TECHNIUM

Technium Vol. 25, pp.34-43 (2024)
ISSN: 2668-778X
www.techniumscience.com

A STUDY ON UTILIZATION OF COAL ASH FOR CONSTRUCTION MATERIALS

Rusdiansyah, Yasruddin, Adriani, and Fauzi Rahman
Civil Engineering Study Program-Faculty of Engineering Lambung Mangkurat University

ABSTRACT
During coal combustion, steam power plants have fly and bottom ash as by-products. However, according to Indonesian Government Regulation No.104 of 2014 on the management of hazardous and toxic waste, both fly ash with B409 code and bottom ash with B410 code are categorized as level-2 hazardous and toxic materials. A material can be categorized as a level-2 dangerous and toxic material due to its contents, has a delayed effect, an indirect effect on humans and the environment, and has sub-chronic or chronic toxicity.
One of the proposed solutions for this problem is to utilize fly ash and bottom ash as an added material or substitute material for paver blocks, concrete blocks, road curbs, and road bases. This study aimed to determine the right composition of fly ash and bottom ash on paver block, concrete block, road curb, and road base to meet the minimum requirements. This study is expected to confirm the utilization of coal ash material for construction materials.
Based on the results, the coal ash material in the form of fly ash and bottom ash could be used as an added material or substitute material for paver blocks, concrete blocks, road curbs, and road bases. The composition of fly ash and bottom ash as construction materials have met SNI 03 - 0349 - 1989 requirements on compressive strength for class II (K-70) concrete quality, then Job Mix Formula K-250 which refers to SNI 03-2834-2000 for road curb, then SNI 03 - 0691 - 1996 on the compressive strength requirements for quality B concrete bricks for paver blocks and roadblocks.

Keywords: Fly ash, bottom ash, paving blocks, concrete block, road curb, road base, compressive strength, and CBR

INTRODUCTION

One of the complicated problems lately is the by-product of the steam power plant in Pulangpisau, Central Kalimantan in the form of coal ash, specifically fly ash and bottom ash, which should be of serious concern to PLN. If these two types of ash are simply disposed of, they can endanger the environment and require large costs.

Fly ash and bottom ash are solid waste in the form of light fly ash and relatively heavy ash as a result of the coal combustion process in steam power plants. There are three types of coal combustion in the electricity industry, namely dry bottom boilers, wet bottom boilers, and cyclon furnaces. One of the by-products of coal combustion is 5% solid waste with a proportion of 80-90% fly ash and 10-20% bottom ash (Wardani, 2008).

Fly ash and bottom ash are coal combustion waste in which the amount will continue to increase as long as the industries still using coal. It can be shown from the proportion of coal in the national energy supply which reached around 12% in 1999 and 39.6% in 2022. (Wardani, 2008).

According to Government Regulation No.104 of 2014 on the management of hazardous and toxic waste, both fly ash with B409 code and bottom ash with B410 code are categorized as level-2 hazardous and toxic materials. A material can be categorized as a level-2 hazardous and toxic material due to its contents, a delayed effect, an indirect effect on humans and the environment, and sub-chronic or chronic toxicity. Therefore, due to the increasing amount of fly ash and bottom ash, optimal utilization is needed to minimize the impact on the environment.

At the Pulangpisau steam power plant, fly ash and bottom ash of 150 tons per day become by-products from the combustion of 4 units of coal-fired steam turbine engines. Therefore, a solution to this problem is needed, namely by maximizing the use of fly ash and bottom ash as additional materials or substitute materials for one of the materials in the paver block, concrete block, road curb, and road base. This study aimed to determine the right composition of fly ash and bottom ash on paver block, concrete block, road curb, and road base to meet the minimum requirements. This study is expected to confirm the utilization of coal ash material for construction materials.

Sherman (2015) conducted a study on pre-placed aggregate concrete from the volcanic ash of Mount Kelud as a cement substitute. Volcanic ash was chosen because it is based on its characteristics including class-N fly ash through the natural combustion process. The study aimed to find out the mechanical properties of concrete with a volume ratio of cement and sand of 1:0.5; 1:1; 1:1.5;1:2, and the use of volcanic ash of 0%, 20%, 40%, and 60% of the weight of cement using a 15x30 cm cylinder to test the compressive strength at the age of 7 days and 28 days. The results showed that volcanic ash as a cement substitute significantly increases the compressive strength of concrete so volcanic ash is effective as a cement substitute.

In addition, Suarnita (2011) conducted a study on the compressive strength of concrete with the addition of 5%, 10%, 15%, 20% and 25% fly ash. The compressive strength of concrete without the addition of fly ash was 32.2718 Mpa then 33.9137 Mpa with 5% fly ash; 35.3291 with 10% fly ash; 36.1783 with 15% fly ash; 36.8011 with 20% fly ash; and 37.2541 with 25% fly ash.

1. METHOD

2.1 Research Design

This research design used is as follows :

1. Preparation and inspection of materials
2. Production of mortar samples for mix design of grout materials
3. Production of cylindrical concrete sample test objects
4. Concrete Compressive Strength Testing
5. Analysis of experimental results

The above steps can be explained as follows:

Preparation and inspection of materials

After the materials such as cement, sand, gravel, and water are prepared, laboratory tests are needed to determine the characteristics in detail, including:

Examination of PCC "Tiga Roda" cement (SNI 15-2049-2004): specific gravity, normal consistency, setting time, and cement volume weight. Examination of aggregates: fine aggregate and coarse aggregate sieves (SNI 03-1968-1990), volume weight of fine aggregate and coarse aggregate (SNI 03-4804-1994), mud content of fine aggregate and coarse aggregate (SNI 03-4428-1997), organic content in fine aggregate (SNI-2816-1992), water content of fine aggregate and coarse aggregate (03-1971-1990), specific gravity and absorption in fine aggregate (SNI 03-1970-1990). Preparation of fly ash (ASTM C 311): Drying, measuring the specific gravity of fly ash, and separating fly ash and bottom ash

Technium Vol. 25, pp.34-43 (2024)
ISSN: 2668-778X
www.techniumscience.com

2.2 Tools and Materials

The materials used in this study were coarse aggregate in the form of crushed stone (from Katunum areas), fine aggregate in the form of Barito sand zone III (rather fine), PCC-type cement (Tiga Roda brands), distilled water, fly ash, and bottom ash. Meanwhile, the tools used to process the materials were cylindrical concrete formwork with a diameter of 100 mm and a height of 200 mm, a scale with an accuracy of 0.01 grams, a set of flow cone tests, 5x5x5 cube mortar formwork, soaking tank, compression testing machine, Los Angeles abrasion machine, steel balls (11 pieces), 250 ml Le Chatelier bottle, Thermometer, Mixer, Vicat apparatus, Mold and glass plate, Measuring cup, Stopwatch, Tray, Leveling ruler, Small shovel or spoon, cylindrical steel container (Bohler), Balance Scale, One set of sieves, Oven with temperature control, Vibration test machine, Rubber hammer, Basin, Vibrator, and Pipe. Table 2.1 shows the amount of mixture for the road curb in 1 bag of cement.

Table 2.1 Mix design for the road curb in 1 bag of cement.

No	Composition	Water		Cement		Sand		Aggregate		Fly Ash		Bottom Ash	
		Litre	Litre	Kg	Bag	Kg	Mold	Kg	Mold	Kg	Mold	Kg	Mold
1.	Fly ash (10%), Bottom Ash (5%)	23.47	23.47	50	1	62.68	1.24	129.19	1.47	7.37	0.18	3.69	0.07
2.	Fly ash (15%), Bottom Ash (5%)	23.47	23.47	50	1	62.68	1.24	129.19	1.47	11.06	0.27	3.69	0.07
3.	Fly ash (25%), Bottom Ash (5%)	23.47	23.47	50	1	55.30	1.09	129.19	1.47	14.75	0.36	3.69	0.07
4.	Fly ash (35%), Bottom Ash (5%)	23.47	23.47	50	1	44.24	0.88	129.19	1.47	25.81	0.64	3.69	0.07

The table above shows the composition of the mixture per 1 m3 that has been adjusted to the equipment usually used in the field for road curbs. Table 2.2 shows the composition for paver blocks, while Table 2.3 is for Roadbase.

Table 2.2 Mix design for the paver block in 1 bag of cement (1 cement: sand with 15% Fly Ash Bottom Ash, 20% Fly Ash Bottom Ash, 25% Fly Ash Bottom Ash, and 30% Fly Ash Bottom Ash)

No	Composition (%)	Water		Cement		Sand		Fly Ash		Bottom Ash	
		Litre	Litre	Kg	Bag	Kg	Mold	Kg	Dolak	Kg	Mold
1.	Fly ash (10%). Bottom Ash (5%)	24.06	24.06	50	1	127.5	2.17	1155	0.3737	7.57.5	0.114
2.	Fly ash (15%). Bottom Ash (5%)	24.06	24.06	50	1	120	2.05	22.522,5	0.5555	7.57.5	0.140,14
3.	Fly ash (20%). Bottom Ash (5%)	24.06	24.06	50	1	112.5	1.92	30300	0.7474	7.57.5	0.140,14
4.	Fly ash (25%). Bottom Ash (5%)	24.06	24.06	50	1	105	1.79	37.537,5	0.9292	7.57.5	0.140,14

Notes: Mixture ratio (1 cement : 3 sand : 0.48 water)
Where sand is tested to be substituted by fly ash and bottom ash

Table 2.3 Mix design for the roadbase

Number	Fly Ash		Bottom Ash		Cement	
	%	Ratio	%	Ratio	%	Ratio
1.	60	6	10	1	30	3
2.	70	7	10	1	20	2

3.	80	8	10	1	10	1
4.	87.5	8.75	2.5	0.25	10	1
5.	92.5	9.25	2.5	0.25	5	0.5
6.	85	8.5	5	0.5	10	0.1
7.	90	9	5	0.5	5	0.5
8.	85	8.5	10	1	5	0.5
9	82.5	8.25	7.5	0.75	5	0.5

2. RESULTS AND DISCUSSIONS

Compressive Strength of concrete blocks with Fly Ash and Bottom Ash mix

The composition of fly ash and bottom ash as additional materials for concrete blocks refers to Table 3.1. In addition to the difference in composition, concrete blocks also have different soaking times, namely 7 days, 14 days, and 28 days to then observe their compressive strength. Figure 3.1 shows the difference in compressive strength at each soaking time. The best compressive strength that certainly meets the criteria is obtained at a composition of 10% Fly Ash and 5% Bottom Ash through a soaking time of 7 days. Compressive strength begins to decrease at a soaking time of 14 days due to the larger amount of water mixture in the mixing process.

Table 3.1 Compressive Strength of Concrete Block

No	Composition (%)	Compressive Strength (Kg/cm^2)		
		I	II	III
1.	Fly ash (10%), Bottom Ash (5%)	89.65	43.69	58.73
2.	Fly ash (15%), Bottom Ash (5%)	13.02	15.15	18.94
3.	Fly ash (20%), Bottom Ash (5%)	11.36	18.84	22.29
4.	Fly ash (25%), Bottom Ash (5%)	22.51	56.82	71.97

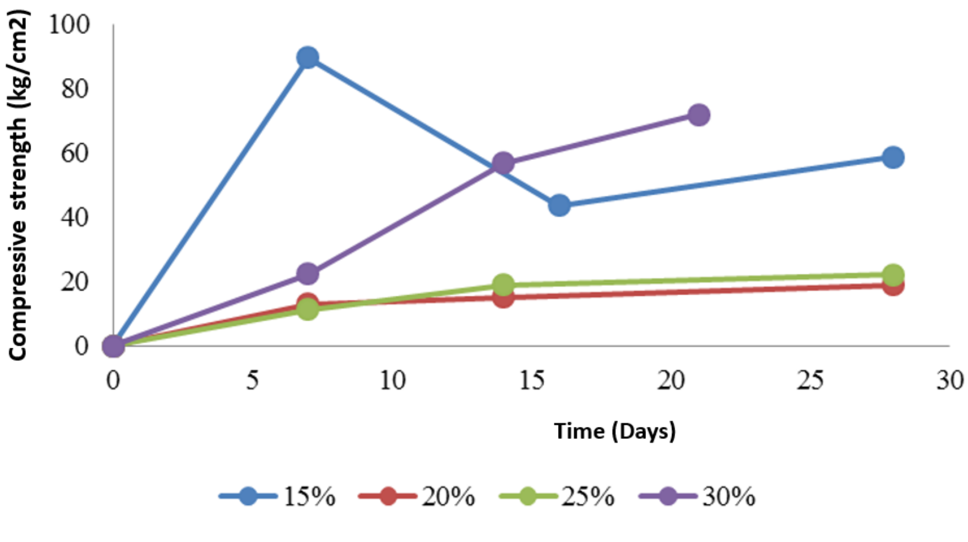

Figure 3.1. Compressive strength of concrete block

Compressive Strength of road curb with Fly Ash and Bottom Ash mix

A road curb is a protective edge of the sidewalk that can be in direct contact with vehicle wheels. Therefore, the structure of the road curb with sufficient material strength is the main consideration which consists of cement, sand, and gravel (aggregate). In this study, the amount of sand used was partly substituted with fly ash and bottom ash.

The composition of fly ash and bottom ash as additional materials for road curbs refers to Table 3.2. In addition to the difference in composition, road curbs also have different soaking times, namely 7 (seven) days, 14 (fourteen) days, and 28 (twenty-eight) days to then observe their compressive strength.

Table 3.2 Compressive Strength of Road Curb

No	**Composition (%)**	**Compressive Strength (Kg/cm^2)**		
		I	**II**	**III**
1.	Fly ash (10%), Bottom Ash (5%)	299.26	289.48	324.44
2.	Fly ash (15%), Bottom Ash (5%)	328.89	371.26	355.56
3.	Fly ash (25%), Bottom Ash (5%)	302.22	371.26	339.26
4.	Fly ash (35%), Bottom Ash (5%)	205.93	294.81	324.44

Figure 3.1 shows the difference in compressive strength of road curb.

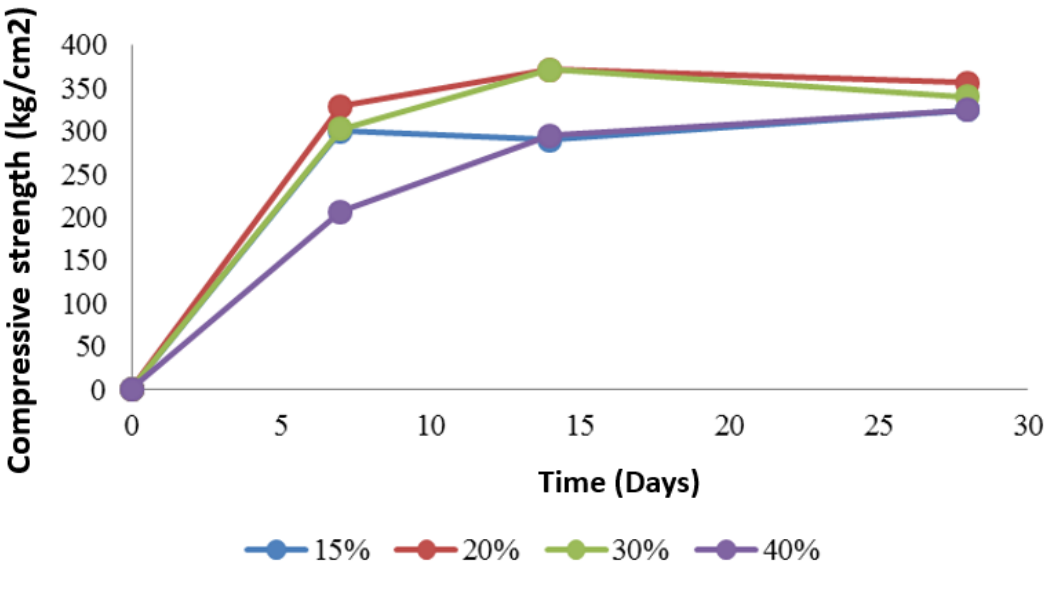

Figure 3.2. Compressive strength of road curb

Figure 3.2 shows the difference in compressive strength at each soaking time. The best compressive strength that certainly meets the criteria of K-250 concrete was obtained in the composition of 25% fly ash and 5% bottom ash with a soaking time of 7 (seven) days, as well as for the composition of 35% fly ash and 5% bottom ash with a soaking time of 14 (fourteen) days. In addition to the quality criteria of K-250 concrete, it is necessary to conduct further testing of Specific Gravity Absorption on fly ash and bottom ash to consider the use or addition of water. This can affect the compaction process which causes low workability because if the water factor is 0.46 with a water requirement per m3 of 205, the slump value is only 1.

Compressive Strength of Paver Block with Fly Ash and Bottom Ash mix

The composition of fly ash and bottom ash as additional materials for paver blocks refers to Table 3.3. In addition to the difference in composition, paver blocks also have different soaking times, namely 7 (seven) days, 14 (fourteen) days, and 28 (twenty-eight) days to then observe their compressive strength. Figure 3.3 shows the difference in compressive strength at each soaking time.

Table 3.3 Compressive Strength of Paver Block

No	Composition (%)	Compressive Strength (Kg/cm^2)		
		I	II	III
1.	Fly ash (10%), Bottom Ash (5%)	250.87	250.87	271.00
2.	Fly ash (15%), Bottom Ash (5%)	125.44	126.98	173.44
3.	Fly ash (20%), Bottom Ash (5%)	71.23	55.75	65.04
4.	Fly ash (25%), Bottom Ash (5%)	60.39	56.68	72.78

Figure 3.3 shows the increase in compressive strength along with the length of soaking time, where the longer the soaking time, the more the compressive strength increases. Based on SNI 03 – 0691 – 1996 on compressive strength requirements, grade B concrete bricks have a minimum compressive strength of 20 MPa. Therefore, the composition of 10% fly ash and 5% bottom ash with a soaking time of 7 (seven) days meets the specifications for grade B concrete quality.

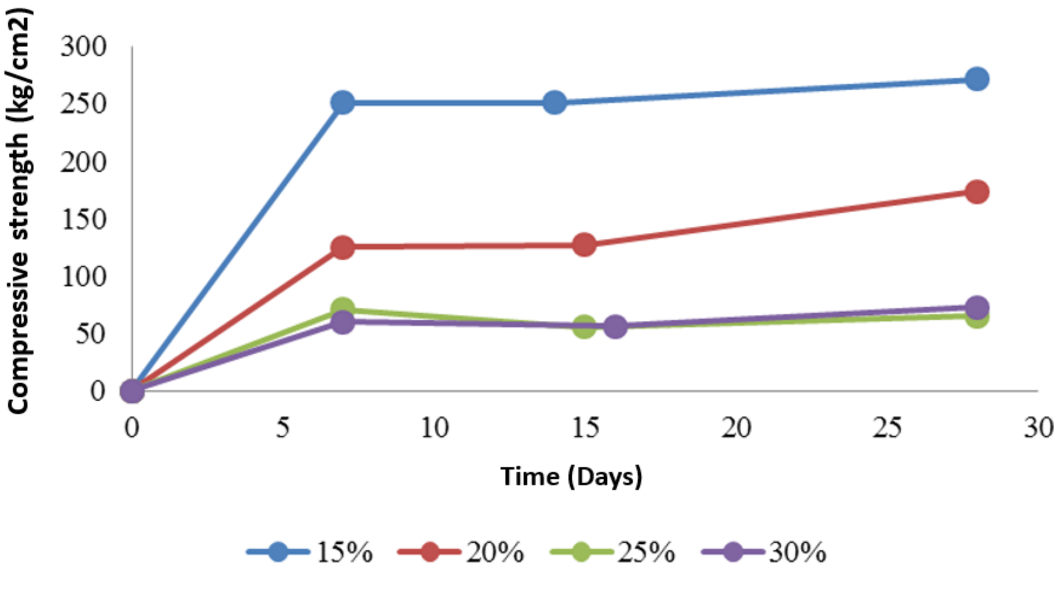

Figure 3.3 Compressive strength of paver block

Technium Vol. 25, pp.34-43 (2024)
ISSN: 2668-778X
www.techniumscience.com

Characteristics of Road Base with Fly Ash and Bottom Ash

In general, a road base is usually formed from selected fill soil material. This study tried to utilize fly ash and bottom ash to substitute soil in the road base. Of course, in the mixing process, fly ash and bottom ash binders are needed, in this case, cement. Table 3.4 shows the results of road base testing with the addition of fly ash and bottom ash.

Table 3.4 Results of Roadbase Material Testing

No	Test	Method	Results	Criteria	Description
Composition Fly Ash (60%). Bottom Ash (10%). Portland Cement (30%)					
1.	Atterberg Limit : Liquid Limit (LL) Plastic Limit (PL) Plasticity Index (PI)	 SNI 1967-2008 SNI 1966-2008 SNI 1966-2008	 31.56% 24.82% 6.74%	 - - Max 10%	 - - Passed
2.	Sieve Analysis	SNI 03-1968-1990		-	-
3.	Spesific Gravity (GS)	SNI 1964-2008	2.75	Min 2	Passed
4.	Compaction Standart : Max. Dry Density Opt. Moisture Content	 SNI 1742-2008 SNI 1742-2008	 2.04 gr/cm^3 19%	 - -	 - -
5.	CBR Soaked	SNI 1744: 2012	215%	Min. 60%	Passed
Composition Fly Ash (70%). Bottom Ash (10%). Portland Cement (20%)					
1.	Atterberg Limit : Liquid Limit (LL) Plastic Limit (PL) Plasticity Index (PI)	 SNI 1967-2008 SNI 1966-2008 SNI 1966-2008	 32.03% 26.335 5.70%	 - - Max 10%	 - - Passed
2.	Sieve Analysis	SNI 03-1968-1990		-	Passed
3.	Spesific Gravity (GS)	SNI 1964-2008	2.68	Min 2	Passed
4.	Compaction Standart : Max. Dry Density Opt. Moisture Content	 SNI 1742-2008 SNI 1742-2008	 1.90 gr/cm^3 19.62%	 - -	 - -
5.	CBR Soaked	SNI 1744: 2012	203%	Min. 60%	Passed
Composition Fly Ash (80%). Bottom Ash (10%). Portland Cement (10%)					
1.	Atterberg Limit : Liquid Limit (LL) Plastic Limit (PL) Plasticity Index (PI)	 SNI 1967-2008 SNI 1966-2008 SNI 1966-2008	 29.20% 25.11% 4.09%	 Max 10%	 Passed
2.	Sieve Analysis	SNI 03-1968-1990		-	Passed
3.	Spesific Gravity (GS)	SNI 1964-2008		Min 2	
4.	Compaction Standart : Max. Dry Density Opt. Moisture Content	 SNI 1742-2008 SNI 1742-2008	 1.73 gr/cm^3 20.69%	 - -	 - -
5.	CBR Soaked	SNI 1744: 2012	111.7%	Min. 60%	Passed
Composition Fly Ash (87.5%). Bottom Ash (2.5%). Portland Cement (10%)					
1.	Atterberg Limit : Liquid Limit (LL) Plastic Limit (PL) Plasticity Index (PI)	 SNI 1967-2008 SNI 1966-2008 SNI 1966-2008	 34.12% 24.38% 9.74%	 - - Max 10%	 - - Passed
2.	Sieve Analysis	SNI 03-1968-1990		-	Passed
3.	Spesific Gravity (GS)	SNI 1964-2008	2.58	Min 2	Passed
4.	Compaction Standart :				

Technium Vol. 25, pp.34-43 (2024)
ISSN: 2668-778X
www.techniumscience.com

	Max. Dry Density Opt. Moisture Content	SNI 1742-2008 SNI 1742-2008	1.69 gr/cm^3 23.42%	- -	- -
5.	CBR Soaked	SNI 1744: 2012	89.4%	Min. 60%	Passed
Composition Fly Ash (92.5%). Bottom Ash (2.5%). Portland Cement (5%)					
1.	Atterberg Limit : Liquid Limit (LL) Plastic Limit (PL) Plasticity Index (PI)	 SNI 1967-2008 SNI 1966-2008 SNI 1966-2008	 38.42% 26.36% 12.06%	 - - Max 10%	 - - Passed
2.	Sieve Analysis	SNI 03-1968-1990		-	Passed
3.	Spesific Gravity (GS)	SNI 1964-2008	2.57	Min 2	Passed
4.	Compaction Standart : Max. Dry Density Opt. Moisture Content	 SNI 1742-2008 SNI 1742-2008	 1.64 gr/cm^3 20.35%	 - -	 - -
5.	CBR Soaked	SNI 1744: 2012	60.2%	Min. 60%	Passed
Composition Fly Ash (85%). Bottom Ash (5%). Portland Cement (10%)					
1.	Atterberg Limit : Liquid Limit (LL) Plastic Limit (PL) Plasticity Index (PI)	 SNI 1967-2008 SNI 1966-2008 SNI 1966-2008	 38.92% 26.85% 13.07%	 - - Max 10%	 - - Failed
2.	Sieve Analysis	SNI 03-1968-1990		-	Passed
3.	Spesific Gravity (GS)	SNI 1964-2008		Min 2	
4.	Compaction Standart : Max. Dry Density Opt. Moisture Content	 SNI 1742-2008 SNI 1742-2008	 1.715 gr/cm^3 23.44%	 - -	 - -
5.	CBR Soaked	SNI 1744: 2012	79.88%	Min. 60%	Passed
Composition Fly Ash (90%). Bottom Ash (5%). Portland Cement (5%)					
1.	Atterberg Limit : Liquid Limit (LL) Plastic Limit (PL) Plasticity Index (PI)	 SNI 1967-2008 SNI 1966-2008 SNI 1966-2008	 37.59% 25.68% 11.91%	 - - Max 10%	 - - Failed
2.	Sieve Analysis	SNI 03-1968-1990		-	Passed
3.	Spesific Gravity (GS)	SNI 1964-2008	2.58	Min 2	Passed
4.	Compaction Standart : Max. Dry Density Opt. Moisture Content	 SNI 1742-2008 SNI 1742-2008	 1.68 gr/cm^3 21.84%	 - -	 - -
5.	CBR Soaked	SNI 1744: 2012	63.5%	Min. 60%	Passed
Composition Fly Ash (85%). Bottom Ash (10%). Portland Cement (5%)					
1.	Atterberg Limit : Liquid Limit (LL) Plastic Limit (PL) Plasticity Index (PI)	 SNI 1967-2008 SNI 1966-2008 SNI 1966-2008	 40.86% 26.53% 14.33%	 - - Max 10%	 - - Failed
2.	Sieve Analysis	SNI 03-1968-1990		-	Passed
3.	Spesific Gravity (GS)	SNI 1964-2008	2.58	Min 2	Passed
4.	Compaction Standart : Max. Dry Density Opt. Moisture Content	 SNI 1742-2008 SNI 1742-2008	 1.69 gr/cm^3 22.76%	 - -	 - -
5.	CBR Soaked	SNI 1744: 2012	80%	Min. 60%	Passed
Composition Fly Ash (82.5%). Bottom Ash (7.5%). Portland Cement (5%)					
1.	Atterberg Limit : Liquid Limit (LL) Plastic Limit (PL) Plasticity Index (PI)	 SNI 1967-2008 SNI 1966-2008 SNI 1966-2008	 36.36% 28.97% 7.39%	 - - Max 10%	 - - Passed

2.	Sieve Analysis	SNI 03-1968-1990		-	Passed
3.	Spesific Gravity (GS)	SNI 1964-2008	2.62	Min 2	Passed
4.	Compaction Standart : Max. Dry Density Opt. Moisture Content	 SNI 1742-2008 SNI 1742-2008	 1.73 gr/cm^3 23.36%	 - -	 - -
5.	CBR Soaked	SNI 1744: 2012	99.2%	Min. 60%	Passed

Figure 3.4 shows the relationship between composition of fly ash and bottom ash with CBR Soaked.

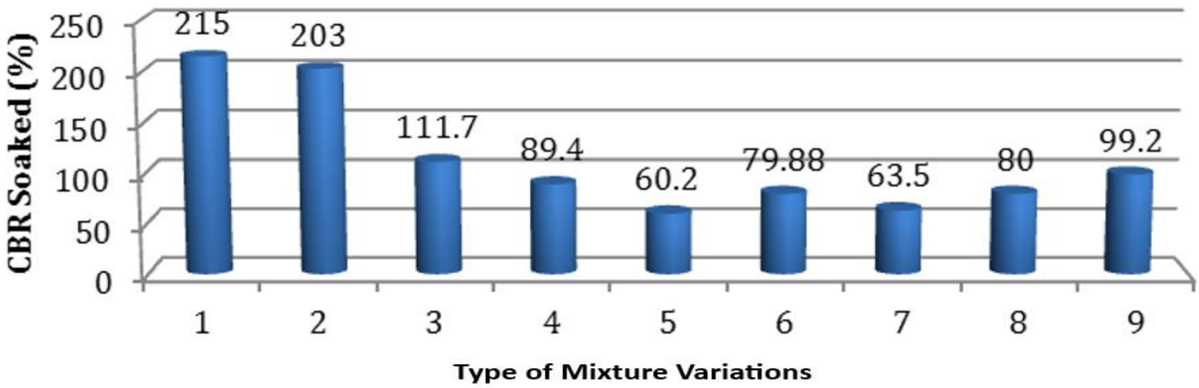

Figure 3.4 Comparison of CBR values for each composition

Figure 3.4 shows that all compositions meet the requirements for roadbase technical specifications because they produce CBR values that exceed the minimum CBR value for road bases. Based on the 2010 Technical Specifications Revision III by the Directorate General of Highways, Ministry of Public Works and Housing, the minimum CBR value for class B road bases is 60%. By considering the ease of implementation of physical characteristics in the form of progressive brittleness that quickly breaks (fails), the use of composition 4 (87.5% FA + 2.5% BA + 10% Cement) with a CBR value = 89.4%, and composition 6 (85% FA + 5% BA + 10% Cement) with a CBR value = 79.9% are suitable mixture compositions that meet the requirements for road bases.

3. CONCLUSION

Based on the results, it can be concluded that :

1. To meet SNI 03 – 0349 – 1989 on compressive strength requirements for class II concrete block quality (K-70), the best composition for concrete blocks is 1 cement: 3 sand: 0.48 water with the addition of 10% fly ash and 5% bottom ash soaked for 7 (seven) days.
2. To meet Job Mix Formula K-250 referring to SNI 03-2834-2000 after meeting the compressive strength test, the best composition for road curbs is 1 cement: 2.58 Gravel: 1.25 sand: 0.47 water with the addition of 0.15 fly ash and 0.07 bottom ash soaked for 7 (seven) days.
3. To meet SNI 03 – 0691 – 1996 on compressive strength requirements for grade B concrete bricks, the best composition for paver blocks is 1 cement: 3 sand: 0.48 water and the addition of 10% fly ash and 5% bottom ash soaked for 7 (seven) days.
4. Based on the tests that have been carried out for the mixture on the road base, the best composition for implementation in the field is 85% fly ash, 5% bottom ash, and 10% Portland cement.

ACKNOWLEDGEMENT

A gratitude is expressed to PT. Pembangkit Jawa Bali O & M Business Unit, Pulangpisau Steam Power Plant, Central Kalimantan, which has given the author the trust to conduct a study on the utilization of fly ash and bottom ash from coal ash from the Pulangpisau Steam Power Plant.

REFERENCES

[1] ACI Committee 304.1, *Guide for the use of preplaced aggregate concrete for structural and mass concrete applications* (Farmington Hills, Michigan, USA, 2005).
[2] Antono, A, 1971, *Diktat Teknolog Beton*, FT UGM, Yogyakarta.
[3] ASTM C 618-05, *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete.*
[4] ASTM C 9391, *Flow of Grout for Preplaced-Aggregate Concrete (Flow Cone Method).*
[5] ASTM C3, *Standard Specification for Concrete Aggregates*.
[6] Badan Standarisasi Nasional, 2004, SNI 15-2049-2004, *Semen Portland*, Jakarta: Badan Standarisasi Nasional.
[7] Badan Standarisasi Nasional, 2014, SNI 03-2460-2014, Spesifikasi Abu Terbang, Jakarta: Badan Standarisasi Nasional.
[8] Badan Standarisasi Nasional, 2016, SNI 03-641-2016, Spesifikasi Pengencer Graut untuk Beton Agregat Praletak, Jakarta: Badan Standarisasi Nasional.
[9] Bouzoubaâ, N., Bilodeau, A., Sivasundaram, V., Fournier, B., and Golden, D. 2004. Development of Ternary Blends for High-Performance Concrete. ACI Materials Journal,, 101: 19-29
[10] Joshi RC, 1979, Sources of pozzolanic activity in fly ashes—a critical review. In: Proceedings of the 5th International Fly Ash Utilization Symposium, Atlanta, GA, USA, pp 610–623.
[11] Mulyono, Tri, 2005, Teknologi Beton. Yogyakarta , C.V ANDI OFFSET.
[12] Satyarno, Imam, 2015, Perancangan Praktis Campuran Beton, Universitas Gadjah Mada.
[13] Siddique, R., Iqbal dan Khan M., 2011, Supplementary Cementing Materials, Springer-Verlag, Berlin Heidelberg.
[14] Soeherman,Ogi, 2015, Pemanfaatan Abu Vulkanik Gunung Kelud Sebagai Bahan Substitusi Semen Untuk Graut Mortar Pada Beton dengan Metode Pengerjaan Preplaced Aggregate Concrete, Teknik Sipil, Universitas Gadjah Mada.
[15] Soetjipto, Ismoyo, 1978, Konstruksi Beton 1, PT.Gaya Tunggal G.T, Jakarta
[16] Taylor, 1997, Cement Chemistry. London: Thomas telford.
[17] Tjokrodimuljo, K., 1996, Teknologi Beton, Nafiri. Yogyakarta
[18] Tjokrodimuljo, K., 2007, Teknologi Beton, Biro Penerbit Teknik Sipil Keluarga Mahasiswa Teknik Sipil dan Lingkungan, Universitas Gadjah Mada Yogyakarta.
[19] Yung, Wang H., Ten, Kuo W.,Chung Lin C., and Yo, C. 2013. Study of the Material Properties of Fly Ash Added to Oyster Cement Mortar. Construction and Building Materials.