Pak. J. Engg. & Appl. Sci. Vol. 20 January, 2017 (*p*. 94–101)

Influence of Primer on Bond Integrity between Concrete-Polymer Cement Mortar at Elevated Temperature: in Tension, Shear and Moment

Khuram Rashid[1], Dawei Zhang[2] and Tamon Ueda[3]

1. *Department of Architectural Engineering and Design, University of Engineering and Technology, Lahore, Pakistan.*
2. *Institute of Structural Engineering, Zhejiang University, Hangzhou, China.*
3. *Faculty of Engineering, Hokkaido University, Sapporo, Japan.*

* **Corresponding Author:** E-mail: rashid@eng.hokudai.ac.jp; khuram_ae@uet.edu.pk

Abstract

In this experimental investigation, influence of temperature was investigated on composite specimens, which were prepared by spraying polymer cement mortar (PCM) on treated surface of concrete. The weakest part of the composite specimen is interface between concrete and PCM. To strengthen this part, primer was used which dense the interface. Two types of composite specimens were prepared in this experimental work, one by using primer at interface and second was without using it. Bond integrity of both types of composite specimens were investigated in tension, shear and moment. Tensile behavior was investigated by conducting interfacial split tensile strength and shear behavior was evaluated by conducting Bi-Surface shear strength. While moment was investigated by performing three and four point loading tests on strengthened beams. All tests were performed at 20 and 60°C. Reduction in interfacial tensile strength, interfacial shear strength and ultimate moment were observed at elevated temperature. Failure mode of strengthened beams also shifted from flexural to debonding mode. While the influence of primer was ignorable in this work.

Key Words: Composite specimen, Primer, Interfacial tensile strength, Interfacial shear strength, Ultimate moment, Temperature, Failure mode.

1. Introduction

Concrete structures are usually exposed to severe environmental conditions which deteriorate them and reduced the intended service life significantly. So, repairing of the deteriorated structures is the major concern now. Along with repairing, strengthening is another issue of RC structures which was incorporated in last few decades. Both objectives, repairing and strengthening, are achieved by overlaying of RC structure by using polymer cement mortar (PCM). PCM is cementitious material and used for repairing. PCM have superior properties than other cementitious materials in term of durability and also have good adhesion strength with the concrete at macro and micro level [1-4]. Composite specimens, after proper curing again exposed to such severe conditions, so, compatibility of composite structures must be ensured under such conditions.

Bond strength can also be evaluated by several methods, depend upon the objective to investigate the bond behavior in tension or shear [2, 5-8]. In tension, split tensile strength is as adequate method to get the tensile strength. Although, it is indirect measurement of the tensile strength, but widely used [2]. Bond strength can also evaluated by conducting interfacial split tensile strength because the tensile stresses are uniform along the entire interface [2, 5]. Bond strength in shear can be evaluated by conducting Bi-surface shear strength test. Direct shear strength test also gives the shear strength but large scattering of results were observed, whereas, Bi-Surface interfacial shear strength test is stable test as compared to direct shear test [1, 5].

Strengthening of RC structure by overlaying method is a most common method of repairing/strengthening [9, 10]. In which, different amount of reinforcement were used at soffit of beam.

Desired failure mode of RC beams is the flexural failure due to its ductile behavior. But for strengthened beams, debonding mode of failure is the common failure mode which is brittle failure and must be investigated in detail at design level [9-11].

Due to non-sustainable development, rapid industrialization and increase in traffic volume the environmental temperature increases day by day and may exceed to 60°C. So the behavior of composite specimens must be checked under such severe environmental temperature. Because polymers are sensitive to high temperature and may degrade significantly, depends upon the types of polymers [12, 13]. To incorporate such temperature condition on real structures, detailed experimental programme were designed. In which tensile and shear behavior were investigated by conducting interfacial split tensile strength test and Bi-Surface shear strength test, respectively. At structure level, RC beams were strengthened and tested under such conditions. Primer was also used at interface with the objective of increase in interfacial strengths and results were compared with the specimen having no primer at both temperature levels.

2. Experimental Setup

In this experimental investigation, large number of specimens were prepared by using concrete and PCM. Concrete is historic material and well recognized and used in almost all parts of the world. In this work, ready mix concrete was used having design cubical compressive strength of 30 MPa. While PCM is a new material and widely used in last few decades in different civil engineering works. And due to excessive use of polymers in construction industry, it was commercially manufactured and available in most parts of the world. Here, commercially available PCM was used, in which polymers were copolymers of vinyl acetate and ethylene. Silica sand was used along with the ordinary Portland cement to prepare PCM.

Concretes cubes of 150 x 150 x 75 and 150 x 150 x 100 mm were casted and one surface of each cube of size 150 x 150 was treated to prepare rough surface [14], on which PCM was sprayed to prepare composite specimens. Testing set-up and geometry of different composite specimens are explained in following subsections.

2.1 Test for Tensile Behavior

Bond in tension was investigated by conducting interfacial split tensile strength, in which composite specimen was prepared by spraying PCM on treated surface of concrete of size 150 x150 mm. 150 mm cube composite specimen was prepared. Specimen geometry and testing set-up is shown in Fig. 1. Total twelve specimens were casted, primer was sprayed at interface only on six specimens. Interfacial tensile strength was determined by using following Eq. (1) [6, 7, 15].

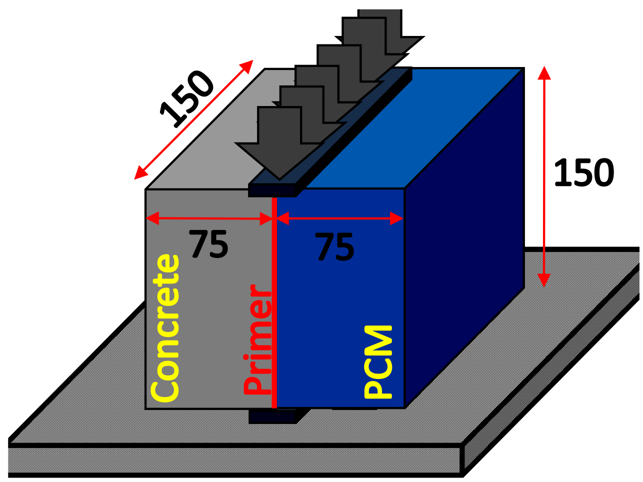

Fig.1 Specimen configuration and set-up for interfacial tensile strength.

$$f_t = \frac{2P_u}{\pi A} \quad (1)$$

where,

f_t = Interfacial split tensile strength (MPa);

P_u = Ultimate load (N);

A = Area of interface (mm^2)

2.2 Test for Shear Behavior

Fig. 2 presents the configuration and testing set-up of Bi-Surface interfacial shear strength, which was conducted to investigate the bond integrity in shear. Six specimens were prepared by applying primer at interface and remaining six specimens were prepared without using any primer. Bi-Surface shear strength is as adequate method to evaluate the shear behavior and bond integrity of composite specimens [5]. Interfacial shear strength was evaluated by using following Eq. (2).

$$\tau_v = \frac{P_u}{2A} \qquad (2)$$

where,

τ_v = Interfacial shear strength (MPa) ;

P_u = Ultimate load (N);

A = Area of interface (mm^2)

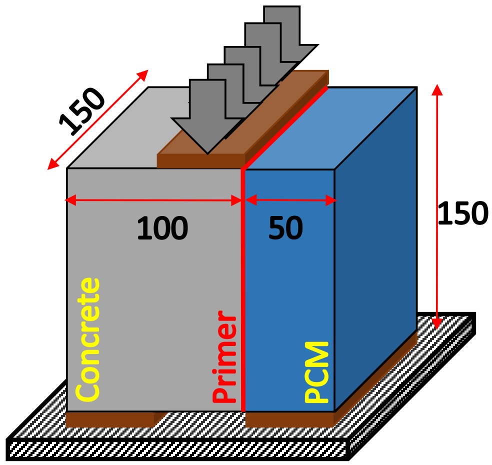

Fig. 2 Specimen configuration and set-up for interfacial shear strength.

2.3 Test for Moment Behavior

Ultimate moment was investigated by conducting three point loading (3PL) and four point loading (4PL) test. In 4PL, RC beams were strengthened by using two deformed bars of diameter 10 mm at soffit of RC beam. Longitudinal and cross sectional details along with the testing set-up are shown in Fig. 3(a, b). Total four beams were casted to test under 4PL. Two beams were casted by using primer at interface between concrete and PCM.

In three point loading (3PL) test, strengthening reinforcement were increased as compared to beams tested in 4PL. Three deformed bars of diameter 10 mm were used in overlay part instead of two bars. Cross section details of strengthened beam is presented in Fig. 3(c). Same number of strengthened beams were prepared for testing in 3PL as prepared for testing in 4PL.

2.4 Exposure Conditions

Influence of environmental temperature was incorporated in this work by exposing all types of composite specimens at elevated temperature of 60°C in laboratory [2]. Effect of temperature was evaluated by comparing the respective strengths tested at control condition of 20°C. Exposure conditions, types of composite specimens, types of tests and number of specimens at concerned condition are presented in Table 1.

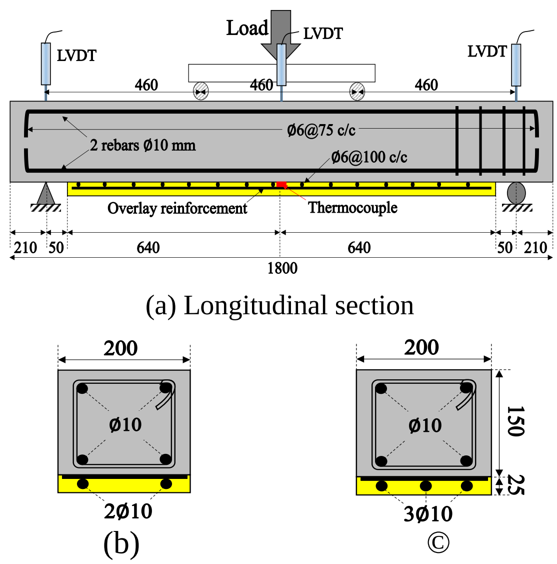

Fig. 3 Specimen configuration and set-up for beam test (a) Longitudinal section for 4PL (b) Cross section for 4PL (c) Cross section for 3PL.

Table 1 Summary of specimens for testing in tension, shear and moment.

Temperature	Primer	Shear Test		Tensile Test		Beam Test	
		No.	Abb.*	No.	Abb.	4PL**.	3PL***
20°C	Yes	3	$\tau_{v,20}WP$	3	$f_{t,60}NP$	$4PL_{20}WP$	$3PL_{20}WP$
	No	3	$\tau_{v,20}WP$	3	$f_{t,60}NP$	$4PL_{20}NP$	$3PL_{20}NP$
60°C	Yes	3	$\tau_{v,20}WP$	3	$f_{t,60}NP$	$4PL_{60}WP$	$3PL_{60}WP$
	No	3	$\tau_{v,20}WP$	3	$f_{t,60}NP$	$4PL_{60}NP$	$3PL_{60}NP$

*Abbreviation; ** Four point loading test; *** Three point loading test

3. Results and Data Discussion

3.1 Tensile Strength

Fig. 4 presents the interfacial split tensile strength of concrete-PCM composite specimens at 20 and 60°C. Average of three specimens were reported and standard deviation is presented by error bars in Fig. 4. Reduction in interfacial strength was observed with the increase in temperature. At 20°C, composite specimens with primer (WP) have lower strength than the specimens having no primer (NP) at interface between concrete and PCM. Primer improves the adhesion between concrete and PCM by penetration of polymers film into pores of the concrete and this adhesion is considered as to provide anchorage at micro level. This layer observed stronger than adhesion of aggregate cement paste. This was verified by visual inspection after failure of specimen. Although the failure was the interface failure but most of the concrete part attached to PCM side and the failure presented by concrete cohesion failure and presented by “C” in Fig. 1. Small crack initiated at middle of interface and propagated abruptly along the interface and the failure is sudden failure. There were negligible difference on the crack initiation load and ultimate load. NP specimen just provides the anchorage of polymer film by polymers in PCM. And the weakest zone was the interface and the failure was presented by “I” in Fig. 4. Due to stronger adhesion between concrete and PCM than the aggregate-cement paste the strength was higher than WP specimen. At 60°C, degradation in the interfacial strength was observed with and without primer case, the influence of primer seems to be insignificant at elevated temperature and almost similar strengths were observed. At 20°C, NP specimen’s strength was 25.6% more than WP specimen. And at 60°C, NP specimen was only 8.5% more than WP specimen and the failure mode was also shifted from “C” to “I” for WP specimen and “I” to “P” for NP specimens. Where “P” is the PCM cohesion failure and most of the PCM part was attached to the concrete side after visual inspection of failed surface.

3.2 Shear Strength

Fig. 5 presents the interfacial shear strength at both temperature levels. Standard deviation presented by error bars and mode of failure was presented by same notations as presented in Section 3.1. At 20°C, NP specimens have lower strength than WP specimens, 25.9% increase in strength was observed by using primer at interface. In case of shear, aggregate interlocking and roughness highly influence the interfacial shear strength [1]. The failure surface shows that the failure mode is cohesion failure of concrete and failed surface shows that the resistance was created by aggregate interlocking and that was the reason in increase in shear strength at control condition of 20°C, whereas in case of NP specimen the weak layer was concrete and PCM and due to limited adhesion of concrete and

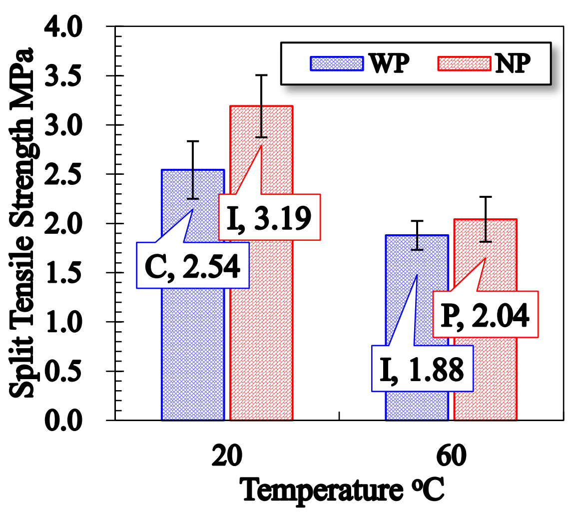

Fig.4 Influence of primer on tensile strength at elevated temperature.

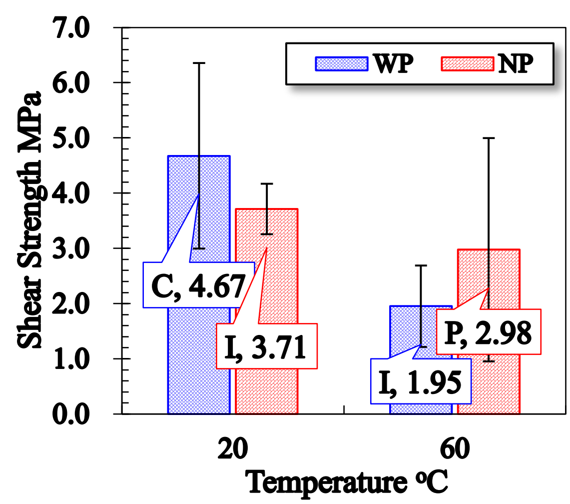

Fig.5 Influence of primer on shear strength at elevated temperature.

PCM, failure was observed at interface and clear separation of concrete and PCM was observed after failure. At elevated temperature of 60°C, reduction in interfacial shear strength was observed, reduction in WP specimen was more as compared to NP specimen. The failure of WP specimen was the interface failure which was smoother surface as compared to the concrete cohesion or PCM cohesion failure modes. NP specimens, have cohesive PCM failure and that was the reason that the interfacial strength was more by an amount of 52.8% from WP specimen at 60°C.

3.3 Comparison of Tensile and Shear Behavior

Fig. 6 presents the influence of temperature of the interfacial tensile and shear strengths. Reduction in strengths was observed with the increase in temperature. In tension, 26.13 and 35.99% reduction in strength was observed in WP and NP specimen, respectively, as compared to respective strengths at 20°C. Whereas in shear, 58.21% reduction in strength was observed of WP specimens at elevated temperature. Significant reduction was due to reduction in adhesion between concrete-PCM. And the failure was purely interfacial failure, no resistance was provided by interlocking of aggregates. But, specimens of NP specifications, reduction in interfacial shear strength was only 19.81% as compared to strength at 20°C. The failure was also

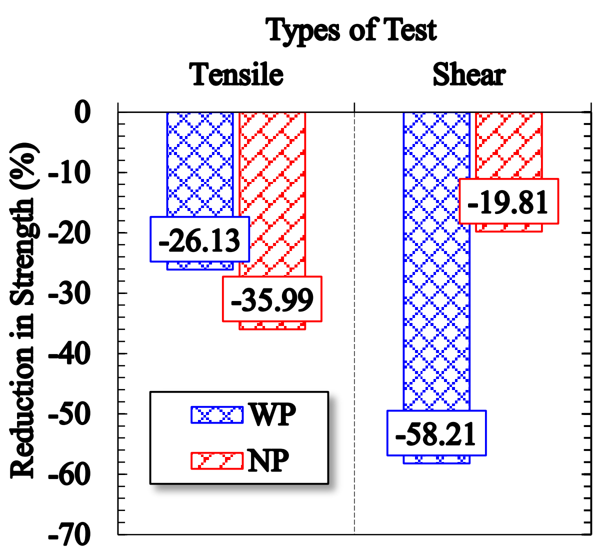

Fig.6 Influence of primer on shear strength at elevated temperature.

shifted from interface failure to PCM cohesion failure and resistance was provided by strong cohesion of PCM as compared to concrete-PCM adhesion. The reduction in strengths were due to the following reasons;

i) Reduction in mechanical strength of concrete was observed with the increase in temperature. Similar results was reported by several researchers and summary of many researchers were compiled by Bazant and Kaplan [16]. And also reported that reduction in tensile strength was more as compared to compressive strength at elevated temperature.

ii) Amount of cement also influences the strength at elevated temperature. More reduction in strength was observed with the increase in the amount of cement [16].

iii) Porosity is another factor which influence the strength of cementitious materials and increase in porosity was observed with the increase in temperature that is responsible for the reduction in strength [17].

iv) PCM is a cementitious material and rich in cement as compared to concrete so above mentioned three factor are responsible for severe reduction in strength of composite specimens at elevated temperature [2].

v) Polymers are sensitive to temperature and degraded at elevated temperature and may responsible for the degradation of polymer films and finally the mechanical strength of PCM [12, 13, 18, 19].

vi) Reduction in strength was also due to the different in coefficient of thermal expansions of aggregate, cement paste and PCM. Due to different rate of expansion, micro-cracks were generated at interface between respective materials and finally responsible for reduction in strength [16, 20].

Fig. 7 presents the ultimate moment of the strengthened beams, tested in four point loading (4PL), at both temperature level of 20 and 60°C. At 20°C, both types of beams, with and without primer, have almost similar ultimate moment value and the

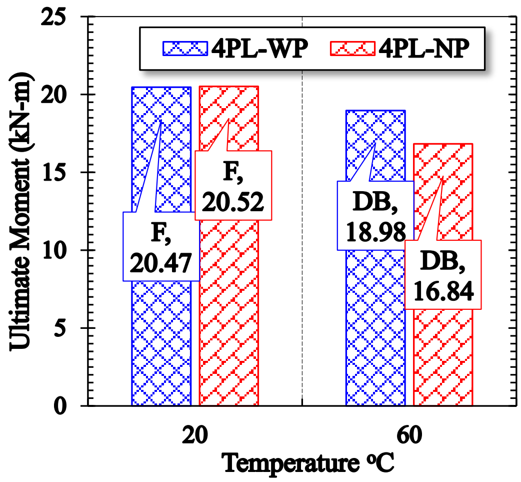

Fig.7 Ultimate moment of strengthened beams in 4PL at elevated temperature.

mode of failure is the flexural failure and presented by "F" in Fig. 7. Ultimate moment at 20°C, can be obtained by using conventional approach for RC beams. But at 60°C, reduction in the ultimate moment was observed and the mode of failure also shifted from flexural "F" to debonding "DB" mode as presented in Fig. 7. Observed failure mode was the brittle failure at elevated temperature whereas ductile failure was observed at 20°C. No further propagation of crack was observed with load, just separation of concrete and PCM was observed at the cut-off point. Higher interfacial stresses generated near the cut-off point and at elevated temperature reduction in interfacial stresses was observed and the resistance against debonding was limited and debonding occurred at elevated temperature.

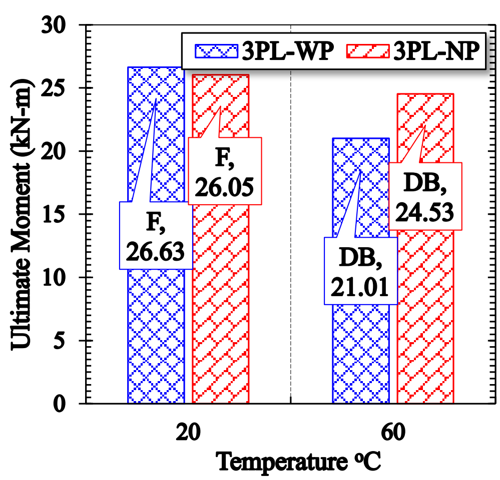

Fig.8 Ultimate moment of strengthened beams in 3PL at elevated temperature.

Fig. 8 presents the ultimate moments of strengthened RC beams at both temperature level. Similar trend was observed as it was seen in case of four point loading test results. At 20°C, ultimate moment was almost similar with and without any contribution of primer at interface between concrete and PCM. Observed moments at 20°C in 3PL test were more than as compared to the observed values in 4PL test, due to increase in shear span and more amount of reinforcement in overlay part. The observed failure mode was also the flexural failure which shows very ductile and desired failure mode of strengthened beams. But at elevated temperature, the failure loads were decreased significantly in both cases, with and without primer. So, corresponding moments also decreased and failure mode was also shifted from flexural failure to debonding failure (Fig. 8). The reduction in ultimate moment was due to the deterioration of bond between PCM and steel or concrete and steel, that basic assumption of designing of reinforced concrete structure that plane section remain plane may not valid [21, 22].

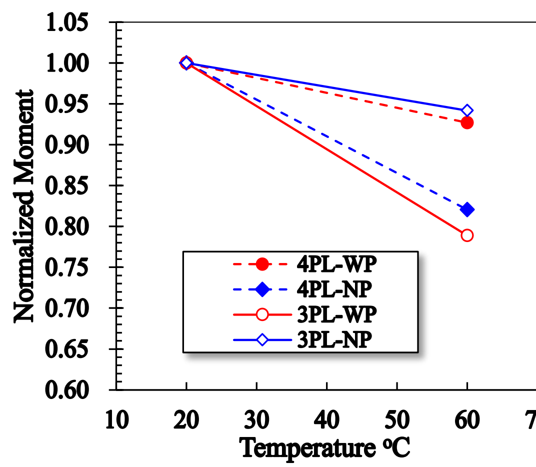

Fig.9 Influence of temperature on ultimate moment of strengthened beams in 4PL and 3PL.

Fig. 9 presents the normalized moment versus temperature. And reduction was observed in moment with the increase in temperature. Influence of primer seems to be insignificant at control condition, and even at elevated temperature. By visual inspection of failure surface, clear separation of concrete and PCM was observed at elevated temperature in both cases, with and without primer. So aggregate interlocking was not enough or due to lower adhesion of concrete and PCM, debonding was occurred. Due to only endpeeling failure, type of tests, 3PL or 4PL, were not affected by temperature. Similar trend was observed in both types of test and both types of beams in terms of ultimate moment and mode of failure.

4. Conclusions

Temperature is the fundamental parameter of our environment and its influence was observed on the bond integrity of concrete and PCM. In this work, tensile and shear behavior were investigated by conducting interfacial split tensile strength and Bi-Surface shear strength test, at 20 and 60^oC. Moment capacity was also observed by conducting four point and three point loading tests on strengthened beams at both temperature levels. One set of tests were also conducted by using primer at interface between concrete and PCM and following conclusions were extracted;

1) Interfacial tensile strength reduced significantly at elevated temperature and influence of primer was marginal and can be neglected.
2) Interfacial shear strength also reduced significantly at elevated temperature. Aggregate interlocking affects significantly the shear strength and at elevated temperature, clear separation of concrete and PCM was observed when primer was used.
3) At 20^oC, ultimate moment of strengthened beams were same in both cases, with and without primer and mode of failure was flexural failure. But at elevated temperature, reduction in ultimate moment was observed and failure mode also shifted from flexural to debonding mode of failure.
4) Effect of primer was inadequate at both temperature levels in tension, shear and moment.

5. Acknowledgements

The financial supports from 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 are greatly appreciated.

6. References

[1] Zhang D, Ueda T, Furuuchi H. Fracture mechanisms of polymer cement mortar: concrete interfaces. Journal of EngineeringMechanics. 2012;139(2):167-176.

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

[3] Rashid K, Ueda T, Zhang D, Fujima S. Tensile strength and failure modes of concrete repaired by polymer cement mortar in hot region. In: ACF, editor. 6th International Conference of Asian Concrete Federation. Seoul, Korea2014. pp. 1438-1445.

[4] Fowler DW. Polymers in concrete: a vision for the 21st century. Cement and Concrete Composites. 1999;21(5–6):449-452.

[5] Momayez A, Ehsani MR, Ramezanianpour AA, Rajaie H. Comparison of methods for evaluating bond strength between concrete substrate and repair materials. Cement and Concrete Research. 2005;35(4):748-757.

[6] Hassan KE, Brooks JJ, Al-Alawi L. Compatibility of repair mortars with concrete in a hot-dry environment. Cement and Concrete Composites. 2001;23(1):93-101.

[7] Hassan KE, Robery PC, Al-Alawi L. Effect of hot-dry curing environment on the intrinsic properties of repair materials. Cement and Concrete Composites. 2000;22(6):453-458.

[8] Espeche AD, León J. Estimation of bond strength envelopes for old-to-new concrete interfaces based on a cylinder splitting test. Construction and Building Materials. 2011;25(3):1222-1235.

[9] Zhang D, Ueda T, Furuuchi H. Concrete cover separation failure of overlay-strengthened reinforced concrete beams. Construction and Building Materials. 2012;26(1):735-745.

[10] Zhang D, Ueda T, Furuuchi H. Intermediate Crack Debonding of Polymer Cement Mortar Overlay-Strengthened RC Beam. Journal of

Materials in Civil Engineering. 2011;23(6):857-865.

[11] Smith ST, Teng J. FRP-strengthened RC beams. I: review of debonding strength models. Engineering Structures. 2002;24(4):385-95.

[12] Ohama Y. Handbook of polymer-modified concrete and mortars-properties and process technology. New Jersy: Noyes Publications; 1995.

[13] Rashid K, Ueda T, Zhang D, Fujima S. Study on behavior of polymer cement mortar in severe environmental conditions. 37th Annual Conventionof Japan Concrete Institute (JCI). Chiba, Japan2015. pp. 1597-1602.

[14] Santos PMD, Júlio ENBS. A state-of-the-art review on roughness quantification methods for concrete surfaces. Construction and Building Materials. 2013;38:912-923.

[15] Rocco C, Guinea GV, Planas J, Elices M. Size effect and boundary conditions in the brazilian test: theoretical analysis. Material Structures. 1999;32(6):437-444.

[16] Bazant PK, FM. Concrete at high temperature-Material properties and mathematical methods,: Harlow:longman; 1996.

[17] Gallé C. Effect of drying on cement-based materials pore structure as identified by mercury intrusion porosimetry: A comparative study between oven-, vacuum-, and freeze-drying. Cement and Concrete Research. 2001;31(10):1467-1477.

[18] Sakai E, Sugita J. Composite mechanism of polymer modified cement. Cement and Concrete Research. 1995;25(1):127-135.

[19] Reis JMLd. Effect of temperature on the mechanical properties of polymer mortars. Materials Research. 2012;15(4):645-649.

[20] Rashid K, Ueda T, Zhang D, Miyaguchi K. Study on influence of temperature on bond integrity between polymer cement mortar and concrete. Advances in Construction Materials. Whistler, BC, Canada, 2015. (9 Pages).

[21] Rashid K, Zhang D, Ueda T, Jin W. Investigation on concrete-PCM interface under elevated temperature: At material level and member level. Construction and Building Materials, (2016) 125: 465-478.

[22] Rashid K, Tamon U, Dawei Z. Study on Shear Behavior of Concrete-Polymer Cement Mortar at Elevated Temperature. Civil Engineering Dimension, 2016, Vol. 18, No. 2, 93-102.