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Effect of controlled environmental conditions on mechanical, microstructural and durability properties of cement mortar

Alireza Joshaghani [a,*], Mohammad Balapour [b], Ali Akbar Ramezanianpour [c]

[a] *Zachry Department of Civil Engineering, Texas A&M University, College Station, TX, USA*
[b] *CAEE Department, Drexel University, Philadelphia, USA*
[c] *Concrete Technology and Durability Research Center, Department of Civil Engineering, Amirkabir University of Technology, Tehran, Iran*

HIGHLIGHTS

- Effect of temperature and relative humidity on durability properties.
- Use of thin sections method for investigating microstructure.
- Higher relative humidity improved the durability properties of mortar.
- Pearson correlation coefficient among test results was calculated.
- DC and the sorptivity results were strongly related.

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ABSTRACT

Environmental conditions, such as temperature and relative humidity, impact the rate of evaporation, mechanical properties and durability of concrete. Thus, they have a direct effect on the development of transport properties. The purpose of this study is to investigate the effect of controlled environmental conditions on moisture retention, dielectric constant (DC), compressive strength, shrinkage, water sorptivity index, rapid chloride migration test (RCMT), microscopical analysis (thin sections) and electrical resistivity. The mortar specimens were prepared using Ordinary Portland Cement with two water-to-cement ratios of 0.42 and 0.52. The specimens cured in the controlled environments of 25, 46 and 65 °C for temperature, and 30% and 90% for relative humidity. The results showed that curing under higher temperature cause reduction in compressive strength and increase in the sorptivity index. Moreover, a great correlation between DC measurements and sorptivity, the RCMT and electrical resistivity was found. Higher relative humidity helped the performance of samples, considering the durability and mechanical properties.

1. Introduction

It is well-known that environmental conditions, such as relative humidity and temperature, can have a great influence on both mechanical and especially durability-related properties of concrete, which control the final quality. One of the key factors that controls the concrete's quality is moisture evaporation through the concrete that can cause cracking, therefore reducing the durability of concrete in terms of service life. Thus, in order to optimize chemical reactions, providing a suitable temperature and relative humidity in the curing process seems necessary to prevent excessive water loss through the surface of concrete during the hydration process [30,8,62]. During continuous evaporation on the surface of early-age concrete, a negative capillary pressure is built-up and continues to rise with the progress of moisture loss that causes surface tension forces, and eventually cracking [56]. Bakhshi et al. [15] with the use of a fluid-mechanic based approach, provided a model for the prediction of evaporation rate and concluded that an increase in the ambient temperature would lead to an extreme rate of water content evaporation in concrete that will be escalated by a decrease in ambient relative humidity and an increase in wind speed [25].

Determining the dielectric constant (DC) of concrete is a nondestructive test (NDT), which can show the water content of concrete in various stages. Basically, the DC is a material's physical characteristic that demonstrates its ability to store electrical

* Corresponding author at: 199 Spence St., Suite 508K DLEB, 3135 TAMU, College Station, TX, USA.
E-mail address: joshaghani@tamu.edu (A. Joshaghani).

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energy. The DC of free water is 80.1 at 20 °C, which is considerably higher than solids, such as aggregate, cement and hydration products, which have a DC around 3–8. Therefore, a shift in the free water content in concrete can cause a change in DC values [23,57,66]. Water in concrete can be divided into three categories, including chemically bound water, physically bound water, and free water. Considering that chemical and physical water has a powerful molecular bond, their DC is not remarkable. Hence, a shift in free water content can affect DC and demonstrate the alteration of free water into chemically or physically bounded water, which is evidence of the continuous hydration process and consumption of free water over time. Shen et al. [55] stated that free water content is alluded to capillary pores at early ages, therefore DC can reflect the capillary pores. They also observed that there is a linear relationship between free water content DC. This method is excellent to determine water content in the fresh concrete mixture.

Chen et al. [23] observed a significant change in the DC value of the fresh concrete mix with the alteration in temperature. In fact, with an increase in temperature, the DC value will reduce owing to the fact that the higher temperature will help the evaporation of water from the surface of the concrete. They have also investigated the effect of the water-to-binder ratio (w/b) of fresh concrete from 0.45 to 0.57, which showed the increment in DC values with the growth in w/b. This enhancement in DC values can be explained by an increase in free water content, which was provided in the fresh concrete mix by an increase of w/b. The reduction of DC with an increase in temperature was also observed by Yehia et al. [70].

Several studies have been conducted on the effect of curing temperature on compressive strength, and the general conclusion was that the higher temperature leads to greater compressive strength values at early ages, but the concrete loses this compressive strength over time [59,65]. This matter can be explained by the fact that an increase of temperature will speed up the hydration process reactions at early ages and lead to the formation of a more C-S-H gel, and, as a result, greater values of compressive strength. But it should be noted that high temperature will cause a non-uniform distribution of C-S-H gel at long-term ages owing to inadequate time for diffusion through concrete, which contributes to larger pores in the microstructure of concrete and weaker mechanical and durability properties [5,73]. Atiş et al. [14] investigated the effect of both w/c and two relative humidity percentages of 65% and 100% on the compressive strength of concrete containing silica fume. They have reported that drying the curing condition can notably influence the compressive strength of concrete and it is more sensitive to this curing condition when the w/c increases. This matter can be explained by considering an enhancement in w/c led to the presence of greater porosity content and bigger capillary pores, thereby letting the free water to evaporate easily.

Generally, shrinkage may induce microcracking in the structure of concrete that can cause problems relating to the durability properties of concrete and lead to costly repairing implementations for enhancing the service life of concrete structures [71,33]. Autogenous shrinkage relates to the development of a hydration process and formation of cement-based productions, which happens with the consumption of free water. On the other hand, drying shrinkage of concrete occurs due to the water evaporation from the matrix and this kind of shrinkage can be pronounced if the curing condition is not properly provided [2,54]. Several studies have been conducted and proposed methods for reduction of shrinkage and its consequent cracks, such as microfibers, mineral and chemical admixtures, cement modification and control of the curing conditions [45,35].

Yalçınkaya and Yazıcı [69] in part of their study investigated the effect of relative humidity and temperature on the shrinkage of high-performance concrete. They have observed in conditions with constant relative humidity at 50%, an increase in temperature from 20 °C to 40 °C not only can enhance the shrinkage strain values due to water evaporation, but also can accelerate its progress in the first hours. They have also observed that temperature rise, especially from 30 °C to 40 °C caused considerably more intense enhancement in water evaporation from the specimens compared to a temperature rise from 20 °C to 30 °C. It should be noted that although the high temperature in curing leads to high water evaporation from the surface of concrete, it also helps to speed up the hydration process, which contributes to more non-evaporable water or chemically bound water, therefore reducing in autogenous shrinkage [58]. Piasta and Zarzycki [48] conducted a study on the influence of w/c and paste volume of concrete on shrinkage. They stated that considering both effects of hydration degree development and increase in w/c, which leads to an increment of capillary porosity, the growth of shrinkage during drying can be explained because of excessive water loss through the surface of the concrete. Furthermore, the effect of paste volume can be notably enough to yield higher shrinkage values in specimens with lower w/c, but higher volume paste in comparison to specimens with higher w/c and lower paste volume.

Curing conditions, such as temperature and relative humidity, play a key role in improving the microstructure of concrete and minimizing the cracks that can speed up the process of penetration of aggressive ions, such as chloride, into concrete. In practice, concrete structures in harsh environments experience temperature and relative humidity different than that of the standard curing condition in the laboratory. Therefore, it seems vital to study the influence of different curing conditions on the penetration of chloride ions into concrete [18,31,43,17]. Jiang et al., [31] investigated the effects of curing temperature on the chloride migration coefficient with the use of the rapid chloride migration test (RCMT). They have observed in concrete without the pozzolan materials (ordinary concrete) an increase in temperature will decrease the migration coefficient (D_{RCMT}) values at early ages while at longer ages higher temperature contributes to a slight enhancement in D_{RCMT} values. Ogirigbo and Black [42,43] evaluated the effect of curing temperature at 20 °C and 38 °C on the penetration of chloride ions into concrete. They have observed that at the higher curing temperature (38 °C) bounded chloride content will grow. It is expected that free chloride ions in the pore solution decrease, thereby decreasing chloride penetration depth. Although, this trend was observed at early ages (14 days), long-term ages had a higher depth of penetration. This phenomenon was explained by the fact that, despite that the higher temperature increases the bound chloride, it makes the pore structure coarser, which in turn facilitates the penetration of chloride ions into concrete [39,44]. Caré [20] investigated the effect of w/c and different temperatures included 45 °C, 80 °C and 105 °C on chloride diffusion in cement paste. The results of this study showed that both increases in temperature and w/c ratio lead to growth in chloride diffusion values.

Almusallam [5] examined porosity of concrete specimens subjected to a temperature of 30 °C and 45 °C with different relative humidity of 25%, 50% and 90%. In this study, it was observed that at a constant temperature, an increase in curing relative humidities followed by a decrease in the magnitude of coarse pores (pore size more than 1000 A) and total porosity of the specimens. Higher relative humidity can exclude the immoderate water evaporation from the structure of concrete by providing a higher volume of water vapor in the atmosphere, thereby helping the further hydration and production of C-S-H gel for making the microstructure denser.

The resistivity of concrete is an indicator of its resistance against the penetration of aggressive agents. Thus, it can be considered as a parameter to show durability. The microstructure of con-