Using calcium chloride as an accelerator for Portland pozzolan cement concrete compressive strength development

I M A K Salain
Civil Engineering Department, Udayana University, Bali, Indonesia
imaksalain@unud.ac.id

Abstract. The influence of calcium chloride (CaCl₂) as an accelerator for the compressive strength development of concrete made with type I Portland pozzolan cement (PPC) as a hydraulic binder has been investigated. Natural sand and crushed stone were used as fine aggregate and coarse aggregate, respectively. The mix proportion of concrete, by weight, was 1.0 binder: 2.1 fine aggregate: 3.4 coarse aggregate and the water-binder ratio was 0.57. The calcium chloride added to the concrete mixture was 0%, 1.0%, 1.5%, and 2.0% by binder weight. The compressive strength test was performed at 1, 3, 7, 28, and 90 days. The test results show that adding CaCl₂ to a concrete mixture accelerates the development of compressive strength. The compressive strength gain was about 36–48% at 1 day and about 29–33% at 3 days, compared to control concrete. Moreover, it increases the compressive strength of PPC concrete about 3–16% at 28 days and about 7–19% at 90 days. The optimum dose of CaCl₂ to accelerate the development of compressive strength at the early age and to produce the highest compressive strength in the long-term was about 1.5%.

1. Introduction
Portland pozzolan cement (PPC) is a blended Portland cement that was developed to meet specific needs in the concrete construction industry. It is a hydraulic binder produced by pulverizing Portland cement (PC) clinkers and pozzolan, or by blending PC powder and fine pozzolan uniformly and intimately. Pozzolan is a siliceous or silica-aluminous material which, in itself, has little or no cementitious properties but which will, in finely divided form and in the presence of water at normal temperature, react chemically with calcium hydroxide to produce compounds having cementitious properties [1]. Based on the origin, pozzolan is classified as natural pozzolan (volcanic ash or pumice) or artificial pozzolan (fly ash, rice husk ash, combustible clay, etc).

In the concrete industry, the use of pozzolan in PPC ranges around 15–40% of the total cement weight depending on the origin as well as the chemical and physical properties of pozzolan. The development of PPC has been realized in many countries in the world and its use tends to increase over time. This is related to the benefits contributed by using pozzolan in cement and concrete. It is well known that pozzolan can be used to ameliorate workability, strength, durability and other properties [2–4]. Using pozzolan will also reduce cost and pollution caused by greenhouse gases liberated during PC production. However, the strength development of PPC concrete is slower in early hydration than that of PC concrete, although it gives a better strength in long-term hydration [2–4]. This phenomenon is related to the fact that the reaction between pozzolan and calcium hydroxide resulting from Portland cement hydration is relatively slow so that the rate of strength development will be accordingly slow. This
problem, to a certain degree, can limit the use of PPC in concrete mixtures, such as in winter concreting. In this condition, sufficient early strength is needed to permit earlier removal of formwork and earlier opening of the construction for service [3]. Similarly, in the precast concrete industry sufficient early strength is also needed to enable earlier removal of formwork to reduce the cycle time and produce cost-saving benefits [5]. Therefore, studies related accelerating the development strength of PPC concrete must be carried out so that its use in concrete technology can be maximized.

It is well known that the most cost-effective accelerator for all kinds of Portland cement systems is calcium chloride (CaCl_2). This chemical admixture provides both set and hardening acceleration. Numerous studies have been done in the past to evaluate the effect of CaCl_2 as an activator or accelerator in various types of hydraulic binder. Shi and Day [6] found that using 4% CaCl_2 2H_2O on a blend composed of 80% ground volcanic ash and 20% hydrated lime reduced the early strength; however, it increased the long-term strength at 23°C. Nevertheless, this use increased both the early and long-term strengths of the blend from 35°C to 65°C. Furthermore, they also reported [7] that a solid solution of C3A Ca(OH)_2·H_2O - C3A CaCl_2·10H_2O was formed that gave, after a certain hydration time, a better strength in the blend with CaCl_2 than the blend without CaCl_2. The result of a study realized by Makaratat et al. [8] showed that using 3% CaCl_2 clearly accelerated the compressive strength development of concrete at early hydration times. They used a binder composed of 30% ground calcium carbide residue and 70% classified fly ash. In their experimental study, Huang and Shen [9] showed that a binder additive composed of CaCl_2 and Ca(NO_3)_2 could increase the early strength of the binder significantly. They also noted that CaCl_2 was more effective than Ca(NO_3)_2 during this hydration period. Kishar et al. [10] observed that using CaCl_2 accelerated the hydration of ordinary Portland cement and also blended Portland cement with ground clay bricks (GCB). At all hydration times, the compressive strengths of the mixtures with CaCl_2 were higher than those without CaCl_2. Using 10% GCB in blended Portland cement with the addition of 0.50% CaCl_2 was the optimum ratio giving the maximum compressive strength. Salain [11] studied the effect of CaCl_2 on concrete compressive strength development made using a mixture of 90% type I Portland cement and 10% class F fly ash as a hydraulic binder. He noted that adding CaCl_2 to a concrete mixture accelerated concrete compressive strength development during early hydration and produced higher compressive strength in long-term hydration than concrete without CaCl_2. The optimum use of CaCl_2 was found to be 2.5%.

The results of those studies indicate that the addition of CaCl_2 in various types of hydraulic binder accelerates binder hydration and, in certain cases, increases the early and long-term strengths of the hydrated binder. It was noted however that the optimum quantity of CaCl_2 used in a concrete mixture varies strongly with many variables such as the physical and chemical properties of the hydraulic binder, CaCl_2 type and curing temperature. Therefore, a study on using CaCl_2 as an accelerator according to the type of hydraulic binder used in a concrete mixture to optimize its performance it is always interesting.

In this study, using CaCl_2 as an accelerator in PPC concrete was observed. The goal of this study is to assess the performance of CaCl_2 on the compressive strength development of PPC concrete.

2. Materials and experimental method

2.1. Materials
This experimental study used concrete-forming material consisting of water, hydraulic binder, fine aggregate and coarse aggregate. Tap water was used for mixing concrete while type I Portland pozzolan cement (PPC) from a Portland cement plant in Indonesia was used as a hydraulic binder.

Natural sand (NS) was used as fine aggregate and crushed stone (CS) was used as coarse aggregate. The grain distribution of NS was designed to meet the gradation of zone 2 while that for CS was designed for a maximum grain size of 40 mm in accordance with SNI 03-2834-2000 [12]. The fineness modulus of fine aggregate and coarse aggregate were 2.74 and 7.25, respectively. The physical properties of these aggregates are presented in table 1 and figure 1 shows the grain distribution of these aggregates. Anhydrous CaCl_2 was used as an accelerator. This chemical admixture was purchased from a building material supplier.
### Table 1. Physical properties of natural sand and crushed stone.

| Physical Properties | Natural Sand | Crushed Stone |
|---------------------|--------------|---------------|
| Abrasion (%)        | -            | 18.30         |
| Absorption (%)      | 1.01         | 3.60          |
| Specific gravity SSD| 2.51         | 2.45          |
| Unit weight (g/cm³) | 1.45         | 1.23          |

![Figure 1. Natural sand and crushed stone grading design with SNI 03-2834-2000 grading limits.](image)

2.2. **Experimental method**

2.2.1. **Mixture proportion.** Four concrete mixtures, named M1, M2, M3 and M4, were prepared for this study. In each of the four mixtures, the proportion of PPC, NS and CS and the water to cement ratio (w/c) was held constant. The proportion of material in M1, M2, M3 and M4, by weight, was 1.0 PPC: 2.1 NS: 3.4 CS and the w/c was 0.57. The content of CaCl₂ in M1, M2, M3 and M4 was 0%, 1.0%, 1.5%, and 2.0% by weight of PPC, respectively. The mixture proportion of these mixtures are presented in table 2.

### Table 2. Mixture proportions.

| Material (kg/m³) | Mixture |
|------------------|---------|
|                  | M1      | M2      | M3      | M4      |
| PPC              | 325     | 325     | 325     | 325     |
| NS               | 681     | 681     | 681     | 681     |
| CS               | 1089    | 1089    | 1089    | 1089    |
| Water            | 185     | 185     | 185     | 185     |
| CaCl₂            | 0       | 3.25    | 4.87    | 6.50    |

2.2.2. **Preparation and specimen casting.** The process of concrete mixing for all mixtures was done by the same procedure to provide a constant treatment [13]. First, anhydrous CaCl₂ was dissolved in water. Next, the PPC, NS and CS were mixed for 2 minutes in the concrete mixer. After that, 75% of the water was added and mixed for 3 minutes. Finally, the remaining water was added, and the mixture was mixed for an additional 2 minutes until it became homogenous. After mixing, each mixture was used to cast 30 cubical specimens, sized 150 mm x 150 mm x 150 mm. These specimens were kept in moulds for 1...
day and then demoulded and cured in water until the time for the compressive strength test. The preparation of the cube specimens, according to Indonesian Standard SNI 2493:2011 [13], is presented in figure 2.

![Preparation of cube specimens](image)

**Figure 2.** Preparation of cube specimens.

2.2.3. Compressive strength test. The compressive strength tests were conducted at the hydration ages of 1, 3, 7, 28 and 90 days. Six cube specimens were used for each mixture and each hydration age. Figure 3 shows the equipment used for the compressive strength test of the specimens conducted according to SNI 03-1974-1990 [14].

![Compressive strength test equipment](image)

**Figure 3.** Compressive strength test equipment.

3. Results and discussion

3.1. Results

The average compressive strength values of the specimens for various CaCl₂ percentages at 1, 3, 7, 28 and 90 days are shown in table 3. The data are also represented graphically in figure 4.

These results show that the compressive strength of concrete with and without CaCl₂ increases with increasing the hydration time. It increases strongly for the first seven days of hydration and tends to increase gradually after that period. This increase is related to the progress of the PPC hydration, which is clearly influenced by the presence of CaCl₂.
Table 3. Compressive strength test results.

| Mixture | Accelerator Content (%) | Compressive Strength (MPa) |
|---------|--------------------------|-----------------------------|
|         |                          | 1 day | 3 days | 7 days | 28 days | 90 days |
| M1      | 0                        | 13.00 | 23.74  | 29.70  | 36.15   | 42.37   |
| M2      | 1.0                      | 17.74 | 30.63  | 33.56  | 41.93   | 49.74   |
| M3      | 1.5                      | 17.67 | 31.11  | 34.52  | 41.96   | 50.22   |
| M4      | 2.0                      | 19.26 | 31.63  | 37.19  | 40.89   | 45.26   |

With respect to using CaCl₂ as an accelerator, the rate of the compressive strength development of concrete with CaCl₂ is clearly faster compared to that of control concrete M1 without CaCl₂, particularly for the 1 day hydration period. In this case, the compressive strength of all the mixtures with CaCl₂ (M2–M4) were higher than that of the control concrete at all hydration ages. These results are in agreement with those reported by Khisar et al. [10] and Salain [11].

At the age of 1 day, and compared to concrete without CaCl₂, the compressive strength gain of M2, M3 and M4 are about 36.5%, 35.9% and 48.2%, respectively. They are about 29.0%, 31.0% and 33.2% at 3 days; about 13.0%, 16.2% and 25.2% after 7 days; about 16.0%, 16.1% and 13.1% after 28 days and about 17.4%, 18.5% and 6.8% after 90 days of hydration. In this case, the strength gain clearly tends to decrease with increasing hydration time, especially for concrete with 2.0% CaCl₂. However, in concrete with 1.0% and 1.5% CaCl₂, the strength gain tends to stabilize after 3 days of hydration.

Figure 4. Compressive strength versus hydration time of various mixtures.

3.2. Discussion

The compressive strength development presented by PPC concrete mixtures is strongly influenced by the quantity of CaCl₂ used. The presence of this chemical admixture in the mixtures not only accelerates the hydration process but also improves the compressive strength values of PPC concrete.

In the Portland cement hydration process, from its four main minerals (C₃S, C₂S, C₃A and C₄AF), only C₃S and C₂S present an important role in the strength development of the paste hydrate [2–4]. C₃S contributes to the development of early strength while C₂S contributes to long-term strength. It seems that the presence of CaCl₂ in the mixture accelerates the dissolution of calcium ions and silicate ions from the C₃S and C₂S of PPC to produce the main hydration product, calcium silicate hydrate C-S-H and free calcium hydroxide Ca(OH)₂. Moreover, the pozzolanic reaction involving liberated free Ca(OH)₂ and reactive silica and alumina from the pozzolan of PPC occurs to produce additional cementitious products such as C-S-H and calcium alumina hydrate C-A-H. With the accelerated
hydration process of C3S and C2S, the pozzolanic reaction is also accelerated to produce additional binder compound. This condition accelerates the hydration and the hardening process so that the development of compressive strength in concrete with CaCl₂ becomes faster compared to that of the concrete without CaCl₂. This phenomenon is more pronounced at 1 day of hydration compared to the next period of hydration. This can be related to the availability of more free water in the early hydration, which facilitates the ionization of PPC compounds and minerals.

The use of CaCl₂ as an accelerator also contributes to increasing the compressive strength of concrete at all hydration times. It is possible that this phenomenon is related to the development of a solid solution of C₃A Ca(OH)₂ H₂O - C₃A CaCl₂ 10H₂O in the hydrated PPC paste [7]. This development provides a denser structure in the hydrated PPC paste and a better compressive strength on PPC concrete with CaCl₂ compared with that without CaCl₂.

Based on the strength test results, the optimum dose of CaCl₂ to accelerate the compressive strength development at early ages and to give simultaneously the highest compressive strength of concrete in the long-term is around 1.5%. Furthermore, these results demonstrate also that they meet the requirements of both European and American standards concerning concrete admixtures. In fact, EN 934-2:2009 [15] limits the compressive strength of concrete with an accelerator to a minimum 120% and 90% of control concrete at 1 day and 28 days, respectively. The corresponding limit of ASTM C494/C494M-17 [16] is 125% and 100% of control concrete at 3 days and 28 days, respectively. According to this study, the compressive strength of PPC concrete with the addition of 1.0%, 1.5% and 2.0% CaCl₂ are about 136.5%, 135.9% and 148.2%, respectively, at 1 day; about 129.0%, 131.0% and 133.2%, respectively, at 3 days; and about 116.0%, 116.1%, and 113.1%, respectively at 28 days of hydration.

4. Conclusion
Referring to the test results and discussion, the subsequent conclusions are presented:

- Using CaCl₂ in PPC concrete mixtures not only accelerates the hydration process but also improves the compressive strength of PPC concrete.
- The optimum dose of CaCl₂ in PPC concrete mixtures to accelerate the development of compressive strength at the early age and to produce the highest compressive strength in the long period is about 1.5%.
- On that optimum utilization, and compared to concrete without CaCl₂, the compressive strength gain is about 35.9% at 1 day and about 18.5% at 90 days of hydration.

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