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Evaluation of *Syzygium myrtifolium* leaves extract as an eco-friendly inhibitor for steel in reinforced concrete

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Abstract. Reinforced concrete is a concrete mixture that is reinforced with steel to strengthen the concrete in a building construction. One of the problems with steel is corrosion which can damage the concrete structure. One way to inhibit the corrosion process is to inhibit the corrosion rate using organic/eco-friendly inhibitors. A potential eco-friendly inhibitor is Syzygium myrtifolium leaves. This study aims to determine the corrosion rate and inhibition efficiency in reinforcing steel (BjTP) 280. This research method begins with maceration of Syzygium myrtifolium leaves using 96% alcohol for 96 hours. Then BjTP 280 is immersed in concentrated extract with variations in immersing time of 0 hours, 24 hours, 72 hours, 120 hours, and 168 hours. Furthermore, BjTP 280 is used in K350 quality concrete structures. Calculation of corrosion rate using weight loss method based on ASTM G 31-72, corrosion testing based on ASTM C 876-91 by immersing concrete in 3.5% NaCl corrosive media solution and flowing 6 V DC current for 14 days. The corrosion rate (mm/year) in each variation of immersion in inhibitor decreased, respectively 875.95 (0 hours); 298.66 (24 hours); 99.55 (72 hours); 79.73 (120 hours); 42.66 (168 hours). Meanwhile, the inhibition efficiency value (%) increased successively, namely -% (0 hours); 65,9% (24 hours); 88,63% (72 hours); 90,93% (120 hours); 95,12% (168 hours). The results showed the best corrosion rate reduction of 42.66 mm/year with inhibition efficiency of 95,12% obtained at 168 hours of immersion.

Keywords : Corossion, concrete, eco-friendly inhibitor, steel, sustainability

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Introduction

Reinforced concrete is a construction material used to make buildings. Reinforced concrete is a combination of concrete and reinforcing steel that is specifically designed to strengthen concrete in a building construction.[1]. Reinforced concrete generally has a longitudinal reinforcement structure (flexible) and stirrup reinforcement (shear). The use of flexible reinforcement aims to withstand the bending load that occurs in concrete beams, while shear reinforcement is to withstand shear forces. Flexural reinforcement usually uses Deform threaded reinforcement steel (BjTD), while stirrup reinforcement uses plain reinforcement steel (BjTP)[2].

Plain reinforcing steel that can be used as stirrup reinforcement based on SNI 2017 is plain reinforcing steel with the name BjTP 280. BjTP 280 quality steel is steel with a yield strength characteristic of min. 280 Mpa [3]. Reinforcing concrete structures using reinforcing steel has many benefits, but a common problem experienced by steel is corrosion.

Corrosion is damage or a decrease in the quality of metal due to an electrochemical reaction of a metal with its environment [4], [5]. Under normal conditions, concrete cover can protect reinforcing steel from corrosion, because concrete cover is alkaline (pH = 12-13) so that it can form a passive layer of iron oxide compounds (Fe_3O_4/Fe_2O_3). However, if the environmental conditions are very aggressive, namely if the ions exceed the critical limit, then the ions will be able to enter the concrete structure and damage the passive layer, causing corrosion to the steel [5].

Efforts to overcome corrosion problems can be done through prevention, namely by coating the metal surface (coating), cathodic protection, anodic protection, use of inhibitors and others. The use of inhibitors is considered one of the easy, economical and efficient prevention methods [1], [5], [6]. Inhibitors can come from organic and inorganic materials. Inorganic inhibitors that are often used are arsenate, chromate, silicate, phosphate, nitrite [1], [6], [7]. However, the use of inorganic inhibitors is considered to be expensive and less environmentally friendly. While inhibitors that are considered safe, environmentally friendly and economical are organic inhibitors [8], [9].

Research into the use of organic inhibitors has been widely conducted, including guava leaf extract[1], coffee extract [6], papaya leaf extract[7], [10], rice husk ash [9], [11], olive leaf extract [12] tobacco extract [13], and green bambusa leaves extract [14] One of the plants known to have potential as an organic inhibitor is the Syzygium myrtifolium leaves. Syzygium myrtifolium leaves extract known to contain tannins, flavonoids, saponins and triterpenoids [15]. In this study, plain reinforcing steel (BjTP) 280 was used which was immersed in Syzygium myrtifolium leaves extract inhibitor medium. This study aims to determine the corrosion rate on BjTP 280 steel and the inhibition efficiency of Syzygium myrtifolium leaves extract on BjTP 280 steel.

Experimental

The Equipments and Materials. The tools needed in this study are Ohaus scales, measuring cups, iron sandpaper, sieves, tripods, spirit burners, stirring rods, hacksaws, thermometers, spoons, pipes, and pestles. The materials needed in this study are Syzygium myrtifolium leaves, BjTP 280 steel, 96% ethanol, 3.5% NaCl, carbon graphite, distilled water, cement, sand (fine aggregate), gravel (coarse aggregate), water, cement mixer, and PVC pipe.

Preparation of Eco-friendly Inhibitors. 150 grams of Syzygium myrtifolium leaves were sun-dried for three days. The dried Syzygium myrtifolium leaves were ground into powder. A total of 65 grams of powder was soaked in 96% ethanol with a ratio of 1: 2 (w / w) for 4 × 24 hours. The filtrate obtained was evaporated using a rotary vacuum evaporator. Evaporation with this vacuum machine is carried out by rotating at a speed of 60 rpm and a temperature of 60 ° C to produce a concentrated extract.

Preparation of BjTP 280 Steel Specimens. The specimen used was BjTP 280 steel with a diameter of 10 mm, the specimen was cut to a length of 100 mm. Furthermore, the steel specimen was smoothed with iron sandpaper. The smooth surface was cleaned with distilled water, then dried at room temperature for 10 minutes. After drying, the specimen was weighed to determine the initial weight of the specimen. Furthermore, the BjTP 280 steel specimen was immersed in an inhibitor solution with variations of immersion of 0 hours, 24 hours, 72 hours, 120 hours, and 168 hours. The height of the inhibitor solution reached 120 mm.

Preparation of K350 Concrete Specimens. Concrete specimens were made with K350 quality according to ASTM C-39. The prepared concrete composition materials, namely cement, sand (fine aggregate), gravel (coarse aggregate), and water were mixed with a mixer until evenly mixed. Then, the concrete mixture was molded with a PVC pipe mold measuring 50.8 mm in diameter and 100 mm in height like Figure 1.

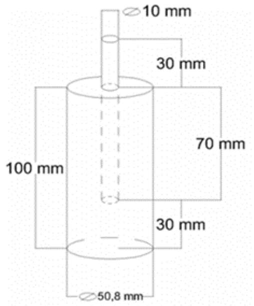

Figure 1. Specimen size of concrete

Corrosion Testing Process. In this study, corrosion testing based on ASTM C 876-91 [11], BjTP24 steel specimens that have been soaked in inhibitor solution, are embedded into concrete cylinders. Furthermore, the concrete is soaked in a 3.5% NaCl corrosive solution to a depth of 75 mm for 14 days. This testing process is carried out using a 6 V DC current from a rectifier as an aid to accelerate corrosion in reinforced concrete specimens. Reinforced concrete specimens are treated as anodes, while the cathode uses carbon graphite like Figure 2. This process aims to accelerate the transfer of Fe^{3+} ions and their electrons. Data analysis used to determine the corrosion rate is the weight loss method based on ASTM C 31-72 [1]. The amount of weight loss due to corrosion can be calculated using equation 1.

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

(Description: K = Corrosion Constant; W = Mass Loss (grams); D = Density (ρ) g/cm^3; A = Surface Area (cm^2); T = Exposure Time (hours)).

After obtaining the corrosion rate calculation, the inhibitor efficiency is calculated using equation 2.

(Description: CRa = Corrosion rate without inhibitor (mm/year); CRb = Corrosion rate with inhibitor (mm/year)).

$$Inhibitor\ Efficiency\ (\eta) = \frac{CR_a - CR_b}{CR_a}\ x\ 100\% \quad \textbf{(2)}$$

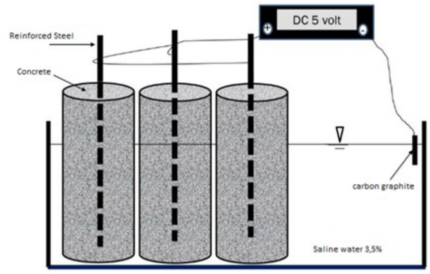

Figure 2. Corrosion testing equipment series adapted from Harsimi (2019) [11]

Result and Discussion

Visual Observation. Comparison of the results of immersion of plain steel SNI tp24 for 0 hours (control) Figure 3a there is thick rust and the steel is porous on the entire surface. In Figure 3b with a soaking time of 24 hours on the surface of plain steel SNI tp24 there is rust that is found almost on the entire steel part. In Figure 3c after a soaking time of 72 hours on the surface there is rust with a black color and porous on the surface. In Figure 3d with a soaking time of 120 hours the surface of the steel shows corrosion and porosity at the ends. In Figure 3e with a soaking time of 168 hours shows the results on the surface of plain steel SNI tp24 there are slight changes on the surface, namely black spots and a thick black layer on the surface of the steel. Unprotected steel is quickly attacked by the aggressive NaCl ions, which causes this corrosion. In the meantime, the corrosion that develops is decreased in conjunction with the addition of inhibitors to the reinforced steel samples. This is due to the fact that the inhibitor that soaks the steel can shield the sample by covering its surface with a protective coating [16], [17].

Evalulation of inhibiton on corrosion rate. Determination of corrosion rate is obtained from the results of weight reduction before and after SNI BjTP 280 reinforced steel concrete is immersed in a 3.5% NaCl corrosive solution for ± 14 days. Weight loss as shown in Table 1.

In Table 1 it can be seen that the percentage of weight loss of control steel (without extract immersion) can decrease drastically after immersion of steel for 24 hours from 8.63% to 3.23%. The percentage of weight loss also decreases with increasing immersion time of steel in extract. The corrosion rate shows a significant decrease from 875.95 mm/years to 42 mm/years (Figure 4). This shows that the

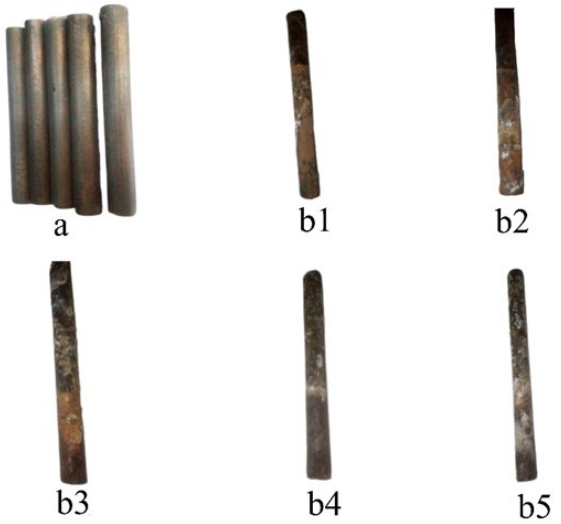

Figure 3. Visual observation of BjTP 280 steel (a) before testing (b) after testing: BjTP 280-0 (b1), BjTP 280-24 (b2), BjTP 280-72 (b3), BjTPe 280-120 (b4), BjTP 280-168 (b5)

Table 1. Inhibitor evaluation results on corrosion rate

Immersion Time (h)	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Percentage Weight Loss (%)	Percentage inhibition efficiency (%)	Corrosion rate (mm/ years)
0	55,6	50,8	4,8	8,63	-	875,95
24	55,7	53,9	1,8	3,23	65,9	298,66
72	55,5	50,5	1,2	2,16	88,63	99,55
120	55,4	54,5	0,9	1,62	90,93	79,73
168	56,0	55,7	0,3	0,53	95,12	42,66

extract has a significant impact on reducing the weight of steel and the corrosion rate of steel in concrete in 3.5% NaCl medium. The longer the steel is immersed in the extract, the lower the corrosion rate. The success of reducing the corrosion rate is the same as that carried out by Abbas Abdulsada (2017) [9] which has succeeded in making rice husk ash an environmentally friendly inhibitor in reinforced concrete steel. Barmawi (2021) [13] also reported that tobacco leaf extract was also successful in reducing the corrosion rate of concrete reinforcement steel.

The inhibition efficiency of the extract shows that the longer the steel is soaked in the extract, the more it increases the inhibition efficiency of the corrosion rate. The inhibition efficiency in the 3.5% NaCl medium that occurred was from 65.90% to 95.12% (Figure 5). This increase in efficiency is the same as the research of Otaibi, et.al (2021) [8] which successfully increased inhibition efficiency by 98% using inhibitors from harmal leaf extract. Elfidiah, et.al. (2020) [16] also reported that starfruit extract can increase the corrosion inhibition efficiency of reinforced concrete steel by 99.7%.

The decrease in corrosion rate is inversely proportional to the inhibition efficiency. The lower the corrosion rate, the higher the inhibition efficiency. The decrease in corrosion rate is caused by organic compounds that have polar groups such as -NH2, -OH, NO2, -CN, or -SH. This is influenced by the absorption of organic compounds that contain π electrons other than oxygen and azote in their molecules [12], [18]. These organic compounds can form a protective layer on the metal surface [17].

Conclusion

The results of the evaluation of Syzygium myrtifolium leaf extract showed that Syzygium myr-

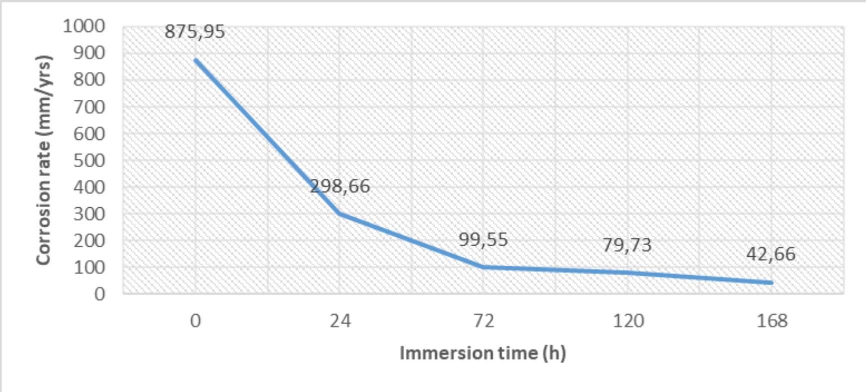

Figure 4. Corrosion rate decline graph (mm/years)

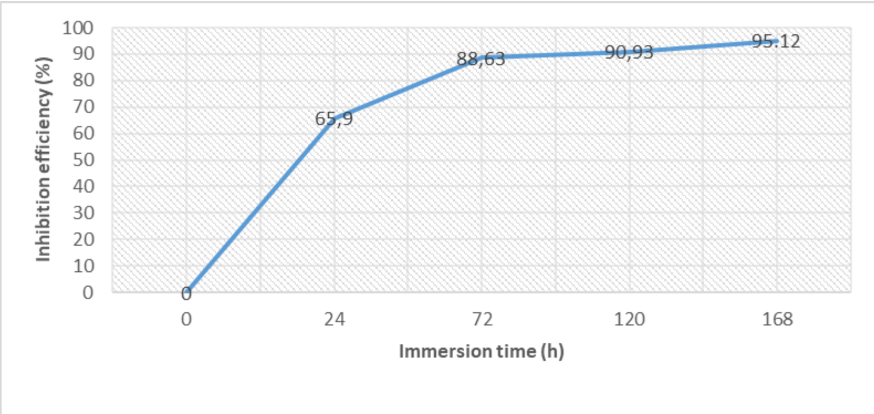

Figure 5. Inhibition efficiency increase graph

tifolium leaf extract can be an environmentally friendly inhibitor because it showed the best reduction in corrosion rate of 42.66 mm/year with an inhibition efficiency of 95.12% obtained at a soaking time of 168 hours. The inhibitor's ability shows that Syzygium myrtifolium leaf extract can be an environmentally friendly corrosion rate inhibitor. Because the extract can be adsorbed on the steel surface, thus inhibiting corrosion in saline/acid solutions, and stopping the cathode and anode processes at the steel/acid interface. This is due to the presence of heteroatoms O, S, and N in the chemical compounds of most organic inhibitors.

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