Coal Ash Waste Utilization for Environmentally Friendly Road Pavement Materials

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Abstract. Indonesia is boosting electricity supply, where coal fired power plants are most widely used. Burning coal activity will produce Fly Ash Bottom Ash (FABA) that categorized as Hazardous and Toxic Substances. The production of FABA are 6,598,493 tons (2019) and will increase along with the 35,000MW program. The research purpose is to study the utilization of FABA from PLTU Labuan Angin as road pavement material that not only fulfill required specifications, but has better performance and environmentally safe. The experimental method was chosen by laboratory testing. Criteria for utilization of FABA as road pavement material, must be carried out with the use of materialthat capable to binding FABA so that it doesn’t disintegrate. Test results showed that FA is type F with CaO levels <10% and LoI 4.27%. Characteristics testing also showed results such as specific gravity of FA 2.64 and BA 2.56, absorption 3.24%, sand equivalent 95.35%. Utilization for base layers with a composition of 75% BA, 25% FA, and 9% PCC produce γd 1.71%, Wopt 5.84%, and UCS 33.05kg/cm². This utilization is the most effective, because it absorbs more volumes, binding cement, and compaction with heavy equipment can also prevent FABA from released so it is environmentally safe.

1. Introduction
The acceleration of industrial sector growth in Indonesia, is the government's effort to improve the nation's economic sector. But one of the negative impacts of the increasing industrial sector is the amount of waste generated was increased. Industrial waste that has large amount deposits, are causing serious environmental problem in term of disposal or safe storage. This issue has received serious attention from national or international environmental agencies. The government is constantly trying to develop environmentally clean industries and developing research on the use and improvement of the efficiency of industrial waste towards the application of sustainable material technology [1]. On the other hand, due to considerable usage of various naturally accruing materials for building road and other infrastructure, these have started depleting gradually. The cost of procurement and processing of such materials are increasing day by day [2]. It is in this connection, road researches have been trying to find out posible ways to use some of the waste material as alternative materials for road construction [3]. Technical feasibility, environmental consequences, and economic benefits are the main thing that was taken into utilization industrial waste as road pavement materials [4]. That why, road research is needed to be able to utilize waste as road material, so that in addition to reducing pollution, it can also reduce dependence on standard materials for road.
The type of waste that is very potential to be used as a substitute for road material is coal ash waste. Deposit of coal ash waste very large, because the majority electric supply in Indonesia used coal as fuel. Estimated that until 2050, contribution coal as source of energy is still high, reaching up to 31%. Beside that, development program of several coal fired power plants with total capacity of 35,000 MW will also affected in the increasing volume of coal ash waste so that is needed massive utilization to maintain the environmental balance [5]. One type of coal combustion remains consist of fly ash and bottom ash (FABA). In general proportion of FABA waste in the combustion process is 80%-90% Fly Ash dan 10%-20% Bottom Ash [6].

In 2019, the volume of FABA was 6,598,493 ton, it will increase in line with government policy on 35,000 MW that must be completed at 2024. The possible metal content, large volume, and specially for fly ash which is easily carried by wind causing coal ash classified as Hazardous and Toxic Waste in category 2 from specific sources [7].

The utilization of coal ash for road pavement depends its properties of ashes, which are determined by the chemical content in them [8]. The characteristic of FABA is also highly determined by characteristic of the coal. Fly ash generally has physical form such as cement and is pozzolanic, but can be mixed by Portland cement and added water, it become has ability to bind. Fly ash material in its application can be a substitute for portland cement for road pavement. While the bottom ash has a coarser grading than fly ash and is more suitable as aggregate in the mixture [9]. Criteria for utilization of FABA as a road pavement material, must be carried out with the use of substance that capable to binding FABA so that it does not disintegrate [10]. Classification of chemical properties of fly ash according to SNI 2640:2014 concerning the specifications of coal fly ash can be divided into 3 types, according to Table 1.

**Table 1. Chemical Properties of Fly Ash**

| Parameter                                      | Type Fly Ash |
|-----------------------------------------------|--------------|
| Silicon dioxide (SiO₂) + aluminum oxide (Al₂O₃) + iron oxide (Fe₂O₃), min. | 70 F 50     |
| Sulfur trioxide (SO₃), max., %                | 4 5 5       |
| Moisture Content, max. %                      | 3 3 3       |
| Loss on ignition (LoI, max. %)                | 10 6 6      |

Pavement structures generally consist of sub grade, base, and surface [11]. Layers in the pavement construction have their respective functions, namely:
- Surface layers, function is to secure the pavement from the influence of water, reduce stress, and withstand the highest loads due to traffic loads so they must have sufficient strength;
- Base layer, functions is to support the surface layer and reduce stress and strain, and spread the load from above;
- Subgrade layer, function is to supports the load distributed through the foundation layer above it

Labuan Angin PLTU is a power plant located in Sibolga City, North Sumatera. The existence of this PLTU is to meet the electricity supply needs in Sibolga City and Central Tapanuli District, and has an important role in maintaining electricity supply in the North Sumatra and Sumatra Islands. Capacity of Labuan Angin PLTU is 2 x 115W which was built in the context of the acceleration of the first phase 35,000 MW project. The type of boiler in this PLTU is a Circulating Fluidized Bed with the type of coal used is subbituminous. The total volume of fly ash and bottom ash that was produced at the Labuan Angin power plant is currently around 240,515.39 tons. Until now the utilization of FABA in the Labuan Angin PLTU has only been used as paving and brick making. In 2019, efforts will be made to trying utilization FABA as a road infrastructure that is expected to replace standard material requirements. So the purpose of research was to conduct an analysis of the utilization of FABA waste from the Labuan Angin power plant as a road pavement material that meets technical aspects, good performance, and environmentally friendly.
2. Research Method
Research on the utilization of FABA from the Labuan Angin PLTU as road pavement material was carried out by experimental methods through laboratory testing. The tests included material quality tests, chemical properties tests, and tests of mixture strength. The test was conducted at the Pavement Research and Development Center, Institute of Road Engineering, Ministry of Public Works and Housing.

3. Analysis and Discussion

Physical Properties Laboratory Testing Results
To utilize FABA waste from PLTU Labuan Angin as road pavement material, it must be tested of the physical properties material. The main physical properties to be tested are atterberg limits, gradation, specific gravity, absorption, and sand equivalent. The results of physical properties test from the Labuan Angin FABA PLTU is in accordance with Table 2. The physical form of fly ash and bottom ash is in accordance with Figure 1.

| Type of Testing | Result of Testing |
|-----------------|-------------------|
|                 | Fly Ash           | Bottom Ash       |
| Plastic Limit   | Non Plastic       | Non Plastic      |
| Spesific Gravity| 2.64              | 2.56             |
| Absorption      | -                 | 3.27             |
| Sand equivalent | -                 | 95.35            |
| Gradation       |                   |                  |
| - 9.52 (3/8”)   | 100               |                  |
| - No. 4         | 99.47             |                  |
| - No. 8         | 98.93             |                  |
| - No. 16        | 97.90             |                  |
| - No. 20        | 96.33             |                  |
| - No. 30        | 91.43             |                  |
| - No. 40        | 100               | 80.48            |
| - No. 50        | 99.82             | 57.91            |
| - No. 80        | 99.74             | 14.50            |
| - No. 100       | 99.67             | 8.10             |
| - No. 200       | 95.54             | 0.43             |

Figure 1. Physical form of Fly Ash and Bottom Ash

The physical characteristics of the specific gravity required by the General Specifications of Bina Marga 2018, namely the difference in density of fine aggregate and coarse aggregate must not be more than 0.2 for the FABA of the Labuan Angin PLTU was fulfilled. Difference in density greater than 0.2
will cause the surface area of the material to become wider, so that more binding material is needed. This has the potential to be used by FABA together for asphalt mixtures, concrete mixes, or base layers in road pavement.

**Chemical Properties Laboratory Testing Results**

Chemical properties were carried out by testing the chemical content of the FABA and the value of Loss of Ignition (LoI). The results of chemical properties testing from Labuan Angin FABA PLTU are in accordance with Table 3.

| Chemical Parameter | Result testing |
|--------------------|----------------|
|                    | Fly Ash        | Bottom Ash |
| SiO₂               | 61.63          | 45.59      |
| Al₂O₃              | 17.71          | 27.06      |
| Fe₂O₃              | 9.30           | 6.87       |
| CaO                | 4.24           | 6.87       |
| MgO                | 1.98           | 1.94       |
| SO₃                | 2.83           | 1.73       |
| Na₂O               | 1.31           | 4.97       |
| K₂O                | 1.28           | 0.78       |
| H₂O                | 1.45           | 2.13       |
| LoI                | 4.27           | 3.35       |

Based on the results of chemical properties testing in Table 3, the type of fly ash from the FABA tested can be determined in accordance with the classification in Table 1. The results of the classification of fly ash properties are type F with criteria SiO₂ + Al₂O₃ + Fe₂O₃ > 70%, CaO <10%, SO₃ <5%, LoI <6%. Silica or SiO₂ is the most dominant element in the fly ash and bottom ash of the Labuan Angin PLTU. Silica is an important compound in the cement hydration process, meaning that there will be stronger bonds when acting with cement and water. While the characteristic of silica tends to be incompatible with asphalt, the presence of silica will reduce its adhesion to asphalt. So the utilization of FABA from the Labuan Angin PLTU in this research will be directed to a mixture of concrete and foundation layers with cement.

The elements SiO₂, Al₂O₃, Fe₂O₃, CaO are the main chemical elements in the process of making cement, so that must be observed in the utilization of FABA because it will affect the bonding process that occurs. The amount of SiO₂ + Al₂O₃ + Fe₂O₃ > 70% will have a tighter bond than the <70% one.

LoI is the value of the amount of unburnt carbon. LoI is the carbon content in fly ash, measured using the Loss of Ignition Method, which is a state of potential loss of coal fly ash. The relationship with the physical properties of FABA, the higher the value of LoI, the higher the bond between the minerals in FABA and cement will be weaker because of the carbon barrier. LoI levels in the Labuan Angin FABA PLTU still meet the requirements of <6%, so it is classified as low in carbon content which prevents bonding with the binding material.

**Study on the Utilization of FABA as Road Base Layer**

In the utilization test of FABA as the foundation layer, selected portland cement as a binding material, because the main elements of cement and FABA from the Labuan Angin power plant are not much different and the cement is easily obtained from lime in the Sibolga area. In the foundation layer mixture plan designed in this study, fly ash is fine aggregate while bottom ash is coarse aggregate and cement as a binder.
The more bottom ash composition is the reason for the use of bottom ash which is still very low, and is different from fly ash which has been widely used as material for making cement. The results of proctor and UCS testing used FABA from the Labuan Angin power plant are in accordance with Table 4.

Table 4. Result proctor and UCS testing

| Description | UCS Value (kg/cm$^2$) |
|-------------|----------------------|
|             | 15% FA + 85% BA | 20% FA + 80% BA | 25% FA + 75% BA | 30% FA + 70% BA |
| Cement      | 7% | 8% | 9% | 7% | 8% | 9% | 7% | 8% | 9% | 7% | 8% | 9% |
| γd maks     | 1.65 | 1.59 | 1.68 | 1.68 | 1.68 | 1.67 | 1.67 | 1.57 | 1.59 | 1.70 |
| Wopt        | 6.82 | 6.94 | 7.08 | 7.08 | 7.30 | 7.46 | 7.12 | 7.51 | 7.63 | 7.91 | 7.89 | 7.74 |
| 7 day       | 18.2 | 20.86 | 22.60 | 19.50 | 26.53 | 30.21 | 25.47 | 28.82 | 33.05 | 8.00 | 12.46 | 23.7 |
| 14 day      | 20.9 | 24.84 | 28.05 | 24.11 | 29.69 | 31.11 | 23.56 | 29.40 | 33.40 | - | - | - |
| 28 day      | 23.0 | 29.82 | 32.44 | 28.46 | 31.30 | 36.66 | 28.82 | 31.89 | 36.79 | - | - | 29.5 |

In Table 3, the composition that meets the specifications of the foundation layer is 20% fly ash + 80% bottom ash + 9% cement and 25% fly ash + 75% bottom ash + 9% cement. The composition was obtained by the UCS value that entered the required specifications of 25 kg/cm$^2$ - 40 kg/cm$^2$ which had been reached at the age of 7 days. Graphs of UCS values of the two compositions are in accordance with Figure 2 and Figure 3.
Study of Utilization of FABA for Concrete Mixture of Surface Layer

In general, the characteristic of concrete is easy to be processed or workability, and has the durability and strength needed in a construction. For this reason, this research will conduct a study to obtain the required concrete mixture. Utilization of FABA for concrete mixes in this study was carried out with a mixture of geopolymer and conventional concrete.

Geopolymer Concrete Mixture of FABA PLTU Labuan Angin

Geopolymer concrete is a new type of concrete that does not use cement as a binding material. The use of other materials that contain a lot of silica and alumina completely as a substitute for cement through the process of inorganic polymerization (geopolymer) [12]. In this study, cement for concrete mix was replaced by fly ash, NaOH as an activator, and SiO₂ as a catalyst. There is a problem in fly ash Labuan Angin when it is mixed with geopolymers, it does not form a workable paste. This was proven when mixed with NaOH and SiO₂ with composition of 0.45 to 0.50 to the weight of fly ash, the mixture was not workable, and clumped as in Figure 4.

Conventional Concrete Mixture of FABA PLTU Labuan Angin

FABA Labuan Angin has also been tried into a conventional concrete mixture using water. In the implementation of concrete mixture testing with FABA, the water content needed to make a workable concrete mixture is very high, reaching 0.90 to the weight of fly ash. This is ineffective because it makes the mortar compressive strength low. The results of testing the use of FABA as a conventional concrete mixture are in accordance with Table 4.

| % FA | Cement (gr) | Weight FA (gr) | Weight BA (gr) | Water Weight (gr) | Flow (cm) | Compressive Strength (MPa) |
|------|-------------|----------------|----------------|-------------------|-----------|---------------------------|
| 0    | 500         | 0              | 1375           | 470               | 18.5      | 18                        |
| 30   | 350         | 150            | 1375           | 470               | 15.6      | 15.7                      |
| 40   | 300         | 200            | 1375           | 470               | 17        | 16.8                      |
| 50   | 250         | 250            | 1375           | 470               | 16.5      | 16                        |
| 60   | 200         | 300            | 1375           | 470               | 17        | 16.5                      |
| 70   | 150         | 350            | 1375           | 470               | 15.5      | 14.5                      |

Note. FA: fly ash; BA: bottom ash

Based on the compressive strength of the specimens, conventional concrete mixtures using FABA from the Labuan Angin power plant cannot be used for concrete road surface layers because the values

![Figure 4. The mixture of fly ash Labuan Angin and geopolymer](image-url)
are very low. The concrete mixture can be used as a layer of thin concrete or lean concrete because it is equivalent to K100.

4. Conclusions
Based on the results of the analysis of the testing that has been done, physical properties of fly ash are like cement with fine granules and are non-plastic. While the bottom ash granules are more rough like sand. The difference in density of fly ash and bottom ash is less than 0.2, which means it can be used together. Test of chemical properties of fly ash and bottom ash are dominated by SiO$_2$. The nature of the SiO$_2$ compound is very good as a cement hydration material so that the bond will be stronger when mixed with cement. LoI fly ash level is less than 6% so the carbon blocking bonds are in the low category. The test results on the mixture for the road foundation layer obtained UCS values that enter the required specifications of 33.05 kg/cm$^2$ on the composition of 25% fly ash + 75% bottom ash + 9% cement and UCS 30.21 kg/cm$^2$ on the composition 20% fly ash + 80% bottom ash + 9% cement. Utilization of FABA from the Labuan Angin PLTU as a concrete mixture material does not show good performance as evidenced by a mixture that is not workable and a low compressive strength value. A full scale test needs to be carried out on the utilization of FABA from the Labuan Angin PLTU as a road foundation material to determine the performance and environmental influences that occur.

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