maturity Concept" should be carefully applied in evaluating the compressive strength of concrete that is heated by high temperature.

REFERENCES

Chen, H. J., Yen, T., and Chiu, J. D. (1996). "Strength Development of High Performance Concrete at Early Ages", Proceeding of 4th International Symposium on the Utilization of High Strength/High Performance Concrete, Vol. 2, Paris, France, 719-724.

Kehl, R. J., Constantino, R. A., 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, 1-3.

Mehta, P. K., and Monteiro, P. J. M. (1993). "Concrete - Structure, Properties, and Materials", 2nd ed., Prentice Hall, New Jersey.

Pinto, R. C. A., and Hover, K. C. (1999). "Application of Maturity Approach to Setting Times", ACI Materials Journal, 96(6), Nov-Dec, 676-691.

Rumania, N. and Rumania, N. (2002). "Perbandingan Kekuatan Beton Umur Muda pada Uji eksperimental dan Analisa Konsep Maturity Pasca Pemanasan dengan Variasi f.a.s", Tugas Akhir, Jurusan Teknik Sipil, Fakultas Teknik, Universitas Katolik Soegijapranata.

Shetty, M. S. (1982). "Concrete Technology – Theory and Practice", S. Chand & Co., Ltd., New Delhi.

Soemardi, B. W., and Munaf, D. R. (1998). "Aplikasi Rekayasa Forensik dalam Struktur Bangunan", Seminar Paper, Fakultas Teknik Sipil dan Perencanaan, Universitas Islam Indonesia, Yogyakarta.

Sumardi, P. C. (2000). "Aspek Kimia Beton Pasca Bakar", Proceeding, Short Course,Teknologi Bahan Lokal dan Aplikasinya di Bidang Teknik Sipil, Pusat Antar Universitas Ilmu Teknik Universitas Gajah Mada, Yogyakarta.

Tjokrodimuljo, K. (2000). "Pengujian Mekanik Laboratorium Beton Pasca Bakar", Proceeding, Short Course, Evaluasi dan Penanganan Struktur Beton yang Rusak Akibat Kebakaran dan Gempa, Universitas Gajah Mada, Yogyakarta.