STUDIES ON THE EFFECT OF FLUCTUATING AND HOT WEATHER ON CONCRETE STRENGTH AND DURABILITY

Lazarus Lemi Chacha Costa [(1)], * Prof. Takeshi IYODA [(2)]
Graduate School of Engineering and Science, Shibaura Institute of Technology, 7-5, Toyosu 3 - chome, Koto Ward, Tokyo 135 - 8548
Department of Civil Engineering, Shibaura Institute of Technology, 7-5, Toyosu 3 - chome, Koto Ward, Tokyo 135 - 8548
***Corresponding author: me17109@shibaura-it.ac.jp**

ABSTRACT

Higher concrete temperature above 35°C leads to reduced 28-day strengths and durability deteriorations problems due to exothermic reactions, evaporation, frictions and condensation among many others. With addition of water to the concrete mix at higher temperatures to maintain or keep workability, the water cement ratio definitely will be increased, subsequently resulting to a loss of both potential strength and durability. Results from this study present how hardened properties of concrete are significantly affected by temperature fluctuations (rise of temperature in day time and drop at the nighttime). Several tests were conducted on; compressive strength and durability of different concrete mixes, using ordinary Portland cement (OPC), and blast furnace slag type B (BB), water cement ratio 50% (W/C) and the performance of concrete at temperature 20°C, 35°C and 45°C was investigated. The tendency of differences in Ignition loss of cement paste was observed at the early age but have almost similar results at 28 days. Nevertheless, the degree of hydration at temperature 45°C was extremely low causing significant low compressive strength compared to 20°C and 35°C. Electric resistivity technique is used to check the effect of fluctuating temperature on hydration process and transportation mechanism. The electrical resistivity results show great correlation with ignition loss. This shows that it is possible to measure the degree of hydration using electric resistivity. The analysis and results revealed a great effect of hot and fluctuating temperature on compressive strength and durability of concrete materials.

Keywords: *Temperature fluctuation, hydration process, compressive strength, durability designs, electrical resistivity.*

1. INTRODUCTION

Recently, the World has experienced the effect of global warming, in South Sudan temperature has reached 41°C and a record-breaking 41.1°C was recorded in the Kumagaya city, north-west of Tokyo in 2018, meanwhile according to Japan society of civil Engineers (JSCE). "The upper limit of concrete temperature at the time of placing is less than 35°C as a standard. When the temperature exceeds the limit, the quality of concrete shall be checked to satisfy the requirement" JSCE 2012. This means the specified maximum temperature for casting concrete is 35°C. However, within the past few years Japan as well as other countries have experience higher temperatures during summer seasons. And with the 2018 heat wave, the effect can be realized on human being, environment and the concrete materials used during the heat wave time. Few literatures seldom discuss about this trend of changes in weather, but the recent high temperatures, intense rains and droughts in line with global warming recount the necessities to study the effect of hot and fluctuating temperature on concrete properties. The phenomena of fluctuating temperature i.e. high temperature during the day and low temperature during the night was realize in different places round the world.

1.1 Mechanism of hydration reaction, concrete strength development and deterioration in concrete materials

1.1.1 Hydration reaction Mechanism

Rate of hydrations increase with rise in temperature according to:

$$\text{Arrhenius equation} = d(\ln k)/dT = A/RT^2 \qquad (1)$$

Where:
k is the specific reaction velocity, T is the absolute temperature, A is a constant usually referred to as the energy of activation, and R is the gas law constan*t, i.e.* R=8.314J/mol°C.

The active compounds in Portland cement, providing the strength and engineering characteristics to the concrete, consist mainly of calcium silicates compounds Tricalcium silicate and Dicalcium silicate and upon reaction with water, they produce C-S-H gel (amorphous in nature) and $Ca(OH)_2$ (CH), which is in a crystalline form.

$$(C_3S\ C_2S) + H \longrightarrow C\text{-}S\text{-}H + CH \qquad (2)$$

The rate of reaction of C_3S is higher than C_2S, and the C-S-H formed has an average C/S ratio of about 1.5, which are similar. Thus from the stoichiometric considerations, the hydration of C_3S produces more crystalline CH than C_2S. The C-S-H gel has a very high intrinsic surface area, which provides sites for strong physical interactions across the surfaces. Hence, the hydration products mechanism.

1.1.2 Deterioration mechanism in concrete

The ability of a structure or component to withstand the design environment over the design life, without undue loss of serviceability or need to major repair (ASTM, E623, 1996) and to understand the phenomena of the deteriorations in concrete structures it is necessary to understand the mechanism of concrete deteriorations. Deterioration usually involves the movement of liquids, gases, and ions through the concrete pore structure, hence the importance of transport properties.

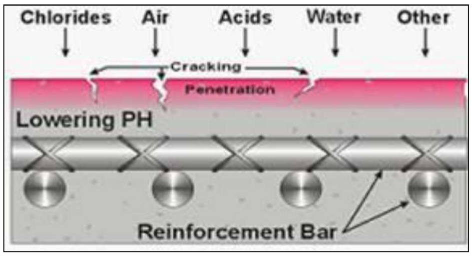

Fig.1. Deterioration mechanism in concrete surface of structure

Deterioration mechanisms can be divided into two broad categories: those caused mainly by physicomechanical effects and those caused mainly by chemical effects. In principles the deterioration of concrete depend on the environment factors where the concrete structure are built, under the water, above the ground. Therefore, in this research the transport behavior that leads to the deterioration of concrete materials were studied.

2. EXPERIMENT

2.1 Experimental Procedures

In this research, two experiments were carried out: The cement mortars experiment and concrete experiment of (OPC and BFS) to clarify the effect of rise and fluctuating temperature on cement and concrete materials. To simulate the hot and fluctuating weather two cases of casting and curing conditions were considered: In the first series, the specimens were cast at different temperatures (20°C, 35°C, and 45°C) sealed and maintained under the same different temperatures until tested at age of 3, 7, 28, 56 and 91 days. In the second series, specimens were cast sealed and maintained at different temperatures (20°C, 35°C, and 45°C) for 24 hours and then all the specimens were maintained at temperature 20°C until tested. These simulations is to check the effect resulting from drop of temperature after the casting day in real situations.

2.1.1 Materials

Table. 1. Experimental mix deign materials

Concrete Temp (°C)	W/C (%)	Air (%)	s/a (%)	Unit volume(Kg/m^3)				
				W	OPC	BFS	S	G
20	50	4.5	46	170	170	170	811	850
35								
45								

The cement mortar specimen used is a prism of sizes 4x4x16mm for compressive strength. Concrete specimens used were cylinders 100x200mmØ for compressive strength test at 3, 7, and 28, 56 and 91 days accordingly. 100x100x400mm specimens for carbonation and chloride ion penetration and embedded 4 electrical probes in 100x100x400mm specimen for electrical resistivity. To attain the specific different temperatures of the cement and concrete materials. All the materials were stored in different control temperatures (20°C, 35°C, and 45°C) respectively and 8°C was increase in the chamber of 35 and 45°C.

2.2 Electric resistivity in concrete test

Electric resistivity test is an important physiocoelectromechanical property that has effect concrete materials. This technique is used to check how greatly effect of temperature on hydration process. The readings of the resistivity were measured from the casting time. Table 2 and figure 2 show the details of the technique used in the electric resistivity test of concrete materials in this research:

Table. 2. Equipment used for electrical resistivity test

Measurement method	DC four electrode method
Applied voltage	10 V (Pulse wave)
Electrode props interval	50mm
The energize depth	50 mm
Electrode metal	stainless

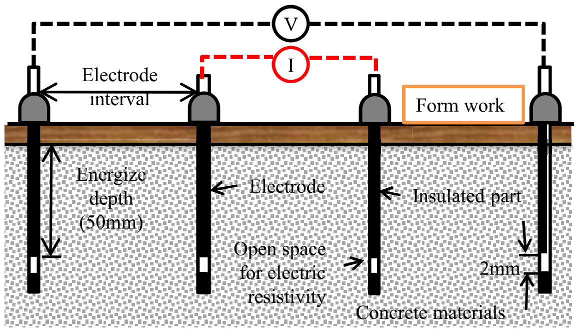

Fig. 2. Four probes electrical resistivity test of concrete

2.3 Ignition loss test

In the ignition loss test the specimens were stop from further hydration at the specified days using acetone and then put inside vacuum machine, then grinded and tested in electric muffle furnace at temperature 700°C. OPC and BFS 50% were used.

2.4 Compressive strength test

All the specimens were tested immediately after the specified day for compressive strength using the compressive machine. Compressive is one the most valued concrete specifications made by designers, practitioners, and contractors. In this research the tests method were carried out in accordance with Japan Industrial Standard (JIS A1108-2006). The specimens were tested immediately the specified ages.

2.5 Accelerated carbonation test

Carbonation is the reaction of carbon dioxide in the environment with the calcium hydroxide in the cement paste. This reaction produces calcium carbonate and lowers the pH to around 9. For the carbonation test the phenolphthalein was used. Calcium hydroxide ($Ca(OH)_2$, produced by the hydration reaction of cement changes to calcium carbonate ($CaCO_3$) by reacting with carbon dioxide in air. the carbonation tests specimens were put under accelerated chamber of 5% and the specimens were measured after 1,4,8 and 13 weeks.

2.6 Accelerated chloride ion penetration

Chloride iron can penetrate through concrete pore network, potential leading to the corrosion. Penetration test is another durability test used in this research. In this experiment prism bars were immersed in salt water of 10% NaCl after 28 curing days. The specimens were measured after 1, 4, 8 and 13 weeks.

3. RESULTS AND DISCUSSION

3.1 Electrical resistivity results

From the results in figure 3 and 4, regardless of the curing temperature conditions, concrete specimen cured at 45°C drastically increases from the early age to 28 days. There was no significant difference in electrical resistivity at 5 seconds of testing time in specimens exposed to fluctuating temperature shown in figure 4. From these results there are two main factors influencing the electrical resistivity, the moisture content in the specimen and the chemical reactions inside the specimen with temperature as factor.

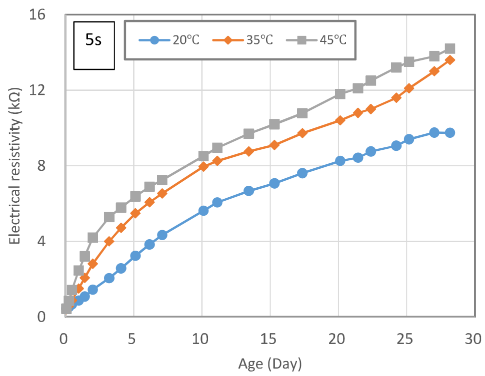

Fig. 3. Electric resistivity of concrete OPC: BFS 50% cast at and cured at constant temperatures 20, 35 and 45°C

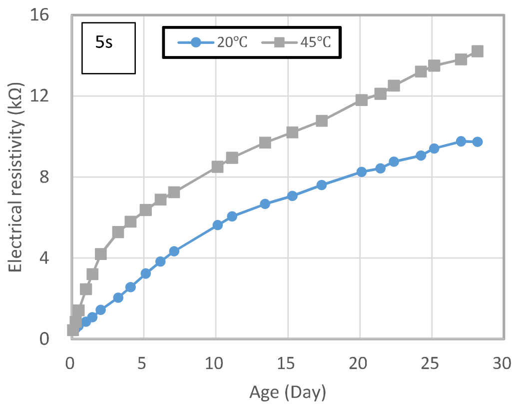

Fig. 4. Electric resistivity of concrete OPC: BFS 50% cast at different temperatures, maintained and after 24 hours cured at 20°C

3.2 Compressive strength results

3.2.1 Cement paste results

From the analysis of the data in figure 5, cement mortars cast at 35 and 45°C have higher compressive strength at 7 days but at 28 days have reduced. On the other hand cement mortar cast at 20°C has lower strength at the early age but gradually increases, this is due to undisturbed hydration reaction, while at higher temperatures due to high acceleration resulting from high curing temperature. This rapid hydration reactions at early age influence compressive strength reduction at 28 days. The results of cement mortar in figure 6 show no difference from the early age however, slide difference was noticed at 28 days.

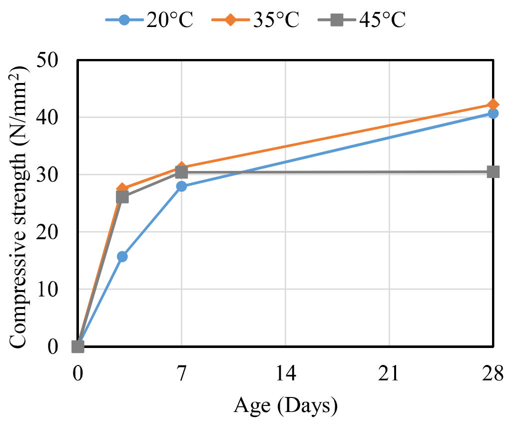

Fig. 5. Cement mortar OPC: BFS 50% cast and cured at different temperatures 20, 35 and 45°C

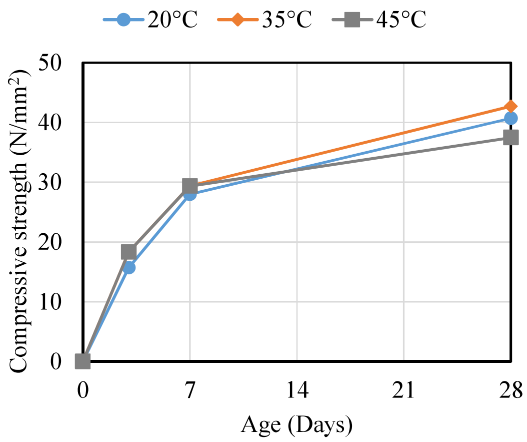

Fig. 6. Cement mortar OPC: BFS 50% cast at different temperatures, maintained and after 24 hours cured at 20°C

3.2.2 Concrete compressive strength

Results from figure 7 show 45°C concrete compressive strength was extremely low at 28days, unlike concretes cast at 20°C and 35°C. This is thought to be, during the hydration process the heat of hydration was faster in high temperatures and the chemical water at the intrinsic surface blocks or entrapped some hydration products leaving hydration process not to proceed to the other layer. This greatly affects the hydration process, subsequently reducing the hydration process which affects the compressive strength development of the materials. The results from the specimens cast at different temperatures, sealed and maintained for 24 hours then cured at 20°C have similar results from the early age 3 to 7 days, however the strength development is different from 28 to 91days as shown in figure 8.

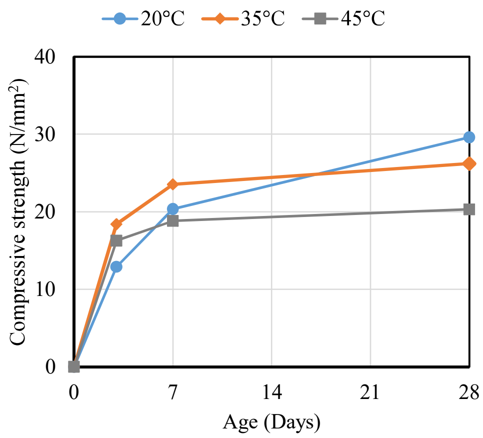

Fig. 7. Concrete of OPC: BFS 50% cast and cured at different temperatures 20, 35 and 45°C

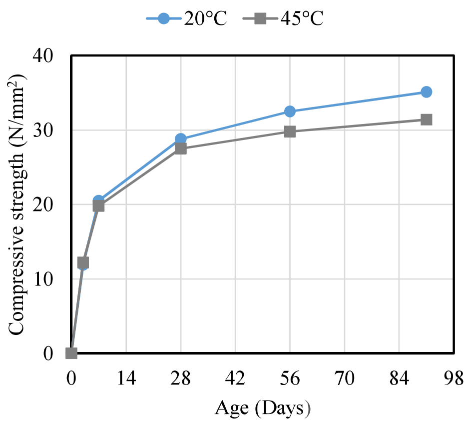

Fig. 8. Concrete of OPC: BFS 50% cast at different temperatures, maintained and after 24 hours cured at 20°C

3.3 Ignition loss and electrical resistivity correlations

The establishment of the ignition loss relation to electrical resistivity is proposed to monitor the hydration process from early age until 28 days, because hydration rate has great influences in the compressive strength development and durability. The result of the ignition loss shown in figure 9 is used, to correlate with results of electrical resistivity shown in figure 3. From figure 10, the ignition loss and the electrical resistivity shows close relation, these results is an indicator that, it possible to monitor the hydration process.

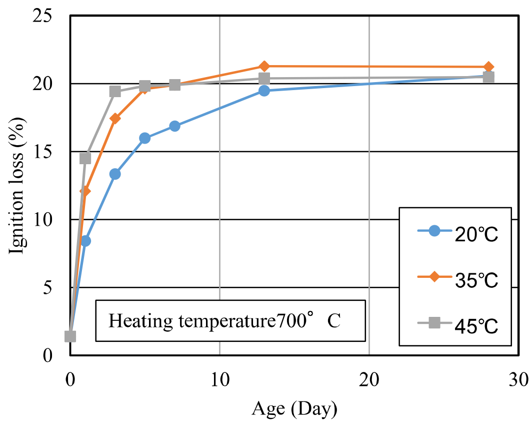

Fig. 9. Ignition loss of cement paste OPC: BFS 50% cast and cured at constant temperatures 20, 35 and 45°C

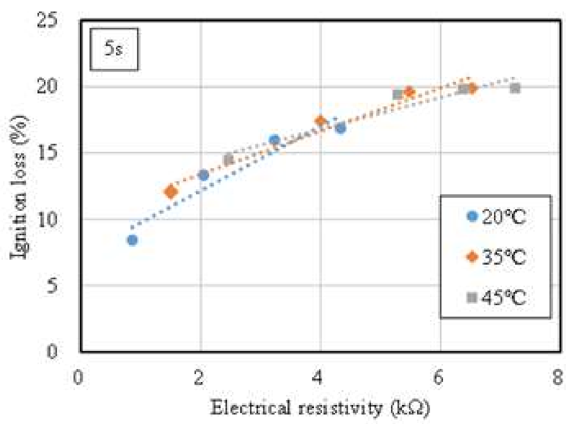

Fig. 10. Ignition loss and electrical resistivity of OPC: BFS 50% cast and cured at different temperatures 20, 35, and 45°C

3.4 Concrete durability results

3.4.1 Accelerated carbonation test

Figure 11 below shows the carbonation of the concrete specimen, when phenolphthalein was sprayed to fresh broken specimen; measured and then plot the results in the graph shown in figure 12. Figure 12 shows the results of experiments of OPC and BFS 50% cast, sealed and maintained at different temperatures (20°C, 35°C, and 45°C) have similar trend, however, concrete specimen of 45°C have slightly higher carbonation depth. Meanwhile concrete specimens cast at 20 and 35°C have almost the same results at 13 weeks after been immersed in accelerated NaCl water.

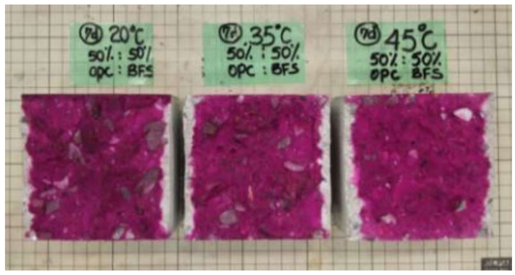

Fig. 11. Carbonation of concrete OPC: BFS 50% cast and cured at different temperatures 20, 35 and 45°C

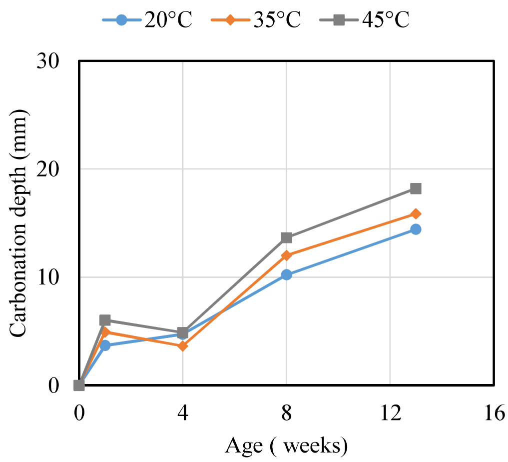

Fig. 12. Carbonation depth of concrete OPC: BFS 50% cast and cured at temperature 20, 35 and 45°C

3.1.5 Accelerated chloride ion penetration tests

Chloride ions can penetrate through the concrete pore network, potentially leading to the corrosion of steel reinforcement and subsequently deterioration of the structure.

Figure 13 shows the sample of the chloride ion penetration when silver nitrate was sprayed on fresh broken specimens. When the specimens were exposed to accelerated salt water till 13 weeks, the penetration of chloride ions into the specimens of concrete cast at 20°C was less than concretes cast at 35°C and 45°C as shown in figure 14. This is because the surface of the specimens cast at temperature 20 is more dense that the specimens 35 and 45°C. This explains that when considering the durability properties how concretes cast at different temperature is prone to chloride ion penetration.

Fig. 13. Chloride ion penetration of concrete OPC: BFS 50% cast and cured at different temperatures 20, 35 and 45°C

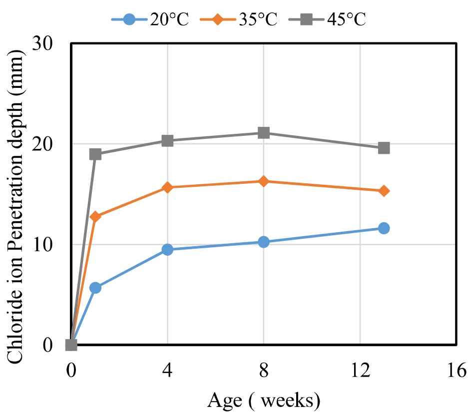

Fig. 14. Chloride ion penetration of concrete OPC: BFS 50% cast and cured at temperatures 20, 35 and 45°C

4. CONCLUSIONS

From this research the following are the conclusions:

1. Concrete cast at higher temperature of 35 and 45°C have high compressive strength at early age, however, low compressive strength at 28 due to the accelerated hydration.
2. Concrete cast at fluctuating weather, shows similar results at early age but different compressive strength at 91 days.
3. Electric resistivity technique use in the results can be used to check the hydration process in concrete materials. This can enhance more clarification in hydration process.

ACKNOWLEDGMENT

I appreciate the great contribution from co-author Prof. IYODA, Mr. Misaka PhD candidate, my Laboratory members, Shibaura Institute of Technology and JICA.

REFERENCES

Mark A, Arnon B and Sidney M., Durability of concrete, design and construction. Modern concrete Technology 20. Chapter 4, concrete deterioration, vol. 1, no. 5, pp. 66-68, 2018.

Soroka I., Concrete in hot environment. Modern concrete Technology 3. Chapter 2, setting and hardening, first edition, pp. 27-28, 1993.

PHOTOS AND INFORMATION

	**Lazarus Lemi Chacha Costa** received the B.Sc. “Honors” degree in Civil Engineering, College of Engineering and Architecture, University of Juba (2010), currently, a Masters candidate, in Department of Architecture and Civil Engineering. Shibaura Institute of Technology, his interests include: Cement hydration, concrete durability, concrete designs, concrete microstructure, and concrete structures.
	**Prof. Takeshi IYODA** received his B.E from Shibaura Institute of Technology, Master of Engineering, from Shibaura Institute of Technology, Doctor (Engineering) from the University of Tokyo. His research interest is in Construction Material, Concrete Engineering, Cement Chemistry, and Construction Material Design.