Effect of water curing duration on strength behaviour of portland composite cement (PCC) mortar

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Abstract. Cement manufacturing of Indonesia has been introduced Portland Composite Cement (PCC) to minimize the rising production cost of cement which contains 80% clinker and 20% mineral admixture. A proper curing is very important when the cement contains mineral admixture materials. This paper reports the results of an experimental study conducted to evaluate the effect of water curing duration on strength behaviour of PCC mortar. Mortar specimens with water to cement ratio of (W/C) 0.5 were casted. Compressive strength, flexural strength and concrete resistance were tested at 7, 28 and 91 days cured water. The results indicated that water curing duration is essential to continue the pozzolanic reaction in mortar which contributes to the development of strength of mortar made with PCC.

1. Introduction
Cement manufacturing companies in Indonesia has been introduced Portland Composite Cement (PCC) to minimize the rising production cost of cement. The PCC equivalent with CEM Type II/A-M cement which contains 80% clinker and 20% mineral admixture including ground granulated blast furnace slag, silica fume, fly ash and gypsum. The use of the PCC on concrete production requires a proper curing due the presence of mineral admixture. Although it is very simple and inexpensive procedure, proper initial curing has an important influence on improving the concrete quality [1-2]. The objective of curing is considered by the duration of providing concrete with sufficient humidity and appropriate temperature conditions to reduce the loss of moisture to ensure the progress of hydration reactions causing the filling and segmentation of capillary voids by hydrated compounds [3-4]. The matter would be more critical in the case of the cement containing supplementary cementitious material because the pozzolanic reaction is very sensitive to the curing procedure. According to the ACI Committee 308 [5], the curing period should be extended to 14 days when the cement contains supplementary cementitious materials, owing to the slow hydration reactions between supplementary cementitious materials and the calcium hydroxide. Furthermore, curing condition also could be an important parameter in controlling durability of the reinforced concrete exposed to the marine environment [6].

In this study, the effect of water curing duration on strength behaviour of mortar made from PCC was evaluated. Mortar specimens with water to cement ratio of (W/C) 0.5 were casted. Compressive strength, flexural strength and concrete resistance were tested at 7, 28 and 91 days cured water.
2. Experimental procedure

2.1. Material and mix proportion
Portland Composite Cement (PCC), Ordinary Portland Cement (OPC), washed sea sand were used and physical properties of material is shown in table 1. Further, the chemical compounds of the PCC and OPC is presented in table 2. For all specimens a mortar mix with water to cement ratio (W/C) 0.5 was casted. The mix proportion of mortar used is described in table 3.

Table 1. Physical properties of materials.

| Material                        | Description                                      |
|---------------------------------|--------------------------------------------------|
| Portland Composite Cement (PCC)| SSD density = 3.08 g/cm$^3$                       |
|                                 | Specific surface area (SSA)= 3410 cm$^2$/g       |
| Ordinary Portland Cement (OPC)  | SSD density = 3.16 g/cm$^3$                      |
|                                 | Specific surface area (SSA) = 3390 cm$^2$/g      |
| Washed sea sand                 | SSD density = 2.58 g/cm$^3$                      |
|                                 | Fineness modulus (F.M) = 2.77                    |

Table 2. Chemical compounds of cement.

| Chemical compounds (%)         | PCC     | OPC     |
|--------------------------------|---------|---------|
| Magnesium oxide (MgO)          | 0.99    | 1.2     |
| Sulfur trioxide (SO$_3$)       | 1.81    | 2.23    |
| Silicon dioxide (SiO$_2$)      | 18.39   | 19.71   |
| Aluminium oxide (Al$_2$O$_3$)  | 5.15    | 5.20    |
| Ferric oxide (Fe$_2$O$_3$)     | 3.14    | 3.73    |
| Calcium oxide (CaO)            | 61.79   | 62.91   |
| Loss of ignition (LOI)         | 4.61    | 2.15    |

Table 3. Mix proportion of mortar.

| W/C   | Water (kg/m$^3$) | Cement (kg/m$^3$) | Sand (kg/m$^3$) |
|-------|------------------|-------------------|-----------------|
| 0.5   | 255              | 510               | 1508            |

2.2. Mixing and curing
Water and cement were first placed in a standard mortar mixer and mixed for about 1 min. Then, the sands were added and mixed for 2 min. Finally, the mixture was mixed for an additional 2 min to complete the whole mixing process. The fresh mortar samples were then put into the steel moulds in two layers of similar depths. After filling up each layer, compaction was achieved by placing the moulds on a mechanical vibrating table. Thereafter, the mortar specimens were covered with a plastic sheet and allow to cure in the laboratory environment at 20 ± 2 ºC for 24h. After 24h, the samples were demoulded and cured in water until further testing.

2.3. Specimens and testing
The flow table test was used for determining the fluidity of fresh mortar mix as described by ASTM C1437 [7]. A three-point flexural strength test in conformity with ASTM C348 [8] was performed at 7, 28 and 91 days on prism specimens with a size of 40 x 40 x 160 mm (figure 1). The remaining portions of the broken prisms in the flexure strength test were used for determining the equivalent compressive strength according to ASTM C349 [9] as shown in figure 2. In addition, the electric resistance of mortar was measured on prism specimen (40 x 40 x 160 mm) with steel bar of 10 mm in
diameter centrally located with a length of 120 mm. Mortar resistance was performed by immerse method using portable rebar corrosion meter as shown in figure 3.

Figure 1. Three-point flexural strength test  Figure 2. Compressive strength test

Figure 3. Mortar resistance measurement

3. Results and discussion

3.1. Slump flow
The slump flow results of the fresh mortar mixes are shown in figure 4. The results show that the PCC decreased the fluidity of the mortar due to the higher surface area of PCC than OPC which cause low workability. The slump flow of PCC and OPC mortar were 160 mm and 165 mm, respectively.

3.2. Flexural strength
The flexural strength of PCC and OPC mortar was determined at the ages of 7, 28 and 91 days. Figure 5 shows the development of flexural strength with age for PCC and OPC mortar. The flexural strength of PCC mortar is found lesser than of OPC mortar at all the ages, which could be attributed for slow hydration process of PCC. The percentage increase in flexural strength from 7 to 28 days and 28 days to 91 days has been 4.95% and 6.32%, respectively for OPC mortar. The increase in strength for similar comparison is observed as 12.37% and 14.36%, respectively for PCC mortar.
3.3. Compressive strength

Figure 6 shows the development of compressive strength of PCC and OPC mortar at 7, 28, and 91 days cured water. The compressive strength of mortar increased with increasing curing time. Test results showed that the 7 days compressive strength for OPC mortar is 25.05% higher than PCC mortar. After 28 days, PCC and OPC mortar reached the compressive strength of about 34.38 MPa and 42.19 MP. A significant increasing in compressive strength of PCC mortar was noticed at 91 days. The PCC mortar shows that compressive strength is almost identical with that of OPC mortar after 91 days cured water. This indicates that PCC mortar have lower strength than OPC mortar at early ages (7 and 28 days), but achieved similar compressive strength at 91 days.

3.4. Resistivity measurement

The resistivity of PCC and OPC mortars specimens at 7, 28, and 91 days are shown in Figure 7. Similar trends to that flexural and compressive strength can be observed. The resistivity of mortar increased with increasing curing time. The resistivity of PCC and OPC mortar is found similar at 7 days. At 28 days, OPC mortar showed higher resistivity value than PCC mortar due to the slow hydration process in the presence of mineral admixture of PCC. But at later ages, the resistivity of PCC and OPC mortar is almost same.
The properties of mortar are significantly influenced by duration of curing since it greatly effects the hydration of cement. A proper curing maintains a suitably warm and moist environment for the development of hydration products and thus reduces the porosity in hydrated cement paste and increases the density of microstructure in mortar [10]. The chemical composition of the calcium silicate formed in hardened blended cement paste was different from that of Portland cement hydration products. For this reason, mortar made with PCC will have lower strength than OPC at early ages and reached almost similar strength at longer ages of curing (91 days).

4. Concluding remarks
This experimental study has investigated the effect of water curing duration on strength behaviour of Portland Composite Cement (PCC). The strength at early ages of PCC mortar is lower than that of OPC mortar whereas, at later ages both of the mortar is providing approximately similar strength due to continuous curing condition and well performed pozzolanic reaction activities. It can be concluded that adequate curing at early ages as well as later ages is essential to continue the pozzolanic reaction in mortar which contribute to the development of strength of mortar made with PCC.

5. References
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