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The Impact of Climate Change and Carbonation on the Durability of Concrete Structures in Afghanistan

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ABSTRACT

Infrastructure plays an important role in human settlements, offering essential facilities such as buildings, transportation and other necessary systems. However, the impacts of climate change, whether direct or indirect, create various challenges for human settlements and ecosystems. This study investigates the dual impact of climate change and carbonation on the durability of concrete structures in Afghanistan. The durability of reinforced concrete is significantly affected by the corrosion of steel reinforcement, and carbonation is the main factor causing corrosion of steel bars in concrete. With shifting climate patterns influencing environmental conditions, this study aims to analyze how these changes contribute to the carbonation process in concrete and the results will contribute to a deeper understanding of the challenges posed by climate-driven changes and carbonation, thereby providing the basis for necessary measures to minimize the environmental impacts. To facilitate this investigation, (75x75x75mm) concrete cubes were prepared and after 28 days of curing in laboratory conditions, the specimens were exposed in four different regions: Afghanistan, Japan, Indonesia and Malaysia. The carbonation depths were measured at the ages of 6 months and one year. Considering the environmental and climatic conditions of all mentioned regions, despite Kabul's lower humidity and temperature, the carbonation was still significant compared to the other regions. This substantial carbonation poses a threat to structures, emphasizing the need for special attention in the design phase to ensure resilience against climate-induced challenges.

Keywords: Climate change, Carbonation, Durability, Environmental factors

INTRODUCTION

Infrastructure plays an important role in human settlement by facilitating the population by providing facilities such as structures, transportation and other necessary systems (Mark G. Stewart, Wang, & Nguyen, 2011), but on the other hand, the climate change directly or indirectly affects the human settlement and ecosystem in different ways (Stewart et al., 2011). The environmental actions are affecting the durability, serviceability, and safety of the structures. Among these actions, the carbonation induces the corrosion of steel bars in concrete and reduce the longevity of the RC structures. The experiments indicate that the carbonation is highly affected by the environmental and climatic conditions of the surrounding environment. As per the International Panel of Climate Change (IPCC), by the year 2100, the CO_2 concentration could increase to nearly 1000 ppm (IPCC, 2007). As per the reports published by the Earth System Research Laboratory Global Monitoring Division, the CO_2 concentration has increased from 403 ppm in April 2014 to 407 ppm in April 2015 (ESRL, 2016). Usually, the concentration of CO_2in a typical urban environment compared to rural environment is approximately 5 to 10% higher. The concentration of CO_2 in urban areas are widely influenced by the fuel consumptions by cars, local heating, power generation and etc (M G Stewart, Teply, & Kralova, 2002).

Kabul city which was famouse for its clear environment and optimal climate in 1980s has now become the most polluted capitals (Popal, 2017), due to the increased population from 300000 in 1977 to roughly 6 million today suffer from poor air quality (Torabi, Amin, Phairuang, Hata, & Furuuchi, 2023). Population is a major factor of CO_2 emission; the increase in population will lead to increase in CO_2 due to demand for usage of fossil fuels and natural gas (Yeh & Liao, 2017). According to a preliminary assessment of air quality in Kabul by Atiq Sediqi, the CO_2 air emission is calculated 1382323.09 ton/year (Sediqi, 2010). In this study the effects of carbonation on concrete structures have been studied in terms of environmental and climatic conditions of Kabul city.

MATERIALS AND METHODS

Materials

In this research, OPC was the binder, while fine aggregate consisted of crushed stone with a maximum size of 20mm and washed sea sand were used. The concrete mix utilized tap water as the mixing water. Table 1 outlines the mix proportion and fresh properties of concrete.

Table 1: Mix proportion and Fresh properties of the Concrete

Mix	W/C %	Unit Content (kg/m^3)						Slump (cm)	Air Content %	Temp °C
		Water	Cement	Gravel	Sand	WR	AE (ml)			
N-60	60	165	275	1114	800	1031	1586	5.5	4.9	22

Methods

In this study the concrete cubes of (75x75x75mm) with given mix design in Table 1 were prepared and after curing for 28 days in laboratory under standard temperature and relative humidity (20 0C, 60% RH). After 28 days of curing, 4 sides of the cubes were coated with epoxy and two parallel sides were kept un-coated for CO_2 diffusion. The cubes were then exposed in four different countries (Afghanistan, Japan, Indonesia, and Malaysia) having different climate conditions. At 6 months and 1 year of age, the carbonation depths were measured in the laboratory, the specimens were split and cleaned, and 1% of phenolphthalein 90% ethyl alcohol solution was applied to the freshly cut surface.

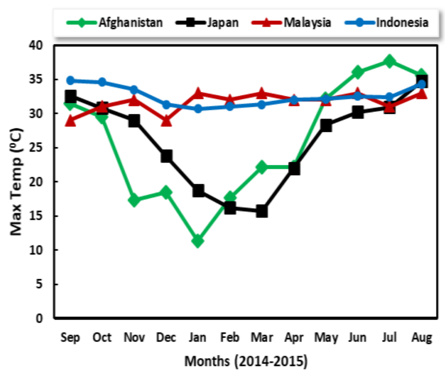

Figure 1: shows the max temperature

RESULTS

Climatic Conditions

Exposure tests in the natural environment were conducted in four different regions, such as Kabul (Afghanistan), Fukuoka (Japan), Makassar (Indonesia), and Batu Pahat (Malaysia). These regions exhibit diverse climates and environmental characteristics. Figures 1 and 2 describes the average relative humidity and maximum temperature data for mentioned regions, respectively. In the case of Afghanistan, hydrometer equipment was employed to collect the temperature and relative humidity data, while for the remaining three regions, the climatic data was sourced from online platforms (*Fukuoka, Japan*, n.d.).

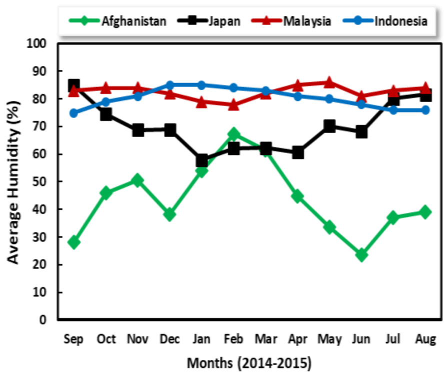

Figure 2: shows the average RH%

Carbonation Depth

Figure 3 shows the carbonation depth of the concrete specimens at the age of 6 months and 1 year. Where the specimens were cut in laboratory and the phenolphthalein solution was sprayed on the cut surface to determine the carbonated and non-carbonated sections. The carbonated concrete remains uncolored, while the non-carbonated sections change the color to purple. Figure 4 shows the visual observation of carbonation depth for concrete specimens exposed in four distinct regions.

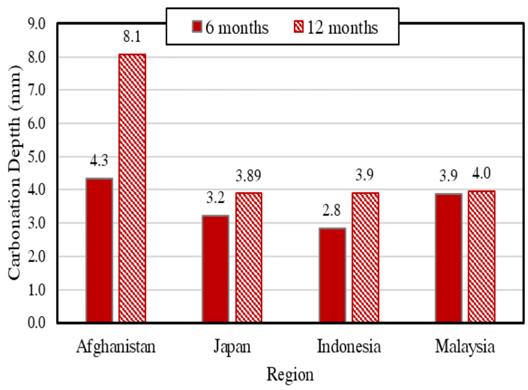

Figure 3. Shows the carbonation depth of concrete

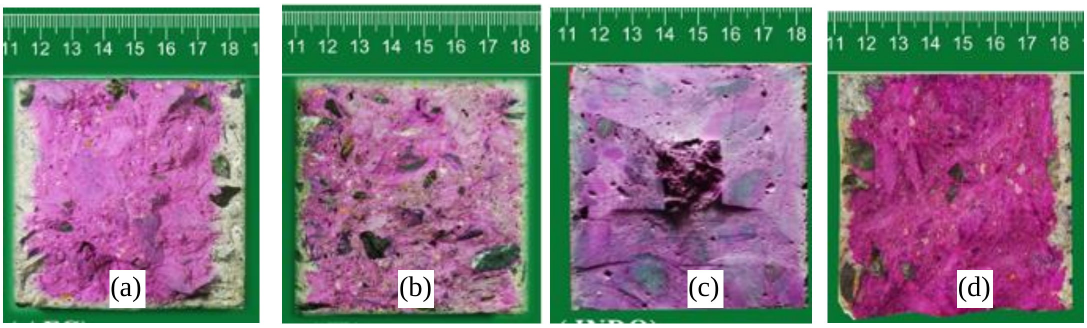

Figure 4: Graphical representation of carbonation depth of concrete for (a) Afghanistan, (b) Japan, (c) Indonesia, and (d) Malaysia specimens

DISCUSSION

Figure 3 depicts the carbonation depth of concrete exposed in four distinct regions having varying climate conditions. The observations indicate that climatic and environmental factors have had a noticeable impact on the carbonation progress. Afghanistan, in particular, exhibits higher levels of carbonation in comparison to other regions, primarily attributed to the lower annual rainfall in Afghanistan. Furthermore, it was found that carbonation progress was particularly significant at relative humidity below 50%. In the case of Afghanistan, the average annual RH was in the range of 45%. In Fukuoka (Japan) the average RH was recorded in the range of 65 to 70%, and the temperature was 17 °C. In contrast, Indonesia and Malaysia had higher average annual RH (75-80%) and temperatures ranging from 28 to 30°C. The carbonation rate was lower in Indonesia and Malaysia compared to Japan and this due to the presence of high humidity and average temperature. The high humidity and temperature exhibit lower carbonation.

Indonesia possesses high average annual temperature and relative humidity compared to Afghanistan and Japan. (Matsuzawa et al., 2010) has found that carbonation occurs more rapidly in warmer and sheltered environments; however, despite Indonesia's higher annual temperature compared to Afghanistan and Japan, it exhibits lower carbonation depth, a phenomenon attributed to higher relative humidity. Moreover, in high temperatures, concrete experiences increased carbonation unless relative humidity is lower. Likewise, in Malaysian environment, the substantial carbonation progress was found within the initial six months, linked to dry weather conditions from January to March, while the subsequent months, constituting the rainy season from March to February, the carbonation increment was less significant, particularly under high humidity conditions. This observation suggests that drying and wetting processes play a crucial role in influencing carbonation progress in different climate conditions.

CONCLUSION

Climate change significantly affects concrete durability, primarily through carbonation, leading to steel bar corrosion. Despite Kabul's lower humidity and temperature, substantial carbonation poses a threat to structures, emphasizing the need for special attention in the design phase to ensure resilience against climate-induced challenges.

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