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Effect of low air pressure on the durability of concrete

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HIGHLIGHTS

- Severe environment of high-elevation regions was simulated.
- Effect of low air pressure was shown to be more significant after 28 days.
- The number of pores (500–1000 nm) increased with a decrease in low air pressure.
- Morphological studies showed wider gap in ITZ under low air pressure.

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ABSTRACT

Severe environment in plateau regions plays a significant role in the mechanical property and durability of concrete. In this study, an environmental control system was designed to simulate the severe environment in plateau regions. Low air pressure as a new factor was examined to explore its effect on the properties of concrete. The effect of low air pressure ranging from 51 to 101 kPa on the compressive strength and durability of concrete with water/cement ratio of 0.46 was studied. It has been observed that low air pressure could reduce the compressive strength and the durability of concrete, including permeability, deicer salt scaling, water variation and water absorption, especially after 28 days. The mercury intrusion porosimetry (MIP) results exhibited that the total porosity and number of pores in the range of 500–1000 nm increased with a decrease in air pressure. A wider gap between aggregate and matrix under lower air pressure was observed in SEM (Scanning Electron Microscopy) analysis. The observed results of compressive strength, water absorption, deicer salt scaling and mass variation on air pressure were approximately linear.

1. Introduction

Concrete is the most widely used artificial material in the infrastructure constructions all over the world. Durability of concrete is considered to be one of the most important properties to evaluate the service and stability requirements throughout its working life [1,2].

The mechanical and durability properties of concrete such as compressive strength, water absorption, permeability, freeze-thawing have been intensively studied [3]. The hardened concrete is usually being employed in various and distinct environments such as in marine, saline, cold and plateau regions. In practice, different environments or climates could accelerate the deterioration of the durability of concrete structures [4]. On this context, understanding the effect of severe environment is a key factor in the optimization of the performance of concrete.

Different severe environments during concrete constructions have distinct features to affect the mechanical property and durability of concrete. In marine regions, concrete suffers from corrosion due to immersion in the sea for long time, and specially several factors affect the lifespan and serviceability of concrete that include chloride, sulfate, alkalinity and electrochemical action [5]. Permeability resistance is one of the most important property required for concrete to prevent the invasion of chloride and sulfate ions into concrete. In heavy saline regions, the pressure of saline crystallization due to wetting-drying cycles accelerate the deterioration of concrete. Appropriate water-binder ratio and supplementary materials should be paid attention in the selection except the case of routine protection [6]. The concrete in cold regions is mainly damaged by freeze-thaw actions, and an improvement in the pore structure by an air-entraining agent

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was considered as an effective method to improve the freeze-thaw and deicer salt scaling of concrete [7,8].

In 2011, investigations at several plateau regions in China indicated the more serious damage of concrete than in the plain regions as shown in Fig. 1. As one of the most typical climatic features in plateau regions, low air pressure intensified the destructive effect on concrete [9]. Many cities in the world are located in plateau regions, and the air pressure and elevation of some of the cities are shown in Table 1. Until now, the macroscopic characteristics of concrete under low air pressure are rarely studied through experiments. Therefore, it is necessary to understand the degree of impact of low air pressure on the mechanical property and durability of concrete in the plateau regions.

Generally, air pressure in plateau regions is lower compared to plain regions due to their high-elevation. As shown by Dalton's Law, low air pressure could accelerate the velocity of water evaporation from wet soil, wet mortar and wet concrete [10–13]. Under the conditions of low air pressure, the movement of water from inside to outside of the concrete is getting accelerated so that the inner water content of concrete is reduced.

In recent years few studies have been carried out about the effect of inner water content on the mechanical and durability properties of concrete. The observations from these studies concluded that an insufficient amount of water in concrete could decrease the anti-permeability [14] and strength [15–17], whereas it could increase the water absorption and carbonation depth [18] of concrete. The interfacial transition zone (ITZ) and pore structure were also deteriorated because of an insufficient amount of water content [19,20]. Several studies concerning the moisture migration in the inner parts of concrete were also widely examined by the technology of Finite Element Method and simulation models were established to predict the macro-performance [21–23]. Moreover, a few practical methods were carried out to improve the inner humidity of concrete, for instance, curing in water, painting waterproof coating, water-saturated ceramsite as aggregate, etc [24,25]. But, all of these studies as mentioned above were carried out under standard conditions of air pressure, and the degree of impact of low air pressure on the properties of concrete has rarely been discussed.

Based on this, in this study, an environmental control system has been developed to simulate severe environment existing in plateau regions, and also the effect of low air pressure on the mechanical property and durability of concrete was studied using the following tests of compressive strength, rapid chloride permeability, deicer salt scaling, water absorption and mass variation. In addition, MIP and SEM tests were employed to study the pore structure and morphology of concrete, respectively. Finally, the relationship between air pressure and some of the properties of concrete were analyzed and fitted based on the experimental data.

Table 1
Air pressure and elevation of some cities.

City	Elevation (m)	Air pressure (kPa)
El Alto in Bolivia	4150	54.5
Lhasa in China	3658	65.2
Shigatse in China	3840	58.7
Mexico City in Mexico	2240	78.6
La Rinconada in Peru	5100	43.7

Note that the data are from Wikipedia (https://en.wikipedia.org/wiki/List_of_highest_cities_in_the_world).

2. Experimental program

2.1. Materials and mix proportion

The physical and chemical properties of type I Ordinary Portland cement used in this study are presented in Table 2. River sand as a fine aggregate with a fineness modulus of 2.9 was used. Continuous grading stone as coarse aggregate with a maximum size of 20 mm was used. Polycarboxylate superplasticizer with a water reduction rate of 25–35% and a density of 1.07 ± 0.02 g/ml was used to improve the workability of concrete. The followed mix proportion is presented in Table 3.

2.2. Environmental control system

The environmental control system was designed to control temperature, relative humidity and air pressure in the test chamber to simulate the severe environment of plateau regions, and the schematic diagram of which is shown in Fig. 2. Cooling pipe, refrigeration equipment and heater were used for controlling the temperature in the test chamber, while humidifier and dehumidifier were used for adjusting the inside relative humidity. Moreover, a vacuum pump was used to pump the air out to establish a low-pressure environment in the test chamber. The chiller and heater were arranged in the internal surface of the test chamber, whereas the refrigeration equipment, humidifier, dehumidifier and vacuum pump were placed outside the test chamber connected with the pipes. Gasket and glass cover were used to cover the test chamber for sealing. Finally, the temperature, humidity and air pressure in the test chamber could be adjusted by the control panel. The cameras were used to clearly observe and record the changes occurring in the concrete.

Fig. 1. Concrete damage in low air pressure regions.