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The Effect of Changes in Carbon-dioxide Concentrations on Corrosion Initiation of Reinforced Concrete Structures

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ABSTRACT: Carbon dioxide and carbonation in concrete structures after several years may leads to corrosion of the reinforcements, and consequently reduces the life of concrete structures. According to reports of Intergovernmental Panel on Climate Change (IPCC), uncertainty to predict the weather conditions is very high. The annual growth rate of carbon dioxide concentrations from 1.4 ppm during the period of 1960 to 2005 has increased to 1.9 ppm during the period of 1995 to 2005. Two predictions of A1F1 and A1B are presented for changes in carbon dioxide concentrations. In A1F1 high economic growth, population growth will continue in the mid-21st century with high speed, and the use of fossil fuels will also continue as before. In A1B, using clean energies is common. In fact, A1F1 and A1B are respectively pessimistic and optimistic predictions for the concentration of carbon dioxide in the environment. According the analysis results base on Monte Carlo simulation, global warming and climate change lead to an increase in average temperature of earth and atmospheric carbon dioxide concentrations, and finally, it can reduce the durability of concrete structures. Also, it was observed that ignoring changes in concentration of carbon dioxide can have a significant effect on the results obtained for carbonation depth. It was also observed that considering each of predictions for changes in carbon dioxide concentrations does not substantially influence the depth of carbonation.

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1- Introduction

Penetration of carbon dioxide and carbonation in concrete structures after several years may leads to corrosion of the reinforcements, and consequently reduces the life of concrete structures [1]. In general, factors affecting the carbonation, and in other words, durability of concrete structures can be divided into three major groups of external factors or environmental conditions, internal factors or concrete structure, and administrative and operating conditions [2]. One of the most important environmental factors is the carbon dioxide concentrations in the environment and ambient temperature [3]. Empirical evidence suggests that penetration of carbon dioxide is deeply under the influence of environmental factors such as the concentrations of the carbon dioxide in the atmosphere [4].

According to reports of IPCC, uncertainty to predict the weather conditions is very high. The annual growth rate of carbon dioxide concentrations from 1.4 ppm during the period of 1960 to 2005 has increased to 1.9 ppm during the period of 1995 to 2005 [5] (Figure 1). Studies estimate that carbon dioxide concentrations in the atmosphere could increase from 379 ppm in 2005 to 1000 ppm in 2100 [5]. In addition to changes in carbon dioxide concentration, changes in ambient temperature and relative humidity can cause corrosion to start and expand, and eventually cause structural failures and reliability reduction [6]. Reinforcement corrosion is one of the main reasons for the reduction in capacity and failure of concrete structures. Effective cross-sectional area decreases by corrosion of the reinforcement; in addition to this increase, the volume of impurities generated during the process of corrosion, creates cracks in the concrete structure [7]. Since the beginning of this corrosion, the effective cross-section reduction and generation of cracks is begun and will continue until complete failure of structures. So, to calculate the life of the structure, it is necessary to predict the onset of corrosion. Considering the carbon dioxide concentration to be constant does not seem very accurate to calculate the onset of corrosion. Moreover, no detailed study has taken place to compare the two modes (constant and variable consideration of concentration) [8]. In addition to concentrations of carbon dioxide, the Earth's temperature will increase due to climate change which can influence the durability of concrete structures [9]. Accordingly, this paper aims to examine the effect of changes in carbon dioxide concentrations and also global mean temperature on the possibility of corrosion onset, and to compare the methods in which the changes in the carbon dioxide concentrations are considered in the calculation of the probability of corrosion onset with the mode in which the concentration is considered constant.

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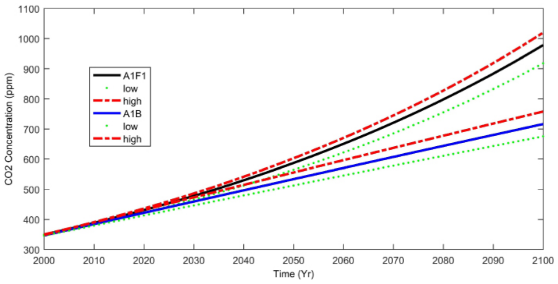

Figure 1: CO_2 concentration for various global warming scenarios

2- Results and Discussion

Carbonation depth (X_c in cm) can be calculated from formulas 1 to 3 [6, 7 and 9].

$$X_C(t)=\sqrt{\frac{2D_{CO_2}(t)}{a}k.C_{CO_2}.t.(\frac{t_0}{t})^{n_m}} \quad (1)$$

$$X_C(t)=\sqrt{\frac{2D_{CO_2}(t)}{a}C_{CO_2}(t)\ .t(\frac{t_0}{t})^{n_m}} \quad (2)$$

$$X_C(t)=\sqrt{\frac{2f(t)D_{CO_2}(t)}{a}k\int_0^t C_{CO_2}(t)dt\ (\frac{1}{t})^{n_m}} \quad (3)$$

In the formula above, C_{CO2} is the concentration of carbon dioxide in the environment, and its unit is kg/m^3 multiplied by 10^{-3}. K is a factor for considering the non-uniform effect of carbon dioxide concentration in different environments [6]. nm is the age factor of concrete which is considered for changes in ambient temperature in the above model [7].$D_{CO_2}(t)$ is the time-dependent diffusion coefficient of carbon dioxide in concrete [10]. In Formula 3, f (t) is a function to consider the effect of temperature changes on the carbonation which is obtained using the Arrhenius law. It should be noted that rising temperatures will lead to increased penetration rate and have effects on the depth of carbonation [11].

Difference of Equations 1, 2 and 3 are in the way they consider the depth of carbonation calculation of carbon dioxide concentration. It is known that considering the concentration of carbon dioxide during a specified period, equal to the concentration of the last year of the mentioned period, due to the increasing concentration over time, the results will be presented more than the amount which will happen for depth of carbonation. Two predictions of A1F1 and A1B are presented for changes in carbon dioxide concentrations (Figure 1). In A1F1 high economic growth, population growth will continue in the mid-21st century with high speed, and the use of fossil fuels will also continue as before. In A1B, using clean energies is common [12]. In fact, A1F1 and A1B are respectively pessimistic and optimistic predictions for the concentration of carbon dioxide in the environment.

3- Conclusions

In this paper, the results obtained were initially compared using the proposed two methods to calculate the depth of carbonation with regard to changes in carbon dioxide concentrations. It was found that the method proposed by Stewart et al. is more accurate than other existing methods. Then, the results obtained with regard to concentration changes, were compared with the results used to calculate the carbonation depth of the constant concentration; and it was observed that ignoring changes in concentration of carbon dioxide can have a significant effect on the results obtained for carbonation depth. It was also observed that considering each of predictions for changes in carbon dioxide concentrations does not substantially influence the depth of carbonation.

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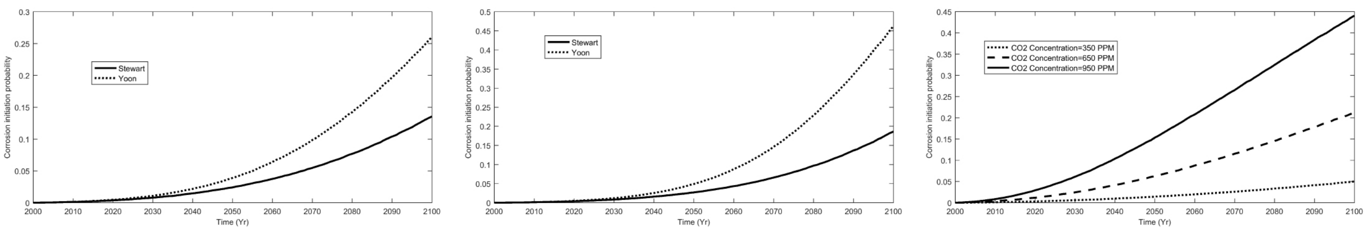

a) Yoon and Stewart method (A1B) b) Yoon and Stewart method (A1F1) c) Assuming constant concentration

Figure 2: Probability of corrosion initiation in duration 100 year

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