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The Effect of Using Coal Fly Ash as a Fine Aggregate Substitute on the Compressive Strength of Concrete

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ABSTRACT

Concrete is a composite material consisting of Portland cement, fine and coarse aggregates, and water that hardens into solid mass. Coal fly ash, a pozzolanic by-product of coal combustion, exhibits comentitous properties due to its high silica content, which reacts chemically with calcium hydroxide. This study investigates the effect of coal fly ash as a partial fine aggreagate replacement on the compressive strength of concreate at 28 days. The results demonstrate that te incorporation of coal fly ash enhances compressive strength compared to conventional concrete. The mixture with 15% fly ash substitution achieved a compressive strength of 25.08 MPa, while the 30% substitution reached 29.33 MPa, both exceeding the target strength of 20 MPa. The finding highlights the potential of coal fly ash as a sustainable alternative to natural fine aggegate in concrete production.

Keywords: Concrete, Fine Aggregate, Coal Fly Ash, Compressive Strength

1. Introduction

The construction industry continues to expand rapidly, driven by population growth and the rising demand for infrastructure. According to Central Bureau of Statistic, Indonesia's population reached 278.696 million in 2023, an increase of 1,06% from the previous year, with further growth projected in the coming decades [1]. This demographic trend intensifies the need for construction materials, particulary concrete, which remains the most widely used material in civil engineering application [2]. Concrete as defined by SNI 7656-2012, is a mixture of Portland cement or other hyrdraulic cement, fine aggreagate, coarse aggregates, and water, with or without admixtures [3]. Given its widespread consumption, continuous innovation in concrete technology is essential to ensure both structural performance and sustainability. One approach involves the incorporation of supplementary materials, such as pozzalanic admixtures, to enhance mechanical and durability properties [4].

Fly ash, a fine particulate by-product of coal combustion, has gained attention as a pozzolanic material capable of improving the performance of concrete. Its silica and alumina contents react with calcium hydroxide during cement hydration, forming additional cementitious compounds that contribute to strength development [4, 5]. Previous studies have reported improvements in compressive strength when fly ash is used either as a cement replacement or as a partial aggregate substitute. For example, [6] showed that the incorporation of bottom ash as a fine aggregate replacement at 9% produced a 3.4% increase in compressive strength compared to control mixes, suggesting that similar benefits may be expected from fly ash. In Indonesia, the production of fly ash and bottom ash (FABA) from coal-fired power plants was estimated to reach 12 million tons in 2021 [7-9]. Without proper management, this waste poses significant environmental challenges. Therefore, its reuse in concrete production offers both technical and ecological benefits [10, 11] While numerous studies have

investigated fly ash as a cement replacement, its potential as a fine aggregate substitute remains less explored [12, 13].

Based on this context, the present study examines the effect of using coal fly ash as a partial replacement for fine aggregate on the compressive strength of concrete. The research was conducted at the Civil Engineering Laboratory, Institut Teknologi Padang, with fly ash substitutions of 0%, 15%, and 30% by weight of fine aggregate. The findings are expected to contribute to the understanding of alternative aggregate utilization and support sustainable practices in concrete production.

2. Research method

This study is an experimental investigation using coal fly ash as an admixture in the production of normal concrete, with substitution levels of 0%, 15%, and 30% by weight of fine aggregates. The research was carried out in the Civil Engineering Laboratory of Institut Teknologi Padang. The test specimens were cylindrical (15 cm × 30 cm), and compressive strength was evaluated at 28 days. A 3-day trial test was conducted beforehand to verify the target strength.

Table 1. Research sample

Concrete Mix Variation	28-Day Test Specimens
Normal Concrete	3
15% Fly Ash	3
30% Fly Ash	3
Total Specimens	9

Research Procedure

1. **Material Procurement**
   - **Cement:** Portland Composite Cement (PCC) from PT Semen Padang.
   - **Coarse Aggregate:** Crushed stone passing sieve No. 3/6 with max size >5 mm, sourced from Padang.

Figure 1. Coarse Aggregate

   - **Fine Aggregate:** Sand passing 12 mm sieve with grain size distribution of 0–5 mm, sourced from Padang.

Figure 2. Fine Aggregate

- **Coal Fly Ash:** Obtained from the Padang area, West Sumatra.
- **Water:** Borewell water from ITP.

2. **Material Properties Testing**
   - **Fine Aggregate:**
     1. Gradation analysis

        From the test results obtained fine aggregates can be seen that the fine aggregate material meets the gradation specifications according to the zone IV standard (Fine Sand). Based on the weight results obtained, which is 2.52, the grain fineness modulus value is 2.52. This value meets the SNI 7675-2012 standard.
     2. Organic content test
     3. Passing No. 200 sieve
     4. Bulk density test
     5. Specific gravity and water absorption
   - **Coarse Aggregate:**
     1. Gradation analysis
     2. Passing No. 200 sieve
     3. Bulk density
     4. Specific gravity and water absorption
     5. Los Angeles abrasion test

3. Results and discussion (11 pt, Sentence case)

3.1 Material Properties

- **Fine Aggregate Gradation:** The fine aggregate falls into Zone IV (fine sand) with a fineness modulus (FM) of 2.52, complying with SNI 7675:2012.

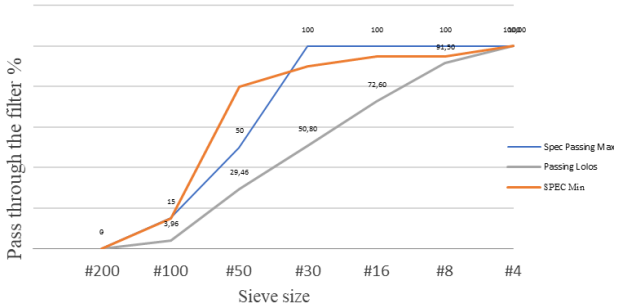

Figure 3. Fine Aggregate Gradation

- **Coarse Aggregate Gradation:** The coarse aggregate has a gradation FM of 6.86 and meets the 40 mm maximum size requirement, in accordance with SNI ASTM C136:2012.

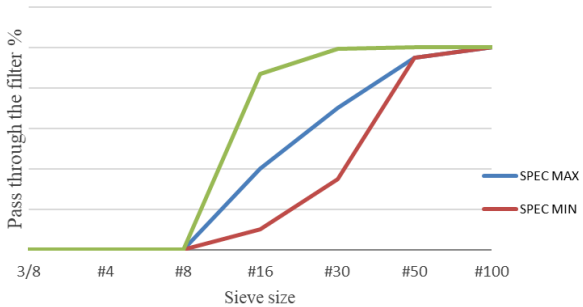

Figure 4. Coarse Aggregate Gradation

3.2 Trial Mix

Material	Weight/m³	Volume (m³)	Mix (kg)	Mix for 3 cylinders +15% (kg)
Cement	324.5	0.0053	1.72	5.94
Fine Aggregate	877.7	0.0053	4.65	14.64
Coarse Aggregate	983.1	0.0053	5.21	16.41
Water	147.48	0.0053	1.01	3.48
Fly Ash 15%	131	0.0053	10.6	33.39
Fly Ash 30%	263.31	0.0053	10.03	31.59

3.3 Mix Design for Admixture

- 15% Fly Ash Replacement: [Fly Ash = (15/100) = 0.891 / 2.95 = 0.3 (300 g)]
- 30% Fly Ash Replacement: [Fly Ash = (30/100) = 1.782 / 2.95 = 0.6 (600 g)]

3.4 Compressive Strength Results

Variation	Sample	Area (mm²)	Load (kN)	Strength (MPa)	Average (MPa)
0% Normal	1	17662	384	21.74	21.42
	2	17662	378	21.40	
	3	17662	373	21.12	
15% Fly Ash	1	17662	443	25.08	24.69
	2	17662	436	24.69	
	3	17662	429	24.29	
30% Fly Ash	1	17662	518	29.33	28.20
	2	17662	490	27.74	
	3	17662	486	27.52	

The compressive strength results for 28-day concrete show that - The control (0% fly ash) achieved an average compressive strength of 21.42 MPa. - The 15% fly ash mixture reached a peak strength of 25.08 MPa. The 30% fly ash mixture reached a peak of 29.33 MPa, with an average of 28.20 MPa.

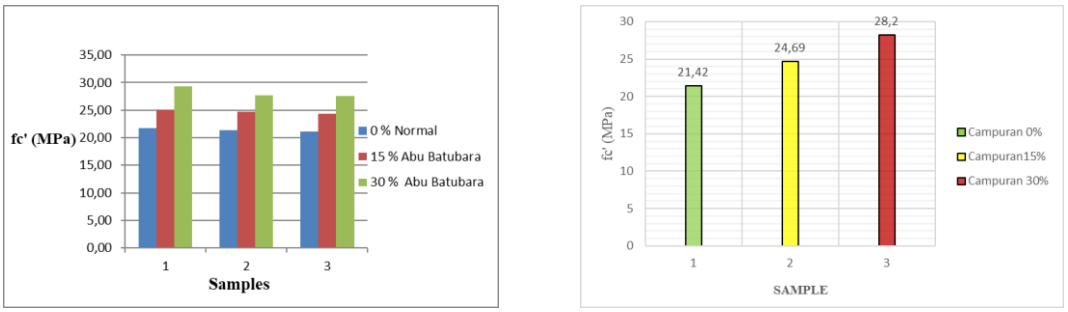

Figure 5. Compressive and average strength

These results indicate a significant increase in compressive strength with higher fly ash substitution. Although fly ash lacks the binding properties of cement, its fine particle size and silica oxide content allow it to react with calcium hydroxide during hydration, forming additional cementitious compounds that contribute to strength development.

4. Conclusions

The experimental results confirm thate the [partial substitution of fine aggregate with coal fly ash significantly improves the compressive strength of concrete. Mixtures with 15% and 30% fly ash replacement achieved average strength of 24.69 MPa and 28.20 MPa, respectively, both exceeding the target strength of 20 MPa and

the control mix at 21.42 MPa. The highest performance was obtained at 30% replacement, indicating that coal fly ash is a promising sustainable alternative to natural fine aggregate in concrete production.

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