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EFFECT OF POST-CURING REGIME ON DENSITY, COMPRESSIVE STRENGTH AND CROSSLINKING OF POLYMER CONCRETE

Nur Hafizah A. Khalid[a], Mohd Warid Hussin[a*], Mohammad Ismail[a], Mohamed A. Ismail[b], Azman Mohamed[c], Nur Farhayu Ariffin[a], Nor Hasanah Abdul Shukor Lim[a], Mostafa Samadi[a]

[a]Institute for Smart Infrastructure and Innovative Construction (ISIIC), Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Johor, Malaysia
[b]Civil and Construction Engineering Department, Faculty of Engineering and Science, Curtin University, Sarawak Malaysia, Miri, Sarawak, Malaysia
[c]Department of Geotechnics and Transportation, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Johor, Malaysia

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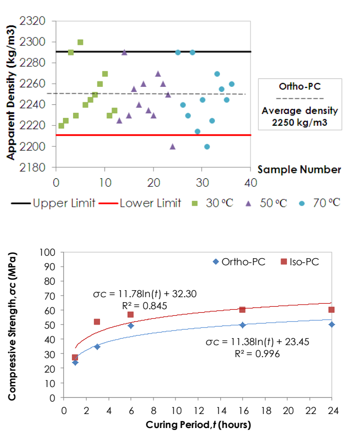
*Corresponding author
warid@utm.my

Graphical abstract



Abstract

Polymer concrete is produced from polymer binder, aggregates, and filler. Its curing follows the polymerization process once polymer additive is added, and can be accelerated through post-curing. In this study, the Orthophthalic- and Isophthalic-based polymer concrete (Ortho-PC and Iso-PC) were cured and investigated at different curing temperature (30°C, 50°C and 70°C) and period (1, 3, 6, 16, 24 hours) to complete the compressive strength development. Effect of curing temperature and period on apparent density, compressive strength, and morphology properties were investigated. The outcomes exhibited that all specimens had achieved full compressive strength within 6 hours of curing time at both 50°C and 70°C. When cured at 30°C, this went up to more than 16 hours of curing period to achieve the same compressive strength. The form of crosslinking at different curing conditions was captured in Scanning Electron Microscope, SEM images. Results also showed that curing temperature and period insignificant affected the apparent density. This study can be used as references to manufacturer, fabricator, and engineers when dealing with polymer concrete which goes for post-curing method as curing process.

Keywords: Polymer concrete, post-curing temperature, post-curing period, compressive strength, crosslinking

1.0 INTRODUCTION

Polymer concrete (PC) is produced from polymer resin, which acts as the only concrete binder; dry inert granular aggregate; and filler. Sometimes, polymer concrete is mistaken for geopolymer concrete, but it is actually a concrete made by replacing all cement hydrate binders of conventional concrete with polymer binder. The hardening of polymer concrete occurs without any water and through the polymerization process when additives, catalysts, or accelerators are added.

The major material commonly used in polymer concrete is thermosetting resin, which is usually used as a superior material in structural applications. Because of this, thermosetting resins such as unsaturated polyester, acrylic and epoxy resin are preferred over thermoplastic resins though the selection is still dependent on specific applications.

Generally, polyester resin is used in the composites industry and is the cheapest among thermosetting resins. It can be easily handled, pigmented, filled, and fiber-reinforced in liquid form [1-3]. Polyester resins are the product of polycondensation reactions of dicarboxylic acids with dihydroxy alcohols [1]. From different reactants, Isophthalic and Orthophthalic polyester can be produced from Isophthalic acid and phthalic acid, respectively [1].

Polymer concrete can be cured in two ways – air-dried or heat-cured (post-curing). Water curing had been performed by Ohama and Demura [4] for polyester polymer concrete, but the compressive strength of the polymer concrete was consistently poor regardless of the curing time (1, 5, 15 and 24 hours). The reason is that the water saturated condition has significantly disturbed the exothermic reaction during polymerization process. Therefore, water curing is not an appropriate curing method for polymer concrete.

Most published works resolved to air curing at ambient room temperature for long period of time (10 to 168 hours) before the specimen was subjected to heat curing (post-curing) [5-10]. In countries with colder climates, the curing process begins with pre-curing at room temperature for long period of time. Additionally, polymer concrete is normally cast during winter seasons/cold conditions since it is very sensitive towards high temperature. However, the specimen has to be further heat-cured (post-curing) for several hours to obtain the full strength of polymer concrete.

All in all, there is no specific curing temperature and period for post-curing to ensure sufficient development of target strength for polymer concrete. Therefore, the main objective of this research is to determine the optimum post-curing temperature and time period needed for both Orthophthalic and Isophthalic based polymer concrete.

2.0 EXPERIMENTAL

2.1 Materials

2.1.1 Polyester Binder and Additive

Polyester resins used in polymer concrete are commonly unsaturated orthophthalic and isophthalic polyester resins [11]. In this study, polyester additive with 0.5% of promoter of cobalt naphthenate (CoNp) and 1% of crosslinker of methyl ethyl ketone peroxide (MEKP) by resin weight were added into the polymer binder formulation.

2.1.2 Aggregates and Filler

Oven-dried and crushed coarse aggregates and river fine aggregates were used and the moisture content was kept consistently below 0.1% for both. The size of coarse aggregate in this study was limited to10-12 mm only; smaller single sizes of coarse aggregate are preferred to give high compressive strength, as suggested by Rashid and Mansur [12].

Palm Oil Fuel Ash (POFA) was ground and the particles that had passed through 45 μm sieve were used as filler in polymer concrete. This was done based on the researchers' preference to use waste resources as an alternative innovative filler [12-14]. Incorporating filler with low binder content in this study is possible to obtain high strength polymer concrete. Figure 1 shows the information of particle size distribution of ground POFA.

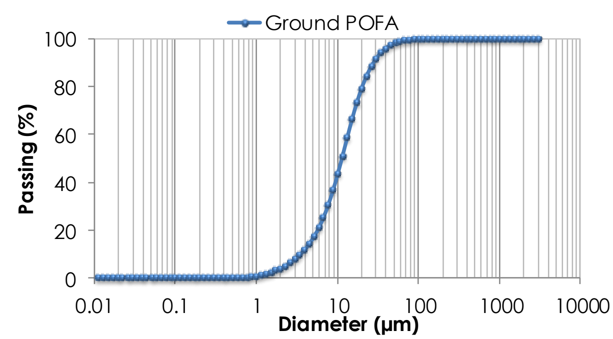


Figure 1 Particle size distribution of ground POFA

2.2 Mix Proportions

Polymer concrete mixes incorporating ground POFA-based Orthophthalic and Isophthalic polyester resin were used. Two mix proportions of PC were properly designed and manufactured as shown in Table 1 with the binder content limited to about 12% of resin, as suggested by published works [14, 15]. In this study, the low amount of polymer binder was able to produce PC with adequate strength at low cost. The filler content varied from 8% to 16%; the coarse aggregate was limited to 30 % for all mix proportions and the rest was fine aggregates, i.e., sand. The PC type was labeled using the following notations: Ortho-PC; Orthophthalic based polymer concrete and Iso-PC; Isophthalic based polymer concrete.

Table 1 Mix proportions of polymer concrete

Polymer concrete type	Mix proportion: Polyester binder (kg/m³)	Filler (kg/m³)	Sand (kg/m³)	Coarse aggregate (kg/m³)
Ortho-PC Iso-PC	146	116	711	750

2.3 Specimen Preparation

Orthophthalic and Isophthalic-based polymer concrete (Ortho-PC and Iso-PC) were prepared strictly according to Japanese Industrial Standard, JIS A 1181 [16]. A total of 72 specimens with dimension of 100 mm x 100 mm x 100 mm size were prepared. The specimens were left at room temperature of 30 ± 2°C for an hour and then oven-dried as a form of post-curing to complete the curing process. The specimens were cured at 30°C, 50°C and 70°C and at different curing period - 1, 3, 6, 16 and 24 hours. Temperature of oven was controlled by modern digital thermostat. Compression test was conducted by using a compression machine with capacity of 200 kN and loading rate of 6 kN/s. All specimens were tested according to design of curing temperature and period. The compressive strength was obtained from the average of three specimens for each condition. The weight of every specimen was recorded to obtain apparent density of overall specimens, which is the weight over the volume. The region of density characteristic (upper and lower limit region) can be calculated from basic statistic as stated in Equation 1 and Equation 2.

$$\rho_{upper\ limit} = \rho_{avg} + (1.64 \times SD) \quad (1)$$

$$\rho_{lower\ limit} = \rho_{avg} - (1.64 \times SD) \quad (2)$$

2.4 Morphology

After all specimens were tested, miniature specimens (only Iso-PC with desirable curing temperature) were taken to investigate their morphology properties by using Scanning Electron Microscope (SEM). Fractured miniature specimens were immersed into acetone for 24 hours before it was observed under SEM to completely cease the polymerization process of polymer concrete.

3.0 RESULTS AND DISCUSSION

3.1 Apparent Density

Apparent density is the weight per unit volume of a material including the void inherent in the tested material. This is the compulsory parameter before the specimens are tested to gauge the consistency of concrete production. Figure 2 and Figure 3 show the apparent density of polymer concrete for all 72 specimens produced at different curing temperature and period. The average apparent density was 2250.82 kg/m³ and the standard deviation (SD) was 24.28.

Even though the polymer concrete had different maturity, the apparent density for Ortho-PC and Iso-PC had similar apparent density of 2250 kg/m³. Most specimens had its apparent density fallen within the region of apparent density characteristics (within upper and lower region). Effect of curing temperature and period were insignificant to the apparent density of polymer concrete.

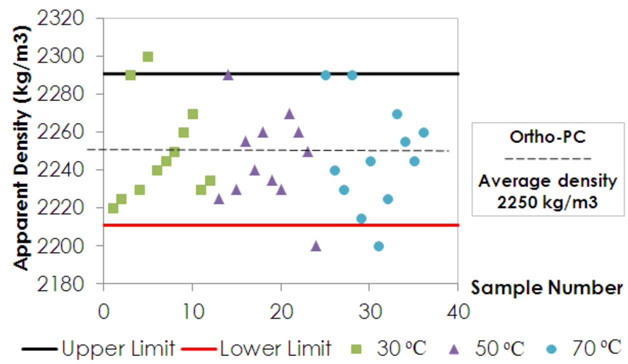


Figure 2 Apparent density of Ortho-PC after cured at different curing temperature and period

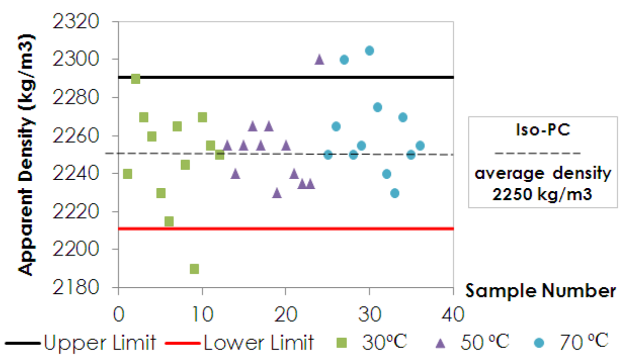


Figure 3 Apparent density of Iso-PC after cured at different curing temperature and period

3.2 Compressive Strength

Figure 4 shows the compressive strength of all Ortho-PC and Iso-PC. Results indicated that compressive strength and curing period had non-linear relationship in which the compressive strength had gradually increased with increasing curing period and getting constant at specific curing period. At an initial curing period of one hour, the compressive strength was negligible. However, after being cured for up to 16 hours, the compressive strength progressively reached approximately about 50 MPa for Ortho-PC and 60 MPa for Iso-PC. These outcomes clearly demonstrated that the highest compressive strength had been achieved after 16 hours of curing time for both polymer concrete.

Additionally, it was clear that Iso-PC had superior compressive strength to Ortho-PC due to its molecular structure being denser [17, 18]. Strong relationship has been exhibited between compressive strength and curing period of all polymer concrete since both regression values, R^2, were more than 0.80.

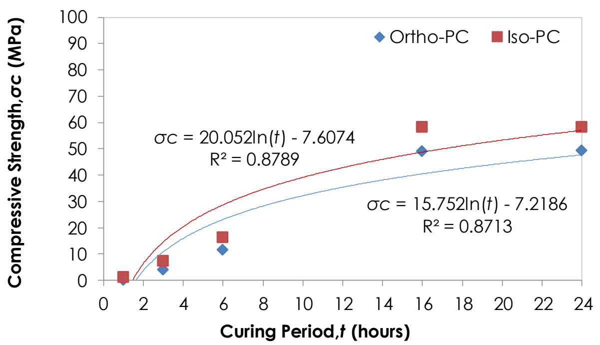


Figure 4 Compressive strength of Ortho-PC and Iso-PC at different curing period with curing temperature of 30°C

Similar results between Orthophthalic and Isophthalic-based polymer concrete cured at 50°C and 70°C are shown in Figure 5 and 6, respectively. Both figures showed that the relationship between compressive strength and curing period was also non-linear regardless of the curing temperature. Nevertheless, it followed the earlier notion of compressive strength increasing with prolonged curing period. At both curing temperatures, the polymer concrete achieved constant compressive strength when exposed to post-curing approximately about 50 MPa for Ortho-PC and 60 MPa for Iso-PC. This shows that complete crosslinking had occurred within the first six and three hours when the polymer concrete was exposed to a curing temperature of 50°C and 70°C, respectively. The strong relationship between compressive strength and curing temperature at both temperatures was demonstrated through the high R^2 values, which was more than 0.80 for overall types of PC.

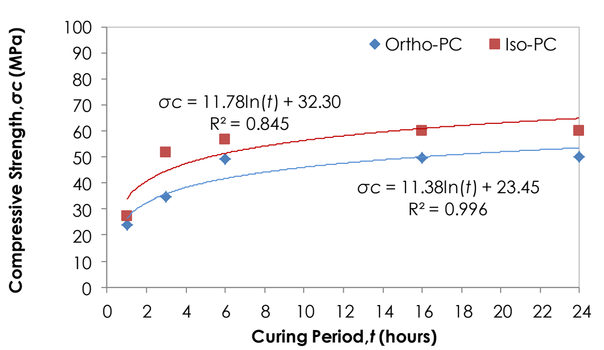


Figure 5 Compressive strength of Ortho-PC and Iso-PC at different curing period at curing temperature of 50°C

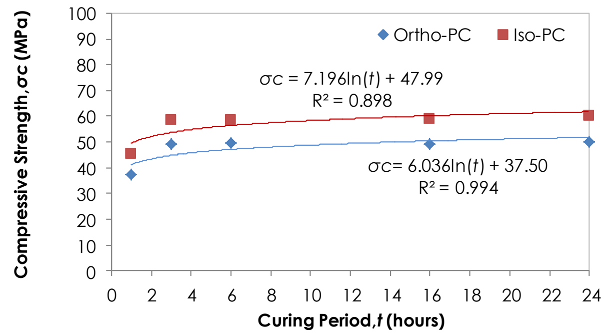


Figure 6 Compressive strength of Ortho-PC and Iso-PC at different curing period at curing temperature of 70°C

Overall Isophthalic-based polymer concrete continued to demonstrate higher compressive strength than Orthophtalic-based polymer concrete at all curing temperature. It is because of the former's denser molecular structure. At this curing temperature, the compressive strength progressively increased to about 50 MPa for Ortho-PC and 60 MPa for Iso-PC.

3.3 Morphology

The maturity of polymer concrete is shown through the completeness of the crosslinking of polyester resin. This was captured in SEM images with 250 times magnifications. Figure 7 shows the SEM image of Isophthalic-based polymer concrete within 6 hours of curing period and being cured at 70°C. The form of crosslinking is pointed in red. Additionally, strength development in this study related with the rate of attainment of kinetic energy of the particle. Condensation stage progressively was achieved simultaneously with the progress of crosslinking of polyester resin and this resulted in the formation of polymer concrete.

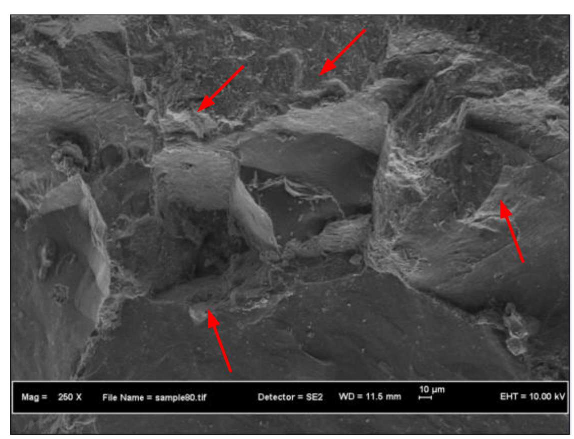


Figure 7 SEM image of Isophthalic based polymer concrete with 6 hours of curing period at 70°C of curing temperature

4.0 CONCLUSION

From the results of the experiments on the effect of post-curing on density, compressive strength and crosslinking of polymer concrete, the following conclusions can be drawn:

1. Apparent density of Orthophthalic- and Isophthalic-based polymer concrete was about 2250 kg/m^3.
2. Curing temperature and period insignificantly affected the apparent density of all polymer concrete specimens.
3. Orthophthalic- and Isophthalic-based polymer concrete had higher compressive strength after being subjected to sufficient curing period of six hours and three hours at curing temperature of 50 °C and 70 °C, respectively. At 30 °C, the complete development of compressive strength was only achievable at 16 hours of curing period.
4. The fully-developed compressive strength of Orthophthalic- and Isophthalic-based polymer concrete was about 50 MPa and 60 MPa, respectively, when sufficient crosslinking of polymer binder had been formed.

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