

STUDY ON BEHAVIOR OF POLYMER CEMENT MORTAR IN SEVERE ENVIRONMENTAL CONDITIONS

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ABSTRACT

In this experimental work, splitting tensile strength on composite specimen of polymer cement mortar (PCM)-concrete were conducted under various environmental conditions. To investigate the behaviour of polymers in PCM, gel permeation chromatography (GPC) and differential scanning calorimeter (DSC) tests were performed on extracted polymers. Reduction in split tensile strength was observed under all conditions. GPC results showed the degradation in polymers and DSC analysis showed insignificant variation of polymer properties under given exposure conditions.

Keywords: PCM, environmental conditions, tensile strength, GPC analysis, DSC analysis

1. INTRODUCTION

The application of polymers in concrete has significantly progressed in last four decades and were used in various amounts and ways in concrete to form; (1) polymer concrete (2) polymer modified concrete (3) polymer impregnated concrete. All types have superior properties than ordinary Portland cement concrete and were widely used as either precast members such as bridge decks, pipes, floor tiles etc., or repairing and rehabilitation works in construction industry [1]. For repairing purpose, the deteriorated part of concrete is removed and reinstated with the polymer modified cement mortar (PCM). Durability of an integrated structure may be described as ability of the system to maintain designed performance strength and behaviour over harsh and changing environmental conditions. The adverse conditions that may affect the durability of PCMs can be hypothesized to be: freeze thaw cycles, alkali silica reaction, chloride attacks, carbonation, chemical attacks, repeated loading and elevated temperature conditions. These conditions may change the microstructure and morphology of PCM due to physical and chemical aging. Thus, durability of polymeric materials deals with the assessment of design strength of the repaired structure that may be lost due to physical-chemical attacks during service life.

Polymers particles in the mortar or concrete are coalesced to form polymer films which surround the hydrated products and fill the pores and gaps and improve the mechanical properties by reducing the porosity and permeability, which make the mortar or

concrete more durable under harsh environments [2,3].

The objectives of this research were to characterize the degradation behaviour of the PCM in isolation and when integrated with concrete under the influence of different environmental conditions. To this aim, experiments were designed in two series. In first series integrated specimens were exposed to different cyclic and constant temperature conditions for more than 30 days. In second series, PCM specimens were exposed to different temperature for short duration, and to investigate the behaviour of PCM in moisture, bulk specimens were exposed to different wetting and drying cycles and continuous immersion in water at 20°C. After exposure, tensile strengths were evaluated by using splitting tensile test. Molecular weight of polymers were measured by using gel permeation chromatography (GPC). Properties of polymers such as glass transition temperature (T_g) and melting point (T_m) were also analysed by using differential scanning calorimetry (DSC) on extracted polymers after designed exposure conditions.

2. EXPERIMENTATION

2.1 Materials

Experimental program in this study was consisted of two series and in first series two types of materials were used. First one is the concrete, which is widely used material all over the world. Concrete in this work was casted in laboratory by using ordinary Portland cement and locally available gravel and river sand. Second type is the PCM which is commonly used in

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repairing strengthening and rehabilitation works. It was prepared by mixing different amount of polymers and additives in ordinary cement mortar. In this work commercially available PCM was used which was prepared by using acrylic polymer.

In second series two types of PCM were used to investigate their mechanical and physical properties. In first type, styrene-butadiene rubber (SBR) polymer was used and in second type polyacrylic ester (PAE) was used to prepare PCM and narrated as SBR and PAE PCMs respectively. The properties of polymer used in SBR PCM and compounding ratio for PAE PCM materials are presented in Table 1 and Table 2 respectively. Table 3 shows 28 days cylinder compressive strength of each material used in both series.

Table 1 Properties of polymer used in SBR PCM

Property	Description
Main component	SBR type gum latex
Solid component	45-46 % (mass)
Apparent condition	white or pink color
Viscosity	500-1500 (mPa.s)
pH	8~9
Density	1.0 g/cm ³

Table 2 Compounding ratio of PAE PCM materials

Material	Emulsion	Type-I	Type-II
Unit volume mass (kg/L)	1.02	2.74	2.70
Acrylic acid ester copolymer (%)	27.0	---	---
Water (%)	73.0	---	---
White cement (%)	---	40.0	33.0
Silica sand (%)	---	60.0	67.0

Table 3 28 days cylinder compressive strength of concrete and PCMs

Series No.	Materials	Compressive strength (N/mm ²)
series-I	Concrete	38.29
	PCM	42.93
series-II	SBR PCM	54.37
	PAE PCM	55.90

2.2 Specimen Preparation

For series-I, concrete was casted of size 100 x 100 x 600mm prism and after 28 days curing specimen was cut into pieces of size 100 x 100 x 50mm for making composite specimens. At micro-scale PCM shows good adhesion with the matrix and aggregate in concrete when compared to ordinary cement mortar [2,3]. And at meso and macro scale concrete-PCM adhesion was improved by providing adequate interlocking at interface. Therefore before casting of PCM, one concrete side of size 100 x 100mm was roughened by sand blasting and then PCM was casted

over it to make the composite specimen of size 100mm cube in which 100 x 100 x 50mm was concrete and 100 x 100 x 50mm was PCM (Fig.1(a)). These composite specimens were cured in wet and dry environment. First seven days after casting was the wet curing for proper hydration of cementitious products. And remaining 21 days was dry curing which was done in laboratory at control temperature of 20°C and humidity was maintained at 60%. Polymer films are formed during curing of PCM in dry environment that fill the pores and surround the hydration products and increase the mechanical strength. Wet and dry curing is the most effective method for the curing of PCM [2].

For series-II, both types of PCMs were casted in laboratory. SBR PCM was prepared by mixing of 25kg of PCM with 1.1kg of liquid polymer and 2.25kg of water. PAE PCM was composed of three units (Table 2); one for emulsion and other two for cement and silica sand. All units were mixed according to guidance provided by manufacturer. PCMs were casted of size 100mm cube (Fig.1(b)) and cured in wet condition for 7 days and then exposed to dry condition for 21 days at 20°C and 60% humidity to complete 28 days curing.

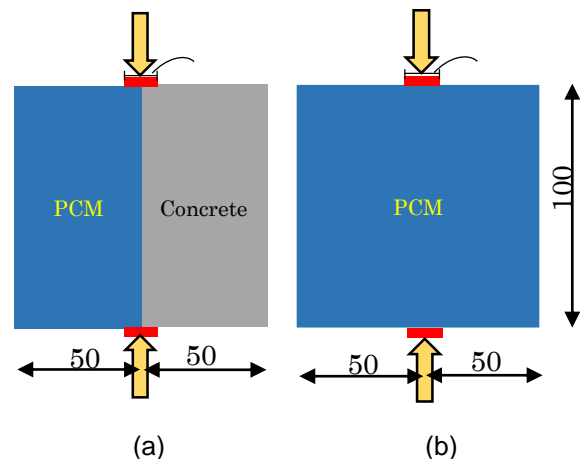


Fig. 1 Schematic diagram for tensile test (a) composite specimen (b) bulk specimen (unit: mm)

2.3 Exposure Conditions

Temperature and moisture are two important parameters of the real environment, which deteriorate the concrete structure and reduce the intended service life. Influence of both parameters were studied in this work. All specimens were exposed to different conditions and divided into two series.

(1) Series-I

In this series, three exposure conditions were selected as mentioned in Table 4. Temperature of the environment rises up to 60°C in some regions of the world. So accelerated effect was simulated by giving 60°C temperature for 30 days which may be equal to the entire hours of peak summer in that region for one season of a year. Second condition is the cyclic condition that presents the day-night cycle of peak summer season and specimens were tested after 30th cycle. Third condition is also a cyclic condition and

variation of four seasons (summer, raining, winter and autumn) of one year is presented by one cycle. One day presents one season, so in this condition one cycle consist of four days and specimens were tested after 10th cycle. All composite specimens were exposed to such conditions (Table 4) before testing and compared with the control specimen, which was not exposed to such conditions.

(2) Series-II

In series-II, effect of temperature and moisture was separately investigated on bulk PCM specimens. Specimens of PCMs were subjected to 20, 40 and 60°C temperature by two means; (a) oven (dry) (b) water (wet), only for short duration (16 hours). Moisture effect was also investigated by two means, first one is through wetting and drying cycles (W/D cycle), with two days wet and two days dry condition presenting one cycle. Second is the continuous immersion in water up to the age of test. In both moisture condition temperature of water and dry environment was maintained at 20°C. Specimens were tested after 0, 4 12, 24 and 48 days of continuous immersion and 0, 1, 3, 6 and 12th W/D cycles.

Table 4 Exposure conditions for series-I

Exposure conditions	Notation
(i) Constant temperature of 60°C for 30 days	T _{co}
(ii) 12 hour at 60°C and 12 hour at 30°C (thermal cycle 1)	TC1
(iii) 24 hour at 60°C, 24 hour at 20°C in water, 24 hour at 0°C and finally at 25°C ambient condition (thermal cycle 2)	TC2

2.4 Testing Procedures

(1) Split tensile strength test

Bond strength was evaluated in this study by conducting split tensile strength test on the cubical specimen of size 100mm (Fig. 1) by following ASTM C 496 [4]. In this work cubical specimens were used instead of cylindrical specimens because the effect on maximum tensile stress was less than 2%. Some evidences are also available for measuring interfacial tensile strength by using split tensile strength of cubical specimens [5,10]. Two wooden strip of 12 mm width and equal length of specimen was used at top and bottom of the specimen for even distribution of load. The interface area between concrete and PCM was 100 x 100mm. Split tensile strength was evaluated by using Eq. (1).

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

where

- f_t interfacial tensile strength (N/mm²)
- P_u ultimate load (N)
- A area of interface (mm²)

(2) Tests on properties of polymer

Different forms of polymers were used in the construction industry and the properties of the polymers such as glass transition temperature, melting point and molecular weight have significant importance and change in these properties may result in the change of the behaviour of polymers. In PCM, small amount of polymers are present as compared to other constituents and to evaluate the properties of polymers they were extracted form PCM by using Tetrahydro furan (THF) as solvent. The extraction procedure adopted is presented in Fig. 2. PCM were pulverized after performing split tensile strength test into very fine powder that is able to pass 150 µm sieve (Fig. 2(a)). Some amount of THF was put into fine powder container and filtered after 24 hours (Fig. 2(b)) and then filtrate was evaporated to get only polymers (Fig. 2(c)). In this work glass transition temperature (T_g) and melting point (T_m) of polymers were analysed by using differential scanning calorimetry (DSC). DSC test was performed on extracted polymers by following ASTM E 1356 [6]. T_g was selected from the DSC curve as a midpoint of a tangent between the extrapolated baseline before and after transition and endo-thermal peak represents the T_m of polymers. Both, T_g and T_m were evaluated from temperature of -50 to 150°C at heating rate of 10°C/min from second cycle of heating. Molecular weight (M_w) of polymers was measured by using gel permeation chromatography (GPC), which is widely used technique for measuring molecular weight of polymers [7].

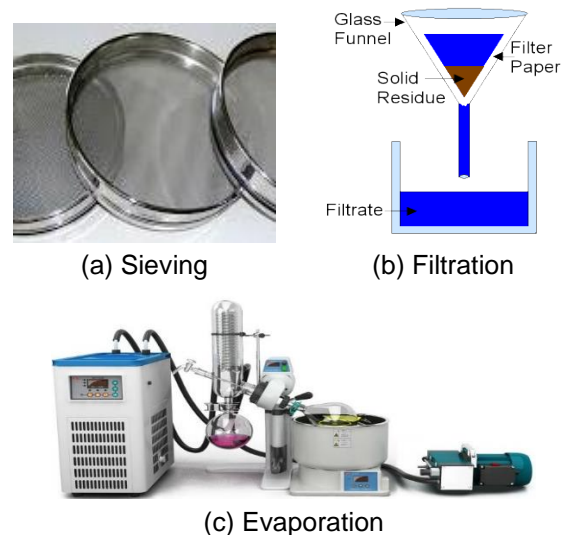


Fig. 2 Procedure for extraction of polymers from PCM

3. RESULTS AND DISCUSSIONS

3.1 Tensile Strength and Failure Modes

Split tensile strength test in both series were conducted to evaluate the interfacial tensile strength of composite specimens of series-I and split tensile strength of PCM specimens of series-II. In series-I all

specimens were tested at high temperature (60°C) after their respective exposure conditions and reduction in bond strength was observed in all cases. Fig. 3(a) shows the normalized tensile strength with respect to the control specimen tested at 20°C. More than 40% reduction in strength was observed from the control specimen under thermal cycle 2 (TC2) exposure condition. Constant temperature also affected the bond strength but only 8% reduction in strength was observed from the control specimen. After performing split tensile test failure surfaces were visualized and different modes of failure were observed. Adhesive failures were observed for control specimens and under different exposure conditions failure mode shifted from adhesive to partially adhesive and partially cohesive of PCM, which indicates the degradation in strength of PCM with different exposure conditions. Failure mode was quantitatively evaluated by mapping on failure surfaces of both substrate concrete and PCM and percentage attached on each surface was measured and presented in Fig. 3(b). Under all exposure conditions significant amount of PCM was attached on the surface of concrete.

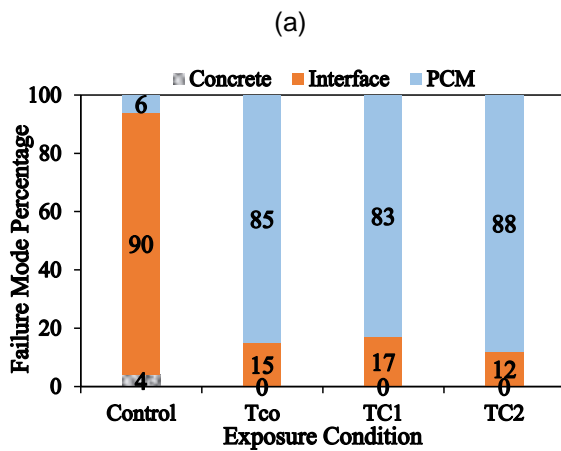
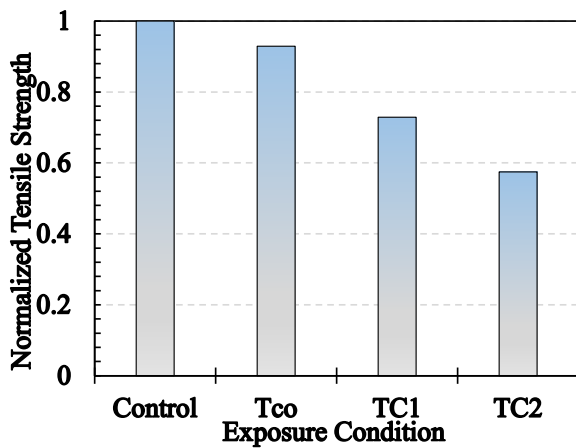


Fig. 3 (a) Normalized tensile strength of series-I (b) Failure modes of series-I

Fig. 4 shows the normalized tensile strength with respect to control specimen of both type of PCMs in

series-II. Reduction in the tensile strength of PCMs were observed by the increase in temperature by both methods of heating (dry and wet). At 60°C the reduction in tensile strength of SBR PCM was more than 35% from the control specimen tested at 20°C (4.80N/mm²) and for PAE PCM specimens about 25% reduction in tensile strength from control specimen (4.05N/mm²) was observed. The reduction in the strength may be due to thermal incompatibility of aggregate and cement paste. At high temperature the porosity increases and fine pores collapse and resulted in increase of coarser pores [8-10]. Method of heating did not affect significantly and all reduction in strength may be only due to temperature and not by moisture. The moisture effect was also observed independently by exposing bulk specimens of PCMs to several W/D cycles and continuous immersion in water for several days. Table 5 shows the split tensile strength of PCMs under both moisture conditions. Properties of PCM highly depend upon the type of polymer used in it. Some polymers may react with water and lose its strength by swallowing or by losing cohesion and some may become stronger due to additional hydrogen bonding. In this study slight improvement in strength was observed for PAE PCM under both conditions of moisture.

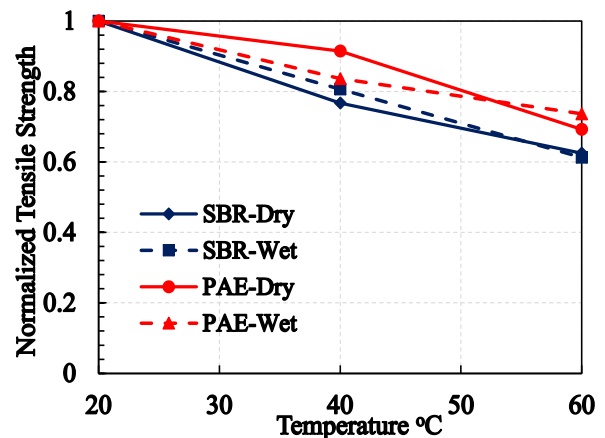


Fig. 4 Effect of temperature on tensile strength of PCMs of series-II

Table 5 Moisture effect on tensile strength of PCMs

W/D cycle	Tensile strength (N/mm ²)		Continuous immersion days	Tensile strength (N/mm ²)	
	SBR	PAE		SBR	PAE
No.	SBR	PAE	days	SBR	PAE
0	4.80	4.05	0	4.80	4.05
1	4.54	4.59	4	4.82	4.26
3	4.60	4.70	12	4.85	4.75
6	4.55	4.43	24	4.82	4.80
12	4.70	4.25	48	4.89	4.96

3.2 Molecular Weight

Higher the molecular weight gives the higher degree of polymerization and gives higher mechanical strength and vice versa [7,11]. Degree of

polymerization for impregnated concrete was investigated by Chen *et al.* [11], who observed the greater improvement in mechanical strength and reduction in porosity than ordinary concrete under higher degree of polymerization. Degree of polymerization in the impregnated concrete might be compare with the polymer film in the polymer modified concrete or mortar. The contribution to the property improvement of modified concrete is almost similar. In both cases, impregnated concrete and polymer modified concrete, polymer film fills the pores and surrounds the hydration products and gives the higher strength than ordinary concrete or mortar. In opposite way, decomposition in the polymer film by harsh environment may decrease the mechanical properties of PCM and also may degrade the properties of polymer used in PCM.

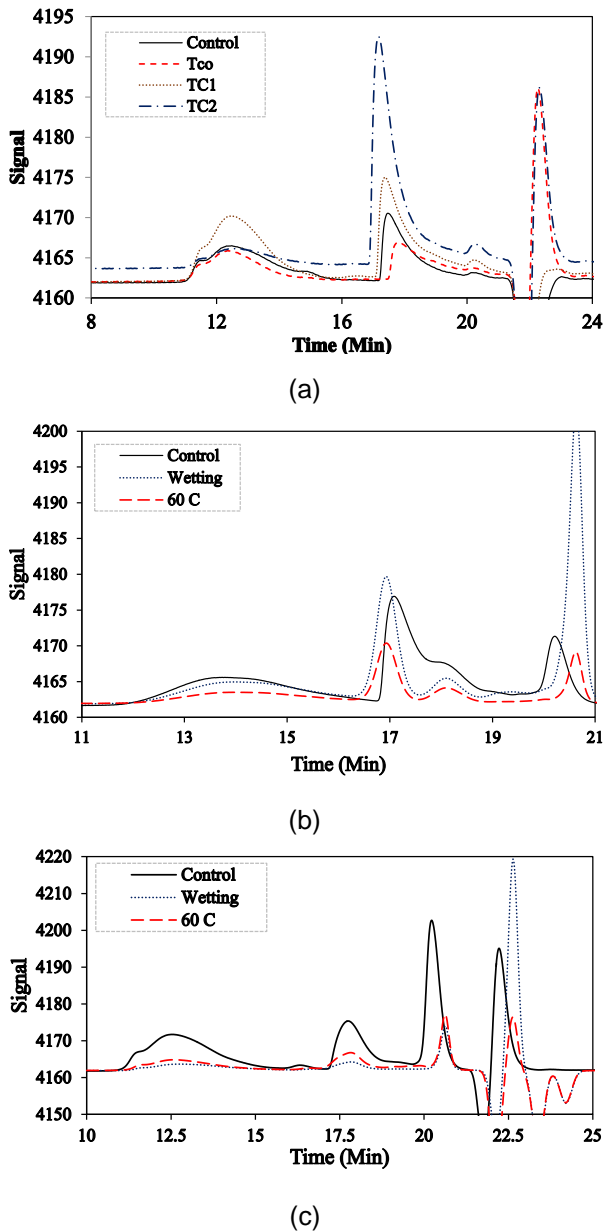


Fig. 5 GPC analysis of (a) series-I polymers (b) SBR in series-II (c) PAE in series-II

Molecular weight (M_w) of polymers were investigated in this work by performing GPC test on extracted polymers. Polymers were extracted after conducting tensile strength test of both series. Molecular weight was obtained by the distribution under the first peak of GPC curve and distribution under the second peak shows the amount of oligomers (Fig. 5). The molecular weight under all conditions remains same and its value was in the range of 70,000 to 90,000 for polymers in series-I. Under given exposure conditions the amount of oligomer increases, which may be observed in the increase in second peak and the degradation in the first peak in Fig. 5(a). But this change is insignificant and did not affect so much. GPC test was performed at 40 °C but interfacial tensile strength of composite specimens of series-I was conducted at 60°C. Polymer properties may recover due to lowering of temperature so experimentation is still needed to conform the relationship between molecular weight and strength.

Similar behaviour was observed for polymers in series-II, which is presented in Fig. 5(b) and Fig. 5(c). The molecular weights of polymer in SBR PCM are in the range of 30,000 to 40,000. The molecular weights of polymer used in PAE PCM vary from the 75,000 to 90,000.

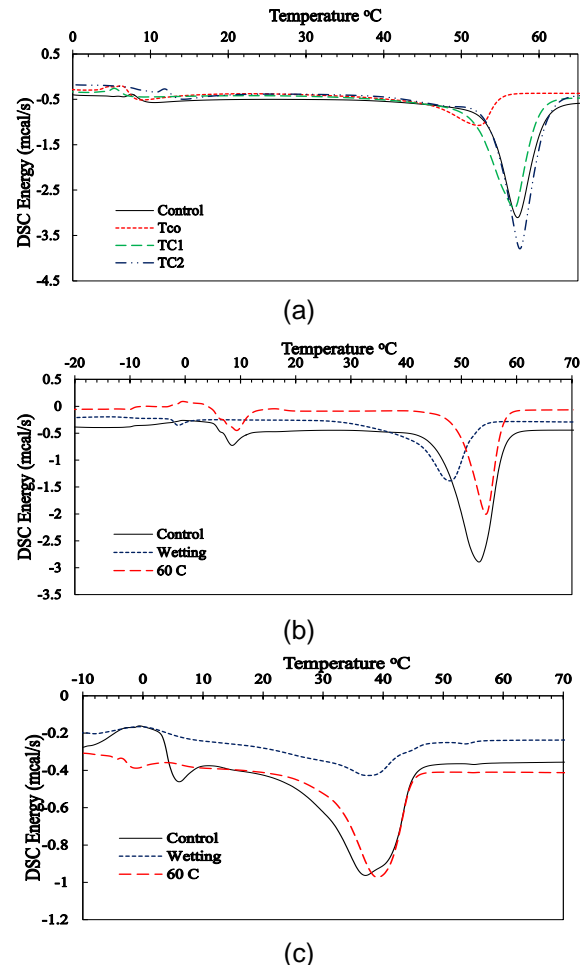


Fig. 6 DSC analysis of (a) series-I polymers (b) SBR in series-II (C) PAE in series-II

3.3 Glass Transition and Melting Point Temperature

DSC test was performed to evaluate the glass transition temperature (T_g) and melting point (T_m) of the extracted polymers. Fig. 6 shows the DSC curves of polymers used in both series. The T_g of all polymers was below 8°C and slight variation in T_g was observed under the influence of temperature and moisture exposure. Moisture and temperature can greatly influence the physical properties of polymers and its composites. Once polymers composites exposed to variation of temperature and moisture that may alter properties of the polymers either in irreversible manner (by hydrolyzation, cracking or crazing), or a reversible manner (plasticization). Ohama [2] shows that flexural and compressive strength of polymer modified cement mortar change with the T_g and reduced with the reduction in T_g . Polymer mortar shows exponential degradation in tensile strength after glass transition temperature [12]. Melting point T_m of polymers of series-I is slightly less than 60°C (Fig. 6(a)) and slight reduction in T_m was also observed and significant reduction in tensile strength was observed above this temperature. For series-II, the melting temperature of polymer of SBR PCM was about 56°C and for PAE it was about 38°C. Reduction in these temperatures may reduce the mechanical properties of the polymer cement mortars.

4. CONCLUSIONS

Concrete-PCM bond and the polymers in the PCM were investigated under this experimental study and the following conclusion can be drawn out.

1. Significant reduction in tensile strength was observed with increase in temperature. Maximum reduction in tensile strength was observed under thermal cyclic 2 (TC2) exposure condition and reduction amount was 47% from the control specimen.
2. Failure mode of integrated specimens shifted from adhesive concrete-PCM interface to cohesive PCM under all exposure conditions of series-I.
3. Insignificant effect was observed in molecular weight (M_w) of polymers.
4. Insignificant effect on glass transition temperature (T_g) and melting point (T_m) values of polymers were observed under all exposure conditions. Significant reduction in tensile strength of composite specimens and bulk PCM specimen was observed above T_m .

ACKNOWLEDGEMENT

The authors are grateful to Denki Kagaku Kogyo Kabushiki Kaisha and Maeda Kosen Co. Ltd. for providing polymer cement mortar. The authors are paying special thanks to Mr. Nakai for providing necessary information about polymers and Prof. Dr.

Toshifumi Satoh for helping in the GPC and DSC analysis of polymers. The first author is very thankful to University of Engineering and Technology, Lahore, Pakistan for scholarship grant.

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