Material Substitution for Flexible Pavement Using Waste Material Fly Ash and Bottom Ash from Bukit Asam Electric Steam Power Plant

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Abstract. Indonesia is one of the largest coal producers in the world. In 2019, based on Indonesia's coal production, it reached 565.81 million tons with domestic consumption of 128.38 million tons. South Sumatra Province is one of the provinces that produces the largest coal production in Indonesia through one of the state-owned companies, namely PT. Bukit Asam Tbk. PLTUs by PT. Bukit Asam Tbk in South Sumatra Province can produce a lot of fly ash and bottom ash (FABA) waste in a day, 250 tons of bottom ash and 200–1000 tons of fly ash per day. Fly ash and bottom ash waste of PLTU Banjarsari and PLTU Tanjung Enim contains high pozzolan materials of total content SiO_2, Al_2O_3, Fe_2O_3 more than 70%. Flexible pavement is made in layers and consists of surface course, a subbase course, a base course, and a subgrade. This research focuses on flexible pavement on the surface course. Fly ash as a substitution for filler and bottom ash as a substitution for fine aggregate (sand), fly ash and bottom ash (FABA) replaced 100% of filler and sand material in this research, not as an additive. On this paper, only bring up physical, sieve analysis and chemical properties of fly ash and bottom ash (FABA) compared with cement as filler and river sand as fine aggregate in a standard flexible pavement. Aggregate inspection was conducted to determine whether fly ash and bottom ash used in this study met the requirements The General Specifications of Highways (Bina Marga) 2018 Revision 2, Ministry Public Work of Indonesia.

Keywords: *Fly ash* · *Bottom ash* · FABA · *filler* · *fine aggregate (sand)* · XRF

1 Introduction

1.1 Research Background

Indonesia is considered as one of the world's largest coal producers. In 2016, Indonesia ranked in the top 5 coal producers. Indonesia has managed to surpass Australia as a leading exporter in term of thermal coal since 2005 [1]. Coal is one of the largest exports and at the time of the pandemic this had a severe impact on the Indonesian

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coal industry. The country, which in 2019 was the world's largest exporter of thermal coal, has experienced a decline in demand in major export markets including China and India [2]. In 2019, Indonesian's coal output totaled 565.81 million tons with domestic consumption totaling 128.38 million tons.

Coal is a fossil fuel which is the most important source of energy for power generation and is also the basic fuel used steel and cement's production. From burning coal, there is a production of ±5% solid pollutants in the form of ash (fly ash and bottom ash). Fly ash is a fine residue produced by coal's burning that is smoothed and transported from the combustion chamber by exhaust gases. In 2001, fly ash production reached 68 million tons (more than 61 million metric tons) [3]. Fly ash and bottom ash (FABA) waste are categorized as B3 (Hazardous and Toxic Materials) waste which means it can pollute and damage the environment, as well as endanger the health of humans and other living things. The percentage of ash produced from burning coals is about 10–20% is bottom ash and about 80–90% fly ash and contains hazardous toxic waste or also called as B3 and musts to be handle in the right way [4]. Based on Government Regulation (PP) No. 101 of 2014, fly ash and bottom ash (FABA) is included within B3 waste category so that handling it becomes difficult and costs up to reach trillions [5]. In fact, based on TCLP and LD50 or parameters that measure a material entering B3 or not, FABA has proven to qualify as waste that is not classified as B3. Management of fly ash and bottom ash (FABA), as B3 waste and non-B3 waste, is governed by Government Regulation (PP) No. 22 of 2021 on the Implementation of Environmental Protection and Management, FABA material which is waste from combustion residue at Steam Power Plant (PLTU) becomes non-B3 waste [6]. This is because coal combustion in pltu activities is carried out at high temperatures, so that the unburnt carbon content in fly ash and bottom (FABA) becomes minimum and more stable when stored.

One of the provinces that produces coal largest production in Indonesia is South Sumatra Province through one of the state-owned companies, namely PT. PT. Bukit Asam Tbk which focuses on coal mining was established in 1950. PLTU (Steam Power Plant) is one of fly ash and bottom ash (FABA)'s the largest producers waste due to the use of coal as its main fuel. This research will focus on Electric Steam Power Plant (PLTU) from PT. Bukit Asam Tbk. is the Banjarsari Power Plant located in Lahat Regency in South Sumatra Province and the Tanjung Enim Power Plant located in Banko Barat Lingga, Lawang Kidul, Muara Enim, South Sumatra Province. PLTU Banjarsari is run by PT. Bukit Pembangkit Innovatif (BPI) was formed in 2005 with a 59.75% share ownership, engaged in the field of 2 × 135 MW steam power plant, PT. BPI is a subsidiary of PT. Bukit Asam, Tbk. Located on Jalan Lahat-Muara Enim, Gunung Kembang Merapi Timur, Lahat Regency, South Sumatra. PLTU Tanjung Enim 3x10 MW which is the grandson of PT. Bukit Asam with its subsidiary, PT. Bukit Energi Investama and in 2015 PT. Bukit Energy Integrated Service (PT. BEST). PT. Bukit Asam Tbk's waste production has produced significant fly ash and bottom ash in a day, which is reported that have 250 tons of bottom ash and 200–1000 tons of fly as. Thus, the proper utilization is mostly needed for the good waste treatment (Figs. 1 and 2).

The technical considerations that form the basis for the use of FABA in this study are the content of SiO_2 (Silicon Dioxide), Al_2O_3 (Aluminum Oxide), and Fe2O3 (Ferricoxide) which are quite high in FABA PLTU waste, especially PLTU PT. Bukit Asam. Faba

Fig. 1. PLTU Banjarsari

Fig. 2. PLTU Tanjung Enim

laboratory test results PLTU PT. Bukit Asam has a content of SiO_2 (Silicon Dioxide) 50–60% a, Al_2O_3 (Aluminum Oxide) 20–30%, and Fe_2O_3 (Ferricoxide) 6–10%, the results show that FABA has high Pozolan properties, which can help the binding process between aggregates and can also increase strength in highway construction.

The large amount of FABA waste production is also the reason this research was carried out because so far PT.Bukit Asam FABA waste is only used by the cement industry, namely PT. Baturaja cement as an added raw material for cement production. Given the high silica content of FABA, this is also what underlies FABA can be used as an alternative material substitution in this study, considering that so far, especially in South Sumatra, the most widely used filler is cement and the fine aggregate used is river sand.

The purpose of this study was to determine the characteristics and performance of waste material fly ash and bottom ash (FABA) from coal combustion residue of Electric Steam Power Plant (PLTU) PT. Bukit Asam on laboratory provision as substitution of filler and fine aggregate that will be used on flexible pavement, not as an additive. This step is early stage to prove that fly ash and bottom ash (FABA) can be replaced 100% to other material on flexible pavement, fly ash can be used as a substitution of filler and bottom ash can be used as a substitution of fine aggregate (sand) on the surface layer of asphalt concrete (AC) according requirements The General Specifications of Highways (Bina Marga) 2018 Revision 2, Ministry Public Work of Indonesia.

1.2 Research Limitations

The limitations of this research to get the expected results and focus on the desired goals are:

1. The standard for testing the characteristics of the aggregate used in this research is The General Specifications of Highways (Bina Marga) 2018 Revision 2, Ministry Public Work which includes the Indonesian National Standard (SNI), AASHTO, ASTM, and BS.
2. Fly Ash and Bottom Ash (FABA) used in this research are the residue from the combustion of PLTU from PT. Bukit Asam Tbk. Namely PLTU Banjarsari and PLTU Tanjung Enim, South Sumatra Province.
3. Fly Ash test include Sieve Analysis and Specific Gravity, Bottom Ash test include Sieve Analysis and Physical Properties for Fine Agregate
4. XRF (X-Ray Fluoresence) chemical inspection was conducted to determine chemical composition on FABA
5. Fly ash as a substitute for filler and bottom ash as a substitute for sand (fine aggregate), the substitutions that will be made are 100% pure substitutes, not as additives or additives. Substitutions were also carried out simultaneously in the laston mixture, not separately or unlike most previous studies that used only fly ash or bottom ash.

1.3 Benefits of Research

1. Contribute to science, especially in the field of civil engineering, especially pavement material regarding the use of FABA waste as a substitute for aggregate material.
2. Contribute to the environment by turning FABA waste into a high-efficiency material that can improve pavement performance and durability, so that in large-scale use it can reduce environmental pollution and has economic value in the field of highway construction.
3. Provide an overview of the advantages and disadvantages of using FABA on flexible pavement.

2 Literature Review

2.1 Previous Research

Studies with the theme of fly ash in road pavements include class F fly ash from PLTU Sijantang, Sawah Lunto City, the study was conducted on rigid pavement [7]. The fly ash used came from PLTU Bukit Asam, Tanjung Enim, South Sumatra, the research was carried out on the AC-WC layer, the test was only limited to the Marshall test [8]. Making paving blocks using fly ash to replace 10–80% cement material, samples with a ratio of 30% and 50% fly ash replacement were used in combination with 5 mm and 10 mm bottom ash sieves to increase the density of the matrix [9]. Fly ash (FA) obtained from the Kolaghat thermal power plant located in West Bengal, India is used as a filler, the variation of fly ash added is 2–8%, the test carried out is the Marshall Test [10]. TDF fly ash as filler in hot mix asphalt (HMA), the layer under review is HMA, the tests

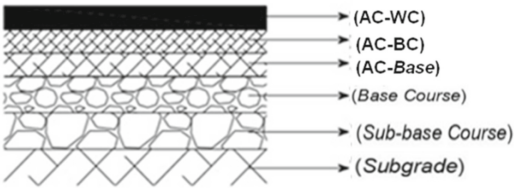

Fig. 3. Asphalt Concrete (AC) Structure

carried out are marshall test, immersion and whell tracking (Choi, Min ju 2020). The FA (Fly Ash) used was provided by the Second Power Station in Changchun. Classified in class F, the layer under review is subgrade, the tests carried out are CBR and Triaxial [11].

Previous studies on Bottom Ash are very diverse, among others, bottom ash used is taken from PT. Suparma, Surabaya, which is engaged in paper mills, focuses on research on asphalt-concrete mixtures [12]. The FABA used by the Pangkal Pinang, Ombilin and Sibolga power plants, focuses on research on the concrete road foundation layer [13]. The FABA used was obtained from PT. Indah Kiat Pulp and Paper (IKPP), research focus on base layer [14]. Bottom ash used obtained from the Tanjung Bin Power Plant is used as a filler material, the focus of this research is on hot mix asphalt and binder course, the tests carried out are the marshall test and the resiliency modulus test [15]. The bottom ash used is derived from the ENEL thermal power plant in Brindisi (Italy), the research focus is on the binder course layer, only limited to testing marshall and cantabro [16].

2.2 Asphalt Concrete

Asphalt concrete layer (Laston or AC) consists of three types of mixtures, namely AC Lapis Wear (AC Wearing Course), AC layer Between (AC Binder Course), and AC layer foundation (AC Base). Every mixture has maximum aggregate particle size of 19 mm, 25.4 mm, and 37.5 mm.

The asphalt concrete (AC) layers as a base layer on the top of road pavement construction was developed by The Asphalt Institute, which acts as a structural construction cover. According to the Public Works Department of Highways, the composition of the AC layers were mixed with continuous graded aggregate and hard asphalt. These compounds have been blended, dispersed, and solidified, in hot temperatures. Moreover, the mixing temperature were fixed by the asphalt type. The asphalt concrete with a continuous gradation mixture is mixed with coarse-fine aggregate, mineral filler (filler), and asphalt (bitumen). Therefore, asphalt concrete is more stable, because there are no voids, and it has good interlocking aggregates and a rigid structure. Asphalt concrete layers are surface layers that use well-graded aggregates. Laston is suitable for heavy traffic [17] (Fig. 3).

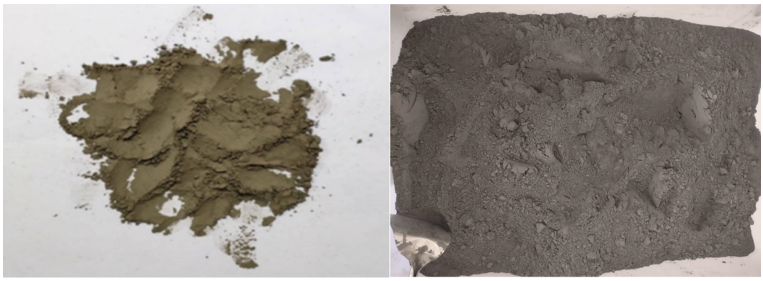

Fig. 4. *Fly Ash* PLTU Banjarsari &Tanjung Enim

2.3 Fly Ash and Bottom Ash

Fly ash is in the form of fine particles and is pozzolan in nature. Fly ash consists of dry fly ash and wet fly ash/boiler slag based on the type of stove, namely dry fly boiler which produces dry fly ash and slag-tap boiler and cyclone boiler which produces wet fly ash (boiler slag). The properties of fly ash vary widely and are influenced by the type of coal and its combustion system.

Basically, Chemical components included in fly ash are silica (SiO2), calcium oxide (CaO), alumina (Al2O3), and ferrous oxide (Fe2O3), also contains magnesium oxide (MgO), alkaline (Na2O and K2O), titanium oxide (TiO2), sulfur trioxide (SO3), carbon and phosphorus oxides (P2O5) as other additional elements. The variety of coal, the purity of the coal, the degree of crushing, the type of heating and operation, the technique of storage and stockpiling have an impact on the chemical, technical properties and physical of fly ash.

With fly ash and bottom ash which have physical characteristics have the shape of grain and dust, so that they can be used as a substitute for a material mixture of a road pavement structure, especially fine aggregate and filler.

Due to the cement hydration process, the silica dioxide that has contained in fly ash could be react chemically with calcium hydroxide. It process has encouraged the fly ash to bind like cement, due to its fine size and water content (Fig. 4).

Bottom ash is waste material from the coal combustion process at power plants which has a bigger particle size and also heavier than fly ash, therefore bottom ash falls to of the fireplace (boiler) and collect in the ash hopper and then removed from the furnace by spraying it with water to be disposed of or used as an additional material on road pavements. Bottom ash is categorized into dry bottom ash and wet bottom ash/boiler slag based on the kind of stove, namely dry bottom boiler which produces dry bottom ash and slag-tap boiler and cyclone boiler which produces wet bottom ash (boiler slag). The properties of bottom ash vary widely because it is influenced by the type of coal and the combustion system (Fig. 5).

The classification of Ash based on Chemical Composition is as follows ASTM (American Standard Testing Method) No. C618 Standard Specification for Coal Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete.

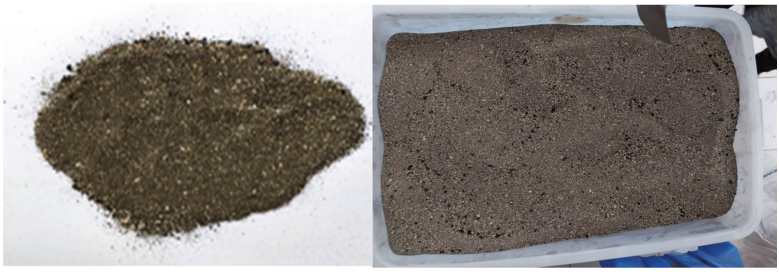

Fig. 5. Bottom Ash PLTU Banjarsari&Tanjung Enim

Fig. 6. XRF Test

The physical properties of bottom ash based on shape, color, appearance, dry unit weight, size, specific gravity and absorption from wet and dry bottom ash, Physical properties of bottom ash [18].

2.4 XRF (X-Ray Fluoresence)

XRF (X-Ray Fluoresence) test which is a test that serves to analyze the elemental composition in a sample using the principle of determining composition based on the interaction of X-rays with the material (Fig. 6 and Tables 1 and 2).

3 Results and Discussion

3.1 The Physical Properties of Fly Ash and Bottom Ash (FABA)

Fly ash and bottom ash (FABA) used in this study are two samples, FABA from PLTU Banjarsari and FABA from PLTU Tanjung Enim.

The physical properties of bottom ash based on shape, color, appearance, dry unit weight, size, specific gravity and absorption from wet and dry bottom ash refers to Physical properties of bottom [18], PLTUs PT. Bukit Asam bottom ash is categorized into Dry Bottom Ash because of the type of boiler is dry bottom boiler.

Table 1. Type of Ash based on Chemical Composition [19]

Chemical Composition of Type F	Chemical Composition of Type C
Type F fly ash is a fly ash containing less than 10% CaO which is produced from burning anthracite or bituminous coal.	Type C fly ash is fly ash containing CaO above 10% which is produced from burning lignite or sub-bituminous coal (brown coal).
Fly ash type F has a total content of SiO2, Al2O3, Fe2O3 more than 70%.	For type C fly ash, the total content of SiO2, Al2O3, Fe2O3 is greater than 50%.
CaO content of type F fly ash is less than 5%.	CaO levels reach 10%.
In the concrete mixture, the amount of fly ash used is 15%–25% of the cylinder	In the concrete mixture, the amount of fly ash used is 15%–35% of the cylinder weight.

Table 2. Physical Properties of Bottom Ash [18]

Physical Properties of Bottom Ash	Wet	Dry
Shape	Angular	Granular
Color	Black	Dark Gray
Look	Hard, Shiny	Like fine sand, very porous
Size (% pass the sieve)	Numb. 4 (90–100%)	1,5–¾ inc (100%)
	Numb. 10 (40–60%)	Numb.4 (50–90%)
	Numb. 40 (10%)	Numb.10 (10–60%)
	Numb. 200 (5%)	Numb.40 (0–10%)
Specific Gravity	2,3–2,9	2,1–2,7
Dry Unit Weight	960–1440 kg/m^3	720–1600 kg/m^3

Fly ash and bottom ash (FABA) inspection according to the The General Specifications of Highways (Bina Marga) 2018 Revision 2 Division 6 Section 6.3, Ministry Public Work of Indonesia [20]. Fly ash as substitution of filler and bottom ash as a substitution of fine aggregate (sand). The result of properties tests on Tables 3 and 4 show that FABA characteristics met with the specifications and almost have similar properties with standard material (cement portland and river sand).

3.2 The Sieve Analysis Properties of Fly Ash and Bottom Ash (FABA)

After testing each fine aggregate (sand), filler and FABA, a sieve analysis is carried out for each sample. The sieve analysis is carried out to determine the distribution of the gradation or aggregate grain according to the sieve size of the surface layer Asphalt Concrete (AC) based on The General Specifications of Highways (Bina Marga) 2018 Revision 2 Division 6 Section 6.3, Ministry Public Work of Indonesia. The result of sieve analysis tests on Tables 5 and 6 show that distribution of the gradation between FABA and standard material (cement portland and river sand) almost have a similar gradation:

Table 3. Comparison of Filler Physical Properties

		Test Results				
No.	Characteristics of	Fly Ash PLTU Banjarsari	Fly Ash PLTU Tanjung Enim	Cement Portland	Standard Test	Spec.
1.	Passing Sieve No. 200 (%)	100	100	100	SNI M-02-1994-03	Min 70%
2.	Specific Gravity (g/cm^3)	2.39	2.27	3.15	SNI 15-2531-1991	–

Table 4. Comparison of Fine Aggregate Physical Properties

		Test Results				
No.	Characteristics of	Bottom Ash PLTU Banjarsari	Bottom Ash PLTU Tanjung Enim	River Sand	Standard Test	Spec.
1.	Bulk Specific Gravity (g/cm^3)	2.56	2.55	2.50	SNI 1970: 2016	Min 2.5
2.	SSD Specific Gravity(g/cm^3)	2.63	2.61	2.54	SNI 1970: 2016	Min 2.5
3.	Apparent Specific Gravity (g/cm^3)	2.75	2.72	2.63	SNI 1970: 2016	Min 2.5
4.	Water Absorption (%)	2.65	2.57	2.24	SNI 1970: 2016	Max 3%
5.	Weight Content (%)	1.48	1.24	1.41	SNI 03-4804-1998	–
6.	Value Equal to Sand (%)	90.36	82.42	79.20	SNI 03-4428-1997	Min 50%
7.	Passing Sieve No. 200 (%)	0.30	0.30	0.34	ASTM C117 2012	Max 10%

3.3 Chemical Composition of Fly Ash and Bottom Ash (FABA)

The classification of Coal Ash based on Chemical Composition, ASTM (American Standard Testing Method) No. C618 Standard Specification for Coal Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete. XRF (X-Ray Fluoresence) test which is a test that functions to analyze the elemental composition of a sample using the principle of determining composition based on the interaction of X-Rays with the material. To determine the chemical composition of fly ash and bottom ash XRF testing was carried out.

Table 5. Comparison of Bottom Ash Sieve Analysis

Sieve Size		Percent Passing Gradation (%)		
Inch	mm	Fine Aggregate (Sand)		
		River Sand	Bottom Ash PLTU Banjarsari	Bottom Ash PLTU Tanjung Enim
1”	25	100	100	100
3/4”	19	100	100	100
1/2”	12.5	100	100	100
3/8”	9.5	100	100	100
No. 4	4.75	100	100	100
No. 8	2.36	98.7	99.25	98.75
No. 16	1.18	95.13	93.48	93.78
No. 30	0.600	69.16	71.54	55.57
No. 50	0.300	15.64	35.28	40.83
No. 100	0.150	2.02	5.12	14.73
No. 200	0.075	0.85	1.15	7.99

Table 6. Comparison of Filler Sieve Analysis

Sieve Size		Percent Passing Gradation (%)		
Inch	mm	Filler		
		Cement Portland	Fly Ash PLTU Banjarsari	Fly Ash PLTU Tanjung Enim
1”	25	100	100	100
3/4”	19	100	100	100
1/2”	12.5	100	100	100
3/8”	9.5	100	100	100
No. 4	4.75	100	100	100
No. 8	2.36	100	100	100
No. 16	1.18	100	100	100
No. 30	0.600	100	100	100
No. 50	0.300	100	100	100
No. 100	0.150	100	100	100
No. 200	0.075	100	100	100

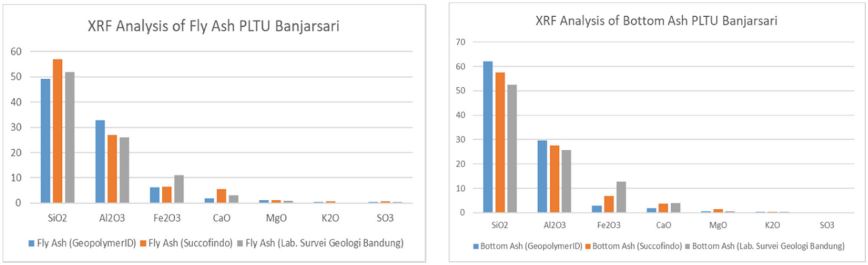

Fig. 7. XRF Analysis of Fly Ash and Bottom Ash PLTU Banjarsari

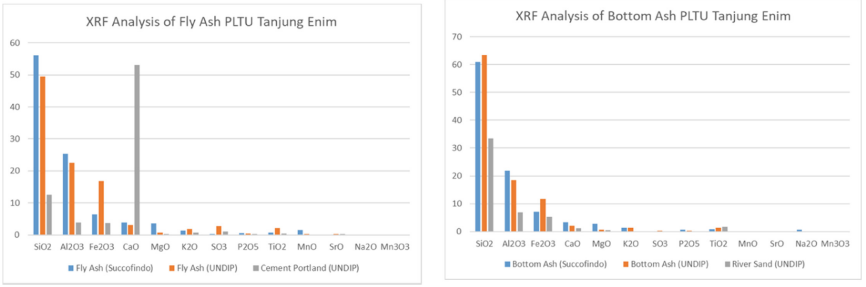

Fig. 8. XRF Analysis of Fly Ash and Bottom Ash PLTU Tanjung Enim

Fly Ash and Bottom Ash PLTU Tanjung Enim (PT. BEST) XRF Test has been carried out by PT. Sucofindo. Fly Ash and Bottom Ash (PT. BPI) TCLP + XRF Test has been carried out by Geopolymer ID and PT. Sucofindo. For comparison on XRF data, on this research also conducted XRF test, FABA PLTU Banjarsari at Lab. Survei Geologi Bandung, and FABA PLTU Tanjung Enim at UPT Lab. Terpadu UNDIP. The result of FABA XRF tests show on charts below that FABA of PLTUs Bukit Asam is Type F which contain high pozzolan materials according chemical composition (Figs. 7 and 8).

4 Conclusions

FABA PLTUs PT. Bukit Asam according to Physical Properties, Fly Ash as a substitution for filler and Bottom Ash as a substitution for fine aggregate (sand) can be used to replaced 100% material of filler and fine aggregate (sand) on the flexible pavements, because the Physical Properties characteristics of the Fly Ash and Bottom Ash is in consistent with The General Specifications of Highways (Bina Marga) 2018 Revision 2 Division 6 Section 6.3, Ministry Public Work of Indonesia. FABA PLTUs PT. Bukit Asam according from Sieve Analysis shown that Fly Ash have similar gradation with Cement Portland as a filler and Bottom Ash also have almost similar gradation with River Sand as a fine aggregate.

FABA PLTUs PT. Bukit Asam is Type F according to Chemical Composition is in consistent with the ASTM (American Standard Testing Method) No. C618 Standard Specification for Coal Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral

Admixture in Portland Cement Concrete. Fly Ash and Bottom Ash (FABA) waste of PLTU Banjarsari and PLTU Tanjung Enim contains high pozzolan materials of total content SiO2, Al2O3, Fe2O3 more than 70%.

So by this research can be conluded that from The Physical Properties, Sieve Analysis, and Chemical Composition of FABA PLTUs PT. Bukit Asam can be used as an alternative material substitution in flexible pavement, considering that so far in Indonesia, especially in South Sumatra, the most widely used as standard filler is cement portland and the standard fine aggregate is river sand. Next step of this research is going to analyze FABA performance as a material substitution in flexible pavement mixture.

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