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EFFECT OF FLY ASH AND SILICA FUME ON THE ABRASION RESISTANCE OF CONCRETE IN MARINE ENVIRONMENT

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ABSTRACT

Cement, as a concrete-forming material, is a contributor to CO2 emissions around the world. One technique to make concrete green without sacrificing quality is to use less cement and substitute ingredients like fly ash and silica fume. A durable concrete material is required since the marine environment's concrete is frequently harmed by harsh environmental elements, such as abrasion by waves and ocean currents. This study aimed to examine the impact of different substitutions for additional materials on concrete's compressive strength and mass loss due to abrasion. The test object is thereafter partially submerged in freshwater and seawater. Furthermore, the specimens underwent laboratory testing to get specific performance metrics including compressive strength and abrasion coefficient. The strength value for the test object treated with freshwater or seawater has exceeded the compressive design strength of 30 MPa, according to an analysis of the compressive strength test findings. Testing for abrasion on the specimens resulted in substituting additive materials in the optimal amount for the concrete, which can reduce mass loss due to abrasion. According to the overall results of concrete testing, which are influenced by seawater, fly ash substitution improves concrete's compressive strength and resistance to abrasion. In contrast, the values of compressive strength and abrasion in silica fume concrete with replacement variations of 5%, 7%, and 10% have a value equivalent to the required accomplishments.

Keywords: fly ash, silica fume, concrete, abrasion.

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INTRODUCTION

Concrete is one of the main components of construction, both for construction on land and at sea. Standards that apply to concrete materials used in marine environments must have a higher compressive strength value than buildings on land. Research on seawater's effect on concrete's compressive strength shows that the compressive strength value decreases if the concrete is soaked continuously for 28 days. In this study, concrete exposed to seawater for seven days reached a compressive strength of 20 MPa before declining to 14 MPa at the end of the experiment. [1,2].

Buildings in a marine environment require more specific characteristics, including high concrete quality, low permeability, and abrasion resistance. These buildings require building materials impervious to seawater so that the rate of chloride penetration into the concrete becomes slower or longer because chloride and sulfate chemicals in seawater are corrosive to concrete and reinforcing steel. [3]

The performance of coastal structures like piers, revetments, groins, and breakwaters is declining as a result of marine environment actions like sea waves [4]. Sea waves are a cyclical force that will act on buildings on the sea coast and cause abrasion on the concrete construction. In addition to these environmental factors, vehicular traffic and loading and unloading activities at the harbor also affect the condition of the wharf structure, especially the plates that experience surface erosion/abrasion due to vehicle wheels.

Innovations in concrete technology are always required to answer the challenges of concrete needs. The resulting concrete is expected to have good quality, strength, and durability in corrosive environments and be aggressive without neglecting the economic value. It is necessary to find alternatives to obtain quality concrete resistant to aggressive environments by adding additives or substitutes to cement [5-8]. The use of concrete in construction is closely related to cement production as one of the elements in making concrete. Production of Portland cement during the manufacture of cement clinker will result in considerable CO2 emissions [9,10].

Reducing the amount of cement by adding or completely replacing cement is also expected to reduce production, which impacts reducing carbon dioxide exhaust emissions and global warming. Green Concrete enhances three factors of sustainability: environmental, economic, and social impact. The factors in identifying green concrete are the amount of Portland cement substitute, manufacturing process, method, performance, and sustainability impact [11,12].

The use of additional materials to replace cement in this study is related to the large amount of industrial waste in Indonesia, namely fly ash and silica fume, which are large in number and can pollute the environment. Utilization of this waste is expected to be one of the things to improve the quality of the nature affected.

Due to the use of industrial waste or power plant leftovers in these types of concrete, which can result in environmental damage, eco-friendly concrete (green concrete) is sometimes referred to as concrete with fly ash and silica fume substitutions. This waste material needs an extensive disposal area. Besides, silica fume and fly ash have the potential to pollute the air and affect public

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health. Researchers in this subject have studied the impact of utilizing fly ash and silica fume on concrete [8-13].

Numerous investigations on compressive strength, flexural strength, and permeability have been done. There haven't been many tests on concrete impacted by seawater abrasion.

This study aimed to analyze the effect of variations in substitutes for fly ash and silica fume on the compressive strength of concrete affected by seawater and the mass loss of concrete due to abrasion.

The abrasion resistance needs to be tested. This matter relates to buildings in the sea that will receive the force of wave debris and the impact of drifting objects. The amount of mass loss will show the resistance of the concrete to the abrasion effect.

MATERIALS AND METHODS

Mixing of Concrete

Mixing concrete is selecting concrete constituents and determining their quantity to produce economic concrete that maintains its strength properties. Planning of ordinary concrete mixes and concrete mixes with fly ash based on regulations in force in Indonesia include SNI-7656-2012, SNI-03 6468-2000 and ACI 211.1-91, ACI 211.4R-93

Adding substitute materials such as silica fume or fly ash in the concrete mixture can provide advantages because it can improve mechanical properties, including increasing compressive strength, flexural and tensile strength, and good performance [19]. The addition of substitute materials to concrete is based on the cement's weight. The amount of fly ash additives in concrete is 10%, 20%, and 30% by weight of cement in the concrete mix. Adding this value yields a good value for concrete's mechanical qualities. [16, 17].

Adding silica fume over concrete can also increase the mechanical properties of the concrete. However, replacing cement with silica fume, which exceeds 10% of cement's weight, can reduce the concrete's strength and modulus of elasticity. Adding a 5% or more silica fume can increase the compressive strength value [19]. In this study, the amount of replacement of cement with silica fume in concrete was 5%, 7%, and 10%, which was determined based on the results of several other previous studies.

Two forms of procedure are used in the treatment of mixed concrete. The test object is immersed in freshwater, and some other test objects are immersed in seawater to determine its effect on the concrete. The treatment was carried out at a room temperature of 20^{o}C [21]. Immersion was carried out until the age of the concrete reached 90 days to check the increased compressive strength from 28 days to 90 days and see the level of influence of seawater on compressive strength and resistance to abrasion.

Fly Ash

The fly ash utilized in this test comes from the Suralaya power plant in Banten, Indonesia. The fly ash produced is type F, which, according to ASTM C 618, is fly ash produced by burning bitumen or anthracite coal and contains less than 10% CaO.

Low-calcium fly ash, commonly known as Class F fly ash, is only pozzolanic and does not have cementitious characteristics. Less than 20% lime is present in Class F fly ash, which also has cementitious qualities similar to Portland cement. Class F fly ash is suitable for use in high-sulfate environments, structural concrete, and high-performance concrete. It can also be used at high concentrations in concrete mixes.

Silica Fumes

Silica fume is also known as micro silica, which results from reduced quartz with coke in electric furnaces to produce silicon and ferrosilicon alloys. Before the mid-1970s, almost all silica fume was vented into the atmosphere. However, after environmental problems occurred and the results of research on silica fume can be used as a concrete mixture, silica fume was finally applied to concrete with high quality performance [22].

The addition of silica fume to Portland cement improves the properties of the concrete. According to research, silica fume improves bond strength, compressive strength, and abrasion resistance. Adding silica fume to cement paste improves the mechanical properties of the concrete due to the addition of very fine powders and pozzolanic interactions between the silica fume and free calcium hydroxide in the cement paste.

A further benefit of silica fume addition is a decrease in the permeability of concrete to chloride ions, which prevents steel reinforcing concrete from corroding, particularly in settings with high chloride ion concentrations, such as bridges in contact with seawater.

Silica fume in concrete mixtures is intended to produce concrete with high compressive strength. For example, high-strength concrete is used for structural columns or shear walls, pre-cast or prestressed concrete, and several other purposes.

Low levels of silica fume (less than 5% by cement weight) do not result in stronger strength than concrete because the quantity of silica fume is insufficient to cover the surface of all coarse aggregate particles. However, the beneficial use of silica fume is also limited to no more than 10% of the weight of the cement used, due to the use of excess silica fume that will not be able to cover the aggregate's surface. [17]

Figure-1. Fly ash and silica fumes.

Portland Cement

The cement used to manufacture the test specimens is type II cement, which, according to SNI 15-2049 2004 and ASTM C 150 classification, is cement with moderate sulfate resistance.[10] This type of cement has a modest sulfate resistance and hydration heat. It is made up of 46% C3S, 29% C2S, 6% C3A, 11% C4AF, 2.9% MgO, and 2.5% SO3. Type II Portland cement is utilized for buildings in marine, dam, and irrigation environments, as well as mass concrete that requires low hydration heat and surface conditions with high sulfate exposure.

Compressive Strength

Concrete's compressive strength is defined as its ability to withstand a compressive force per unit area. The compressive strength of concrete reflects the quality of the construction. The targeted level of structural strength will decide how high the quality of the concrete is created.

A compressive testing machine applies a multilayer compressive load to a concrete cylinder test object until it cracks to determine the compressive strength value of concrete using standard testing procedures. For the compressive strength test, SNI 1974-2011 and ASTM C39-99 were employed as standards.

The concrete cylinder specimen, which has a 15 cm diameter and a 30 cm height, is compressed until it cracks by a load P. The concrete experiences compressive stress (fc') as a result of the compressive load P, which is equal to the load (P) divided by the cross-sectional area of the concrete (A) and written with the following formula:

$$f_c' = \frac{P}{A} \quad (1)$$

fc' is compressive strength (N/mm2 or MPa)

Compressive strength testing was carried out on specimens aged 28 days, 52 days, and 90 days. The tests were carried out on samples treated with freshwater and seawater.

Abrasion Coefficient

Wear tests are usually carried out using testing standards based on SNI 3419-2008 and the Manual for Concrete Abrasion Machine, 1985 Tanifuji & Co-Japan, concerning laboratory abrasion tests. In principle, this concrete abrasion testing machine imitates the flow of debris flowing through the building, which causes the abrasion force of the impact flow on the concrete surface of the building. It is vital to identify the quality of the concrete through which the debris flows so that the structure resists the abrasion forces of the debris flow and the age of the building as planned when designing the building.

The percentage of loss in weight of the test object indicates the durability, quality, and quantity of the binder. This procedure can also be modified for use in other mixtures. The test object is made in the form of a block with dimensions of width x length x height = 15 cm x 30 cm x 4 cm or 15 cm x 30 cm x 6 cm.

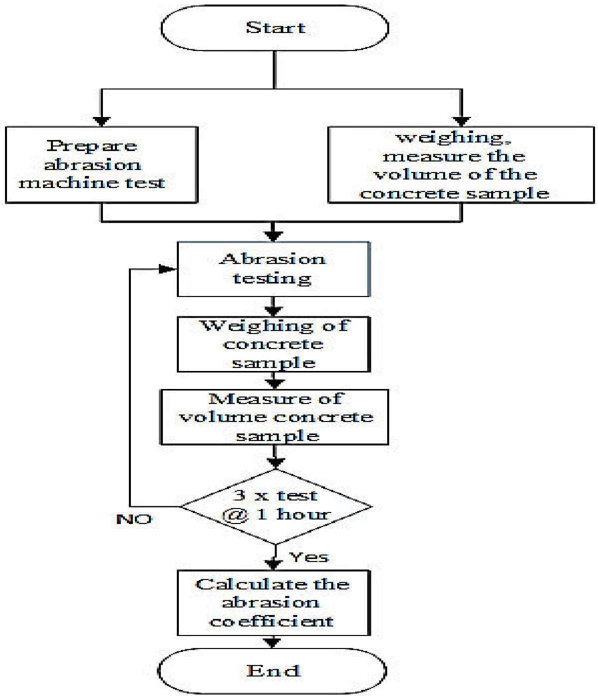

Figure-2. Abrasion testing flowchart.

Testing the specimens was carried out in stages, namely 1 hour, 2 hours, and 3 hours. Each time step on the test object is measured by weight to calculate the mass loss due to abrasion testing. Calculate the abrasion volume and concrete coefficient in each test period using the following formula.

$$\text{Abrasion Volume } V_n = \frac{W_0 - W_n}{V} \times 100\% \quad (2)$$

Where

W_0 = Total weight of mold and specimen before testing (kN)

Wn = Total weight of mold and sample after testing (kN)

Vn = Volume of abrasion (cm^3)

$$\text{Abrasion Coefficient } K = \frac{V}{A} \quad (3)$$

K = Abrasion coefficient (cm^3/cm^2)

V = Volume of the test object (cm^3)

A = Surface area of the test object (cm^2)

$$\text{Average Abrasion Coefficient } K_a = \frac{\sum K_i}{6} \quad (4)$$

Ka = Abrasion coefficient (cm^3/cm^2)

Ki = Abrasion coefficient of each test object (6 pieces)

Figure-3. Abrasion test machine.

Microstructure Test

To ascertain the microscopic morphology of regular concrete and concrete with material substitution, scanning electron microscopy (SEM) and energy dispersive X-ray (EDX) microstructure tests were conducted. According to ASTM-1723-10, the test was conducted.

SEM-EDX uses an electron microscope to see the size and shape of the particles making up a material. This method can also be used to analyze crystallographic data, which can then be used to determine the elements or compounds present in the sample. SEM is used to perform a comprehensive morphological examination of concrete. The basic principle is to project a high-energy electron beam onto a material and reflect the electron beam or secondary electron beam in all directions to define the surface of the material.[23].

RESULTS AND DISCUSSIONS

Fly Ash and Silica Fume Concrete Mix

The manufacture of concrete test specimens is based on the results of the ordinary concrete mix where the fly ash and silica fume added material is substituted by reducing Portland cement. Variations in adding fly ash and silica fume as a substitution material are based on previous studies conducted by other researchers. The following is the composition of the substitution material on the test object. The substitution value of fly ash in concrete is 10%, 20%, and 30% by weight of cement, while the substitution of silica fume is 5%, 7%, and 10% by weight of cement.

In this study, the use of fly ash in concrete did not include activating materials such as sodium hydroxide (NaOH) and sodium silica dioxide (Na2SiO3) to see to what extent the effect of fly ash on compressive strength without an activator in concrete. Table 1 shows the composition of the concrete mixture with 10%, 20%, and 30% fly ash substitution variations, while Table 2 shows the concrete mix composition with 5%, 7%, and 10% silica fume substitution.

Table-1. Fly ash concrete mixture.

Materials (Kg/m3)	FA10%	FA20%	FA30%
Water	205.00	205.00	205.00
OPC type II	384.38	341.67	298.96
Fly Ash	42.71	85.42	128.13
Fine Aggregate	645.32	639.13	632.22
Coarse Aggregate	1028.30	1028.30	1028.30

Table-2. Silica fume concrete mixture.

Materials (Kg/m3)	SF 5 %	SF 7 %	SF 10 %
water	205.00	205.00	205.00
OPC type II	405.73	397.19	384.38
Silica Fume	21.53	29.9	42.71
Fine Aggregate	652.19	652.19	652.19
Coarse Aggregate	1028.30	1028.30	1028.30

Compressive Test Results

The primary and most essential factor in establishing the quality of concrete and the strength achieved is compression strength testing. Compressive strength of ordinary concrete employing a specific cement type II. Compressive strength testing is advised until the concrete reaches 90 days of age because it is projected that it will only achieve the desired compressive strength at that point. The specimens were evaluated at various stages of the concrete's life, including 28, 56, and 90 days.

Figure-4. Compressive strength test.

Fly Ash Concrete Compressive Test Result

Substitution of fly ash is expected to reduce the cement used in concrete while maintaining the planned compressive strength value. Adding variations of fly ash into the concrete of 10%, 20%, and 30% impacts the compressive strength of this concrete. Table 3 below is the average compressive strength of fly ash concrete with variations of fly ash mixture from the test results:

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Table-3. Fly ash concrete compressive strength.

No	Specimen codes	Average compressive strength (MPa)		
		days		
		28	56	90
1	COC 0%	38.05	50.05	55,22
2	COS 0%	34,42	49.97	54,76
3	CFCs 10%	43,37	48,77	49,34
4	CFS 10%	37.01	43,67	45.30
5	CFCs 20%	36.65	50.08	55.02
6	CFS 20%	37.73	45.69	50.88
7	CFCs 30%	34.28	46.56	49.24
8	CFS 30%	34.27	43.81	46.60

The specimen code indicates the variation of fly ash substitution and the specimen's treatment method. COC is ordinary concrete with freshwater treatment, whereas COS is ordinary concrete with seawater treatment. CFC denotes fly ash substituted concrete with freshwater treatment, and CFS is fly ash concrete with seawater treatment. The percentage shows the variation of fly ash substitution in concrete.

Seawater used for curing concrete is original seawater that has not been affected by pollutant waste and is taken from Rancabuaya Beach in the south of Java Island. The results of the salinity test showed a salinity level of 6.82%.

The compressive strength of ordinary concrete was reached at 28 days, which is 38.05 MPa. This value has exceeded the planned compressive strength of 30 MPa (fc'), and the targeted average compressive strength (fcr') is 33.9 MPa; as time goes on, the average compressive strength value of ordinary concrete increases to reach 55.22 MPa at the age of 90 days concrete.

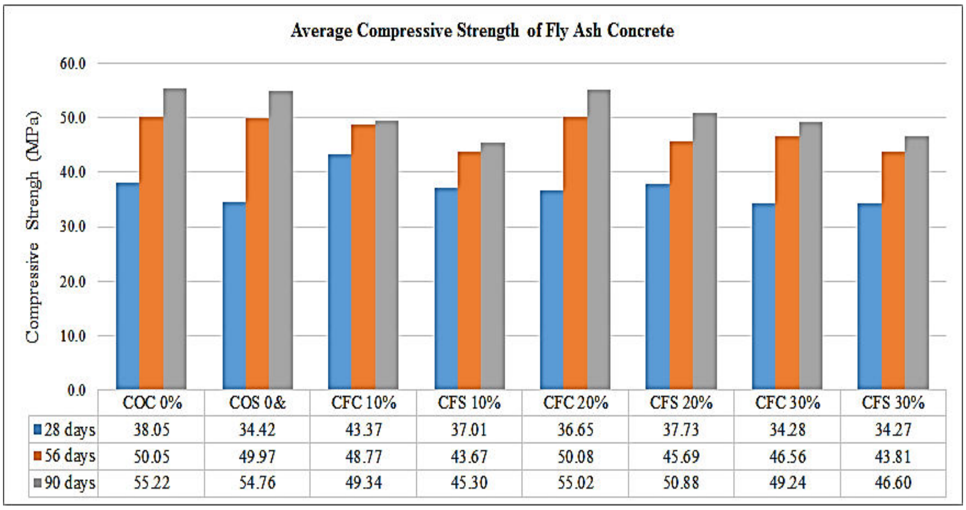

Figure-5. Average compressive strength of fly ash concrete.

In ordinary concrete treated with seawater immersion (COS0%), when the concrete is 28 days old, the average compressive strength reaches 34.42 MPa. This value has a small but considerable effect on the decline in compressive strength. The compressive strength continues to meet the design compressive strength as well as the requisite average (target) compressive strength. At 56 days and 90 days, the compressive strength of concrete increased linearly up to 54.76 MPa. This value has no significant difference with freshwater-treated concrete (COC0%). The best compressive strength value achieved by fly ash concrete with freshwater treatment was a fly ash substitution variation of 20% (COC20%), gaining a compressive strength of 55.02 MPa at 90 days of concrete age.

In fly ash concrete immersed in seawater, the compressive strength value of fly ash concrete reached the highest compressive strength value in 20% (COS 20%) of fly ash concrete, where the compressive strength achieved was 50.88 MPa. This value also shows that seawater reduces the compressive strength of this fly ash concrete. The optimal mixture variation in this study was a variation of 20% fly ash concrete. Giving fly ash as much as 10% and 30% compressive strength results are still below the concrete with 20% fly ash.

Silica Fume Concrete Compressive Test Result

Table-4 shows the average compressive strength of silica fume concrete with variations using silica fume substitution obtained from the test results. Silica fume concrete has reached the design compressive strength at the age of 28 days. At 28 days, all concrete with substitution variations of 5%, 7%, and 10% reached the targeted average compressive strength value (fcr').

The highest strength value of silica fume concrete at the age of 90 days is concrete soaked in freshwater with 7% (CSC7%) silica fume substitution, which is 51.6 MPa. Meanwhile, the highest compressive strength value of silica fume concrete immersed in seawater is concrete

10% (CSS10%) silica fume with an average compressive strength value of 48.31 MPa.

The strength test results that had been carried out on the silica fume concrete test specimens showed a tendency to decrease compressive strength compared to ordinary concrete at the age of 90 days. However, this value still has a compressive strength value above the targeted average compressive strength (*fcr*').

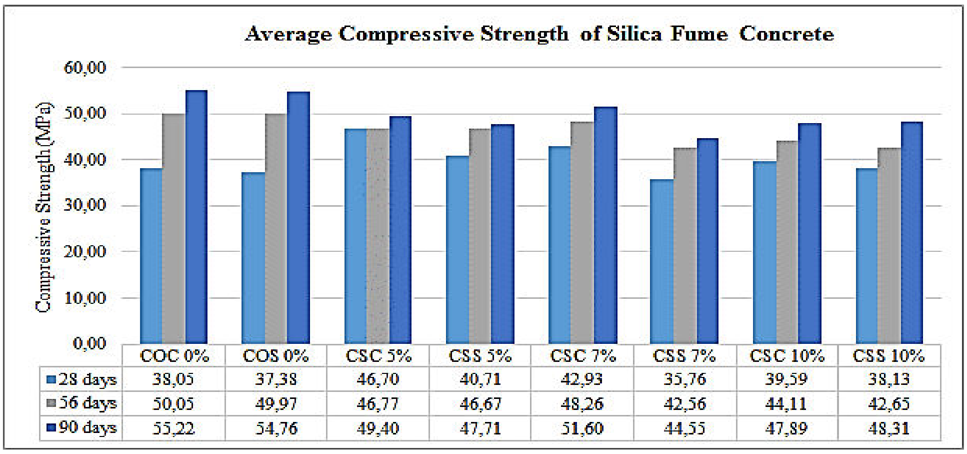

Figure-6. Average compressive strength of silica fume concrete.

Table-4. Silica fume concrete compressive strength.

No	Specimen codes	Average compressive strength (MPa) days		
		28	56	90
1	COC 0%	38.05	50.05	55.22
2	COS 0%	37.38	49.97	54.76
3	CSC 5%	46.70	46.77	49.40
4	CSS 5%	40.71	46.67	47.71
5	CSC 7%	42.93	48.26	51.60
6	CSS 7%	35.76	42.56	44.55
7	CSC 10%	39.59	44.11	47.89
8	CSS 10%	38.13	42.65	48.31

CSC denotes Silica Fume substitution concrete with freshwater treatment, and CSS is silica fume concrete with seawater treatment.

SEM-EDS TEST RESULTS

SEM Test Results

Testing was carried out using a scanning electron microscope (SEM) and energy dispersive X-ray spectroscopy (EDS) on both ordinary concrete and substitute concrete submerged in seawater for 56 days. In the Scanning Electron Microscope (SEM) test, image data is obtained as follows:

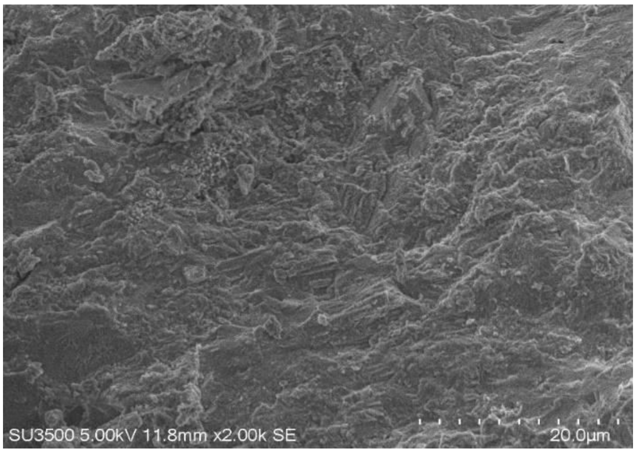

Figure-7. SEM test of COC.

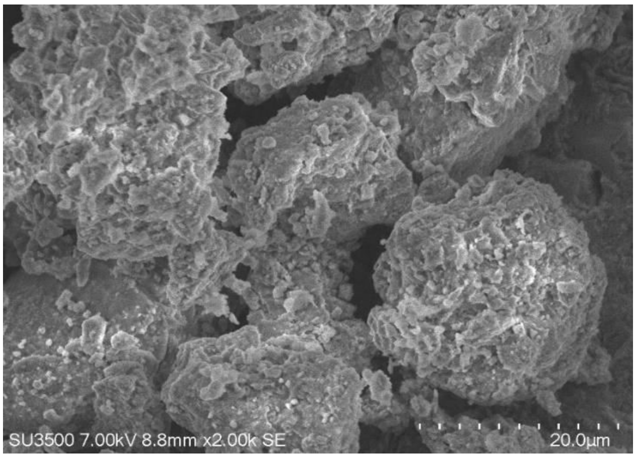

Figure-8. SEM test of COS.

From a microscopic enlargement of concrete images on ordinary concrete specimens, we can determine the effect of seawater on concrete by looking at the morphological conditions of the concrete surface. Freshwater-immersed concrete has higher density and particle density than seawater-immersed concrete.

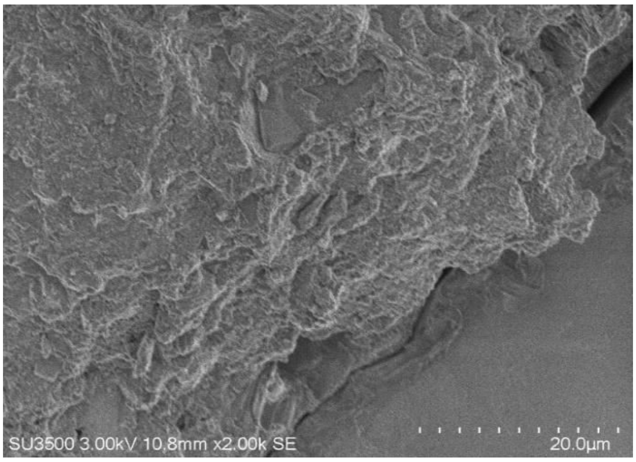

Figure-9. SEM test of CFS.

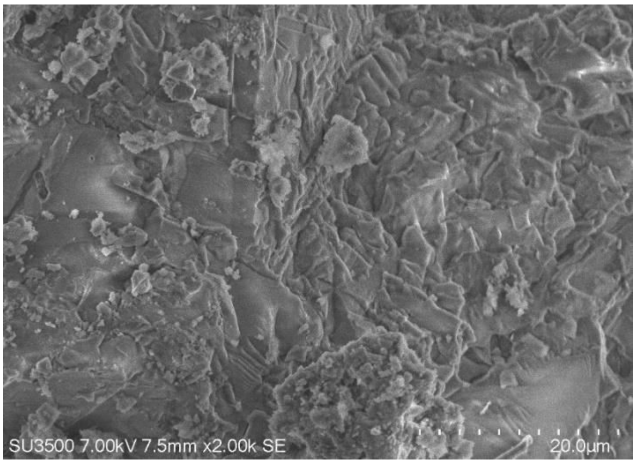

Figure-10. SEM test of CSS.

Figure-9 shows that the addition of fly ash to concrete results in changes in the morphology of the concrete microstructure. The concrete particles become flakier than ordinary concrete particles, which look agglomerated. Fly ash concrete soaked in seawater has a lower density than fly ash concrete treated with freshwater.

Figure-10 shows the results of the microscopic enlargement of silica fume concrete where treatment with seawater affects the density of silica fume concrete microstructure. Seawater-soaked concrete is more porous and hollow in the concrete. The mixing results form a more considerable particle structure than the silica fume concrete particles submerged in seawater.

EDS Test Results

The analytical method of energy-dispersive X-ray spectroscopy (EDS) is used to characterize materials chemically or analytically. Transmission electron microscopes (TEM) and scanning electron microscopes (SEM) are two instruments of electron microscopy devices that are frequently coupled. The EDS is based on the specimen's characteristic X-ray emission. A beam of high-energy charged particles (protons or electrons) is directed at a sample. When an electron from a level with a more significant electron binding energy enters the core hole, an X-ray is produced with the energy difference in the electron level's binding energy. A spectrum produced by an EDS analysis contains peaks that correspond to the sample's elemental composition. Four components determine the quality of cement, as written in the following Table-5 [24].

Table-5. OPC chemical content.

Chemical components		
3 CaOSiO2	C3S	Tricalcium silicate
2 CaOSiO2	C2S	Dicalcium silicate
3 CaO. Al2O3	C3A	Tricalcium Aluminate
4 CaO.Al2O3.Fe2 O3	C4AF	Tetracalcium Aluminoferrite

EDS testing is carried out on specimens immersed in freshwater and seawater. Seawater contains about 3.5% salt, with the main salts containing elements: 55% chloride (Cl), 31% sodium (Na); 8% sulfate (SO_4); 4% magnesium (Mg), 1% calcium (Ca), and less than 1% the rest contains other substances. Considering that the most dominant salt elements contained in seawater are Na and Cl, it is suspected that the type of salt formed from these two elements, namely NaCl, is the cause of damage to concrete or mortar that is submerged in and or affected by seawater.

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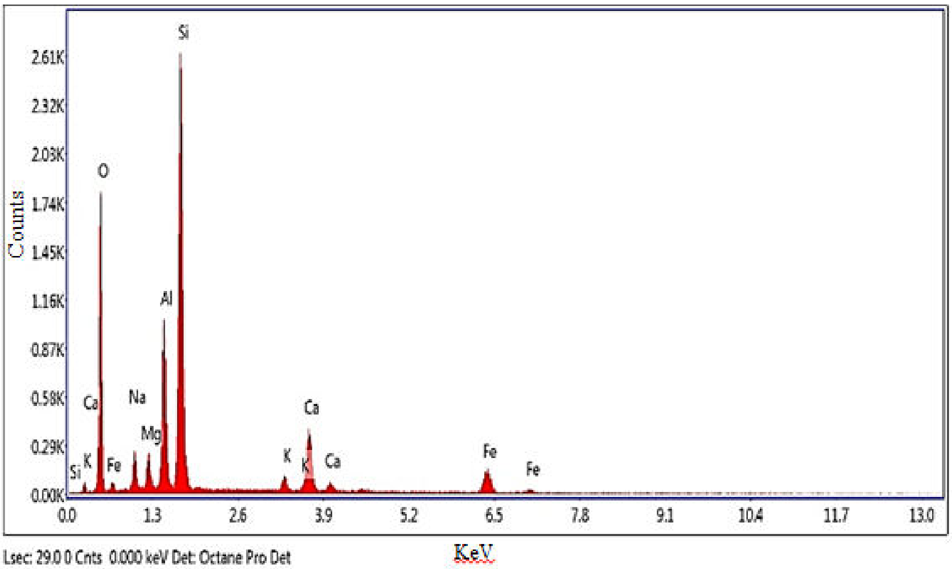

Figure-11. EDS test result of COC.

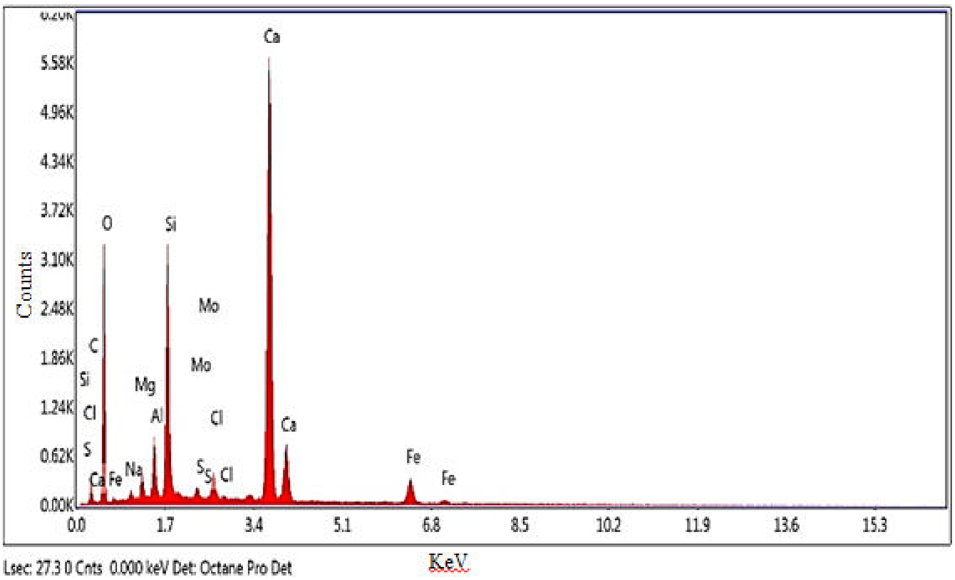

Figure-12. EDS test result of COS.

Figure-11 and Figure-12 show the EDS test results for ordinary concrete soaked in freshwater (COC) and seawater (COS). Ordinary concrete that was soaked in general reached a weight of 18.70%. In concrete soaked in seawater (COS), element O reaches 50.94% by weight and Ca by 24.09%. The slight difference between the two is that in element COC, and there are K minerals that are not visible in concrete soaked in seawater. While the Mo element is not visible from the results of the EDS test on COS. The minerals Mo and Fe appear in the specimens submerged in seawater, even on a small scale. From the results of the EDS test, it appears that the components contained in ordinary concrete samples with freshwater treatment have chemical compounds C3S, C2S, and C3A, while the mineral element Fe is not visible.

In ordinary concrete treated with seawater (COS), all components are visible, namely C3S, C2S, C3A, and C4AF. From the results of the EDS, it appears that the value of the mineral elements increased so that in this concrete, Friedel salt formation occurred where the compressive strength test results of concrete with seawater treatment had a lower value than ordinary concrete. There is an element of Cl chloride in concrete with seawater immersion, which shows the formation of Friedel salts (3CaO.Al2O3.CaCl2.10H2O) in concrete.

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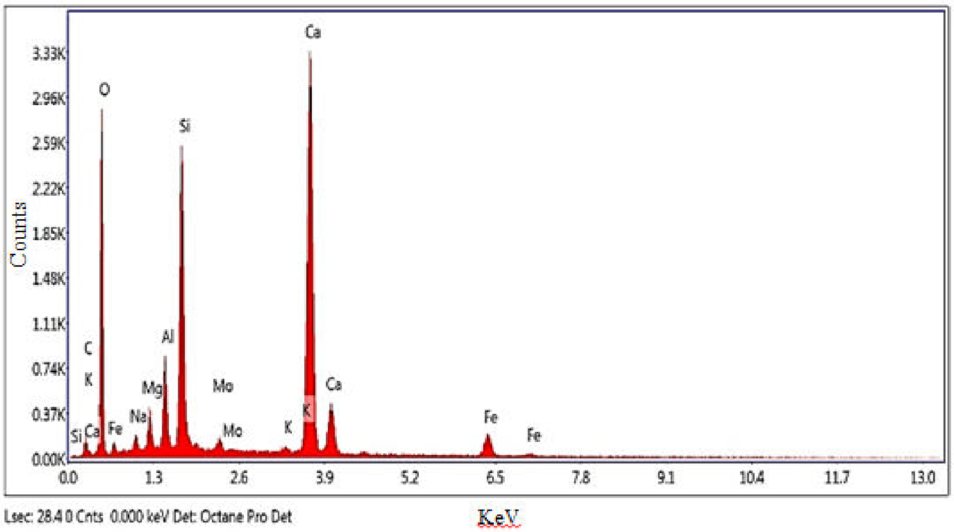

Figure-13. EDS test result of CFS.

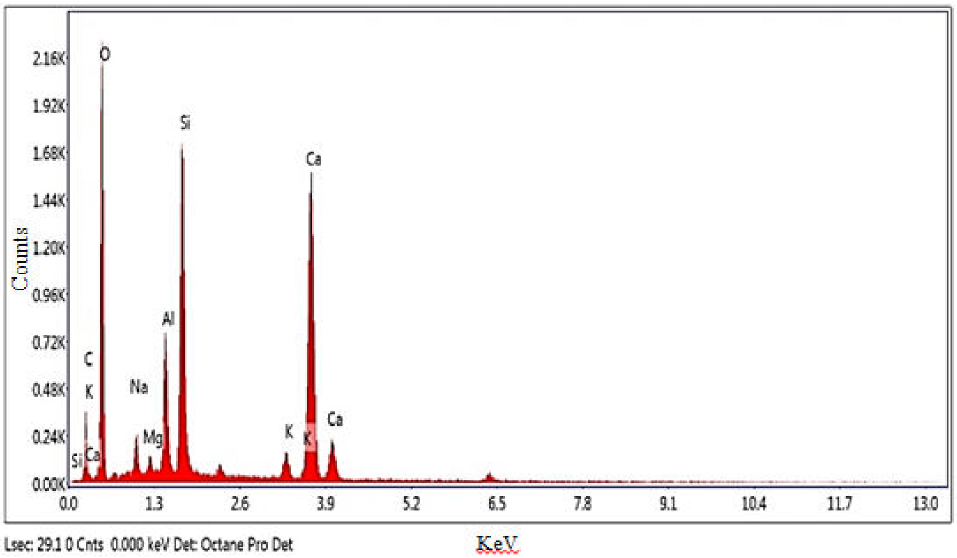

Figure-14. EDS test results of CSS.

Table-6. EDS quant result.

Element	CFS		CSS	
	Weight %	Atomic %	Weight %	Atomic %
O K	48.30	64.10	45.20	60.51
NaK	1.62	1.50	3.89	3.62
MgK	1.79	1.56	1.24	1.10
AlK	3.30	2.59	10.12	8.04
SiK	9.79	7.40	27.07	20.65
CaK	26.47	14.02	7.28	3.89
K K	0.23	0.12	1.23	0.67
MoL	0.79	0.17	-	-
Fe	-	-	3.96	1.52
C K	4.02	7.11	-	-

Figure-13, Figure-14, and Table-6 are the EDS test results containing fly ash concrete (CFS) and silica fume concrete (CSS). The chemical elements in the two test objects have the same majority of mineral elements, namely Ca, O, Si, C, and others. The difference between the two scales is the amount of Ca and Si in concrete. There was a decrease in Ca in CSS concrete compared to CFS, whereas the amount of Si increased in CSS by adding silica fume in concrete. From the composition of the elements contained in concrete, all chemical compounds such as C3S, C2S, C3A, and C4AF are present in silica fume concrete.

Figure-14 shows that adding the mineral element silica fume makes the mineral composition of concrete different from the others. Si mineral is the second dominant mineral in silica fume concrete, weighing 27.07%.

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ABRASION TEST RESULT

Fly Ash Concrete Abrasion Test Result

Figure-15 and Table-7 illustrate the results of a 3-hour abrasion test on ordinary concrete, which revealed that the weight loss in ordinary concrete soaked in freshwater (SOA) was 107.18 grams and 130.17 grams in ordinary concrete soaked in seawater (COS). Weight loss increased in the two ordinary concretes with these varied treatments. This evidence suggests that seawater increases the volume of degraded concrete particles.

In the fly ash substituted concrete, the weight loss after testing for 3 hours was in the range of 95.61 grams to 115.44 grams, with the abrasion coefficient values being in the range of 0.22 cm^3/cm^2 to 0.25 cm^3/cm^2. Adding fly ash to concrete with freshwater treatment with 10% and 20% substitution slightly reduced the weight loss in the concrete samples after abrasion testing. In fly ash concrete soaked in seawater, there is a reasonably good decrease in weight loss compared to ordinary concrete soaked in seawater. The weight loss value in ordinary concrete soaked in seawater of 130.17 grams can be reduced to 106.25 grams with a 10% fly ash substitution. The abrasion coefficient value in ordinary concrete is 0.29 $cm^3/cm^{2,}$ which decreases to 0.24 cm^3/cm^2 in seawater-treated concrete.

Table-7. Average mass loss of fly ash concrete.

Specimens	Average Mass Loss (gr)			Average abrasion coefficient (cm^3/cm^2)		
	1 hour	2 hours	3 hours	1 hour	2 hours	3 hours
COA	45.05	75.02	107,18	0.08	0.16	0.24
SOA	50.88	64,26	130,17	0.11	0.21	0.29
CFAC 10%	34,56	66,81	95.61	0.08	0.15	0.22
CFAS 10%	38,23	72,87	106.25	0.09	0.16	0.24
CFAC 20%	37,74	68,20	102.81	0.08	0.16	0.24
CFAS 20%	39,14	74,14	106,82	0.09	0.17	0.24
CSAC 30%	41,72	73.95	102.85	0.09	0.17	0.23
CSAS 30%	36,47	76,57	115,44	0.08	0.17	0.25

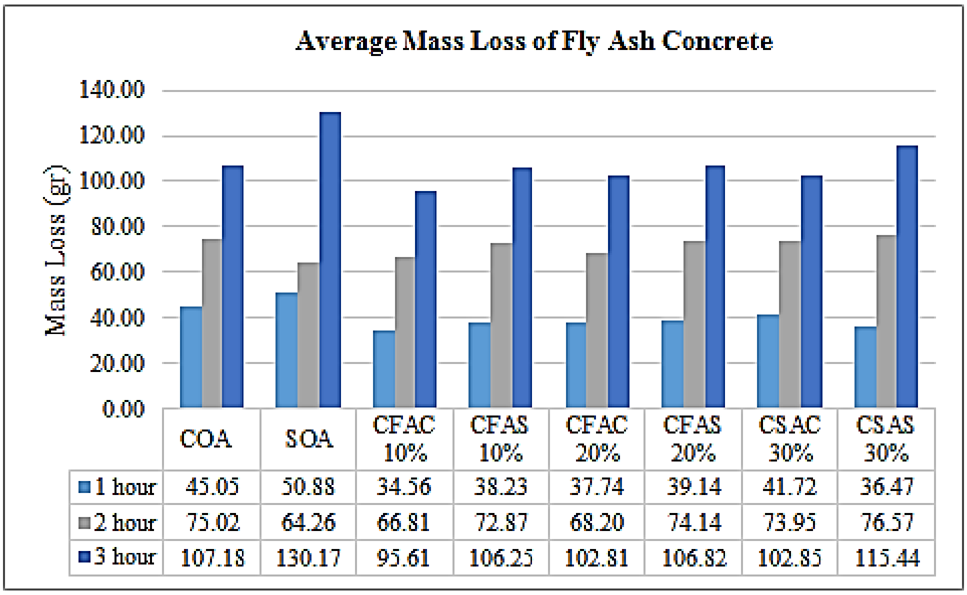

Figure-15. Average abrasion mass loss of fly ash concrete.

Silica Fume Concrete Abrasion Test Result

Abrasion testing on substituted concrete with silica fume shows the test results shown in Table-8 and Figure-17, where the addition of silica fume to ordinary concrete (COA) by soaking in fresh water slightly increases the average mass loss after abrasion testing from 107.18 grams on ordinary concrete to 120.15 gram on 5% silica fume concrete (CSAC5%). Whereas in 10% silica fume substituted concrete (CSAC10%), it achieved an average weight loss due to abrasion of 111.97 grams.

In ordinary concrete (SOA) soaked in seawater, there was a decrease in the average weight loss due to abrasion from 130.17 grams to 126.03 grams with 5% silica fume substitution (CSAC5%) and 115.44 grams in

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concrete with 7% silica fume substitution (CSAC7%). The average weight loss value in 10% silica fume concrete (CSAC10%) increased to 133.78 grams.

The abrasion coefficient ranges from 0.25 cm^3/cm^2 to 0.28 cm^3/cm^2 for both freshwater and seawater immersion concrete curing. The abrasion coefficient of substituted concrete immersed in seawater silica fume with 5% and 7% substitution has a better coefficient value than ordinary concrete. This matter shows that adding 5% and 7% silica fume provides better abrasion resistance than ordinary concrete in marine environments.

Figure-16. Concrete surface after 3 hours of abrasion testing.

Table-8. Average mass loss of silica fume concrete.

Specimens	Average Mass Loss (gr)			Average abrasion coefficient (cm^3/cm^2)		
	1 hour	2 hours	3 hours	1 hour	2 hours	3 hours
COA	45.05	75.02	107.18	0.08	0.16	0.24
SOA	50.88	64.26	130.17	0.11	0.21	0.29
CSAC 5%	37.52	81.99	120.15	0.08	0.18	0.26
CSAS 5%	44.28	88.58	126.03	0.10	0.19	0.27
CSAC 7%	39.47	75.35	113.14	0.09	0.17	0.25
CSAS 7%	36.47	76.57	115.44	0.08	0.17	0.25
CSAC 10%	30.03	74.44	111.97	0.07	0.16	0.25
CSAS 10%	46.20	93.80	133.78	0.10	0.21	0.28

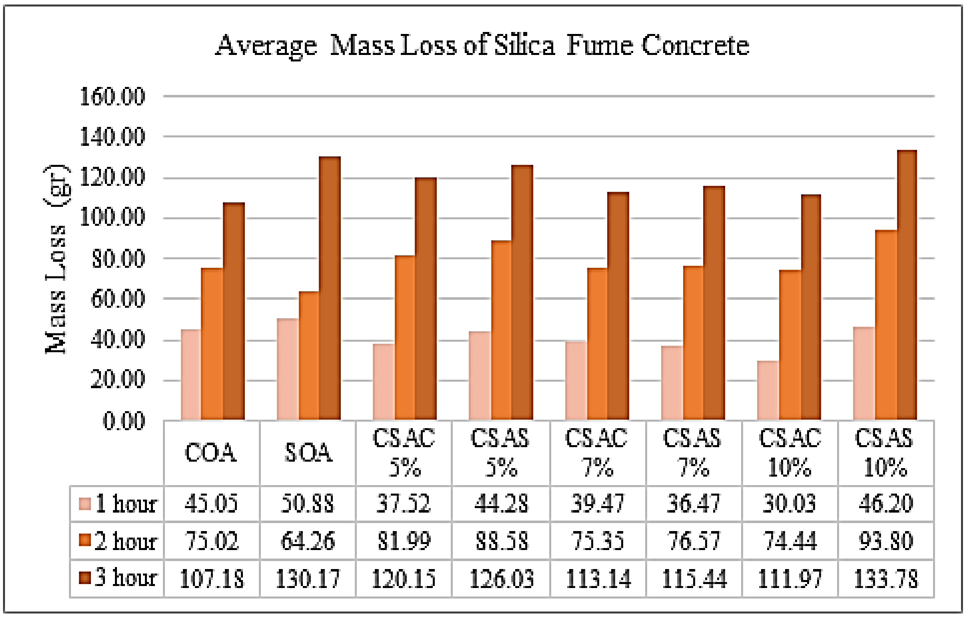

Figure-17. Average abrasion mass loss of silica fume concrete.

CONCLUSIONS

The substitution of fly ash and silica fume affects concrete. 20% fly ash substituted concrete at 90 days, the average compressive strength value has exceeded the *fc'* and *fcr'* values of 55 MPa. In 20% fly ash replaced concrete with seawater treatment, the compressive strength value achieved at 90 days of concrete is 50 MPa. These values are slightly higher than ordinary concrete with the same curing method.

Concrete with Silica fume substitution has the best compressive strength value at 5% substitution variation with fresh water treatment, which is 49.4 MPa at 90 days of concrete age. The best compressive strength results were obtained at a 5% Silica fume substitution variation of 47.71 MPa at 90 days of age for silica fume concrete treated with seawater. This value is slightly lower than that of ordinary concrete. Concrete with these two types of additional material achieves the specified design value.

Adding fly ash of all variations to concrete reduces the mass loss compared to ordinary concrete. In silica fume concrete soaked in fresh water, adding silica fume increases the mass loss and abrasion coefficient value. In 5% and 7% of silica fume concrete immersed in seawater, the mass loss and abrasion coefficient values are smaller than in ordinary concrete.

The results of abrasion testing for 3 hours on concrete showed that the mass loss and abrasion coefficient on fly ash concrete had better values for concrete with seawater and freshwater immersion than concrete with silica fume substitution.

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