BIO Web of Conferences **159**, 06002 (2025) https://doi.org/10.1051/bioconf/202515906002
SAFE 2024

Concrete durability with fly ash blended cement for coastal construction

I Sudarsono[1], *S* I Wahyudi[2] and *Henny* Pratiwi A[2]

[1] Department of Civil Engineering, Langlangbuana University, Bandung, Indonesia
[2] Department of Civil Engineering, Sultan Agung Islamic University, Semarang, Indonesia

Abstract. Cement, as a concrete-forming material, is a contributor to CO2 emissions in the world. Reducing cement and replacing it with fly ash material can make green concrete without lowering the quality of the planned concrete. Concrete in marine environments is often damaged by aggressive environmental factors. The study aims to analyze the effect of fly ash substitution in cement on substantial performance. The test object is made and treated with seawater. Furthermore, the test specimens were tested in the laboratory to obtain performance and durability variables based on the mechanical properties of the concrete, namely compressive strength, flexural strength, and permeability of weight loss due to abrasion. Analysis of the compressive strength, flexural strength, permeability, and abrasion coefficient tests showed that concrete with seawater treatment has good durability for all variations.

1. Introduction

Construction on the coast often uses concrete materials. Coastal structures, including revetments, breakwaters, and others, are usually damaged by aggressive marine environmental factors due to the nature of seawater or the forces at work. Waves and sea currents are abrasive to the concrete, so construction in this environment requires concrete materials with good quality and performance [1,2]. This concrete must be of better quality and waterproof than ordinary concrete. The rules stated in SNI 03-2914-1992 and DIN 1045-2 require the seawater penetration value into moderately aggressive watertight concrete to be 50 mm and strong, aggressive impervious concrete at 40 mm. This determination is because seawater contains corrosive chloride and sulfate compounds, so a more waterproof material is needed, which slows the rate of chloride penetration. [3].

According to a study on the impact of seawater on concrete's compressive strength, if concrete is repeatedly wet for 28 days, it will lose its compressive strength. The compressive strength of concrete soaked in seawater for seven days in this investigation was 200 MPa; after twenty-eight days, it dropped to 140 MPa. [4,5].

Concrete technology must advance to meet the need for high-performance concrete. Without sacrificing economic value, the final concrete should have acceptable quality,

[1] Corresponding author: ignazsd2@gmail.com

strength, and durability in harsh and corrosive coastal conditions. Adding extra or substitute components to Portland cement (PC) is an innovation that has been implemented and is still being studied to achieve this [6]. Because manufacturing cement clinker would result in massive CO2 emissions, reducing PC consumption is also essential to combating carbon dioxide pollution [7]. It is anticipated that lowering the PC content of concrete and adding full or partial additives will lessen carbon dioxide emissions and global warming while making concrete more environmentally friendly. The environmental, economic, and social facets of sustainability are all enhanced by green concrete. Performance, sustainability, and the production process are crucial elements to consider while making green concrete. [8]. This study examines how seawater affects the durability of concrete made with fly ash blended cement in coastal buildings.

2. Research methods and test result

Tests carried out on several mechanical properties of concrete are compressive strength test, flexural strength test, water penetration test, and abrasion.

2.1. Concrete mix design

Preparing the necessary fly ash, cement, fine and coarse aggregate, and other concrete-forming components is what is being done. This material underwent several tests, such as cement and fly ash gravity, fineness level, and aggregate sieve testing. Next, utilizing cement type II and concrete exposure class S1, the concrete mix planning is completed following SNI 2847-2019. According to this analysis, the planned concrete's compressive strength was 30 Mpa. In concrete, fly ash material (also known as supplemental cement material) is used in amounts of 10%, 20%, and 30% instead of cement. Table 1 shows the composition of the concrete mixture based on the concrete material's test results.

Table 1. Concrete mix plant with fly ash substitution per m^3

Material (Kg/m^3)	Fly Ash 10 %	Fly Ash 20 %	Fly Ash 30 %
Water	205.00	205.00	205.00
PC (Type II)	384.38	341.67	298.96
Fly Ash	42.71	85.42	128.13
Fine aggregat	645.32	639.13	632.22
Coarse aggregate	1028.30	1028.30	1028.30

2.2. Specimen curing

The specimens were cured in two procedures: partial freshwater submersion and partial seawater immersion. Samples are submerged in seawater to determine how seawater affects the performance of concrete. The seawater salinity test result is 6.83%. The duration of the specimens' immersion was modified for the 28-, 56-, and 90-day compressive and flexural strength tests.

2.3. Compressive strength test

The compressive strength test followed ASTM C39-99 and SNI 1974-2011 guidelines. The concrete cylinder specimen with compressive strength measures 15 cm in diameter and 30 cm in height. The concrete experiences compressive stress (fc'), which is calculated by dividing the load (P) by the cross-sectional area (A).

$$fc' = P/A \quad (1)$$

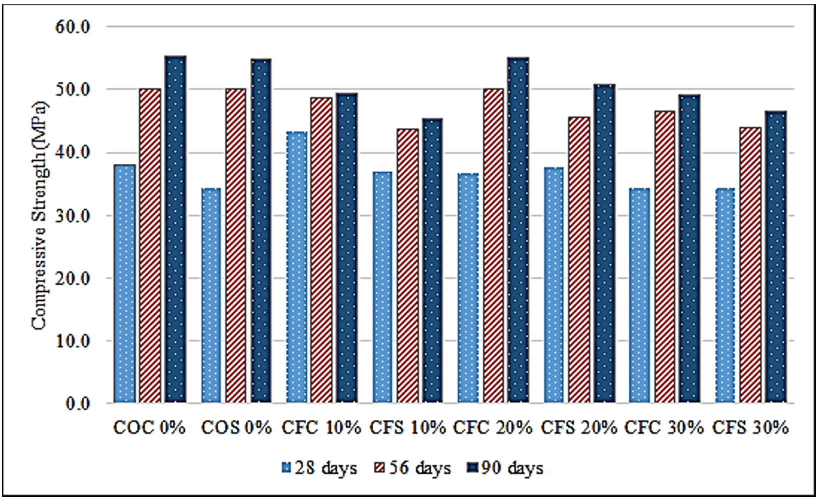

Fig. 1. Average compressive strength results.

When fly ash concrete was immersed in freshwater, the 20% fly ash substitution variant (COC 20%) produced the best compressive strength value, reaching 55.02 MPa after 90 days of concrete age. 20% (COS 20%) fly ash concrete has the highest realized compressive strength of all fly ash concrete in seawater immersion, with a value of 50.88 MPa. This number indicates that the compressive strength of this fly ash concrete is weakened by seawater. The best mixture variation in this experiment was a 20% fly ash concrete variety. Even with 10% and 30% fly ash additions, the results are still inferior to concrete containing 20% fly ash.

The durability of concrete containing fly ash and slag has been studied. Compressive strength is one of numerous characteristics that are tested for 28 days. The study's findings demonstrate that the relationship between the modulus of elasticity and compressive strength increases linearly. In contrast, the relationship between surface resistance and absorption coefficient suggests that concrete's surface resistance will gradually decrease as the absorption coefficient rises. Overall test findings, however, indicate that concrete that substitutes fly ash is durable for coastal or marine environments [9].

2.4. Flexural strength test

This test makes use of ASTM C1609 and SNI 4431-2011 standards. The flexural strength of the concrete is assessed using the 4-point bending test. The specimen is 15 x 15 x 60 cm in size. The flexural strength value of concrete is calculated using the formula below:

$$f = (F.L) / (b.h2) \quad (2)$$

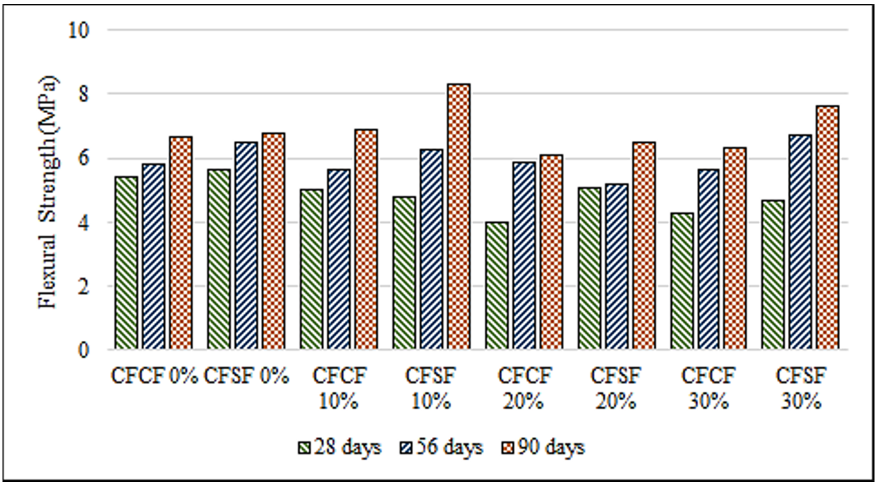

Fig. 2. Average flexural strength results.

All combination variants showed good flexural strength values; the flexural strength measured at 90 days of concrete ranged from 6.11 MPa to 7.61 MPa, except the 10% fly ash substitution variation, which reached 8.30 MPa. The flexural strength determined using the empirical formula in SNI 2847-2019 is marginally lower than the flexural strength value derived from the test data.

2.5. Water penetration test

Water penetration through concrete is measured using concrete permeability testing. The test object's measurements are 20 x 20 x 12 cm, flowing with liquid for three 24-hour periods. The water absorption is then measured by applying pressure on the test object. According to DIN 1045-1-2002, concrete permeability standards state that water absorption cannot exceed 5 cm.

Fig. 3. Water penetration measurement.

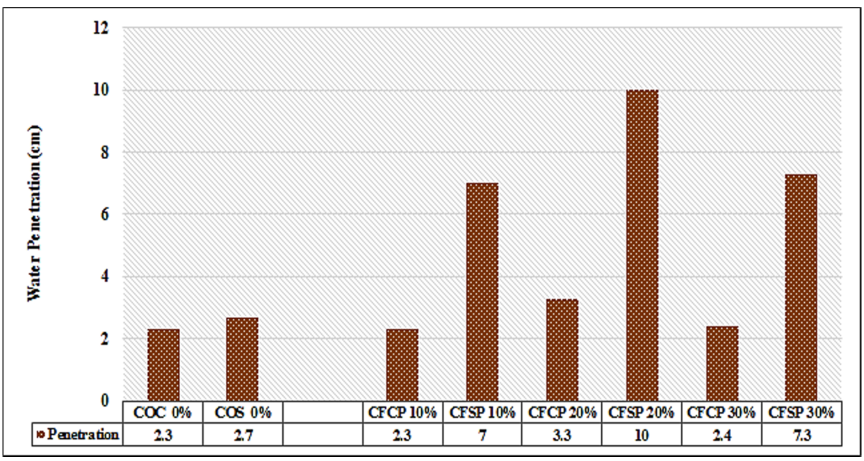

Fig. 4. Water penetration result.

Water penetration for concrete immersed in freshwater (CFCP) has a reasonably good value, below 5 cm. Substitution of fly ash in concrete immersed in freshwater does not affect concrete permeability. On the other hand, when immersed in seawater (CFSP), adding fly ash increases the water penetration value into the concrete up to 10 cm at 20% substitution.

2.6. Abrasion Test

Testing criteria for abrasion volume (Vn) are SNI 3419-2008, which deals with laboratory abrasion tests, and the Manual for Concrete Abrasion Machine, 1985 Tanifuji & Co-Japan. The test object has dimensions of 15 cm x 30 cm x 4 and is constructed as a block. Three distinct sessions of one, two, and three hours were used to test the samples.

$$V_n = \frac{W_0 - W_n}{V} \times 100\% \tag{3}$$

Fig. 5. Abrasion specimen after 3 hours of test

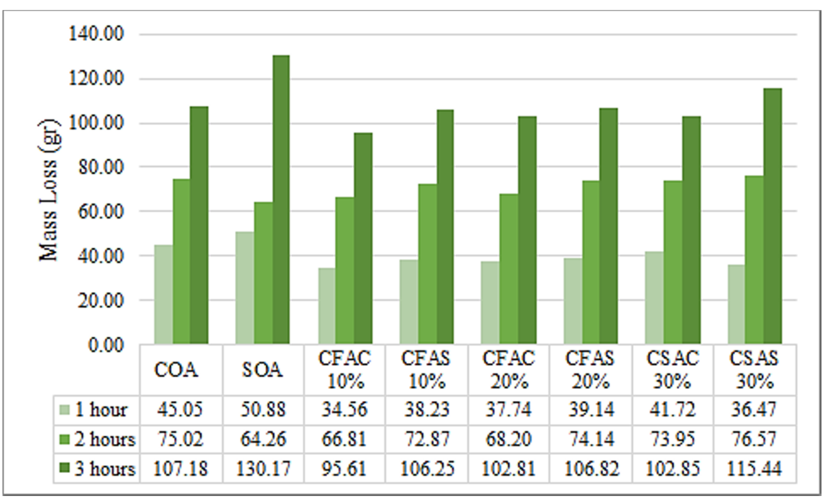

Fig. 6. Average mass loss result.

After three hours of testing, the weight loss in fly ash substitute concrete ranged from 95.61 to 115.44 grams, and the abrasion coefficient value was between 0.22 and 0.25 cm3/cm2. The weight loss of concrete samples during abrasion testing decreased by substituting 10% and 20% fly ash into fresh water-immersed concrete (CFAC). Weight loss is somewhat less in fly ash concrete soaked in seawater (FCAS) than in regular concrete (COA and SOA).

3. Discussion

3.1. Modulus elasticity of fly ash concrete

The modulus of elasticity of concrete, a key component in estimating building deformation and a fundamental factor in calculating the modular ratio, n, used for the cross-sectional design of structural elements that undergo bending, is one of the key variables determining concrete's strength.

Two methods are used to calculate the modulus of elasticity of concrete: the empirical formula in SNI 2847-2019 and ACI 318, which is a function of the concrete's compressive strength during the compressive strength test, and a basic equation that is a function of concrete's specific gravity and compressive strength [10]. The Noguchi equation is used in this work to calculate Ec.

$$E_c = k_1 k_2 * 3{,}35.* 10^4 \left(\frac{\gamma}{2400}\right)^2 * \left(\frac{\sigma_B}{60}\right)^{1/3} \quad (4)$$

Based on the use of coarse aggregate originating from quarries, which are crushed andesite rocks, the k1 value is 0.902, and for the use of fly ash as an added material, the k2 value is 1.1. The modulus of elasticity value for ordinary concrete (Ec) for concrete immersed in fresh water and seawater increases with the age of the concrete. The Ec value of ordinary concrete immersed in fresh water at 28 days reaches 25,965.56 MPa, then increases to 29,393.08 MPa at 90 days. For the Ec value of ordinary concrete immersed in seawater, the modulus of elasticity at 28 days is 25,113.02 MPa and increases to 29,311.91 MPa at 90 days.

According to Noguchi, these Elastic Modulus values can still be at the upper and lower limits of up to ± 20% of the achieved value so that the calculated Ec value, when compared to the Ec SNI 2847-2019 or ACI 318 value, has to close to the difference and should not too large to be usable for design purposes. Overall, the modulus of elasticity value increases linearly according to the increase in concrete compressive strength.

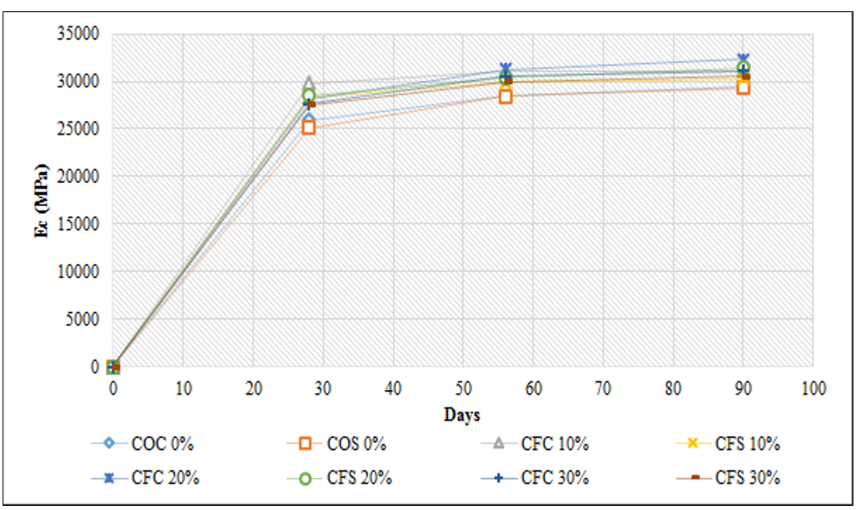

Fig. 7. Modulus elasticity of fly ash concrete.

3.2. Durability of fly ash concrete

Concrete durability is influenced by various factors, including the concrete material system, which includes intrinsic and exotic factors and aggressive environmental influences [11].

In this study, the reliability of concrete with variations in substitute materials can be reviewed from several mechanical property test results that have been carried out, namely compressive strength, flexural strength, permeability, and abrasion coefficient. For each concrete variation, a cumulative weight value (scoring) is determined based on the results of the values achieved compared to the requirements that must be met. The assessment scale is based on several references, including the PUPR Ministerial Decree No.1/SE/M/2011 concerning Guidelines for the operation and maintenance of coastal buildings, which divides the physical value scale of coastal buildings into reasonable, fair, needs repair, and damaged. Basuki (12), in his research on the durability aspects of concrete materials, divided the assessment of substantial quality based on ultrasonic testing of concrete density into very good, good, doubtful, bad, and worse.

The assessment of abrasion values refers to BS 882-1992 and IS383-1970, where the maximum abrasion value is a weight loss of 30% of the initial weight for concrete pavement layers and 50% for other concrete structures. The assessment of abrasion in this study uses a maximum value of 30% because marine structures always experience repeated cyclical impact loads on the concrete surface.

Table 2. Assessment of the durability of fly ash substitute concrete

Type of Concrete	Fc'	Score	Water penetration	Score	ʃ	Score	ka (%)	Score	Average Score
OPC-FWT	55.22	5	2.3	5	6.66	4	3.68	5	4.75
FA 10% - FWT	49.34	5	2.3	5	6.89	4	3.49	5	4.75
FA 20 %- FWT	55.02	5	3.3	4	6.11	4	3.73	5	4.5
FA 30% - FWT	49.24	5	2.4	5	6.3	4	3.82	5	4.75
OPC-SWT	54.76	5	2.7	4	6.79	4	4.39	5	4.5
FA10%- SWT	45.30	5	7.0	2	8.3	5	3.78	5	4.25
FA 20%- SWT	50.88	5	10.0	1	6.52	4	3.94	5	3.75
FA 30%- SWT	46.60	5	7.3	1	7.61	5	4.15	5	4

The assessment scale for durability is as follows:

- score 1 – not good
- score 2 - poor
- score 3 – fair
- score 4 – good
- score 5 – very good

Meanwhile, the assessment interval for determining the average durability is:

- 0 - 2 Concrete durability is not good
- 2 - 3 Concrete durability is poor
- 3 - 3,5 Concrete durability is fair

- 3,5 - 4,5 Concrete durability is good
- 4,5 - 5 Concrete durability is excellent

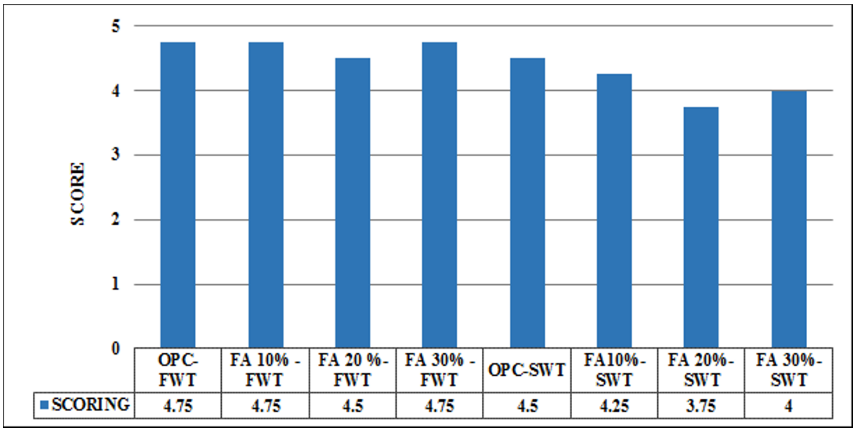

Fig. 8. Fly ash concrete durability.

Assessment based on the mechanical properties of the fly ash substitution concrete tested showed that concrete immersed in fresh water and seawater had good durability values, namely in the interval 3.75 – 4.75. The use of fly ash substitute concrete as environmentally friendly concrete (green concrete) for buildings in coastal environments can be used by substituting a variety of added materials (cement replacement material), which produces good durability. The results of this dissertation research can be compared to several research results and literature studies by other researchers.

A literature review shows that replacing cement with chemical and mineral admixtures improves concrete's strength and durability. Microstructure, morphological structure by SEM, lower shrinkage, higher mechanical strength, and superior durability with environmental sustainability have been observed [13,14].

4. Conclusion

The substitution of fly ash for cement has a good effect on reducing cement in concrete. The mechanical properties achieved in concrete, such as compressive strength, permeability, flexural strength, and abrasion resistance, have good values, especially in freshwater immersion concrete. For concrete soaked in seawater, poor grades were only achieved for seawater penetration values, but in general, the compressive strength, flexural strength, and abrasion resistance were good. Based on the four mechanical properties of concrete, the assessment of the durability of concrete treated with fresh water and sea water can be classified as good durability.

References

[1] W. D. Pratiwi, F. D. D. Putra, T. Y. Triwulan, N. A. Husin, and K. D. Wulandari. A review of concrete durability in marine environment. IOP Conf. Ser. Mater. Sci. Eng. **1175**, 1 p. 012018. (2021). doi: https://doi.org/10.1088/1757-899X/1175/1/012018

[2] S. I. Wahyudi and H. P. Adi. Evaluating Environment, Erosion and Sedimentation Aspects in Coastal Area to Determine Priority Handling (A Case Study in Jepara Regency, northern Central Java, Indonesia). IOP Conf. Ser. Earth Environ. Sci. **140**, 1. (2018). doi: https://doi.org/10.1088/1755-1315/140/1/012042
[3] R. Armynah and G. P. Lo. The rate of chloride penetration on concrete using rapid migration test, Hasanudin University. (2015)
[4] S. Wedhanto. Pengaruh air laut terhadap kekuatan tekan beton yang terbuat dari berbagai merk semen yang ada di kota malang. J. Bangunan **22**, 2 p. 21–30. doi: http://dx.doi.org/10.17977/um071v22i22017p%25p
[5] N. Suhana and A. Mualifah. Pengaruh Rendaman Air Asam Sulfat Pasca Curing Terhadap Kuat Tekan Beton. Gema Wiralodra**, 8**, 1 p. 42–51. (2017). doi: https://doi.org/10.31943/gemawiralodra.v8i1.45
[6] S. Joel. Compressive strength of concrete using fly ash and rice husk ash: A review Civ. Eng. J. **6**, 7 p. 1400–1410. (2020). doi: https://doi.org/10.1016/j.proeng.2014.12.190
[7] P. K. Mehta. Greening of the Concrete Industry for Sustainable Development Concr. Int. **24**, 7 p. 23–28. (2002)
[8] B. Suhendro. Toward green concrete for better sustainable environment Procedia Eng. **95**, Scescm p. 305–320. (2014). doi: https://doi.org/ 10.1016/j.proeng.2014.12.190
[9] A. Noushini. Durability of geopolymer concrete in Marine Environment. TU Delft Rep. July. (2018)
[10] T. Noguchi, F. Tomosawa, K. M. Nemati, B. M. Chiaia and A. R. Fantilli. A practical equation for the elastic modulus of concrete. ACI Struct. J. **106**, 5 p. 690–696. (2009)
[11] Y. Ballim, M. Alexander, and H. J. Beushausen. Durability of concrete. Fulton's Concr. Technol. p. 155–188. (2009)
[12] A. Basuki. Aspect of Concrete Materials At Bridge. J. Teknol. Bahan Dan Barang Tek. **3 No.2** p. 61–68. (2013)
[13] M. Niveditha and S. Koniki. Effect of Durability properties on Geopolymer concrete - A Review. E3S Web Conf. **184** p. 1–4. (2020). doi: https://doi.org/10.1051/e3sconf/202018401092
[14] J. R. Mackechnie and A. C. N. Scott. Durability properties of inorganic polymer concrete using fly ash and slag. Concr. Repair, Rehabil. Retrofit. III - Proc. 3rd Int. Conf. Concr. Repair, Rehabil. Retrofit. ICCRRR 2012 p. 168–174. (2012)