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Determination of the Composition of Fly Ash, Bottom Ash and Lime or Cement Mixtures as Road Base Material. Case Study: Road Preservation of Sp. Kereng - Bereng Bengkel – Pilang – Pulang Pisau, Central Kalimantan

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ABSTRACT

Aggregate material for road subbase layers that meet specifications is hard to find in Kalimantan Island. One alternative material is a mixture of fly ash and bottom ash (FABA) with the addition of other substances such as lime or cement as binders. It is essential to determine the optimum percentage of the fly ash, bottom ash, and lime or cement mixture to meet the requirements as road subbase material. This study was conducted by creating compositions of FABA with variations 100:0; 75:25; 50:50; 25:75; and 0:100; they were tested to determine the optimum mixture of FABA as a road subbase. Afterwards, additional materials that were cement (3%, 5%, and 7%) or lime (2%, 4%, and 6%) were added to the optimum mixture of FABA; and then, they were tested to obtain the subbase material that meets the requirement of Bina Marga specification criteria. The results show that the optimum FABA material mixture is 50:50 which has the soaked CBR value of 17.03%. Additional 7% of cement or 6% of lime give the highest values of soaked CBR and UCS. For cement, the soaked CBR value is 75.68% and the UCS value is 21.448 kg/cm^2; for lime, the soaked CBR value is 60.16% and the UCS value is 27.70 kg/cm^2. Based on Bina Marga specifications, SKh 1.15.1, it is known that the FABA mixture 50:50 ratio and the additional of 7% cement or 4% lime can be uses as road base materials.

Keyword : bottom ash, cement, fly ash, lime, road base material.

INTRODUCTION

Types of road pavements in Indonesia generally consist of 2 (two) main layers, namely the surface layer and the foundation layer (Road Pavement Design Manual, 2017). Based on its specifications, the foundation layer is divided into two types, namely the sub-base course and the base course. Referring to the Bina Marga specifications (2018 Revision 2), The sub-base course and the base course must each meet the gradation specifications (Table 1.1) and properties (Table 1.2)

The existence of such specifications has led to difficulties in obtaining aggregate material in Kalimantan Island. Therefore, it very urgent to obtained alternative materials to replacing aggregates in road foundation layers. One approach is to maximize the use of recycled material,

Table 1. Gradation of Aggregate Base Course

Sieve Size		Percentage of Weight Pass	
ASTM	**(mm)**	**Class A**	**Class B**
2"	50		100
1,5"	37.4	100	88-95
1"	25	79-85	70-85
3/8"	9.5	44-85	30-65
Number. 4	4.75	29-44	25-55
Number. 10	2	17-30	15-40
Number. 40	0.425	7-17	8-20
Number. 200	0.075	2-8	2-5

Source: Specifications Bina Marga, 2018

Table 2. Properties of Aggregate Base Course

Properties	Class A	Class B
Abrasion of coarse aggregate (SNI 03-2417-1990)	0-40%	0-40%
Plasticity Index (SNI 03-1966-1990)	0-6	0-10
The product of the plasticity index and the percentage passing through sieve No. 200	max. 25	-
Liquid Limit (SNI 03-1967-1990)	0-25	0-35
Soft Portion (SNI M-0 1-1 995-03)	0-5%	0-5 %
CBR Value (SNI 03-1744-1989)	min. 90%	min. 35%

Source: Specifications Bina Marga, 2018

as suggested by Ari Widayanti et al. (2019), such as the FABA material. FABA is a material for embankments and foundation layers that has been given specific specifications by Bina Marga through SKh-1.5.15 Year 2022. This aligns with Infrastructure Asset Management (IAM) Basic Principles, emphasizing the utilization of recycled materials in the planning and design of the road network (Zhain, I. et al., 2022).

Preliminary studies abroad of using FABA as road foundation material have shown promising results, demonstrating high values of CBR (California Bearing Ratio) and UCS (Unconfined Compressive Strength). According to Wiranata, Didi Yuda, et al. (2022), a mixture with 40% fly ash, 60% bottom ash, and 10% cement yielded a UCS value of 5.2 MPa or 52 kg/cm^2 after a curing period of 28 days. Another study by Gimhan P.G.S, et al. (2018) indicated that a mixture with 50% fly ash, 50% bottom ash resulted in a CBR value of 34.9% with a Maximum Dry Density (MDD) of 1.209 g/cm^3. Comparing these research findings to the requirements for the road foundation layer using coal fly ash and bottom ash specified by Bina Marga (SKh-1.5.15, 2022), it appears that the achieved values surpass the specified limits. The target UCS value for the mixture, according to Bina Marga's specifications, is 25 kg/cm^2.

The research location is situated within the scope of the preservation and widening project towards the road standard of Sp. Kereng – Bereng Bengkel – Pilang – Pulang Pisau in Central Kalimantan province, enabling the use of FABA as a material for road foundation (Dedy Manudianto, et al., 2023). This feasibility is attributed to the presence of the asphalt mixing plant (AMP) service provider located 11 km north of the PLTU Pulang Pisau power plant. Figure 1 illustrates the map of the research location, while Figure 2 shows a photo depicting the field condition of material stockpiling in the service provider's stockyard.

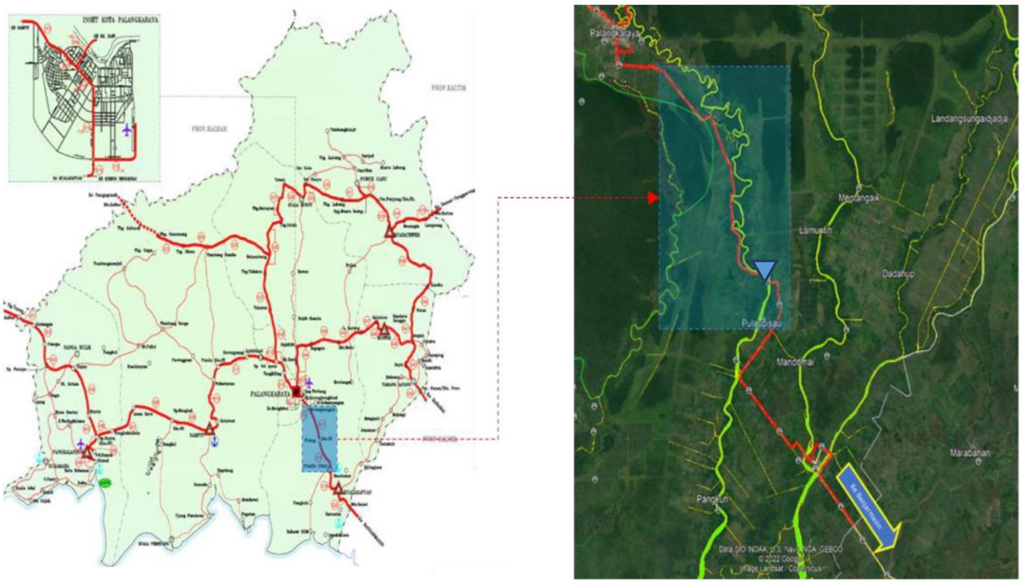


Figure 1. Research location map

Figure 2. Stockpile of ash material from Pulang Pisau Power Plant

Therefore, research needs to be conducted regarding the optimal content of fly ash, bottom ash, as well as additional materials for the foundation layer to ensure that the infrastructure can be effectively utilized, which is one of the prerequisites for infrastructure to function effectively (Soemitro & Suprayitno, 2020). Hence, this study will involve the production of foundation layer material (in accordance with Bina Marga specifications), which is a mixture of FABA, and either cement or lime. The expectation is that this mixed material can be used as an alternative foundation layer material for road construction in Kalimantan, particularly in Central Kalimantan.

LITERATURE REVIEW

Specifications of Road Base Using FABA Mixtures

According to the specific specifications of Bina Marga SKh 1.5-15 regarding embankment choices and the foundation layer using FABA, the foundation layer using FABA is a part of the pavement situated between the surface and the sub-base (or with the natural ground if not using a sub-base). It utilizes coal ash as the primary material, serving as the pavement section that bears wheel loads, acts as a foundation for the surface layer, and has minimum requirements for Unconfined Compressive Strength (UCS) values (Table 1). The mix for the foundation layer, as per these specific specifications, is not allowed to use only bottom ash since it is susceptible to the influence of water.

Table 3. The requirement for Unconfined Compressive Strength (UCS) values in the foundation layer using FABA.

Testing	UCS (Curing 7 days) Minimum	Target	Maximum	Testing Method
UCS, kg/cm^2	20	24	35	SNI 6887:2012

Source: Specifications of Bina Marga, (2022)

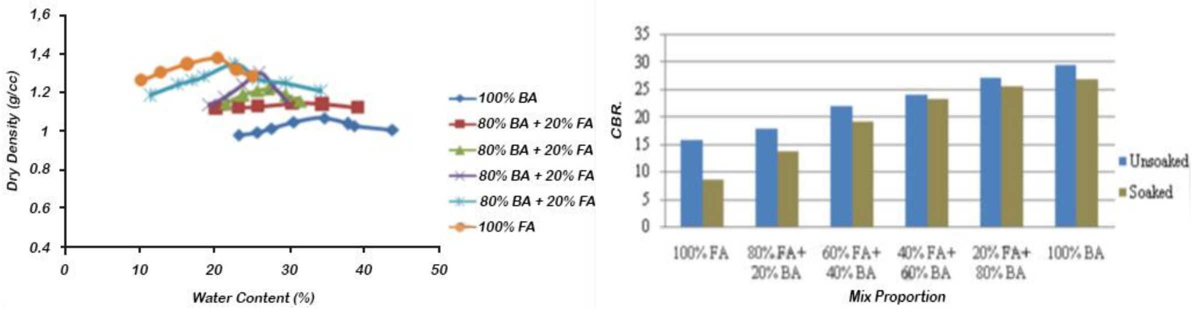
Characteristics of FABA Mixtures as Road Construction Materials

The research by Kumar Dilip et al. (2012) shows that based on the value of Cu and Cc, the mixture of FABA exhibits a well-graded particle gradation. Another impact of increasing the fly ash content in the mixture on physical parameters is evident with the rise in Maximum Dry Density (MDD) values and a decrease in Optimum Moisture Content (OMC), accompanied by a reduction in the coefficient of permeability (Table 2 and Figure 3a). This happens as the mixture's fine aggregate concentration increases and particular surface size is added. The increase in MDD values leads to an improvement in the CBR values, as illustrated in Figure 3b.

Table 4. The Difference in Properties of FABA Mixtures in Various Proportions

Mix Design	**MDD (g/cc)**	**OMC (%)**	**Coefficient of Permeability (cm/sec)**	**Cohesion (c) (Kg/cm^2)**		**Angle of Shearing Resistance (ϕ)**	
				Dry	**Wet**	**Dry**	**Wet**
100% FA	1,370	18,60	5,580 x 10^{-4}	0,205	0,01	25,8°	23,0°
80% FA + 20% BA	1,340	20,86	6,125 x 10^{-4}	0,255	0,025	33,5°	32,0°
60% FA + 40% BA	1,295	23,10	6,80 x 10^{-4}	0,250	0,03	34,5°	31,5°
40% FA + 60% BA	1,220	25,98	7,874 x 10^{-4}	0,230	0,020	30,0°	29,0°
20% FA + 80% BA	1,150	28,98	8,510 x 10^{-4}	0,220	0,004	31,5°	26,5°
100% BA	1,080	32,00	9,613 x 10^{-4}	0,205	0,02	36,0°	34,0°

Source: Kumar, Dilip, et al, (2012)



(a) (b)

(Souce: Kumar Dilip, et al, 2012)

Figure 3. Relationship between: (a) Dry Density and Water Content; (b) CBR Values and Variations in FABA Mixture Content

The Use of FABA as Foundation Layer Material

According to Sahu, Vaishali, (2016), the use of a 50% fly ash content, 50% lime sludge waste, mixed with 12% lime, and 1% gypsum can produce an optimal mixture as a base course material. This is evidenced by the increasingly favorable mechanical properties of the mixture when subjected to prolonged curing, as shown in Table 3.

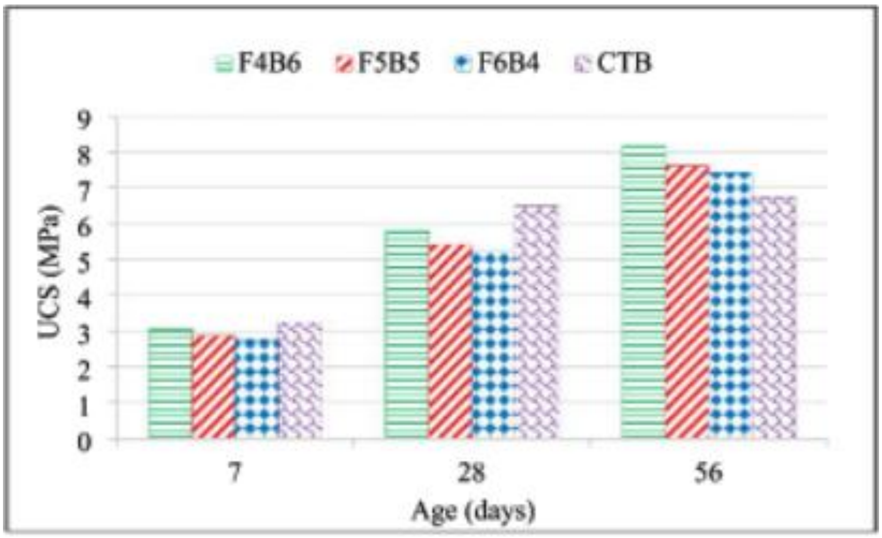
Another study by Wiranata, Didi Yuda, et al. (2022), which utilized the stabilization of a mixture of FABA, and cement as a base material, demonstrated that an increase in the bottom ash content in the mixture leads to higher Unconfined Compressive Strength (UCS) values (Figure 4)

Table 5. The Optimal Properties of the Mixture

Composition	UCS (kPa) for different curing period (days)				CBR (%)		STS (kPa)		
	7	28	45	90	7 days Curing	4 Days Soaked	28 Days	45 Days	90 Days
(50FA + 50LS) + 12 CL + 1G	2084	5871	7021	9354	65	48	940	1263	1862

Source: Sahu, Vaishali, et al, (2016)

Another study by Wiranata, Didi Yuda, et al. (2022), which utilized the stabilization of a mixture of FABA, and cement as a base material, demonstrated that an increase in the bottom ash content in the mixture leads to higher Unconfined Compressive Strength (UCS) values (Figure 4). Additionally, the influence of the curing time on the UCS values exhibited positive behavior across all mixture variations. As the curing time increased, the resulting UCS values also increased (Figure 4). In this investigation, the mixture variation including 40% fly ash, 60% bottom ash, and 10% cement yielded the highest UCS value.



(Source: Wiranata, Didi Yuda, et al, 2022)

Figure 4. Relationship between UCS Values and the Influence of Curing Time

RESEARCH METHODS

Samples for the study taken from the PLTU Pulang Pisau in the form of fly and bottom ash. These materials was tested using X-Ray Fluorescence (XRF) and sieve analysis to get the classification of fly ash and bottom ash. Next, a mixture will be made using FABA with the following FA:BA composition 100:0; 75:25; 50:50; 25:75; and 0:100. All these variations were carried out several tests such as: gravimetric-volumetric, Atterberg limits, sieve and hydrometer analysis and CBR (California Bearing Ratio) equivalent to Proctor test, that being used to determine the optimum mixture use in the blending of FABA materials with cement or lime to obtain a foundation layer material using FABA that meets the Bina Marga specifications.

After obtaining the optimum faba mixture, then the mixture is mixed with cement or lime additives with respective levels given for cement of 3%, 5% and 7% while for lime 2%, 4% and 6%. Each variation of the mixture was tested gravimetric-volumetric tests, CBR and UCS, including CBR and UCS (Unconfined Compressive Strength). Subsequently, the determination of the mixture that meets the Bina Marga specifications Next, a mixture was determined that meets Bina Marga's specifications for each FABA-cement mixture and FABA-lime mixture.

DATA COLLECTION

Fly Ash and Bottom Ash Material from PLTU Pulang Pisau

Determination of mineralogical content in fly ash and bottom ash is carried out in compliance with ASTM C618 guidelines. In this case, XRF test data obtained from the Pulang Pisau Power Plant (PLTU Pulang Pisau) are being used. The test data for January and April 2023 are provided in Table 4.

Table 6. Summary of XRF Analysis Tests

No	Sample	SiO2 %	Al2O3 %	Fe2O3 %	CaO %	MgO %	Na2O %	K2O %	SO3 %
1	Fly Ash January	38,59	10,16	19,98	16,51	9,06	0,42	0,87	3,43
2	Fly Ash April	31,74	16,02	19,78	18,20	8,42	0,79	0,86	2,72
3	Bottom Ash January	82,44	5,00	3,26	3,70	3,12	0,34	0,61	0,03
4	Bottom Ash April	50,76	7,16	16,96	14,38	7,39	0,58	0,54	0,07

No	Sample	Loss On Ignition %	Moisture Content %	Fineness 45 µm %
1	Fly Ash January	0,07	0,08	16,90
2	Fly Ash April	1,47	3.9	0,05
3	Bottom Ash January	0,23	0,03	0,10
4	Bottom Ash April	1,01	6,02	0,02

Source: PT. Sucofindo, 2023

By using the obtained parameters and meeting the chemical and physical requirements of ASTM C618, the classification of fly ash material falls into Class C criteria, and for bottom ash material, it falls into Class N or F criteria.

RESEARCH ANALYSIS

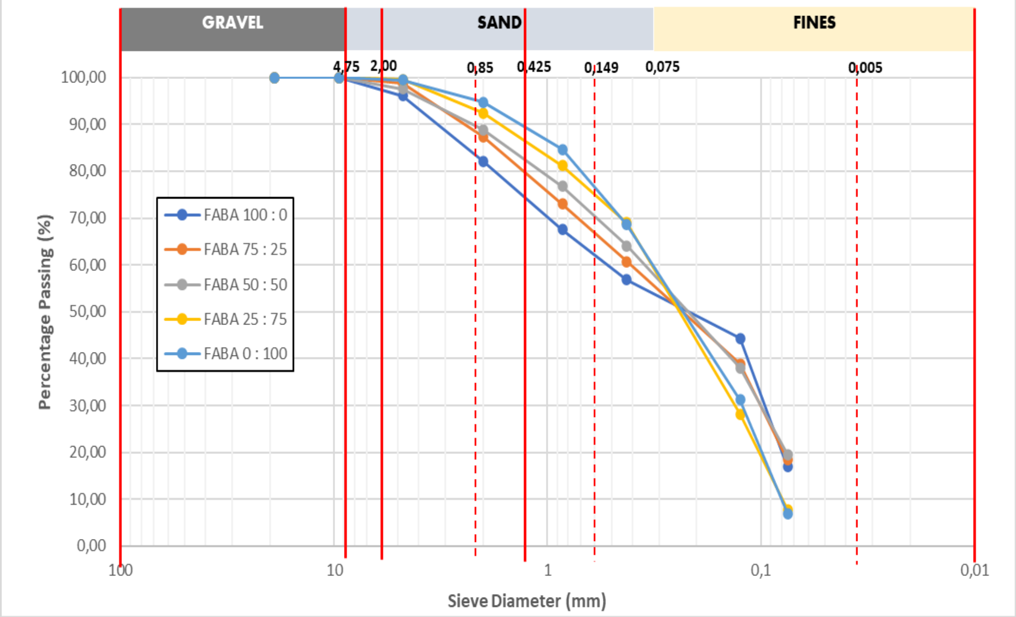
The Classification of FABA Mixture Materials

The determination of the geotechnical classification of FABA material is conducted based on the Unified Soil Classification System (USCS) method, where the classification is determined by the results of grain size analysis and Atterberg limit consistency tests. The summary of the FABA mixture classification obtained from these tests is presented below.

Table 7. Summary of Sieve Analysis

Sieve Number	Sieve Diameters (mm)	Percentage Passing FABA 100 : 0 (%)	75 : 25 (%)	50 : 50 (%)	25 : 75 (%)	0 : 100 (%)
3/4"	19,05	100,00	100,00	100,00	100,00	100,00
3/8"	9,5	100,00	100,00	100,00	100,00	100,00
4	4,76	96,08	98,72	97,62	99,62	99,43
10	2	82,17	87,40	88,90	92,39	94,69
20	0,85	67,58	72,97	76,77	81,18	84,67
40	0,425	56,82	60,76	64,04	68,99	68,64
100	0,125	44,33	38,90	38,02	28,17	31,23
200	0,075	16,92	18,45	19,55	7,77	6,98

Source: Test Result



(Sumber: Test Result)

Figure 5. Graph of Sieve Analysis for the Entire FABA Mixture

Table 8. Summary of the Classification Results of FABA Mixture based on USCS

No	Ratio FA : BA (%)	Cu	Cc	Atterberg Limit LL (%)	PL (%)	IP (%)	Soil Clasification Based on USCS	Explanation
1.	100 : 0 (FA)	38,1	1,5	48,00	28,93	19,07	SM (Silty Sand)	-
2.	75 : 25	21,72	1,33	Non-Plastic			SMN (Non - Plastic Silty Sand, Sand Silt Mixtures)	Using Journal Prakash, K, dan A. Sridharan, 2012
3.	50 : 50	5,00	0,28	Non-Plastic			SMN (Non - Plastic Silty Sand, Sand Silt Mixtures)	Using Journal Prakash, K, dan A. Sridharan, 2012
4.	25 : 75	4,47	0,68	Non-Plastic			SP - SM (poorly graded sand with silt)	-
5.	0 : 100 (BA)	4,52	0,55	Non-Plastic			SP - SM (poorly graded sand with silt)	-

Source: Test Result

From the above recapitulation, it is shown that with the increasing bottom ash content in the mixture, the material classification tends to become SP-SM type or sandy silt with poor gradation. Additionally, an increase in bottom ash content in the FABA mixture can cause the material to become non-plastic. This is because the constituent particles in the bottom ash material are dominated by sand (sieve analysis results), making it difficult to mold the material in Casagrande's cup, both in high and low water content conditions, as it easily slides on the surface of Casagrande's cup. Thus, determining the classification for some mixtures, such as FABA 75:25, and 50:50, requires an approach using the USCS classification system modified by Prakash, K, and A. Sridharan (2012).

The Influence of Fly Ash and Bottom Ash Percentage on the Physical and Mechanical Properties of FABA Mixtures

Determination of the influence of the percentage addition of fly ash and bottom ash in FABA mixtures on physical properties is carried out through volumetric-gravimetric testing. The test involves the molding of specimens cut from the CBR (California Bearing Ratio) test, ensuring that the material is fully saturated. The test results for each variation are obtained as follows:

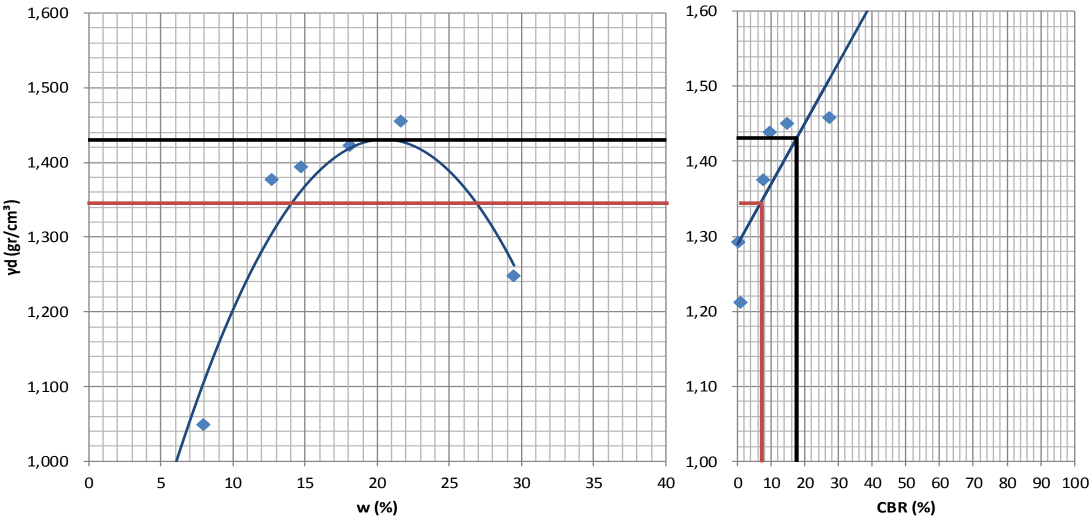
Table 9. Summary of Volumetric-Gravimetric Test Results for FABA Mixture Material

PARAMETERS	UNIT	RATIO FA : BA				
		100 : 0 (FA)	75:25	50:50	25:75	0 : 100 (BA)
Average γt	gr/cc	1,664	1,767	1,736	2,026	2,051
Average γd	gr/cc	1,123	1,263	1,304	1,664	1,716
Average Wc	%	48,081	39,900	33,170	21,777	19,476
Average Porosity (e)	%	1,235	1,040	1,169	0,722	0,685
Average Gs 20°C		2,506	2,571	2,822	2,860	2,886

Source: Test Result

In Table 7, it is found that the total weight and dry weight values for fly ash and bottom ash materials each fall within the criteria for fly ash and bottom ash materials as explained in the journal by Kim Bumjoo, et al (2006). For fly ash material, the dry weight ranges from 1,213 gr/cm3 to 1,906 gr/cm3, while bottom ash material has a dry weight range of 1,183 gr/cm3 to 1,876 gr/cm3. Table 4.11 also indicates that as the percentage of bottom ash in the mixture increases, the total volume weight and dry volume weight of the mixture also increase. This can happen due to particle reactions that fill the voids between fly ash and bottom ash materials, reducing voids in the mixture and increasing the dry weight (ɣd) value. This statement is supported by the porosity values (e), which decrease as the percentage of bottom ash in the mixture increases. Additionally, it can be observed that the increase in dry weight in the mixture also affects an increase in the specific weight, where as the mixture becomes denser, the specific weight increases. This is consistent with the findings of Seals et al (1972), where highly compacted stone ash material can result in a specific weight as high as 2.8.

Determination of the influence of the percentage addition of fly ash and bottom ash in FABA mixtures on mechanical properties is carried out through density testing (Proctor test) and California Bearing Ratio (CBR) testing. The water content used in mixing various FABA variations is obtained from the trial results of one FABA variation, namely, 50:50. This decision is based on the favorable mechanical data obtained in the studies by Sahu, Vaishali, et al. (2016) and Wiranata, Didi Yuda, et al. (2022), Referring to Figure 6, the Maximum Dry Density (MDD) is obtained as 1.431 gr/cm3 at a water content value of 20.49%. Therefore, the Optimum Moisture Content (OMC) is determined to be 20.49%. Subsequently, a series of CBR tests is conducted for all FABA 50:50 specimens, and a graph depicting the relationship between CBR and γd is obtained. By drawing a straight line touching both the polynomial regression curve from the Proctor test results and the linear regression curve from the CBR test results (Figure 4.10), the planned CBR values for the FABA 50:50 mixture with optimal water content of 20.49% are determined to be 17.57%, and for the 95% compaction density condition, the planned CBR value is 8.00%. After obtaining the planned CBR values, CBR test specimens are then prepared for all mixture variations with a water content condition of 20.49%, and the results are shown in Figure 7

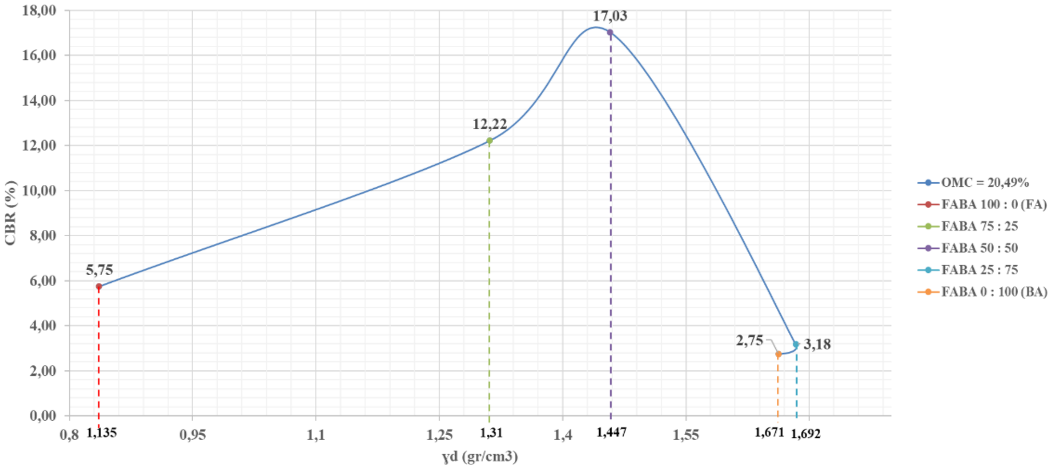


Compaction Method = MODIFIED
OMC = 20,49 %
γd max = 1,431 gr/cm³
95 % γd max = 1,359 gr/cm³
CBR (γd 100%) = **17,57 %**
CBR (γd 95%) = **8,00 %**

Keterangan:
▬ = γd max (Density 100%)
▬ = γd 95% (Density 95%)

(Sumber: Test Result)

Figure 6. Relationship between Proctor test results and CBR test results for the FABA variation of 50:50



(Source: Test Result)

Figure 7. Relationship between yd values and CBR values in all FABA mixes

In Figure 7, the technical behavior is observed that an increase in the percentage of bottom ash in the mixture up to a certain level can enhance the CBR value of the mixture. This phenomenon occurs due to pozzolanic reactions between fly ash and bottom ash materials, causing particles to become larger and stronger (flocculation-agglomeration). Additionally, another behavior is observed that for FABA mixture materials, the highest γd value in a certain variation of the mixture does not necessarily result in the highest CBR value. Therefore, CBR testing is needed for each variation to determine the mixture that yields the maximum CBR value.

The mechanical behavior provided for the CBR values of FABA mixtures in this study differs from the results obtained in the journal by Kumar Dilip et al., 2012. In that research, the highest CBR value was obtained with a bottom ash ratio of 100%. This discrepancy may occur due to differences in the compound content present in the coal ash material between the Indian power plant and the Pulang Pisau power plant.

The Ideal FABA Combination

The determination of the optimum FABA mixture ratio is carried out by selecting the mixture variation with the highest CBR value. This is done because, for road foundation layers, a high CBR value can reduce the thickness of the road pavement layer, thus potentially reducing construction costs. Referring to Table 4.12 and Figure 4.11, the highest CBR value is obtained for the mixture variation with a FABA ratio of 50:50, amounting to 17.03%. Therefore, this ratio will be used in the experimental production of road foundation material using FABA.

The Effect of Increasing Cement or Lime Content to The Physical Properties of Optimum FABA Mixture

Determination of the influence of the percentage addition of cement or lime in the FABA mixture on physical properties is carried out through volumetric-gravimetric testing. The method of specimen molding is same as make for FABA mixtures. The test result are follows:

Table 11. Summary of Volumetric-Gravimetric Test Results for FABA Mixture with Variations in Cement Content

PARAMETERS	UNIT	PERCENTAGE OF CEMENT			
		Cement 0% (Initial)	Cement 3%	Cement 5%	Cement 7%
Average ɣt	gr/cc	1,736	1,842	1,850	1,864
Average ɣd	gr/cc	1,304	1,421	1,464	1,473
Average Water Content (Wc)	%	33,17	29,716	26,392	26,512
Average Porosity (e)	%	1,169	1,048	0,990	0,981
Average Gs 20° c		2,822	2,902	2,906	2,912

Source: Test Result

Table 12a. Summary of Volumetric - Gravimetric Test Results for FABA Mixture with Variations in Lime Content

PARAMETERS	UNIT	PERCENTAGE OF LIME			
		Lime 0% (Initial)	Lime 2%	Lime 4%	Lime 6%
Average ɣt	gr/cc	1,736	1,763	1,773	1,793
Average ɣd	gr/cc	1,304	1,345	1,356	1,390
Average Water Content (Wc)	%	33,17	28,37	30,80	29,05

Table 12b. Summary of Volumetric - Gravimetric Test Results for FABA Mixture with Variations in Lime Content

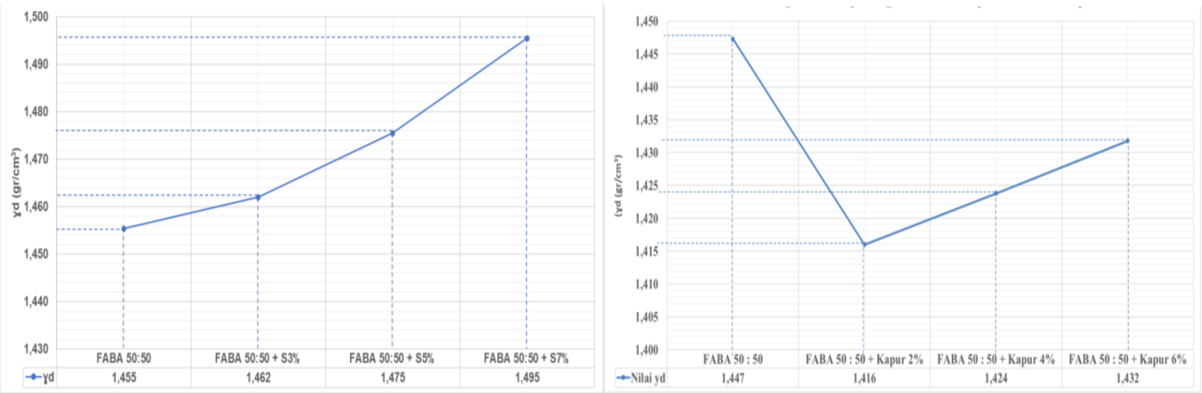
PARAMETERS	UNIT	PERCENTAGE OF LIME			
		Lime 0% (Initial)	Lime 2%	Lime 4%	Lime 6%
Average Porosity (e)	%	1,169	1,103	1,097	1,130
Average Gs 20^{o} c		2,822	2,822	2,837	2,952

Source: Test Result

By examining Table 8 and Table 9, it is observed that an increase in the percentage of cement or lime added to the FABA mixture can enhance the total volume weight and dry volume weight of the FABA mixture by around 8% to 13% for cement and 1.5% to 3.2% for lime. This increase occurs because cement or lime materials have a higher lime content (CaO) compared to FABA making the pozzolanic reaction between these materials stronger than before. Additionally, since cement or lime materials are finely graded materials, they fill the gaps in the FABA mixture, reducing voids and subsequently increasing the density (dry weight) of the FABA mixture.

The Effect of Increasing Cement or Lime Content to The Mechanical Properties of Optimum FABA Mixture

In obtaining the mechanical behavior of the FABA mixture due to the influence of cement or lime, several tests were conducted, including density test (Proctor test), California Bearing Ratio (CBR) test, and Unconfined Compressive Strength (UCS) test. The testing methods for density and CBR were performed similarly to the testing methods for the FABA mixture (initial or before mixing with cement or lime), where the moisture content condition was the same, namely 20.49%. Meanwhile, the UCS testing was conducted according to SNI 6887:2012, and the testing was carried out after a curing period of 7 days. The results of the tests can be seen in the following figures:



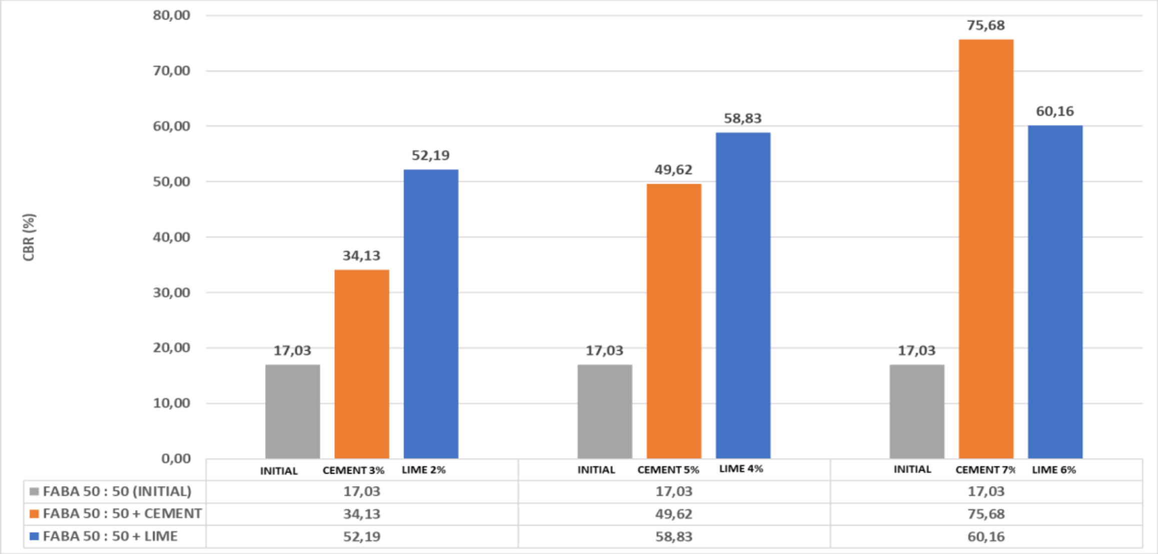
(a) (b)

(Source: Test Result)

Figure 8. Relationship between: dry weight values of soil (γd) and various FABA cement mixtures (a); dry weight values of soil (γd) and various FABA lime mixtures (b)

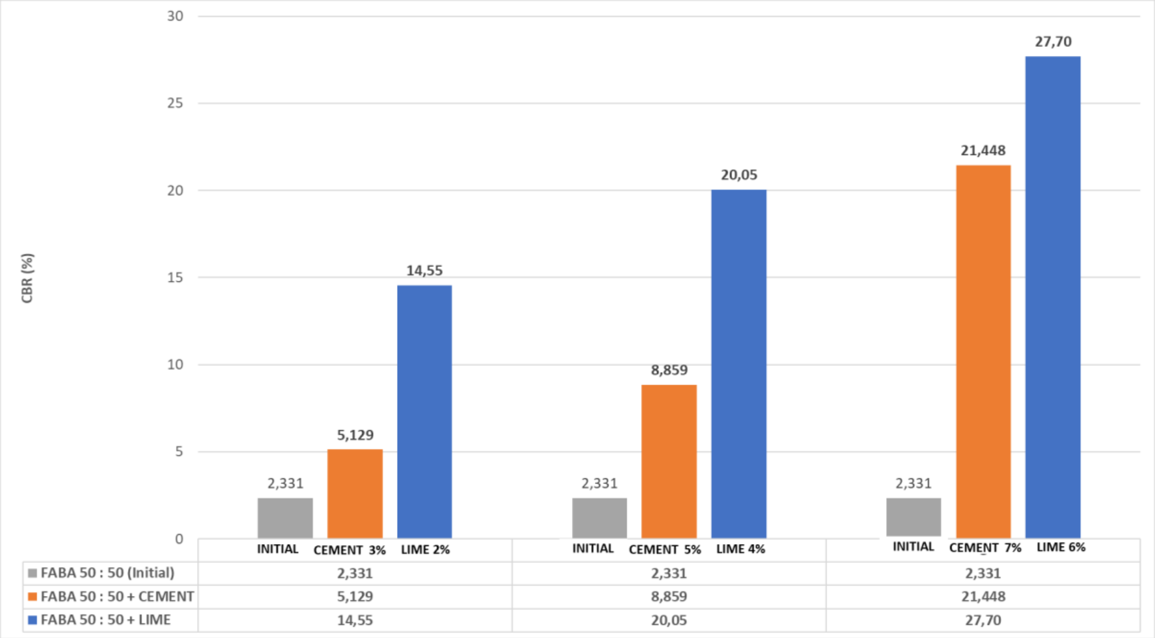
The proctor test results in Figures 8a and 8b show differences between the addition of cement and lime. The compaction behavior with cement as an additive indicates that an increase in the cement content in the mixture can enhance the Maximum Dry Density (MDD) up to 1.495 gr/cm3. On the other hand, when using lime, it is observed that it can reduce the value of γd, but as the lime content increases, it can gradually increase the value of γd. This occurs because the grain gradation of the FABA mixture is dominated by granular sand, making it difficult for lime to react, not as strong as the reaction of lime in clayey soil. The behavior of γd obtained in the proctor compaction test differs from that produced in the volumetric-gravimetric test. This difference is due to variations in cementation reactions. In the compaction test (proctor), the water content used is only the planned moisture content, which is 20.49%. In contrast, in the volumetric-gravimetric test, since the test specimens are made from the results of the CBR soaked method, the test specimens are fully saturated, resulting in better hydration and flocculation reactions compared to the results of the compaction test (proctor).

The CBR testing results in Figure 9 show that the addition of lime with a minimum percentage of 2% significantly increases the initial CBR value by 206.45%. However, the increase in CBR values from 2% to 4% and 4% to 6% lime additions is not as significant. On the other hand, the effect of cement as an additive is influenced by the amount of cement added, with higher cement percentages leading to increased CBR values. The highest increase in initial CBR values by adding cement is observed at a 7% cement content, with a percentage increase of 344.38%. From these results, it can be observed that the effectiveness of lime as an additive tends to be significant at percentages below 4%, while for cement, it tends to be significant at percentages above 5%. his result shares similarities with the findings of the study by Sahu, Vaishali, et al., (2016)



(Source: Test Result)

Figure 9. The comparison of CBR values of Material FABA Initial, FABA + Cement, and FABA + Lime



(Source: Test Result)

Figure 10. The comparison of UCS values of Material FABA Initial, FABA + Cement, and FABA + Lime

The UCS test results in figure 5.8 show that increasing the percentage of cement or lime in the FABA mixture can increase the compressive strength. The highest compressive strength value obtained with cement as an additive was at 7% content, reaching 21.45 kg/cm2, while for lime as an additive, it was obtained at 6% content, reaching 27.70 kg/cm2. From these results, it can be observed that lime as an additive can produce higher compressive strength values than cement within the 7-day curing period. This result differs from the findings in the journal by Wiranata, Didi Yuda, et al., 2022, where the highest UCS value at 7 days was obtained in the FABA 40:60 variation with 10% cement. This difference may occur due to variations in the compound content between coal ash from the Sri Lanka power plant and the Pulang Pisau power plant.

Determination of FABA Mixtures with Cement or Lime to Meet the Specifications of Bina Marga for Foundation Layer Materials

Using the general parameters of Bina Marga as of 2018 revision 2, the grain gradation of FABA material with a 50:50 ratio (initial) does not fall within the criteria for road aggregate foundation layers. However, the physical and mechanical properties obtained from FABA mixtures with 7% cement content or FABA with 2-6% lime content can be classified as class B and class S aggregate foundation layers (Table 10).

Meanwhile, using the foundation layer criteria with FABA according to the special specifications of Bina Marga number SKh 1.15.1, it is found that the minimum compressive strength requirement of 20 kg/cm2 is achieved in the FABA mixture with a 50:50 ratio with the addition of 7% cement or 4% lime (Table 11)

Looking at the economic aspect to reduce construction costs due to the addition of a significant number of additives, the use of lime is more recommended because it is cheaper than cement. The physical and mechanical parameters obtained from the mixture of FABA with lime do not differ significantly from the mixture of FABA with cement. However, further research is needed to determine its durability over an extended period.

Table 10. Summary of the Review of Road Foundation Layer Criteria based on Bina Marga 2018 Revision 2 General Specification

REVIEW	FABA							AGGREGATE BASE COURSE		
	50:50 (Initial)	CEMENT CONTENT			LIME CONTENT			KLS A	KLS B	KLS S
		3%	5%	7%	2%	4%	6%			
Liquid Limit (%)	NP	NP	NP	NP	NP	NP	NP	0 - 25	0 - 35	0 - 35
Plasticity Index (%)	NP	NP	NP	NP	NP	NP	NP	0 - 6	4 - 10	4 - 15
Results of Plasticity Index Multiplied by % Passing Sieve No. #200	NP	NP	NP	NP	NP	NP	NP	Max 25	-	-
Comparison of Percentage Passing Sieve No. 200 and No. 40	0,31	-	-	-	-	-	-	Max 2/3	Max 2/3	-
CBR Value (%)	17,03	34,13	49,62	75,68	52,19	58,83	60,16	Min 90%	Min 60%	Min 50%

Source: Test Result

Table 11. Recapitulation of Review on Road Foundation Layer Criteria based on Special Specification of Bina Marga Number SKh - 1.15.1 Year 2022

REVIEW	FABA							AGGREGATE BASE COURSE		
	50:50 (Initial)	CEMENT CONTENT			LIME CONTENT			MIN	TARGET	MAX
		3%	5%	7%	2%	4%	6%			
UCS (kg/cm^2)	2,33	5,13	8,86	21,45	14,55	20,05	27,70	20	24	35

Source: Test Result

CONCLUSION

Based on the test result and analysis given above it can be concluded that:

1. The fly ash and bottom ash from PLTU Pulang Pisau Kalimantan can be classified as Class C and Class N (raw) or F, respectively.
2. The optimum FABA mixture is 50 (fly ash) and 50 (bottom ash), which has the highest soaked CBR value 17.03%.
3. The additional of 3% to 7% cement in the FABA (50:50) mixture is able to increase the dry unit weight from 8% to 13%. Besides, the addition of 3% cement can increase the soaked CBR value more than 100% and the UCS value more than 16% from the initial value of FABA mixture (50:50)
4. The additional of 2% lime to the FABA (50:50) mixture CBR value can be directly increased to over 200%, and the UCS value can exceed 19%.

5. The compotition that meets the requirement of Bina Marga spesification for base course material is FABA mixture (50:50) with 7% of cement, which has soaked CBR and UCS values are 75.68% and 21.448 kg/cm^2, respectively.
6. The Bina Marga spesification for base course material is also can be met by FABA mixture (50:50) with 6% of lime, which has soaked CBR and UCS values are 60.16% and 27.70 kg/cm^2, respectively.

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