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Carbonation Performance of Concrete due to Effect of Temperature

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Abstract

In this study, the effect of temperature on macro-performance and micro characteristic of carbonized concrete was investigated. The carbonation depth, compressive strength, and surface strain of concrete under different simulated environments for 28 d were measured. XRD and ESEM-EDS analysis were conducted to present the phase composition, types of hydration products, and microstructure characteristics of samples before and after carbonation. The results showed that the effects of temperature on carbonation depth, strain, and compressive strength were significant. There was a linear relation between temperature and carbonation depth as well as compressive strength of concrete. The effects of environment factors on concrete surface strain after carbonation manifested as the strain value and the slope of linear segment of strain curve. Significant differences of phase composition and hydration products were observed before and after the carbonation, which mainly manifested as attenuation and disappearance of diffraction peaks of hydration products. Temperature affects the crystal form of the carbonation products.

1. Introduction

Concrete carbonation is a neutralization reaction between carbon dioxide (CO_2) penetrated into concrete from surrounding atmosphere and the alkaline hydration products (e.g., calcium hydroxide) in concrete [1]. Concrete carbonation can cause a local fall of alkalinity of pore solution due to the consumption of calcium hydroxide [2]. The reduction of the concrete alkalinity can destroy the passive film initially formed around the steel reinforcement and thus lead to the corrosion of reinforcing steel when both moisture and oxygen are present there [3]. During the past few decades, plenty of achievements have been obtained [4, 5], which mainly focused on water to cement ratio [6], crack and freeze-thaw [7], admixtures [8, 9], loading [10], and initial curing period [11]. Meanwhile, the effects of environment factors including temperature, carbon dioxide concentration, relative humidity, and loading on concrete carbonation have also been investigated [12–14]. In view of the increasing amount of temperature around the world, the deterioration effect of temperature on concrete carbonation becomes even more serious. Carbonation of concrete becomes a different durability problem, which accelerates the degradation of reinforced concrete structures. Therefore, it is significant to investigate the effect on concrete carbonation.

The objective of this study is to investigate the effect of temperature on concrete carbonation. Macroperformance (i.e., compressive strength, carbonation depth, and strain) and microcharacteristics (i.e., composition phase, microstructure, and carbonation products) of carbonized concrete under different temperature were measured.

2. Experimental Procedure

2.1. Raw Materials

P·O 42.5 Portland cement was provided by China Building Materials Academy. River sand (i.e., fine aggregate) and continuous grading limestone gravel (i.e., coarse aggregate) with a grain size of 5~20 mm were collected. Tap water which met the JGJ63-2006 *Water Standards for Concrete* was applied in stirring process. Polycarboxylic acid series of the high-efficiency superplasticizer which contained 30% of solid was made by Hunan Changsha Huangteng Co., Ltd. The fly ash was produced by Hunan Xiangtan Power Plant. CO_2 gas was provided by Changsha Fanggang Gas Company. The mix proportion of concrete is listed in Table 1.

Table 1: Mix proportion of concrete (kg·m^{-3})

Composition materials		Cement	Fly ash	Fine aggregate	Coarse aggregate	Water	Water reducer
Concrete strength grade	C20	195	128	785	1045	178	1.8
	C30	270	125	780	1050	172	1.9
	C40	350	122	710	1052	162	2.25

2.2. Experimental Process

According to GBT 50082-2009 *Standards on Test Method of Ordinary Concrete Long-term Performance and Endurance*, the concrete specimens with a size of 100 mm × 100 mm × 300 mm and 100 mm × 100 mm × 100 mm were cast and demoulded after 24 h. The specimens were cured at the temperature of (20 ± 1)°C and the relative humidity of (95 ± 5)% for 28 d. Subsequently, specimens were dried for 48 h at 60°C, and the concrete carbonation test were conducted under different environments (Table 2) provided by the environmental simulation test system. The carbonation depth, compressive strength, and surface strain of concrete were measured, when the carbonation test was lasted for 28 d. The concrete prisms used to test the carbonation depth were prepared as follows: two opposite sides of concrete prism with a size of 100 mm × 300 mm were reserved, and the rest sides were sealed by using epoxy resin. According to GB/T 50082-2009 *Standards for Test Methods of Long-Term of Performance and Durability of Ordinary Concrete*, the carbonation depth of concrete was observed by spraying a phenolphthalein solution onto the surface of a split concrete prism. Ten measured points on the cross section of the specimen were measured, and the corresponding average value was set as the carbonation depth with a precision of 0.1 mm. Mechanical properties of concrete were tested according to GB/T50081-2002 *Standards on Test Method of Ordinary Concrete Mechanical Properties* with the loading rate of 3 kN/s. The prism specimen used to test the concrete surface strain was conducted with the imc data acquisition system, and a strain gage was pasted on the middle of concrete surface.

Table 2: Testing condition

Items	Temperature (°C)	Relative humidity (%)	CO_2 concentration (%)
1	10	70	20
2	20	70	20
3	30	70	20

2.3. Test Instruments and Devices

Test instruments mainly included Quanta-200 environment scanning electron microscope (ESEM) made by FEI Company (USA), BD-86 X-ray diffraction (XRD) produced by Rigaku Company (Japan), WAW-DP Universal tester was provided by Shanghai Sansi Co. Ltd. (China), and the environmental simulation test system was made by Wuhan Jinyatai Instrument Co., Ltd. (China). Moreover, the imc data acquisition system with sixteen channels was provided by Integrated Measurement and Control Co. (Germany).

3. Results and Discussion

3.1. Effect of Temperature on Macro performance of Carbonized Concrete

Due to temperature accelerating the carbonation rate, the effect of different temperatures (i.e., 10°C, 20°C, and 30°C) on concrete compressive strength after carbonation for 28 d was investigated. Figure 1 shows the change of concrete compressive strength with temperature. The corresponding test was set with the carbon dioxide concentration of 20% and relative humidity of 70%.

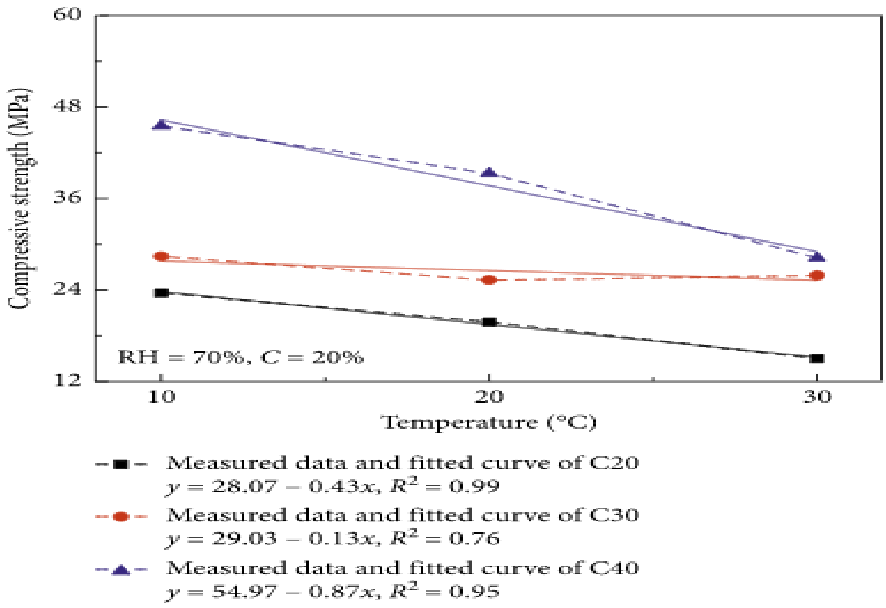


Figure 1: Curves of concrete compressive strength with temperature

Figure 1 indicates that there was a significant relation between carbonation temperature and concrete compressive strength after carbonation, which could be described by a linear function. The concrete compressive strength after carbonation decreased with the increase of temperature, which may be a result of carbonation reaction of CO_2 with hydration products, such as calcium hydroxide (i.e., CH), calcium silicate hydrate (i.e., C-S-H), ettringite (i.e., AFt), and calcium aluminate hydrate (i.e., C-A-H) in concretes. With carbonation, the hydration products of concrete were gradually decomposed, and new substances without cementitious property were generated. Composition change of concrete induced the deterioration of microstructure, which manifested as the degradation of mechanical property in macroperspective. In brief, the carbonation of concrete was the change of hydration products and the destruction of chemical-state equilibrium of the cementitious system. Moreover, the reduction rate of concrete compressive strength after carbonation was also affected by concrete strength grade, and it may be caused by the compactness of microstructure, which could affect the transmission coefficient of CO_2 in concrete.

Macroperformance of carbonized concrete can also be represented by carbonation depth. Hence, the influence on concrete carbonation depth was measured, and Figure 2 shows the change of concrete carbonation depth with temperature.

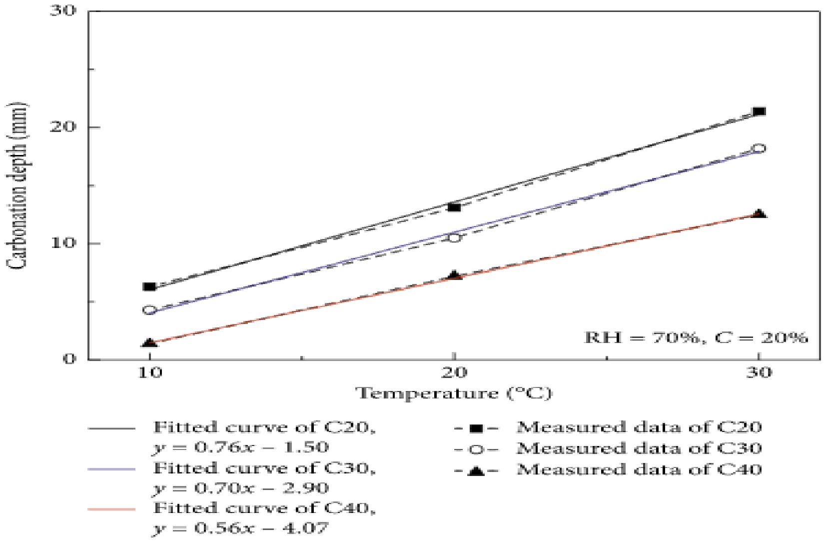


Figure 2 Carbonation depth profiles of concrete with temperature

Figure 2 shows the relation between concrete carbonation depth and temperature could also be characterized by a linear function, which manifested as the concrete carbonation depth increased with temperature. Under the same carbonation condition, the concrete carbonation depth decreased with the increase of concrete strength. That is due to high temperature enhancing the transmission coefficient and reaction rate of carbon dioxide, so the carbonation degree and depth of concrete specimens were more significant. With the increase of concrete strength, the concrete manifested as denser microstructure, lower porosity, more sinuosity, and smaller openness of pores. Therefore, CO_2 transmitted in concrete with difficultly. Moreover, the carbonation products generated in pore of concrete could fill some pores, which improved the characteristic of pore and decreased the carbonation reaction in concrete.

Due to the carbonation that reacted from concrete surface to the inside, the change of concrete surface can be used to represent the characteristic of concrete carbonation. Using C20 as an example, the influence of temperature on concrete surface strain was investigated. The prism concrete specimens were used to measure the surface strain according to Section 2.2. Figure 3 shows the curves of concrete surface strain with temperature.

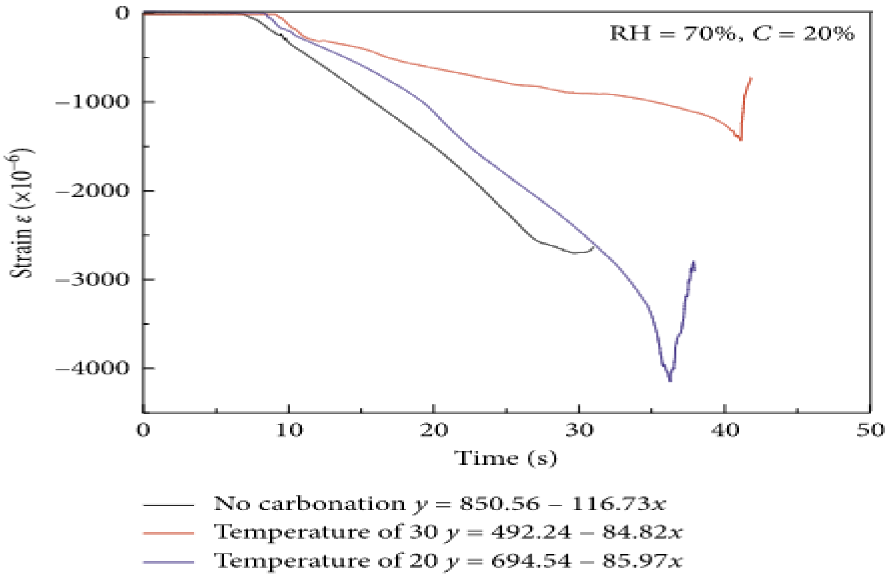


Figure 3 Strain curves of concrete surface with carbonation temperature.

As seen from Figure 3, the effect of carbonation temperature on concrete surface strain was obvious, which manifested as the strain value and slope of linear segment of the strain curve. Compared with non carbonation concrete, the absolute value of slope of the concrete strain curve after carbonation notably decreased with carbonation temperature. Carbonation could induce the degeneration of mechanical performance, decomposition of hydration product, and looseness of microstructure, so the elastic modulus and bearing capacity of concrete after carbonation significantly decreased. The higher the carbonation temperature was, the more significant the concrete carbonation was. Therefore, the concrete surface strain was more obvious with carbonation temperature.

3.2. Effect of Temperature on Micro characteristic of Carbonized Concrete

In order to investigate the characteristic of carbonation, the micro characteristic of carbonized concrete was studied. Figure 4 is the phase composition and hydration products of samples analysed by XRD.

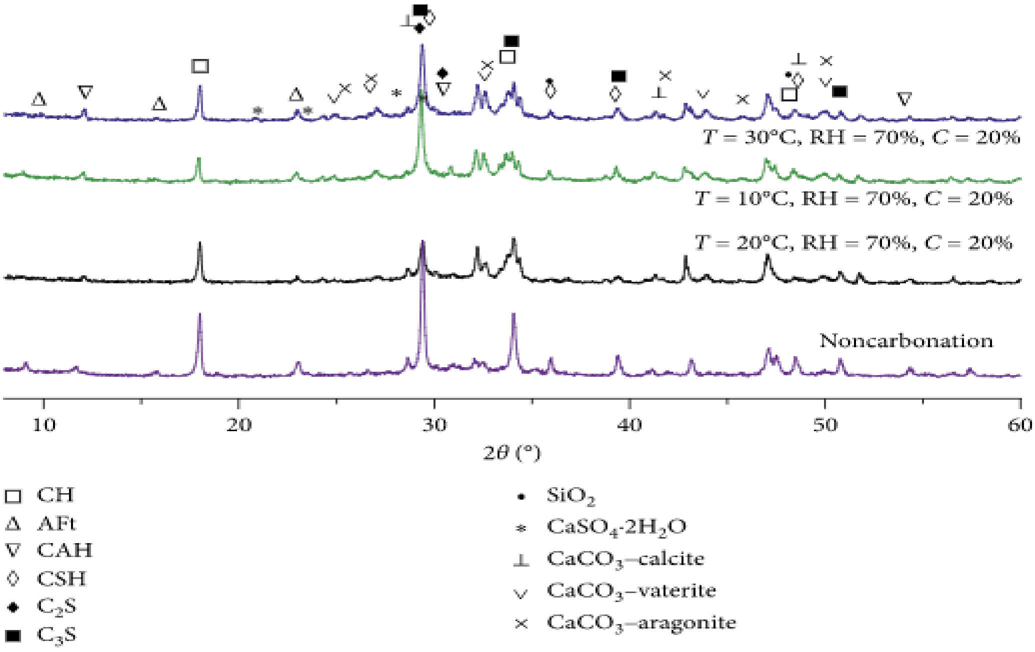
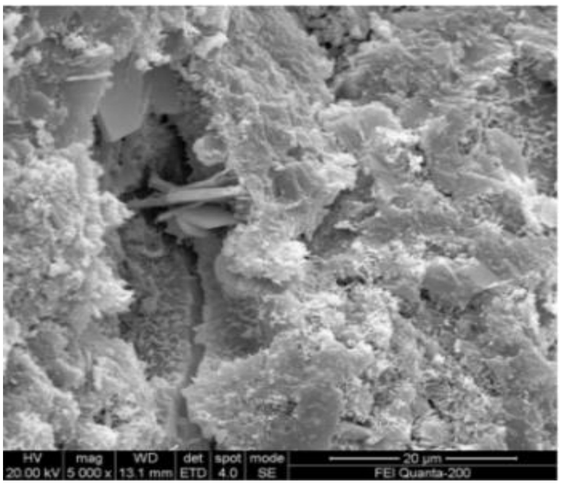


Figure 4_ XRD spectrum of samples under different carbonation conditions.

Figure 4 indicates that there was a significant difference of concrete samples before and after the carbonation. The XRD spectrum of non-carbonation specimens indicated the main hydration products were CH, AFt, C-S-H, and C-A-H. Temperature had an observable effect on carbonation products and phase composition, which manifested as the disappearance and attenuation of some products' diffraction peaks (i.e., CH and AFt) and the generation and enhancement of the carbonation product (i.e., $CaCO_3$). As seen from Figure 4, the intensity of diffraction peaks of carbonation products enhanced with temperature. That may be caused by the temperature inducing the rise of carbonation rate, and more carbonation products were generated.

Microstructure, morphology, and carbonation product of samples under different temperatures were also measured, as shown in Figure 5.



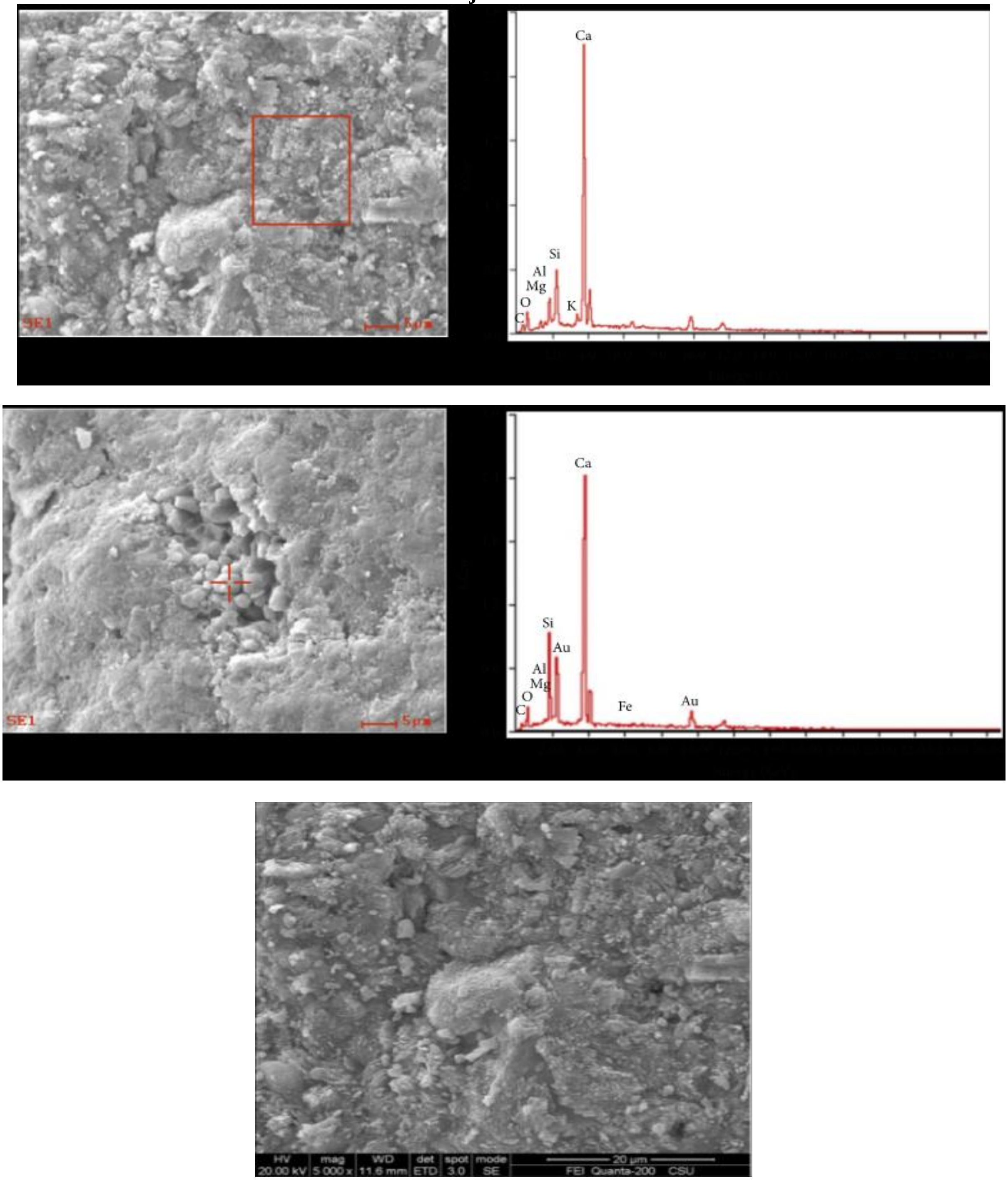


Figure 5 ESEM-EDS spectrum of samples under different temperatures. (a) Noncarbonation. (b) 10°C. (c) 20°C. (d) 30°C.

Figure 5 implied the carbonation temperature had a significant effect on phase composition, microstructure, morphology, and hydration products. Hydration products of noncarbonation sample were mainly hexagonal plate-like CH, rod-like AFt, flocculent C-S-H, and C-A-H (Figure 5(a)). Nevertheless, there were few gelling hydration products in microstructure of carbonized specimens and particulate $CaCO_3$ in pores (Figures 5(b)–5(d)). EDS analysis indicated the carbonation product of the sample at 10°C and 20°C was polyhedral vaterite (Figures 5(b) and 5(c)). However, the hydration product of carbonized samples was aragonite at a temperature of 30°C. The above results implied the temperature could determine the crystal form of carbonation product. In addition, the particle size of carbonation products of the sample was different.

4. Conclusions

(1)The effect of environmental temperature on concrete carbonation was investigated. The experimental results showed the carbonation depth and compressive strength of concrete manifested as a linear relationship with temperature. Concrete carbonation depth increased with the increase of temperature, but the compressive strength of concrete after carbonation decreased with the strength grade of concrete. This was because CO_2 transmission coefficient and chemical reaction coefficient may increase with temperature.(2)The effects of temperature on concrete surface strain after carbonation manifested as the strain value and the slope of linear segment of strain curve. Phase composition, hydration products, and microstructure of concrete changed significantly before and after the carbonation. Such changes were mainly manifested by disappearance and weakening of diffraction peak of some hydration products. XRD and ESEM spectral analysis revealed that the carbonation product was mainly calcium carbonate. Temperature affected the crystal form of carbonation products. Polyhedral spherical vaterite was major carbonation products at 10°C and 20°C, whereas aragonite was the major carbonation products at 30°C.

References

[1] B. Q. Dong, Q. W. Qiu, Z. T. Gu et al., “Characterization of carbonation behavior of fly ash blended cement materials by the electrochemical impedance spectroscopy method,” Cement and Concrete Composite, vol. 65, pp. 118–127, 2016.

[2] M. B. Valcarce and M. Vázquez, “Carbon steel passivity examined in solutions with a low degree of carbonation: the effect of chloride and nitrite ions,” Materials Chemistry and Physics, vol. 115, no. 1, pp. 313–321, 2009.

[3] J. Liu, Q. Qiu, X. Chen et al., “Degradation of fly ash concrete under the coupled effect of carbonation and chloride aerosol ingress,” Corrosion Science, vol. 112, pp. 364–372, 2016.

[4] N. Singh and S. P. Singh, “Reviewing the carbonation resistance of concrete,” Journal of Materials and Engineering Structures, vol. 3, no. 2, pp. 35–57, 2016.

[5] S. O. Ekolu, “A review on effects of curing, sheltering, and CO_2 concentration upon natural carbonation of concrete,” Construction and Building Materials, vol. 127, pp. 306–320, 2016.

[6] C. D. Atis, “Accelerated carbonation and testing of concrete made with fly ash,” Construction and Building Materials, vol. 17, no. 3, pp. 147–152, 2003.

[7] Y. Cheng, Y. Zhang, Y. Jiao, and J. Yang, “Quantitative analysis of concrete property under effects of crack, freeze-thaw and carbonation,” Construction and Building Materials, vol. 129, pp. 106–115, 2016.

[8] S. Kritsada and F. Lutz, “Carbonation rates of concretes containing high volume of pozzolanic materials,” Cement and Concrete Research, vol. 37, no. 12, pp. 1647–1653, 2007.

[9] A. Younsi, P. Turcry, A. Aït-Mokhtar, and S. Staquet, “Accelerated carbonation of concrete with high content of mineral additions: effect of interactions between hydration and drying,” Cement and Concrete Research, vol. 43, pp. 25–33, 2013.

[10] B. Lei, W. G. Li, Z. H. Li, G. Wang, and Z. H. Sun, “Effect of cyclic loading deterioration on concrete durability: water absorption, freeze-thaw, and carbonation,” Journal of Materials in Civil Engineering, vol. 30, no. 9, pp. 109–121, 2018.

[11] Y. Jia, B. Aruhan, and P. Yan, “Natural and accelerated carbonation of concrete containing fly ash and GGBS after different initial curing period,” Magazine of Concrete Research, vol. 64, no. 2, pp. 143–150, 2012.

[12] C.-f. Lu, W. Wang, Q.-t. Li, M. Hao, and Y. Xu, “Effects of micro-environmental climate on the carbonation depth and the pH value in fly ash concrete,” Journal of Cleaner Production, vol. 181, pp. 309–317, 2018.

[13] Y. Chen, P. Liu, and Z. W. Yu, “Effects of environmental factors on concrete carbonation depth and compressive strength,” Materials, vol. 11, pp. 1–11, 2018.

[14] Z. Yu, Y. Chen, P. Liu, and W. Wang, “Accelerated simulation of chloride ingress into concrete under drying-wetting alternation condition chloride environment,” Construction and Building Materials, vol. 93, pp. 205–213, 2015.