

ANALYTICAL COMPARISON OF CONCRETE CARBONATION IN ZAMBIA AND JAPAN

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1. Introduction

Carbonation-induced corrosion has started to attract attention in the 21st century due to the increase in global temperatures and CO₂ concentration in the atmosphere [1] and it has become one of the critical problems that affect the durability of RC structures [2] most especially in areas away from the coast. With the increase in the number/age of RC structures and unsustainable maintenance practices, a huge maintenance need is expected globally. In this study, carbonation rates were compared between Zambia and Japan.

2. Methodology and Analysis

To estimate carbonation rates, ordinary Portland cement type CEM 1 42.5R conforming to EN 197 standard, an initial curing period of 7 days [3][4] and a maximum nominal aggregate size of 20mm [4] from a literature survey on carbonation studies in reinforced concrete were used. The other values obtained from the literature survey on environmental conditions, quality of execution and concrete mix design are shown in Tables 1 and 2. Based on a new meta-model[5], Eqs. (1), (2) and (3) were used to estimate the carbonation coefficient.

$$A = \sqrt{\frac{2D_{co_2} [co_2]_{external}}{a}} \quad (1)$$

Where: A is carbonation coefficient (m/s^{1/2}), D_{co_2} is CO₂ diffusion coefficient (m²/s), $[co_2]_{external}$ is CO₂ concentration in the air (kg/m³) and a is amount of CO₂ required for complete carbonation (kg/m³).

The amount of CO₂ absorbed was obtained using equation 2, below,

$$a = 0.75 \times C \times C_{ao} \times \varphi_{clinker} \quad (2)$$

where: $\varphi_{clinker}$ is cement clinker content (for this study 97.5%), C is cement content (kg/m³), C_{ao} is amount of calcium oxide per weight of cement (for this study 64.4%)

In obtaining the diffusion coefficient, equation 3 below, which considers some other function influencing the carbonation process was used,

$$D_{co_2} = D_{co_2}^{28} \times f_1(T) \times f_2(HR) \times f_3\left(\frac{S+G}{C}\right) \times f_4\left(\Phi, \frac{W}{C}\right) \times f_5(t_c) \quad (3)$$

where: $D_{co_2}^{28}$ is diffusion coefficient (m²/s) in fresh concrete dependent on 28-day compressive strength, $f_1(T)$ is temperature function for ambient and inside concrete, $f_2(HR)$ is a function for different values of relative humidity, $f_3\left(\frac{S+G}{C}\right)$ is a function for the varying aggregate-cement ration, $f_4\left(\Phi, \frac{W}{C}\right)$ is a function of porosity of carbonated concrete and water-cement ratio (W/C), $f_5(t_c)$ is a function for the effect of initial curing on carbonation in concrete.

Table 1 Concrete mix design and quality of execution values

W/C	C (kg/m ³)	a (kg/m ³)	$D_{co_2}^{28}$ (m ² /s)	Φ (%)	S (kg/m ³)	G (kg/m ³)	$f_3\left(\frac{S+G}{C}\right)$	$f_4\left(\Phi, \frac{W}{C}\right)$	$f_5(t_c)$
0.45 [6]	411	151.90	5.77x10 ⁻⁹	12.27	735	1248	1.17	11.98	13.74
0.50 [6]	370	136.75	8.21x10 ⁻⁹	12.32	742	1207	1.18	11.59	15.60
0.55 [6]	336	124.18	1.10x10 ⁻⁸	12.33	746	1072	1.18	9.39	16.71
0.60 [4]	300	110.88	1.41x10 ⁻⁸	11.88	845	1120	1.21	8.74	17.44

Table 2 Environmental conditions values

Ref.	Country - City	$[co_2]_{external}$ (kg/m ³)	$f_1(T)$	$f_2(HR)$
[7]	Japan - Tokyo	6.82x10 ⁻⁴	0.75	0.03
	Zambia - Lusaka	6.69x10 ⁻⁴	1.63	0.04

3.Results

The results show that generally, the carbonation coefficient is directly proportional to the increase in water-cement ratio and that in Zambia it is almost twice that in Japan as shown in Fig.1. This was expected due to higher temperature and lower relative humidity in Zambia. It therefore entails that, when a 5cm cover depth of the same concrete mix design is subjected to these two environments, corrosion initiation of steel bars would be more than 3 times earlier in Zambia compared to Japan as shown in Fig.2.

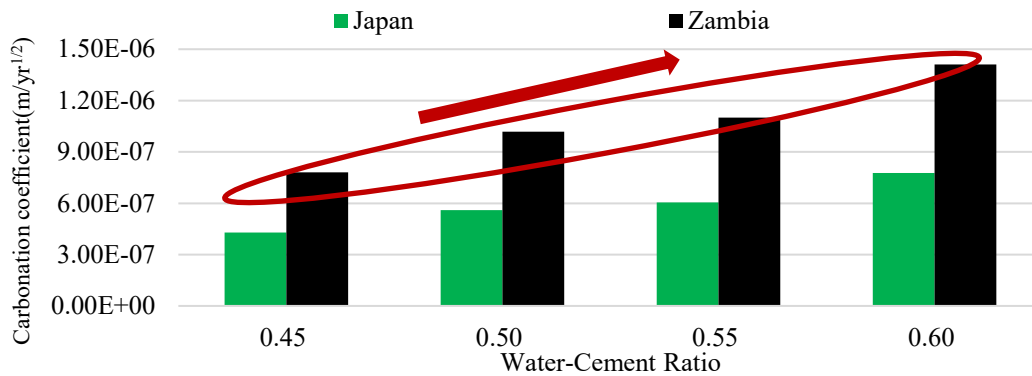


Fig.1 Carbonation coefficient variation

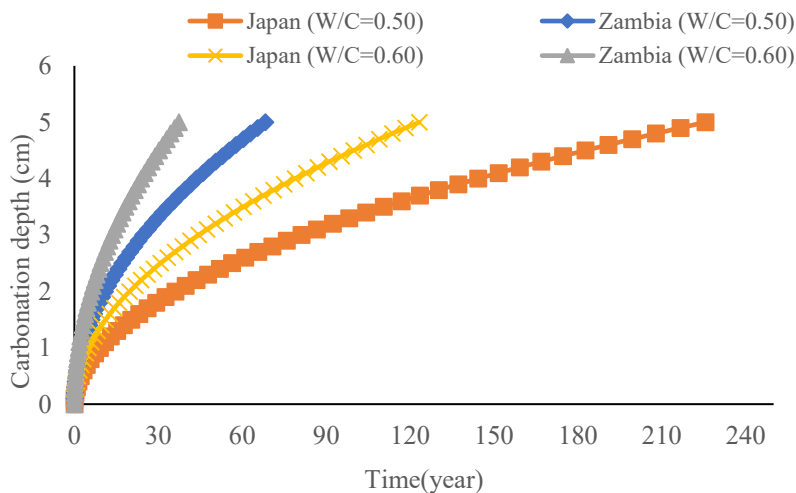


Fig.2 Variation of carbonation depth with time

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