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Experimental Study of the Utilization of Palm Oil Ash as an Additive to Concrete Compressive Strength

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Abstract

The use of biomass waste as a concrete additive is one way to reduce comment consumption, which contributes to carbon emissions. This study examines the effect of palm oil combustion as h on the compressive strength of concrete with a design strength of f'c 26.4 MPa. The ash was added at 0%, 5%, 10% and 15% of cement weight. Specimens were 15 x 30 cm cylinders, three for each variation and each test age (7 and 14 days), giving 24 specimens in total. Mix design followed RSNI T-13-2002 and compressive testing followed SNI 1974:2011. Slump values of all mixes (110-125 mm) meet the target range of 100-140 mm. the 5% variation gave the highest mean compressive strength, 18.07 MPa at 7 days and 22.18 MPa at 14 days, which is 9.8% amd 16.6% higher than normal concrete (16.45 and 19.03 MPa). The 10% and 15% variations did not exceed normal concrete. The advantage and the 5% variation cannot be declared statistically significant because of wide scatter between specimens and no mix reached the design strength at 14 days. Testing at 28 days and characterization of the ash are needed to confirm these findings .

Keywords: palm oil combustion ash; compressive strength; pozzolan; optimum dosage; normal concrete

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1. Introduction

Indonesia's growing infrastructure development keeps concrete demand high, and nearly all structural concrete uses Portland cement as a binder. Cement production requires significant energy and generates significant carbon emissions, so research in recent years has focused on industrial waste materials that can complement or partially replace cement without compromising quality.

Palm oil combustion ash is a solid waste product from the combustion of shells and fibers in palm oil mill boilers. In many locations, this waste is dumped around the mills, and its utilization remains limited. Its high silica content makes it potentially pozzolanic, reacting with calcium hydroxide from cement hydration to form additional calcium silicate hydrate (CSH) (Rahmadi et., 2021; Amran et al., 2021). Its fine grains can also fill micro-voids in the paste.

Previous studies have shown that the effect of palm oil ash on the compressive strength of normal concrete depends on the percentage used (Hidayatullah et al., 2024; Abdullah et al., 2024) and its combination with silica fume can increase compressive strength (Irianti et al., 2025). A study by Chinnu et al. (2022) stated that the optimum content of palm oil ash is around 10% with a tendency for lower initial compressive strength due to the slow pozzolanic reaction. Differences in ash characteristics, usage levels, and planned concrete quality cause the results to be inconclusive. Data for concrete f'c 26.4 MPa with a variation of 0-15% of the cement weight at the initial age is still limited.

This study aims to (1) analyze the effect of 0%, 5%, 10% and 15% palm oil combustion ash on the workability and compressive strength of concrete f'c 26.4 MPa at the age of 7 and 14 days. (2) determine the variation that provides the highest compressive strength, and (3) assess the depth of the conclusion based on the distribution of data.

2. Research methodology

2.1. Type of Research and Location

This research is an experimental laboratory study. The fabrication, maintenance, and testing of test specimens were conducted at the Civil Engineering Laboratory of the Muhammadiyah University of North Sumatra (UMSU) and the Civil Engineering Laboratory of the Islamic University of North Sumatra (UISU).

2.2. Materials

The materials used were Padang Type I Cement, sand as fine aggregate, crushed stone as coarse aggregate,

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water, and palm oil combustion ash. The chemical composition of the ash was not tested in this study; Table 1 contains data from the literature as a reference for pozzolanic potential.

Table 1. Table of Chemical Composition of Palm Oil Combustion Ash (literature reference)

Compound	Content (%)
SiO2	66.24
Al2O3	4.17
CaO	5.21
MgO	4.83
Fe_2O_3	3.28
$SiO_2 + Al_2O_3 + Fe_2O_3$	73.69

2.3. Mixture Design and Test Objects

Mixture planning refers to RSNI T-13-2002 for the design quality f'c 26.4 MPa with a design slump value of 12±2 cm. Material requirements per 1 m^3 are 413 kg of cement, 681 kg of sand, 1,021 kg of gravel and 215 liters of water. Ash variations are set at 0%, 5%, 10% and 15% of the cement weight. With the code BN, BAS 5, BAS 10 and BAS 15. The test specimens are cylinders with a diameter of 15 cm and a height of 30 cm (volume ± 0.0053 m^3), three for each variation and test age, so that the total is 24 test specimens. The proportion of materials per group of three cylinders is presented in Table 2.

Table 2. Table of Material Proportions Per Group of Three Cylinders

Code	Cement (kg)	Ash Palm oil (kg)	Cement + Ash (kg)	Aggregate Fine (kg)	Aggregate Rough (kg)	Water (kg)	Water/Cement
BN	6.57	0.00	6.57	10.84	16.24	3.76	0.57
BAS 5	6.42	0.32	6.74	10.84	16.24	3.76	0.59
BAS 10	6.27	0.63	6.90	10.84	16.24	3.76	0.60
BAS 15	6.12	0.92	7.04	10.84	16.24	3.76	0.61

Ash is calculated as a percentage of the cement weight in each mix (e.g., 0.32 kg is 5% of 6.42 kg), while aggregate and water are kept constant. In practice, the amount of cement decreases by 2.3% to 6.8% compared to normal concrete, the total binder increases by 2.6% to 7.2%, and the water/cement ratio increases from 0.57 to 0.61. The implications of this are discussed in section 3.3.

2.4. Testing

The workability of the mixture was measured by slump test on fresh concrete. The test specimens were cured by immersion in water until the test age (SNI 2493:2011). Compressive strength testing was carried out at the age of 7 and 14 days with a Compression Testing Machine following SNI 1974:2011 (BSN, 2011). The maximum load reading of the machine (ton) was converted into force with the equation W = mxg (g = 9.80665 m/s^2), then the compressive strength was calculated with the equation f'c = P/A, with A = 17,671.46 mm^2.

2. 5. Data analysis

The compressive strength of each variation and age is expressed as the average of three test specimens along with standard deviation and coefficient of variation. The effect of ash is assessed from the relative difference to normal concrete, the increase in compressive strength from 7 to 14 days, and the comparison to the design quality f'c 26.4 MPa. Due to the small number of test specimens, the analysis is descriptive and does not include hypothesis testing.

3. Results and Discussion

3.1 . Mixed Agility

Table 3. Slump Test Results Table

Variation	Slump (mm)
BN	115
BAS 5	125
BAS 10	110
BAS 15	120

All mixtures met the design slump range of 100-140 mm (Table 3). Slump increased at 5%, decreased at 10%, and increased again at 15%, so there was no directional trend with ash content. This fluctuating pattern is more likely attributed to differences in aggregate moisture content, ash absorption, weighing accuracy, and mixing process between mixtures. Because slump was measured once per mixture, a difference of 5-15 mm is considered within the reasonable range of the test, not a definite effect of ash.

3.2 . Compressive Strength

The test results for each test object are presented in Table 4, the average recapitulation in Table 5 and Figure 1 .

Table 4. Table of Compressive Strength of Each Test Object (MPa)

Code	Age	Test object 1	Test object 2	Test object 3	Test object 4
BN	7 days	16.64	16.07	16.64	16.45
BN	14 days	16.64	21.05	19.41	19.03
BAS 5	7 days	21.05	14.94	18.22	18.07
BAS 5	14 days	23.82	20.54	22.18	22.18
BAS 10	7 days	13.69	15.51	14.49	14.56
BAS 10	14 days	16.64	17.77	17.20	17.20
BAS 15	7 days	15.96	17.09	15.51	16.18

BAS 15	14 days	17.60	18.33	17.20	17.71

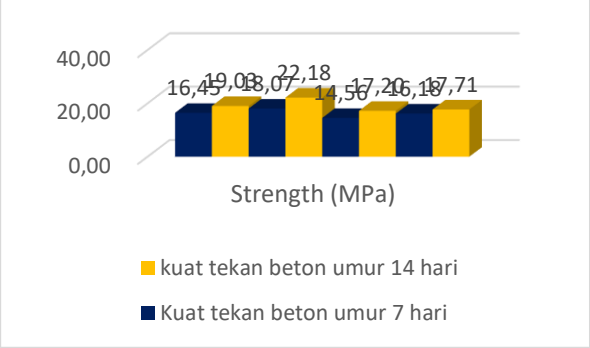


Figure 1. Average Compressive Strength of Concrete at 7 and 14 Days for Each Palm Ash Variation (MPa)

Table 5. Summary Table of Compressive Strength and Comparison to Normal Concrete

Code	7-day average (MPa)	14-day average (MPa)	7/14 day standard deviation (MPa)	Difference vs BN 7/14 days	Increase 7 -> 14 days	14 days against f'c 26.4 MPa
BN	16.45	19.03	0.33/2.23	-	+15.7 %	72.1 %
BAS 5	18.07	22.18	3.06/1.64	+9.8%/+16.6%	+22.7 %	84.0 %
BAS 10	14.56	17.20	0.91/0.57	-11.5%/-9.6%	+18.1 %	65.2 %
BAS 15	16.18	17.71	0.81/0.57	-1.6%/-6.9%	+9.5 %	67.1 %

All variations experienced an increase in compressive strength from 7 to 14 days, indicating ongoing hydration. The BAS 5 variation was the only one to exceed normal concrete at both ages (+9.8% and +16.6%), while BAS 10 and BAS 15 fell below it. The relationship between ash content and compressive strength was linear: compressive strength increased at 5% and then decreased at 10% and 15%.

This pattern is consistent with Chinnu et al. (2022), who reported that pozzolan addition was no longer beneficial above the optimum level, and with Adullah et al. (2024) who reported that the effect of boiler ash was determined by its percentage. The optimum level in this study (5%) was lower than that reported by Chinnu et al. (2022). This difference may be related to untested ash characteristics (fineness, carbon content) and the wide range between levels, so the actual optimum could be between 5% and 10%.

Mechanistically, at low levels silica ash can react with calcium hydroxide and the granules fill microcavities. At higher levels, the unreacted ash only becomes a filler, while the reduction in cement and the increase in the water/cement ratio weaken the matrix. This explanation is still conjecture, because the reactivity of the ash was not tested.

3.3 . Yield Constraints and the Influence of Water/Cement Ratio

The results should be read in conjunction with the data distribution. At 7 days, BAS 5 had a standard deviation of 3.06 MPa (coefficient of variation of approximately 17%) with individual values ranging from 14.94 to 21.05 MPa, which encompasses the full range of values for normal concrete (16.07 to 16.64 MPa). At 14 days, the ranges for BAS 5 (20.54 to 23.82 MPa) and BN (16.64 to 21.05 MPa) still overlapped. The average difference of 3.15 MPa at 14 days is consistent with that at 7 days, but with n = 3, it cannot be declared statistically significant.

A variation of 10%, lower than 15%, also contradicts the assumption that excess ash continues to reduce compressive strength and resembles an irregular slump pattern. This indicates variations in workability between mixes.

In addition, Table 2 shows that the cement decreases and the water/cement ratio increases from 0.57 to 0.61 as the ash increases. Thus, the difference in compressive strength between variations cannot be attributed to ash alone. The most reliable conclusion is that a variation of 5% gives the best indication of the range tested, while 10% and 15% do not provide an advantage over normal concrete.

3.4 Age and Position Development in Relation to Plan Quality

The largest increase in compressive strength from 7 to 14 days occurred in BA 5 (+22.7%), compared to BN (+15.7%), BAS 10 (+18.1%), and BAS 15 (+9.5%). This higher rate is consistent with the contribution of pozzolanic reactions at later ages, although it cannot be separated from the data distribution.

None of the mixtures reached the design quality. The highest compressive strength, 22.18 MPa (BAS 5, 14 days), was only 84.0% of the f'c of 26.4 MPa, while normal concrete was 72.1%. With a ratio of 14-day to 28-day compressive strength of approximately 0.88 in PBI 1971 (Directorate of Building Problem Investigation, 1971), the 28-day compressive strength was estimated to be approximately 25.2 MPa for BAS 5 and 21.6 MPa for normal concrete. These figures are only indicative because the ratios apply to standard curing.

The low compressive strength of normal concrete itself is noteworthy. The water used in calculating the material requirements for the test specimens was 236.5 liters/m3 , higher than the 215 liters/m3 used in the mix design, equivalent to a water/cement ratio of

approximately 0.57 compared to the 0.52 used in the design. A higher ratio reduces the strength of all mixes. Compaction and curing also have an impact (Sariman et al., 2023).

3.5 Implications and Limitations

The potential use of palm oil ash is relevant for Indonesia because palm oil mills are widespread, including in North Sumatra, making ash readily available near construction projects. However, these results are not sufficient to recommend palm oil ash for structural concrete with a f'c of 26.4 MPa. Limitations of the study include testing only up to 14 days, three specimens per group, uncharacterized ash, inconsistent cement proportions across variations, and only three ash content levels.

4. Conclusion

The effect of palm oil combustion ash on the compressive strength of concrete f'c 26.4 MPa is not linear with its content. A 5% variation gives the highest average compressive strength of 18.07 MPa at 7 days and 22.18 MPa at 14 days or 9.8% and 16.6% above normal concrete. Variations of 10% and 15% do not exceed normal concrete, respectively 17.20 MPa and 17.71 MPa at 14 days. All mixtures meet the design slump and experience an increase in compressive strength from 7 to 14 days, with the largest increase at BAS 5.

The superiority of BAS 5 has not been statistically supported because the data are widely spread and no mixtures reached f'c 26.4 MPa at 14 days. Further research is recommended including testing at 28 days or more, increasing the number of test specimens (minimum number of specimens per group), characterization and refinement of ash, constant cement proportions and water/cement ratios between variations, and tighter content variations around 5%.

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