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THE EFFECT OF FLY ASH AS A CEMENT SUBSTITUTION MATERIAL ON THE ELASTIC MODULUS OF CONCRETE

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ABSTRACT

Fly Ash and Bottom Ash are the residue from the coal combustion process originating from the combustion furnace. Fly ash waste will increase every year along with the operation of industries that use coal fuel. Fly ash waste can cause environmental pollution that is quite harmful to human life. On the other hand, the fly ash-forming elements have similarities with the cement-forming elements as a binder in the manufacture of concrete. In this study, fly ash was used as a partial cement substitute for cement as a binder in the manufacture of high-strength concrete. The research objective was to determine the compressive stresses and strains of high-strength concrete with fly ash substitution variations of 10%, 15%, 20%, 25%, and 30%. The results of the compressive strength test of concrete with variations in the percentage of fly ash successively from 0%, 10%, 15%, 20%, 25%, 30% showed that the increase in compressive strength was achieved at a percentage of 20% fly ash, namely 53.376 MPa. The results of the analysis show that the relationship between the elastic modulus of concrete and fly ash is directly proportional to the quality value of the concrete.

Keywords: Fly Ash, Elastic Modulus, Compression Strength, Split Tensile Strength, Stress and Strain

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1. INTRODUCTION

Fly Ash and Bottom Ash are the residue from the coal combustion process originating from the combustion furnace. Fly ash waste will increase every year along with the operation of industries that use coal fuel. Fly ash waste can cause environmental pollution that is quite harmful to human life. On the other hand, the fly ash-forming elements have similarities with the cement-forming elements as a binder in the manufacture of concrete. In this study, fly ash was used as a partial cement substitute for cement as a binder in the manufacture of high-strength concrete.

The research objective was to determine the compressive stresses and strains of high-strength concrete with fly ash substitution variations of 10%, 15%, 20%, 25%, and 30%.

The waste material used for burning coal ash (fly ash) comes from coal combustion waste from the steam power plant of Semen Tonasa Enterprise is located in Pangkajena Regency, South Sulawesi Province. The cement used in this study was Portland Composite Cement (PCC) cement produced by the Tonasa Cement Factory, and using Coarse Aggregate and Fine Aggregate originating from Bili-bili, Gowa Regency, South Sulawesi Province, the study used test objects in the form of cylinders with a diameter 15 cm and 30 cm high, with a sample of 50 concrete cylinders with 5 (five) variations, each variation of 10 samples. The test carried out is the compressive strength test at age 28. The quality of the planned material is the quality of concrete f'c 60 MPa.

Several similar studies have been conducted on concrete production with bottom ash waste material [1-5]. Investigation of concrete performance utilizing bottom ash waste as a substitute for fine aggregate [2], The effect of coal bottom ash as a partial replacement for sand on the workability and strength properties of concrete [3], the role of coal bottom ash as an alternative to cement [4], new coal bottom ash waste composites for sustainable construction [5], new environmentally friendly porous concrete made with coal ash and geopolymer binders: Heavy metal leaching characteristics and compressive strength [6], short-term effects of sulfates and chlorides on ash-containing concrete coal as a complementary material for cement [7]. Effect of coal bottom ash as a substitute for fine aggregate on various concrete properties [8-10]. The objective of this study was to determine the compressive stresses and strains of high-strength concrete with fly ash substitution variations of 10%, 15%, 20%, 25%, and 30%

2. RESEARCH METHODS

The research was carried out at the Structures and Materials Laboratory, Faculty of Engineering, Universitas Muslim Indonesia, Makassar. This research was carried out through several stages, namely: Procurement and inspection of materials, making mixed designs (Mix designs), Making high-quality concrete, Testing specimens, and Analysis of research results.

Mix design and manufacture of test specimens are carried out following the ACI (American Concrete Institute) ACI.211.4R method for high-strength concrete. The results of concrete mix planning can be seen in the following table:

Table 1: Material requirements for 1 m^3 of concrete

NO	Condition	Water	Cement	Sand	Fine aggregate	Total
1	SSD	185.800	410.155	807.222	988.82	2392
2	Water content (%)			1.575	0.960	
3	Absorption (%)			0.806	1.720	
4	Free water (%)			0.769	-0.760	
5	Env. condition	187.108	410.155	813.430	981.308	2392

2.1. Compression strength

The compressive strength of concrete is the amount of load per unit area, which causes the concrete specimen to be destroyed when it is loaded with a certain compressive force generated by the press machine. Concrete compressive strength is the most important characteristic of concrete quality compared to other properties. The compressive strength of concrete is determined by setting the ratio of cement, coarse and fine aggregates, and water. Mathematically it can be written as follows:

$$f'c = \frac{P}{A}. \quad (1)$$

Where:
$f'c$ = concrete compression strength (MPa)
P = Axial compressive force (N)
A = Cross-sectional area of the test object (mm^2)

2.2. Splitting Strength

Splitting tensile strength is the tensile strength of concrete which is determined based on the splitting compressive strength of a concrete cylinder pressed on its long side. The splitting tensile strength of concrete is relatively low, and the compressive strength and splitting tensile strength of concrete is not directly proportional. Every effort to improve the quality of compressive strength is only accompanied by a small increase in the value of the tensile strength. Tensile strength is more difficult to measure than compressive strength due to clamping problems in the machine.

The test uses a concrete cylinder with a diameter of 150 mm and a length of 300 mm, placed in a longitudinal direction on top of the tester and then the compressive load is applied evenly in a perpendicular direction from above over the entire length of the cylinder. If the tensile strength is exceeded, the specimen is split into two parts from end to end. The tensile stress that occurs when the specimen is split is called split cylinder strength or split tensile strength.
The split tensile strength of concrete can be calculated by the formula:

$$Fsp = \frac{2P}{\pi L D}. \quad (2)$$

Where:
Fsp = Splitting Tensile Strength (Mpa)
P = Test limit load (N)
L = Length of Test Object (mm)
D = Diameter of Test Object (mm)

2.3. Stress and strain

Stress and strain are closely related to elasticity, so before discussing stress and strain, it is necessary to know that elasticity is the tendency of a solid material to return to its original shape after experiencing deformation or stretching. The elastic parameter itself consists of three things, namely stress, strain, and elastic modulus.

Stress is the force acting per unit cross-sectional area. That is, when an elastic object is given a certain force, the object will feel tension or stress. Strain is the initial increase in the length of an object due to the tensile force received by the object. So, after experiencing stress, an object then experiences strain or strain.
Voltage can be calculated by the formula:

$$\sigma = F/A \qquad (3)$$

Where :
σ = stress (MPa)
F = force (KN)
A = cross-sectional area (mm2)

The strain was calculated by applying this formula:

$$\varepsilon = \frac{\Delta L}{L} \ldots \qquad (4)$$

where:
ε = strain
ΔL = length change
L = length

The elastic modulus can be calculated by the formula:

$$E = \frac{\sigma}{\varepsilon} \qquad (5)$$

where:
E = elastic modulus (N/M^2)
σ = stress (MPa)
Ɛ = strain

3. RESEARCH RESULTS AND DISCUSSION

3.1. Coarse aggregate characteristic

Table 2 shows the characteristics of the coarse aggregate. The test results show that the coarse aggregate meets the required specifications, so it can be concluded that the tested coarse aggregate is suitable for use in the concrete mixing process (Table 2).

Table 2. Characteristics of coarse aggregate

No	Coarse Aggregate Measure Characteristics	Result	Standard
1	Specific gravity SSD Basic	2.59	2.4 – 2.9
2	Absorption (%)	1.6	≤ 3
3	Water content (%)	2.3	-
4	Wear (%)	19.2	≤ 40
5	Sludge levels (%)	0.36	≤ 1
6	A sieve analysis (Fr) (max. 40 cm)	7.65	-
7	Solid content mass (kg/L)	1.379	1.2 – 1.75

3.2. Characteristics of Fine Aggregate

Table 3 shows the characteristics of fine aggregate. The test results show that the fine aggregate meets the required specifications, so it can be concluded that the coarse aggregate that has been tested is suitable for use in the concrete mixing process.

Table 3. Results of the fine aggregate of bottom ash measurement

No	Coarse aggregate measure characteristics	Result	Standard
1	Specific gravity SSD Basic	2.49	2.4 – 2.9
2	Absorption (%)	2.57	≤ 3
3	Water content (%)	2.94	-
4	Organic content (%)	Lemon	Yellow standard
5	Sludge levels (%)	2.67	≤ 3
6	A sieve analysis (Fr) (max. 40 cm)	2.89	-
7	Solid content mass (kg/L)	1.526	1.2 – 1.75

3.3. Cement characteristic

This study showed that all cement inspection results meet the required specifications, so it can be concluded that the tested Portland composite cement is suitable for use in the concrete mixing process.

Table 5. Portland cement measure results

No.	Cement characteristic	Result	Standard
1.	The specific gravity of cement	3,019	3.05 - 3.25
2.	Cement fineness #NO.100	100	>90
3.	Cement fineness #NO.200	90	>90
4.	Filling mass (solid) (kg/L)	1.208	1.1-1.4
5.	Mass content (loose) (kg/L)	1.127 kg/L	1.1-1.4
6.	Normal consistency (%)	23	22 - 30
7.	Initial binding time	45 minutes	Minimum 45 minutes
8.	Final binding time	120 minutes	Maximum 375 minutes

Source: Idrus, 2022 [11]

3.4. Compression Press

From the results of the concrete compressive strength test with variations in the percentage of fly ash successively from 0%, 10%, 15%, 20%, 25%, 30%, the best increase in compressive strength was achieved at a percentage of 20% fly ash, namely 53.376 MPa (Table 5).

Table 5. Results of the compressive strength test of concrete with the addition of fly ash aged 28 days

No.	Fly ash (%)	f'c (MPa)
1	0	50.460
2	5	52.498
3	10	52.994
4	15	53.376
5	20	52.781
6	25	51.408
7	30	50.460

The results of the correlation analysis show the relationship between the compressive strength of porous concrete and the percentage of variations in the addition of bottom ash 0 – 30% at 28 days of age, where the relationship pattern tends to follow the parabolic equation, as follows:

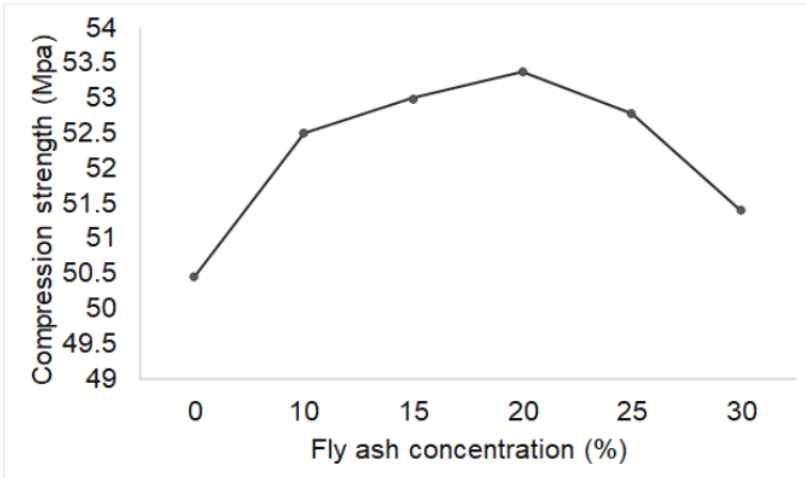

Figure 1. Graph of the Relationship Between Concrete Compression Strength and Fly Ash Variations

3.6. Elastic moddulus

The test results show that the highest average elastic strength of 6.1 MPa is obtained from concrete with a composition of 20% fly ash (Table 6).

Table 6. The results of the flexural strength test of concrete with the addition of fly ash aged 28 days

No.	Fly Ash	Sample dimension (mm)			Maximum load	Elastic strength	
	(%)	b	d	L	(kN)	fr (MPa)	Average (MPa)
1	0	150	150	600	30	5.33	5.27
					31	5.51	
					28	4.98	
2	10	150	150	600	32	5.69	5.57
					31	5.51	
					31	5.51	
3	15	150	150	600	33	5.87	5.93
					35	6.22	
					32	5.69	
4	20	150	150	600	34	6.04	6.10
					34	6.04	
					35	6.22	
5	25	150	150	600	32	5.69	5.81
					34	6.04	
					32	5.69	
6	30	150	150	600	30	5.33	5.45
					32	5.69	
					30	5.33	

Compressive strength shows a positive correlation with elastic strength. The correlation graph formed is fr = 3.8338√f'c - 22.023, with $R^2 = 0.8881$ (Figure 2).

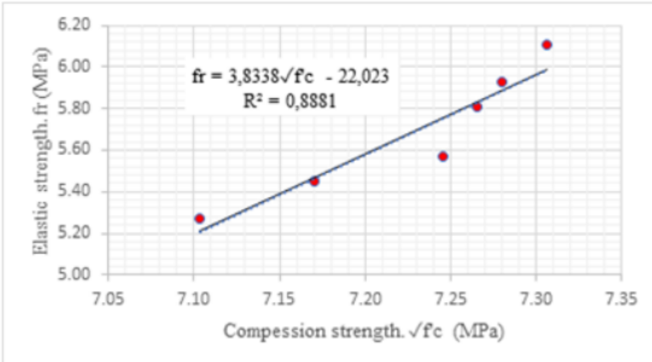

Figure 2. Graph of the Relationship Between Concrete Compressive Strength and Elastic strength

Furthermore, the compressive strength test results data associated with the elastic strength test results can be seen in table 7.

Table 7. Results of the flexural strength test of concrete with the addition of fly ash aged 28 days

Fly Ash	f'c	√f'c	fr
(%)	(MPa)	(MPa)	(MPa)
0	50	7.10	5.27
10	52	7.25	5.57
15	53	7.28	5.93
20	53	7.31	6.10
25	53	7.27	5.81
30	51	7.17	5.45

From the table above table, it can be presented in the figure as follows (Figure 3)

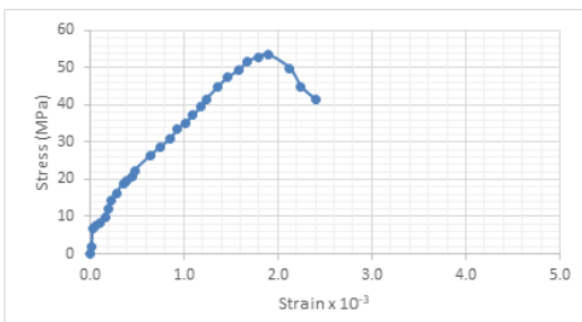

Figure 3. Graph of the Strain-Compression Relationship

Table 8 shows that the fly ash percentage of 0% shows a high strain value of 2.05 and then decreases at a percentage of 10%, 15%, then at a percentage of 20%, 25% and 30% it again increases. This shows that the percentage of fly ash does not affect the increase or decrease in strain values. The test results showed that the lowest strain was achieved at fly ash concentrations of 15 and 20%. At these two concentrations, the strain value is the same, namely 1.89.

Table 8. Relationship between Fly Ash Percentage and Strain

% FA	Maximum strain (x 10^{-3})
0	2.05
10	1.87
15	1.89
20	1.89
25	1.92
30	1.94

From the relationship between fly ash content and strain, it can be seen that the correlation pattern formed is in the form of a concave polynomial graph, with the equation e = 0.0005(FA)2 - 0.0186(FA) + 2.0389 and R^2 = 0.8976 (Figure 4).

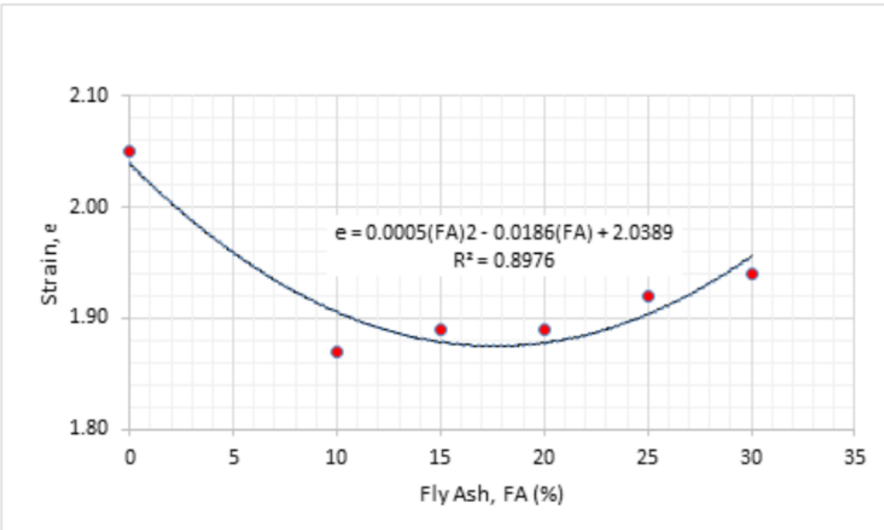

Figure 4. Relationship between Fly ash percentage and strain

Furthermore, from the results of the calculation of the concrete elastic modulus value, it can be seen in table 9. The highest elastic modulus value was obtained at a 20% fly ash concentration, amounting to 4.809.

Table 9. Scores of compression strength, modulus elasticity dan x

% FA	f'c Mpa)	$\sqrt{f'c}$	E (Mpa)	$x = \frac{E}{\sqrt{f'c}}$
0	49.94	7.07	33661.67	4.764
10	50.67	7.12	34144.14	4.797
15	52.37	7.24	34725.27	4.798
20	53.62	7.32	35209.88	4.809
25	52.65	7.26	34821.05	4.799
30	51.07	7.15	34115.23	4.774

From the relationship between compression strength and elastic modulus, the correlation pattern formed is in the form of a linear graph, with the equation y = 296.62x + 33408, with R^2 = 0.9517 (Figure 5).

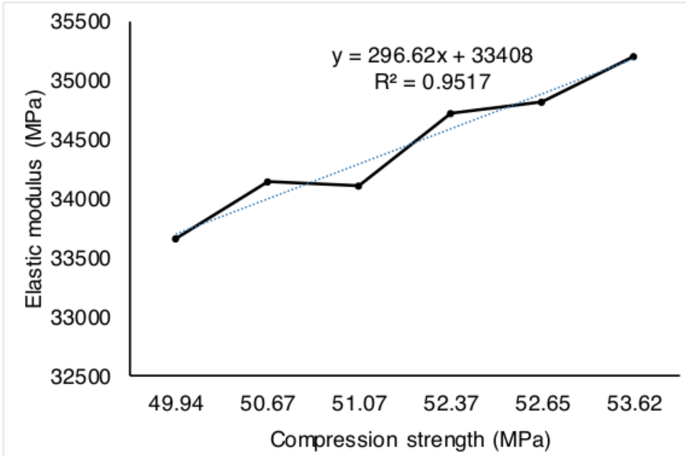

Figure 5. Graph of the relationship between compression strength and elastic modulus

Based on Figure 5, this study demonstrated a positive correlation between compression strength and elastic modulus. Another study reported that the relationship between the elastic modulus and the compressive strength of concrete demonstrated a nonlinear relationship. The elastic modulus increases with an increase in concrete compressive strength. In areas with compressive strength values up to 15 MPa, the elastic modulus increases more sharply compared to the area with a compressive strength greater than 15 Mpa [12]. According to Mehta (Mehta, 1986), concrete with low compressive strength, resulting from the use of high fas, contains relatively more large pores compared to concrete with higher strength. This causes the concrete's ability to transfer the stress to be reduced and consequently the elastic modulus is low [13].

4. CONCLUSION

1. The percentage of fly ash that can contribute to improving the quality of concrete is 20% with a compression strength value of 53.62 MPa

2. The relationship between elastic modulus and compression strength shows a linear positive relationship pattern

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