CARBONATION RATE OF CONCRETE IN DIFFERENT CLIMATE CONDITIONS - AFGHANISTAN, INDONESIA, MALAYSIA AND JAPAN -

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1. Introduction

Recently the concrete deterioration has become serious issue around the world and one of the main factor of deterioration is carbonation. Thus, proper design should be done in order to avoid concrete deterioration due to carbonation. Therefore, many researches have been done; and a lot of concrete carbonation models have been formulated by applying suitable modification using different parameters to Fick's second law of diffusion. However, typically, the carbonation models take the format of $Xc = A\sqrt{t}$; but some models overestimate the carbonation depth after certain period.

Moreover, it is well established that environmental conditions affect on the carbonation progress in concrete. Thus, this study was conducted to evaluate the effects of different environmental and climatic conditions on the carbonation rate of concrete, and prediction of carbonation rate of concrete using carbonation model.

2. Outline of Experiment

2.1 Materials and Mix Proportion

Concrete cubic specimens with dimensions of (75x75x75 mm) were fabricated for exposure test in four different regions with different climate conditions. Two types of concrete mixtures (OPC and FA) were prepared with 60% W/B. FA content was maintained at 20% of cement mass. The physical properties of material and mix proportion of concrete are shown in **Table 1** and **Table 2,** respectively. In order to maintain appropriate fresh properties, both air-entraining admixture; and air-entraining and water-reducing admixture were used based on the cement mass.

2.2 Curing condition

At 24hours after casting the specimens were cured until 28 days in air curing, control room with constant 20 ^{0}C temperature and 60% RH. After 28 days curing, 4 sides of the concrete prisms were coated by epoxy while two opposite sides were exposed to CO_2 diffusion and after 48hours waiting the specimens were moved to expsoure sites in Japan, Afghanistan, Indonesia and Malaysia. The expsorue test was conducted in Normal condition under sheltered and unshelterd exposure.

2.3 Method of evaluation

The carbonation test was conducted by splitting the cubes and applying phenolphytailine solution on fresh cut surface at the ages of 6 months and 12 months. However, in this paper, only 12 months data is presented and compared with prediction model results. In this study for carbonation prediction, a model developed by Papadakis (1992) [1] was used. However, this model overestimate after certain period of time especially in case of long term prediction and does not count the effect of initial curing. Thus, it was attempted to verify the model to predict the carbonation which well match with actual exposure test results.

Table 1: Physical properties of material

Material	Description
Cement	OPC Density = 3.16 g/cm^3, SSA = 3330cm^2/g
FA	Fly Ash Density = 2.26 g/cm^3, SSA = 3970 cm^2/g
Gravel	Crushed stone Density = 2.88 g/cm^3, MSA = 20 mm
Sand	Washed Sea sand Density = 2.53 g/cm^3, FM=2.69

Table 2: Mix proportion of concrete

Mix Type	W/B	s/a	Unite Content (kg/ m^3)				
			W	C	FA	Sand	Gravel
N-60	60%	45%	165	275	-	800	1114
FA-60			165	220	55	793	1103

Table 3: Compressive strength and elastic modulus of concrete

Results	N60		FA60	
	28 Days	91 Days	28 Days	91Days
Compressive strength (MPa)	22.0	26.4	19.4	21.2
Elastic modulus (GPa)	24.1	24.3	21.9	21.4

Table 4: Calculated coefficients based on exposure condition

Exposure area	Sheltered condition					X_c mm
	K_{con}	K_{RH}	K_{temp}	K_{cur}	K_{CO_2}	
Japan	310	0.24	0.97	0.76	0.0224	8.9
Afghanistan		0.25	0.97			9.2
Indonesia		0.16	1.02			6.2
Malaysia		0.19	1.01			7.3
Exposure area	Unsheltered condition					X_c mm
	K_{con}	K_{RH}	K_{temp}	K_{cur}	K_{CO_2}	
Japan	310	0.11	0.97	0.76	0.0224	4.1
Afghanistan		0.22	0.97			7.5
Indonesia		0.10	1.02			3.9
Malaysia		0.10	1.01			3.8

3. Results and Discussion

3.1 Strength development of concrete

The compressive strength and elastic modulus elasticity of concrete at the age of 28 days and 91 days are described in

Table 3. The FA60 specimens with 20% FA replacement show lower strength compared with OPC concrete.

3.2 Carbonation progress in Natural environment

Fig.1 illustrates the carbonation progress for concrete exposed at four different regions with different climate conditions, It was observed that climatic and environmental conditions has influenced the carbonation progress. The higher carbonation was observed in Afghanistan, However, the effect of "sheltered" and "unsheltered" condition was insignificant compared to other regions due to less annual precipitation and relatively dry condition. It was also observed that carbonation is significant in RH <50%; in case of Afghanistan annual average RH was recorded at the range of 45%. The average RH and temperature at Fukuoka was recorded 65-70%, 17 ^{0}C, respectively. While in case of Indonesia and Malaysia the annual average RH and temperature was (75-80%), (28-30^{0}C), respectively.

Moreover, In case of Japan, the carbonation progress was significant in sheltered condition than unsheltered condition compared to other two regions such as Indonesia and Malaysia. This could be due to the temperature effect. The carbonation is lower with high humidity and high temperature [2]. .

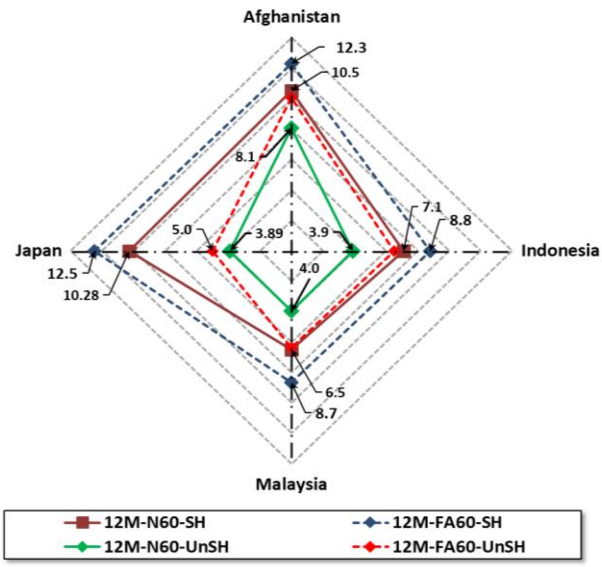

Fig .1 Carbonation depths in different countries (mm)

3.3 Carbonation Prediction model

For this study, the carbonation model developed by Papadakis [1] was used for carbonation prediction as shown in Eq.1. However, curing related coefficient was added to cover the initial curing effect on the carbonation rate of concrete.

$$x_c \approx 350\left(\frac{\rho_c}{\rho_w}\right)\frac{\left(\frac{w}{c}-0.3\right)}{1+\left(\frac{\rho_c}{\rho_w}\right)\cdot\frac{w}{c}}\cdot\sqrt{1+\frac{\rho_c}{\rho_w}\cdot\frac{w}{c}+\frac{\rho_c}{\rho_a}\cdot\frac{a}{c}}\cdot\left(1-\frac{RH}{100}\right)^n\cdot EXP\left(\frac{Q}{R}*\left(\frac{1}{273+T_0}-\frac{1}{273+T}\right)\right)\cdot\sqrt{CO2}\cdot\sqrt{t}---\mathrm{Eq.1}$$

In this equation, the curing factor was not included, while it is well known, initial curing significantly influences that carbonation rate. Thus, by adding curing factor the prediction model leads to close prediction with actual data.

$$Xc = K_{con}\cdot K_{RH}\cdot K_{cur}\cdot k_{temp}\cdot K_{CO2}\cdot\sqrt{t}\;-----\mathrm{Eq.2}$$

K_{con}: the quality related coefficient, K_{cur}**:** the curing related coefficient, K_t**:** temperature related coefficient "T_0: 25 ^{0}C", K_{RH}**:** the relative humidity related coefficient and K_{CO2}: the square root of CO_2 content. **Table 4** represents the calculated coefficients for each exposure area based on climate condition.

Fig.2 describes the carbonation prediction vs. actual measurement for natural exposure. Which shows that the model prediction well match the actual data. The model was evaluated in terms of humidity, temperature and curing parameters for OPC concrete. The humidity and initial curing significantly influence the carbonation rate of concrete.

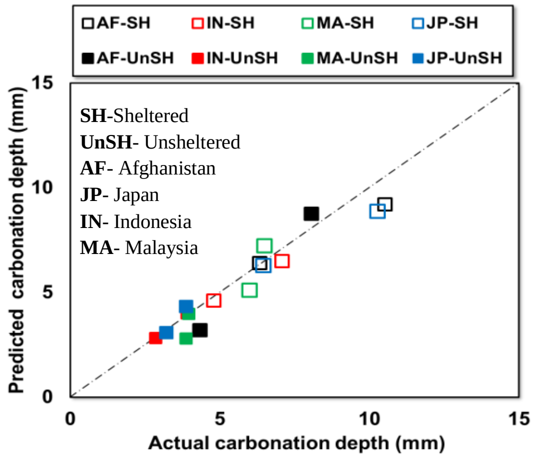

Fig .2 Carbonation prediction vs. actual measurement.

4. Conclusion

From the above description, it can be concluded that climate and environmental condition significantly influence the carbonation rate of both OPC and FA concrete. The carbonation was higher in sheltered condition compared to those of unsheltered condition. However, in case of Afghanistan, the carbonation was higher for both sheltered and unsheltered condition due to low annual precipitation and relatively dry condition. Further, it was found that 20% FA was not effective to provide resistance against carbonation. It was also observed that carbonation prediction based on concrete composition, environmental and curing conditions was very effective which provide close estimation to actual carbonation depths.

Acknowledgement

The authors would like to thank the Hasanuddin University, Indonesia and Universiti Tun Hussein Onn Malaysia (UTHM) for assistance in conducting exposure test.

References

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