Jurnal Teknik Sipil & Perencanaan 26 (1) (2024) p 5-10

UNNES JOURNALS

JURNAL TEKNIK SIPIL & PERENCANAAN

http://journal.unnes.ac.id/nju/index.php/jtsp/index

Feasibility Study on the Use of Fly Ash and Bottom Ash as Aggregate Substitutes in the Subbase Layer of Road Pavement

M. Arief Firdaus[a)], Rini Kusumawardani[2], Nirima Ramadhani[3], Zahra Aulia Putri[4]

[1,2,3,4] Civil Engineering Study Program, Semarang State University, Postal Code 50229

[a)] Corresponding author: marieffirdaus@students.unnes.ac.id

Abstract. This study used fly ash and bottom ash (FABA) waste as a substitute for aggregate in the *road subbase* layer. The initial mixture included FABA with a depth of 1 meter and 7 meters without mixing other materials. This mixture is differentiated into two variations with a ratio of variation I (70:30) and variation II (70:30), each fermented for 14 days. The test results showed that the FABA material did not meet the specification of SNI 6388:2015 for class B foundation layers, with a maximum immersion CBR value of 25.32% in variation I and 18.99% in variation II. This study evaluates the feasibility of using FABA as an aggregate substitute material in the *subbase* layer of road pavement. From the results obtained, FABA material has the potential to be used in *subbase construction*. Still, adding other materials such as cement or lime is necessary to increase the carrying capacity and meet the set specifications.

Keywords: *Bottom ash*, *fly ash*, alternative materials, *subbase*

INTRODUCTION

Along with the increasing demand for electricity in Indonesia's manufacturing industry sector, the use of coal as the primary fuel in coal-fired power plants also continues to grow. The coal that is burned produces electrical energy but also leaves residues in the form of *fly ash* (flying ash) and *bottom ash* (base ash). The demand for coal for power plants has increased significantly from 56 million tons in 2006 to 123.2 million tons in 2025, which is expected to produce around 11.38 million tons of FABA (UGRG FT UGM, 2022).

Government Regulation Number 101 of 2014 concerning the Management of Hazardous and Toxic Waste (B3). FABA is categorized as B3 waste because the content of FABA waste contains heavy metal oxides that will pollute the environment. However, FABA is no longer included in B3 waste by Government Regulation (PP) Number 22 of 2021 as non-B3 waste. One way to determine the concentration of pollutants in FABA is by the *toxicity characteristic leaching procedure* (TCLP) test.

One of the power plant managers in Indonesia is the Tanjung Jati B Jepara Power Plant. The capacity of this coal-fired power plant reaches 4 x 710 MW Gross or 4 x 660 MW Nett, which accounts for around 12% of Java-Bali electricity needs (PLN, 2019). By-products of burning coal include *fly ash*, *bottom ash, and* flue gas desulfurization *(FGD) sludge*. About 80-90% of the combustion residue is fly ash, while the remaining 10-20% consists of base ash (Darwis & Hidayat, 2015).

Fly ash is a fine-grained product from coal combustion, derived from the minerals silicates, sulfates, sulfides, carbonates, and oxides found in coal (ASTM C.618). Meanwhile, *bottom ash* is a coarser and heavier residue, which settles at the bottom of the combustion furnace after the combustion process is complete (Hanafie, 2023). FABA has a very varied material composition, depending on the source and content of the coal used in combustion. Nonetheless, this material mainly contains major inorganic compounds such as silicon dioxide (SiO_2) and calcium oxide (CaO).

FABA material can be used as an alternative material for mixed materials that make up road pavement layers, such as the upper foundation layer (*roadbase*), the lower foundation layer (*subbase*), and the base soil layer (*subgrade*). The utilization of FABA helps reduce waste and supports sustainability by reducing dependence on natural materials. This study evaluates the feasibility of using FABA as the primary material in constructing *road* pavement subbase layers by considering technical, economic, and environmental aspects.

LITERATURE REVIEW

1.1 Bending Pavement

Flexible pavement is pavement that uses asphalt as a binding material. In general, flexible pavement construction consists of four main layers, namely the *surface course*, the upper foundation layer (*base course*), the lower foundation layer (*subbase course*), and the base layer (*subgrade*). Based on the Road Pavement Design Manual No. 03/M/BM/2024 and SNI 6388:2015, the material used for the upper foundation layer (*base course*) is class A aggregate, while the lower foundation layer (*subbase course*) uses class B aggregate.

1.2 Foundation Layer

According to Suprapto (2004), the foundation layer in flexible pavement is part of the road pavement structure that distributes the vehicle load evenly from the surface layer to the layer below it, thereby reducing the direct pressure on the subgrade soil. Determination of materials in the lower foundation layer (subbase) requires sieve requirements and properties of foundation layers for class A, class B, and class S by SNI 6388:2015, as shown in Table 1 and Table 2.

TABLE 1. Sieve size requirements

Ukuran ayakan		Persen berat yang lolos (%)		
		Kelas A	Kelas B	Kelas S
2"	50 mm	-	100	-
1 1/2"	37,5 mm	100	88 - 95	100
1"	25,0 mm	79 - 85	70 - 85	77 - 89
3/8"	9,50 mm	44 - 58	30 - 65	41 - 66
No. 4	4,75 mm	29 - 44	25 - 55	26 - 54
No. 10	2,0 mm	17 - 30	15 - 40	15 - 42
No. 40	0,425 mm	7 -17	8 - 20	7 - 26
NO. 200	0,075 mm	2 -8	2 - 8	4 - 16

TABLE 2. Condition properties of foundation layer, lower foundation layer, and road shoulder

Uraian persyaratan	Standar	Nilai		
		Kelas A	Kelas B	Kelas S
Abrasi/*Los Angeles*	SNI 2417:2008	Maks. 40%	Maks. 40%	Maks. 40%
Butiran pecah, tertahan ayakan No. 3/8 atau 9,5 mm	SNI 7619:2012	95/90[1]	55/50[1]	55/50[1]
Batas Cair (LL)	SNI 1967:2008	Maks. 25%	Maks. 35%	Maks. 35%
Indeks Plastisitas (PI)	SNI 1966:2008	Maks 6%	Maks. 10%	Maks. 10%
Hasil kali Indek Plastisitas dengan % Lolos Ayakan No.200	-	Maks. 25%	-	-
Gumpalan lempung dan butiran - butiran mudah pecah	SNI 03-4141-1996	Maks. 5%	Maks. 5%	Maks. 5%
CBR rendaman	SNI 1744:2012	Min. 90%	Min. 60%	Min. 60%
Perbandingan % lolos ayakan No. 200 dan No. 40	-	Maks. 2/3	Maks. 2/3	Maks. 2/3

1.3 *Fly Ash* and *Bottom Ash* (FABA)

Burning coal produces fly and bottom ash (FABA) waste. According to SNI 2460:2014, *fly ash* is a fine residue from burning coal in a steam power plant (PLTU). *Fly ash* has a high cement content and pozzolan properties, which allows it to react with quenched lime ($Ca(OH)2$) and water at room temperature, resulting in a solid compound that is insoluble in water.

Bottom ash is waste from coal burning at steam power plants (PLTU). The base ash falls to the bottom of the *boiler* and collects in the last *hopper*, also known as the final hopper. After being sprayed with water, the base ash is disposed of or used as an additive or alternative material on road pavement. *Bottom ash* is divided into dry *bottom ash* (*slag-tap boiler* and *cyclone boiler*) and *wet bottom ash* (*boiler slag*). The characteristics of *bottom ash* are very diverse because they depend on the type of coal used and the combustion system (Indriani Santoso et al., 2003).

RESEARCH METHODS

The research was conducted using experimental methods in the laboratory to determine the feasibility of using FABA in constructing *road pavement subbases*. In this study, the SNI 6388:2015 specification and the 2018 Bina Marga general specification were used as a reference to determine the variation of FABA mixture in the lower foundation layer of class B using the soaked CBR test method.

Materials used

1. FABA obtained from the Tanjung Jati B Jepara PLTU in Kembang District, Sekuping, Tubanan, Jepara Regency, Central Java.

FIGURE 1. FABA 1 meter deep

FIGURE 2. FABA 7 meters deep

2. Clean water

Equipment used

1. CBR Laboratory Testing Machine
2. Los Angeles *abrasion testing machine* with steel balls
3. Proctor *compaction machine*
4. Drying oven
5. Soaking tub
6. Scales
7. Test case
8. Other equipment

FABA material testing

The tests that will be carried out to determine the characteristics and feasibility of FABA materials in the construction of the lower foundation layer (*subbase*) are as follows:

1. Specific gravity testing based on SNI 03-1970-2008
2. Permeability test based on SNI 2435:2008
3. Screening analysis testing based on SNI 3423:2008
4. Aggregate wear testing with the Los Angeles abrasion machine based on SNI 2417:2008
5. Testing of 3/8 inch aggregate broken grain percentage based on SNI 7619:2012
6. Testing of clay and grain lumps – easily broken grains based on 03-4141-1996
7. Atterberg limit *testing* based on SNI 1966:2008
8. Density testing or compaction based on SNI 1742:2008
9. Immersion CBR testing based on SNI 1744:2008

Determination of FABA mixture variations

Based on this study, two mixed variations were used, namely variation I, 70% FABA, 1 meter, and 30% FABA, 7 meters. For variation II, the same as variation I, but in fermentation for 14 days.

RESULTS AND DISCUSSION

FABA material *properties* test results

Based on the tests carried out, a recapitulation can be made, which is presented in the following table.

TABLE 3. Recapitulation of *FABA* Properties Test Results

Parameter	FABA 1	FABA 7
Warna	Abu tua	Hitam gelap
Berat jenis, (gr/cm^3)	2,28	2,30
Permeabilitas, (cm/det)	$5{,}19\times10^{-4}$	$3{,}36\times10^{-4}$
Kadar air optimum, (%)	17,94	18,68
Kepadatan kering, (gr/cm^3)	0,85	0,80
Abrasi *Los Angeles*, (% lolos)	73,24	77,77
Batas cair, (%)	31,85	29,87
Plastisitas	Non plastis	Non plastis
Cu/*Uniformity coefficient*	3,11	5,12
Cc/*Coefficient of curvature*	1,10	1,02

Table 3 shows that FABA 1 has properties more similar to *fly ash* than *bottom ash* due to its lighter color, lower specific gravity value than FABA 7, and the Cu value in FABA 1, including sand that has a range of 1 – 3, indicates that the particles have a good or more uniform gradation. In contrast, FABA 7 tends to be more similar to *bottom ash* because of its darker color, higher specific gravity values, and higher Cu values than FABA 1, indicating that the particles are often larger and less uniform.

FABA Eligibility Test Results

Based on the tests carried out, a recapitulation can be made, which is presented in the following table.

TABLE 4. Feasibility Test Results of Class B Foundation Layer on Variation I

Uraian persyaratan	Kelas B	Variasi I 70% FABA 1 - 30% FABA 7	Memenuhi/ tidak
Abrasi/*Los Angeles* (SNI 2417:2008)	0 - 40%	52,17%	TM
Butiran pecah, tertahan ayakan No. 3/8 (SNI 7619:2012)	55/50[1]	77,74%/73,41%[1]	TM
Batas Cair (SNI 1967:2008)	0 - 35%	31,23%	M
Indeks Plastisitas (SNI 1966:2008)	0 - 10%	Non-plastis	TM
Hasil kali Indeks Plastisitas dengan % Lolos Ayakan No.200	-	-	TM
Gumpalan lempung dan butiran - butiran mudah pecah (SNI 4141:2015)	0 - 5%	10,20%	TM
CBR rendaman (SNI 1744:2012)	Min. 60%	25,32%	TM
Perbandingan % lolos ayakan No. 200 dan No. 40	Maks. 2/3	0,56	M

TABLE 5. Results of the Class B Foundation Layer Feasibility Test in Variation II

Uraian persyaratan	Kelas B	Variasi II 70% FABA 1 - 30% FABA 7 Peram 14 hari	Memenuhi/ tidak
Abrasi/*Los Angeles* (SNI 2417:2008)	0 - 40%	52,17%	TM
Butiran pecah, tertahan ayakan No. 3/8 (SNI 7619:2012)	55/50[1]	77,74%/73,41%[1]	TM
Batas Cair (SNI 1967:2008)	0 - 35%	31,23%	M
Indeks Plastisitas (SNI 1966:2008)	0 - 10%	Non-plastis	TM
Hasil kali Indeks Plastisitas dengan % Lolos Ayakan No.200	-	-	TM
Gumpalan lempung dan butiran - butiran mudah pecah (SNI 4141:2015)	0 - 5%	10,20%	TM
CBR rendaman (SNI 1744:2012)	Min. 60%	18,99%	TM
Perbandingan % lolos ayakan No. 200 dan No. 40	Maks. 2/3	0,56	M

FABA material does not meet the specifications of SNI 6388:2015, so it is not recommended to use it as the primary aggregate material for grade B aggregate foundation layers. However, some parameters meet the requirements of SNI 6388:2015, such as liquid limit (LL) tests with a value range of 0 – 35%. It is therefore recommended that FABA material be added with other materials such as cement or lime, as this can increase the carrying capacity of the material and change some of its properties.

CONCLUSION

From the results of the feasibility study on the use of *fly ash* and *bottom ash* (FABA) in construction *Subbase* of road pavement can be concluded as follows:

1. The effect of FABA mixture variation as the primary material in the construction of the lower foundation layer of class B, which has the potential to increase the bearing capacity of *the subbase layer* with the CBR value of immersion without mixing with other materials, a maximum result of 25.32% was obtained in variation I of a mixture of 70% FABA 1 and 30% FABA 7 without marinating.

2. FABA material that was given a curing treatment in variation II had a lower CBR value of immersion than in the non-fermentation condition, with a value of 18.99%.

3. The feasibility of FABA materials in the construction of the lower foundation layer (*subbase*) of the two variations does not meet the requirements of specification 6388:2015 and the general specification of Bina Marga 2018 because the minimum CBR value of immersion is 60%.

REFERENCES

[1] Badan Standardisasi Nasional. (2015). *Standar Nasional Indonesia. Spesifikasi agregat untuk lapis fondasi, lapis fondasi bawah, dan bahu jalan*. SNI 6388:2015.

[2] Darwis, M., & Hidayat, R. (2015). *Karakteristik dan Pemanfaatan Abu Terbang dan Abu Dasar dari Pembakaran Batu Bara*. Jurnal Teknologi Lingkungan, 6(2), 123-130.

[3] Hanafie, M. (2023). *Karakteristik Fly Ash dan Bottom Ash dari Proses Pembakaran Batu Bara pada Pembangkit Listrik Tenaga Uap*. Jurnal Teknologi Lingkungan, 15(1), 45-60.

[4] Indriani Santoso, Patrick Patrick, Andarias Andarias, & Salil Kumar Roy. (2003). Pengaruh Penggunaan Bottom ash Terhadap Karakteristik Campuran Aspal Beton. *Civil Engineering Dimension, 5*, 75-81.

[5] UGRG FT UGM. (2022). *Limbah Padat Pembakaran Batubara: Potensi Sumber Daya Non-Konvensional di Masa Depan*. Tersedia di: https://ugrg.ft.ugm.ac.id/artikel/batubara- sebagai-sumber-energi-asal-jenis-dan-kegunaannya/ [Diakses 20 Maret 2025].

[6] Peraturan Pemerintah Republik Indonesia Nomor 101 Tahun 2014 tentang Pengelolaan Limbah Bahan Berbahaya dan Beracun. (2014). Ditetapkan pada 17 Oktober 2014. Tersedia di: https://peraturan.go.id/id/pp-no-101-tahun-2014 [Diakses 20 Maret 2025].

[7] Peraturan Pemerintah Republik Indonesia Nomor 22 Tahun 2021 tentang Penyelenggaraan Perlindungan dan Pengelolaan Lingkungan Hidup. (2021). Ditetapkan pada 2 Februari 2021. Tersedia di: https://jdih.maritim.go.id/id/peraturan-pemerintah-republik-indonesia-no-22- tahun-2021# [Diakses 20 Maret 2025].

[8] PT PLN (Persero). (2019, 10 Desember). *Melihat Lebih Dekat Pembangkit Besar PLTU Tanjung Jati B*. Tersedia di: https://web.pln.co.id/cms/media/siaran-pers/2019/12/melihat-lebih- dekat-pembangkit-besar-pltu-tanjung-jati-b/ [Diakses 20 Maret 2025].