Use of Polymercrete® as Admixture for Durability Enhancement in Concrete

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Executive Summary

The fresh and hardened properties of Portland cement-based materials were concrete mixtures containing Polymercrete® (PC) were investigated in this study. First, the effect of PC on the early-age hydration of cement paste was investigated. Thereafter, the influence of PC on the air content and workability of fresh 0.5 water-to-cement (w/c) ratio concrete over a 30 – 60 minutes test duration was evaluated. Moreover, the mechanical strength and durability properties of PC modified concrete exposed to air and moist-curing conditions were also compared to those of plain unmodified reference concrete.

The early-age hydration result indicate that, contrary to the established tendency of polymer emulsion to delay the cement hydration process, the hydration of PC modified cement paste was similar to that of the plain unmodified reference paste. Results also showed that while the addition of PC to mixture increased concrete workability, comparable initial air content which reduced slightly over time, was also observed.

For both air and moist-curing conditions investigated, the compressive strength of PC modified concrete was about 6 – 9% higher than that of the unmodified reference concrete after 30 days of curing. Interestingly, and opposite to the generally expected decrease in the compressive strength of moist-cured polymer modified concrete specimens in comparison to air-cured specimens, moist-cured PC modified concrete specimens out-performed the air-cured specimen at all test ages. Furthermore, the addition of PC to concrete caused a small reduction in the total porosity and chloride permeability of concrete.

Overall, these preliminary results suggest potentials for PC modified cement-based materials in the construction industry. However, optimum dosage of PC across different w/c ratios of cement-based materials needs to be determined. Furthermore, more tests to clarify the underlying mechanisms behind the improved performance of PC modified concrete should be performed.

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1. Introduction

1.1 Background

For several decades, cement and concrete researchers have investigated the performance of different types of polymer emulsions utilized as chemical admixture in the manufacture of cement-based materials. Kim et al. (1999) reported reduced water absorption and porosity of polyvinyl alcohol-modified cement mortar. Similarly, Aggarwal et al. (2007) observed reduced permeability and increased bond strength of mortar mixtures modified with epoxy and acrylic polymer emulsions. Increased heat of hydration, hardness, fracture toughness and corrosion resistance of polymer modified cement mortar has also been reported (Singh et al., 2003).

However, some drawbacks have also been observed with respect to polymer-modified cement-based materials. First, these studies (Singh et al., 2003; Knapen and Van Gemert, 2009) have shown that polymer emulsion causes various degrees of delay in the hydration and hardening process of cement composites. According to Singh et al. (2003), a chemical accelerator was required in order to reduce the setting time of cement paste modified with hydroxyethyl cellulose. In a related study, Knapen and Van Gemert (2009) reported mild to severe retardation of the hydration process in cement paste mixtures modified with water-soluble polyvinyl acetate, methylcellulose and hydroxyethyl cellulose. With respect to mechanical strength, Ohama (1986) was of the opinion that while polymers enhance tensile and flexural properties, there is no improvement in compressive strength in comparison to plain ordinary Portland cement mortar and concrete.

On the other hand, it has also been shown that water-curing condition is inimical to the mechanical strength development of polymer modified cement composites. Ohama (1986) observed reductions in the mechanical strength of water-cured polymer-modified mortar and concrete. Compared to dry-cured specimens, research findings by Jenni et al. (2006) indicated lower mechanical strength for polymer-modified mortar mixtures subjected to a wet-curing condition.

1.2 Objectives and scope

In the light of the highlighted shortcomings of the presently available commercial polymer emulsions, the construction industry is in need of a new generation, normal setting polymer emulsion, which is not only unaffected by water-curing environment, but would also outperform conventional ordinary Portland cement (OPC) matrices in terms of strength and durability properties. Therefore, this preliminary study is investigating the effects on Polymercrete® (PC) emulsion on the hydration, strength and durability properties of cement paste and concrete exposed to dry and moist-curing conditions.

2. Experimental Methods

2.1 Materials

General use Portland cement (GU), natural fine aggregate and crushed rock coarse aggregate with a maximum size of 12 mm were used in mixture preparations. The only chemical admixture used in this study is Polymercrete®, a milky-white colored polymer emulsion dubbed here as PC. A pictorial view of PC appears in Figure 1.

Figure 1: Polymercrete®

2.2 Methods

2.2.1 Mixture proportion and specimen preparation

Cement paste and concrete mixtures were investigated. The cement paste with water-to-cement (w/c) ratio of 0.50, and PC contents of 0% and 0.5% by mass of cement were used for the early-age hydration studies. On the other hand, 0.50 w/c ratio concrete mixtures with and without PC were also prepared.

The information about the concrete mix proportion used is given in Table 1. While a hand mixer was used for the paste preparation, a rotary pan mixer was used for the concrete.

For the concrete mixing, sand and coarse aggregates were first premixed, before GU cement was then added and the mixing process continued for a further three minutes. Thereafter, approximately two thirds of the mix water was added and mixed for an additional two minutes, then the remaining water was subsequently added and mixed for a further 2 minutes. The required amount of PC was then added to the concrete and mixed for an additional three minutes.

Table 1: Mixture Proportion

Materials	**kg/m^3**
Cement	385
Water (w/c=0.5)	192.5
Coarse Aggregate	972
Fine Aggregate	738
Polymercrete® (PC)	2 L/m^3

For the concrete, 100 x 200 mm cylindrical molds were filled, and covered with a plastic bag for 24 hours. Thereafter, specimens were de-molded, and subjected to moist and air-curing regimens. Specimen curing conditions are shown in Figure 2.

Figure 2: Cylinder specimens in the conditioning room: a) Dry curing, b) Moist curing

2.2.2 Early-age hydration

Immediately after mixing, two glass jars filled with 200 g paste were placed inside a semi-adiabatic insulated container, and with inserted thermocouples, the temperature evolution overtime of the hydrating pastes was monitored for 48 hours.

2.2.3 Time-dependent workability of concrete

The possibility that the addition of PC could negatively affect the placement and compaction of concrete, slump test at 15 minutes intervals was conducted. The test was performed according to ASTM C143 (2015) specifications.

2.2.4 Air entrainment and air retention

The effect of PC on the air entrainment process and its retention over time in concrete was investigated based on ASTM C231 guidelines. For each mixture, four air content measurements were performed within one hour period of concrete mixing.

2.2.5 Compressive strength of concrete

A Forney FX 600 series testing machine was used to measure the compressive strength of concrete mixtures (Figure 3) as per ASTM C-39: Standard Test Method for Compressive

Strength of Cylindrical Concrete Specimens. The compressive strengths of all mixtures were obtained at 7 and 30 days after casting, and three 100 x 200 mm specimens from each mixture was tested. The loading rate for each test was maintained at 0.24 MPa/sec.

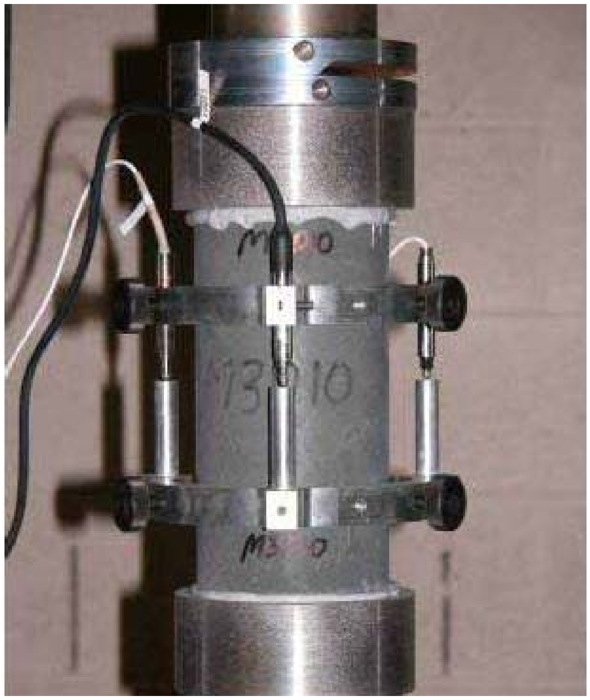

Figure 3: Test set up for determining cylinder compression strength

2.2.6 Rapid chloride permeability test (RCPT)

For this test, the 30 days air-cured specimens were prepared according to ASTM C1202 (2012) guidelines. Three cylindrical specimens from each mixture measuring 100 x 50 mm were cut and subjected to de-airing and water saturation as shown in Figure 4.

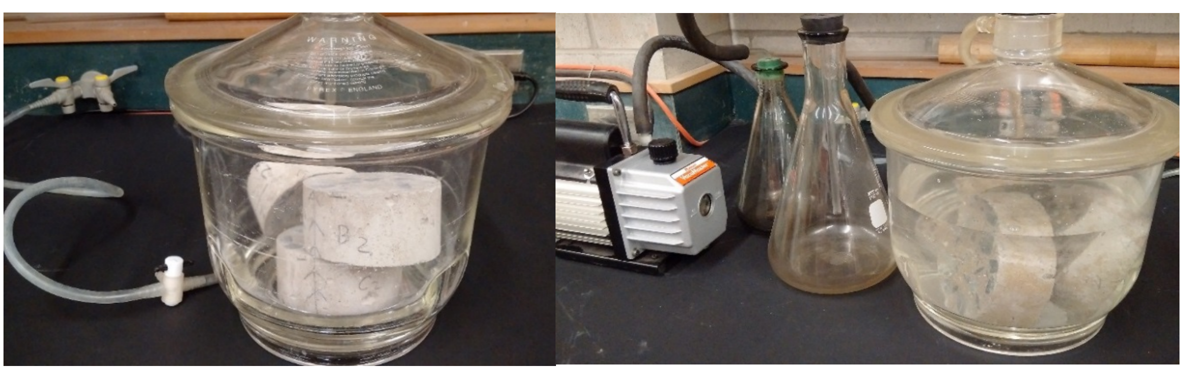

Figure 4: RCPT samples preparation

Thereafter, the charges transmitted through specimens over a six hour period were determined using a “Prove it classic” RCPT equipment connected to a computer system. Specimen preparation and RCPT test set up are shown in Figure 5.

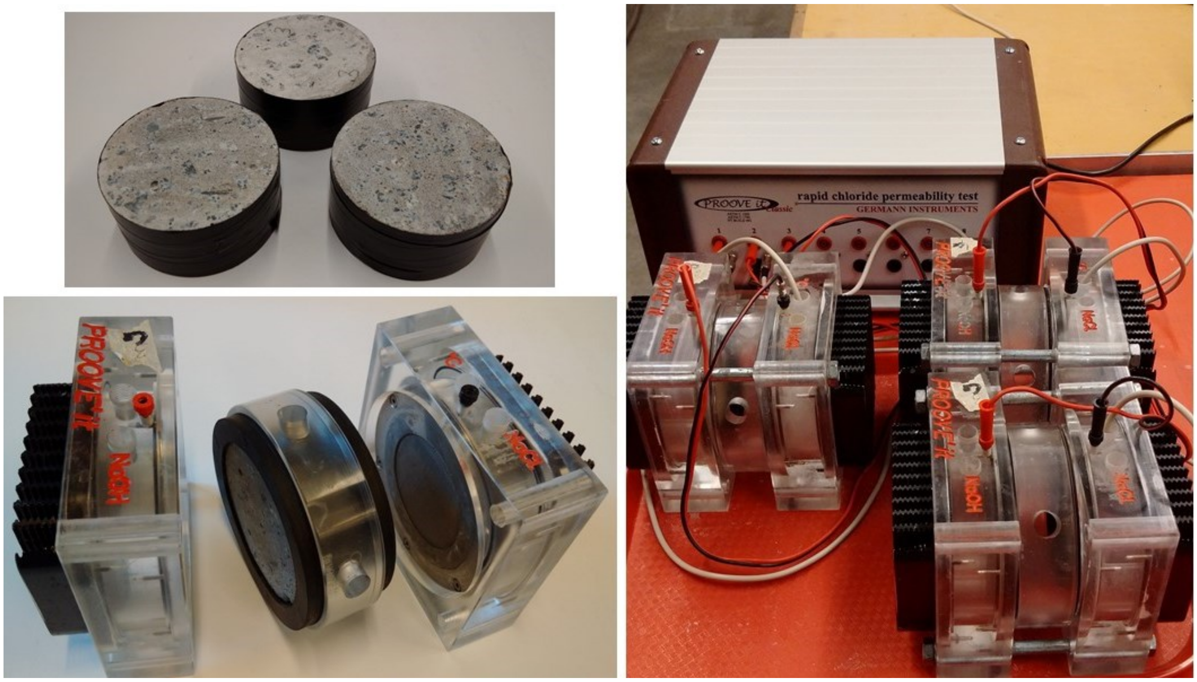

Figure 5: Sealed concrete discs and RCPT instrument

2.2.7 Total porosity

After 30 days of air-curing, the total porosity of concrete mixture was determined according to ASTM C642 (2013) specifications. Three cylindrical specimens from each mixture measuring 100 x 50 mm were used for this test.

3. Results and Discussions

3.1 Early-age hydration

The hydration temperature evolution of cement paste with and without PC is shown in Figure 6, and it highlights the absence of any negative interactions between PC and cement. This result is interesting given the well-known retardation effect of polymer emulsion on the cement hydration process. Although it can be argued that the PC content of paste (0.5% by weight of cement) which translates to approximately 2 liter per m^3 of the concrete used in this study is insufficient to cause any delay in the hydration process. However, a related study on 0.5% HEC modified paste by (Singh et al., 2003) showed significant retardation of about 3 hours in comparison to the final setting time of the plain reference mixture. Therefore, the hydration results obtained in the present study is indicating that PC has a desirable attribute that would be useful to the construction industry.

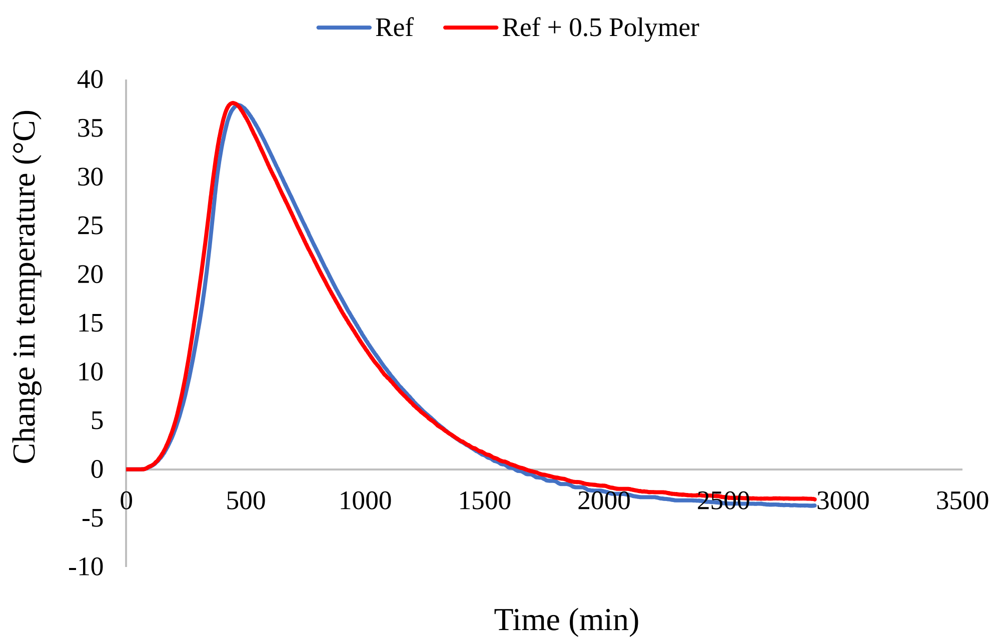

Figure 6: Temperature profile of cement paste

3.2 Time-dependent workability

Figure 7 shows the initial slump of concrete mixtures, and the reduction of slump within the first 30 minutes of mixing. Figure 7 indicates that the initial workability of the PC modified concrete was slightly better than that of the unmodified reference concrete, and this trend was maintained throughout subsequent measurements. Compared to the reference mixture, the improvement in the slump retention of the PC modified mixture 20% after 30 minutes of mixing. This result was expected given the findings in the literature on the positive effect of polymers on the workability of cement-based materials. Increases in the workability of styrene-acrylic ester copolymer latex modified mortar (Wang and Wang, 2010) and acrylic emulsion modified mortar (Aggarwal et al., 2007) have also been reported. Aggarwal et al. (2007) attributed the increased workability they observed to the reduced surface tension of polymer molecules and the presence of surfactants in the latex.

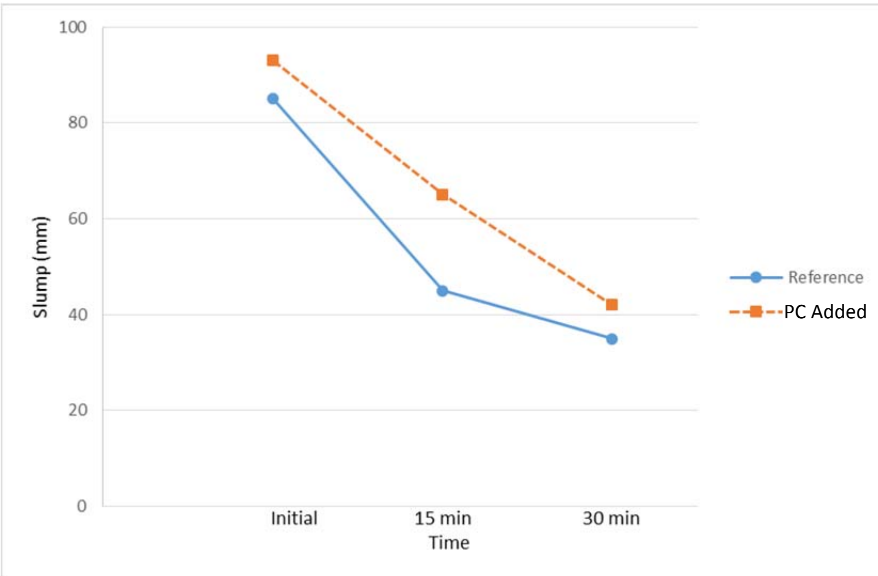

Figure 7: Slump and slump retention

3.3 Air entrainment and air retention

The air content (entrapped air since no air entraining agent was used) of concrete mixtures is shown in Figure 8. The results showed that the initial air contents of the reference and PC modified concrete mixtures were comparable. However, from 15 minutes onward, the air content of the PC modified concrete gradually became slightly lower than that of the reference concrete. This result is surprising given that de-foaming agents have been used in previous studies to control the air content of polymer modified cement-based materials. Research findings by Wang and Wang (2010) indicated that the air content of styrene-acrylic ester copolymer latex modified cement mortar increased as the polymer-cement ratio became higher. Although at this point, the reason why the air content of the PC modified concrete is similar to that of the reference concrete is unclear, this development is quite interesting and deserves further evaluation.

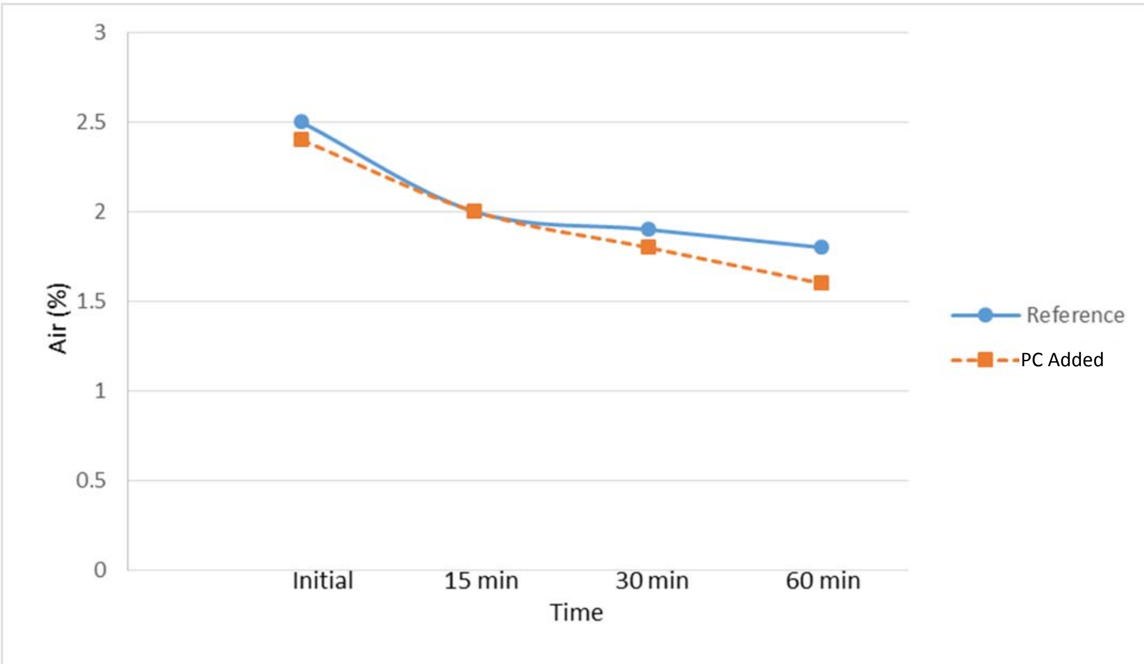

Figure 8: Air entrainment and air retention

3.4 Compressive strength

Figure 9 shows the compressive strength of the concrete mixtures after 7 days and 30 days of curing. At 7 days, there is no difference in strength for the moist-cured and dry-cured reference specimens, and this is understandable given that the internal humidity of specimens are still high. However, by the 30th day, the effect of curing condition on the compressive strength of reference specimen became clear, with the moist-cured specimens recording the highest strength. Conversely, Figure 9 also shows that the compressive strength of the dry-cured PC modified specimens were lower than those of the moist-cured specimens at both 7 and 30 days. This development was unanticipated given that it has been reported in the literature that moist-curing has a negative influence on the compressive strength of polymer modified cement composites (Ohama, 1987).

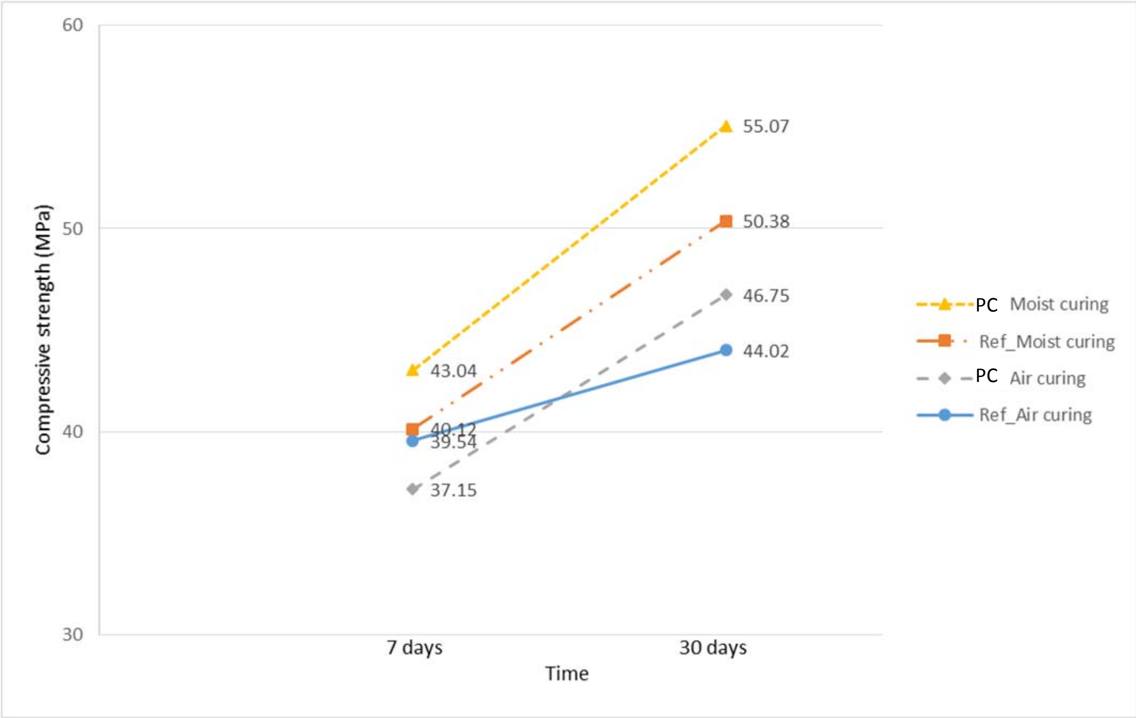

Figure 9: Compressive strength of concrete

The percentage increases in the compressive strength of the PC modified concrete relative to the reference concrete are 6.2 % and 9.3 % in dry curing and moist curing condition, respectively. In addition to usual hydration induced strength gain, Ohama (1987) suggested that the formula of polymer film, especially during dry curing, contribute to the increase strength of polymer modified cement composites. However the validity of this reason for the findings in the present study is uncertain. It is suspected that the absence of delayed hydration and the reduced air content/porosity might have contributed more to the enhanced performance of the PC modified mixtures.

3.5 Total porosity and chloride permeability

The total porosity of concrete mixtures is shown in Figure 10, and it indicates reduced air void content for the PC modified concrete in comparison to the reference mixture. This slight reduction in porosity has two important implications; first, it corroborates the submission in Section 3.4 about reduced porosity contributing to the enhanced compressive strength of PC modified concrete. Secondly, the reduced porosity is equally an indicator of possible enhanced microstructure of the PC modified mixture.

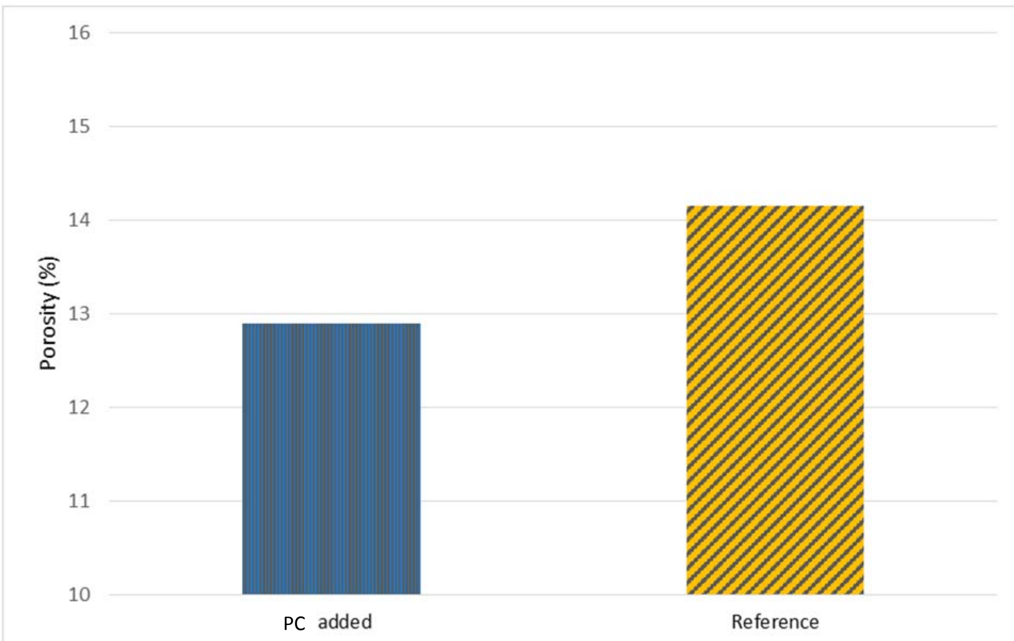

Figure 10: Total porosity

Figure 11 which shows the total charges transmitted through air-cured specimens after a six hours RCPT test period, and it confirms the improved durability of PC modified concrete mixtures. The results shown in Figure 11 indicate that the addition of PC to concrete reduced the total charge by aPCroximately 21%. A similar trend was also repeated for the 40 MPa moist-cured concrete specimens also shown in Figure 11. However, compared to the RCPT data for dry-cured specimens, the absence of moist-curing induced durability enhancement is traceable to difference in mechanical strength. Moreover, the outer circumference of the 40

MPa specimens were unsealed during the test, hence the ionic flow might have been multi-directional instead of one-directional, thereby increasing the total charges passed.

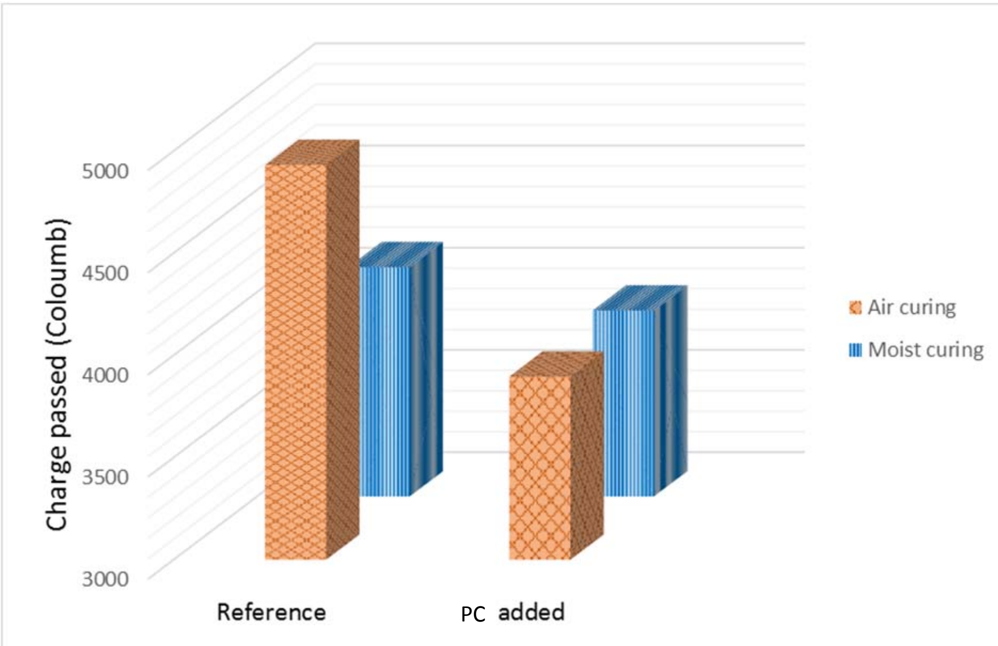

Figure 11: Total charge passed

4. Conclusions and Recommendations

4.1 Conclusions

In this study, the effect of PC on the early-age hydration, compressive strength and durability properties were investigated. Based on the experimental results obtained in this study, the following conclusions are drawn:

- Unlike some commercial polymer emulsion found in the literature, the addition of PC to cement paste did not have any negative effect on the early-age hydration process.
- The initial workability of PC modified concrete was slightly better than those of the unreinforced reference concrete, and this improved workability of PC mixture was

maintained over time. On the other hand, the fresh state air content of both PC and reference mixture were comparable.

- The compressive strength of moist-cured and dry-cured PC modified concrete were higher than those of the reference mixture at both 7 and 30 days. This result is quite interesting, especially the result of the moist-cured PC specimen which deviated from the usual strength loss trend reported in the literature for PC modified concrete subjected to moist-curing condition.
- The addition of PC to mixtures enhanced the durability of concrete as highlighted by the reduced the total porosity and chloride ion penetration of specimens.

4.2 Recommendations

- Although preliminary results indicate that PC did not retard the hydration of cement, the effect of increased content of PC on cement hydration needs to be explored further. This will help in determining the optimum content of PC in cement-based materials.
- Similarly, the effect of increased dosages of PC on the fresh and hardened properties of concrete should be studied. Moreover, it is important to understand the influence of PC across different concrete w/c ratios.
- While additional mechanical and durability tests are required, the actual mechanism causing the improvements in compressive strength and durability properties observed in this preliminary study needs to be understood.
- Commercially viable cement-based applications for PC modified cement composites should be developed.

References

ASTM C143/C143M – 2015a, Standard Test Method for Slump of Hydraulic-Cement Concrete

ASTM C173/C173M – 2016, Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method

ASTM C39/C39M – 2016b, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens

ASTM C1202 – 2012, Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration

ASTM C642 – 2013, Standard Test Method for Density, Absorption and Voids in Hardened Concrete

Aggarwal L K, Thapliyal P C, and Karade S R, (2007); Properties of polymer-modified mortars using epoxy and acrylic emulsions, *Construction and Building Materials,* 21: PC 379–383

Jenni A, Zurbriggen R, Holzer L, and Herwegh M (2006); Changes in microstructures and physical properties of polymer-modified mortars during wet storage. *Cement and Concrete Research*, 36: PC 79–90

Kim J H, Robertson R E, and Naaman A E, (1999); Structure and properties of poly(vinyl alcohol) modified mortar and concrete, *Cement and Concrete Research*, 29: PC 407–415

Knapen E, and Van Gemert D, (2009); Cement hydration and microstructure formation in the presence of water-soluble polymers. *Cement and Concrete Research*, 39: PC 6–13

Ohama Y (1987); Principle of latex modification and some typical properties of latex modified mortar and concrete. *ACI Materials Journal,* 86: PC 511–518

Singh N K, Mishra P C, Singh V K, and Narang K K (2003); Effects of hydroxyethyl cellulose and oxalic acid on the properties of cement. *Cement and Concrete Research*, 33: PC 1319–1329

Wang R, and Wang P M (2010); Function of styrene-acrylic ester copolymer latex in cement mortar. *Materials and Structures*, 43(4): PC 443–451.