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Original Article

Utilization of Fly Ash and Bottom Ash Coal-Fired Power Plant Teluk Balikpapan as Subgrade

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Abstract - *Coal-Fired Power PlantTeluk Balikpapan is a power plant located in the Kariangau Industrial Estate, Balikpapan, Indonesia, with a capacity of 2 x110 MWMW with coal consumption reaching 140 tons/hour or 3,360 tons/day. Besides generating electricity, burning coal also produces waste in the form of fly ash (fly ash/FAFA) and bottom ash (basic ash/BABA) with 150 tons and 18 tons, respectively. FAFA and BABA are waste from coal combustion from several studies state that FAFA and BABA can be used as supporting materials or substitutes for cement. Therefore, the Balikpapan Bay, which produces FAFA and BABA, has the potential to support the construction of the new National Capital. Research on FAFA and BABA of Teluk Balikpapan as a subgrade was carried out through the CBR (California Bearing Ratio) with 5 mixed compositions of FAFA, Cement, Aggregate, and Sand. The test results show that the Subgrade with a composition of 100% FAFA has a quality of 15.32%. These results show that FAFA and BABA have excellent quality and are in accordance with the standards to be used as supporting materials for developing the National Capital.*

Keywords - *Fly Ash, Bottom ash, Subgrade.*

1. Introduction

Electrical energy has become a primary need for today's society. Based onelectricity statistical data in 2016, electricity consumption in all regionsof Indonesia reached 247,416.06 MWh with around 258 million. So thatIndonesia's per capita electricity consumption reaches 0.95 MWh with a high electrification ratiopower plants in Indonesia, both from the State Electricity Company (PLN) and fromthe private sector, have reached 60 MWMW, which is dominated by coal by 57.22%; followed by gas 24.82%; water 7.06%, fuel oil (BBM) 5.81%; and geothermal energynew renewable energy (EBT) of 5.09% (Directorate General of Electricity MinistryESDM, 2017). Indonesia's electricity needs will certainly continue to grow along withthe increase in population and lifestyle changes; in 2017, electricity consumption per capita reached 1,012 MWh, and in 2018 it is targeted to reach1,129 MWh. The electricity consumption per capita is one indicator of the growthcommunity economy (Anonymous, 2017).

One of the power plants that use coal as fuel is*Coal-Fired Power Plant*Teluk Balikpapan which PTPT manages. PLN (Persero) UPDK Balikpapan. Located in the Kariangau Industrial Estate (KIK) with a capacity of 2x110MWMW, with coal consumption reaching 140 tons/hour or 3,360 tons/day. Besidesgenerating electricity, burning coal also produces waste in the form of flyash (fly ash/FAFA) and bottom ash (basic ash/BABA) with 150 tons and 18 tons, respectively. According to Government Regulation No. 101 of 2014, fly ash, and bottom ashfrom Teluk Balikpapan are hazardous and toxic (B3) waste.Therefore, special handling and utilization of fly ash waste are required, and bottom ash is not to pollute the environment and provide added value.Hazardous waste can substitute raw materials, energy sources,or raw materials. Utilization of these raw materials can be done by:considering several things, including the availability of technology, product standards, andenvironmental standards. One example is fly ash and bottom ashas a substitute for cement in manufacturing concrete and mortar. Thisprocess is also knownas stabilization/solidification (S/S), which uses cement to bind andstabilize the hazardous and toxic components of fly ash and bottom ash(immobilization). In addition, the presence of fly ash and bottom ash, which are pozzolant, canincrease the concrete's overall strength.

Teluk Balikpapan, which is located in Kariangau, is close to the new national capital development project, which has the potential to utilize fly ash and bottom ash as a subbase or Subgrade. The construction project for the new national capital is estimated to have an area of 256,142 hectares (ha). With such an area, the construction project for the new nation's capital city certainly requires a lot of backfills to stabilize the soil in the area. Fly ash and bottom ash, which can be used as subgrades and subbases that can stabilize the soil, can save the national capital development budget.

2. Literature Review

2.1. Subgrade

The Subgrade serves as a place for laying the pavement layer and supports the road pavement construction above it. According to the specifications, the Subgrade is the topmost layer of the road barrier with a thickness of 30 cm, which has certain requirements according to its function, namely density and carrying capacity. The Subgrade can be in the form of compacted original soil if the original soil is good, backfill imported from other places or stabilized soil, and others. Judging from the original soil surface, the subgrade layers are divided into:

- Subgrade layer excavated soil.
- Subgrade layer, backfill soil.
- Subgrade, original soil.

The strength and durability of road pavement construction are highly dependent on the properties and bearing capacity of the Subgrade. In general, issues relating to Subgrade are as follows:

- Permanent deformation (permanent deformation) due to traffic loads.
- The nature of swelling and shrinking of the soil is due to changes in water content.
- Uneven soil bearing capacity due to differences in soil properties at adjacent locations or implementation errors such as poor density.

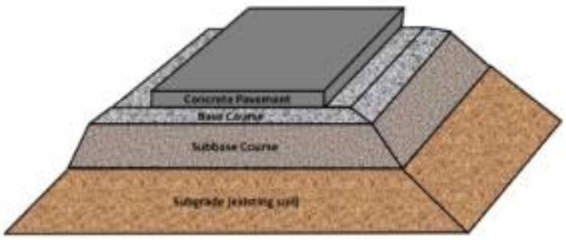

Fig. 2.1 Arrangement of pavement layers in road works

2.2. Subgrade Standard

The quality of subbase and subgrade products is determined based on the CBR (California Bearing Ratio) test and is regulated in SNI No. 1744 of 2012 concerning the Laboratory CBR Test. The minimum standard for CBR test results is regulated in the 2018 General Specifications for Road and Bridge Construction Works by the Ministry of Public Works and Public Housing, Directorate General of Highways; for subgrades, it is regulated in chapter 5.1 concerning Aggregate Foundation Layers Point 5.1.2 No. 5 where the minimum standard of CBR class B (for the sub-base layer) is above 12%.

Table 2.1. CBR Specification for Subgrade

	CBR in Base	CBR is Subbase	CBR in Subgrade
Excellent	100	50	-
Good	80	40	12+
Fair	-	30	9 - 12
Poor	50	-	4 - 8
Very Poor	1	-	<4

2.3. Fly Ash and Bottom Ash

Fly ash is a by-product of the coal combustion process in power plants. Fly ash can be obtained in boilers through several methods, including cyclone separation or electrostatic precipitation. Fly ash particles generally have a spherical shape with a diameter between 1 m to 150 m. More than 85% of the chemical content of fly ash consists of chemical compounds and glass formers, including Silicon (Si), Iron (Fe), Calcium (Ca), and Magnesium (Mg). In general, fly ash from sub-bituminous combustion has a higher Ca and lower Fe content than fly ash from Bituminous. The Canadian Standards Association (CSA) and the American Society for Testing and Materials (ASTM) classify 2 types of fly ash, namely: type C fly ash and type F fly ash. The following table shows the differences between types C and F.

Table 2.2. Fly Ash dan Bottom Ash Class

	Class		
	N	F	C
Silicon Dioxide (SiO_2) plus Aluminium Oxide (Al_2O_3) plus Iron Oxide (Fe_2O_3), min %	70.0	70.0	50.0
Sulfur Trioxide (SO_3), max (%)	4.0	5.0	5.0
Moisture Content, max (%)	3.0	3.0	3.0
Loss on Ignition, max (%)	10.0	6.0	6.0

Fly ash was known to have pozzolanic properties in the early 20th century, but until 1930 there was no significant development. In 1937 Davis et al. restarted pozzolanic properties in the FAFA, and the University of California, Berkeley used it majorly on the Hungry Horse Dam construction project in Montana. Currently, fly ash as a raw material for concrete has expanded throughout the world. Fly ash is added either as a separate component or as a component mixed with common. Concrete with fly ash mixture has had a significant meaning in some phenomenal construction works, including the Sunshine Skyway (Florida), San Francisco-Oakland Bay Bridge (California), Channel Tunnel (connecting England and France), Three Gorges Dam (China), and most recently for the tallest building in the world, the Burj Khalifa (Dubai). The presence of fly ash in concrete is known to influence several parameters, including:

a) Wet properties of concrete, including workability, rheology, water content, and pumpability

b) Rate of hydration and heat exchange (including the maximum temperature reached an early age)

c) Changes in microstructure and pores (size distribution, connectivity, and pore bends) further increase permeability.

d) Mechanical properties of concrete (compressive strength, tensile strength, flexural strength, and modulus of elasticity)

e) Volume stability (Shrinkage and creepage behavior in the long term)

f) The resistance of concrete includes, among others, chloride ion aggression and corrosion of embedded steel, alkali-aggregate reactions, sulfate attack, liquefaction, scale formation, and abrasion.

Bottom and fly ash produced from the same coal will have a similar chemical composition. Still, bottom ash has a higher amount of unburned coal so that the carbon content is greater and simultaneously has a high loss on ignition value. Bottom ash differs from fly ash in shape and particle size; bottom ash experiences agglomeration during the cooling process. It is coarser than fly ash, with a maximum particle size of 12mm (0.5 inches). Due to this fusion, bottom ash has a high crystallinity content and is less glassy than fly ash. Bottom ash generally has low pozzolanic properties, so it is less effective in being used as a substitute for cement for cementitious materials.

Table 2.3. Comparison Bottom Ash Compound

Compound	Symbol	Bottom Ash from Bituminous Coal % (Mass*)	Bottom Ash from Sub-Bituminous Coal % (Mass*)
Silicon Dioxide	SiO_2	61.0	46.7
Aluminum Oxide	Al_2O_3	25.4	18.8
Iron Oxide	Fe_2O_3	6.6	5.9
Calcium Oxide	CaO	1.5	17.8
Magnesium Oxide	MgO	1.0	4.0
Sodium Oxide	Na_2O	0.9	1.3
Potassium Oxide	K_2O	0.2	0.3

The table above shows the composition of bottom ash which is similar to fly ash, so bottom ash can also be classified into class C and class F. The fly ash and bottom ash composition tests routinely carried out at Teluk Balikpapan also show the same composition results and show that fly ash and bottom ash belong to type F.

Table 2.4. Fly Ash dan Bottom Ash Teluk Balikpapan Composition Test Result

Parameter	**Unit**	**Results**		**Method**
		Fly Ash	**Bottom Ash**	
Moisture Content	%wt	1.86	0.25	Gravimetric
Unburned Carbon	%wt	0.20	1.52	ASTM D 6316
Loss on Ignition	%wt	2.10	1.07	Gravimetric
Ash Analysis:				
Silicon Dioxide	%wt	39.55	74.47	ASTM D 3682 - 13
Aluminium Trioxide	%wt	12.72	8.22	ASTM D 3682 - 13
Iron Trioxide	%wt	20.87	6.66	ASTM D 3682 - 13
Calcium Oxide	%wt	11.20	4.81	ASTM D 3682 - 13
Magnesium Oxide	%wt	7.48	2.08	ASTM D 3682 - 13
Potassium Oxide	%wt	0.68	0.36	ASTM D 3682 - 13
Sodium Oxide	%wt	0.16	0.42	ASTM D 3682 - 13
Manganese Dioxide	%wt	0.21	0.10	ASTM D 3682 - 13
Titan Dioxide	%wt	1.71	1.47	ASTM D 3682 - 13
Phosphorus Pentaoxide	%wt	0.55	0.60	ASTM D 2795 - 95
Sulfur Trioxide	%wt	4.23	0.12	ASTM D 5016-08e1
Undeternibed	%wt	0.64	0.69	Calculation

The test results show that fly ash and bottom ash of Teluk Balikpapan are type F, where the total content of SiO_3, Al_2O_3 and Fe_2O_3 is < 70%.

3. Methods

The method used for this research is to test the California Bearing Ratio (CBR) on a predetermined composition. The test results will be adjusted to the 2018 General Specifications for Road, and Bridge Construction Works by the Ministry of Public Works and Public Housing, Director General of Highways.

3.1. Subgrade

3.1.1. Subgrade Technical Specifications

The subgrade material tested is not a chemically corrected soil material through FABA but is a subgrade replacement material that uses all FABA material combined with cement. This study uses CBR testing with the following composition:

Table 3.1. Subgrade Composition

Subgrade
- Composition 1 (100% Fly Ash)
- Composition 2 (90% Fly Ash, 10% Bottom Ash)
- Composition 3 (85% Fly Ash, 10% Bottom Ash, 5% Cement)
- Composition 4 (80% Fly Ash, 15% Bottom Ash, 5% Cement)
- Composition 5 (75% Fly Ash, 20% Bottom Ash, 5% Cement)

3.1.2. Subgrade Making Process

The testing method is done by testing the California Bearing Ratio (CBR) laboratory. Laboratory CBR tests the bearing capacity of subgrade materials and foundation layers, including recycled materials for road and airfield pavements carried out in the laboratory. The implementation is carried out with a different number of collisions: 51 collisions, 25 collisions, and 56 collisions.

4. Result and Discussion

4.1. Sub Grade Laboratory Test Results

4.1.1. Test results for Material Subgrade Composition 1 (100% Fly Ash)

The graph for testing CBR composition 1 with a mixture of 100% fly ash is shown in the following figure:

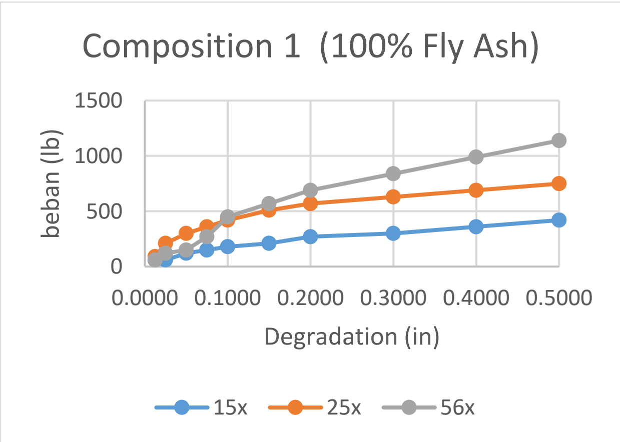

Table 4.1 Mixed Subgrade 1 CBR Graphics (100% FlyAsh)

The CBR value is determined at 0.1-inch and 0.2-inch penetrations from the CBR graph.

- Mixed CBR value of 1 for 15 hits

$$CBR0.1_{15} = \frac{180}{3000} \times 100\% = 5.99\%$$

$$CBR0.2_{15} = \frac{270}{4500} \times 100\% = 5.99\%$$

The CBR value for mixture 1 with the number of strokes 15 times is 5.99%.

- Mixed CBR value of 1 for 25 hits

$$CBR0.1_{25} = \frac{420}{3000} \times 100\% = 13.99\%$$

$$CBR0.2_{25} = \frac{569}{4500} \times 100\% = 12.65\%$$

From the calculation of the CBR value for mixture 1 with the number of strokes, 25 times is 13.99%.

- Mixed CBR value of 1 for 56 hits

$$CBR0.1_{56} = \frac{450}{3000} \times 100\% = 14.99\%$$

$$CBR0.2_{56} = \frac{689}{4500} \times 100\% = 15.32\%$$

The CBR value for mixture 1 with the number of strokes 56 times is 15.32%.

4.1.2. Test results for Material Subgrade Composition 2 (90% Fly Ash, 10% Bottom Ash)

The graph for testing CBR composition 2 with a mixture of 90% Fly Ash, 10% Bottom Ash is shown in the following figure:

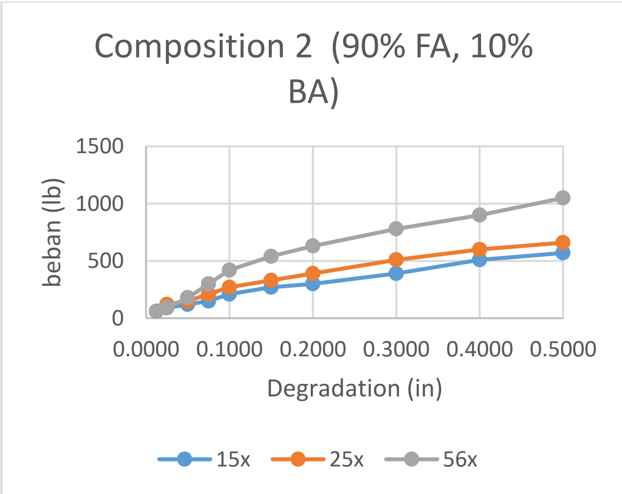

Table 4.2 Mixed Subgrade 2 CBR Graphics (90% Fly Ash, 10% Bottom Ash)

The CBR value is determined at 0.1-inch and 0.2-inch penetrations from the CBR graph.

- Mixed CBR value of 2 for 15 hits

$$CBR0.1_{15} = \frac{210}{3000} \times 100\% = 6.99\%$$

$$CBR0.2_{15} = \frac{300}{4500} \times 100\% = 6.99\%$$

The CBR value calculation for mixture 2 with the number of strokes 15 times is 6.99%.

- Mixed CBR value of 2 for 25 hits

$$CBR0.1_{25} = \frac{270}{3000} \times 100\% = 8.99\%$$
$$CBR0.2_{25} = \frac{390}{4500} \times 100\% = 8.66\%$$

The CBR value calculation for mixture 2 with the number of strokes 25 times is 8.99%.

- Mixed CBR value of 2 for 56 hits

$$CBR0.1_{56} = \frac{420}{3000} \times 100\% = 13.99\%$$
$$CBR0.2_{56} = \frac{629}{4500} \times 100\% = 13.99\%$$

The CBR value calculation for mixture 2 with the number of strokes 56 times is 13.99%.

4.1.3. Test results for Material Subgrade Composition 3 (85% Fly Ash, 10% Bottom Ash, 5% cementCement)

The graph for testing CBR composition 3 with a mixture of 85% Fly Ash, 10% Bottom Ash, 5% Cement is shown in the following figure:

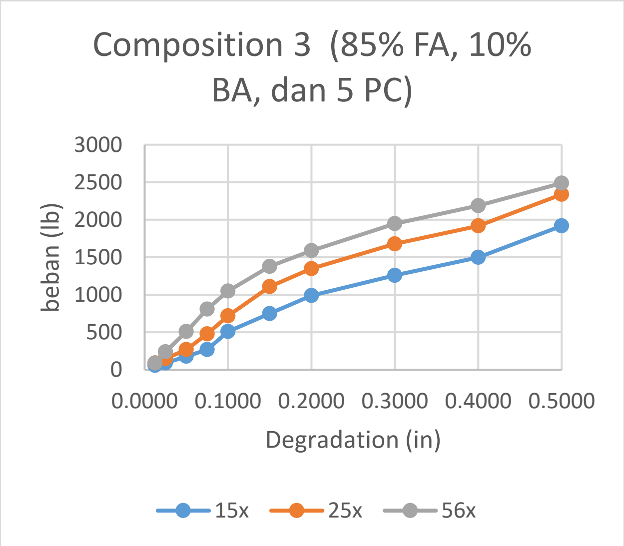

Table 4.3 Mixed Subgrade 3 CBR Graphics (85% Fly Ash, 10% Bottom Ash, 5% Cement)

The CBR value is determined at 0.1-inch and 0.2-inch penetrations from the CBR graph.

- Mixed CBR value of 3 for 15 hits

$$CBR0.1_{15} = \frac{509}{3000} \times 100\% = 16.98\%$$
$$CBR0.2_{15} = \frac{989}{4500} \times 100\% = 21.98\%$$

The CBR value calculation for mixture 3 with the number of strokes 15 times is 12.98%.

- Mixed CBR value of 3 for 25 hits

$$CBR0.1_{25} = \frac{719}{3000} \times 100\% = 23.98\%$$

$CBR0.2_{25} = \frac{1349}{4500} \times 100\% = 29.97\%$The CBR value calculation for mixture 3 with the number of strokes 25 times is 29.97%.

- Mixed CBR value of 3 for 56 hits

$$CBR0.1_{56} = \frac{1049}{3000} \times 100\% = 34.97\%$$
$$CBR0.2_{56} = \frac{1588}{4500} \times 100\% = 35.30\%$$

The CBR value calculation for mixture 3 with the number of strokes 56 times is 35.3%.

4.1.4. Test results for Material Subgrade Composition 4 (80% Fly Ash, 15% Bottom Ash, 5% cementCement)

The graph for testing CBR composition 4 with a mixture of 80% Fly Ash, 15% Bottom Ash, 5% Cement is shown in the following figure:

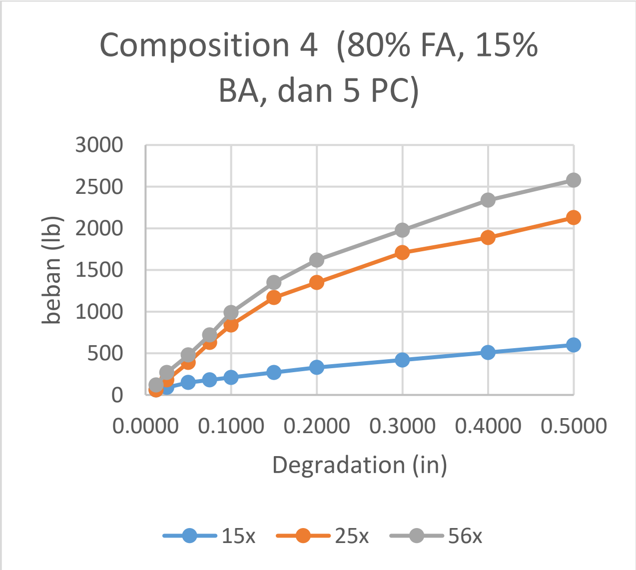

Table 4.4 Mixed Subgrade 4 CBR Graphics (80% Fly Ash, 15% Bottom Ash, 5% Cement)

The CBR value is determined at 0.1-inch and 0.2-inch penetrations from the CBR graph.

- Mixed CBR value of 4 for 15 hits

$$CBR0.1_{15} = \frac{210}{3000} \times 100\% = 6.99\%$$
$$CBR0.2_{15} = \frac{330}{4500} \times 100\% = 7.33\%$$

The CBR value calculation for mixture 4 with the number of strokes 15 times is 7.3%.

- Mixed CBR value of 4 for 25 hits

$$\text{CBR0.1}_{25} = \frac{839}{3000} \times 100\% = 27.97\%$$
$$\text{CBR0.2}_{25} = \frac{1349}{4500} \times 100\% = 29.97\%$$

The CBR value calculation for mixture 4 with the number of strokes 25 times is 29.97%.

- Mixed CBR value of 4 for 56 hits

$$\text{CBR0.1}_{56} = \frac{989}{3000} \times 100\% = 32.97\%$$
$$\text{CBR0.2}_{56} = \frac{1618}{4500} \times 100\% = 35.96\%$$

The CBR value calculation for mixture 4 with the number of strokes 56 times is 35.69%.

4.1.5. Test results for Material Subgrade Composition 5 (75% Fly Ash, 20% Bottom Ash, 5% cementCement)

The graph for testing CBR composition 4 with a mixture of 80% Fly Ash, 15% Bottom Ash, 5% Cement is shown in the following figure:

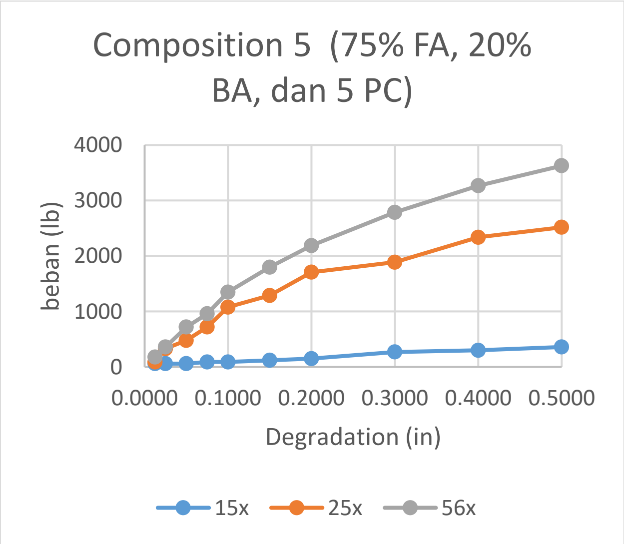

Table 4.5 Mixed Subgrade 5 CBR Graphics (75% Fly Ash, 20% Bottom Ash, 5% Cement).

- Mixed CBR value of 5 for 15 hits

$$\text{CBR0.1}_{15} = \frac{90}{3000} \times 100\% = 3.00\%$$
$$\text{CBR0.2}_{15} = \frac{150}{4500} \times 100\% = 3.33\%$$

The CBR value for mixture 5 with the number of strokes 15 times is 3.33%.

- Mixed CBR value of 5 for 25 hits

$$\text{CBR0.1}_{25} = \frac{1079}{3000} \times 100\% = 35.96\%$$
$$\text{CBR0.2}_{25} = \frac{1708}{4500} \times 100\% = 37.96\%$$

The CBR value for mixture 5 with the number of strokes 25 times is 37.96%.

- Mixed CBR value of 4 for 56 hits

$$\text{CBR0.1}_{56} = \frac{1349}{3000} \times 100\% = 44.96\%$$
$$\text{CBR0.2}_{56} = \frac{2188}{4500} \times 100\% = 48.63\%$$

The CBR value for mixture 5 with the number of strokes 56 times is 48.62%.

5. Conclusion

Based on the circular letter of the Director-General of Highways Number 02 SESE/Db/2018, the Subgrade of each place must have a CBR of at least 6%. The overall composition can reach CBR above 12% of the five compositions. It can be concluded that the five compositions can be used as subgrade substitute materials. The largest CBR value was found in a mixture of 75% Fly Ash + 20% Bottom Ash + 5% Cement, with the maximum CBR that could be achieved was 48.63%, and the largest Fly Ash utilization was found in a mixture of 100% Fly Ashwith the maximum CBR that could be achieved was 15.32%. The recapitulation and graph of the CBR test results are shown in Table 5.1.

Table 5.1. CBR Test Result Subgrade for 5 Composition

No	Composition	CBR (%)		
		15 hit	25 hit	56 hit
1	Komposisi 1 (100% FA)	5.99	13.99	15.32
2	Komposisi 2 (90% FA, 10% BA)	6.99	8.99	13.99
3	Komposisi 3 (85% FA, 10% BA, 5% PC)	21.98	29.97	35.3
4	Komposisi 4 (80% FA, 15% BA, 5% PC)	7.33	29.97	35.96
5	Komposisi 5 (75% FA, 20% BA, 5% PC)	3.33	37.96	48.63

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