



Mechanical Properties of Cement Mortar after Dry–Wet Cycles and High Temperature

Xiong Liang-Xiao^{a, b}, Song Xiao-Gang^{c*}

^a School of Civil Engineering and Architecture, East China Jiaotong University, Nanchang 330013, P. R. China.

^b Guangxi Key Laboratory of Disaster Prevention and Engineering Safety, Guangxi University, Nanning 530004, P. R. China.

^c Faculty of Civil and Environmental Engineering, Ningbo University, Ningbo 315211, P. R. China.

Received 01 December 2019; Accepted 19 March 2020

Abstract

The dry–wet cycle and high temperature exposure are important factors affecting the normal use and durability of concrete structures. The objective of this work is to investigate the mechanical properties of cement mortar specimens after combinations of dry–wet cycles and high temperature exposures, uniaxial compressive tests on cement mortar specimens were carried out under the following two sets of conditions: (1) high temperature treatment followed by a dry–wet cycle and (2) a dry–wet cycle followed by high temperature treatment. The results show that the compressive strength of specimens increases with the number of dry–wet cycles. After a dry–wet cycle and then a high temperature treatment procedure, the compressive strength of a specimen will first decrease and then increase with the number of dry–wet cycles. The strain at the peak stress of cement mortar decreases as the number of dry–wet cycles increases. At present, there are few research results about the mechanical properties of concrete first after combinations of dry–wet cycles and high temperature exposures. The work in this paper can enrich the results in this area.

Keywords: Cement Mortar; Mechanical Properties; Uniaxial Compression Test; Dry–Wet Cycle; High Temperature.

1. Introduction

The dry–wet cycle and high temperature exposure are important factors affecting the normal use and durability of concrete structures. Hydraulic structures, such as piers, in splash zone environments will be affected by the dry–wet cycle caused by water level changes, and the concrete structure comprising such a pier may also be exposed to fire or high temperatures.

Many scholars have studied the effects of dry–wet cycles on concrete materials. Li and Shen [1] studied the deterioration processes of aeolian sand powder concrete under freeze-thaw and dry-wet conditions. Wei et al. [2] investigated the effect of chloride wet/dry exposure on bonding behavior of BFRP-strengthened concrete beams. Yan et al. [3] investigated the characteristics of unconfined compression strength and pore distribution of lime-flyash loess by means of a series of experiments under freeze-thaw cycles or dry-wet cycles. Li et al. [4] analyzed the physical and mechanical properties of MKPC under dry-wet cycles in 5 wt% Na₂SO₄ solution. Chen et al. [5] presents an experimental study on the damage progress of concrete subject to combined sulfate-chloride attack under drying-wetting cycles and flexural loading. Ma et al. [6] investigated the properties of concrete, including ordinary Portland concrete and high-performance concrete (HPC), subjected to dry-wet cycles in a variety of salt lake brines. Liu et al.

* Corresponding author: songxiaogang@nbu.edu.cn

 <http://dx.doi.org/10.28991/cej-2020-03091526>



© 2020 by the authors. Licensee C.E.J, Tehran, Iran. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC-BY) license (<http://creativecommons.org/licenses/by/4.0/>).

[7] investigated the coupled effects of external multi-ions and wet-dry cycles in sea water on the evolution of autogenous selfhealing in cement paste. Yin et al. [8] studied the mechanical properties of textile reinforced concrete (TRC) under chloride wet-dry and freeze-thaw cycles. Sahmaran et al. [9] found that a dry–wet cycle would accelerate the degradation rate of the compressive strength of ordinary Portland cement specimens, in sulfate solutions. Gong et al. [10] firstly conducted experiments on the creep of concrete subjected to dry-wet cycle and sulfate attack. Wu et al. [11] investigated the transport of chloride ions in concrete under loads and drying- wetting cycles.

A series of related studies have been carried out on the influence of high temperatures on concrete materials. Du et al. [12] investigated the infrared thermal image inspection, coefficient of thermal conductivity, apparent density, and compressive strength test on C80 high-strength concrete (HSC) in the presence and absence of polypropylene fibers under completely heated conditions. Khan and Abbas [13] presented the behavior of high volume fly ash concrete at varying peak temperatures. Meng et al. [14] studied the triaxial compressive properties of recycled aggregate concrete (RAC) after high temperature. Li et al. [15] investigated the static and dynamic mechanical properties of concrete before and after high temperature exposure. Liu et al. [16] experimentally and analytically investigated the residual strength of SRC cross-shaped columns after exposure to high temperatures. Zhai et al. [17] conducted intensive SHPB tests and corresponding quasi-static tests were to study the strain-rate effects on the normal weight concrete after high temperature. Arioz [18] found that as the high temperature exposure was increased, the quality and the relative strength of the concrete specimens decreased significantly. Ma et al. [19] discussed the effects of their tested high temperature methods on the mechanical properties of concrete after exposure, through several sets of experiments.

Although there have been many studies on the mechanical properties of concrete after dry–wet cycles and after high temperature exposures, most of the results only consider single variables; experimental results for pairing dry–wet cycles and high temperatures are rare. The requirements of environments where actual concrete structures are used are complex and variable, ranging from the concrete structures being subject to fire after long periods of continuous wet, due to rainy seasons; although some concrete structures are exposed to fire, they often stay in use due to the damage not being obvious. Such structures could be subjected to dry–wet cycles caused by adverse weather in their subsequent service phases. Therefore, the mechanical properties of concrete after the combination of dry–wet cycles and high temperatures must be studied, that is, the mechanical characteristics of concrete first after high temperatures followed by dry–wet cycles and vice versa.

In order to study the mechanical properties of the cement mortar after these combinations of dry–wet cycles and high temperature exposures, in depth, the cement mortar specimens produced from one batch have been subjected to the dry–wet cycle first and then to the high temperature treatment and vice versa. Uniaxial compression tests were carried out on the specimens, and their compressive strength, peak strain, and elastic moduli were investigated in light of the number of dry–wet cycles and high temperature exposures they had experienced.

2. Research Methodology

The program of this work can be seen in by a flow chart as shown in Figure 1.

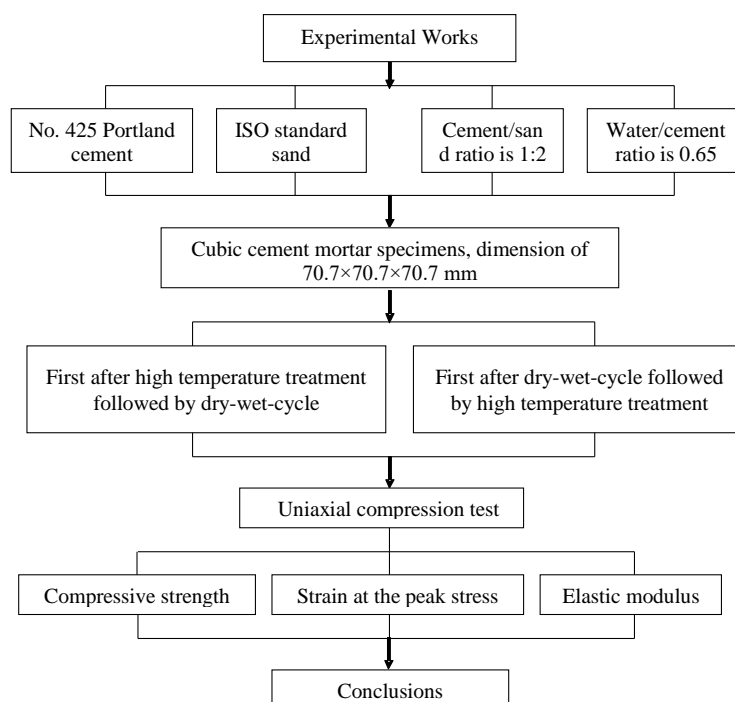


Figure 1. Flow Chart for Research Methodology

3. Test Setup

3.1. Test Instruments

The uniaxial compression test was conducted using the WAW600 universal testing machine. The machine had a maximum displacement loading rate of 60 mm/min and a maximum load of 600 kN. The oven used was the type 101–2 electric heating, constant temperature, blast drying box produced by Shangyu Geotechnical Instrument Co., Ltd. The high temperature box used was the GWM-1100 electric heating, high temperature test box produced by Changchun Fangrui Technology Co., Ltd.

3.2. Sample Preparation

The cement was 42.5 grade ordinary Portland cement. The fine aggregate was freshwater river sand produced in Ningbo; it belongs to the medium sand category, with particle-level matching grid. The mixing water used was ordinary tap water.

The size of each specimen was 70.7×70.7×70.7 mm, and the water/cement ratio was 0.55. A total of 138 specimens were prepared, and their molds were removed after being placed at room temperature for 24 h. All cement mortar specimens were subjected to the next step of the research after 28 days of standard curing.

3.3. Experiment Procedure

(1) High temperature treatment method: the specimens were placed in a high temperature box, after which the temperature was raised to a preset temperature (200°C, 300°C, 400°C) at a heating rate of 10°C/min. The temperature was then kept stable for 2 h, when the high temperature box was turned off to stop heating. The specimens were removed from the box after naturally cooling for 24 h.

(2) Dry–wet circulation treatment method: the specimens were immersed in water for 15 h, after which the specimens were taken out and any surface moisture dried with a dry towel. They were then left to stand for 30 min before being transferred to the 40°C oven for 8 h. They were then removed and allowed to cool to room temperature for 30 min, soaked in water. The cycle was then repeated with each cycle taking 24 h.

(3) Uniaxial compression test: All the specimens were allowed to stand at room temperature for 7 days after their high temperature and dry–wet cycle treatments. They were then subjected to uniaxial compression testing. The test loading mode adopted displacement control with a loading rate of 0.4242 mm/min.

The numbers of the three specimens without high temperature and dry–wet circulation treatments are set as # 0.65-RM-1, # 0.65-RM-2 and # 0.65-RM-3. The loading-time curves of these three specimens are shown in Figure 2.

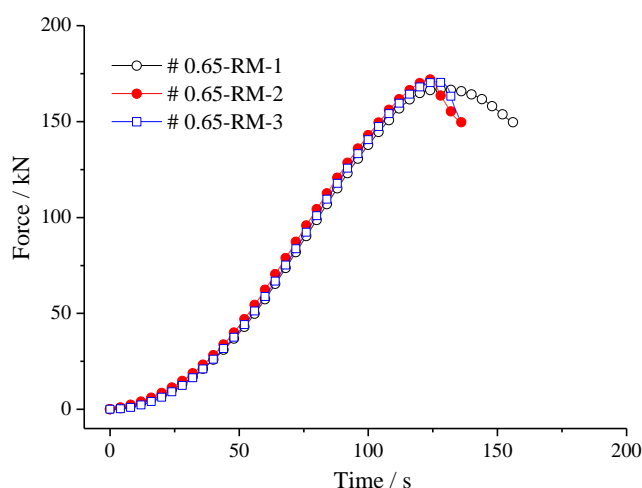


Figure 2. The loading-time curves of specimens

3.4. Test Group

A total of 18 specimens underwent dry–wet cycles at room temperature. A total of 54 specimens had the high temperature exposure first and then the dry–wet cycle. A total of 54 specimens had the dry–wet cycle before the high temperature phase. A total of 12 specimens underwent only the high temperature treatment at different temperatures.

Three specimens were used for each test, and the compressive strength, peak strain, and elastic moduli values used here are the average values for these three specimens.

4. Test Results and Analysis

4.1. Change Law of Compressive Strength

The change law of compressive strength of the specimens with the number of dry–wet cycles is shown in Figure 3. The compressive strengths of specimens after high temperature and then the dry–wet cycle are shown in Figure 3(a), and the compressive strengths of specimens in the dry–wet cycle and then high temperature group are shown in Figure 3(b).

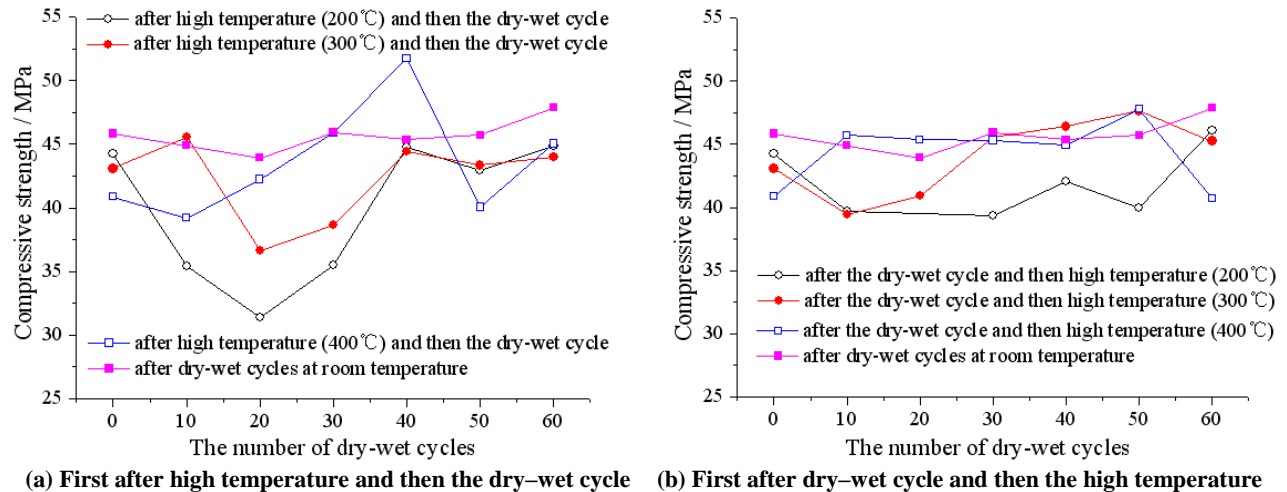


Figure 3. Variation of compressive strength of specimen with dry–wet cycling times

According to Figure 3 (a):

When the number of dry–wet cycles is nil, the specimens having the high temperature and then the dry–wet cycle only show the effects of the high temperature. The compressive strength of specimens gradually decreases as the temperature rises from room temperature (25°C) to the highest temperature used, which is 400°C.

The compressive strength of the specimens that underwent the dry–wet cycles at room temperature increased with the number of dry–wet cycles, mainly because the clinker mineral hydrates in the cement increase with the length of the time spent in sufficient water. The gel is filled with capillary pores making the inside of the specimen more compact, thereby improving the compressive strength of the specimen.

After exposure to high temperatures of 200 and 400°C, the compressive strength of the specimen first decreases and then increases slightly, as the number of dry–wet cycles increases. However, the compressive strength remains lower than that of a specimen having the same number of dry–wet cycles at room temperature.

Due to the different thermal expansion coefficients of the cement slurry and the medium sand, microcracks will appear on the surface of the specimen after experiencing high temperatures. The repeated action of the dry–wet cycle will increase these microcracks. When the number of cycles is small, the continuous increase of microcracks will reduce the overall structural strength of the specimen; as the number of cycles increases, the water gradually enters the inside of the specimen along the numerous microcracks. The water reacts with the unhydrated cement particles. The chemical action brings a certain degree of improvement to the compressive strength, but the high temperatures have a degrading effect on the compressive strength of the specimen, so the compressive strength is still lower than that of a specimen that had the same number of dry–wet cycles at room temperature.

After the same number of dry–wet cycles, the compressive strength of a specimen that underwent dry–wet cycles at room temperature is greater than the compressive strength of a specimen that underwent high temperature exposure and then dry–wet cycle process, with the same number of cycles. At the same time, the compressive strengths of the specimens experiencing high temperatures of 300°C and 400°C, before their dry–wet cycles, are greater than the compressive strength of a specimen experiencing a high temperature of 200°C before the same number of dry–wet cycles. This is because when a specimen is subjected to high temperatures of 300°C and 400°C, the number of microcracks and pores that are formed inside the specimen is greater than that of a specimen subjected to a high temperature of 200°C. The dry–wet cycle allows water to enter the specimen through the pores and cracks, so that the degree of hydration of the cement clinker mineral is increased, increasing the compressive strength too. The denser the distribution of pores inside the specimen, the more the degree of hydration increases, and the greater the strength increase. However, the high temperature still does certain damage, deteriorating the specimen, so the compressive strength is still lower than that of specimen that has not been subjected to the intense heating.

According to Figure 3 (b):

When specimens have their dry–wet cycles before experiencing high temperatures of 200°C and 300°C, their compressive strengths generally first decrease slightly and then increase with the number of dry–wet cycles. There are two reasons: (1) When the number of dry–wet cycles is relatively small, the dry–wet cycling causes microcracks in the cement mortar specimen, reducing the compressive strength of the specimen. (2) When the number of dry–wet cycles is larger, as the number of cycles continues to increase and microcracks continue to expand inside the specimen, the moisture that is present reacts with the unhydrated cement particles, continuously filling the pores, improving the compressive strength of the specimen.

The comparisons of the compressive strengths of the specimens that experienced the dry–wet cycles first with the strengths of those that experienced the high temperatures first, for the same high temperatures, are shown in Figure 4.

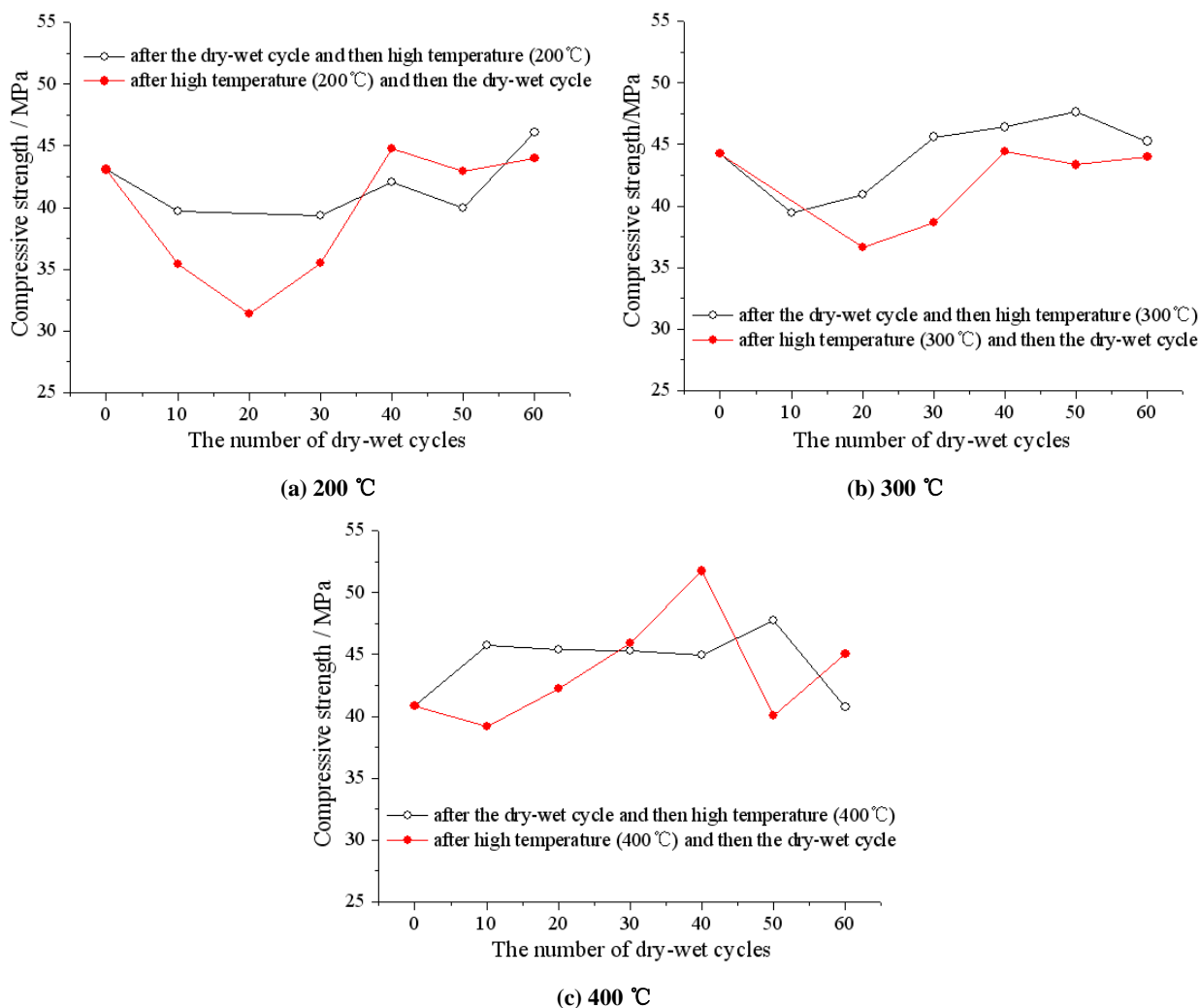


Figure 4. Comparisons of the compressive strengths of the specimens that experienced the dry–wet cycles first with the strengths of those that experienced the high temperatures first, for the same high temperatures

In general, when the number of cycles is the same, the compressive strengths of specimens that experienced the dry–wet cycles first are higher than the strengths of those that experienced the high temperatures first, for the same high temperature.

4.2. Variation Law of Strain at the Peak Stress

The change law of strain at the peak stress of the specimens, with the number of dry–wet cycles, is shown in Figure 5. The strains at the peak stress of the specimens that experienced high temperatures before their dry–wet cycles are shown in Figure 5(a), and the strains at the peak stress of the specimens that had their dry–wet cycles before experiencing high temperatures are shown in Figure 5(b).

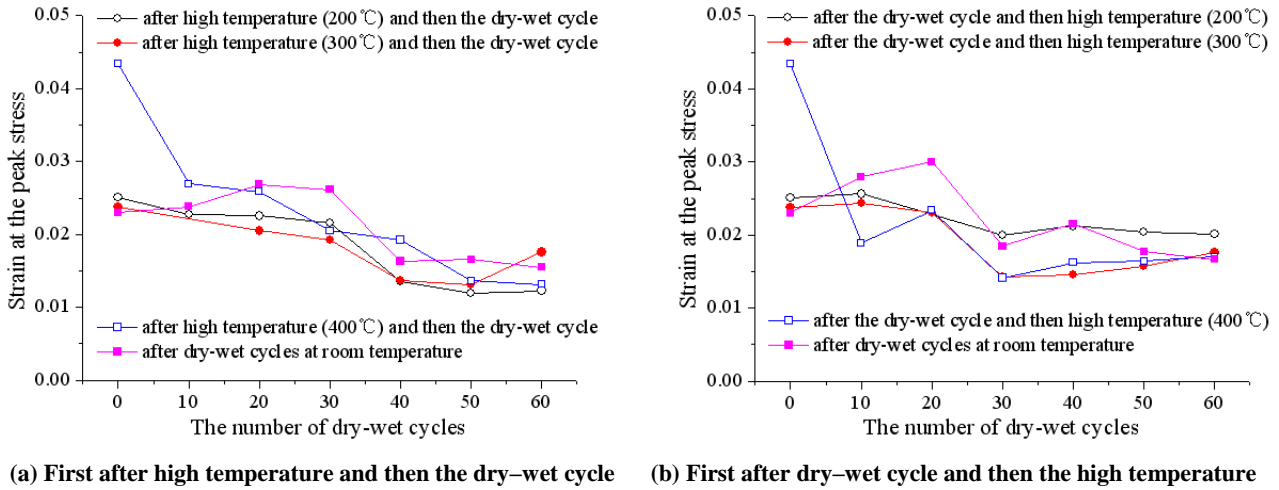


Figure 5. Variation of the strain at peak stress of specimens with dry-wet cycle times

When the specimen only experienced high temperature, when the number of dry-wet cycles was nil, the strain at the peak stress of the specimen increases with the increase in temperature; the strain at the peak stress after the high temperature of 400°C is double that of the room temperature specimen, indicating that the high temperature greatly improves the ductility of the specimen. The strains at the peak stress of specimens that experienced the dry-wet cycles before heating and those that experienced the high temperatures before the dry-wet cycles both showed decreasing trends with the increase in the number of cycles, indicating that the dry-wet cycling reduces the ductility of the specimens.

4.3. Variation Law of Modulus of Elastic Modulus

In this paper, the secant elastic modulus was calculated at a peak stress of 30%, and the corresponding strain was taken as the elastic modulus of the specimen. The change law of the elastic moduli of specimens with the number of dry-wet cycles are shown in Figure 6. The elastic moduli of specimens that experienced high temperatures before their dry-wet cycles are shown in Figure 6 (a), and the elastic moduli of specimens that had their dry-wet cycles first are shown in Figure 6 (b).

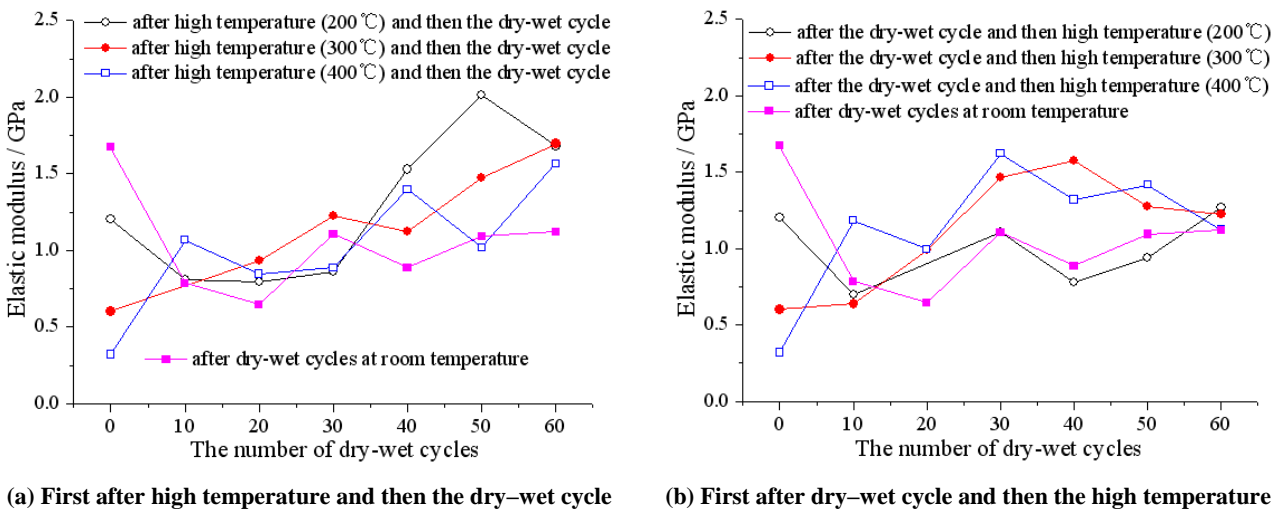


Figure 6. Variation of specimen elastic modulus with dry-wet cycling times

According to Figure 6(a):

When the number of dry-wet cycles was nil, as the high temperature gradually increased from room temperature (25°C) to 400°C, the elastic modulus of the specimens gradually decreased. This is consistent with the findings of Sahmaran et al. [9]. The elastic moduli of the specimens that experienced high temperatures of 200°C, before their dry-wet cycles, first decreased and then increased as the number of dry-wet cycles increased. The elastic moduli of the specimens that experienced high temperatures of 300°C and 400°C, before their dry-wet cycles, increased with the number of dry-wet cycles.

According to Figure 6(b):

The elastic moduli of specimens after dry–wet cycles at room temperature, and dry–wet cycles before experiencing a high temperature of 200°C, generally first decreased and then increased as the number of dry–wet cycles increased. For the high temperatures of 300°C and 400°C before the dry–wet cycles, the elastic moduli of specimens increased with the number of dry–wet cycles.

5. Conclusions

- When the specimens only experienced high temperatures, as the temperature increased gradually from room temperature (25°C) to 400°C, the compressive strengths and elastic moduli of the specimens gradually decreased, while the strain at the peak stress gradually increased. The compressive strengths of the specimens that underwent dry–wet cycling at room temperature increased with the increase in the number of dry–wet cycles. The compressive strength of the specimens that experienced both heating and dry–wet cycles, in either order, generally first decreased then increased as the number of dry–wet cycles increased.
- The peak strains of the heating before dry and wet cycles group and the dry and wet cycles before heating group decreased with the increase in the number of cycles.
- The elastic moduli of specimens that underwent dry–wet cycling at room temperature, and those that had dry–wet cycles followed by a high temperature of 200°C, generally first decreased and then increased as the number of dry–wet cycles increased. The elastic moduli of specimens that had dry–wet cycles followed by high temperatures of 300°C and 400°C increased with the number of dry–wet cycles.

6. Funding Acknowledgements

This work was supported by the Systematic Project of Guangxi Key Laboratory of Disaster Prevention and Engineering Safety (Grant No. 2019ZDK051), and the Open Research Fund of State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin (China Institute of Water Resources and Hydropower Research, (Grant No. IWHR-SKL-201708).

7. Conflicts of Interest

The authors declare no conflict of interest.

8. References

- [1] Li, Gen Feng, and Xiang Dong Shen. "A Study of the Durability of Aeolian Sand Powder Concrete Under the Coupling Effects of Freeze–Thaw and Dry–Wet Conditions." *JOM* 71, no. 6 (April 23, 2019): 1962–1974. doi:10.1007/s11837-019-03440-9.
- [2] Wei, Mu-Wang, Jian-He Xie, Huan Zhang, and Jiang-Lin Li. "Bond-Slip Behaviors of BFRP-to-Concrete Interfaces Exposed to Wet/dry Cycles in Chloride Environment." *Composite Structures* 219 (July 2019): 185–193. doi:10.1016/j.compstruct.2019.03.049.
- [3] Yan, Changgen, Zhiquan Zhang, and Yanlin Jing. "Characteristics of Strength and Pore Distribution of Lime-Flyash Loess Under Freeze-Thaw Cycles and Dry-Wet Cycles." *Arabian Journal of Geosciences* 10, no. 24 (December 2017). doi:10.1007/s12517-017-3313-5.
- [4] Li, Yue, Tongfei Shi, Yaqiang Li, Weiliang Bai, and Hui Lin. "Damage of Magnesium Potassium Phosphate Cement Under Dry and Wet Cycles and Sulfate Attack." *Construction and Building Materials* 210 (June 2019): 111–117. doi:10.1016/j.conbuildmat.2019.03.213.
- [5] Chen, Fei, Jianming Gao, Bing Qi, Daman Shen, and Luyang Li. "Degradation Progress of Concrete Subject to Combined Sulfate-Chloride Attack Under Drying-Wetting Cycles and Flexural Loading." *Construction and Building Materials* 151 (October 2017): 164–171. doi:10.1016/j.conbuildmat.2017.06.074.
- [6] Ma, Haiyan, Wei Gong, Hongfa Yu, and Wei Sun. "Durability of Concrete Subjected to Dry-Wet Cycles in Various Types of Salt Lake Brines." *Construction and Building Materials* 193 (December 2018): 286–294. doi:10.1016/j.conbuildmat.2018.10.211.
- [7] Liu, Hao, Haoliang Huang, Xintong Wu, Huixin Peng, Zhaoheng Li, Jie Hu, and Qijun Yu. "Effects of External Multi-Ions and Wet-Dry Cycles in a Marine Environment on Autogenous Self-Healing of Cracks in Cement Paste." *Cement and Concrete Research* 120 (June 2019): 198–206. doi:10.1016/j.cemconres.2019.03.014.
- [8] Yin, Shiping, Lei Jing, Mengti Yin, and Bo Wang. "Mechanical Properties of Textile Reinforced Concrete Under Chloride Wet-Dry and Freeze-Thaw Cycle Environments." *Cement and Concrete Composites* 96 (February 2019): 118–127. doi:10.1016/j.cemconcomp.2018.11.020.

- [9] Sahmaran, M., T.K. Erdem, and I.O. Yaman. "Sulfate Resistance of Plain and Blended Cements Exposed to Wetting–drying and Heating–cooling Environments." *Construction and Building Materials* 21, no. 8 (August 2007): 1771–1778. doi:10.1016/j.conbuildmat.2006.05.012.
- [10] Gong, Jian, Jian Cao, and Yuan-feng Wang. "Effects of Sulfate Attack and Dry-Wet Circulation on Creep of Fly-Ash Slag Concrete." *Construction and Building Materials* 125 (October 2016): 12–20. doi:10.1016/j.conbuildmat.2016.08.023.
- [11] Wu, Jin, Hongming Li, Zhe Wang, and Jingjing Liu. "Transport Model of Chloride Ions in Concrete Under Loads and Drying-Wetting Cycles." *Construction and Building Materials* 112 (June 2016): 733–738. doi:10.1016/j.conbuildmat.2016.02.167.
- [12] Du, Hongxiu, Jia Wu, Gaili Liu, Huiping Wu, and Ruizhen Yan. "Detection of Thermophysical Properties for High Strength Concrete after Exposure to High Temperature." *Journal of Wuhan University of Technology-Mater. Sci. Ed.* 32, no. 1 (February 2017): 113–120. doi:10.1007/s11595-017-1568-z.
- [13] Khan, M. S., and H. Abbas. "Effect of Elevated Temperature on the Behavior of High Volume Fly Ash Concrete." *KSCE Journal of Civil Engineering* 19, no. 6 (December 12, 2014): 1825–1831. doi:10.1007/s12205-014-1092-z.
- [14] Meng, Ercong, Yalin Yu, Jun Yuan, Ke Qiao, and Yisheng Su. "Triaxial Compressive Strength Experiment Study of Recycled Aggregate Concrete after High Temperatures." *Construction and Building Materials* 155 (November 2017): 542–549. doi:10.1016/j.conbuildmat.2017.08.101.
- [15] Li, Z.W., Xu, J.Y., Bai, E.L. "Static and dynamic mechanical properties of concrete after high temperature exposure." *Materials Science and Engineering A* 544, no.15 (May 2012): 27-32. doi:10.1016/j.msea.2012.02.058.
- [16] Liu, Ziqing, Yuzhuo Wang, Guoqiang Li, Jian Jiang, and Chuanguo Fu. "Mechanical Behavior of Cross-Shaped Steel Reinforced Concrete Columns after Exposure to High Temperatures." *Fire Safety Journal* 108 (September 2019): 102857. doi:10.1016/j.firesaf.2019.102857.
- [17] Zhai, Chaochen, Li Chen, Qin Fang, Wensu Chen, and Xiquan Jiang. "Experimental Study of Strain Rate Effects on Normal Weight Concrete after Exposure to Elevated Temperature." *Materials and Structures* 50, no. 1 (August 10, 2016). doi:10.1617/s11527-016-0879-4.
- [18] Arioiz, Omer. "Effects of Elevated Temperatures on Properties of Concrete." *Fire Safety Journal* 42, no. 8 (November 2007): 516–522. doi:10.1016/j.firesaf.2007.01.003.
- [19] Ma, Qianmin, Rongxin Guo, Zhiman Zhao, Zhiwei Lin, and Kecheng He. "Mechanical Properties of Concrete at High temperature—A Review." *Construction and Building Materials* 93 (September 2015): 371–383. doi:10.1016/j.conbuildmat.2015.05.131.