Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 171 (2017) 71 – 79

Procedia Engineering

www.elsevier.com/locate/procedia

Sustainable Civil Engineering Structures and Construction Materials, SCESCM 2016

Effects of temperature and moisture on concrete-PCM interface performance

Ueda Tamon[a], Khuram Rashid[b], Qian Ye[c], Zhang Dawei[d,]*

[a]Division of Engineering and Policy for Sustainable Environment, Hokkaido University, Kita 13, Nishi 8, Kita-ku, Sapporo 060-8628, Japan
[b]Department of Architectural Engineering & Design, University of Engineering & Technology, Lahore-54890, Pakistan
[c]Department of Civil Engineering and Engineering Mechanics, Columbia University, New York, NY, 10027, USA
[d]College Civil Engineering and Architecture, Zhejiang University, 866 Yuhangtang Road, Hangzhou 310058, China

Abstract

There is a lack of study on effects of temperature and moisture on concrete-polymer cementitious mortar (PCM) interface mechanical properties. This paper briefly introduces the outcomes of two studies; one on effects of exposure with elevated temperature and moisture and the other with freezing and thawing temperature cycles and moisture. The former show that there are significant effects of elevated temperature on both tensile and shear bond strength and that there are small effects of moisture. The bond strength can be estimated by the proposed formula with a function of constituent material strengths after the exposure. On the other hand, the latter show that the tensile bond strength decreases with freeze thaw cycles (FTC), although PCM does not show the reduction with FTC. It is considered that the tensile bond strength reduction is caused by moisture effects on the interface.

Peer-review under responsibility of the organizing committee of SCESCM 2016.

Keywords: Concrete; PCM; interface; bond strength; temperature effect; moisture effect

1. Introduction

Cementitious materials for patching/overlaying of existing concrete structures have been widely used in the world. Generally, materials for patching/overlaying are required to be more durable and have better mechanical property than concrete substrate because of objectives of patching/overlaying. Besides, the thickness of materials is

* Corresponding author. Tel.: +81-11-706-6218; fax: +81-11-707-6582.
E-mail address: ueda@eng.hokudai.ac.jp

Peer-review under responsibility of the organizing committee of SCESCM 2016.
doi:10.1016/j.proeng.2017.01.311

usually thin, meaning that better property of shielding external substances is required. Polymer cementitious mortar (PCM or polymer modified cementitious mortar) is commonly adopted for patching/overlaying due to its good properties. At the same time PCM has some drawbacks. Polymer is known as temperature sensitive material and moisture effects are known to deteriorate polymer's property. Despite those facts there are lack of studies on effects of temperature and moisture on PCM property, especially on concrete-PCM interface property. This paper presents briefly the experimental outcomes on effects of temperature and moisture exposure conditions on concrete-PCM interface properties with several types of PCM commercially used now.

2. Effects of temperature and moisture on interface between concrete and various PCM

2.1. Results of various exposure conditions with elevated temperature and moisture

Effects of temperature on PCM are generally known, however, precise information of each PCM available in actual market is quite limited. Almost no information is available for temperature and moisture effects on interface property between PCM and concrete. Therefore, experimental investigation on PCM and concrete-PCM interface properties under temperature and moisture exposure conditions using 4 different PCM commercially available in Japan and China was conducted. The results show that general tendency for the effects of temperature and moisture on bonding properties is the same among those different PCM cases as shown below.

In order to see tendency of temperature effects on interface property, tension bond tests were conducted using concrete-PCM composite prism specimens with the 1st type of PCM (see Fig. 1) [1]. Test results are shown in Fig. 2. The exposure to 60 ℃ in air reduces tensile bond strength by 30% after 1 day but does not reduce further till 30 days. The tensile bond strength measured at 20 ℃ after 60 ℃ exposure is increased from the strength tested as 60 ℃ but not fully recovered. Some strength increase takes place after 30 days due to further hydration of PCM. Adopted temperature cyclic conditions were TC1 which consists of 60 ℃ in air for 12 hours and 30 ℃ in air for 12 hours and TC2 which consists of 24 hours of 60 ℃ in air, 24 hours of 20 ℃ in water, 24 hours of 0 ℃ in air and 24 hours of 25 ℃ in air. TC1 represents a climatic change for one day, while TC2 represents a climatic change for one year. 30 and 10 cycles were applied for TC1 and TC2 respectively. The reduction in tensile bond strength is more than that under constant 60 ℃ exposure.

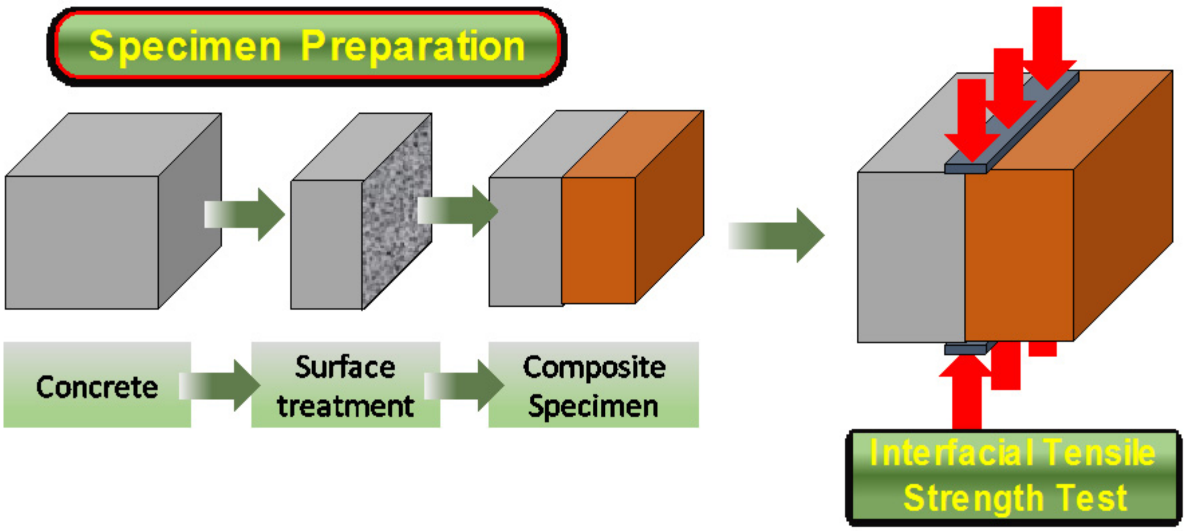

Fig. 1. Interfacial tensile strength specimen and loading condition.

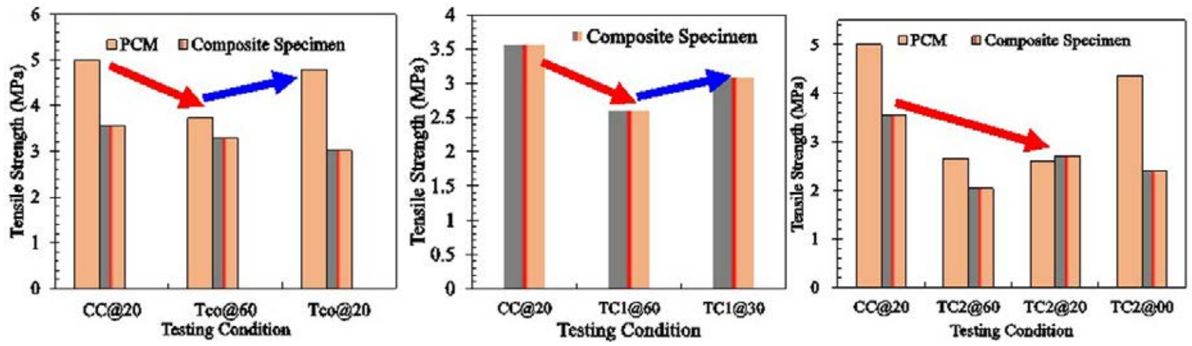

Fig. 2. Interfacial and PCM tensile strength under various temperature conditions.

The 2nd and 3rd types of PCM were used to examine combined effects of temperature and moisture on concrete-PCM interface strength. Figure 3 shows experimental outline. Tensile bond strength at concrete-PCM interface is less than tensile strength of PCM and concrete under any testing condition (see Fig. 4). However, bond strength reduction in % due to temperature increase from 20 °C to 60 °C is smaller than that of PCM. The effects of temperature on tensile bond strength are almost same between wet and dry conditions. Effects of moisture on tensile bond strength are hardly seen under wet/dry cycles and continuous immersion at 20 °C.

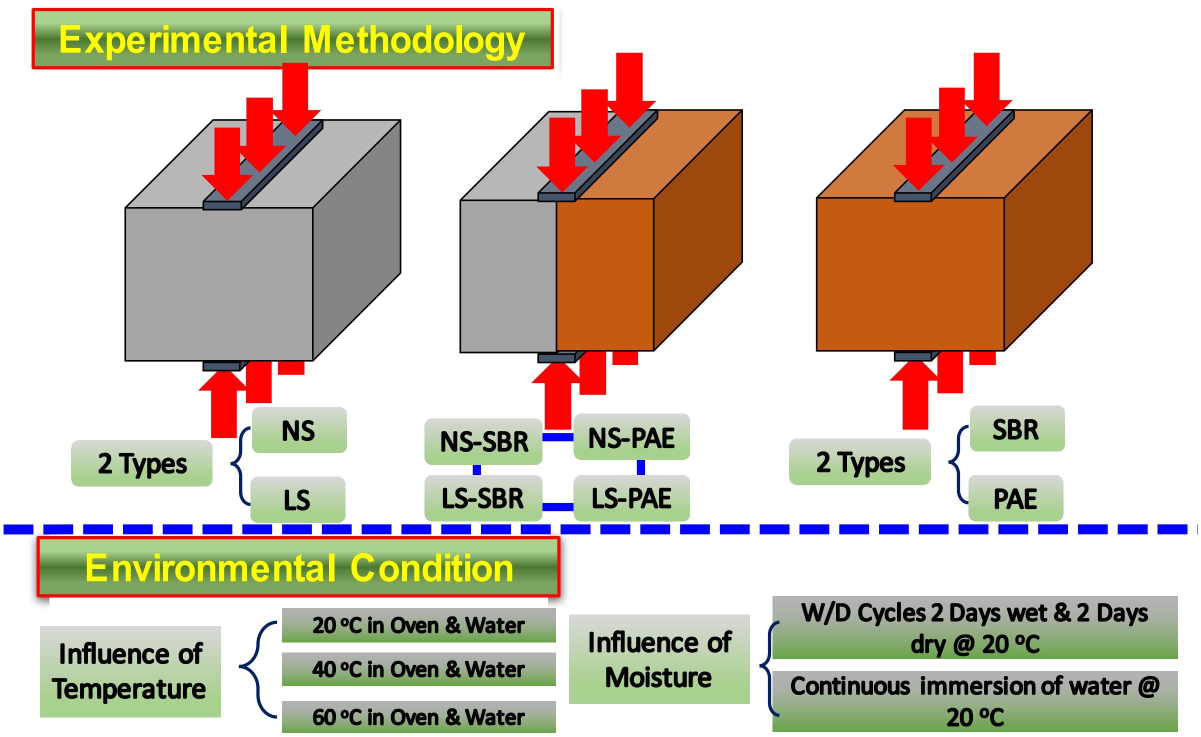

Fig. 3. Experimental outline for combined effects of temperature and moisture.

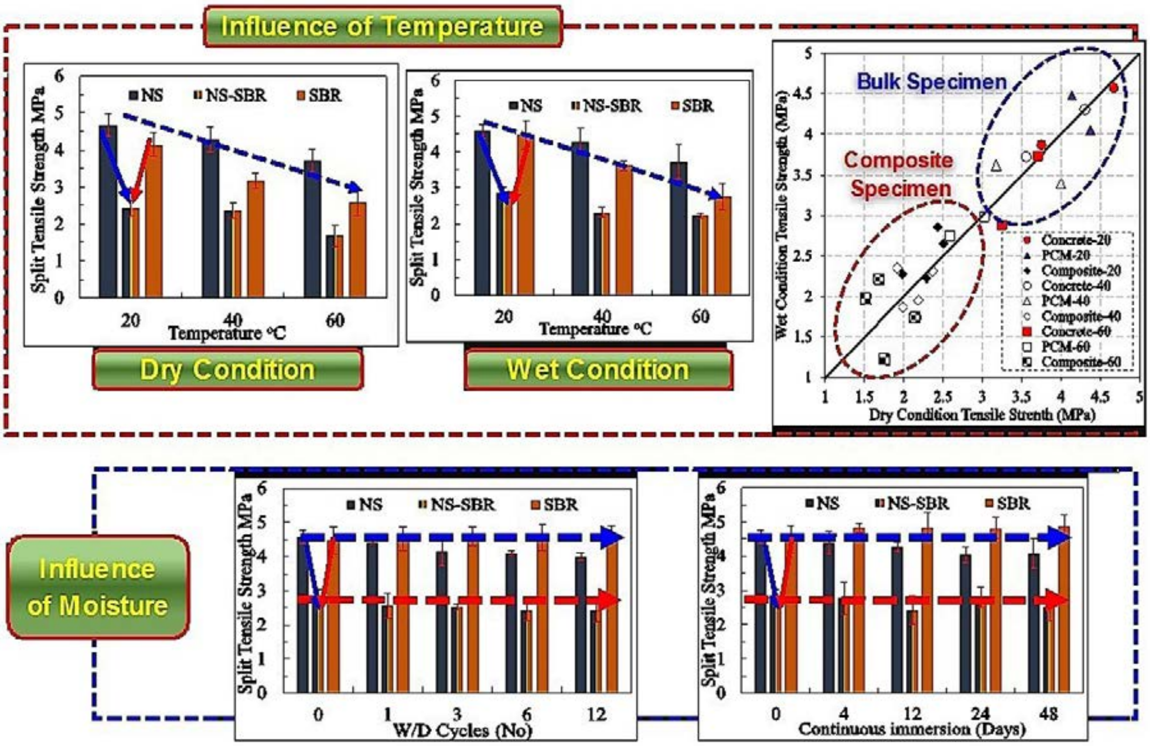

Fig. 4. Experimental results under combined effects of temperature and moisture.

The interfacial bond tests of 4th type of PCM, which was used for investigation of structural performances of beams strengthened by PCM overlaying, was conducted (see Fig. 5). There were two cases of surface treatments with and without primer. Tensile strength of the PCM is larger than the other three types of PCM and interfacial roughness is apparently higher than those for the other concrete-PCM composite specimens. Those facts are considered to be the reason why tensile bond strength is higher than those in the other concrete-PCM composite specimens. Not only tensile bond strength but also shear bond strength decreases with increase in temperature (see Fig. 6). Considering the observed relationship between strengths of constituent materials (PCM and concrete) and bond strength at their interface, the following Eqs. (1) and (4) can be proposed to estimate tensile and shear bond strength:

$$\frac{1}{f_{ITS}} = \frac{A_t}{f_{t.pcm}} + \frac{B_t}{f_{t.conc}} \tag{1}$$

where

f_{ITS} : Tensile bond strength at concerned temperature (MPa)

$f_{t,pcm}$: Tensile strength of PCM at concerned temperature (MPa)

$$= 1.2 f_{to.pcm} exp(-0.0095T) \tag{2}$$

$f_{t,conc}$: Tensile strength of concrete at concerned temperature (MPa)

$$= 1.07 f_{to,conc} exp(-0.004T) \tag{3}$$

$f_{to,pcm}$: Tensile strength of PCM after 28 days standard curing condition (MPa)
$f_{to,conc}$: Tensile strength of concrete after 28 days standard curing condition (MPa)
T : Temperature (20 ℃ < T < 60 ℃)
A_t, B_t : Experimental coefficients in tension

$$\frac{1}{\tau_{ISS}} = \frac{A_v}{\tau_{v.pcm}} + \frac{B_v}{\tau_{v.conc}} \tag{4}$$

τ_{ISS} : Shear bond strength at concerned temperature (MPa)
$\tau_{v.pcm}$: Shear strength of PCM at concerned temperature (MPa)

$$= 2\tau_{vo.pcm} exp(-0.03T) \tag{5}$$

$\tau_{v.conc}$: Shear strength of concrete at concerned temperature (MPa)

$$= 0.99\tau_{vo,conc} exp(0.0015T) \tag{6}$$

$\tau_{vo.pcm}$: Shear strength of PCM after 28 days standard curing condition (MPa)
$\tau_{vo.conc}$: Shear strength of concrete after 28 days standard curing condition (MPa)
T : Temperature (20 ℃ < T < 60 ℃)
A_v, B_v : Experimental coefficients in shear

Figure 7 shows the comparison of predicted bond strength and experimental strength for the 2nd, 3rd and 4th types of PCM. Good agreement can be seen for both cases with and without primer (–WP and –NP).

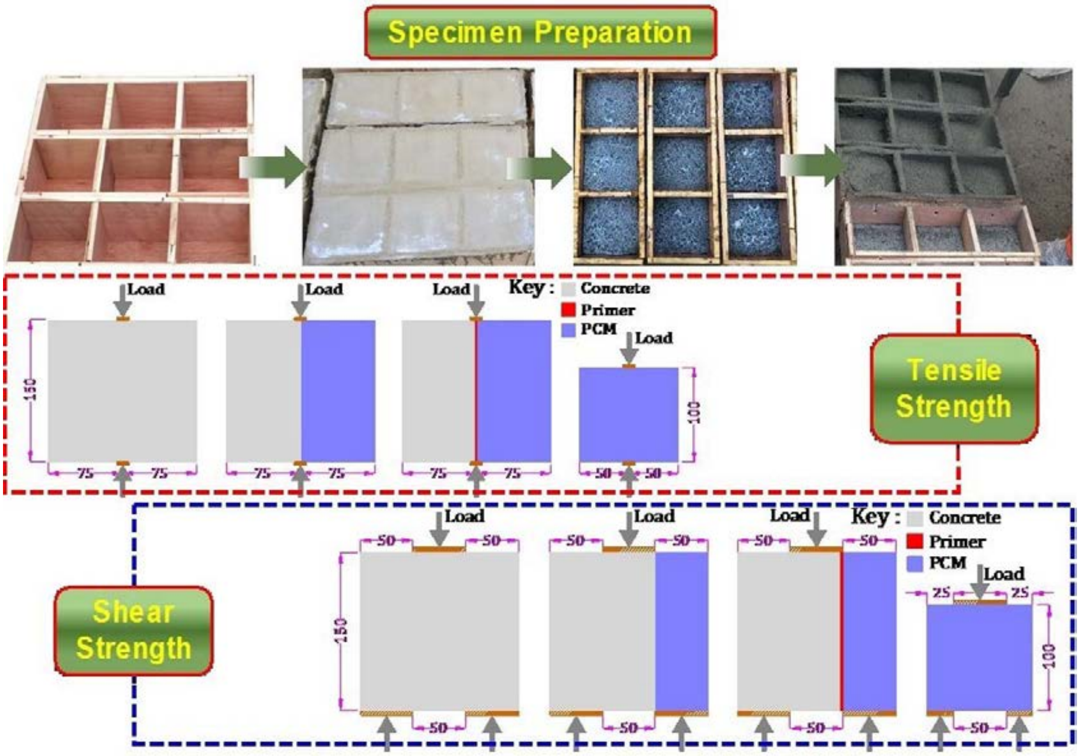

Fig. 5. Experimental outline for bond tests of interface in beam strengthened by PCM overlaying.

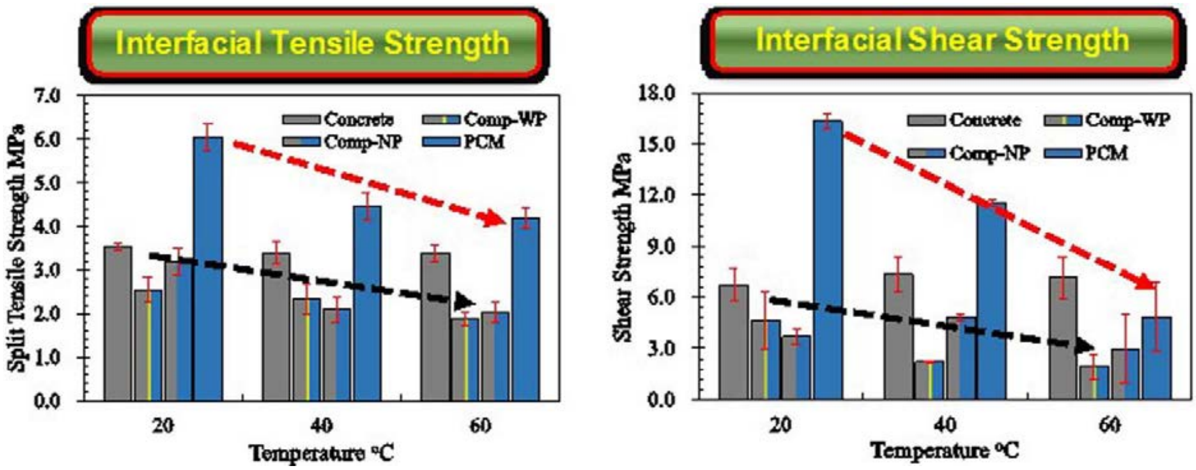

Fig. 6. Effects of temperature on both tensile and shear bond strength.

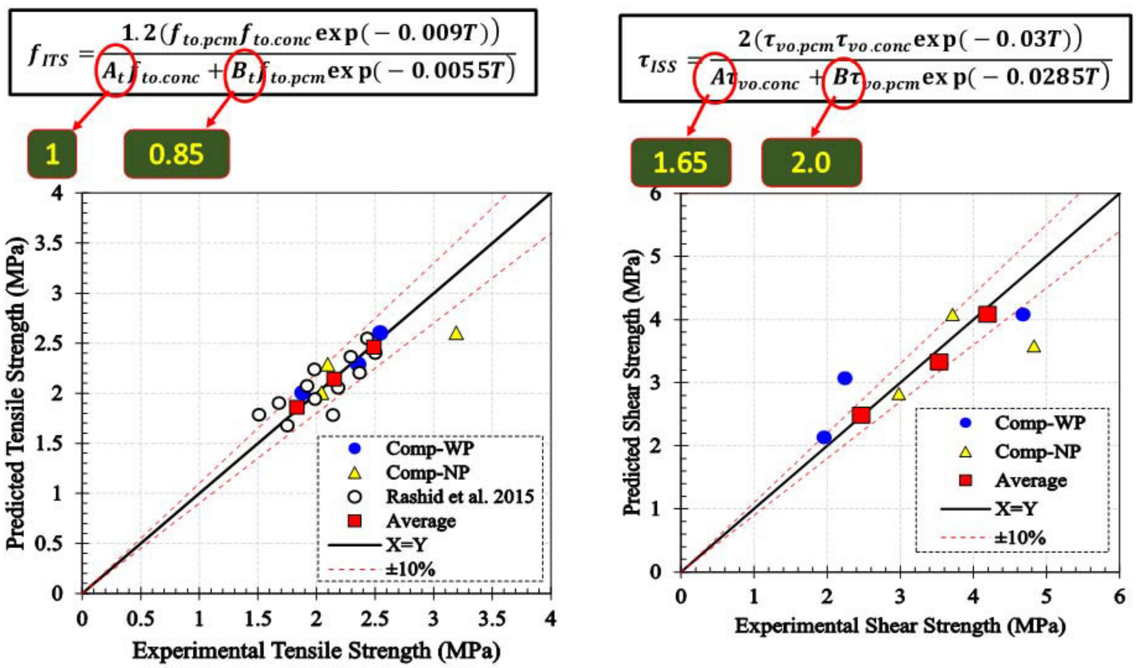

Fig. 7. Comparison between predicted and experimental tensile and shear bond strengths.

2.2. Results of exposure conditions with freeze thaw cycles and moisture

Actual climatic conditions are not only elevated temperature but also freezing temperature. Generally, polymer does not have melting point and glass transition temperature below freezing point. Freeze thaw cycles with wet condition causes frost damage in concrete and wet condition may cause degradation in polymer property. Considering those facts, 5th type of PCM was experimentally examined for mechanical properties of its own and interface with concrete under freeze thaw cycles. For comparison, mortar with Portland cement (ordinary mortar) was also examined. The results show significant difference in the tensile bond strength (or splitting tensile strength at interface obtained as in Fig. 1) as shown below [2].

Ordinary mortar with and without air-entraining agent (MA and MX) were used for the comparison with PCM as repairing material. There were two types of substrate concrete with normal and high strength (N/NA and HA). Figure 8 shows the splitting tensile strength of concrete-ordinary mortar composite together with that of constituent materials. The ordinary mortar is with air-entraining agent (MA). It is clearly shown that the strength at interface is weaker than those of constituent materials. Although the strength reduction with freeze thaw cycles (FTC) is found for normal strength substrate concrete without air entraining agent (N), the interface strength (N-MA) did not show the strength reduction. Once the strength of constituent material (N) became less due to FTC than that of composite interface, the failure mode changed from the interface adhesive failure to the cohesion failure of the constituent material and the splitting strength of the composite showed some reduction (see Fig. 8 (c)). When the constituent material with air-entraining agent (NA, HA and MA), there is no strength reduction with FTC, thus no strength reduction of composite interface. The experimental results of concrete-ordinary mortar without air-entraining agent (MX) composite are shown in Fig. 9. The weakest strength was found with the concrete-mortar composite. The splitting strength of MX and composite were reduced with FTC. Although the substrate concrete does not show the strength reduction, the composite interface shows the strength reduction with FTC due to the strength reduction of the mortar (MX) with FTC.

In the case of PCM the experimental results were different from the cases of ordinary mortar. It can be seen in

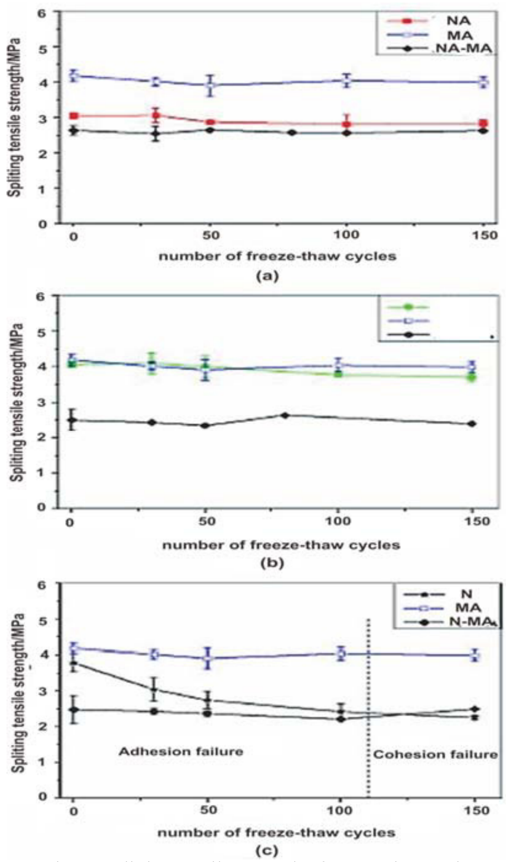

Fig. 8. Splitting tensile strength of composite specimens (concrete-ordinary mortar with air-entraining agent) and those of constituent materials

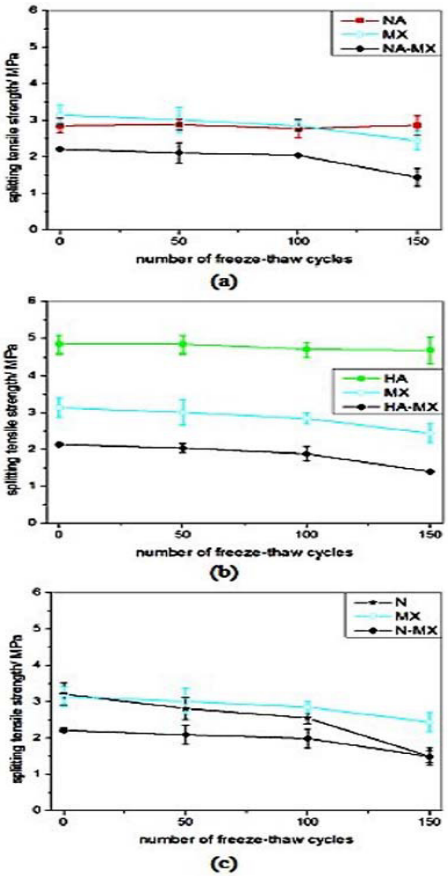

Fig. 9. Splitting tensile strength of composite specimens (concrete-ordinary mortar without air-entraining agent) and those of constituent materials

Fig. 10 that the weakest strength is with the composite interface, and that PCM did not show the strength reduction with FTC. However, the composite interface strength always showed the strength reduction with FTC no matter how the constituent materials, including PCM itself, show the strength performance under FTC. The reason of this strength reduction was considered that there was the moisture effect on concrete-PCM interface. The moisture penetrated gradually from the edge of interface, which was not sealed, causing the bonding deterioration, which causes further moisture penetration, causing further deterioration. Some past studies also show the material degradation of PCM due to moisture. In the experiment the material deterioration was only found at interface and external surface of PCM as shown in Fig. 11.

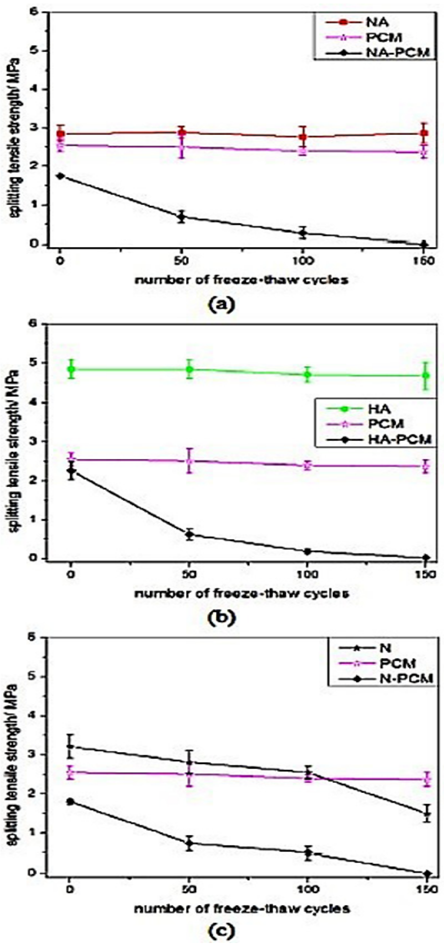

Fig. 10. Splitting tensile strength of composite specimens (concrete-PCM) and those of constituent materials

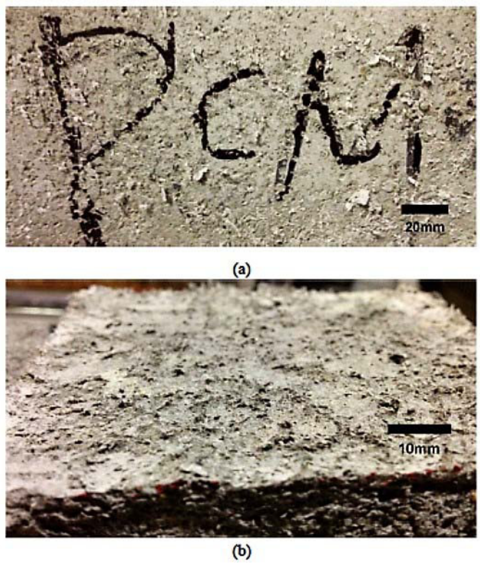

Fig. 11. PCM surface deterioration (flakes dropping) after FTC: (a) External surface, (b) Interface

3. Concluding remarks

The results of experimental investigations on effects of concrete-PCM interface performance with various PCM (1st, 2nd, 3rd, 4th and 5th type of PCM) can be concluded as follows:

3.1. Results of various exposure conditions with elevated temperature and moisture

The experimentation was conducted with four types of PCM (1st, 2nd, 3rd and 4th type of PCM). Tensile/shear bond strength of concrete-PCM interface is affected significantly by elevated temperature but less by moisture. The tensile/shear bond strength is less than tensile/shear strength of constituent materials (PCM and concrete). The reduction in tensile/shear bond strength depends on the reduction in tensile/shear strengths of PCM and concrete and then estimated by proposed equation which is a function of PCM and concrete strength.

3.2. Results of exposure conditions with freeze thaw cycles and moisture

The experiment was conducted with one type of PCM (5th type of PCM) and ordinary cement mortar. Tensile bond strength (splitting tensile strength at interface) does not decrease with freeze thaw cycles (FTC) when ordinary mortar as repairing material shows no reduction with FTC. However, it does show the reduction when ordinary mortar shows reduction. Tensile bond strength of concrete-PCM does show the strength reduction with FTC, even though PCM does not show any reduction with FTC. This reduction is observed for both cases of substrate concrete showing the reduction in its splitting strength with FTC and no reduction.

3.3. Recommendation of further study

Effects of moisture on concrete-PCM interface performance are different between elevated temperature and freezing thawing temperature cycles. Effects may be different when different PCM is applied, meaning that further study is necessary for collection of more data with various PCM. Although the case with elevated temperature does not show significant effects of moisture, further study is necessary by conducting more cycles of wet and dry.

Acknowledgements

The authors are grateful to the Grant-in-Aid for Scientific Research (A) of Japan Society of Promotion of Science (No. 26249064), the Natural Science Foundation of China (Grant Nos. 51308494) and NEXCO Group Companies' Support Fund to Disaster Prevention Measures on Expressways as the financial supports to the studies in section 2.1. The authors are also grateful to the Research and Development Grant of Japan Institute of Construction Engineering (JICE), the Express Highway Research Foundation of Japan and the open fund of state key laboratory of coastal and offshore engineering of Dalian University of Technology (LP1406) for funding the study in section 2.2.

References

[1] K. Rashid, T. Ueda, D. Zhang, K. Miyaguchi and H. Nakai, Experimental and analytical investigations on the behavior of interface between concrete and polymer cement mortar under hygrothermal conditions, Construction and Building Materials, 94 (2015) 414-425.

[2] Y. Qian, D. Zhang, T. Ueda, Interfacial tensile bond between substrate concrete and repairing mortar under freeze-thaw cycles, J. Advanced Concrete Technology, 2016 (to be printed).