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On the Water Absorption and Corrosion Rate of Concrete Using Calcium Stearate

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Abstract: Concrete is a porous material. Chloride ion penetrates into the concrete through capillary pores. Chloride ion is one of the elements generated corrosion on reinforcement of concrete. To protect reinforced concrete due to corrosion attack, some methods can be applied in concrete to improve its property. Hydrophobic additive material, calcium stearate is an additive material increased corrosion attack resistance of concrete. This study, investigates the effect of calcium stearate on concrete grades 20, 30 and 40 MPa. Calcium stearate 0, 1, 5 and 10 kg per is added in concrete per cubic meter. Two types of testing which are water absorption and accelerated corrosion are conducted in the laboratory. Specimen for water absorption is a cylinder with a diameter of 75 and 150 mm in height. Accelerated corrosion is applied in reinforced concrete specimen 100×100×200 mm in order to study the reliability calcium stearate as a protective additive from corrosion. There are thirty six water absorption and accelerated corrosion of concrete specimens. The results show that the water absorption and the corrosion rate decrease significantly due to the addition of calcium stearate. Higher content of calcium stearate, the water absorption and corrosion rate are reduced. Furthermore, when concrete grade increases, the water absorption and corrosion rate in concrete also decline.

Key words: Water absorption, corrosion rate, chloride attack, calcium stearate, investigation, property

INTRODUCTION

We well known that concrete is a porous material. The degradation of reinforced concrete is led by many factors such as mechanical, biological and chemical factor. One of the major degradation of reinforced concrete is induced by corrosion attack. Process of corrosion takes place in reinforced concrete because of infiltration of corrosive ion such as chloride and sulfate through capillary pores. Corrosive ion reaches the surface of reinforcement in concrete through capillary suction mechanism. Concrete absorbs water contained chloride ion because surface tension in the capillary pores in the hydrated cement paste pulls in water by capillary suction. The accumulated chloride in concrete induces corrosion of reinforcement after concrete structure exposed long time on corrosive environment.

Network of capillaries in the concrete form during cement hydration. This capillary is divided into two parts, namely a capillary with a diameter of 10-20 nm and a capillary with a diameter of 1-2 nm (Morin *et al*., 2002). Chloride ions and oxygen diffusion through the capillaries is an important parameter that determines the corrosion of concrete reinforcement (Kahyaoglu *et al*., 2002). After the chloride ions reach the surface of the protective layer passive reinforcement and split the corrosion process begins (Broomfield, 1997). Decrease in bonding strength between reinforcement and concrete results in loss of compatibility between reinforcement and concrete to support the load (Bilcik and Holly, 2013).

Katkhuda *et al*. (2010) studied the effect of micro silica and water-proofer on the resistance of concrete to phosphoric acid attack. Water-proofer used were 10, 15 and 20% by weight of cement. The result showed that the combined effect of micro silica-water proofer improved the durability of concrete to freezing-thawing and to phosphoric acid attack without significantly reducing the compressive strength of concrete. The use of silica fume and meta kaolin with mortar can improve the resistance to corrosion attack (Diab *et al*., 2011). Benzimidazole compound is also applied as an additive for integral waterproofing system on the concrete (Khaled, 2010; Ababneh *et al*., 2009). The results show that use of the material is able to reduce corrosion attack on the reinforcement of concrete structures.

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Waterproofing admixtures may act in several ways but their effect is mainly to make concrete hydrophobic. By this is means an increase in the contact angle between the walls of the capillary pores and water so that water is pushed out of the pores (Neville, 1996). The hydrophobicity of a material is defined as the ability of the material to repel water and depends on the surface chemical composition and the surface geometry (micro-and nano-structural morphology). The contact angle between a drop of water and the surface is generally used as an indicator of hydrophobicity or wettability. When the contact angle is >90°, it indicates hydrophobicity while a contact angle <90° denotes hydrophilicity which is the tendency of a surface to become wet or to absorb water. Concrete is an example of a hydrophilic mesoporous material which absorbs water. The super hydrophobicity corresponds to contact angle between 150° and surface with intermediate p roperties with high contact angle between 120° and 150°, above typical values for the hydrophobic material (Sobolev *et al*., 2013).

Singh *et al*. (2009) conducted an investigation in microscopic scale of concrete with and without calcium stearate. The result showed that the concrete sample with calcium stearate were characterized by less the occurrence of micro cracks, voids and carbonation leading to lower the strength and durability of concrete. The micro cracks and voids were infilled with cementitious material. Therefore, the use of calcium stearate in concrete enhanced the strength and durability of concrete. Maryoto (2015) also conducted an experiment to know the effect of calcium stearate in compressive strength of concrete. The result showed that calcium stearate addition, increased a little compressive strength of concrete.

Maryoto *et al*. (2017) utilized calcium stearate as a hydrophobic additive material. The result showed that the infiltration of chloride ion in concrete reduced significantly due to the addition of calcium stearate. Greater additional of calcium stearate, the infiltration of chloride ion is lower. But the behavior due to the addition of calcium stearate to protect reinforced concrete from corrosion can not be described precisely. The objective of this research is to know the behavior of concrete with and without calcium stearate. The investigation comprises of and the water absorption and accelerated corrosion testing in various grades of concrete.

MATERIALS AND METHODS

Experimental program: Concrete mixture is composed of cement, coarse aggregate, fine aggregate and water. The cement used in this research is ordinary Portland cement type 1. The coarse aggregate is crushed stone with 20 mm of maximum size. Fine aggregate, mountain sand is quarried from Merapi mountain, Central Java and Indonesia. Water is obtained from deep well, Purbalingga, Central Java and Indonesia. Other materials are calcium stearate, natrium chloride 3% solution, plain steel bar diameter 12 mm, copper plate, cable and ammonium citrate solution.

Table 1: Mix proportion of concrete

	Concrete grades (MPa)		
Materials	20	30	40
Cement (kg)	394	530	587
Crushed stone (kg)	1221	1085	1150
Sand (kg)	604	495	479
Water (L)	204	235	235
Calcium stearate doses (kg)	0,1,5,10	0,1,5,10	0,1,5,10

Table 2: Amount of specimens

Codes	Concrete grade (MPa)	Water absorption (pieces)	Accelerated corrosion (pieces)
CaS0-20	20	3	3
CaS1-20	20	3	3
CaS5-20	20	3	3
CaS10-20	20	3	3
CaS0-30	30	3	3
CaS1-30	30	3	3
CaS5-30	30	3	3
CaS10-30	30	3	3
CaS0-40	40	3	3
CaS1-40	40	3	3
CaS5-40	40	3	3
CaS10-40	40	3	3

Calcium stearate used in this study is a compound with white appearance, a fine grain and the chemical formula is Ca $(C_{18}H_{35}O_2)_2$. The melting point is 120° celsius; Fatty acid content is not more than 0.5%; loss on drying is not more than 2%. Other physical characteristics, metal contained and specific gravity are 0.65 ppm and 0.25 consecutively (Maryoto, 2017). Calcium stearate doses added in concrete is 0, 1, 5 and 10 kg/m^3 of concrete. Concrete mix proportion is shown in Table 1.

Specimens: Table 2 shows the amount of specimens. Concrete without calcium stearate is a reference specimen to analyze the effect of concrete with calcium stearate. Dimension of water absorption and accelerated corrosion specimen is a cube with sides 100×100×200 mm and a cylinder with a diameter of 75 mm and height of 150 mm. A plain steel bar diameter 12 and 100 mm length is inserted inside of the concrete cube specimen. The plain steel bar is covered by concrete around 50 mm on all of the sides. Each grade of concrete has four doses of calcium stearate and 12 specimens. Total specimens of concrete are 36 pieces.

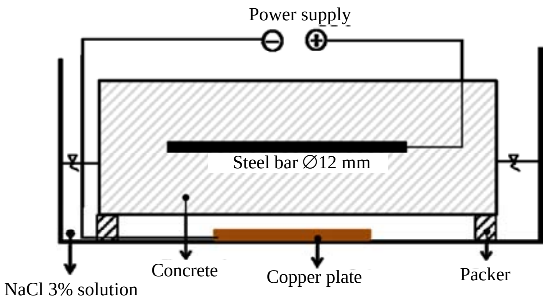

Fig. 1: Scheme of accelerated corrosion Maryoto (2015, 2017)

In Table 2, the code of CaS is a representation of calcium stearate, the number after CaS is calcium stearate dose in concrete and the two last number indicates the concrete grade.

Procedure of water absorption test: Test is conducted after the water absorption specimen treated by soaking in water for 28 days which is referred to SKSNI S-36-1990-03. Furthermore, the specimen is dried in an oven with a temperature of 100±5°C for 3×24 h and then removed from the oven and cooling it in the ambient air for 1 day and the weighed in dry condition. The next step of the water absorption test is immersed the specimen in the water for 10 min, then removed and cleaned from the water to dry saturated wet surface and weighed. The water absorption of the concrete can be calculated using the Eq. 1:

$$\text{The water absorption (\%)} = \frac{b-a}{a} \times 100\% \quad (1)$$

Procedure of accelerated corrosion test: Procedures of accelerated corrosion test are conducted based on the steps as follows. First step connects the plain steel bar diameter 12 mm with a cable by using weld connection. This connection is protected by using a duct tape to avoid contact directly to the concrete. The plain steel bar diameter 12 mm with the cable is then installed in the beam molding. To locate the plain steel bar the centroid of the beam, the plain steel bar is hang up by using a yarn. When the plain steel bar has been already stable, placing the fresh concrete into the beam molding. After 1 day, the beam molding is released to take up the specimen and therefore cure the by covering with a wet mattress for 28 age days.

The next step is connecting the cable in the specimens to the direct current power supply then followed by connecting another cable on the copper plate to the direct current power supply. The copper plate is located under the specimens. Figure 1 shows the scheme of accelerated corrosion tests. One direct current power supply generates accelerated corrosion for four specimens as shown in Fig. 2. The length of accelerated corrosion is specified for 14 days. The voltage is set at around 10 V. After the process of accelerated corrosion reach 14 days, the connection of electric current is ended.

Fig. 2: Accelerated corrosion in laboratory

The plain steel bar is taken out by breaking the concrete specimen. The rust on the plain steel bar is cleaned by using a wire brush and then soaking it in the solution of ammonium citrate 10% to remove all of the rust (Maryoto, 2017). Finally, calculates the percentage of corrosion and analyze using Eq. 2:

$$\text{Corrosion (\%)} = \frac{w_0 - w_1}{w_0} \times 100\% \quad (2)$$

Where:

w_0 = The weight of original steel bar before the corrosion

w_1 = The weight of steel bar after the corrosion

RESULTS AND DISCUSSION

Water absorption: Figure 3 shows the relationship between calcium stearate in the concrete with water infiltration. Based on Fig. 3, the amount of water absorption decreases as the amount of calcium stearate in concrete increases. The decrease follows the quadratic equation. The decline of water absorption occurs in the quality of concrete, 20, 30 and 40 MPa.

Increasing the amount of calcium stearate in the concrete caused the formation of compounds that resemble many waxes. Therefore, this treatment affects to increase the hydropobhicity of concrete. As a result, water is difficult to get into the concrete by capillary formation.

One other thing that can be observed from the Figure that is the higher quality of concrete the water absorption getting smaller. This occurrence is related to the water

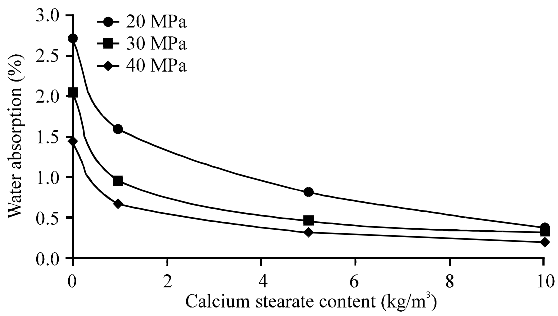

Fig. 3: Water absorption of concrete

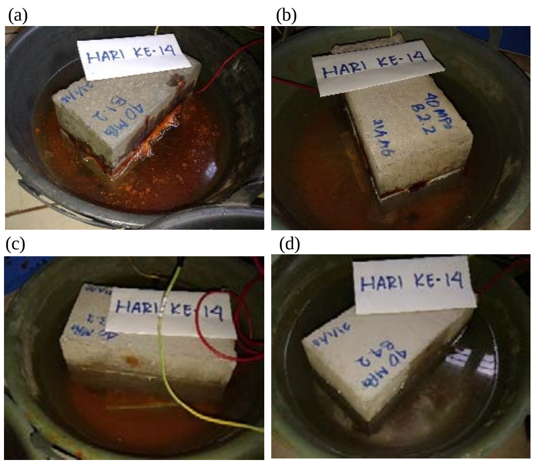

Fig. 4: Appearance of water; a) CaS0-40; b) CaS1-40; c) CaS5-40; d) CaS10-40

cement ratio. The higher the quality of concrete, the lower the water cement ratio. The lower the water cement ratio, water that evaporates in number is small so that the capillaries are formed too little. The effect is the water that infiltrate into the concrete by capillary is also too little.

Accelerated corrosion

Appearance of water: Based on the observation during the process of accelerated corrosion test, corrosion product appears first time on the surface of the specimen without the addition of calcium stearate at the 6th day.

Figure 4 shows the appearance of water used for accelerated corrosion test of concrete grade 40 MPa. When the specimens are 14 days old, the direct current power supply is shut down and take those figure at this time. Figure 4a-d are concrete specimen with calcium stearate 0, 1, 5 and 10 kg/m^3. According to Fig. 4, the most turbid water appears on Fig. 4a and then followed by Fig. 4b, c. The clearest water is shown in Fig. 4d.

The color of water in Fig. 4a is affected by corrosion product. The corrosion is generated in the steel bar

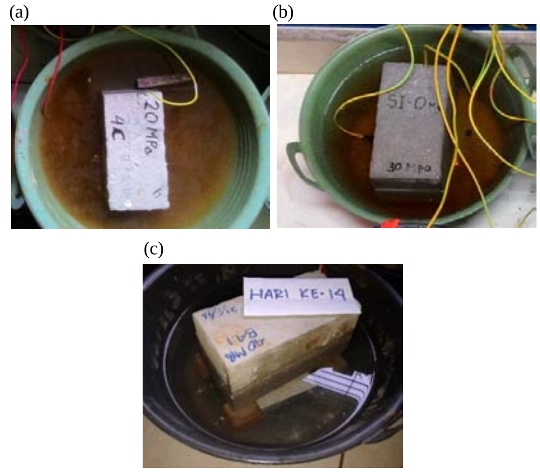

Fig. 5: Water appearance of various concrete grade; a) CaS10-20; b) CaS10-30; c) CaS10-40

in concrete. Because the volume of corrosion product is greater than mother steel, the corrosion product move out from the surface of steel bar through the cracks. As the result, the color of the water is dark reddish brown as shown in Fig. 3a. The appearance of water can be used to predict how much the corrosion occurs in the concrete. Initial prediction based on the appearance of water shows that the addition of calcium stearate in concrete reduces significantly corrosion attack.

Furthermore, the appearance of water during the process of accelerated corrosion in concrete grade 20, 30 and 40 MPa can be reviewed by using Fig. 5. It shows that the darkness water colour due to corrosion product appears on the specimen with concrete grade 20 Mpa (Fig. 5a). On the other hand, the clearest water is found on the specimen with concrete grade 40 MPa (Fig. 5c). It is commonly understood because the water cement ratio of concrete grade 40 Mpa is smaller than the water cement ratio of concrete grade 20 Mpa. The higher concrete grade, usually microstructure of concrete is more solid.

Size of cracks: After specimens take out of water contained natrium chloride 3%, cracks appear clearly on the surface of concrete. Size of cracks, the average length of the crack and maximum crack width are shown in Table 3. Based on this table, it shows that the longest average length of crack occurs in the concrete grade 20 MPa specimen with 0 kg of calcium stearate, then followed by the concrete specimen with calcium stearate 1, 5 and 10 kg/m^3. The average length of crack are 430, 230, 180 and 150 mm in concrete with 0, 1, 5 and 10 kg of calcium stearate consecutively. The maximum crack width

Table 3: Size of cracks

Code	Average cracks Length (mm)	Maximum width (mm)
CaS0-20	430	2.1
CaS1-20	230	1.3
CaS5-20	180	0.9
CaS10-20	150	0.7
CaS0-30	150	0.6
CaS1-30	125	0.4
CaS5-30	110	0.3
CaS10-30	30	<0.1
CaS0-40	140	0.4
CaS1-40	130	0.3
CaS5-40	40	<0.1
CaS10-40	30	<0.2

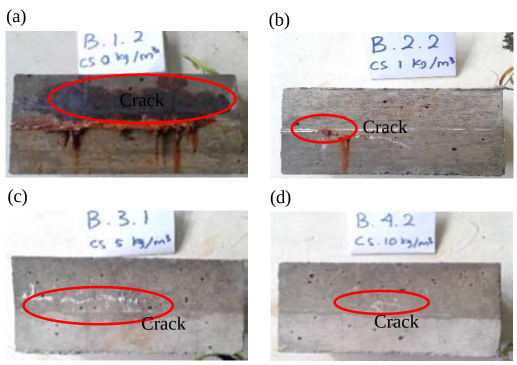

Fig. 6: Cracks on concrete grade 40 MPa; a) Crack of CaS0-40; b) Crack of CaS1-40; c) Crack of CaS5-40; d) Crack of CaS10-40

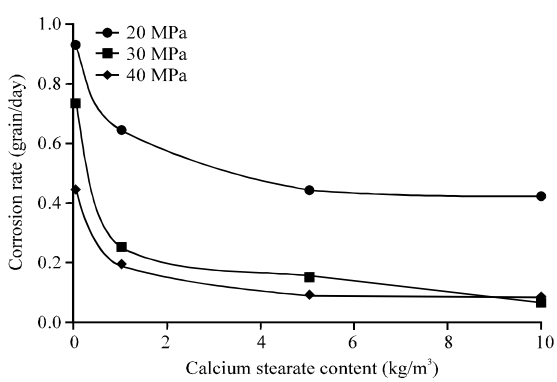

Fig. 7: Corrosion rate of various concrete grade

are 2.1, 1.3, 0.9 and 0.7 mm for concrete with 0, 1, 5 and 10 kg of calcium stearate in sequence. The above tendency can also be confirmed by using Fig. 6. It can be summarized that the addition of calcium stearate in concrete decrease size of the crack due to corrosion expansion.

Figure 6a presents the longest size of crack compare to Fig. 6b-d. Even in Fig. 6d, the size of crack is very short and small width an. Higher concrete grade, size of crack declines as well.

Table 4: Corrosion rate

Codes	Corrosion rate (g/day)
CaS0-20	0.93
CaS1-20	0.65
CaS5-20	0.45
CaS10-20	0.43
CaS0-30	0.74
CaS1-30	0.26
CaS5-30	0.16
CaS10-30	0.06
CaS0-40	0.45
CaS1-40	0.31
CaS5-40	0.10
CaS10-40	0.09

Corrosion rate: Table 4 shows corrosion rate of specimen with and without calcium stearate in reinforced concrete. The corrosion rate on the concrete grade 20 MPa can be observed by using Table 4, Column 1, No. 1 until 4. Corrosion rate of reinforcement in the concrete with calcium stearate 0, 1, 5 and 10 kg are 0.93, 0.65, 0.45 and 0.43 g/day, respectively. The tendency of corrosion rate is presented in Fig. 7.

According to Fig. 7, the trend of corrosion rate of concrete grade 20 MPa declines when the addition of calcium stearate in concrete increase. The decreasing of corrosion rate occurs as well on concrete grade 30 and 40 Mpa. This is because the sizes of voids and capillaries are considerably smaller and partially infilled with cementitious materials in the specimen with calcium stearate. Micro cracks and few voids are infilled with calcium silicate hydrates gel in concrete. These are most probably due to the addition of calcium stearate in the ordinary cement concrete. The use of calcium stearate as additive in concrete can enhance the strength and durability of concrete due to better microstructure, formation of additional Calcium Silicate Hydrate and infilling pores (Singh *et al*., 2009).

Increasing the dosage of calcium stearate reduces the permeability and thus reduces the corrosion to the reinforcement. The impermeability of concrete is improved by the addition of calcium stearate, the life of reinforced concrete is improved as well (Geetha and Perumal, 2011). Calcium stearate reacts with cement to form a wax-like constituent and then coats the inner surface of capillaries (Maryoto, 2017). Consequently, the concrete with calcium stearate behaves as hydrophobic material. As a result, the contact angle between water and concrete is >90° and <120° (Sobolev *et al*., 2013). Due to this physical property, the concrete pushes out water without pressure.

By comparing among the curves of concrete grade 20, 30 and 40 MPa in Fig. 6, it shows that concrete grade 20 MPa has the largest corrosion rate. The lower corrosion rate is then occurs on the concrete grade 30 MPa. The slowest corrosion rate takes place on the specimen with concrete grade 40 MPa.

The higher concrete grade, corrosion rate reduces. It is because affected by water cement ration in the concrete mixture. The water cement ratio are 0.52, 0.44 and 0.35 for concrete grade 20, 30 and 40 MPa, respectively. Cement needs water around 25% of the cement weight to form Calcium Silicate Hydrate. Remain water in concrete due to water cement ratio more than 0.25 is utilized for workability and finally evaporates. During evaporation process, million capillaries pore form in the concrete. The higher water cement ratio, the amount of capillary pores increases pointedly. Concrete with high water cement ratio, the permeability increases. Consequently, water and ion chloride infiltrate easily into concrete. As the result, corrosion rate in the concrete rises as well.

CONCLUSION

Based on the result obtained from this research, the conclusions are drawn as follows; usage of calcium stearate, it can reduce water absorption of concrete. Higher calcium stearate dosage in concrete, water absorption will decrease significantly. Beside that the water cement ratio level in concrete also contributes the reduction of water absorption of concrete.

Addition of calcium stearate contributes significantly to reduce the level of corrosion rate in reinforced concrete. The higher addition of calcium stearate in concrete, level of corrosion rate declines.

Level of corrosion rate is influenced by concrete grade. The higher concrete grade, level of corrosion rate reduces.

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