

Research Article

The Compressive Strength and Resistivity toward Corrosion Attacks by Chloride Ion of Concrete Containing Type I Cement and Calcium Stearate

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This study aims to determine the effect of calcium stearate on concrete. Three kinds of concrete quality are studied, namely, 20, 30, and 40 MPa. Tests performed in the laboratory comprise a compressive strength test and an infiltration test of chloride ion content. The specimens used were cylinders with a diameter of 150 mm and height of 300 mm. The chloride ion infiltration test was carried out on a cube with sides of 150 mm. The infiltration of ions into the concrete was examined at depths of 1, 2, 4, 6, and 8 cm. Four dosages of calcium stearate were added to the concrete, namely, 0, 0.25, 1.27, and 2.53% for 20 MPa concrete; 0, 0.21, 1.07, and 2.48% for 30 MPa concrete; and 0, 0.19, 0.90, and 1.87% for 40 MPa concrete. The results of compressive strength tests indicate that the amount of calcium stearate that could be safely applied to the concrete was 0.25% of the weight of cement. On the other hand, the infiltration of chloride ions at a depth of 6 cm from the unprotected concrete surface decreased by 87, 69, and 113% for the 20, 30, and 40 MPa concrete, respectively, compared to concrete without calcium stearate. The test shows that the use of calcium stearate in concrete significantly increases its resistivity against corrosion attacks because, in the absence of chloride ions, the process of corrosion does not take place in the concrete.

1. Introduction

Generally, steel reinforcement within concrete will not corrode, since concrete mostly has a high pH of around 12.5. A high pH or alkaline property occurs in concrete when cement is mixed with water. Because of this alkaline property, the surface of the steel in the concrete forms a passive layer that protects the steel from corrosion attacks. Steel begins to corrode when the passive layer is damaged. The concrete pH decreases when the chloride ion attacks. The decrease in pH in the concrete is caused by carbonation [1], infiltration of chloride [2, 3], magnesium salts and sulfate, and acid attack by bacteria. Finally, the infiltration of chloride ion in the concrete also decreases the compressive strength [4, 5].

The sulfate and chloride contained in seawater [6] are very corrosive substances. When they interact directly with iron, rust is formed. In the meantime, many infrastructures are built in corrosive environments. Girder bridges in river estuaries, reinforced concrete pier in ports, basement-retaining walls, and hazardous waste collection pools are constructed from reinforced concrete structures that are attacked by corrosion. Although the outside appearance of concrete is a solid material with no cavities, in fact, concrete is a material that has millions of capillaries. These capillaries are formed from the surface of the concrete to a certain depth. These capillaries connect with each other so that they reach the surface of the reinforcement in the concrete. The diameter of these concrete capillaries is of microsize. The capillary

TABLE 1: Mix design of concrete.

Material	Unit Weight (kg/m ³)		
	20 MPa	30 MPa	40 MPa
Slump (cm)	10 ± 2	10 ± 2	10 ± 2
Cement	395	468	535
Crushed stone	1222	1085	870
Sand	605	700	750
Free water	205	205	210
Water–cement ratio (%)	52	44	0.39
Gmax (mm)	20	20	20
s/a (%)	32	39	45
Calcium stearate	0, 1, 5, 10	0, 1, 5, 10	0, 1, 5, 10

diameters were divided into three groups by Thomas and Jennings 2014 [7]. The first group is capillary pores with a size of 10 nm to 10 μm , the second is a porous gel with sizes of 0.5 to 10 nm, and the last is interlayer spaces with capillary sizes smaller than 0.5 nm.

Capillary sizes are very small; however, corrosive compounds, that is, sulfate and chloride [8], can still seep into the concrete because the size of this corrosive compound is less than the capillary diameter. The process of entry of chloride ions into the concrete can occur due to the pressure difference. The liquid pressure outside the concrete is higher, causing the sulfate-containing fluid and chloride to seep into the concrete. In addition, the difference in viscosity of corrosive compounds outside and inside the concrete can also activate the infiltration of the compound into the concrete. Similarly, differences in humidity and temperature in the environment and within the concrete structure are also the cause of penetration of corrosive compounds into reinforced concrete structures. The transport of sea vapor to the land by wind, where it collides with the reinforced concrete structure, is the first stage of the process of chloride ion infiltration [9]. Environmental conditions such as differences in pressure, humidity, and temperature and the physical condition of reinforced concrete that contains many capillaries greatly affect the speed of corrosion of reinforced concrete [10].

The rapidity of the corrosion process in reinforced concrete can be activated by repeated loads, prestressing force [11, 12], shock loads, cyclic drying-wetting loads [13, 14], and shrinkage cracking. The speed of the process can be measured from the velocity with which chloride ions permeate the concrete. Several previous studies [15, 16] have researched and determined a constant to be used to predict the lifespan of concrete structures [17] when corroded. This research is very useful for calculating the capacity of the structures. They [15–17] can determine when the reinforced concrete structure can still be used without repair, when it must be repaired, and when it should be immediately demolished. Unfortunately, the resistance of concrete to corrosion has not been improved yet.

Increased corrosion resistance can be done by protecting the reinforcement with fine materials such as fly ash [18, 19] or an impermeable surface coating [20], by cathodic protection with an electric current on the reinforcement, or by green

inhibitors [21]. It can also be done by coating the surface [22] of the concrete with a membrane or paint so that the concrete becomes impermeable. The disadvantages of this type of protection are that the life of the membrane or coating is only a few years. Another type of protection is achieved by increasing the contact angle between concrete and water by mixing butyl stearate into the concrete. The use of butyl stearate in concrete has been shown to significantly reduce the corrosion rate in concrete reinforcement by the accelerated corrosion method [23–27]. However, it has not been clearly proven whether the corrosion is caused by the infiltration of chloride ions into the concrete. This study aims to determine the effect of calcium stearate on the quality of 20, 30, and 40 MPa concrete with regard to the infiltration of chloride ions. Since concrete compressive strength is a very important mechanical property in the design of reinforced concrete structures, the effect of calcium stearate on concrete compressive strength is also observed and discussed in depth.

2. Experimental Program

2.1. Preliminary Test. The fine aggregate employed in the study is sand from Merapi mountain and the coarse aggregate used is a granite stone produced by a crushed stone company from Banyumas region, Indonesia. Prior to conducting the main test, the physical properties of crushed stone and sand were tested. The physical properties of crushed stone and sand that were analyzed included the specific gravity, volume weight, clay content, and fineness modulus. In addition, crushed stone was also tested for wear resistance using Los Angeles equipment. The sand properties were a specific gravity of 2.75, volume weight of 1.39 ton/m³, clay content of 1.13%, and fineness modulus of 2.2. Furthermore, the specific gravity, volume weight, clay content, and fineness modulus of crushed stone were 2.61, 1.49 tonne/m³, 0.75, and 5.69, consecutively. The wear resistance of the crushed stone was 19%. The wear resistance met the SNI requirement for crushed stone, which should be less than 30%. Based on these physical properties, a concrete mixture design with quality values of 20, 30, and 40 MPa was arranged. The concrete workability was determined to be 10 \pm 2 cm. The complete concrete mix design is shown in Table 1. In order to ensure that the design of the concrete mixture

TABLE 2: The quantity of specimens.

No	Code	Quality of concrete (MPa)	Quantity of specimens	
			Compressive strength	Infiltration of chloride ions
1	St-0.00-20	20	3	3
2	St-0.25-20	20	3	3
3	St-1.27-20	20	3	3
4	St-2.53-20	20	3	3
5	St-0.00-30	30	3	3
6	St-0.21-30	30	3	3
7	St-1.07-30	30	3	3
8	St-2.48-30	30	3	3
9	St-0.00-40	40	3	3
10	St-0.19-40	40	3	3
11	St-0.90-40	40	3	3
12	St-1.87-40	40	3	3

met the desired compressive strength of the concrete, two compressive strength test objects were taken and tested at 28 days for each concrete quality. The type of cement utilized was a Portland pozzolan cement. The water was from a deep well near to the Laboratory of Civil Engineering, Jenderal Soedirman University, Purbalingga, Indonesia.

In Table 1, Gmax is the maximum size of aggregate, w/c is the water to cement ratio by weight, and s/a is the sand to the total aggregate ratio by volume.

2.2. Specimens. Two types of specimens were used in this study for the compressive strength test and chloride ion infiltration test. The compressive strength test specimens were cylindrical in shape with a diameter of 150 mm and height of 300 mm. The specimens for testing the infiltration of chloride ions were in the form of a cube with sides of 150 mm. Table 2 shows the total number and type of specimens used in the study. Three types of concrete mix designs were used: 20, 30, and 40 MPa. Each quality of concrete had four variations of mix design with different calcium stearate contents. The calcium stearate contents in concrete with a quality of 20 MPa were 0, 0.25, 1.27, and 2.53% of the weight of cement. The concrete with a quality of 30 MPa had calcium stearate contents of 0, 0.21, 1.07, and 2.48% of the weight of cement. For the concrete with a quality of 40 MPa, the calcium stearate contents were 0, 0.19, 0.9, and 1.87% of the weight of cement. In total, 36 test specimens were used for the compressive strength test and 36 were used for the chloride ion infiltration test. In Table 2, the first two letters, "St", indicate the calcium stearate content. The three numbers after them indicate the content of calcium stearate in the concrete, where 0.25 means that the calcium stearate content in each 1 m³ of concrete was 0.25% by weight of cement. The last two numbers of the code represent the quality of concrete, namely, "20" for 20 MPa concrete, "30" for 30 MPa concrete, and "40" for 40 MPa concrete. Each code refers to three specimens for the compressive strength test and three for the chloride ion infiltration test.

2.3. Procedure for Making Specimens. The equipment used for making the concrete specimens included cylinder molds with a diameter of 150 mm and height of 300 mm, cubic molds with sides of 150 mm, a tamping rod with a diameter of 16 mm and length of 60 mm, rubber hammers, slump gauges, and concrete mixers. Preparation and curing of specimens were carried out in accordance with SNI 2493: 2011 [28]. The coarse and fine aggregates were conditioned at room temperature between 20 and 30°C. Before agitation was initiated, the coarse aggregate and part of the free water were introduced into the concrete mixer. The next step was to turn on the concrete mixer. Fine aggregate, cement, calcium stearate, and water were put into a rotating concrete mixer. The concrete mixer was allowed to rotate safely for 3 minutes and was then paused for 3 minutes. The gate of the concrete mixer was covered to avoid evaporation during the break period. The concrete mixer was then operated again for 2 minutes to make the concrete mixture more homogeneous. Water was added so that the target fresh concrete slump was achieved.

The slump testing conducted after the concrete mixing process was based on SNI 03-1972-1990 [29]. The equipment used for slump testing was a conical cut mold with a bottom diameter of 203 mm, a top diameter of 102 mm, and a height of 305 mm, a tamping rod of steel with a diameter of 16 mm and a length of 600 mm, a steel plate with a flat and waterproof surface, a concave spoon, and a measuring gauge. The slump testing was done by filling the mold in three layers. Each layer contained fresh concrete filling as much as one-third of the volume of the mold and compacted with a tamping rod 25 times. After this had been completed, the surface of the test bar was flattened with a stick, and then the mold was lifted slowly and perpendicularly upward. The slump testing process from filling fresh concrete into the mold until the mold was removed should be finished within 2.5 minutes. The value of the slump can be obtained by measuring the difference between the average height of the fresh concrete and the height of the mold.

Concrete test specimens can be made immediately after the slump testing is complete. Fresh concrete is put into a



FIGURE 1: The process of compression testing.

cylinder and cube mold in three layers. Each layer contains a volume of fresh concrete filling as much as one-third of the volume of the mold. Each layer is compacted with the tamping rod 25 times. The next part of the process is flattening of the surface of the specimen and closing it with plastic sheets to avoid rapid evaporation. The specimen mold was opened after the concrete was 24 ± 8 hours old. The hardened concrete specimen was then treated by soaking it in water at a temperature of $23 \pm 1.7^\circ\text{C}$ according to SNI 2493: 2011 [28]. The specimens were removed from the water pond after the concrete aged 28 days.

2.4. Compressive Strength. Dirt and water were cleaned from the specimens using a damp cloth. The weight and diameter of the cylindrical specimens were measured. A capping of sulfur mortar was installed with a melting pot on each end surface of the cylinder. The cylindrical specimen was put centrally on the compression machine. The compression machine was run with constant load additions ranging from 2 to 4 kg/cm² per second. Loading was continued until the cylindrical specimen collapsed. The maximum load at the collapse of the specimen was noted. The compressive strength of the concrete could be calculated by using (1). The process of the compression test can be observed in Figure 1.

$$\text{Compressive Strength} = \frac{P}{A} \text{ MPa} \quad (1)$$

In the equation, P is the maximum load in Newtons and A is the average area of the cylinder.

2.5. Infiltration of Chloride Ions. After 28 days of curing treatment in water with a temperature of around 23°C , the water was removed from all of the surfaces of the cubed specimen of 150 mm \times 150 mm \times 150 mm to dry them. A coating system was applied on five of the cube's surfaces

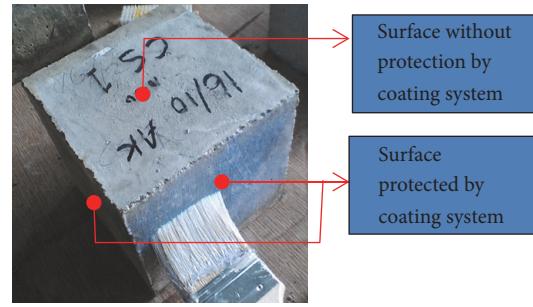


FIGURE 2: The process of surface treatment using coating system.

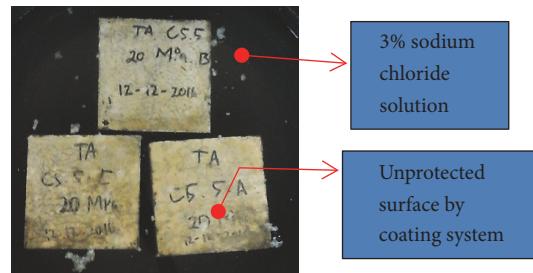


FIGURE 3: The process of soaking the specimen using 3% sodium chloride solution.

so that water could not infiltrate from the surface of the concrete. Only one surface of the cube was not protected by the coating system. The surface protection with the coating system can be seen in Figure 2. The coating system material was a synthetic polymer with a specific gravity of about 1.05. The coating system used in this study had a tensile strength of 1.2–1.5 N/mm².

In order to find out the infiltration of chloride ions in the concrete, the cubic specimens were immersed in water containing 3% sodium chloride. An aqueous solution of 3% NaCl was used to represent sea water. The immersion time was three months. Surfaces that were not protected by the coating system were placed in the upper position so that the water and chloride ions could effectively infiltrate into the concrete. The cubes which are soaking in 3% NaCl solution can be observed in Figure 3.

The next process is to drill a specimen of the concrete cube to the depths of 1, 2, 4, 6, and 8 cm from the surface of the concrete exposed to the solution of chloride. Figure 4 shows the drilling depth of concrete from the surface that was not protected by the coating system. The drilling results in the form of concrete powder can be seen in Figure 5. The amount of concrete powder taken from the drilling process was around 15 g. The concrete powder taken from each drilling depth was wrapped in plastic. Every cubic specimen was drilled in five depths: 1, 2, 4, 6, and 8 cm. Five concrete powders from each cubic specimen were analyzed.

The concrete powder was then analyzed to determine the amount of chloride that had seeped into the concrete. The wet analysis method was chosen and used in this study. The complete chloride content analysis step is as follows.

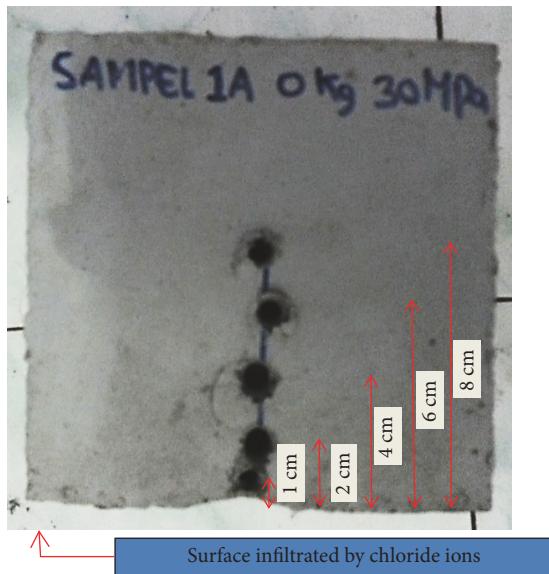


FIGURE 4: Drilling depth from the unprotected surface by the coating system.



FIGURE 5: The concrete powder obtained by drilling the concrete specimen with a quality of 30 Mpa.

- (1) Weigh the 5 g samples and put them into a 300 cc measuring cup.
- (2) Add 50 cc of water and heat it in a water bath for 1 hour while stirring occasionally.
- (3) Filter with filter paper number 40 and insert the filtrate into a 300 cc measuring cylinder.
- (4) Wash the sediment with hot water as many as eight to ten times until the filtrate volume is 200 cc.
- (5) Let the solution cool down and then add five drops of bromophenol blue indicator, so the color becomes blue.
- (6) Add HNO₃ (1 + 65) until the blue color turns yellowish green or the pH becomes 3.2.

- (7) Titrate with Hg (NO₃)₂ 0.014 N until the color becomes purple.
- (8) Record the required volume of the pen.
- (9) Conduct the blank test as follows.
- (10) Prepare 200 cc of distilled water in a 300 cc measuring cup.
- (11) Repeat steps (5), (6), and (7).
- (12) Calculate the chloride content in the concrete powder using the formula below.

$$\text{Cl}^- = \frac{f \times V}{5000} \times 100\%, \quad (2)$$

where f is the equivalence of Hg(NO₃)₂ to Cl⁻ (weight in milligrams of Hg(NO₃)₂ divided by volume in cubic centimeters of Cl⁻) and V is the volume of the penetrant.

2.6. Manufacture of Reagents

- (1) Take 4.84 g of Hg(NO₃)₂ and 0.5 cc of concentrated HNO₃ dissolved in 1 L of distilled water.
- (2) Heat NaCl p.a. to a temperature of 500–600°C.
- (3) Cool it down in the H₂SO₄ desiccator.
- (4) Take as much as 1,648 g and dissolve it in distilled water.
- (5) Put it in a 1 L flask to an official seal mark precisely.
- (6) This solution contains 1 mg of Cl⁻ per cubic centimeter of the solution.
- (7) For standardization, put the 20 cc Hg (NO₃)₂ standard into a 300 cc measuring cylinder and then dilute it to 100 cc with distilled water. Add five drops of bromophenol blue indicator and then HNO₃ (1 + 65) until the color exactly turns yellow, with a pH equal to 3.1. Titrate with Hg (NO₃)₂ until the color becomes purple. Record the volume (V) of neutralizer and determine its equivalence factor (f). $f = V/20 \text{ cc HgNO}_3/\text{mg NaCl}$.
- (8) Create a bromophenol blue indicator. Weigh 0.5 g of diphenyl carbazole, 0.05 g of bromophenol blue, and 0.12 g of xylene cyanol and then dissolve it into 100 cc of 99.5% alcohol.
- (9) Make HNO₃ (1 + 65) by mixing 1 ml of HNO₃ (p) in a glass beaker containing 65 mL of water and then homogenize it.

3. Results and Discussion

3.1. Preliminary Test of Compressive Strength. A preliminary test of compressive strength was conducted in order to ensure that the proposed mix design met the expected concrete quality. The results can be observed in Table 3. It shows that the compressive strength results reached the expected concrete quality. The average compressive strengths of concrete were 23.6, 31.6, and 49.0 MPa.

TABLE 3: Average compressive strength during preliminary test.

No	Quality of Concrete	Compressive Strength		Average (MPa)
		Specimen 1 (MPa)	Specimen 2 (MPa)	
1	20 MPa	26.3	21.00	23.6
2	30 MPa	30.7	32.4	31.6
3	40 MPa	50.6	47.4	49.0

TABLE 4: Percentage reduction of compressive strength.

	20 MPa concrete			30 MPa concrete			40 MPa concrete		
Calcium stearate content (% by cement weight)	0.25	1.27	2.53	0.21	1.07	2.48	0.19	0.90	1.87
Reduction of compressive strength (%)	7.0	17.2	36.4	-10.1	26.1	15.7	3.7	2.6	11.1

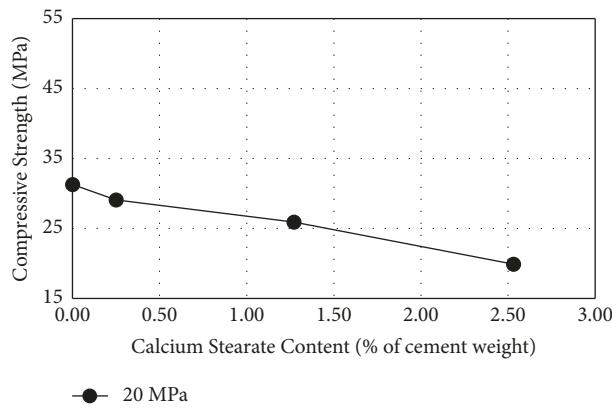


FIGURE 6: The compressive strengths of concrete grade 20 MPa.

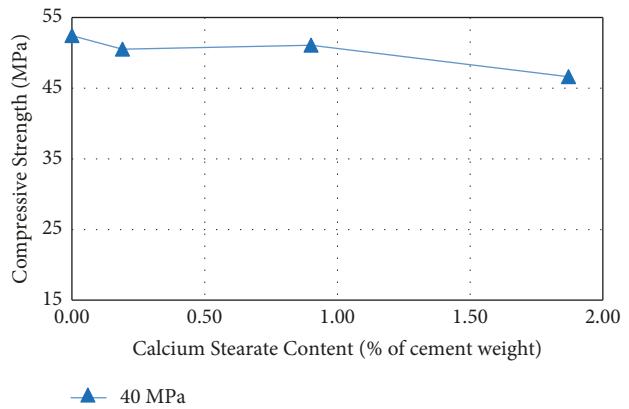


FIGURE 8: Compressive strength of concrete grade 40 MPa.

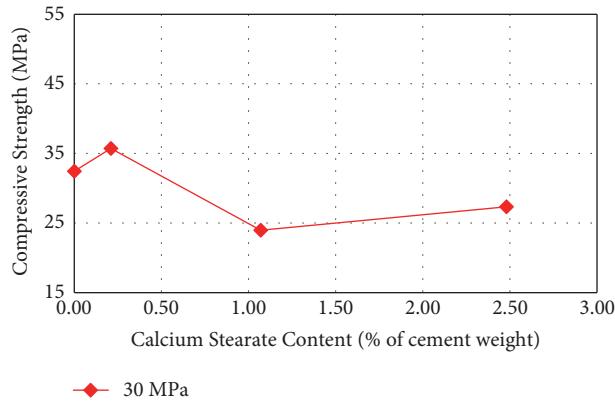


FIGURE 7: The compressive strengths of concrete grade 30 MPa.

3.2. Compressive Strength. The results of the compressive strength tests are shown in Figures 6, 7, and 8. Figure 6 presents the average compressive strength of three specimens for the 20 MPa concrete quality. Based on Figure 6, it can be confirmed that the addition of calcium stearate to the 20 MPa concrete quality decreased the compressive strength. The smallest decrease occurred with the addition of 0.25% calcium stearate by weight of cement and was equal to

7.0%. Furthermore, the influence on the compressive strength decreased by 17.2 and 35.4% when 1.27 and 2.53% calcium stearate by weight of cement were added to the concrete. The percentage reduction in compressive strength of the concrete increased when the calcium stearate content added to the concrete increased.

Slightly different from the concrete with a quality of 20 MPa, the compressive strength of the concrete with a quality of 30 MPa increased slightly when 0.21% calcium stearate by weight of cement was added. However, when the calcium stearate content added to the concrete increased, the compressive strength dropped dramatically. For the concrete with a quality of 40 MPa, the trend of compressive strength decreased due to the effect of adding calcium stearate, as the concrete quality of 20 MPa. The percentage reduction in compressive strength of concrete due to the addition of calcium stearate can be seen in Table 4.

Figure 9 shows the sharpness of the reduction of compressive strength of concrete due to the addition of calcium stearate. After the trend line of the data has been solved, equations for the trend line are then obtained for the 20, 30, and 40 MPa concrete. The equation for the 20 MPa concrete quality is $y = -4.2701x + 30.86$, and those for the 30 and 40 MPa concrete are $y = -2.9801x + 32.66$ and $y = -2.6565x + 52.127$, respectively. Based on Figure 9, it can be

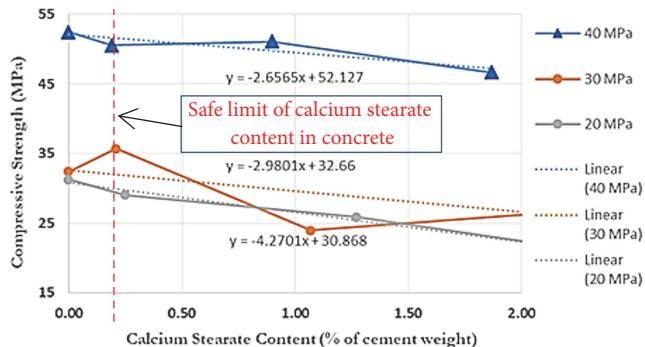


FIGURE 9: The tendency of compressive strength reduction in the concrete.

seen that the use of calcium stearate in the higher quality concrete did not decrease the compressive strength as sharply as it did in the low-quality concrete. The lowest slope among the lines is for the 40 MPa concrete, followed by the 30 MPa concrete and then the 20 MPa concrete.

The decrease in the compressive strength of concrete is most likely caused by the reaction of calcium stearate, water, and cement during the reaction of cement hydration. These three materials in the concrete form a wax-like compound. The wax-like compound is not as strong as the calcium silicate hydrate (CSH) bond. CSH is a compound that is formed when cement and water react. It is understood that when the concrete contains a small amount of cement, the effect of compressive strength on the concrete declines very sharply due to the use of calcium stearate. However, this is not the case when the amount of cement in the concrete is very high, and the use of calcium stearate in concrete does not have a significant influence on the compressive strength.

Another interesting point from Table 4 is that the use of less than 0.25% calcium by weight of cement leads to a decrease of compressive strength of concrete that is still below 10% if compared to concrete without calcium stearate. On page 41 in Section 5.6.3.3.b of SNI 2847: 2013 [30], it is mentioned that the compressive strength of concrete can still be considered satisfactory if the reduction of the compressive strength of concrete does not exceed 10% of the planned concrete compressive strength. Hence, it can be concluded that calcium stearate can be safely utilized in concrete up to a maximum calcium stearate content of 0.25% of the weight of cement.

3.3. Infiltration of Chloride Ions. The amount of infiltration of chloride ions into the 20, 30, and 40 MPa concrete strengths can be seen in Figures 10, 11, and 12. These figures show the relationship of the drilling depth from the unprotected concrete surface with the chloride ion infiltration on the horizontal axis and the infiltration of chloride ion content on the vertical axis. The horizontal axis shows the depth of chloride ion infiltration entering the concrete. In Figure 10, it can be seen that the deeper the drilling from the surface of the concrete exposed to chloride attack, the greater the decrease in the number of chloride ions. The decrease occurs

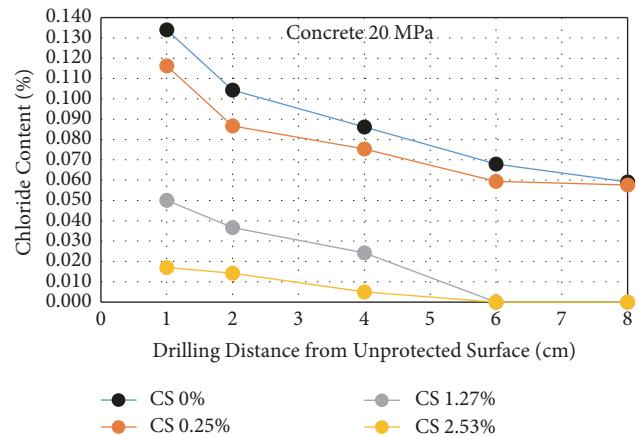


FIGURE 10: Chloride content in 20 MPa concrete.

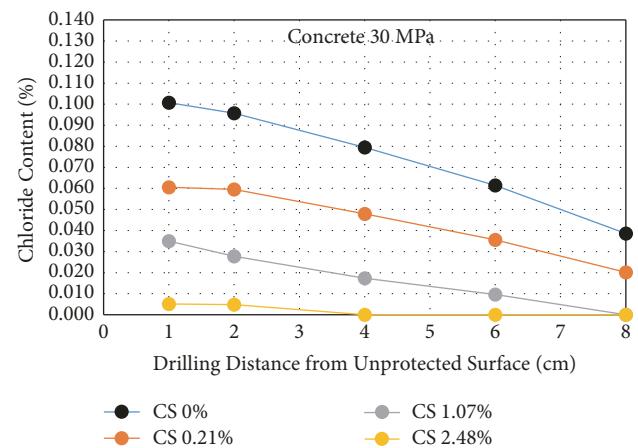


FIGURE 11: Chloride content in 30 MPa concrete.

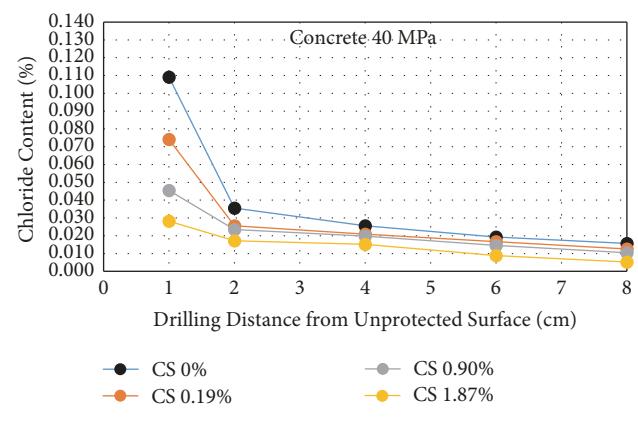


FIGURE 12: Chloride content in 40 MPa concrete.

very drastically when the drilling depth reaches 8 cm. The difference in the content of chloride ions that seeped to depths of 1 and 8 cm from the surface became smaller than 56%. This behavior occurs not only in concrete with 0% calcium stearate content but also in concrete with calcium stearate contents of 0.25, 1.27, and 2.53%.

It can also be seen that, in the concrete with calcium stearate contents (the line marked CS) of 0, 0.25, 1.27, and 2.53, increasing the addition of calcium stearate in the concrete significantly reduces the ingress of chloride ions into the concrete. The same behavior of a decrease in chloride ion infiltration in 20 MPa concrete quality was also observed in the 30 and 40 MPa concrete samples. These behaviors can be observed in Figures 11 and 12. Generally, this indicates that the use of calcium stearate in all concrete grades decreases the infiltration of chloride ions. This is because the cement, calcium stearate, and water react to form a wax-like material. This wax-like material has a hydrophobic property. Because of this property, there is an increase of the contact angle between the concrete surface and water. The increase of the contact angle makes it more difficult for the water to ingress into the concrete. A further effect is that the infiltration of chloride ions into the concrete also decreases notably. Another condition that causes a decrease in the infiltration of chloride ions is the very fine physical properties of calcium stearate. The calcium stearate granules are finer than the cement grains. Hence, calcium stearate granules can fill the smaller-diameter pores and capillaries in concrete. As a consequence, the concrete becomes more solid and more difficult to penetrate by water.

On comparing Figures 10, 11, and 12, it can be seen that the higher the concrete quality is, the more the rate of chloride ion infiltration decreases. This is very easy to understand because concrete with a higher quality usually has a low water-cement ratio. With a low-water-cement ratio, the amount of water that evaporates during the hydration process is very small. The effect of the evaporation of this very small amount of water is that the capillaries formed in the concrete become small. This means that the concrete becomes more solid.

4. Conclusions

Based on the results discussed above, some conclusions are drawn.

- (1) The use of calcium stearate in concrete can decrease the compressive strength of concrete. The amount that can be added safely is no more than 0.25% of the weight of the cement.
- (2) The higher the amount of calcium stearate added to the concrete, the lower the chloride ion infiltration. This is due to the hydrophobic nature of the material formed from the reaction between cement, calcium stearate, and water.
- (3) When the concrete powder is taken from depths further from the surface of the concrete exposed to NaCl solution, the chloride ion content decreases.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest. Funding of this manuscript did not lead to any conflicts of interest with the funder.

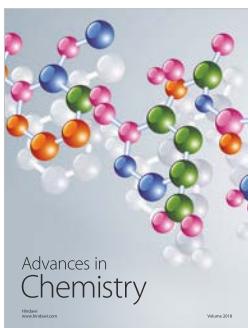
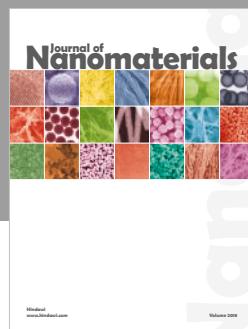
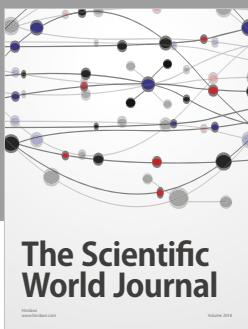
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