Investigation of Corrosion Resistance of Reinforced Concrete Structures with Varying Supplementary Cementitious Materials in Marine Infrastructure

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Abstract

The degradation of concrete strength may occur due to extreme environmental factors such as sea or coastal areas. Those factors can decrease the durability level of concrete structure signified by the corrosion of reinforced concrete structure. The use of fly ash as a concrete mixture is expected to minimize corrosion in concrete structures. Since fly ash has small particles, it can fill small voids in concrete and minimize corrosive substances. The investigation parameters in this study employed two types of corrosion acceleration test modelling using a 15x15x15cm cube tested object with a concrete quality of 40 MPa. Meanwhile, fly ash involves classes F and C within the level of 20% as well as applied corrosion prediction by 10% and 20%. The addition of fly ash to the concrete mixture can reduce the mass loss of reinforced concrete. The maximum mass loss on a normal test object with a corrosion prediction of 20% was obtained at 18.22%, while a 20% corrosion prediction obtained the smallest value for the SCMFA-C test object at 17.04%. The 20% corrosion prediction obtained the largest distribution of 0.355 mm on the normal test object and the smallest distribution of 0.299 mm occurred on the SCMFA-F test object. Thus, the addition of fly ash to the concrete mixture can reduce the distribution of corrosion and mass loss in reinforced concrete.

Keywords: *Corrosion resistance; Fly ash; Marine infrastructure; Reinforced concrete*

1. Introduction

Buildings located in extreme environments such as coastal and marine areas have the potential to experience corrosion. The presence of chloride ions contained in sea water can enter the pores in the concrete and react with the passive layer of the reinforcing steel, causing an oxidation reaction that causes corrosion of the reinforcing steel [1]. Reinforced concrete materials with good concrete mixture properties usually have corrosion resistance capacity [2]. However, it will degrade over time if positioned in extreme environmental conditions.

Various methods have been taken to reduce the impact caused by corrosion attacks, one of which is by using SCM (*Supplementary Cementitious Material*) concrete, namely the addition of coal burning waste material (*fly ash*) as a substitute for cement material in the concrete mixture. The use of fly ash in reinforced concrete can increase durability and resistance to acid attack and decrease the occurrence of corrosion attacks on reinforcement in concrete [3]. So that, the study of fly ash as a concrete mixture is important to enhance. The experimental investigation on the effect of corrosion rate on mass loss of reinforced concrete with various fly ash addition rates will be carried out in this study.

2. Literature Review

The investigation on the effect of fly ash and corrosion in reinforced concrete have been investigated by several studies. Saraswathy et al., 2003 [4] obtained that concrete's corrosion resistance and strength were enhanced by activated fly ash up to a critical replacement level of 20–30%, as indicated by weight loss measurements, visual observations, and anodic polarization tests. Noermalasari, 2009 [5] stated that corrosion at the reinforced concrete can be reduced by using fly ash to strengthen the material's resistance to acid attack and increase its durability.

2.1. Concrete

Concrete is a composite material consisting of a mixture of portland cement or other hydraulic cement, coarse aggregate, fine aggregate and water with or without other added materials, thus forming a dense, strong and stable mass [6]. The process of forming concrete starts with a chemical reaction between cement and water to create *hardened cement paste* (H.C.P.). This paste then bonds with both fine and coarse aggregates to form a dense, hard substance known as concrete.

2.2. Corrosion of Reinforced Concrete

Corrosion is a phenomenon that can cause damage to reinforced concrete structures [7]. Basically, corrosion is the degradation of a material brought on by its environment, and it occurs periodically until the material reaches a stable state. The material can be used normally while this process occurs because of the corrosion process is very slow [8]. The mechanism of corrosion begins with the loss of the passive layer on the surface of the reinforcement which will become the anode. The steel surface, which is still covered in a passive layer, reacts with the release of electrons from this reaction to produce water and O2 gas, which becomes the cathode. The combination of anode and cathode ions produces a corrosion product, namely ferrous hydroxide [Fe(OH)2] [9].

2.3. Accelerated Corrosion Test

The corrosion development stage often occurs slowly, therefore it is not possible to observe this process quickly. Thus, acceleration of corrosion is carried out in order to shorten the time when corrosion occurs in reinforced concrete. Figure 1 shows the modeling of accelerated corrosion test. This test begins by providing an electric current by connecting the positive terminal of the DC power supply to reinforcement embedded in the concrete as an anode. The corrosion process is carried out in a pool or tank containing a NaCl solution as an electrolyte. After that, the negative terminal of the DC power supply and the stainless steel as the cathode were connected. The level of corrosion that occurs can be adjusted based on the length of testing time and the level of electric current applied to the salt solution.

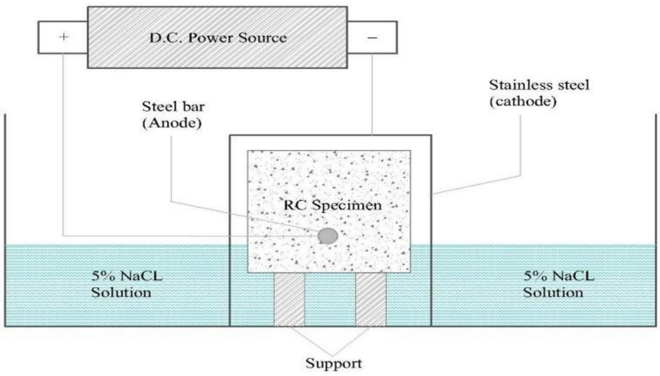


Figure 1. Modeling of accelerated corrosion test

2.4. Concrete Porosity

Porosity is the percentage of voids or pores in concrete, and it can be generated by adding relatively large aggregates to the concrete mix, which makes the concrete porous and has large pores. This may result in a reduction of the concrete's compressive strength [10].

2.5. Water Absorption

Water absorption testing is carried out to determine how much water is absorbed into the concrete. The large amount of water absorption can be caused by the use of relatively coarse aggregates so that there will be voids in the concrete which become a pathway for water to enter the concrete.

3. Method

This research uses modeling of three types of test objects with dimensions of 15x15x15cm at the age of 28 days, namely normal concrete, supplementary cementitious material for fly ash concrete type C (SCM-C), and supplementary cementitious material fly ash concrete type F (SCM-F). The concrete is embedded with D10 size steel reinforcement at the bottom of the concrete to form a blanket measuring 4 cm. The use of fly ash in SCM concrete has a content of 20%. Then an experiment will be conducted on three models using accelerated corrosion tests. Investigations were carried out to determine the level of mass loss in the concrete and the damage caused by corrosion products.

4. Result and Discussion

At this testing stage the test object has reached the age of 28 days. The compressive strength test results can be seen in Table 1.

4.1. Concrete compressive strength test

Table 1. Compressive Strength Test Results

Type	Test Model	Load (N)	Compressive Strength (MPa)	Average (MPa)
Normal	Cylinder (10 x 20) 1	200,000	30.68	33.96
	Cylinder (10 x 20) 2	230,000	35.29	
	Cylinder (10 x 20) 3	234,000	35.90	
SCMFA-F 20%	Cylinder (10 x 20) 1	198,000	30.38	34.72
	Cylinder (10 x 20) 3	232,000	35.59	
	Cylinder (10 x 20) 5	249,000	38.20	
SCMFA-C 20%	Cylinder (10 x 20) 2	275,000	42.19	46.54
	Cylinder (10 x 20) 4	304,000	46.64	
	Cylinder (10 x 20) 5	331,000	50.78	

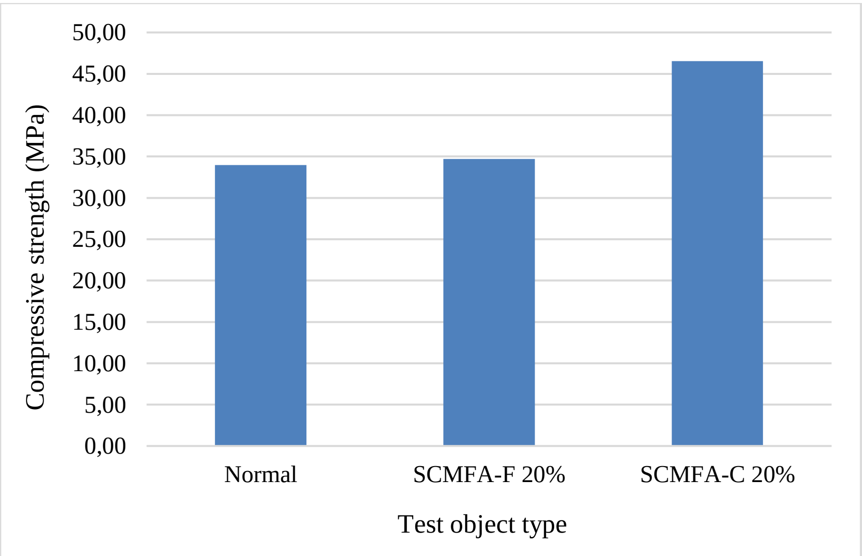


Figure 2. Relationship between compressive strength and type of test object

Based on Figure 2, it can be concluded that the addition of fly ash as a supplementary cementitious material can increase the strength value of concrete at 28 days. The highest compressive strength value occurred in the SCMFA-C 20% test object type, namely 46.54 MPa.

4.2. Concrete porosity test

Porosity testing on concrete is carried out to determine the percentage value of pores in the concrete. This test is carried out when the concrete test object has passed a curing period of 28 days. Porosity in concrete can be seen in Table 2.

Table 2. Concrete Porosity Test Results

Type	Test Model	Porosity (%)	Average (%)
Normal	Cylinder (10 x 20) 1	0	0.21
	Cylinder (10 x 20) 2	0.32	
	Cylinder (10 x 20) 3	0.32	
SCMFA-F 20%	Cylinder (10 x 20) 1	1.27	1.06
	Cylinder (10 x 20) 3	1.27	
	Cylinder (10 x 20) 5	0.64	
SCMFA-C 20%	Cylinder (10 x 20) 2	0.32	0.32
	Cylinder (10 x 20) 4	0.32	
	Cylinder (10 x 20) 5	0.32	

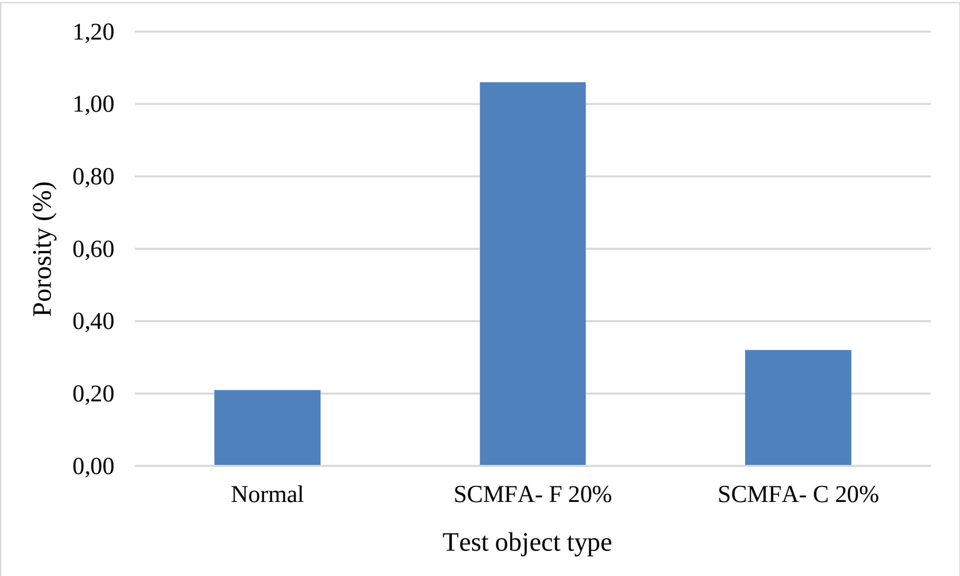


Figure 3. Relationship between porosity and type of test object

Based on the results of concrete porosity testing as shown in Figure 3, it can be concluded that the addition of fly ash material can increase the porosity of the concrete. The highest level of porosity occurred in the SCMFA-F 20% test object, namely 1.06%

4.3. Water absorption test

This test is carried out to obtain the percentage value of absorption and voids in the concrete. The results of the water absorption test can be seen in Table 3.

Table 3. Water Absorption Test Results

Type	Test Model	Water Absorption (%)	Average (%)
Normal	Cylinder (10 x 20) 1	5.83	5.51
	Cylinder (10 x 20) 2	5.68	
	Cylinder (10 x 20) 3	5.02	
SCMFA-F 20%	Cylinder (10 x 20) 1	4.74	3.99
	Cylinder (10 x 20) 3	3.69	
	Cylinder (10 x 20) 5	3.53	
SCMFA-C 20%	Cylinder (10 x 20) 2	3.66	3.42
	Cylinder (10 x 20) 4	3.45	
	Cylinder (10 x 20) 5	3.15	

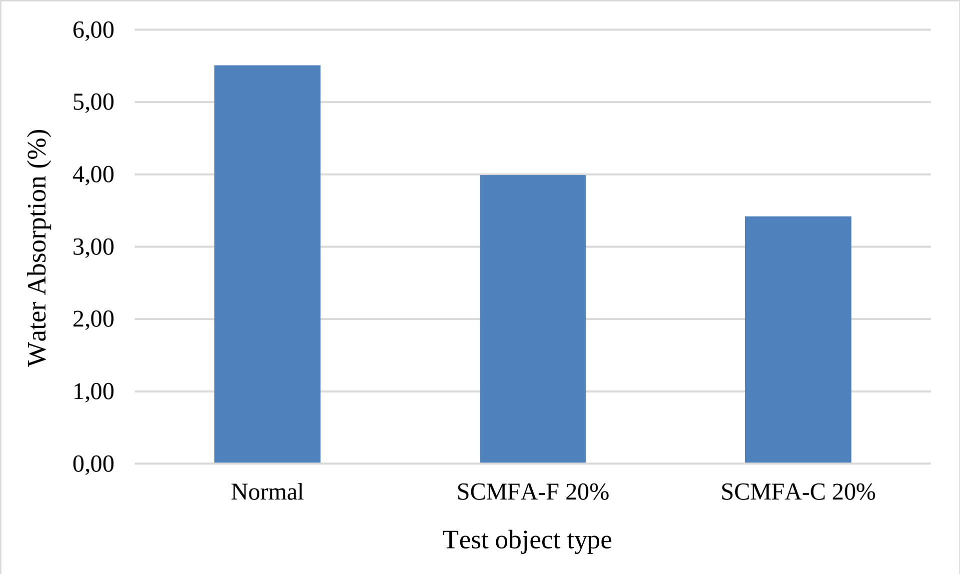


Figure 4. Relationship between water absorption and type of test object

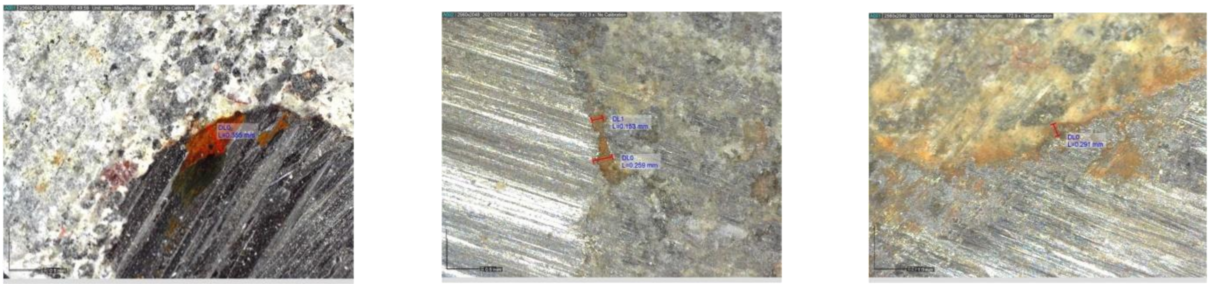
Based on Figure 4, it can be concluded that the substitution of cementitious material in the form of fly ash can reduce the absorption of concrete. The minimum absorption occurred in the SCMFA-C 20% test object, namely 3.42%, while the SCMFA-F 20% test object was only able to produce an absorption in concrete of 3.99%.

4.4. Investigation on the damage of reinforced concrete

Accelerated corrosion test is carried out using 5% of NaCl solution with two types of corrosion prediction rates, namely 10% and 20% depending on the test duration. The test object will be cut to determine the damage and width of rust on the concrete using a *dino lite microscope*. Details of the test results can be seen in Figure 5 and 6 for 10% and 20% corrossion rate.

(a) (b) (c)

Figure 5. Width of carat with 10% corrossion for type (a) Normal (b) SCMFA-F (c) SCMFA-C



(a) (b) (c)

Figure 6. Width of carat with 20% corrossion for type (a) Normal (b) SCMFA-F (c) SCMFA-C

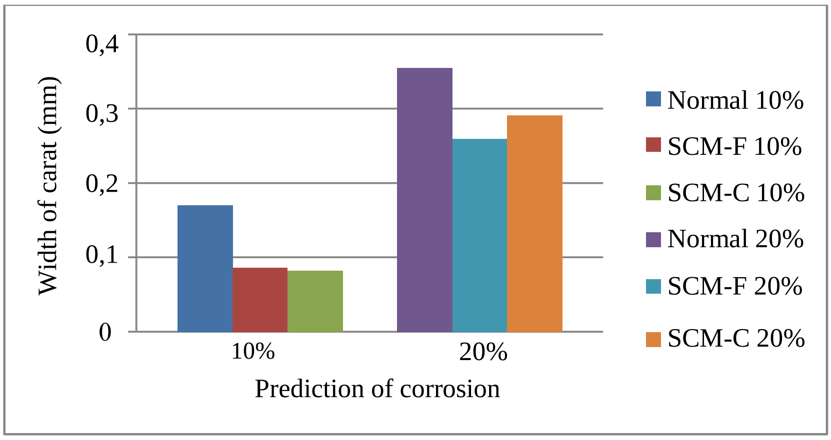


Figure 7. Width of carat

Based on Figure 7, it can be concluded that the use of SCM concrete can reduce the level of rust distribution in reinforcement in concrete. The lowest rust distribution in the 10% corrosion prediction occurred on the SCMFA-C test object, namely 0.082 mm, while the 20% corrosion prediction occurred on the SCMFA-F test object, namely 0.26 mm. Several factors influence the rate of corrosion such as humidity, pH, and temperature.

4.5. Mass loss on corrosion of reinforcement

At this stage, the reinforced concrete will be crushed and the reinforcement inside will be removed after the accelerated corrosion test. From these reinforcements, a mass loss test will be carried out on the reinforcement in the concrete. The results of the investigation can be seen in Figure 8.

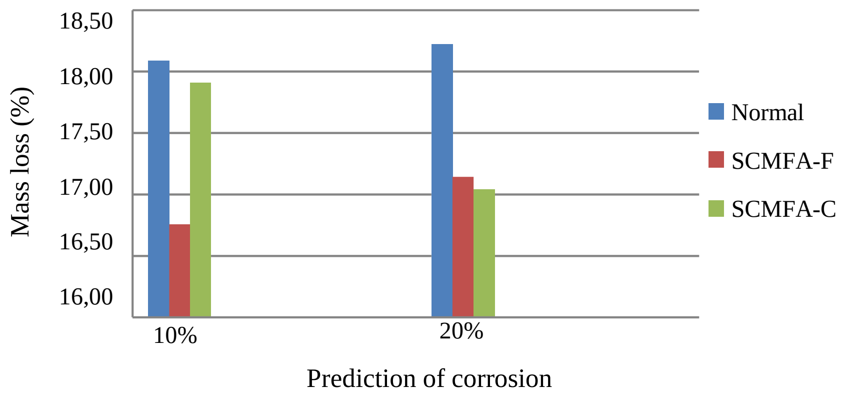


Figure 8. Relationship between mass loss and prediction of corrossion

Based on Figure 8, the addition of fly ash material as a supplementary cementitious material can reduce the percentage of mass loss. The lowest percentage in the 10% corrosion prediction occurred in the SCMFA-F test object, namely 16.75%, while in the 20% corrosion prediction the lowest percentage occurred in the SCMFA-C test object at 17.04%.

5. Conclusion

Based on the test results it can be concluded that accelerated corrosion behavior in normal concrete and SCM concrete can be characterized by mass loss in the reinforcement. In normal concrete there was a mass loss of 18.08%, while in SCM-C and SCM-F concrete there was a mass loss of 17.90% and 16.75%. So that the use of SCM concrete can reduce the level of mass loss of reinforcement in concrete with a maximum reduction difference of 1.33%. The damage pattern and distribution of corrosion were investigated in normal and SCM concrete resulting in no damage such as cracking or spalling was found in normal concrete and SCM concrete due to pitting occurring first in the exposed reinforcement so that the corrosion distribution is uneven. The distribution of corrosion that occurs is in the form of corrosion spots, in normal concrete the rust width is 0.17 mm while in SCM-F and SCM-C concrete it is 0.086 mm and 0.082 mm. So, it can be concluded that the use of SCM concrete can reduce the distribution of rust in the reinforcement in concrete.

The method for investigating accelerated corrosion is carried out using the galvanostatic method, namely by immersing the test object in a NaCl solution which will then pass an electric current through the reinforcement in the concrete. After accelerating corrosion, cutting will be carried out on the test object to determine the damage and distribution of rust on the reinforcement in the concrete, observing the distribution of rust using a dino lite microscope. After these observations have been made, the reinforcement in the concrete will be removed and soaked in rust cleaning fluid to determine the weight of the reinforcement after corrosion and then an analysis of mass loss in the reinforcement will be carried out. Based on the investigations that have been done, it can be concluded that the use of SCM concrete can reduce the level of mass loss and rust distribution in reinforcement in concrete.

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