Effects of Leaching on the Properties of Concrete

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Abstract

The effects of leaching on the properties of concrete has been investigated in this study. A tank leaching test was conducted, where concrete specimens were exposed to demineralized water for different time periods. pH variation of leached water and properties (compressive strength, permeability and weight) of the concrete specimens were evaluated after different leaching periods. The results suggest that the leaching of ions (particularly Ca^{2+}) of concrete increased the alkalinity of leached water. At 90 days leaching periods, compressive strength of concrete was increased by 10.14% with respect to without (0 days) leaching specimen and decreased by 16.36% with reference to 30 days leaching sample. Besides, after 90 days leaching weight of the concrete specimen was reduced by 0.05% and 0.08% compared to 0 and 30 days leaching specimens, respectively. Moreover, after 90 days leaching permeability of the concrete sample rose by 9.89% with respect to 0 days leaching specimen.

Keywords: *Leaching, concrete, hydration products, dissolution.*

1 Introduction

When a cementitious material contacted with external water, there is an ionic transfer happen between the interior pore solution of cementitious material and exterior water (Kamali et al., 2009). This phenomenon is called leaching. Hardened cementitious materials (paste, mortar or concrete) contain pore space and solid hydrates. Usually the pore space is packed up with the highly charged solution which contains K^+, Na^+, Ca^{2+}, OH^- etc. (Faucon et al., 1998). Calcium hydroxide, calcium silicate hydrates, ettringite and monosulfate are the principal solid hydrates. Generally the interstitial solutions and solid hydrates exist in thermodynamic equilibrium condition. However, when a concrete element is immersed in pure water, this equilibrium condition interrupts. Water generates a concentration gradient between pore solution and external water, which leads to diffusion of ions from pore solution to external water (Planel et al., 2006).

As the surface of concrete approaches to poorly mineralized or demineralized water, first stage of dissolution is portlandite (calcium hydroxide). Progressively other hydrates (monosulfate, ettringite and calcium silicate hydrates) also dissolute (Adenot and Buil, 1992). In consequence, porosity of concrete increased. Porosity has significant impacts on physical properties of concrete such as density, water absorption, strength, permeability, etc. Not only the physical properties of concrete, but also chemical properties (pH, element concentration and Eh) of pore solution also influenced by leaching (Haga et al., 2005).

Mainguy et al. (2000) developed a model for leaching of cement paste and mortar to predict long-term evolution of concrete considering calcium in the liquid phase. After that Kamali et al. (2003) developed a model for leaching mechanism of cementitious materials considering several parameters, in particular water binder ratio, content of silica fume, temperature and pH. Haga et al. (2005) investigated the influence of leaching on the porosity and composition of the hardened cement paste. The authors noticed that as the leaching time increased Portlandite dissolution was increased. Not only the dissolution of Portlandite, but also the dissolution and precipitation of ettringite and calcium silicate hydrate occurred due to leaching. They observed that leaching changed the pore volume of the cement paste. They also noticed a linear relationship between depth of Portlandite dissolution front and the square root of the leaching time. Carde and Francois (1997) observed that there was a linear relationship between the strength loss and increase in porosity with respect to the degraded ratio. Roziere et al. (2009) studied the influence of leaching on the durability of concrete. They found that dissolution of Portlandite accelerates the ingress of sulphate ions and produced gypsum and ettringite which are expansive. Therefore, expansive products form cracks in the concrete structure. The authors also suggested that the substitution of OPC by 30% fly ash or 62% GGBFS improved the resistance of concrete against leaching and sulphate attack. Jain and Neithalath (2009) reported that glass powder and fly ash modified pastes showed lower Portlandite (CH) dissolution compared to conventional plain paste specimen. The glass powder modified paste showed higher resistance against calcium leaching due to the existence of the NaOH in its pore solution which minimize the calcium hydroxide (CH) solubility (Jain and Neithalath, 2009). Addition of limestone (Catinaud et al., 2000) and silica nanoparticles (Gaitero et al., 2008) also assist to minimize the calcium leaching from the cement based materials.

From the above discussion, it is noticed that leaching changes the pore structure of concrete which has significant effects on physical, mechanical and durability related properties of concrete structures. Most of the studies were conducted using paste and mortar sample. Therefore, the objective of the study was to investigate the effects of leaching on the properties of concrete. This study presents pH variation of leached water and properties of concrete, particularly compressive strength, permeability and weight of the concrete specimens at different leaching periods.

2 Materials and Methods

2.1 Materials

Ordinary Portland Cement (OPC) was used as the binding material. Fineness and specific gravity of cement were 3600 cm^2/gm and 3.15, respectively. Crushed granite was used as a coarse aggregate where the maximum size of coarse aggregate was 20mm. Natural silica sand was used as a fine aggregate. The physical properties of fine and coarse aggregates are given in Table 1.

Table 1. Properties of fine and coarse aggregates.

Property	Stone chips	Sand
Dry rodded unit weight (kg/m^3)	1575	----
Absorption capacity (%)	1.00	2.48
Bulk specific gravity (oven dry basis)	2.70	2.60
Fineness modulus (FM)	----	2.70

2.2 Mix Proportions and test methods

Mix design of concrete was performed according to ACI 211.1 (2009). Mixture proportions of the concrete specimens are given in Table 2. Trial mixes were prepared to get the target strength of 21 MPa at 28 days curing period with a target slump value of 75-100 mm. A standard slump test was conducted to measure the workability of the fresh concrete. After that 150 mm x 150 mm cylindrical moulds were filled with fresh concrete and compaction was done using a standard rod. The samples were demoulded after 24 hrs and immersed in the water curing tank at ambient temperature. After 28 days curing samples were subjected to tank leaching test.

Table 2. Mix proportions of concrete sample.

Mix ID	Cement (kg/m^3)	Sand (kg/m^3)	Stone chips (kg/m^3)	Water (kg/m^3)
A	372.73	753.20	1002.17	205.00

To conduct the tank leaching test, hardened concrete specimen was submerged to demineralized water as per JSCE standard (Sugiyama et al., 2007) which is consistent with NEN 7345 (1995) standard. Amount of demineralized water was selected according to JSCE standard (5 ml water per 100 mm^2 surface area of the sample). The properties of leached concrete and leached water (leachant) were evaluated at different intervals.

pH of leachant was monitored at different time intervals. The compressive strength test of concrete sample was performed following the ASTM C39/C39M (2018) standard. Compressive strength test of concrete specimen was carried out after 28 days curing (before tank leaching test) in normal water and 15, 30 and 90 days leaching periods. Moreover, weight variations of the specimens were recorded at different leaching periods. Water permeability of concrete was determined in accordance with EN 12390-08 (2009). In water permeability test, the specimen was placed in the permeability testing apparatus and 500 ± 50 kPa water pressure was applied for 48 ±

2 hours. Afterwards the specimen was taken out from the apparatus and split in half across the water pressure applied face. Finally from the split face water penetration depth was measured.

3 Results and Discussions

3.1 Variations of pH of leachant

Figure 1 represents the variations of pH of leachant at different leaching times. From the Figure 1 it is seen that the pH of the leached water varies from around 7 to 10 which indicates the alkalinity of leached water. As calcium and other ions (K^+, Na^+, OH^-, etc.) comes in water from concrete specimen, alkalinity of leachant that is pH of leached water increased with respect to pure or demineralized water. It is also observed that there is not so big difference of p^H for different leaching times as pH also controlled by other aspects (CO_2, temperature, etc.).

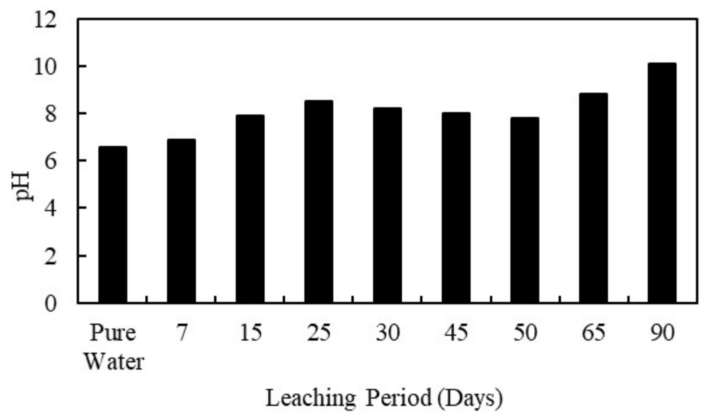

Figure 1. Variations of pH of leachant.

3.2 Variations of compressive strength

Figure 2 represents the compressive strength variations of concrete for different leaching times. From the Figure 2 it is seen that at 0 days leaching (28 days curing and before adding leachants), compressive strength of concrete sample was 17.55 MPa. The compressive strength of concrete specimens were 20.17, 23.11 and 19.33 MPa at 15, 30 and 90 days leaching durations, respectively. It is noticed that after 15, 30 and 90 days leaching periods compressive strength increased by 14.93%, 31.68% and 10.14%, respectively compared to without leached specimen. The improvement of compressive strength for up to 30 days leaching is probably attributed to the evolution of solid substances which might be the outcome of further curing. In contrast, after 90 days leaching durations the compressive strength was reduced by 4.16% with reference to 15 days leaching, and by 16.36% with respect to 30 days leaching. This finding ascribes that dissolution of the hydration substances was occurred after 90 days leaching periods and in consequence compressive strength of concrete sample was declined.

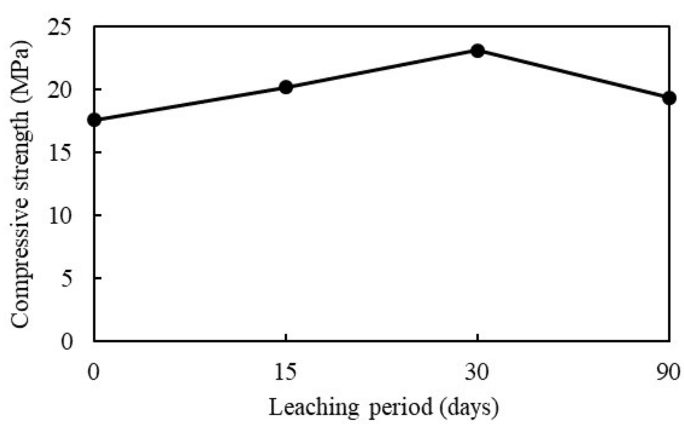

Figure 2. Variations of compressive strength of concrete.

3.3 Variations of weight

Figure 3 presents the weight variations of concrete for different leaching times. From the Figure 3 it is observed that the weight of concrete sample were 6371.5, 6371.5, 6373.5 and 6368.5 gm after 0, 15, 30 and 90 days leaching durations, respectively. It is noticed that at 30 days leaching periods, weight of the sample rose by 0.03% with respect to without leached specimen. This outcome also suggests that there was a growth of solid substances for until 30 days leaching and that might be the result of further curing which leads to rise the weight and strength of concrete sample, as discussed in the previous section. In contrary, at 90 days leaching durations the weight of concrete specimen was reduced by 0.05% with reference to without leaching sample, and by 0.08% with respect to 30 days leaching specimen. This finding also reveals the dissolution of hydration substances after 90 days leaching durations and accordingly weight of concrete sample was minimized.

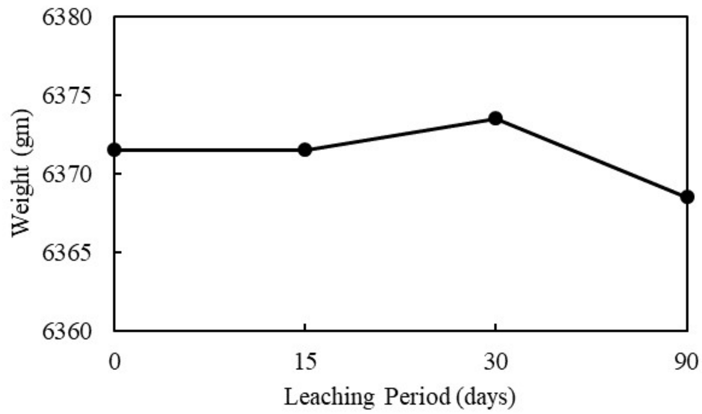

Figure 3. Variations of weight of concrete.

3.4 Water Permeability

Figure 4 shows the water permeability test results of concrete specimens. The depth of water permeability were 100.08 mm and 109.98 mm for without leaching and 90 days leaching sample, respectively. It is observed that the depth of permeability for the 90 days leaching period increased by 9.89% compared to without leaching specimen. This finding also demonstrates the dissolution of hydration products due to leaching which leads to increase porosity of concrete. In consequence, porosity of the concrete leads to increase the permeability of concrete specimens.

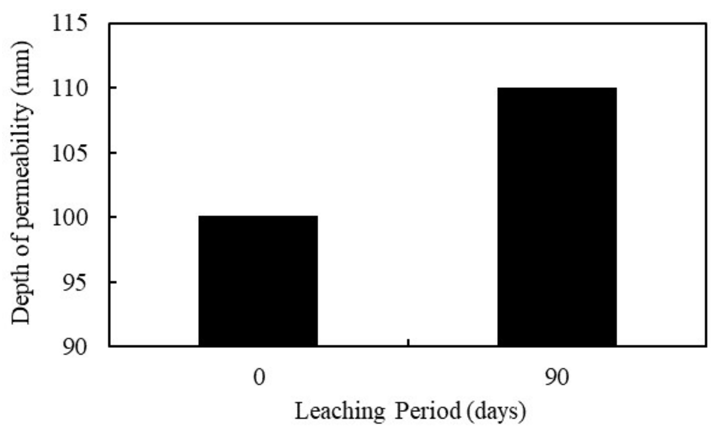

Figure 4. Depth of water permeability of concrete.

4 Conclusions

Leaching effects on concrete specimens was investigated using a tank leaching test. In general, at early (until 30 days) leaching periods there was no remarkable adverse impact on the physical properties of concrete, rather leachant behave as like as a curing medium in that period. Therefore, compressive strength and weight of concrete increased at that period (up to 30 days). However, the performance of concrete gradually degraded after 90 days leaching durations. On the basis of acquired results following conclusions could be made:

- Alkalinity of leachant that is pH of leachant increased with respect to demineralized water for the reason of the dissolution of ions from the concrete specimen.
- After 15, 30 and 90 days leaching periods compressive strength of concrete sample increased by 14.93%, 31.68% and 10.14%, respectively with reference to without leached specimen. In contrast, after 90 days leaching periods, the compressive strength was declined by 4.16% and 16.36% compared to 15 and 30 days leaching periods, respectively.
- Weight of the concrete specimen increased by 0.03% for 30 days leaching compared to without leaching specimen. In contrary, at 90 days leaching durations the weight of concrete sample reduced by 0.05% and 0.08% with respect to without leaching and 30 days leaching samples, respectively.
- The depth of permeability for 90 days leaching periods increased by 9.89% compared to without leaching specimen. This finding demonstrates the dissolution of hydration substances that leads to increase the permeability of concrete.

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