



## Tests on the Mechanical Properties of Corroded Cement Mortar after High Temperature

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Received 22 November 2019; Accepted 21 January 2020

### Abstract

Durability of cement mortar and concrete materials under sea water condition is always an important research topic. The objective of this work is to understand the mechanical properties of corroded cement mortar after high temperature, the cement mortar specimens after high temperature were placed in water and sodium sulfate solution, and then the uniaxial compression tests were carried out on the cement mortar specimens after corroded. Test results show that both the differences of compressive strength and strain at the peak stress after high temperature caused by high temperature, are relatively small when the specimens are eroded in water, and the differences are relatively high when the specimens are eroded in sodium sulfate solution. The compressive strength of the cement mortar specimens under normal temperature eroded in sodium sulfate solution is highest, and that eroded in water is lowest. The compressive strength of specimen after high temperature eroded in water is highest and that eroded in sodium sulfate solution is lowest. The strain at the peak stress of specimen, whether after high temperature or not, is highest when eroded in sodium sulfate solution, and that eroded in water is lowest. At present, there are few research results about the mechanical properties of concrete first after high temperature and then after sea water corrosion. The work in this paper can enrich the results in this area.

**Keywords:** Cement Mortar; High Temperature; Erosive Solution; Mechanical Properties.

### 1. Introduction

As for subsea tunnel concrete lining, one side is basically exposed to air, and the other sides contact with the surrounding rock and the seawater, and the lining concrete of subsea tunnel will be under the erosion of seawater. The durability of the lining concrete determines the service life of undersea tunnel. Therefore, study on the subsea tunnel concrete lining has great practical value. Mechanical properties of concrete in seawater erosion are an important indicator of the durability evaluation of concrete structures in marine environment. Many researchers have conducted test research on the mechanical properties of concrete after sea- water erosion, e.g. Park et al. [1], Lee et al. [2], Çavdar and Yetgin [3], Kathirvel et al. [4], Sirisawat [5], Xiong et al. [6], Han et al. [7], Xie et al. [8] and Li et al. [9].

The above-mentioned studies always placed specimens in erosive solution for long-term immersion, and then took some specimens out for mechanical properties test at intervals. However, fire must be considered in the design of tunnel, i.e. stability of lining structure under high temperature. A number of fire examples show that the fire will cause damage with varying degrees to the lining structure. The tunnel will collapse due to the deterioration of the mechanical

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 <http://dx.doi.org/10.28991/cej-2020-03091483>



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properties of lining concrete, the reduction of the cross-sectional thickness of the lining and the imposed earth pressure. For the post-fire mechanical properties of concrete, many researches have been conducted, e.g. Chan et al. [10], Li et al. [11], Husem [12], Zheng et al. [13], Li et al. [14], Choe et al. [15] and Shumuye et al. [16].

The effect of fire on the safety of concrete structure is remarkably important. And the damage of fire to the durability of concrete structures cannot be ignored, especially for the concrete structures in coastal areas. Although the durability of concrete structures after fire has been concerned by researchers, the research on this subject was rarely reported. These researches mainly focus on the carbonation of concrete and the diffusion law of chloride ions after fire, but other issues were not involved, such as the mechanical properties of concrete under attack of chloride and sulfate erosions after fire, in which the mechanical properties of concrete is an important indicator to evaluate the durability of concrete structures.

In this study, the cement mortar specimens after high temperature were immersed in water and sodium sulfate solution, and then we investigated the differences of mechanical properties of cement mortar specimens immersed in water and sodium sulfate solution through uniaxial compression tests after erosion.

## 2. Research Methodology

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

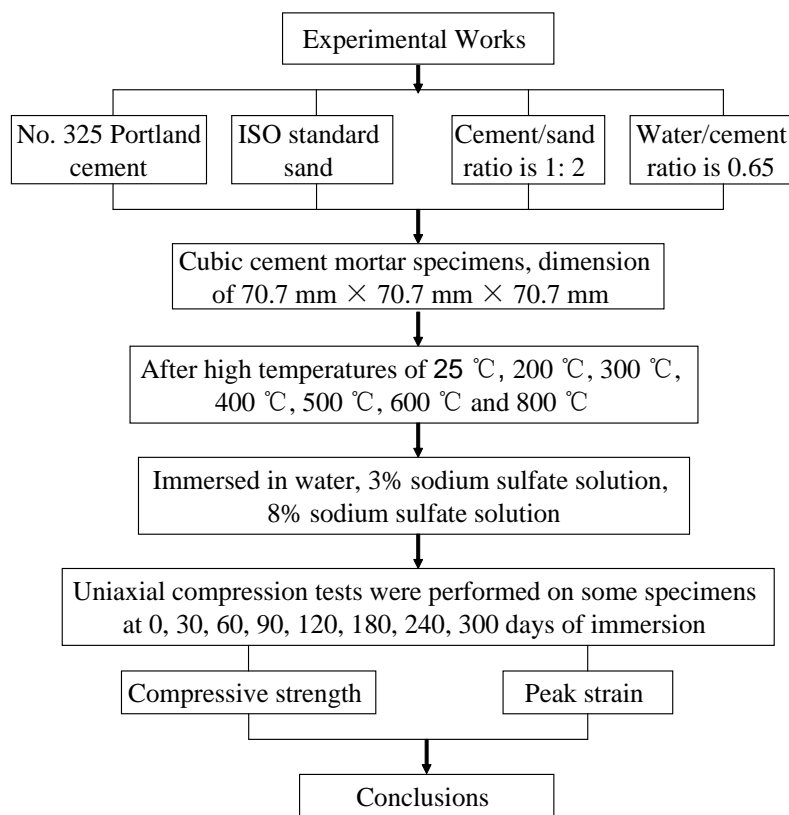


Figure 1. Flow chart for research methodology

## 3. Test Set-up

### 3.1. Specimen Preparation

No. 325 cement employed in this test was normal cement produced by the China Building Materials Academy. The tricalcium aluminate ( $C_3A$ ) constitutes 6% to 8% of the normal cement, the tricalcium silicate ( $C_3S$ ) 50% to 55%, the free lime ( $fCaO$ ) less than 1.2%, and the alkali ( $Na_2O+0.658K_2O$ ) less than 1.0%. The ISO standard sand was used which is conformed to Chinese National Standard GB/T17671-1999. Its particle size ranges from 0.5 mm to 1.0 mm.

### 3.2. Specimen Preparation

Cement mortar specimens have a dimension of 70.7 mm × 70.7 mm × 70.7 mm. The cement/sand ratio of 1: 2 was considered, and w/c (water/cement) ratio was 0.65.

### 3.3. Test Procedure

All the specimens were cured in the room temperature of 20 °C and relative humidity of 95% for 28 days. After that, these specimens were elevated to the peak temperatures of 200 °C, 300 °C, 400 °C, 500 °C, 600 °C and 800 °C at the

heating rate of 10 °C/min, respectively. After the peak temperature was reached, it was maintained for another 2 h; then the specimens were cooled down to the room temperature in the furnace and then were taken out. Specimens after and not after high temperature were immersed in water, sodium sulfate solution with concentration of 3% and sodium sulfate solution with concentration of 8%. The number of specimens after and not after high temperature immersed in each type of erosive solution is the same. Uniaxial compression tests were performed on some specimens at 0, 30, 60, 90, 120, 180, 240, 300 days of immersion. The photos of specimens after high temperature before the corrosion test is shown in Figure 2.

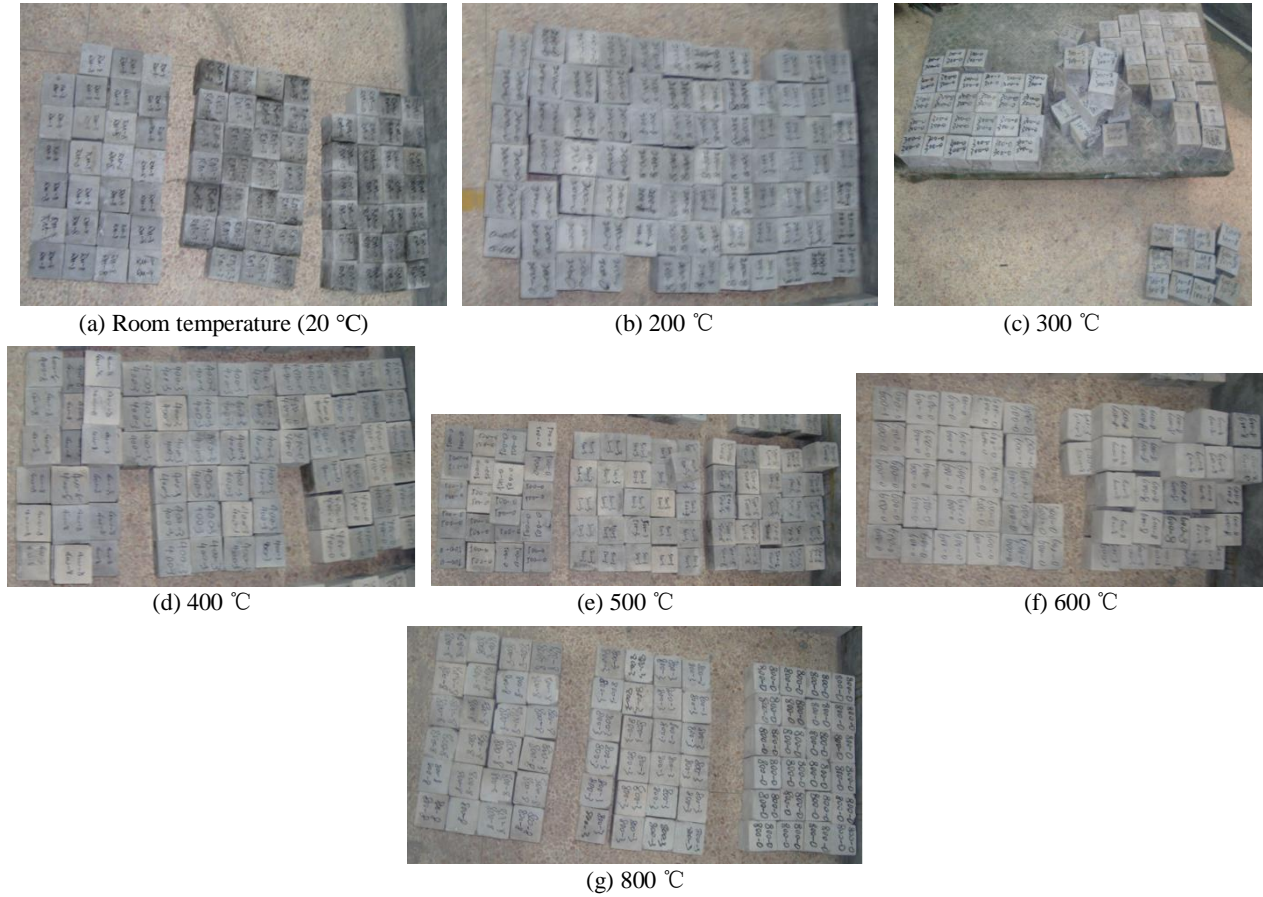


Figure 2. The photos of specimens after high temperature before the corrosion test

### 3.4. Uniaxial Compression Test Machine

Uniaxial compression tests were conducted using WAW-600C universal testing machine. The maximum loading rate of the testing machine is 60 mm / min, and the maximum compression load is 600 kN. Uniaxial compression tests were performed under the strain rate of  $10^{-4} \text{ s}^{-1}$  in this study. The numbers of the three specimens without high temperature and corrosion are set as # RM-0d-1, # RM-0d-2 and # RM-0d-3. The loading-time curves of these three specimens are shown in Figure 3.

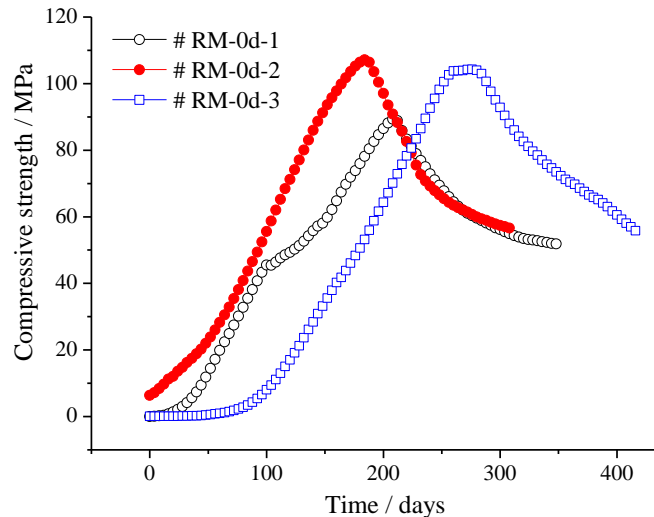
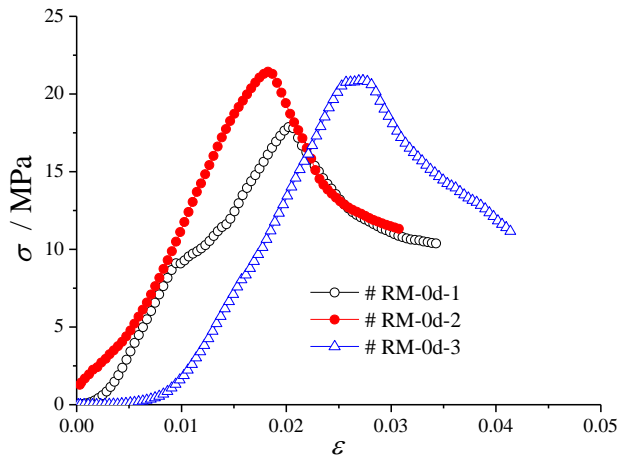
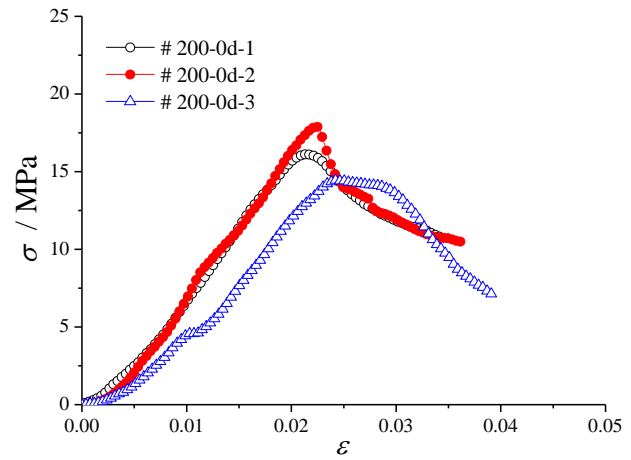


Figure 3. The loading-time curves of specimens

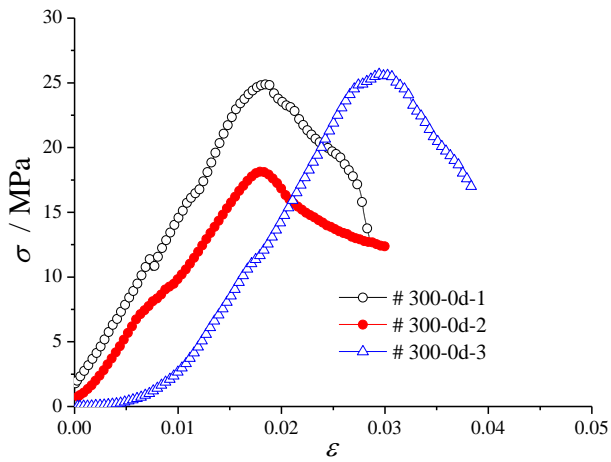
The numbers of specimens for uniaxial compression test after high temperature without corrosion are set as follows: (1) 200 °C, # 200-0d-1, # 200-0d-2 and # 200-0d-3; (2) 300 °C, # 300-0d-1, # 300-0d-2 and # 300-0d-3; (3) 400 °C, # 400-0d-1, # 400-0d-2 and # 400-0d-3; (4) 500 °C, # 500-0d-1, # 500-0d-2 and # 500-0d-3; (5) 600 °C, # 600-0d-1, # 600-0d-2 and # 600-0d-3; (6) 800 °C, # 800-0d-1 and # 800-0d-2. The uniaxial compressive stress-strain curves of these specimens are shown in Figure 4.



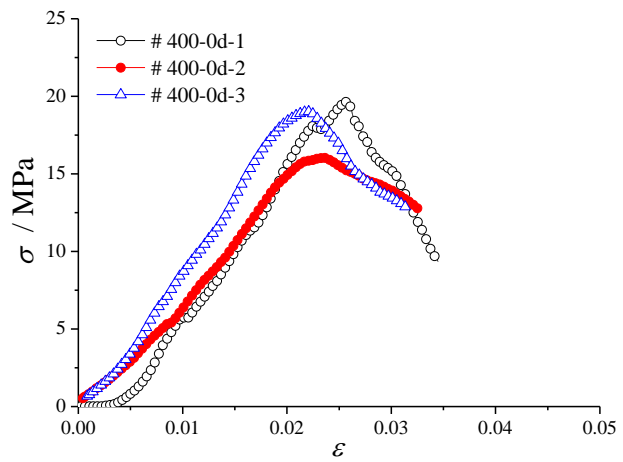
(a) Room temperature (20 °C)



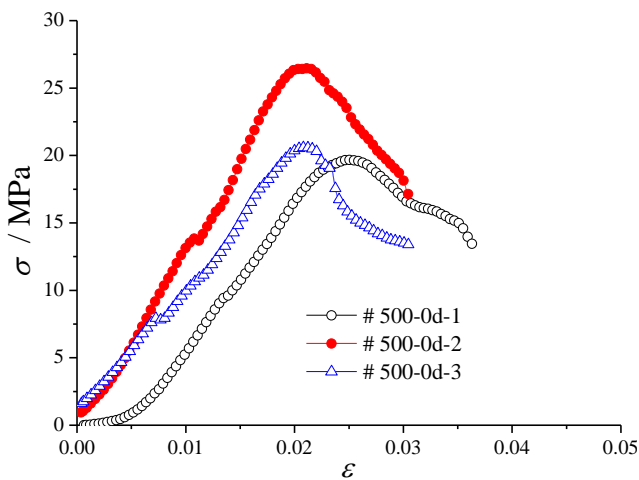
(b) 200 °C



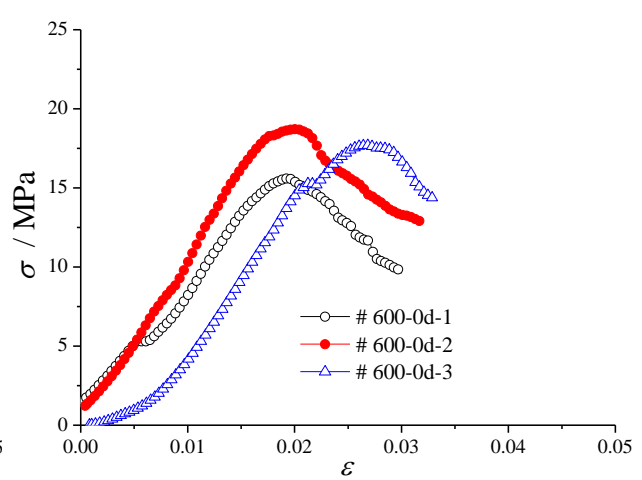
(c) 300 °C



(d) 400 °C



(e) 500 °C



(f) 600 °C

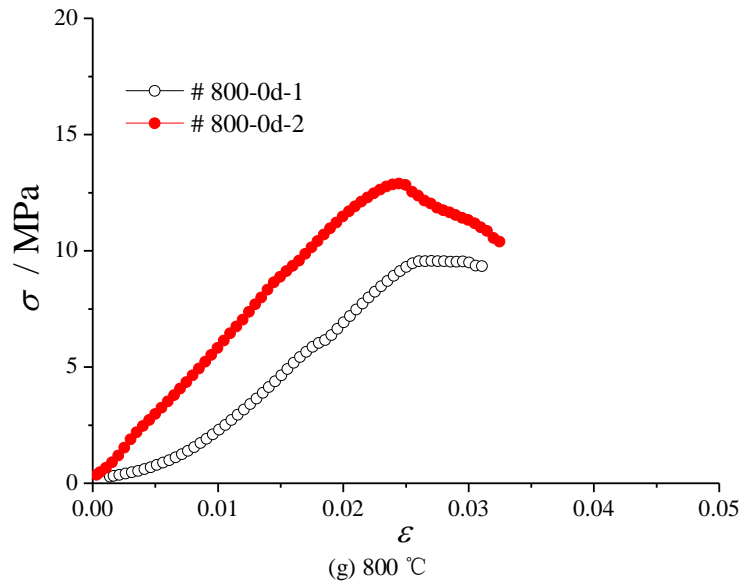


Figure 4. The uniaxial compressive stress-strain curves of specimens after high temperature without corrosion

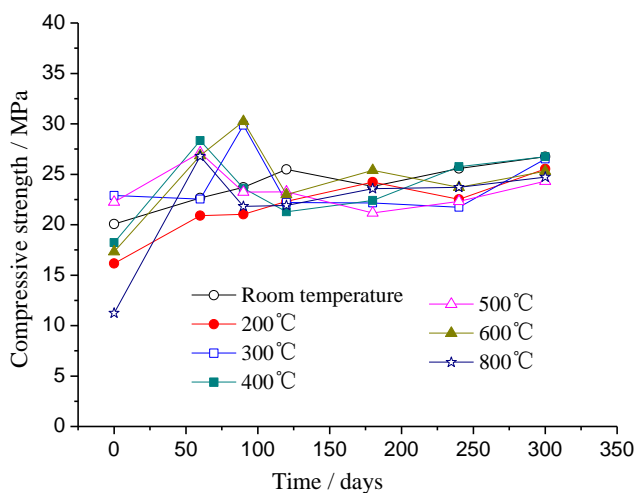
The compressive strengths of the three specimens after each high temperature are basically close, and the average value of the compressive strengths of the three specimens can be used for analysis in the later part.

## 4. The Evolution of Compressive Strength

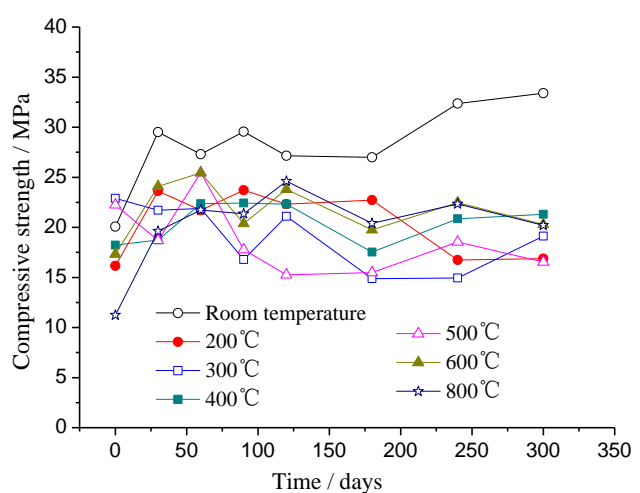
### 4.1. The Influence of Temperature

The compressive strengths of cement mortar specimens immersed in water, sodium sulfate solution with concentration of 3% and sodium sulfate solution with concentration of 8% are shown in Figure 5.

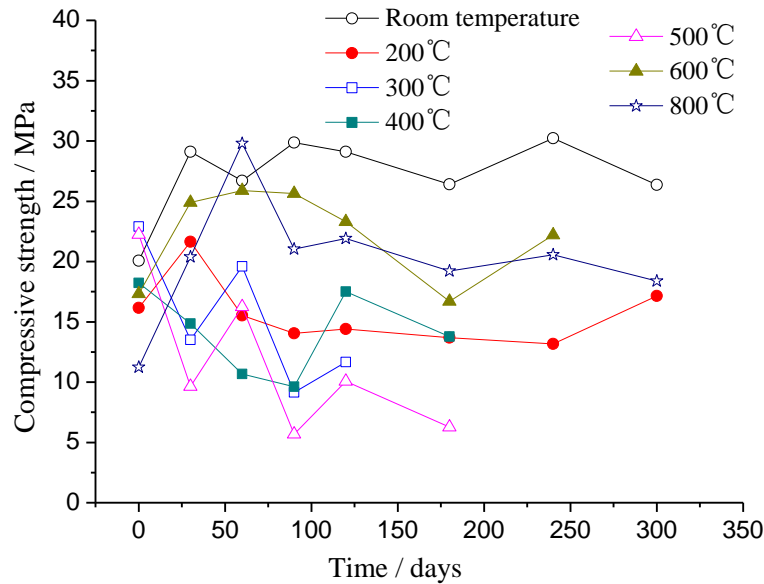
It can be observed that the difference of compressive strength of specimen induced by temperature is relatively small when immersed in water, and the compressive strength of specimen under normal temperature is close to that after high temperature. The compressive strength of specimen under normal temperature is higher than that after high temperature when immersed in sodium sulfate solution with concentration of 3%, and the difference of compressive strength induced by temperature is higher than that immersed in water. The compressive strength of specimen under normal temperature is also higher than that after high temperature when immersed in sodium sulfate solution with concentration of 8%, and the difference of compressive strength induced by temperature is higher than that immersed in water. The influence of temperature on the compressive strength of specimen is varied in three kinds of solutions.



(a) In water



(b) In 3%  $\text{Na}_2\text{SO}_4$  solution

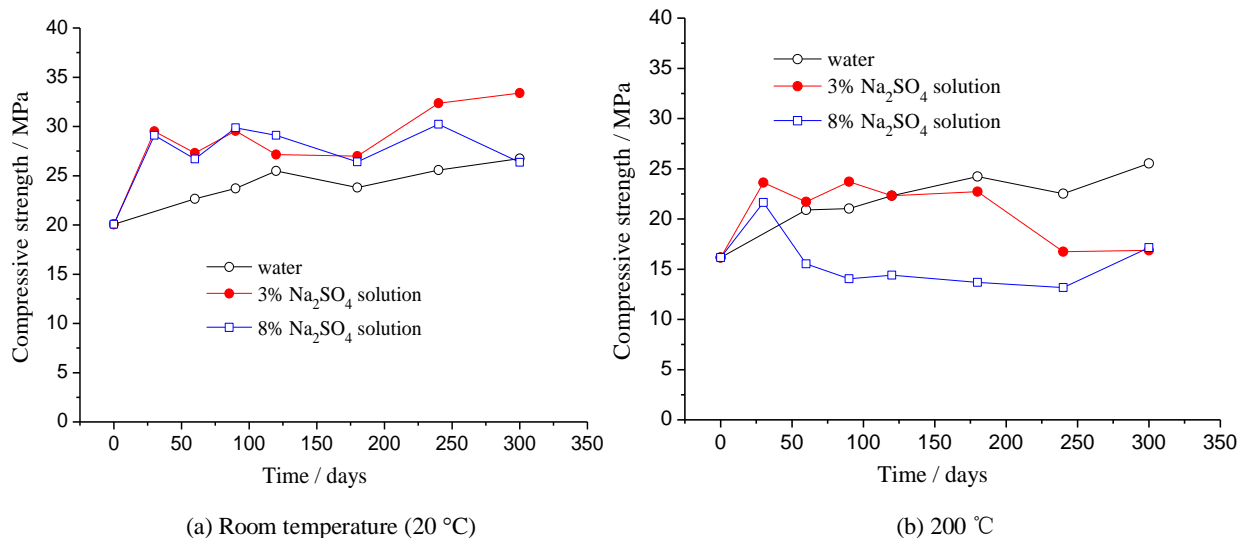
(c) In 8% Na<sub>2</sub>SO<sub>4</sub> solution**Figure 5. The effect of temperature on the compressive strength of cement mortar samples**

After the specimens with not high temperature treatment and with high temperature treatment are immersed in water, water will enter the specimen through the surface cracks and produce hydration products, and the compressive strength of the specimen is continuously improved.

The longer the time the specimen is immersed in water, and the difference of compressive strength of specimen will gradually decrease. When the specimen without subjected to high temperature is immersed in sodium sulfate solution, the surface of the specimen does not have any microcracks, the generated ettringite fills the initial pores and generates internal expansion tensile stress, many new pores and fissures will be generated, but the specimen will undergo hydration reaction during the entire erosion process, and the compressive strength of specimen will gradually increase even after long-term immersion in sodium sulfate solution. When the specimen after high temperature is immersed in sodium sulfate solution, because there are many cracks on the surface of the specimen, the ettringite produced at this time is significantly more than that of specimen that has not been subjected to high temperature. The decrease in the compressive strength of the specimen is significantly greater than the increase in the compressive strength of specimen caused by the hydration product, thus, the compressive strength of the specimen will decrease.

#### 4.2. The Influence of Erosive Solution Type

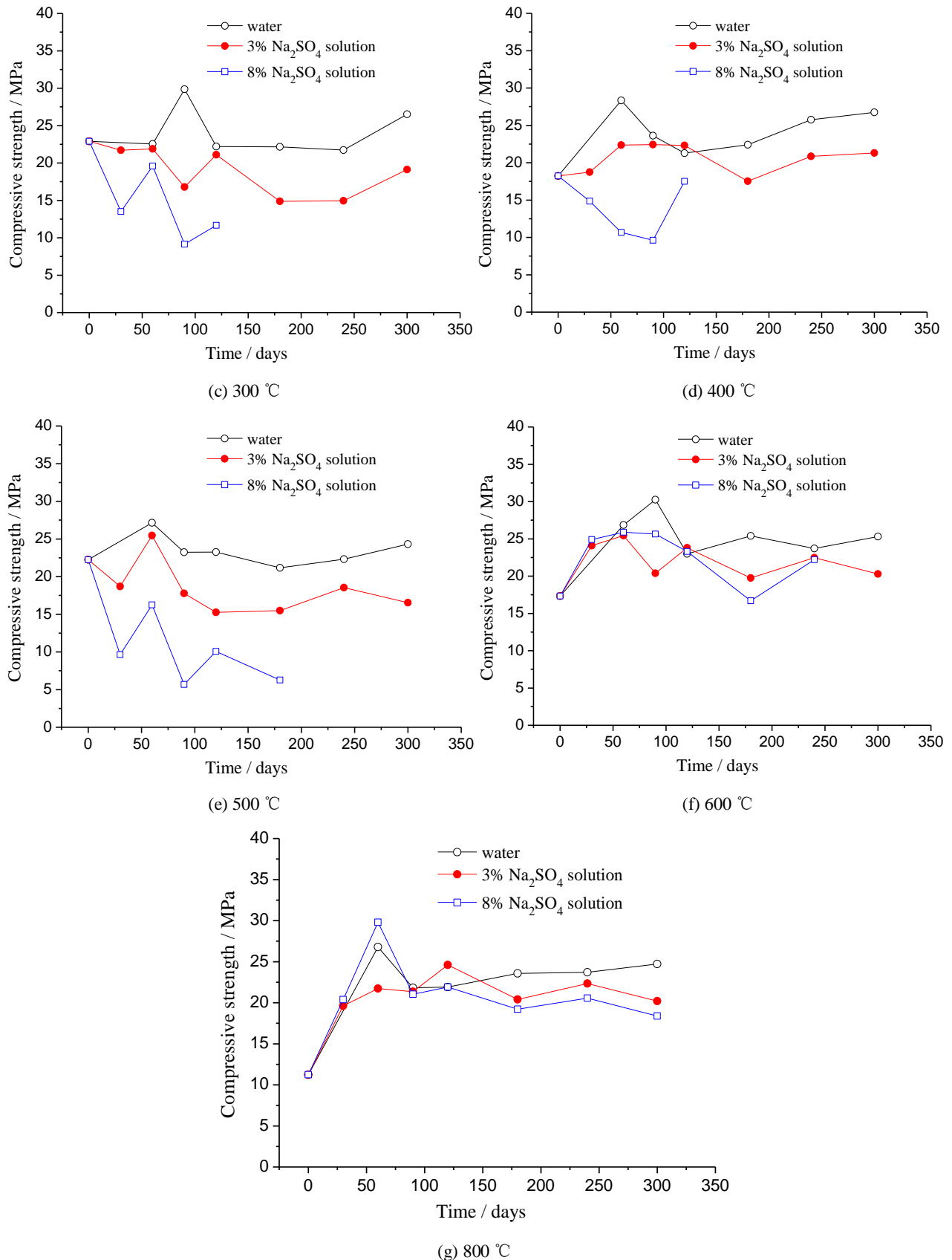
The influence of erosive solution type on the compressive strengths of specimens after each high temperature applied is shown in Figure 6.



(a) Room temperature (20 °C)

(b) 200 °C





**Figure 6. The influence of erosive solution types on the compressive strength of cement mortar samples under various temperatures**

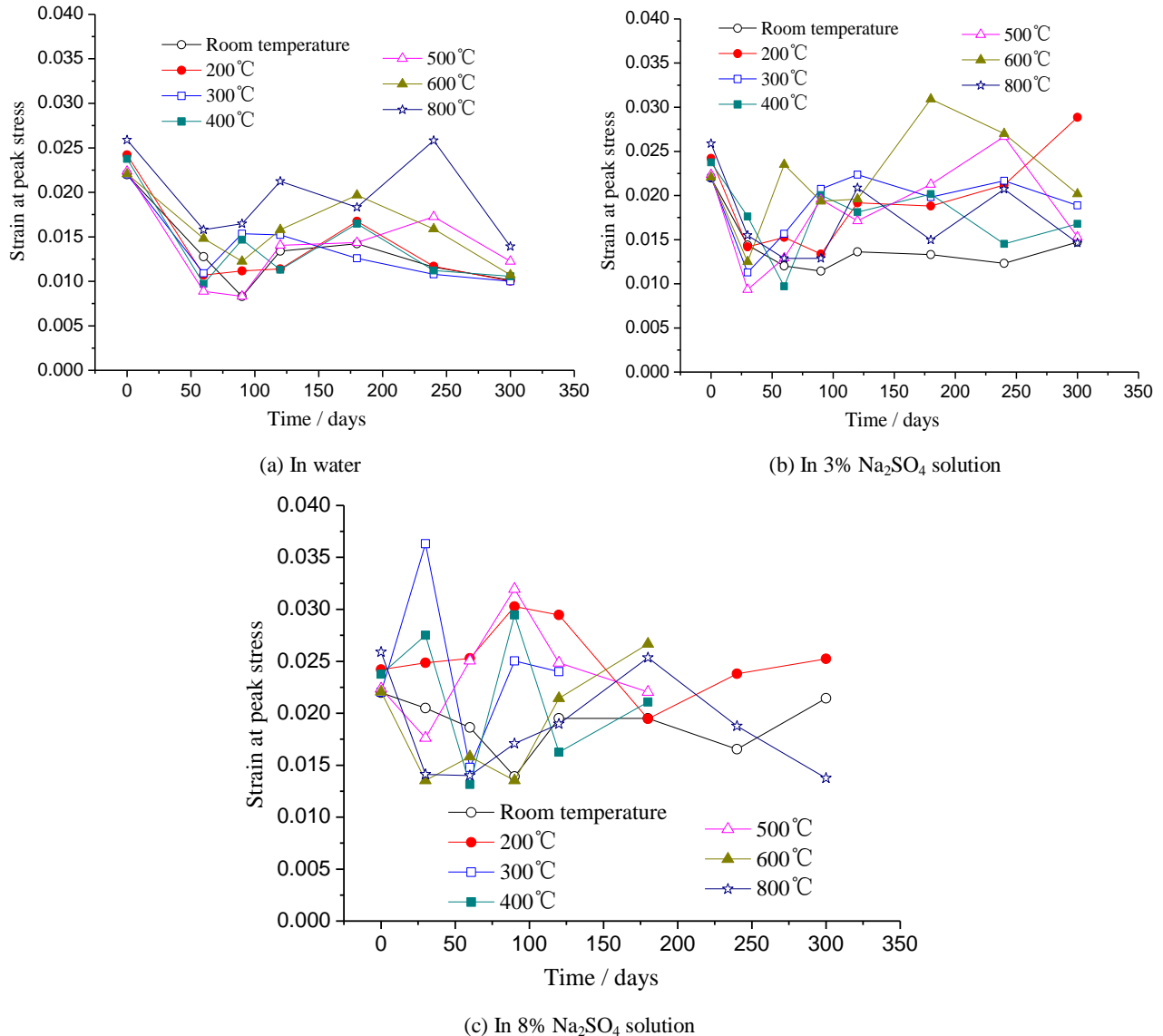
The compressive strength of specimens under normal temperature is the highest when immersed in sodium sulfate solution with concentration of 3%; next is in sodium sulfate solution with concentration of 8%, and the lowest is in water. The compressive strength of specimen after temperature is the highest when immersed in water; next is in sodium sulfate solution with concentration of 3%, and the lowest is in sodium sulfate solution with concentration of 8%.

After the specimen exposed to high temperature is immersed in sodium sulfate solution with concentration of 8%, it will produce significantly more ettringite at the same time than when immersed in the other two types of solutions, and the compressive strength of the specimen is lower than that when immersed in the other two types of solutions.

## 5. The Evolution of Strain at the Peak Stress

### 5.1. The Influence of Temperature

The strains at the peak stresses of cement mortar specimens immersed in water, sodium sulfate solution with concentration of 3% and sodium sulfate solution with concentration of 8% are shown in Figure 7.



**Figure 7. The effect of various temperatures on the strain at the peak stress of cement mortar samples**

The difference of strain at the peak stress of specimen induced by temperature is relatively small when immersed in water, and the difference is relatively large in sodium sulfate solution with concentration of 3% or 8%. The influence of temperature on the strain at the peak stress of specimen also varied in these three kinds of solutions.

### 5.2. The Influence of Erosive Solution Type

The influence of erosive solution type on the strain at the peak stress of specimens after each high temperature is shown in Figure 8. The strains at the peak stresses of specimens after high temperature and normal temperature are the highest when immersed in sodium sulfate solution with concentration of 8%; next is in sodium sulfate solution with concentration of 3%, and the lowest is in water.

After the specimen exposed to high temperature is immersed in sodium sulfate solution with concentration of 8%, the ductility of the specimen is enhanced, and the strain at the peak stress of the specimen is also significantly increased.



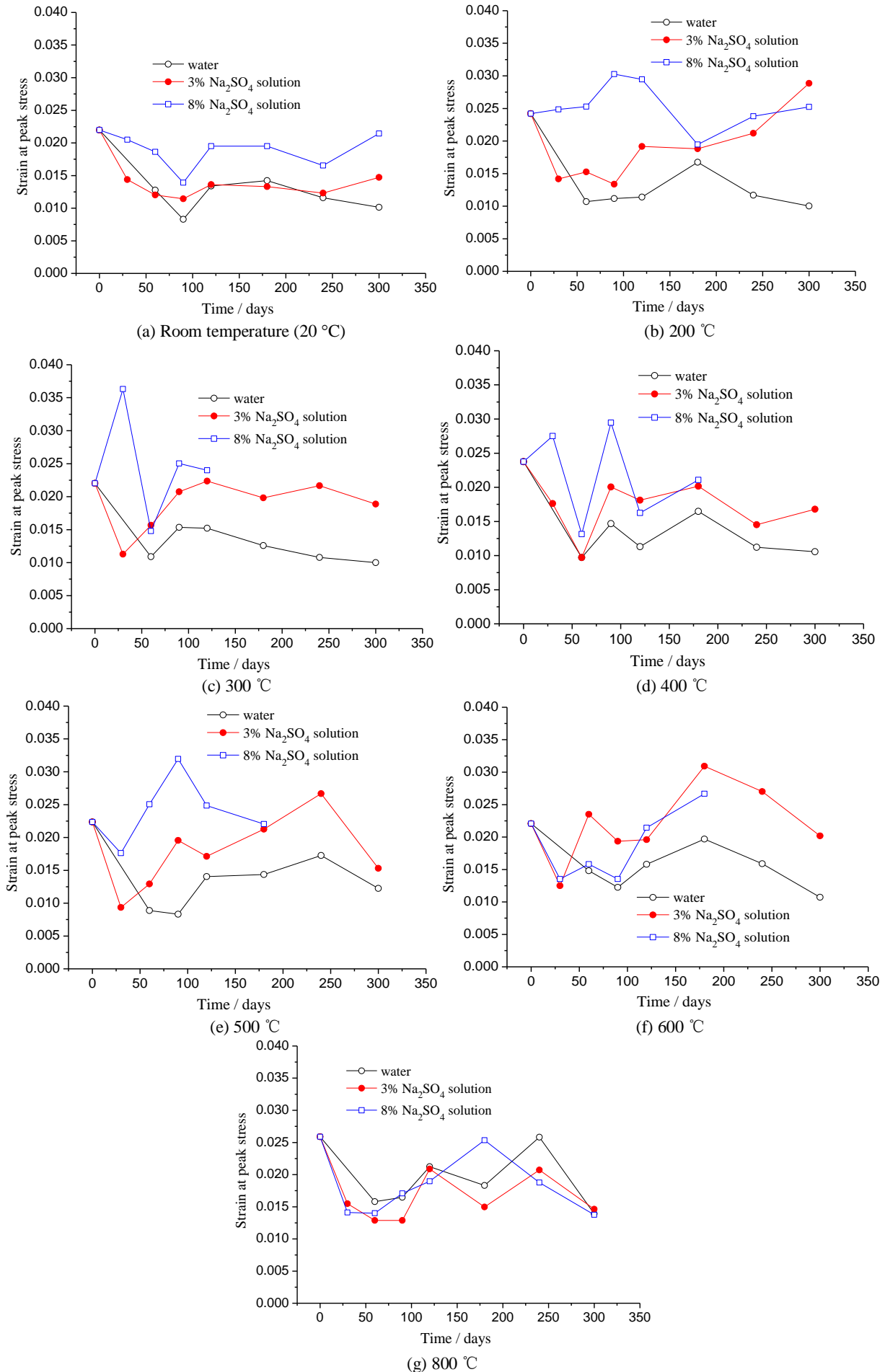


Figure 8. The influence of erosive solution type on the strain at the peak stress of cement mortar samples

## 6. Conclusions

- The difference of compressive strength of specimen induced by temperature is relatively small when immersed in water, and is relatively large when immersed in sodium sulfate solution with concentration of 3% and 8%. The influence of temperature on the compressive strength of specimen varies in water or sodium sulfate solution.
- The compressive strength of specimens under normal temperature is the highest when immersed in sodium sulfate solution with concentration of 3%; next is in sodium sulfate solution with concentration of 8%, and the lowest is in water. The compressive strength of specimen after temperature is the highest when immersed in water; next is in sodium sulfate solution with concentration of 3%, and the lowest is in sodium sulfate solution with concentration of 8%.
- The difference of the strain at the peak stress of specimen induced by temperature is relatively small when immersed in water, and the difference is relatively large in sodium sulfate solution with concentration of 3% or 8%. The influence of temperature on the strain at the peak stress of specimen also varies in water or sodium sulfate solution.
- The strains at the peak stresses of specimens after temperature and normal temperature are highest when immersed in sodium sulfate solution with concentration of 8%; next are in sodium sulfate solution with concentration of 3%, and the lowest are in water.

## 7. 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).

## 8. Conflicts of Interest

The authors declare no conflict of interest.

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