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Performance of Fly Ash Concrete with Nickel Slag Fine Aggregate in the Marine Environment

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Abstract

This research aims to assess the feasibility of the mechanical strength and the durability of the concrete containing 50% nickel slag and a combination of 15% and 30% fly ash with a water-cement ratio of 0.25 and 0.45 in a marine environment. Four types of concrete, namely OPC-sand (C) as control concrete, OPC-50GNS (S), 15FA-50GNS (F1), and 30FA-50GNS (F2) as comparison concrete, were tested with a 100×200 mm cylindrical specimen. The results showed an increase in the mechanical strength and potential resistance of the comparison concrete at the age of 28 days. While at the age of 180 days, fluctuating changes were found. The compressive strength of S concrete increased by 36.9 and 9.3% respectively, F1 concrete by 37.7% and 1.7%, F2 by 33.7% and 5.9% at ratio 0.45 and 0.25. Likewise, the value of the split tensile strength and modulus of elasticity of concrete. This result was followed by reduced porosity, sorptivity, and chloride penetration resistance as an indication of better concrete durability. Fly ash appears to have a greater positive impact on potential durability than mechanical strength at a water cement ratio of 0.25 versus 0.45. Although the chloride penetration resistance is decent, the compressive strength of concrete with a water-cement ratio of 0.45 does not qualify for application in the marine environment. In contrast, concrete with a water-cement ratio of 0.25 containing 50% nickel slag and the addition of class C fly ash up to 30% was declared suitable for application to concrete in the marine environment zone C2 according to ACI 318 -19.

Keywords: Concrete Performance; Nickel Slag; Fly Ash; Marine Environment.

1. Introduction

The increasing growth of infrastructure places concrete as a construction material in the second largest level of users of natural resources, with an estimated over 10 billion tons of concrete used annually [1]. This certainly has an impact on increasing the demand for cement and natural aggregates as the main ingredients of concrete. At the same time, environmental issues and global warming were raised to limit the use of cement and natural aggregates as the main ingredients of concrete. Continuous use of natural aggregates such as gravel, river sand, and river stones are suspected to cause damage to river ecosystems due to uncontrolled exploitation [2]. Besides that, cement production releases carbon dioxide (CO_2) emissions into the air, which are quite high at around 8% every year, with an estimate of about 1 ton of CO_2 per 1 ton of cement [3]. Therefore, research about the properties of concrete using industrial waste materials and recycling it continues to be carried out to produce environmentally friendly concrete equivalent to conventional concrete [4–9].

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In concrete design, performance is indicated by strength and durability, two very important variables. Strength without sufficient resistance will cause the concrete to not have a long service life in accordance with its service life. Buildings exposed to the marine environment with the adequate structural strength of reinforced concrete can experience degradation of their strength due to the environment and salt-induced concrete microstructural properties. Damage will occur within a certain time when salt that contains Na+, Cl-, Mg2+, and sulphate ions enters the pores of the concrete as a chemical attack. The volume, size, and distribution of pores, which are commonly known as the permeability properties of concrete, will affect the rate of damage [10, 11]. The capacity of the concrete is significantly impacted by a weak bond that forms in the concrete microstructure between the rough aggregate surface and cement paste [12-14]. The volume and porosity of the interfacial zone, which have an effect on the permeability qualities of concrete such as absorption and sorptivity, can be affected by the shape and size of aggregate grains [15]. The utilization of a number of industrial waste materials that are pozzolanic as cement additives can improve the transition zone and pore quality. The silica compound content (SiO_2), which after initial hydration reacts with calcium hydroxide (Portlandite) to produce a new calcium silicate hydrated (CSH) compound, is known to improve concrete pores. Several studies have shown that silica fume and also fly ash can reduce porosity in the transition zone and pore size [16], improve cement aggregate matrix bonding and pore structure [17] and at a high enough fly ash percentage up to 50% it can improve the shear capacity of reinforced concrete beam [18]. In addition, the function of fly ash and slag to replace the cement can minimize pores, resulting in a much smaller chloride ion migration coefficient after 90 days compared to cement concrete [19] and effectively decreasing concrete's chloride permeability compared to reducing the water-to-cement (w/c) ratio [20].

Combining industrial waste in different functions as an alternate for the cement and aggregate of the concrete is no less interesting and promising. The use of a combination of F class fly ash industry by product as cement additive with ferronickel slag as a substitute of smooth aggregate obtained resistance with ion diffusion, cement aggregate interface zone, and better pore permeability. Ferronickel slag improves the resistance of fly ash concrete to carbonation to produce better performance [21]. Fly ash serves to compensate for the disappearance of concrete strength, which is contained in the ferronickel slag, so that concrete is obtained that is comparable to the conventional type of concrete [22]. On the other side, the strong binding of the cement paste with the aggregate surface is possibly attributed to a natural aggregate's varying grain form and texture as well as the chemical interactions between the pozzolanic material and the aggregate surface. [23]. The use of a combination of class C fly ash to replace 30% of the cement and nickel slag as a substitute for 50% of the fine aggregate has so far not been carried out, especially in evaluating the feasibility of mechanical strength and durability in the marine environment. Therefore, experimental tests were carried out to evaluate the compressive strength, split tensile strength, modulus of elasticity, porosity, sorptivity, and chloride ion migration in order to obtain a concrete feasibility category at a water-cement ratio of 0.45 and 0.25.

2. Description and Concrete Mix

2.1. Research Methodology

The flowchart of the research methodology is presented in Figure 1.

2.2. Materials and Characteristic

Natural sand is extracted Lasape stream, Pinrang Regency, South Sulawesi, and crushed stone are taken from the Bili-Bili River, Gowa Regency, South Sulawesi with the aggregate properties shown in Table 1. The combined gradation analysis in terms of the maximum percentage of nickel slag was 50% as seen in Figure 2. The incorporation of aggregates produces a gradation that has the maximum of grain size about 20 mm as seen in Figure 3. Chemical admixture type sika-viscocrete 3115N superplasticizer is used as a water reducer. PC Cement Type I from Semen Bosowa, South Sulawesi. Fly ash from PLTU Punagaya in Jeneponto Regency, South Sulawesi. Nickel slag comes from PT Vale, Soroako, South Sulawesi, Indonesia. In Table 2 indicate about chemical structure of class C fly ash [24] based on ASTM C618-03 [25] and nickel slag [26].

Table 1. Characteristic of aggregate

Inspection	Sand	Slag	Stone
a. The apparent density	2.63	3.36	2.76
b. The surface dry density	2.41	3.33	2.66
c. The oven dry density	2.26	3.32	2.60
Water absorption	6.38%	0.40%	2.25%
Fineness modulus	2.08%	4.99%	6.88%

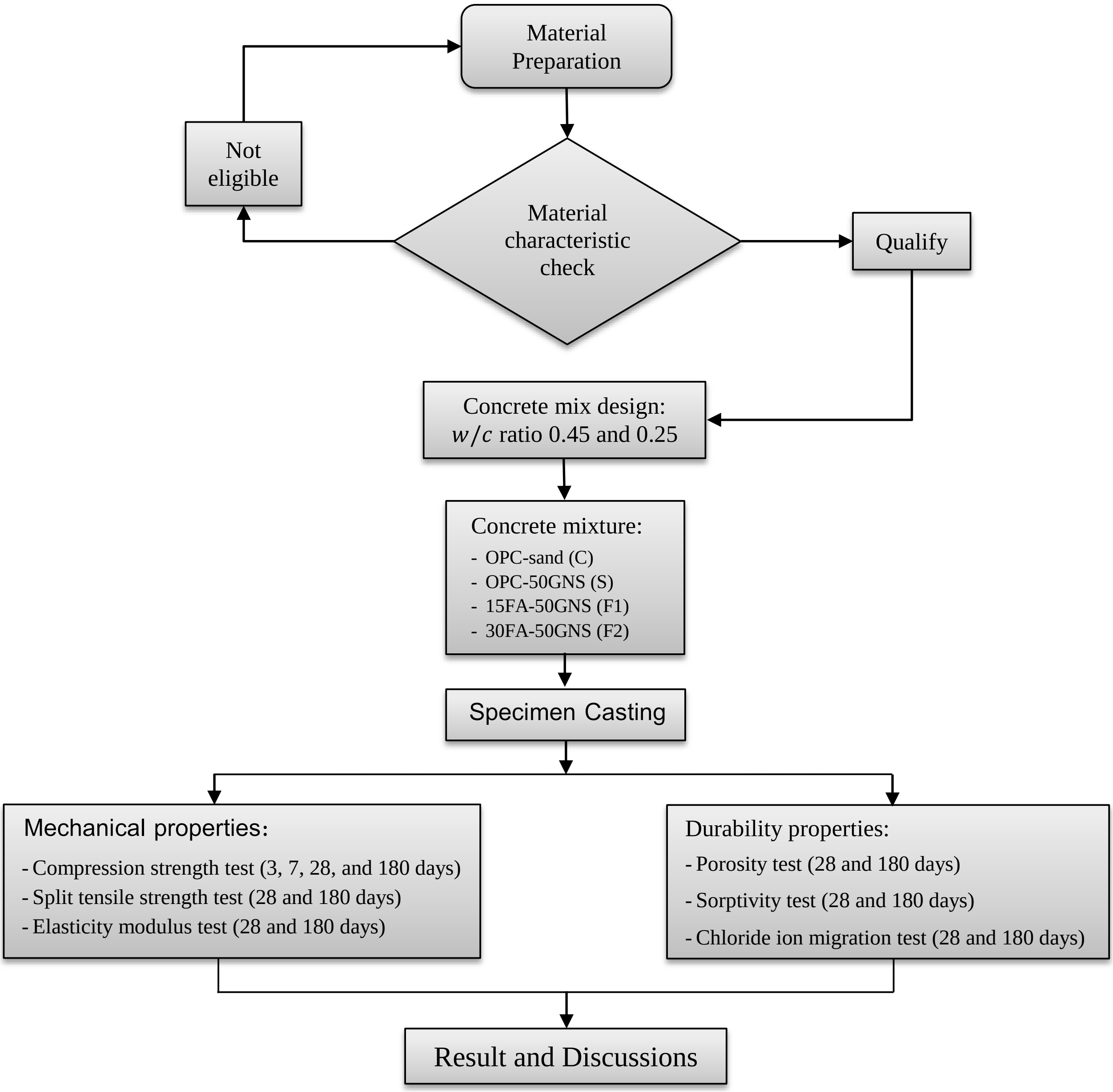


Figure 1. Flowchart of the research methodology

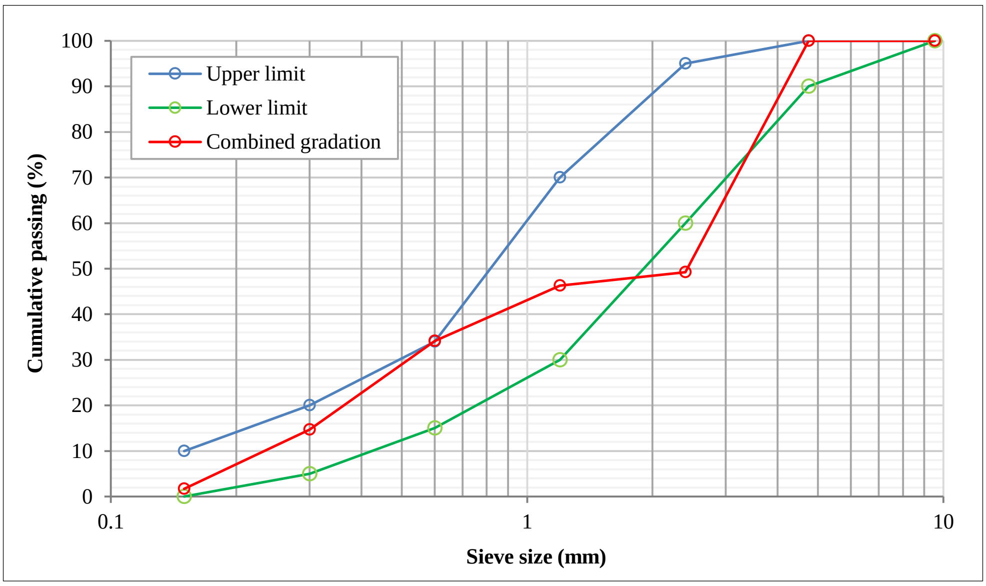


Figure 2. Fine aggregate combined gradation

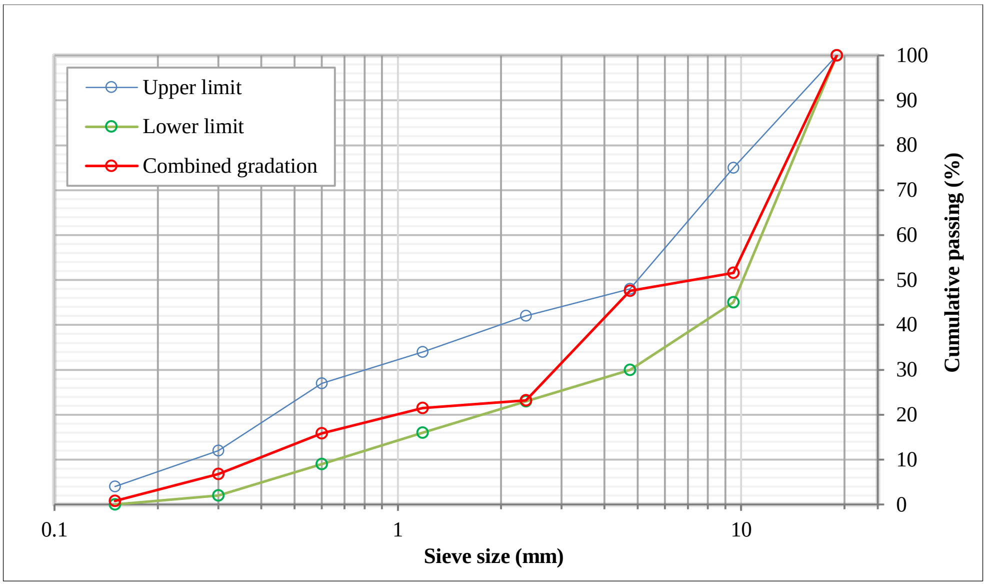


Figure 3. Aggregate combined gradation of 20 mm

Table 2. Fly ash and nickel slag's chemical compound (% by mass)

Compound of chemical	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	Na_2O	K_2O	H_2O	R.45	SO_3	loI
Fly Ash (%)	34.9	12.41	10.9	5.36	20.5	0.71	0.9	0.12	4.8	2.15	1.1
Slag Nickel (%)	46.73	21.73	3.93	-	0.88	-	-	-	-	-	-

2.3. Concrete Mixture

In Table 3, the composition of concrete mixtures with OPC cement and natural sand are shown as the control concrete (C), the concrete with 50% nickel slag (S), 15% fly ash (F1), and 30% (F2) are shown as the comparison concrete, respectively.

Table 3. Concrete Mixes (kg/m^3)

no.	Mixture of concrete	C		S		F1		F2	
	(w/c)	0.45	0.25	0.45	0.25	0.45	0.25	0.45	0.25
1	Water	175	175	175	175	175	175	175	175
2	Cement	389	700	389	700	331	595	272	490
3	Class C fly ash	-	-	-	-	41	74	82	147
4	River sand	604	514	441	375	441	375	441	375
5	Nickel slag	-	-	441	375	441	375	441	375
6	Crushed stone	1090	928	941	800	941	800	941	800
7	Viscocrete 3115N	1,17	2.1	1,17	2.10	1.17	2.10	1,17	2.10

3. Experimental Program

3.1. Concrete Mechanical and Fresh Properties

3.1.1. Slump and Compressive Strength

According to ASTM C143/143M-15a [27] the slump of fresh concrete was assessed and using SNI 1974–2011 [28] the compressive strength is tested by a UTM (Universal Testing Machine) machine that has a loading speed about 0.15 – 0.35 MPa/sec and a cylindrical test object with dimensions of (100±2) mm in diameter and (200±2) mm in height. Concrete was tested for compressive strength on days 3, 7, 28, and 180 following treatment by immersion in water drawn from the immersion bath 24 hours before. In Equation 1, the concrete's compressive strength is computed.

$$fc = {}^{P}/_{A} \tag{1}$$

where, fc is the concrete compressive strength (MPa, N/mm^2), P is compressive load maximum (N), A is cross-sectional region that bears the load (mm^2).

3.1.2. Splitting Tensile Strength

The split tensile strength of concrete was tested following the ASTM C496-2004 [29] standard with a cylinder sample having a diameter (100±2) mm and a height (200±2) mm. A uniform load is applied to the test object at the cross-midpoint sections along with the cylinder from above. Equation 2 is used to get the concrete's split tensile strength.

$$Pct = \frac{2P}{\pi LD} \quad (2)$$

where, Pct is load at split time (N), D is cylinder diameter (mm), L is cylinder length (g).

3.1.3. Elasticity Modulus of Concrete

The ASTM 469-02 [30] is referenced in the procedure for determining the concrete's modulus of elasticity. Equation 3 can be used to compute the results of the test's modulus of elasticity.

$$Ec = \frac{(S_2 - S_1)}{(\varepsilon_2 - \varepsilon_1)} \quad (3)$$

where, Ec is elasticity modulus (N/mm^2), S_2 = 40% maximum stress, or 0.4 f'c (N/mm^2), S_1 is stress at longitudinal strain ε_1 is 0.00005 dan ε_2 is longitudinal strain with stress S_2.

3.2. Durability Properties

3.2.1. Porosity of Concrete

Porosity is defined like an empty space inside the concrete that occupied by gas and liquid phases [31]. The maximum porosity value of concrete required for concrete in contact with seawater or chloride does not yet exist. However, from several previous studies, the maximum value is 15%. The concrete porosity test refers to ASTM C642-13 [32].

3.2.2. Sorptivity of Concrete

Sorptivity is the amount of capillary force exerted by the pores that cause the liquid to be drawn into the concrete. Usually, the water absorption of the concrete surface contains two phases: an initial phase, 6 hours according to the ASTM C1585 method, with a greater adsorption capacity, and a second phase with a lower absorption capacity [31]. In this study, the method of testing and calculating sorptivity refers to ASTM-C1585-13 [33].

The structure of sorptivity test is showing up to Figure 4. The relationship between the cumulative amount of water absorption and surface area, I (mm^3/mm^2 or mm) and the time t when water absorption crosses the concrete surface is found to be on a scale with the square root of the absorption time t(s), mathematically shown in Equation 4.

$$I = S.\sqrt{t} \quad (4)$$

where S is the absorption coefficient or water sorptivity (mm/s$^{1/2}$).

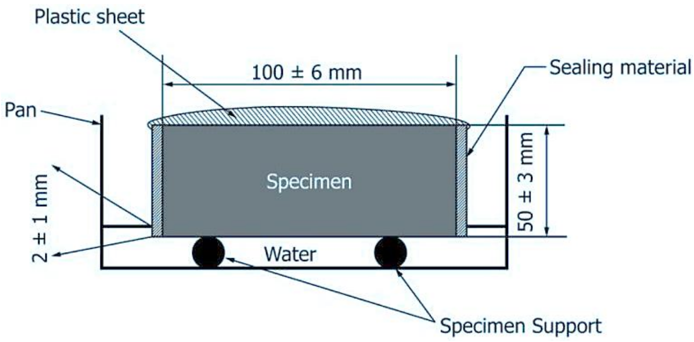


Figure 4. Concrete sorptivity testing

3.2.3. Chloride Ion Migration

Migration is the movement of ions in the electrolyte due to an external electrical action on the NaCl solution and NaOH solution which forces the ions to move. The chloride ion migration method refers to the Nordic Test Build 492 / RCMT which is the Scandinavian standard NTBuild 492 and was carried out at a voltage of 30 Volts and a NaCl concentration of 10% [34]. The test object is a concrete cylinder that has a diameter about 100 mm, a thickness (50 ± 2) mm, and a length (100 ± 2) mm, the length of the test is 6 to 96 hours, usually 24 hours. The set up of the chloride ion migration test test is shown in Figure 5 with the test steps presented in Figure 6. The criteria for the chloride penetration resistance value of concrete according to ASTM C1202 in the marine environment are shown in Table 4.

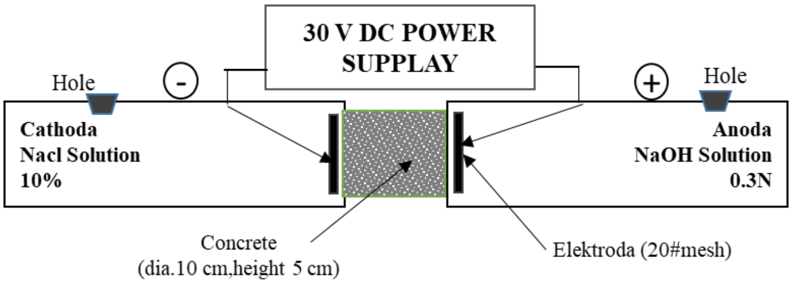


Figure 5. Setup of chloride ion migration test

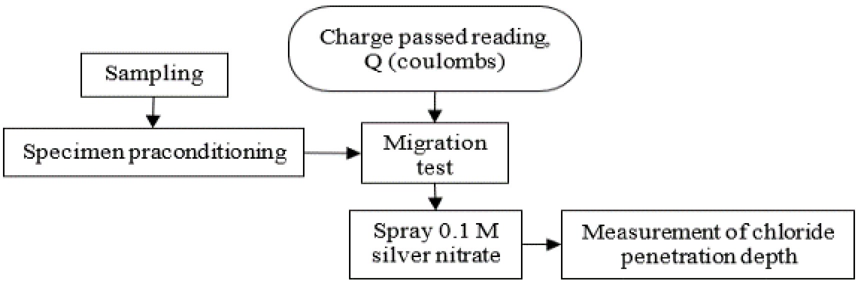


Figure 6. Flowchart of chloride ion migration test

Table 4. Rating of chloride penetration resistance

Charge Passed (coulombs)	Chloride Ion Penetrability	Suitability for marine concrete
> 4.000	High	Not suitable
2.000 - 4.000	Moderate	Not recomended
1.000 - 2.000	Low	Recomended
100 - 1.000	Very Low	Desirable
< 100	Negligible	

4. Results and Discussion

4.1. Fresh Concrete Workability

Nickel slag utilization to the concrete mixture can increase the slump of concrete, as shown in Figure 7. When fly ash is used in place of cement, the slump tends to rise. Additionally, it appears that the water-cement ratio has an impact on the slump value, which rises as the water-cement ratio rises. This illustrates how the use of fly ash, nickel slag, and high water-cement (w/c) ratio reduces the cement paste's surface area.

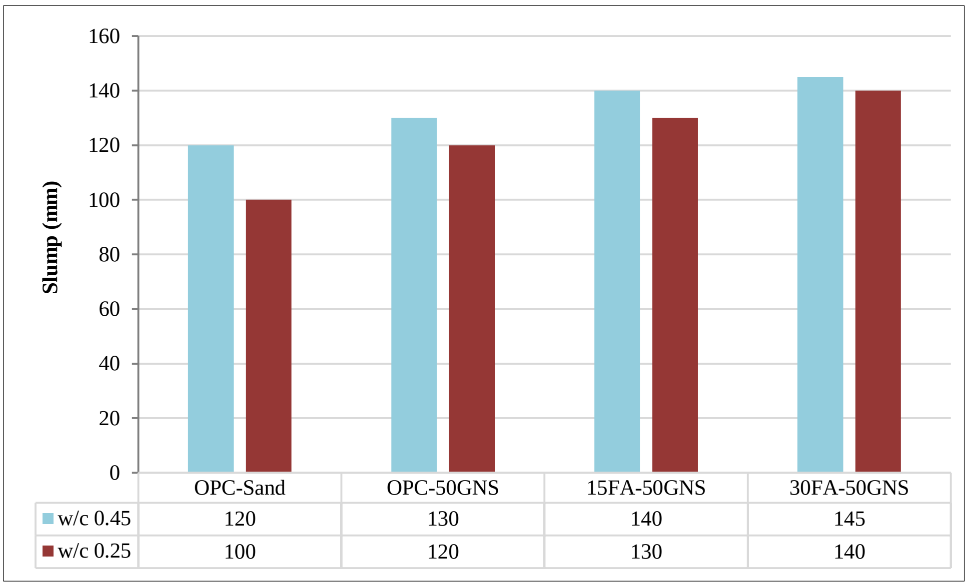
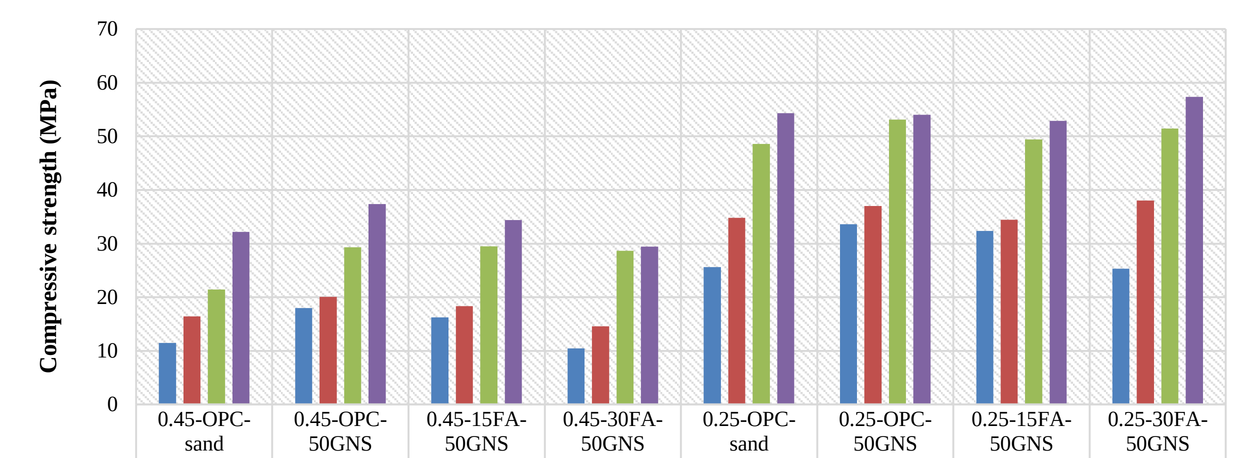


Figure 7. Slump of concrete mixture

4.2. Concrete Compressive Strength

Figure 8 demonstrates the two cement-water ratios (w/c) of 0.45 and 0.25 at the age of 28 days; S, F1, and F2 concrete have a higher compressive strength than control C concrete. The respective percentages were 36.7%, 35%, and 37.6% at a ratio of 0.45; and 12.8%, 4.6%, and 8.4% at a ratio of 0.25. After 180 days, the compressive strength of concrete F2 ratio (w/c) was slightly lower than control concrete C. However, concrete S and F1 showed higher compressive strengths at a ratio (w/c) of 0.45. Furthermore, at a ratio (w/c) of 0.25, the opposite occurs: the S and F1 concretes are slightly lower, and the F2 concrete is higher than the C control concrete. The S concrete with 50% nickel slag gave higher compressive strengths than control concrete in both water-cement ratios but was slightly different after 180 days of concrete age at a 0.25 w/c ratio with the same relative compressive strengths as control concrete. The use of fly ash seems to have a better effect on increasing the compressive strength of concrete at a ratio (w/c) of 0.45 compared to a ratio (w/c) of 0.25. The compressive strength of concrete can be increased by adding 15% fly ash at a ratio (w/c) of 0.45. However, fly ash has a significant effect on increasing the compressive strength of F2 concrete at a ratio (w/c) of 0.25 compared to a ratio (w/c) of 0.45, which results in a higher compressive strength than control concrete C. This gives an indication of limitations: the use of fly ash is only 15% to get a better compressive strength at a ratio (w/c) of 0.45 and 30% at a ratio of w/c of 0.25.

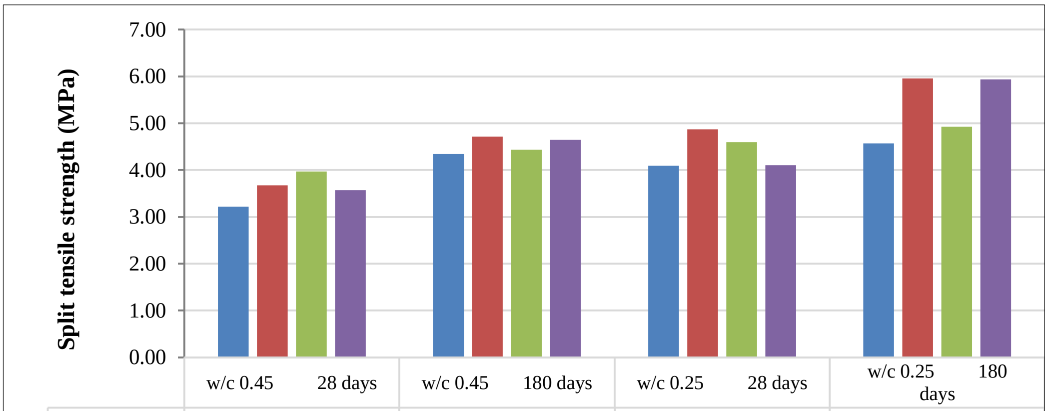


	0.45-OPC-sand	0.45-OPC-50GNS	0.45-15FA-50GNS	0.45-30FA-50GNS	0.25-OPC-sand	0.25-OPC-50GNS	0.25-15FA-50GNS	0.25-30FA-50GNS
3 days	11.48	17.99	16.24	10.46	25.62	33.64	32.36	25.35
7 days	16.40	20.06	18.33	14.60	34.80	36.99	34.46	38.05
28 days	21.42	29.33	29.49	28.64	48.60	53.14	49.45	51.46
180 days	32.19	37.39	34.39	29.44	54.34	54.00	52.90	57.33

Figure 8. Concrete compressive strength

4.3. Split Tensile Strength

Figure 9 shows the split tensile strength of concrete at ages of 28 and 180 days. The split tensile strength of concrete S, F1, and F2 was higher than that of control concrete C. It was proven that replacing sand with nickel slag 50% increased the split tensile strength of concrete. Class C fly ash appears to reduce the tensile strength of concrete with nickel slag, although this effect is not significant so that it still produces a higher split tensile strength than the control concrete.

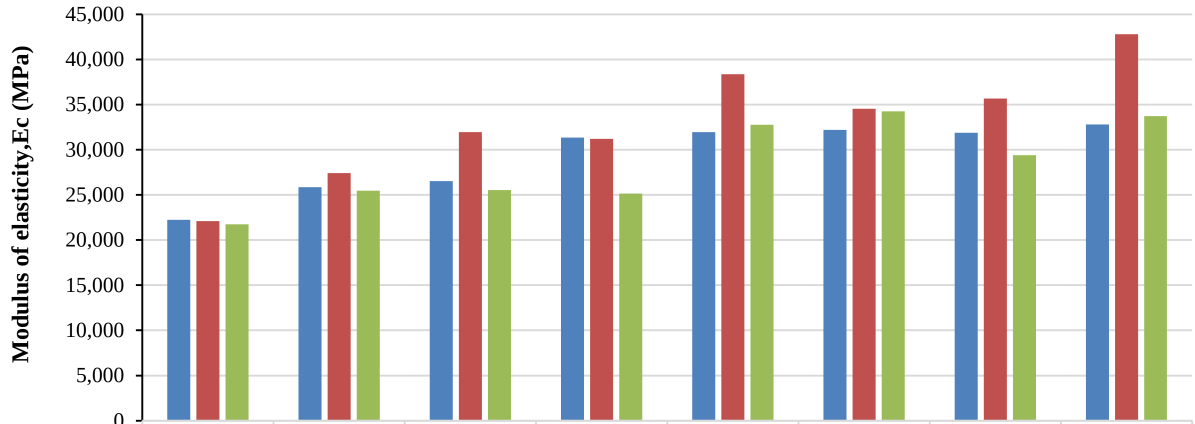


	w/c 0.45 28 days	w/c 0.45 180 days	w/c 0.25 28 days	w/c 0.25 180 days
OPC-sand	3.22	4.34	4.09	4.57
OPC-50GNS	3.68	4.71	4.87	5.96
15FA-50GNS	3.97	4.43	4.60	4.93
30FA-50GNS	3.57	4.65	4.10	5.94

Figure 9. Concrete split tensile strength

4.4. Concrete Elasticity Modulus

Figure 10 demonstrates that both ratios (w/c) 0.45 and 0.25 at the age of 28 days showing that the modulus of elasticity of the S, F1, and F2 concrete is greater than that of the control concrete C. Similar results were obtained at 180 days, with the exception of concrete S and F1 at ratio (w/c) of 0.25. Premised on. the concrete compressive strength of 28 days it can be considered that the experimental modulus of elasticity exceeds the theoretical value Ec = 4700f'c28 at ACI 318-08 The exception, F2 concrete still produces a higher modulus of elasticity, slightly different from other concretes with a ratio (w/c) of 0.25. These results indicate that nickel slag can increase concrete's elasticity modulus and the addition of class C fly ash has a tendency to increase at 28- and 180-day age.

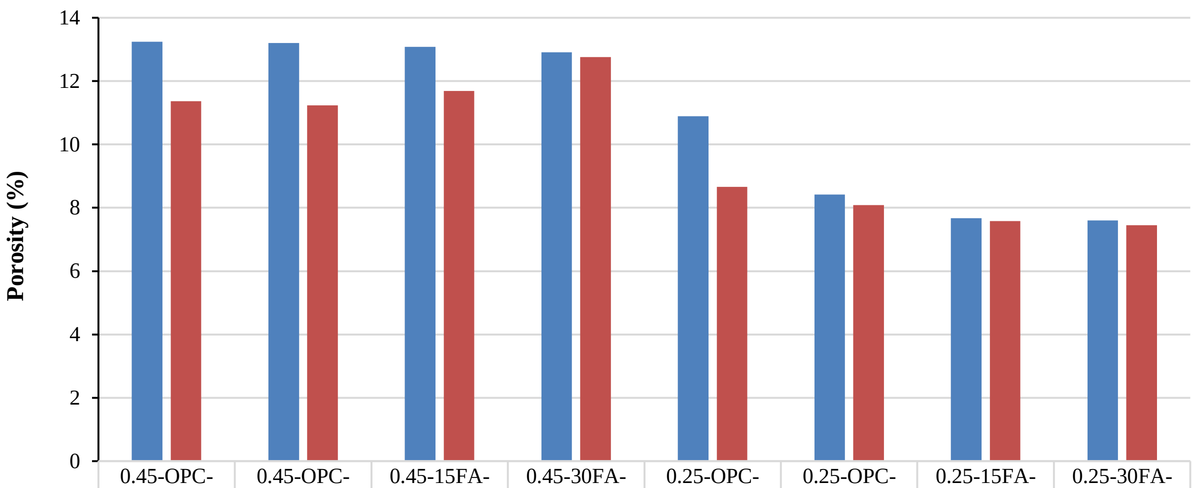


	0.45-OPC-sand	0.45-OPC-50GNS	0.45-15FA-50GNS	0.45-30FA-50GNS	0.25-OPC-sand	0.25-OPC-50GNS	0.25-15FA-50GNS	0.25-30FA-50GNS
28 days	22226	25873	26527	31355	31944	32189	31887	32814
180 days	22101	27421	31938	31215	38383	34536	35662	42795
Ec,theoritical	21752	25454	25523	25153	32767	34263	29409	33717

Figure 10. Modulus elasticity of concrete

4.5. Concrete Porosity

Figure 11 demonstrates how concrete porosity and water-cement ratio change as it ages. Concrete S, F1, and F2 demonstrated lower porosity than concrete C at a ratio (w/c) of 0.25 with percentage decreases of 22.68%, 29.57%, and 30.21%, respectively. Likewise, the ratio (w/c) of 0.45 shows the same thing with the percentages of each variation of concrete being 0.30%, 1.21%, and 2.5%. This shows that there are pozzolans in the fly ash and nickel slag, which bind the hydration product OH to produce another C-S-H being in the pores and provide the denser concrete. In addition, when the concrete ages and the ratio (w/c) is lower, the volume of cement that was substituted tends to have an impact on how much the porosity of the concrete decreases.



	0.45-OPC-sand	0.45-OPC-50GNS	0.45-15FA-50GNS	0.45-30FA-50GNS	0.25-OPC-sand	0.25-OPC-50GNS	0.25-15FA-50GNS	0.25-30FA-50GNS
28 days	13.24	13.20	13.08	12.91	10.89	8.42	7.67	7.60
180 hari	11.37	11.24	11.69	12.76	8.66	8.09	7.58	7.45

Figure 11. Porosity of concrete

4.6. Concrete Sorptivity

Figure 12 displays the concrete sorptivity calculation findings, which demonstrate that at weight ratios (w/c) of 0.25 and 0.45, S, F1, and F2 concrete produced less initial sorptivity than the control C concrete. A reduced sorptivity is also indicated by the aging of the concrete and a lesser water-to-cement ratio. Even though it differs slightly from adding fly ash to 180-day-old F1 and F2 concrete at a ratio (w/c) of 0.45. However, S, F1, and F2 concrete had a lower initial absorption than C concrete at a ratio (w/c) of 0.25. These results imply that smaller ratios of water-cement (w/c) result in decreased absorption. Fly ash has an impact on lowering absorption, as seen in concrete with a ratio (w/c) of 0.25. After 180 days, it is different with F1 and F2 concrete at the ratio of 0.45, which possess a little more sorptivity than the control concrete. The decrease in sorptivity, which was lower than control C, was seen compared with it at a ratio of 0.25. It seems that the cement content affects the pore quality and the C-S-H gel in reducing the sorptivity.

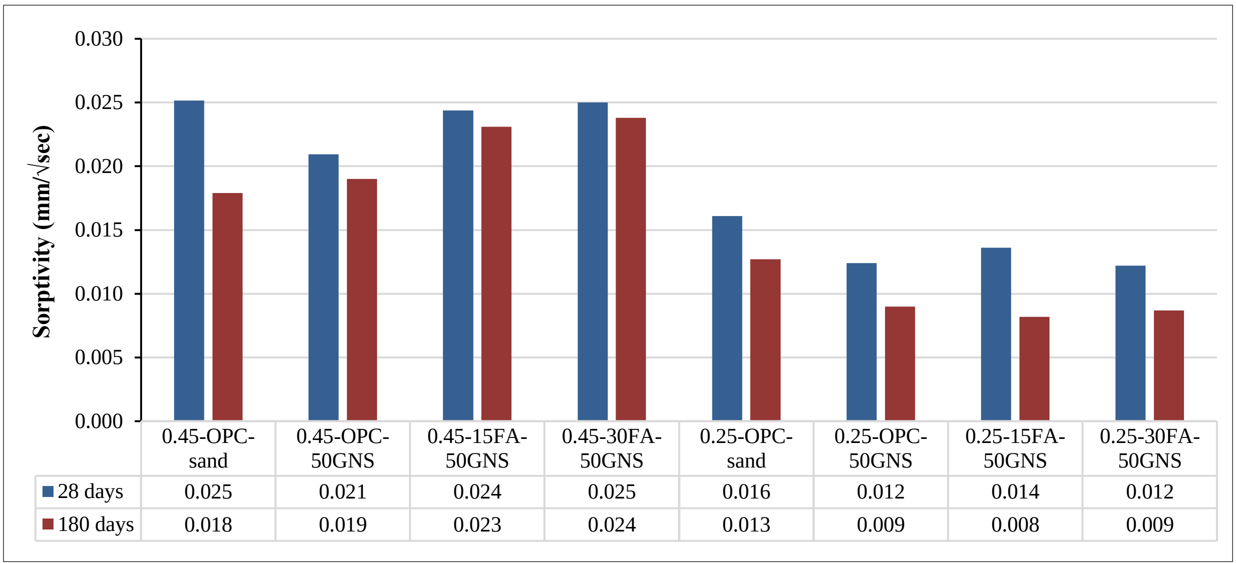


Figure 12. Sorptivity-initial of concrete

4.7. Chloride Ion Migration

When chloride ions in the seawater environment seep into the pores of the concrete to reach the reinforcement in the reinforced concrete, then one day the concrete will be damaged. The decrease in strength will occur because the protective layer of reinforcement is disturbed and the initial corrosion process begins to occur until a certain time will eventually cause the concrete cover to crack and then break (spalling).

The acceleration test for chloride ion migration into concrete using the ND Test 924 method is presented in Figure 13. The results of the calculation of the charge passed Q (coulombs) in the chloride ion migration acceleration test are shown in Figure 14. Each concrete mixture on this figure can be categorized based on chloride penetration and the level of compatibility for the marine environment, which is shown in Table 5 [35]. Table 12 shows that the concrete at a ratio (w/c) of 0.25 with an age of 28 and 180 days, namely S, F1, and F2 concrete which produced a lower penetration resistance value (coulombs) than control C concrete. The concrete at a ratio (w/c) of 0.45 is valid as well, with the exception of S concrete at 28 days, which is not advised but is acceptable after 180 days. These results indicate that nickel slag can improve chloride penetration resistance at a ratio (w/c) of 0.25 as an indicator of increased durability. The fly ash's advantages perhaps seen in the decrease in charge passed after passing 28 days age so the addition fly ash to slag nickel concrete can be recommended for concrete submerged in marine environments.

Figure 13. Chloride ion migration acceleration test

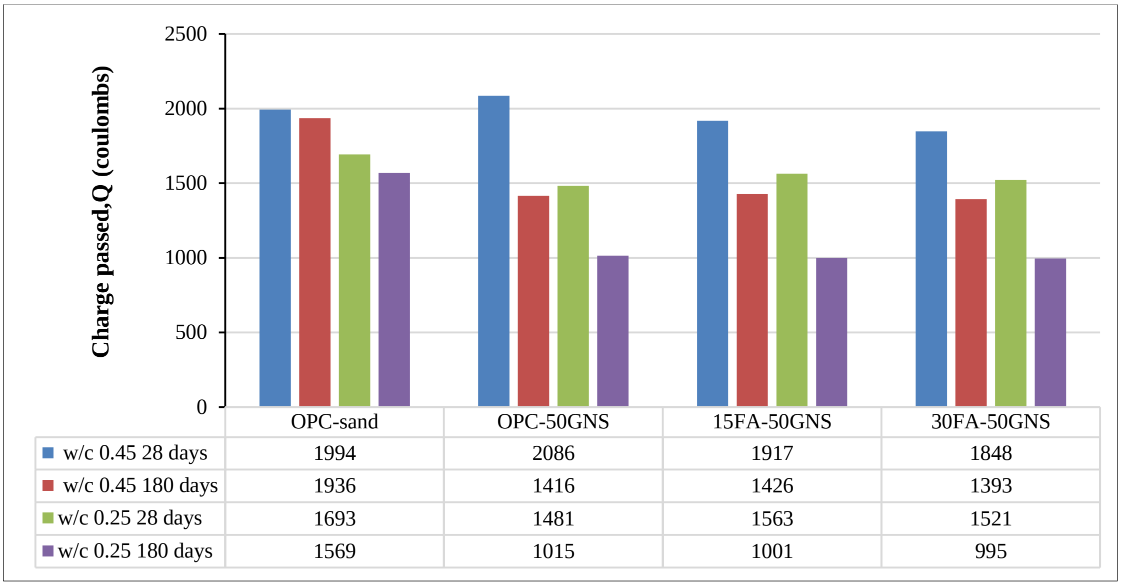


Figure 14. Charge passed of concrete (coulombs)

Table 5. Chloride ion penetrability of concrete

Concrete code	(w/c) 0.25		(w/c) 0.45	
	28 days	180 days	28 days	180 days
C	low/recommended	low/recommended	low/recommended	low/recommended
S	low/recommended	low/recommended	not recommended	low/recommended
F1	low/recommended	low/recommended	low/recommended	low/recommended
F2	low/recommended	Very low/desirable	low/recommended	low/recommended

5. Conclusions

- The mechanical strength of concrete, such as compressive strength, split tensile strength, and elasticity modulus, at a ratio (w/c) of 0.25 and 0.45 can be increased by using 50% nickel slag instead of sand. The addition of 15% C class fly ash relatively maintains the mechanical strength. Although the compressive strength was a little bit lower than the control concrete at the percentage of fly ash class C 30% aged 180 days with a ratio (w/c) of 0.45, the addition of class C fly ash in nickel slag concrete seems to be able to maintain better mechanical performance.
- The chloride penetration resistance (coulombs) was higher than the control concrete at a water-cement ratio of 0.45. However, at a ratio (w/c) of 0.25, this value decreases, which indicates that the concrete can be repaired using 50% nickel slag. Thus, the use of class C fly ash up to 30% is more dominant in reducing porosity, absorption, and chloride penetration resistance in the combination of nickel slag and fly ash, as an indicator of higher concrete resistance, at a water-cement ratio of 0.25 compared with 0.45 at 28 days.
- The use of 50% nickel slag and combination with C class fly ash of 30% can be applied to concrete in a seawater environment with a ratio (w/c) of 0.25 with better performance than conventional concrete.

6. Declarations

6.1. Author Contributions

Conceptualization, S.B.A.; methodology, S.B.A.; software, S.B.A.; validation, R.I., S.H.A and A.A.; formal analysis, S.B.A.; investigation, S.B.A.; resources, S.B.A.; data curation, S.B.A.; writing—original draft preparation, S.B.A.; writing—review and editing, S.B.A.; visualization, S.B.A.; supervision, R.I., S.H.A. and A.A.; project administration, S.B.A.; funding acquisition, S.B.A. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available in the article.

6.3. Funding

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6.5. Conflicts of Interest

The authors declare no conflict of interest.

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