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Contribution of coal waste as a partial substitutional material for cement for increasing concrete compression strength

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Abstract
Concrete is the most widely used building material in construction. Starting from buildings, roads, bridges, and other construction work that uses concrete as a basic material in its construction. In general, concrete consists of a mixture of water, cement, fine aggregate and coarse aggregate. The purpose of this study was to measure the effect of coal waste as a substitute for cement on increasing the compressive strength of concrete. In this study, the method used is laboratory-based research. The initial stage of the research was in the form of material inspection including inspection or testing of coarse and fine aggregate materials, after the inspection of the materials was carried out and met the standard requirements, then proceed with making a job mix design. In this study, researchers used fly ash as a partial substitution for cement. The specimen will be tested by compressive strength test. The test object used is cylindrical in shape. The use of fly ash is 0%, 5%, 10%, 15%, 20% and 25% of the amount of cement. The test was carried out when the concrete was 28 days old for the compressive strength test. The contribution of coal fly ash to compressive strength made a positive contribution to the addition of coal fly ash up to 12.49%, there was an increase in compressive strength, whereas an addition above 12.49% resulted in a decrease in compressive strength. The optimal percentage obtained is 12.49% resulting in a concrete compressive strength of 35.59 MPa.

Keywords: bottom ash, porous concrete, compressive strength, split tensile strength, porosity

1. Introduction

The rise of infrastructure development to improve facilities that are expected to be able to answer all the needs of human daily activities in supporting their lives. One of the most rapid improvements is in the field of concrete technology. Concrete is the most widely used building material in construction [1, 2]. Starting from buildings, roads, bridges, and other construction work that uses concrete as a basic material in its construction. In general, concrete consists of a mixture of water, cement, fine aggregate and coarse aggregate. However, the increasing use of concrete means that usually we can substitute concrete mixture ingredients or add other ingredients that can provide and change certain properties in concrete. The increasing use of concrete results in the need for concrete of good quality increasing. The quality of concrete as one of the main elements in all types of construction is greatly influenced by the mixture of materials.

So far in Indonesia, the majority of electricity supply is met by utilizing non-renewable energy sources such as fuel oil, natural gas and coal. Increasingly this makes more and more electric steam power plants use coal as fuel it produces waste that can damage the environment if not fully utilized. As an innovation in concrete technology, we can replace this waste with cement. Currently, fly ash in South Sulawesi is a by-product of waste from the Semen Tonasa Electric Steam Power Plant which uses coal as a fuel for power plants, in the form of light, round, and pozzolanic fine grains. The addition of fly ash to the concrete mixture is pozzolanic, so it can be a good mineral additive for concrete.

Pozzolans are materials containing silica and aluminum which react chemically with calcium hydroxide at ordinary temperatures to form cementitious (binding) compounds. The use of fly ash as a concrete-forming material has a positive impact from an environmental perspective because fly ash is also considered a dangerous and toxic waste. In addition, the current handling of fly ash is still underutilized. Fly ash also has a lower price compared to cement. And if used properly we can make concrete of a certain quality at a more economical price. The purpose of this study was to determine the effect of Coal Fly Ash as a partial substitute for cement in concrete mixes and to find out what percentage of Coal Fly Ash gives the greatest compressive strength to concrete.

Bottom ash has been extensively researched and studied because of its potential to be used as a substitute for fine aggregate, coarse aggregate, or both [3-10]. Bottom ash can be a substitute for fine aggregate [3] or as a substitute for sand [4]. Other studies examined the effect of coal bottom ash as a substitute for fine aggregate on various concrete properties [5-7]. The use of bottom ash is known as a supplementary ingredient in cement to increase the workability and durability of concrete [8-13]. Recently, investigations regarding the reuse of bottom ash as a construction material are being carried out aggressively performed among researchers [10, 11, 14]. The use of bottom ash has brought a lot of benefits to the industry because of its low cost, low bulk density and suitability for use as a substitute for natural excavated sand or natural coarse aggregate which makes it more sustainable as a construction material. Many experimental works reveal that bottom ash can be used in appropriate proportions to enjoy the benefits of ease of workability and increased strength and durability of concrete. Almost all researchers promote the idea of turning various wastes into wealth to save valuable green areas for better use than landfills and reduce the high dependence on river sand mining supplies to ensure the environmental sustainability of green rivers [15]. The purpose of this study was to measure the effect of coal waste as a substitute for cement on increasing the compressive strength of concrete.

2. Materials and methods

In this study, the method used is laboratory-based research. The initial stage of the research was in the form of material inspection including inspection or testing of coarse and fine aggregate materials, after the inspection of the materials was carried out and met the standard requirements, then proceed with making a job mix design. In this study, researchers used fly ash as a partial substitution for cement. The specimen will be tested by compressive strength test. The test object used is cylindrical in shape. The use of fly ash is 0%, 5%, 10%, 15%, 20% and 25% of the amount of cement. The test was carried out when the concrete was 28 days old for the compressive strength test. The data used is a statistical analysis using the Microsoft Excel program. The data from the test results can later be concluded on how much compressive strength is using fly ash as an added material for concrete material.

Table 1: Number and code of Compressive Strength test object (Test Using Fly Ash as Cement Substitution)

No.	Fly ash variation	Sample code	Number of samples
1	0%	FA – 0%	5
2	5%	FA – 5%	5
3	10%	FA – 10%	5
4	15%	FA – 15%	5
5	20%	FA – 20%	5

2.1. Portland cement

Based on SNI-15-2049-2015 concerning specifications for Portland cement, Portland Composite Cement (PCC) is defined as a hydraulic binder resulting from grinding together Portland cement clinker and gypsum with one or more inorganic materials, or the result of mixing between Portland cement powder and powdered materials. another organic. Inorganic materials include pozzolans, silicate compounds, and limestone with a total inorganic content of 6-35% by mass of cement.

From this description, PCC is included in the category of special blended cement which has different specifications from OPC cement. These inorganic materials are mineral materials that have pozzolonic properties or have pozzolanic properties, namely mineral materials whose elements do not have cementitious properties independently, but when they react with calcium oxide and water at ordinary temperatures, they can form compounds that have the characteristics of cement PCC is a type of cement product designed to meet special needs, both in technical and on the aspect of costs that cannot be met by ordinary Portland cement (OPC). According to the intended use, portland cement in Indonesia can be divided into several types, namely: (Based on SNI-15-2049-2015)

a. Type I is a hydrolyzed adhesive produced by grinding clinker which mainly contains calcium silicate and grinding it together with additional ingredients in the form of one or more crystalline forms of calcium sulfate compounds. The composition of the compounds present in this type is 49% (C3S), 25% (C2S), 12% (C3A), 8% (C4AF), 2.8% (MgO), 2.9% (SO3). Type I Portland cement is used for paving roads, buildings, bridges, and other types of construction where there is no possibility of sulfate attack from the soil and high hydration heat generation.
b. Type II Cement of this type in use requires moderate resistance to sulfate and heat of hydration. Its composition: 46% (C3S), 29% (C2S), 6% (C3A), 11% (C4AF), 2.9% (MgO), 2.5% (SO3). Type II Portland cement is used for waterfront buildings, dams, and irrigation, or mass concrete that requires low hydration heat.
c. Type III Cement of this type in use requires high strength in the initial phase after binding. The C3S content is very high and the granules are very fine. Type III Portland cement is used for buildings that require high (very strong) compressive strength, such as bridges and heavy

foundations.

d. Type IV Portland cement which is in use requires low hydration heat, so C3S and C3A levels are low. Type IV Portland cement is used for casting needs that do not generate heat, casting by spraying (long setting time).
e. Type V Portland cement which is in use requires only a high sulfate resistance. The composition of the compounds present in this type is 43% (C3S), 36% (C2S), 4% (C3A), 12% (C4AF), 1.9% (MgO), 1.8% (SO3). Type V Portland cement is used for industrial wastewater treatment plants, underwater construction, bridges, tunnels, ports, and nuclear power plants.

2.2. Aggregate

Aggregate is a natural mineral that functions as a filler in concrete or mortar mixes. The aggregates used in the concrete mix can be natural aggregates or artificial aggregates. In general, aggregates can be distinguished based on their size, namely coarse aggregate and fine aggregate. The aggregate used in concrete mixes is usually smaller than 40 mm. Fine aggregate is usually called sand and coarse aggregate is called gravel, split, crushed stone, and others [16]. According to Indonesia National Standard, aggregates can be distinguished based on their size, namely coarse aggregate and fine aggregate. To get good concrete, it is necessary to have an aggregate that has good aggregate quality, good aggregate in the manufacture of concrete must meet the requirements, namely:

1. Must be eternal, sharp-grained and strong.
2. Does not contain more than 5% silt for fine aggregate and 1% for coarse aggregate.
3. Does not contain organic materials and alkaline reactive substances.
4. Must consist of hard and non-porous grains.

`The aggregate itself has an important role in the concrete mixture, the specific gravity of the aggregate itself ranges from 2400 – 2900 kg/m3. Apart from being a filler in the concrete mixture, aggregate has several advantages including:

1. Can save the use of cement.
2. Can reduce shrinkage in concrete hardening.
3. With good aggregate gradation, high-quality concrete can be achieved

Based on ASTM, fine aggregate is generally in the form of sand with grain particles smaller than 5 mm or passes the No.4 sieve and is retained on the No.200 sieve. According to SNI 03-6820-2002, fine aggregate is aggregate with a maximum grain size of 4.76 mm originating from nature or natural products, while processed fine aggregate is the fine aggregate produced from breaking and separating grains by screening or other means from rock or slag. blast furnace. In using fine aggregate as a mixture in concrete, the following conditions need to be considered:

1. Sand consists of sharp, hard grains. Being eternal means not easily weathered by the influence of the weather.
2. Does not contain more than 5% sludge. Mud is the part that can pass through a 0.063 mm sieve. If the mud content is more than 5%, it must be washed. Especially sand for making concrete.
3. It doesn't contain too many organic ingredients as proven by the color trial from Abrams-Harder. Aggregate that does not meet the requirements of this experiment can be used if the compressive strength of the aggregate mixture at the age of 7 and 28 days is not less than 95% of the strength of the concrete mixture with the same aggregate but washed in 3% NaOH solution which is then washed with water until clean at the age of the same one.

The fine aggregate gradation requirements based on ASTM C33 can be seen in Table 2 below:

Table 2: Gradation of Fine Aggregate according to ASTM C33-93

Sieve diameter	Pass percentage
9.5 mm	100
4.75 mm	95 – 100
2.36 mm	80 – 100
1.18 mm	50 – 85
600 µm	25 – 60
300 µm	10 – 30
150 µm	2 – 10

Source: Annual Book of ASTM Standards Volume 04.02 "Concrete and Aggregates". 1994

2.3. Water

Water is needed in the manufacture of concrete to trigger the chemical process of cement, wet the aggregate and provide convenience in concrete work. Potable water can generally be used as a concrete mix. Water containing dangerous compounds, which is contaminated with salt, oil, sugar, or other chemicals, when used in the concrete mixture will reduce the quality of the concrete, and can even change the properties of the resulting concrete. Because cement paste is the result of a chemical reaction between cement to water, it is not the ratio of the amount of water to the total weight of the mixture that is important, but rather the ratio of water to cement or commonly referred to as the Water Cement Ratio (water-cement ratio). Too much water will cause lots of water bubbles after the hydration process is complete, while too little water will cause the hydration process to not be fully achieved, which will affect the strength of the concrete. For water that does not meet the quality requirements, the strength of concrete at the age of 7 days or 28 days may not be less than 90% when compared to the strength of concrete using standard/distilled water.

2.4. Added Material

Admixture is an ingredient in the form of powder or liquid, which is added to the concrete mix during mixing, to change the properties of the mix or concrete. (Specification of Additives for Concrete, SK SNI S-18-1990-03). According to the ACI (American Concrete Institute), additives are materials other than water, aggregate and hydraulic cement mixed in concrete or mortar that are added before or during the mixing. The addition of additives in a concrete or mortar mixture does not change the composition of the other ingredients, because the use of these additives tends to be a substitute or a substitute for the concrete mixture itself. Because the goal is to improve or change certain properties and characteristics of the concrete or mortar that will be produced, the tendency to change the composition in weight volume is not felt directly compared to the initial composition of the concrete without added ingredients. The types of additives are mineral additives, liquid additives, and fiber.

2.5. Coal Fly Ash

1. Physical Properties

According to ACI Committee 226, it is explained that fly ash has fine grains, which pass through the No. sieve. 325 (45 mili micron) 5-27 %. Fly Ash is generally in the form of solid or hollow balls. Fly ash has a density of 2.23 gr/cm3, with a moisture content of around 4%. Fly ash has a specific gravity between 2.15-2.6 and is gray-black in color. The particle size of fly ash from burning bituminous coal is smaller than 0.075 mm. Fly ash has a specific area of 170-1000 m2/kg. The average particle size of sub-bituminous coal fly ash is 0.01 mm – 0.015 mm, the surface area is 1-2 m2/g, and the particle shape is mostly spherical, that is, most of it is spherical, resulting in better workability [17].

2. Chemical properties

The chemical properties of fly ash are affected by the type of coal burned, storage techniques and handling. Burning of lignite and sub-bituminous coals produces fly ash with more calcium and magnesium oxide than bituminous types. The main components of coal fly ash are silica (SiO2), alumina (Al2O3), iron oxide (Fe2O3), calcium (CaO); and magnesium, potassium, sodium, titanium, and trace amounts of sulfur.
The composition and classification of fly ash can be seen in the following table.

Table 3: Composition and Classification of Fly ash

Komponen	Bituminous	Sub-bituminous	Lignit
SiO2	20-60	40-60	15-45
$Al2O_3$	5-35	20-30	20-25
$Fe2O_3$	10-40	4-10	4-15
CaO	1-12	5-30	15-40
MgO	0-5	1-6	3-10
SO_3	0-4	0-2	0-10
Na2O	0-4	0-2	0-6
K2O	0-3	0-4	0-4
LOI	0-15	0-3	0-5

3. Result and discussion

3.1. Fine Aggregate Characteristics

Coarse aggregate is crushed gravel or natural rock where the size is larger than 5 mm. In this study, several characteristic checks were carried out, along with the results of the measurement of the characteristics of the coarse aggregate inspection.

Table 4: Results of fine aggregate analysis

No	Fine aggregate measure characteristics	Result	Standard
1	Fineness modulus	2.763	-
2	Water content (%)	1.575	-
3	Solid content mass (kg/L)	1.580	1.2 – 1.75
4	Loose bulk (kg/L)	1.502	-
5	Specific gravity	2.680	2.4 – 2.9
6	Absorption (%)	0.806	≤ 3
7	Sludge levels (%)	3	≤ 3
8	Organic matter	Lemon	Yellow standard

Based on Table 4 above, all the results of the inspection of fine aggregate meet 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.

3.2. Coarse Aggregate Characteristics

Table 5: Results of fine aggregate analysis

No	Coarse aggregate measure characteristics	Result	Standard
1	A sieve analysis (Fr) (max. 40 cm)	6.970	-
2	Water content (%)	0.96	-
3	Solid Volume Weight (kg/L)	1.426	1.2 – 1.75
4	Loose Volume Weight (kg/L)	1.308	
5	Specific gravity SSD Basic	2.65	2.4 – 2.9
6	Absorption (%)	1.72	≤ 3
7	Sludge levels (%)	0.402	≤ 1
8	Coarse Aggregate Wear (%)	28.81	

Based on table 5 above, all the results of the coarse aggregate measurement meet the required specifications, so it can be concluded that the coarse aggregate is suitable as material in the concrete mixing process.

3.3. Cement quality

Cement is a hydraulic material, that is, an inorganic material that is finely ground and when mixed with water, using reactions and hydration processes forms a paste that binds and hardens.

Table 6: Cement measurement results

No.	Cement characteristic	Result
1.	The specific gravity of cement	3.1
2.	Cement fineness #NO.100	100
3.	Cement fineness #NO.200	90
4.	Filling mass (solid) (kg/L)	1.237
5.	Mass content (loose) (kg/L)	1.130
6.	Normal consistency (%)	25
7.	Initial binding time	90 minutes
8.	Final binding time	105 minutes

It can be seen from Table 6 above that all cement inspection results meet the required specifications, so it can be concluded that the cement is suitable as material in the concrete mixing process.

3.4. Characteristics of Fly Ash

On this material, we tested the initial and final setting times and tested the chemical content of fly ash which was carried out at the Testing Laboratory of the Industrial Research and Development Agency (BBIHP) Makassar. 10%, 15%, 20%, and 25%. Obtained inspection results can be seen in Table 7

Table 7: Examination results of Fly Ash binding time

Fly Ash (%)	Binding time (minutes)	
	Initial	Final
0	30	105
5	35	120
10	45	135
15	60	165
20	65	185
25	70	200

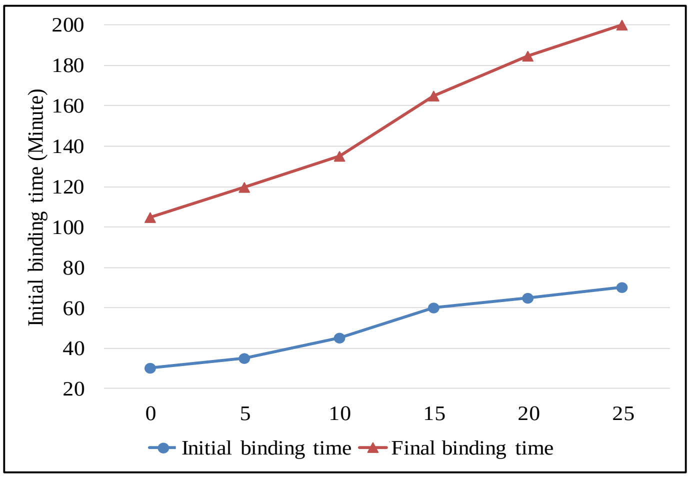

Fig 1: Graph of Fasting Time with Fly Ash Variations

Based on the measurement data for coarse aggregate, fine aggregate and cement then those materials were processed using the SNI 2012 mix design method, the results of normal concrete mixing were obtained in the following table (Table 8). The weight of coarse aggregate, fine aggregate and water were fixed at 908.91 kg, 781.10 kg and 201.45 kg respectively, while the weight of fly ash and cement varied upon the fly ash percentage (Table 8).

Table 8: Composition of concrete mix for every 1 m3 of concrete based on variations in the use of Fly Ash

Fly Ash percentage (%)	Coarse aggregate (kg)	Fine aggregate (kg)	Fly Ash weight (kg)	Cement (kg)	Water (kg)
0	908.91	781.10	0	496.11	201.45
5	908.91	781.10	23.455	445.65	201.45
10	908.91	781.10	46.911	422.20	201.45
15	908.91	781.10	70.366	398.74	201.45
20	908.91	781.10	93.822	375.29	201.45
25	908.91	781.10	117.28	351.83	201.45

3.5. Concrete Compression Strength Test

The results of normal concrete compressive strength variations of fly ash aged 28 days can be seen in table 9 below.

Table 9: Results of normal concrete compression strength with a variation of fly ash aged 28 days

Fly Ash Concentration (%)	Sample wide (m^2)	Slump value (mm)	The average of compression strength (Mpa)
0	0.01766	75-100	31.08
5	0.01766	75-100	33.01
10	0.01766	75-100	34.03
15	0.01766	75-100	36.29
20	0.01766	75-100	35.05
25	0.01766	75-100	29.38

The table above shows that with the addition of 0% fly ash, compression strength was 31.08 Mpa, 5% was 33.01 Mpa, 10% was 34.03 Mpa, 15% was 36.29 Mpa, 20% was 35, 05 MPa, and 25% was 29.38 MPa (Table 9).

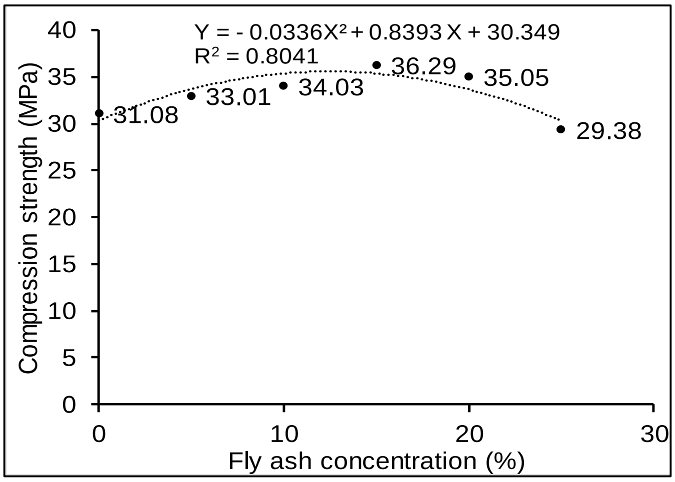

Fig 2: Polynomial regression between fly ash concentration (%) and compression strength

After carrying out the regression analysis, grafik yang terbentuk sesuai dengan model polinomial dengan formula of $Y = - 0.0336X^2 + 0.8393 X + 30.349$ with a R^2 correlation of 0.8041. The contribution of coal fly ash to compressive strength made a positive contribution to the addition of coal fly ash up to 12.49%, there was an increase in compressive strength, whereas an addition above 12.49% resulted in a decrease in compressive strength (Figure 2).

4. Conclusion

1. The contribution of coal fly ash to compressive strength makes a positive contribution to the addition of coal fly ash up to 12.49%, there is an increase in the compressive strength value, conversely, an addition above 12.49% decreases the compressive strength value.
2. The optimal percentage obtained is 12.49% resulting in a concrete compressive strength of 35.59 MPa.

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