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The Effectiveness of Fly Ash as a Substitute of Cement For Marine Concrete

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Abstract

The purpose of this research is to know the effectiveness of fly ash waste in marine concrete related to the average compressive strength to be used as a substitute for cement. The test is done for concrete base material, namely: coarse aggregate (gravel), fine aggregate (sand), fly ash, cement (PC = Portland Cement), water and additional material (superplasticizer). 10 cylinders were given each treatment with (0 %, 10 %, 20 %, 25 %) percentage of fly ash addition. The samples then soaked for 26 days in seawater. At 28th day, the sample was subjected to a compression test. Based on the results of analysis and discussion, then obtained: (1) The use of 10% fly ash amount will produce the biggest compressive strength $fc - mean =$ 65.84 MPa; (2) When compared with the average compressive strength, the sample without using fly ash (0 %) has compressive power 62.02 MPa and 6.16 % increase in average compressive strength on the addition of 10 % fly ash 65.84 MPa, but in addition to 20 % fly ash there was a decrease of 9.13 % (56.36 MPa) and in addition of 25 % fly ash the average compressive strength decrease to 22.49 % (48.07 MPa).

Keywords: Fly Ash; Marine Concrete; Compressive Strength Value; Cement's Substitute.

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1. Introduction

At this time, humans are never far from concrete buildings. In the field of civil engineering, concrete structures are used to construct foundations, columns, beams, plates or shell plates. All structures in civil engineering will use concrete, at least in the foundation work [1]. The term 'Marine Concrete' (MC) is reserved for concrete materials for structures in coastal areas with extreme conditions [2]. Many civil engineering buildings in the suburbs, for example, docks and retaining walls of sea waves. It is hoped that the utilization of fly ash waste will be able to answer the demand of "market" (which represent the world of construction) for ready-mix concrete demand for the more economical price but with maintained quality [3]. The purpose of this research is to know how many percentages of fly ash waste usage as the most optimum cement's substitute to produce higher compressive strength in the marine concrete making. From this research, it can be known how much the effectiveness of the use of fly ash as a substitute for cement from marine concrete, in view of the compressive strength of the concrete.

2. Literature Review

Concrete is made with coarse aggregate, fine aggregate (sand), Portland cement, water and, selected admixtures such as fly ash, air-entraining agents, water-reducing agents, retarders, etc. [4]. Each constituent affects the characteristics of the concrete and must be controlled in accordance with the desired composition and quantity of concrete if the final product is within the limits of uniformity, workability, and strength desired [5]. Typically, in concrete, rough aggregates and sand will occupy about 80 percent of the total volume of the final mixture. The amount of cement depends mainly on the volume of aggregates in the concrete mix [6]. Specifications for the fine aggregate fraction of concrete have been

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developed based on experience with natural sand for years, as it is the only type used. The clean natural sand has spherical particles that give concrete good working ability without the excessive amount of water or cement. When fine minerals are contained in natural sand, the particles are often formed clay or mud particles that may be "disturbing" particles [7]. This results in undesirable effects on water requirements, workability, and strength characteristics of concrete mixtures [8].

The durability of concrete is generally regarded as its ability to withstand environmental influences while performing the desired function [9]. In offshore or marine environments, concrete may be subject to wetting and drying, freezing and liquefaction, abrasion by ice and other waste, chemical attack or mineral depletion by the water present, salt accumulation, and attack by marine organisms [10]. In accordance with its function, marine concrete (MC) is a material that meets the criteria of high-performance concrete (HPC) that is structurally strong, resistant to chemical attacks, and resistant to the impact of physical events. As a basic feasibility study of a structure, HPC is defined as a concrete material that meets the following criteria [11]:

Characteristics of strength

- 4 days, $f'c \geqslant$ 2500 psi → (17.5 MPa)
- 24 days, $f'c \geqslant$ 5000 psi → (35 MPa)
- 28 days, $f'c \geqslant$ 10000 psi → (70 MPa)
- Have durability factor > 80% after 300 cycles (freezing and thanking)
- Has a water factor of cement ≤ 0.35

From these explanations, it can be seen that HPC has requirements that are totally required for marine structures, ie high strength, high durability and high hardness. High-performance concrete is a concrete mixture, which possesses high durability and high strength when compared to conventional concrete [12]. This concrete contains one or more of cementitious materials such as fly ash, Silica fume or ground granulated blast furnace slag and usually a superplasticizer [13]. The term 'high performance' is somewhat pretentious because the essential feature of this concrete is that its ingredients and proportions are specifically chosen so as to have particularly appropriate properties for the expected use of the structure such as high strength and low permeability. Hence HPC is not a special type of concrete. It comprises of the same materials as that of the conventional cement concrete.

Cement is a material of fine powder that has adhesive or cohesive properties, which is a material used as a binder. A cement is a binder, a substance used in construction that sets, hardens and adheres to other materials, binding them together [14]. Cement is seldom used solely but is used to bind sand and gravel (aggregate) together. Cement is used with fine aggregate to produce mortar for masonry, or with sand and gravel aggregates to produce concrete [15]. Cement used in construction are usually inorganic and can be characterized as being either hydraulic or non-hydraulic, depending upon the ability of the cement to set in the presence of water [16]. In its definition, Portland cement is hydraulic cement produced by smoothing the clinker whose base material comprises hydraulic calcium silicates [17]. Cement is a binding material for incorporating fine aggregate and coarse aqueous aggregates for the occurrence of reactions caused by the cement content. The grains of cement will be filling and binding together so as to unite the pebbles and sand. The cement commonly used for concrete is called Portland cement because after the hardening process takes place, the structure is similar to Portland stone in England. We know that cement is the most expensive material of concrete making, therefore it must meet the following requirements [17] as follows:

1. Cement should be gray.
2. It should not contain water.
3. Not mixed with loose lime.
4. Not clot because of air and water.
5. The cement grains are very fine and pass 200 mesh screen.
6. The cement used in this research is Portland Cement undre the brand of Semen Gresik Indonesia Type 1.
7. The reaction between cement and water is divided into two distinct periods, i.e: 1) The binding period is the transition from the plastic state to the harsh state of the initial binding period (from the foundry up to 1 hour) and the final binding period (from the end of the initial binding period up to 3 hours); and 2) Hardening period is the addition of strength after binding is complete. The most important period is the initial period of binding, ie when the commencement of cement becomes stiff, which should not occur less than an hour.

The complete composition of Portland cement is presented in the following table:

Tabel 1. The Composition of Portland Cement

Oxide	Composition (%)	Oxide	Composition (%)
CaO	60 – 67	$Na_2O + K_2O$	0.5 – 1.3
SiO_2	17 - 25	TiO_2	0.1 – 0.4
Al_2O_3	3 - 8	P_2O_3	0.1 – 0.2
Fe_2O_3	0.5 - 6	SO_3	1 -3
MgO	0.1 – 5.5	-	-

Fly ash is a material derived from unused coal burning waste [18]. Fly ash is a coal combustion product composed of fine particles that are driven out of the boiler with the flue gases. Fly ash is generally captured by electrostatic precipitators or other particle filtration equipment before the flue gases reach the chimneys. Fly ash includes substantial amounts of silicon dioxide (SiO_2) (both amorphous and crystalline), aluminum oxide (Al_2O_3) and calcium oxide (CaO) [19]. Burning coal is mostly used in steam power plants, where the waste product from the plant reaches 1 million tons per year. But, most of the chemical composition of light ash depends on the type of coal used. Fly ash can be divided into 3 types [20], namely:

1. C-Class. Fly ash containing CaO above 10% produced from lignite burning or sub-bituminous coal (young coal).
   a. Level of ($SiO_2 + Al_2O_3 + Fe_2O_3$) > 50 %
   b. CaO levels reach 10%
2. F-Class. Fly ash containing CaO is less than 10% resulting from the burning of anthracite or bitumen coal.
   a. Level of ($SiO_2 + Al_2O_3 + Fe_2O_3$) > 70 %
   b. Level of CaO < 5%
3. N-Class. Natural pozzolans or combustion products that can be classified include diatomic, opaline and shales, tuff and volcanic ash, which can be processed through combustion or not through combustion.

The use of fly ash in concrete mixtures has many advantages, namely [18]:

a. On fresh concrete

1. Subtle smoothness and shape of fly ash particles can improve workability.
2. Reduce the occurrence of bleeding and segregation.

b. On hard concrete

1. The contribution of the increased compressive strength of concrete at an age after 52 days.
2. Increasing the durability of concrete.
3. Increasing the density of concrete.
4. Reduce the occurrence of concrete shrinkage.

Sand is a natural aggregate that comes from volcanic eruptions, rivers, deep soil and beaches. Sand is a naturally occurring granular material composed of finely divided rock and mineral particles [21]. It is defined by size, being finer than gravel and coarser than silt. Sand can also refer to a textural class of soil or soil type; i.e., a soil containing more than 85 percent sand-sized particles by mass [22]. Therefore, sand can be classified into three types, namely sand digging, sea sand and river sand. According to SNI-03-1750-1990 [23] on the quality and method of aggregate test, the mention of good fine aggregate requirements is as follows:

1. The fine aggregate shall consist of sharp and hard grains with a hardness index < 2.2.
2. The eternal properties when tested with a saturated solution of sulfate salt are as follows:
   a. If sodium sulfate is used, the crushed part is a maximum of 12%.
   b. If magnesium sulfate is used, the crushed part is a maximum of 10%.
3. It should not contain more than 5% sludge and if the sand contains more than 5% sludge then the sand should be washed.
4. Sand should not contain too much organic matter, which must be proven by color experiments from Abrams-Harder with a saturated solution of 3% NaOH.
5. The large grain arrangement of sand has a fineness modulus between 2.5 to 3.2 and comprises various grains.
6. For concrete with a high degree of durability, the sand reaction to alkali should be negative.
7. Sea sand shall not be used as fine aggregate for all concrete grades except by guidance from a recognized building material government institution.
8. Sand used this research comes from Malang named Kalimanjing Sand.

Pebble is a clast of rock with a particle size of 2 to 64 millimeters based on the Krumbein phi scale of sedimentology [24]. Pebbles are generally considered larger than granules (2 to 4 millimeters diameter) and smaller than cobbles (64 to 256 millimeters diameter). A rock made predominantly of pebbles is termed a conglomerate [25]. Pebbles are coarse aggregates derived from broken rocks or laps of natural rocks, mentioned in terms of good aggregate requirements in accordance with SNI 03-1750-1990 [23] on quality and aggregate test methods such as the following:

1. The maximum nominal aggregate size of 20 mm or 25 mm to make concrete up to 62.1 Mpa and 10 mm or 15 mm for concrete loaded over 62.1 Mpa.
2. Crude aggregates should have rough and hard surfaces without any cavities.

3. It should not contain more than 5 % sludge and if the aggregate contains more than 5 % sludge then the sand should be washed.
4. Aggregates should not contain too much organic material, as it affects when gravel binds to other aggregates.
5. Large arrangement of grains must be diverse and have irregular shapes.
6. The aggregate must be solid because it indicates a little cavity inside the aggregate to reduce water absorption.
7. The coarse aggregate used in this research is the breaking stone from Pasuruan residence.

Superplasticizers, also known as high range water reducers, are chemical admixtures used where well-dispersed particle suspension is required [26]. These polymers are used as dispersants to avoid particle segregation (gravel, coarse and fine sands), and to improve the flow characteristics (rheology) of suspensions such as in concrete applications. Their addition to concrete or mortar allows the reduction of the water to cement ratio, not affecting the workability of the mixture, and enables the production of self-consolidating concrete and high-performance concrete [27]. This effect drastically improves the performance of the hardening fresh paste. The strength of concrete increases when the water to cement ratio decreases [28]. Superplasticizer is a chemical additive that can increase the tear without adding water, so the concrete work can be easier to do. Even the amount of water can be reduced until the water-cement ratio decreases, the shrinkage loss also decreases and the quality of the concrete can be increased. This chemical additive according to Mailvaganam and Rixom [29], "The Chemical Admixtures for Concrete" is categorized into seven types, namely:

- Type A - Water-reducing admixtures; serves to reduce the amount of water mixing for a certain consistency.
- Type B - Retarding admixtures; serves to inhibit the binding time of concrete.
- Type C - Accelerating admixtures; Serves to accelerate the time of concrete binding and the development of the initial strength of the concrete.
- Type D - Water-reducing and Retarding admixtures; double function to reduce the amount of water and inhibit the time of concrete binding.
- Type E - Water-reducing and Accelerating admixtures; double function to reduce the amount of water and accelerate the binding time of the concrete.
- Type F - Water-reducing high range admixtures; serves to reduce water and produce concrete with a certain consistency of more than 12 %.
- Type G - Water-reducing high range and Retarding admixtures; serves to reduce water by more than 12% to produce concrete with a certain consistency and inhibit concrete binding.

The material for structures in the marine environment must fundamentally meet the HPC criteria with particular attention to the aspect of durability. The material requirements relating to HPCs for structures in extreme environments must fundamentally focus on concrete 'permeability' as long-term durability parameters. Clearly, the following three aspects must be taken fully in order to make a concrete construction for such structures:

- Material selection and composition arrangement
- Implementation in the field including curing and maintenance
- Prevention of possible widening of pre-existing microcrack.

Basically, the concrete mixture consists of four main components, namely cement, water, fine aggregate and coarse aggregates. However, the development of material technology in this modern era produces the fifth component as an additional element (admixtures) that is economically able to reduce the cost of the final product while affecting its behavior in service time. The concrete composition of the marine structure provides three options for cement paste (as a binder) in which the admixture plays a partial substitution of cement, ie:

- Portland cement only
- Portland cement plus fly ash or blast furnace with 75: 25 volume ratio
- Portland cement plus fly ash or blast furnace and fused with a volume ratio of 75: 15: 10

Several previous research references on cement and fly ash mixtures on concrete have been performed. A study conducted by Sugiharti in 2010 [30] discussed the optimization of cement and light ash mixes on high-quality concrete. From the research, it can be concluded that the optimum amount of fly ash reached from some concrete quality at 28 days old is 30.71 %; 15.86 %; 9.23 % of the weight of cement in the quality of the concrete is as big as (f_c = 45 Mpa); (fc = 50 Mpa); (f_c = 55 Mpa); where type of cement used in this experiment is Portland type I cement-OPC (Ordinary Portland Cement). An earlier study by Kumar in 1992 [31] discusses the influence of water quality on the strength of plain and blended cement concretes in marine environments. Thus research used fly ash substitution with amount = 0%; 10 %; 20 % and 30 % by weight of cement, using several types of cement type I, II, V and F-type fly ash species where fine aggregate and coarse aggregate and WCF (Water Cement Factor) are fixed variables. In the test, three treatments were made, namely: (1) the specimen was made and immersed in fresh water; (2) the test specimen is made and immersed by sea water; and (3) the specimen is made with fresh water and soaked in sea water. The test was performed after 365 day sample for type I treatment condition 1. From the observation result, the addition of fly ash 20 % had the highest strength.

3. Methodology

This research was conducted in the laboratory of Building Materials and Structural Laboratory of Civil Engineering, Department of Malang State Polytechnic with the duration of the implementation started in August - September 2011. The materials used for the research are:

1. Portland Cement Type I, with "Semen Gresik" brand.
2. The fine aggregate used is natural sand from Lumajang area.
3. The coarse aggregate of broken stone used is Batu Kali Welang Ampuh (BKWA) from the village of Waleng Pasuruan produced by CV ETIKA.
4. Fly ash obtained from PLTU (steam power plant) of Paiton through PT. Merak Concrete in Malang

The tools used for this research are:

1. A set of sieves.
2. Scales
3. Measuring cup for water measurement
4. Pyknometer to find the specific gravity of sand with a capacity of 500 grams.
5. Oven.
6. Cylindrical concrete mold with 15 cm diameter and 30 cm side length.
7. Concrete stirring machine.
8. The slump cone test equipment.
9. Soaking tub for curing on the concrete test object.
10. Compressometer with 2000kN capacity used to test the compressive strength of the specimen.

Figure 1. Marine Concrete Making Process

The design of concrete mix according to ACI (American Concrete Institute) ACI 211. 1-91 suggests a way of designing the mixture which shows the economic value, the available materials, workability, durability and the desired strength. The way ACI sees the fact that at a certain maximum aggregate size and the amount of water per cubic meter the mortar determines the level of consistency or the slump of the concrete. Broadly speaking, the concrete mix concrete planning step is as follows:

a. Determine or select a suitable slump value for a concrete construction designed according to Table 2.

Table 2. Slump value (mm)

Concrete Use	Max	Min
Foundation and/or foundation walls that use frames	75	25
Frameless foundation, caisson, and sub-structural walls	75	25
Beams and walls reinforced	100	25
Building column	100	25
Slabs and pavement	75	25
Massive concrete or mass	75	25

a. Determine the maximum aggregate grain size (can be determined based on the analysis of grain/grain aggregate gradation or reinforcement detail).

b. Estimate the amount of stirring water and the amount of air content for 1 m^3 of concrete, using Table 3.

Table 3. Estimated amount of stirring water and amount of air content for different maximum slump value and size of aggregate

Slamp (mm)	The amount of Water (per kg / m3 of concrete) for the							
	9.5	12.5	19	25	37.5	50	75	150
Concrete Without Air content								
25 - 50	207	199	190	179	166	154	130	113
75 - 100	228	216	205	193	181	169	145	124
150 - 175	243	228	216	202	190	178	160	*
Estimated stored air content (%)	3	2.5	2	1.5	1	0.5	0.3	0.2
Concrete with air content (using AEA)								
25 - 50	181	175	168	160	150	142	122	107
75 - 100	202	193	184	175	165	157	133	119
150 - 175	216	205	197	184	174	166	154	*
Average recommended air amount (%) for weather impact rate								
Mild weather	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0
Medium weather	6.0	5.5	5.0	4.5	4.5	4.0	3.5	3.0
Dangerous and extreme weather	7.5	7.0	6.0	6.0	5.5	5.0	4.5	4.0

Table 3a. Relationship between Water Cement Factor (WCF) and Strong Press Concrete (Cylinder Ø15 cm, height 30 cm)

28 days Compressive Strength (Mpa)	Comparison of Water / Cement or WCF in weight	
	Airless Concrete (without AEA)	Concrete with Air Level
40	0.42	*
35	0.47	0.39
30	0.54	0.45
25	0.61	0.52
20	0.69	0.60
15	0.79	0.70

Table 3b. Maximum WCF allowed for concrete in extreme weather

Structure Type	The structure which always wet or often wet and the structures are affected by the dry and frosty climate	Structures related to seawater or sulfate
Concrete thin cross section (railing, turban, threshold, goal, and ornament work) and cross section with concrete cover less than 5 mm above its reinforcement	0.45	0.40
Other concrete structures	0.50	0.45

c. Estimate the amount of cement used. With the estimated moisture content of Table 3 and WCF values from Table 3.a and 3.b, it can be calculated the amount of cement required.

d. Estimated number of coarse aggregates. The number of dry crude aggregates as listed in Table 4 is multiplied by the weight of the volume of solid powder in kg/m^3.

Table 4. The approximate need for gross aggregate volume for each unit of concrete volume based on the maximum aggregate size and the fine modulus of sand (m^3)

Aggregate Max Size (mm)	Modulus Fine Sand			
	2.4	2.6	2.8	3.0
9.5	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
19	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
37.5	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
75	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

e. Estimated number of aggregate subtle

To determine the amount of fresh concrete per m3 then used the following equation:

$$U_M = 10.G_a (100 - A) + C_M (1 - G_a/G_c) - W_M (G_a - 1) \tag{1}$$

Where:

U_M = Fresh concrete weight (kg/m^3)

G_a = Coarse-aggregate and coarse-average aggregate type weights in the state of the DSS (dry saturated surface).

G_c = The weight of Portland cement type, the average used 3.15

A = Air content (%)

W_M = The amount of stirred water required (kg/m^3)

C_M = Number of Portland Cement Required (kg/m^3)

The coarse and fine aggregates are separated according to the grain size of the sieve and then washed to remove the plates. To keep the mixture elastic at the time of variation with the 11-cylindrical stone broken it is used admixture in the form of "Plasticizer silica-crete" during the mixing process. The results of the following concrete mixture planning will be corrected according to the fine aggregate condition data and the coarse aggregate.

Table 5. Concrete Mixture Planning Results

Number of Sieves	Combined Space (slip %)	Ideal (%)	Particle stuck between sieves (%)	Rough Aggregate Composition (%)
19	95 - 100	95.0	5.0	5
12.5	85 - 92	90.0	10.0	10
9.5	80 – 85	81.5	18.5	18.5
4.75	20 – 60	40.0	26.5	26.5
2.36	22 – 42	32	8.0	
1.18	15 - 35	25	7.0	
0.60	8 - 28	18	7.0	Total Amount = 60% Rough Aggregate and = 40 % Fine Aggregate
0.30	4 - 12	8	10	
0.15	2 - 6	4	4	
Pan	0	0	4	

This research use four treatment that are:

1. Material composition for 11 cylinders with 0% fly ash

2. Material composition for 11 cylinders with 10% fly ash
3. Material composition for 11 cylinders with 20% fly ash
4. Material composition for 11 cylinders with 25% fly ash

4. Results and Discussion

To obtain the perfect results of the study then the needle reading on the test machine must be thoroughly accurate and all the cylinders are weighed with a weight-sensitive device in grams.

Table 7. Average Concrete Compression Strength According to the Addition of Fly Ash

No.	**Fly Ash = 0 %**		**Fly Ash = 10 %**		**Fly Ash = 20 %**		**Fly Ash = 25 %**	
	Compression ($N \times 10^3$)	f_c' = (MPa)	Compression ($N \times 10^3$)	f_c' = (MPa)	Compression ($N \times 10^3$)	f_c' = (MPa)	Compression ($N \times 10^3$)	f_c' = (MPa)
1	1190	67.34	1270	71.87	920	52.06	865	48.95
2	1210	68.47	1140	64.51	1080	61.12	850	48.10
3	1200	67.91	970	54.89	1165	65.93	845	47.82
4	1020	57.72	1285	72.72	1035	58.57	875	49.51
5	990	56.02	950	53.76	1010	57.15	795	44.99
6	1120	63.38	1220	69.04	955	54.04	910	51.50
7	950	53.76	1250	70.74	910	51.50	820	46.40
8	1180	66.77	1280	72.43	1010	57.15	805	45.55
9	1140	64.51	1110	62.81	875	49.51	870	49.23
10	960	54.32	1160	65.64	1000	56.59	860	48.67
	f'_{c-mean}	= 62.02	f'_{c-mean}	=65.84	f'_{c-mean}	= 56.36	f'_{c-mean}	= 48.07

The following figure describes the compressive strength calculation results of each treatment.

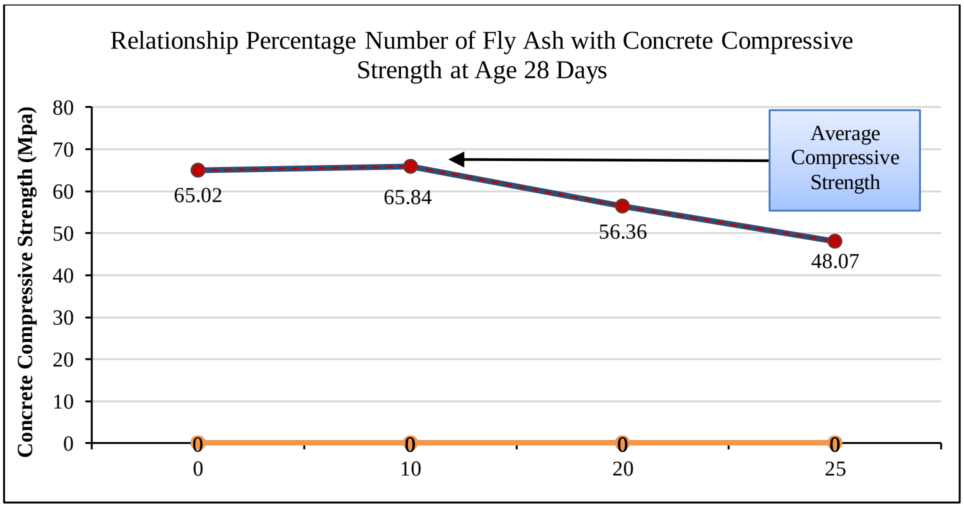

Figure 2. Relationship Percentage Number of Fly Ash with Concrete Compressive Strength at Age 28 Days

The figure above shows the number of fly ash relationship curve with the compressive strength of the average concrete at the age of 28 days described in the form of polynomial regression. The figure shows that the use of 10 % fly ash amount will produce the largest compressive strength f'_{c-mean} = 65.84 MPa. The large decrease in compressive strength of the percentage added to fly ash can be seen in the following table:

Table 8. Decrease and increase the strength of compressive strength on the addition of fly ash percentage

Compressive Strength	**Based on Fly Ash Mix (%)**		
	10%	20%	25%
Decrease/Increase	+ 6.16%	- 9.13%	- 22.49%

5. Conclusion

Based on the results of the analysis and discussion, the conclusions can be drawn from the research on the Use of Fly Ash as a Substitute of Cement for Marine Concrete in terms of Concrete Compressive Strength is the use of fly ash amount of 10% will produce the largest compressive strength = 65.84 MPa. Compared to the average compressive strength without the use of fly ash, that 6.16% is an increase in average compressive strength in the addition of 10% fly ash, but in the use of 20% there is a decrease of 9.13% and in the use of 25% there is a decrease average compressive strength to 22.49%. The selection of material quality, procedures in the process of execution and treatment of test specimens after casting it is recommended that strict supervision is necessary in order to generate the maximum compressive strength of the field. We recommend that the fly ash used is actually tested for its chemical content more thoroughly since the multiple sources of different fly ash will produce different chemical content as well. So that will be seen the suitability of the chemical content of fly ash with chemical content of cement.

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