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Effect of Adding Inhibitors from Dried Tea Leaf Powder and Calcium Nitrate to Concrete and Reinforcement on the Corrosion Rate of Reinforcement and Concrete Compressive Strength

Efek Penambahan Inhibitor Serbuk Daun Teh Kering dan Calcium Nitratepada Beton dan Tulangan Terhadap Laju Korosi Tulangan dan Kuat Tekan Beton

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Abstract

Indonesia has many coastal areas; sometimes coastal areas have a typical problem like seawater intrusion, causing seawater to be forced to be used as a solution, replacing fresh water in concrete mixtures. However, using seawater can be harmful to the reinforcement because of the chloride ion content in seawater. The result of this study is to determine the effect of seawater on reinforced concrete, as well as examine corrosion inhibitors that can reduce the corrosion rate of concrete reinforcement, the effects of reinforcement on corrosion rate, and the effect of concrete on compressive strength when added inhibitor material. Research method using experimental by making concrete specimens using seawater as a mixing agent for concrete mortar, adding calcium nitrate to it, and in other concrete specimens adding crushed tea leaves. Concrete bar using a plain round reinforcing bar with a diameter of 10 mm and 280 MPa tensile strength. The results of the analysis showed that concrete with a mixture of tea leaves weighing 1.6 kg/m^3 of concrete produced the smallest iron weight loss; the largest compressive strength for concrete with inhibitor was produced by concrete specimens with tea leaves weighing 0.8 kg/m^3 of concrete.

Keywords: inhibitor, corrosion, tea leaves, corrosion rate, weight loss.

***SDGs*:**

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

Abstrak

Indonesia memiliki banyak daerah pesisir, di daerah pesisir memiliki masalah yang khas yaitu intrusi air laut, sehingga menyebabkan air laut terpaksa di jadikan solusi pengganti air tawar dalam campuran beton. Pengunaan air laut ini dapat membahayakan pada tulangan karena adanya kandungan ion klorida dalam air laut. Tujuan penelitian ini untuk mengetahui efek dari air laut terhadap beton bertulang, dan meneliti efek yang di timbulkan pada tulangan terhadap laju korosi serta pada beton terhadap kuat tekan apabila sudah di tambahkan bahan inhibitor. Metode penelitian menggunakan cara eksperimental dengan membuat spesimen beton menggunakan air laut sebagai bahan pencampur adukan beton, lalu ditambahkan kalsium nitrat,dan pada spesimen beton lainya akan di tambahkan daun teh giling. Batang beton menggunakan tulangan bulat polos diameter 10 mm dan kuat tarik 280 MPa. Hasil analisis menunjukan bahwa beton dengan campuran daun teh 1,6 kg/m^3 beton menghasilkan kehilangan berat besi terkecil, untuk beton dengan inhibitor kuat tekan terbesar di hasilkan oleh spesimen beton dengan daun teh 0,8 kg /m^3 beton.

Kata Kunci: inhibitor, korosi, daun teh, laju korosi, kehilangan berat.

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1. INTRODUCTION

As an archipelagic country, islands in Indonesia reaches 17,508 islands (Rochwulaningsih *et al.*, 2019), and Indonesia's land area is only about 1/3 of the total area of Indonesia, while 2/3 is in the form of oceans, so it can be assumed that there are many dwellings that are close to water areas such as seashore.

Residential or coastal settlements and settlements on remote islands are inseparable from scarcity of fresh water due to seawater intrusion which of course this will be a problem in terms of residential development both involving the construction of structures and the construction of infrastructure related to reinforced concrete, water scarcity freshwater in this coastal area, causing seawater to be used as a solution to replace fresh water in concrete mixtures. However, the use of seawater or seawater can be harmful to the reinforcement because of the chloride ion content in the seawater and seawater (Mangi *et al.*, 2021). whereas in the world of construction it is common belief that sea water is one of the elements that can damage reinforced concrete structures quickly. According to SNI 7974 – 2013 (BSN, 2013), sea water is included in elements that may not be used in concrete mixtures.

To overcome the adverse effects of sea water on corrosion, various materials can be used to become corrosion inhibitors for concrete reinforcement. Materials that can be used to inhibit corrosion are natural corrosion inhibitors and chemical corrosion inhibitors.

In previous research regarding the effectiveness of corrosion inhibitors on contaminated concrete, four types of corrosion inhibitors (calcium nitrite, calcium nitrate and two organic inhibitors at recommended doses) were evaluated at five different levels of contamination, namely chloride 0.8%; 0.8% chloride plus 1.5% SO3; sea water; sea water; and unwashed aggregate (Al-Amoudi *et al.*, 2003). The concrete specimens were used to assess the effect of the corrosion inhibitors on the compressive strength of the concrete and the corrosion of the reinforcement. The results show that corrosion inhibitors do not adversely affect the compressive strength of concrete. Furthermore, calcium nitrite is efficient in delaying initiation of reinforcement corrosion in chloride-contaminated concrete specimens, whereas calcium nitrite and calcium nitrate reduce the corrosive effect of chloride plus sulfate salts or seawater. On concrete specimens prepared with seawater with unwashed aggregates, it was concluded that all inhibitory materials proved effective in reducing the corrosion rate of reinforcement. The types and doses of corrosion inhibitors observed depend on their nature and degree of contamination.

Tannin extracts from the quebracho were tested for anticorrosion for mild plate, and able to protect from the effects of corrosion (Vorobyova *et al.*, 2023). Tannin is natural inhibitor for corrosion (Nardeli *et al.*, 2019), Tannin Element can be found in mangrove bark (Rahim *et al.*, 2008), They are also present in high concentrations in several species such as black mimosa bark, oak bark, and chestnut wood, but can also be found in various seeds and leaves like cocoa and tea (Lamprakou *et al.*, 2022).

Based on the background, the formulation of the problem is sought, namely what is the effect of using seawater on the corrosion rate of concrete reinforcement, and how is the effect of using seawater in concrete mixtures on compressive strength. Furthermore, how effective are calcium nitrate and tea leaf extract concrete corrosion inhibitors in reducing the adverse effects of seawater on the corrosion rate of reinforcement, and what effect does concrete corrosion inhibitors have on compressive strength.

2. METHODOLOGY

This study uses experimental method techniques, the experimental method is to examine causal relationships.

The purpose of conducting this experiment is to determine the effects of seawater induced by seawater penetration on reinforced concrete, as well as to examine the effect of corrosion inhibitors to reduce the corrosion rate on concrete reinforcement, the effects it has on concrete on compressive strength if the concrete mixture is given this corrosion inhibitor additive. The technical stages can be seen in (Figure 1).

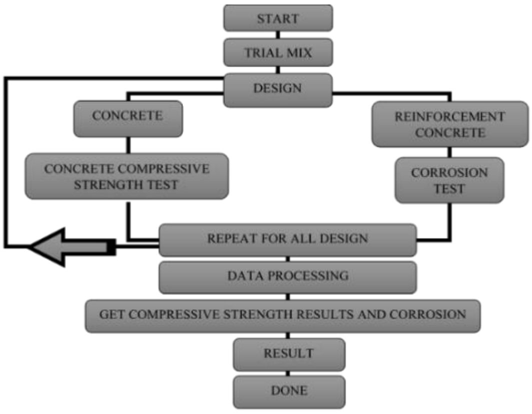

Figure 1. Flowchart.

2.1. Weight Loss Calculation

Weight loss is one of many kind model calculation for seeing corrosion effect with simple way, several data were collected, including the submerged surface area, immersion time and the density of the metal being tested so that the corrosion rate was produced, based on ASTM G31-72 standard (ASTM, 2004). The corrosion rate equation can be shown in the following equation (1):

$$\text{Corrosion Rate (CR)} = \frac{(K \, x \, W)}{(A \, x \, T \, x \, D)} \quad (1)$$

where:

K = Constants, see (Table 1)
T = Time of exposure (hour)
A = Area (cm^2)
W = Lost weight (grams)
D = Density (ρ)

This allowed us to calculate the effectiveness of the inhibitor by calculating the inhibition efficiency (Bouraoui *et al.*, 2019), the following equation (2) can be used to determine the efficiency of the inhibitor.

$$IE = \frac{(Xa - Xb)}{Xa} x \, 100 \quad (2)$$

where :

Xa = Corrosion rate without inhibitor (g/m^2h)
Xb = Corrosion rate with inhibitor (g/m^2h)
IE = Inhibitor efficiency (%)

2.2. Research Procedure

There are several stages in the research to compare one test object to another, the test object made has met the requirements of the provisions in the applicable SNI.

Table 1. Constant (ASTM, 2004).

No	Corrosion rate	Constant (K)
1	Mils per year (mpy)	$3{,}45 \, x \, 10^6$
2	Inches per year (ipy)	$3{,}45 \, x \, 10^3$
3	Inches per month (ipm)	$2{,}87 \, x \, 10^2$
4	Milimeter per year (mm/y)	$8{,}76 \, x \, 10^4$
5	Micrometer per year (μm/y)	$8{,}76 \, x \, 10^7$
6	Picometres per second (pm/s)	$2{,}78 \, x \, 10^6$
7	Grams per square metre per hours (g/m^2h)	$1{,}00 \, x \, 10^4 x \, D$
8	Miligrams per square decimetre per day (mdd)	$2{,}4 \, x \, 10^6 x \, D$
9	Micrograms per square per second ($\mu g/m^2s$)	$2{,}78 \, x \, 10^6 \, x \, D$

In the early stages, samples of seawater were taken from muara baru beach in Jakarta utara. Continuing to carry out tests on concrete forming materials such as aggregate, sand and cement from the Jakarta area to obtain the material characteristics to be used in designing a concrete mix design with reference to SNI 03-2834-2000 (BSN, 2000), with the strength plan that must be achieved is fc' 25 MPa.

2.3. Corossion Acceleration

The corrosion acceleration process is carried out by providing current as a tool to accelerate the process of corrosion based on ASTM G31-72 (ASTM, 2004), specimens are immersed in seawater. In this process the circuit is arranged in series and uses graphite carbon as the cathode, for the anode it uses reinforcing steel that directly sticks into the concrete cube.

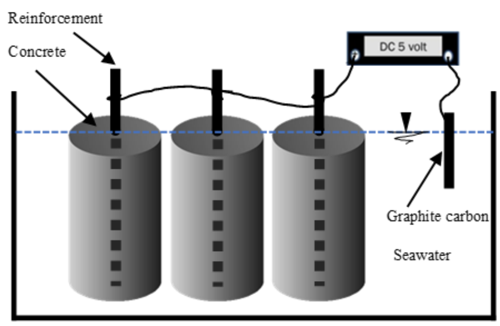

Figure 2. Corrosion acceleration scheme.

The current process uses a DC current of 5 volts, this process is to accelerate the transfer of Fe2+ ions and electrons, for the mechanism can be seen in Figure 2.

2.4. Corrosion Decay Process by Electrochemical Method

The process of corrosion decay in reinforcing iron uses electrochemical methods, Electrochemical processes are based on standard guidelines according to ASTM G1-90 (ASTM, 2017). This is to minimize the results of more precise corrosion decay, in contrast to corrosion decay using sandpaper, which can experience unnecessary weight loss from sanded iron. Process of corrosion decay can be seen in Figure 3.

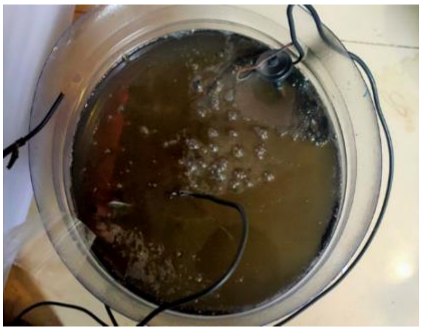

Figure 3. Result of corrosion decay

2.4.1. Experiment Stage

For concrete cylinders it was made with dimensions of 15 cm in diameter and 30 cm in height as show in Figure 4, and for reinforced concrete cubes it was made with dimensions of 15 cm x 15 cm x 15 cm, the distance between the reinforcement and the fiber the outermost or concrete cover is 4 cm as many as 4 pieces per sample can be seen in Figure 5.

Figure 4. Concrete cylinder

The test material for concrete cylinders and concrete cubes fc'25 MPa was made, Material calculation procedures in accordance with regulations (BSN, 2000). Concrete compressive strength test can be seen in Figure 6.

Figure 5. Concrete cube

Figure 6. Concrete compressive

1) Non-reinforced concrete cylinder, the number of samples is 3 per specimen.
   a) Concrete with normal water without inhibitors (control concrete) = B1.
   b) Seawater concrete without inhibitors (control concrete) = B2.
   c) Seawater concrete with 4% calcium nitrate inhibitor = B3.
   d) Seawater concrete with 3% calcium nitrate inhibitor = B4.
   e) Seawater concrete with dry tea leaf inhibitor at a concentration of 0.8 kg/m^3 = B5.
   f) Seawater concrete with dry tea leaf inhibitor at a concentration of 1.6 kg/m^3 = B6.
2) Reinforced concrete cube, 4 specimen reinforcement embedded, reinforcement using plain round steel bar Φ10 mm with 280 MPa tensile strength (bjtp 280 Indonesian Standart), 2.5 cm clear cover concrete, 4

specimen embedded in every corner to see the effect of corrosion and inhibitor.

a) Concrete with normal water without inhibitors (control concrete).
b) Seawater concrete without inhibitors (control concrete).
c) Seawater concrete with 4% calcium nitrate inhibitor.
d) Seawater concrete with 3% calcium nitrate inhibitor.
e) Seawater concrete with dry tea leaf inhibitor at a concentration of 0.8 kg / 1 m^3.
f) Seawater concrete with dry tea leaf inhibitor at a concentration of 1.6 kg / 1 m^3.

3) All 15 non-reinforced seawater mixed concrete will be treated by soaking in seawater for 28 days, in accordance with normal concrete manufacturing regulations detail can be seen in Figure 7 (BSN, 2000).

Figure 7. Concrete immersing with seawater.

4) For reinforced concrete, special treatment will be carried out by providing 5 volts for 2 days to the reinforcing steel to accelerate the corrosion process on the reinforcing steel and continue to soak the concrete until it is 28 days old can be seen in Figure 8.

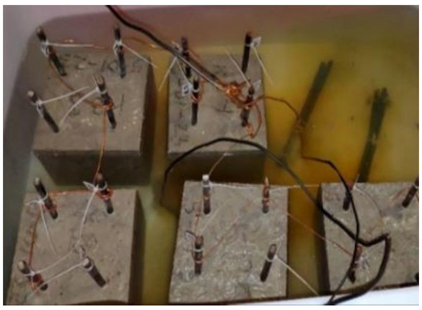

Figure 8. Special curing for cube.

5) The reinforced concrete cube was dismantled at the age of 28 days and specimens of the reinforcing steel were taken and then the corrosion rate was examined using the weight loss method. Tests were carried out to determine the effect of using calcium nitrate inhibitors and tea leaves.
6) Concrete cylinder specimens were tested on concrete characteristics: compressive strength at 28 days of age to determine the effect of using non-inhibitor seawater and with inhibitors can be seen in Figure 9.

Figure 9. Concrete cylinder loading.

3. RESULTS AND DISCUSSION

3.1. Compressive Strength of Concrete

The results of concrete compressive strength vary depending on the composition of the concrete mixing material, strength test was performed on the concrete cylinder and tested when the concrete is 28 days old.

As per the table below, the best compressive strength of concrete is B6, B6 is Seawater concrete with dry tea leaf inhibitor at a concentration of 1.6 kg/m^3. The following results can be seen in Table 2.

3.2. Results of Weight Loss Test Research

In the results of the trial obtained concrete with a mixture of seawater without inhibitors experienced the largest weight loss of 2.58 grams. the lowest weight loss reduction was obtained from the results of the trial of adding a tea leaf powder inhibitor 1.6 kg/m^3 of concrete with a weight loss of 0.89 grams. in full result can be seen in Table 3.

Table 2. Result of compressive test.

Code	Slump Test (cm)	Fc (MPa)	Average (MPa)
B1	10.50	29.99	29.91
	10.50	29.59	
	10.50	30.15	
B2	11.00	32.64	33.14
	11.00	32.93	
	11.00	33.83	
B3	11.50	28.68	29.20
	11.50	28.68	
	11.50	30.21	
B4	12.00	29.53	29.91
	12.00	29.99	
	12.00	30.21	
B5	11.00	32.47	32.97
	11.00	33.21	
	11.00	33.21	
B6	11.00	30.32	30.78
	11.00	30.21	
	11.00	31.80	

Table 3. Result of weight loss test.

Desk	Steel Code	Weight Loss (g)	Average (g)
CC	1.1	0.05	0.05
	1.2	0.08	
	1.3	0.03	
SC	2.1	2.14	2.58
	2.2	3.04	
	2.3	2.55	
SC with calcium nitrate 3%	3.1	1.81	2.45
	3.2	2.97	
	3.3	2.57	
SC with calcium nitrate 4%	4.1	1.51	1.48
	4.2	1.75	
	4.3	1.17	
SC with tea leaves 0.8 kg/m^3	5.1	1.2	1.04
	5.2	0.83	
	5.3	1.08	
SC with tea leaves 1.6 kg/m^3	6.1	0.77	0.89
	6.2	0.94	
	6.3	0.96	

CC = Normal Concrete

SC = Seawater Concrete

3.3. Results Corrosion Rate

The largest corrosion rate value is obtained in seawater concrete without additional inhibitors. In fact, because concrete has absolutely no protection against exposure to chloride ions contained in seawater. while the smallest corrosion rate of 0.2081 g/m^{2}h is obtained from a mixture of concrete with tea leaf inhibitors of 1.6 kg/m^3 of concrete. The following results can be seen in Table 4.

Table 4. Corrosion rate.

Desk	Steel Code	Average weight loss (gr)	Corrosion rate (g/m$^2\cdot$h)
CC	1.1 1.2 1.3	0.05	0.012
SC	2.1 2.2 2.3	2.58	0.602
SC with calcium nitrate 3%	3.1 3.2 3.3	2.45	0.572
SC with calcium nitrate 4%	4.1 4.2 4.3	1.48	0.345
SC with tea leaves 0.8 kg/m^3	5.1 5.2 5.3	1.04	0.242
SC with tea leaves 1.6 kg/m^3	6.1 6.2 6.3	0.89	0.208

3.4. Inhibitor Efficiency

In concrete with 3% calcium nitrate has the lowest inhibitor efficiency of 4.916% and followed by concrete with 4% calcium nitrate with an efficiency of 42.691%. Concrete with 0.8 kg/m^3 tea leaves has an inhibitor efficiency value of 59.767% and the highest value is concrete with a mixture of 1.6 kg/m^3 tea leaves concrete with an inhibitor efficiency of 65.459%. The following results can be seen in Table 5.

Table 5. Inhibitor efficiency.

No	Specimen	Inhibitor Efficiency (%)
1	SC with calcium nitrate 3 %	4.91%
2	SC with calcium nitrate 4 %	42.69%
3	SC with tea leaves 0.8 kg/m^3	59.76%
4	SC with tea leaves 1.6 kg/m^3	65.45%

3.5. Previous Research Studies

In a journal entitled The Influence of Sea Water on the Compressive Strength of Concrete Made from Various Cement Brands in Malang City (Wedhanto, 2017), that the test results stated that for 28 days immersion of concrete in seawater using Type I cement had the highest compressive strength relatively. where it could be stated that seawater had a positive effect on strength. According to research test data in the Mercubuana laboratory. the compressive strength value has increased between normal concrete using fresh water and concrete using sea water.

Calcium nitrate can be used as an ingredient for inhibitors according to the appropriate dosage. Al-Amoudi et al., explained by making a concrete cylinder specimen with a width of 75 mm and a height of 150 mm (Al-Amoudi *et al.*, 2003). for the treatment process it was served with chloride. sulfate and salt solution. with what was stated that calcium nitrate could be used as an inhibitor material. In this study using cylindrical concrete specimens with a width of 150 mm. 300 mm high. while for reinforced concrete specimens using concrete cubes with dimensions of 150 mm x 150 mm x 150 mm. reinforcement was planted with a concrete cover distance of 25 mm from the edge of the concrete fiber and it was found that calcium nitrate can be an inhibitor chemically.

Table 6. Comparison of compressive strength yield of concrete.

No	Description	CC (MPa)	SC (MPa)	Dev. (%)
1	CC: river sand SC: sea sand.seawater location : china (Xiao *et al.*, 2017)	33.1	36.54	10.39
2	CC : river sand SC : river sand.seawater location : lagos state.nigeria (Adeyemi and Modupeola, 2014)	19.98	21.93	9.76
3	CC : readymix SC : readymix. retarder. seawater location : Al-Khor. Qatar (Younis *et al.*, 2018)	63	64.5	2.38
4	CC : bangka sand SC : bangka sand. seawater location : Jakarta **(Experiment)**	29.91	33.14	10.78

Tannins can be used as a choice of natural inhibitors. Lubis and Dahlan in a journal entitled Synthesis of Anticorrosive Coatings Using Tannins from Mangrove Bark as an Inhibitor (Lubis and Dahlan, 2020). It was found that tannin from mangrove bark could become an inhibitor for steel plates with a thickness of 1 mm. the research was continued by the authors using tannins from dry ground tea leaves. which would examine their effects on concrete reinforcement planted in cube-shaped concrete. and the data resulted that the tannin taken from dry milled tea leaves with a composition of 1.6 kh/m^3 concrete was able to withstand the corrosion rate so that the highest inhibitor efficiency of 65.459% was obtained.

The other research from several journal about Comparison of compressive strength yield of concrete can be seen in Table 6 and research from several journal about Comparison of compressive strength yield of concrete can be seen in **Error! Not a valid bookmark self-reference.**.

Table 7. Comparison of efficiency.

No	Description	Efficiency (%)
1	copper.corrosive NaCl inhibitor : tanin from guava leaves (Sanjaya *et al.*, 2019)	96
	copper. corrosive HCl inhibitor : tanin from guava leaves	94
2	Steel plate. corrosive NaOH Inhibitor : mangrove bark (Lubis and Dahlan, 2020)	60
3	Reinforcement Φ12 corrosive seawater calcium nitrate 2% (Al-Amoudi *et al.*, 2003)	8.47
	calcium nitrate 3%	11.48
	calcium nitrate 4%	10
4	Reinforcement Φ10 corrosive seawater calcium nitrate 2% **(Experiment)**	4.9
	calcium nitrate 3%	42.7
	Tea leaves 0.8 kg/m^3	59.8
	Tea leaves 1.6 kg/m^3	65.5

4. CONCLUSION

Based on the results of research and experiments. it was found that sea water can be used as a substitute for fresh water in concrete mixes. Corrosion effects caused by the content of chloride ions in seawater can be minimized by mixing inhibitors into the concrete mix. In accordance with the results of the study that mixing inhibitors in addition to causing a decrease in the corrosion rate also causes a change in compressive strength. The best compressive strength with the highest inhibitor efficiency is obtained from a mixture of concrete with tea leaves 1.6 kg/m3 of concrete with an efficiency value of 65.45%.

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