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Application Of Waste Fly Ash In Roadbed Construction

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***Abstract* - The amount of fly ash from the operations of thermal power plants is now sharply increasing. It not only occupies a very large area of land but also causes serious pollution to the land, water, and air environment and harmful effects on human health. Finding a consumption source for fly ash waste is always a top concern for management agencies and thermal power operators. Many researches show that fly ash is also considered a green raw material source. It has a relatively high tensile and bending strength, low shrinkage, good acid resistance, high-temperature resistance, and low production cost, etc. Therefore, the application of fly ash in the production of construction materials allows for protecting the environment, creating a ground for sustainable development of the construction industry and opening a new route for the material production industry. This article focuses on the combination of fly ash, sand, and Alkali solution (geopolymer technology) to create an optimal mixture that is cured at normal temperature and suitable for roadbed, especially the subgrade at least 30cm below the road pavement.**

***Keywords* - Fly ash, roadbed, Akali, materials, aggregate.**

I. INTRODUCTION

Fly ash is a waste product from the fuel burning of thermal power plants. It accounts for about 80% of the mass of unburned inorganic matter in the coal combustion process [1], it is discharged and collected in an electrostatic precipitator. Its output is associated with the continuous development of coal-fired power plants. The research on fly ash states that it is usually spherical, very fine, light, and can be pyrolyzed into several hydraulically active substances. Fly ash particles usually have a size of 1µm to 15µm, a dry volume of about 0.95g/cm3 to 1.44g/cm3, and a particle volume of about 2.4g/cm3 [2]. Normally, fly ash contains an amount of unburned coal particles, which reduces its functional ability.

The density of fly ash is lower than that of sand (the density of sand is about 2.65g/cm3 [2]) and it has small particle sizes and uniform shapes so it is easily compacted. As a result, it is suitable for use as a material for soft ground to reduce the load acting on the foundation. Fly ash has a chemical composition of more than 30 oxide elements: SiO2, Al2 O3, CaO, MgO, Fe2 O3, FeO, SO3, Na2 O, K2O,... while SiO2, Al2O3, CaO, MgO are the components that determine the basic properties of fly ash, Na2 O, K2O, SO3, and residual coal are harmful components in the activation reactions of fly ash.

Fly ash is currently divided into two main types: type C and type F. Type C is better than type F due to its lower impurity content. Type C has a CaO content of ≥ 5% and is usually > 15% with a low content of unburned impurities (< 2%). Type F has a CaO content of < 5% with its impurity content greater than 2%. Fly ash in our country is mostly type F with unburnt coal content of up to 25 ÷ 30%. [3]

Currently, large thermal power plants in our country release a large amount of fly ash every day. For example, the Vinh Tan thermal power plant discharges 4,500 tons of fly ash per day [4]. To handle the amount of slag and ash from thermal plants, our country is aiming to use fly ash as an additive for the cement industry and some other material industries. However, the challenge is that the amount of unburned coal in our fly ash is too high (exceeding the allowable limit in ASTM 628:99 of 12%), so foreign material manufacturing technologies can hardly be applied to recycle the amount of fly ash discharged.

To reduce the amount of unburned coal in fly ash, Vietnam Cement Industry Corporation has built a slag and ash flotation separating line. This line generates a product with an amount of unburned coal of less than 7%, however, its output is quite low at 700 tons/month. For the entire amount of fly ash discharged to be used by the cement industry, reducing its unburned coal content is a difficult and very expensive task. Several projects have taken into account advanced solutions to reduce the rate of unburnt coal in fly ash (for example, using electrostatic precipitators to separate it...) but have not found them economically feasible.

In addition to seeking technologies for handling unburnt coal in fly ash to meet the requirements of material manufacturing industries, our country also has several studies on treating the amount of discharged fly ash, which are the application of Geopolymer technology. This technology is not too harsh in removing the amount of unburned coal in fly ash and it is suitable for the quality of fly ash in our country. This is expected to be a step forward in finding a consumption source for waste from thermal power plants. Furthermore, we need a specific standard in terms of fly ash quality and a policy to encourage the development of treatment and recycling technologies that are suitable for slag and ash in our country.

Because fly ash has very small and light particles with high expansion in a wet environment, we propose mixing it with backfilling sand of larger particle sizes to create higher strength

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for the mixture. Backfilling sand is black and gray with fine and non-uniform particles, which contain impurities and its requirements for physical and mechanical criteria are not too strict. Its sulfur-based content is ≤ 1% and its clay and organic mud content is ≤ 5% without course-grained gravel. For this type of sand, the unique concern is its required cleanliness. It is often used to level the foundation for stronger and more stable structures that can withstand natural impacts.

For the optimal strength of the mixture and promotion of its clear advantages compared to conventional materials, we add an alkaline solution to the mixture. The alkaline solution acts as an activator to enhance the polymerization process, which is a mixture of sodium hydroxide solution (NaOH) and liquid glass (Na2SiO3). The activated alkaline solution must be prepared by dissolving dry NaOH flakes (97-98% purity) in water at a concentration of 12M [5]. Sodium silicate solution has a ratio of SiO2 /Na2O = 2.5 (also known as silicon module), (% Na2O = 11.8; % SiO2 = 29.5 and 58.7% water by weight) [5]. NaOH solution and Na2SiO3 solution is mixed in a ratio of 1:2.5. Both these dissolution and mixing processes are exothermic reactions. The temperature of this mixture is about 70 oC. Therefore, the alkaline activating solution should be prepared at least one day before adding it to concrete to activate the fly ash [5].

II. RESEARCH METHOD

A. Status of research and application of fly ash materials

Many researches on fly ash materials in particular and waste products from coal-fired plants in general have been made around the world to utilize their great potential as well as solve environmental pollution problems. Many of them have applied Geopolymer technology with alkaline activators that react with fly ash to increase the strength of materials and replace traditional binders such as cement, and lime,...

Fernandez-Jimenez and Palomo studied the characteristics of fly ash and potential reactions such as alkalized cement [6]. This study was significant for building the concept of fly ash materials in the world. It published several typical properties of fly ash: the percentage of completely unburned particles is less than 5%, about 80-90% of particles are smaller than 45 µm, the content of Fe2O3 (Iron III oxide) is less than 10%, CaO (calcium oxide) content is almost negligible and about 40-50% of SiO2 (silicate) in fly ash reacts with alkaline active ingredients.

Ma et al studied the effects of the method for activating the strength of fly ash materials [7]. They found a new mechanism that increasing the alkali content will form a product with a denser structure and higher strength. Water is not involved in the activation reaction of fly ash, it only has the effect of improving the workability of the material as a lubricant, however, it reduces the strength of the material if it is too much.

Davidovits has published his findings of the ratios of molecules constituting fly ash to prepare products that have higher durability and strength: The ratio of M2O: SiO2 is 0.2 :0, 48, SiO2: Al2 O3 is 3.3:4.5, water: M2O is 10:25 and M2O: Al2O is 0.8-1.6 (with M being an alkali metal). The fly ash mixture activated with alkali will be set within a few hours at normal temperature (about 30°C), within a few minutes under the temperature of 85°C, and within a few seconds under microwaves. Its compressive strength will be increased over time similar to the use of Portland cement up to about 28 days. The compressive strength can be 20MPa after four hours at 20°C and 70-100Mpa for 28 days [8-10].

Dinh Quoc Dan et al [11] considered the use of slag for backfilling work based on experiments to determine the physical and mechanical characteristics and evaluate the strength of a slag-cement mixture with different ratios of cement. They made compression, tensile, and shear strength tests and evaluated the strength development over time for test samples with a ratio of 100% ash : 0% cement, 95% ash: 5% cement, 90% ash: 10% cement, 85% ash: 15% cement, 80% ash: 20% cement. Then they concluded that the mechanical properties of the ash and slag are further improved when they are combined with inorganic binders. The ash and slag have satisfactory geotechnical characteristics as a backfill material.

Tong Ton Kien et al [12] studied and evaluated the chemical properties, elemental composition, benefits, and applications of fly ash materials. They concluded that geopolymer concrete has many advantages in terms of strength, corrosion resistance, and reduction of CO2. In addition, they covered the disadvantages of geopolymer concrete: alkaline active ingredients can cause pollution to soil and water sources, and greenhouse effect, etc. Geopolymer is most suitable for the production of unburned and precast structures.

The National Agency for Science and Technology Information [3] has announced the composition and properties of ash and slag discharged from our country's thermal power plants. They presented several inventions, research works, and practical applications of fly ash in countries around the world and in Vietnam. They introduced the application of ash and slag for producing coating materials for industrial solid waste dumps at the Vietnam Institute for Building Materials. They made compressive strength and flowing tests of the mixture of fly ash and cement with cement ratios of 4%, 6%, and 8%, respectively, and fly ash from different thermal power plants, to choose a suitable fly ash source. At the same time, they poured additives to form a suitable mixture for their intended use.

In addition to backfilling sand, this article introduced an alkali solution into the material mixture to activate the chemical reactions of fly ash to create a binder and increase the strength of the material. Therefore, the chemical mechanism of geopolymer technology needs to be researched further.

In 1979, Professor Davidovits first used the term "Geopolymer" to mention the materials derived from aluminosilicate (silicon and aluminum) that can form good strength through chemical reactions in an alkaline medium. Common materials that provide silicon and aluminum elements are kaolinite, fly ash, slag, etc. Alkali solutions such as NaOH, KOH, and liquid glass (Na2 SiO3), etc. are commonly used as activators for the Geopolymeization process

Geopolymer is found with solid spatial network structure and high compressive strength. It has low porosity and and small pore size for low water permeability. Besides, its outstanding advantage is that it originates from waste products of thermal power plants, which are discharged at high

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temperatures, so it has high heat resistance and absorption. Its structure contains physical and chemical bonds of water so that water molecules can move on the surface and evaporate without harmful effects. Geopolymer is found with more perfect mechanical properties because it has a two-way vertical bonder with fiber reinforcement (carbon, glass, steel). Geopolymer is used to produce fire prevention materials, especially for industrial fields such as transportation (aviation, ships, cars, trains...) [13-19].

III. APPLICATION

A. Use waste fly ash in road base construction

This study uses a mixture of sand and fly ash with the respective ratio of 70%: 30%, which is added with 4% alkali solution (by dry weight). It is suitable for building a roadbed due to its elastic modulus of 189 Mpa after 28 days and density of 2.075g/cm3. This mixture shall be applied to the roadbed design of the Phu My II Industrial Park Project in Tan Thanh District, Ba Ria - Vung Tau Province, to have a more accurate conclusion on the advantages of this material compared to conventional ones.

B. Project Overview

D3 road belongs to Phu My II Industrial Park in Tan Thanh District, Ba Ria - Vung Tau province, which is invested by Investment - Development City And Industrial Zone Joint Stock Company:

- Road grade : Road of industrial parks;
- Required elastic modulus : Eyc $\geq$ 155 MPa;
- Length : 1,423m;
- Road surface : (12 +12)m;
- Sidewalk : (8+8)m;
- Middle median : 3m;
- Roadbed : 43m;

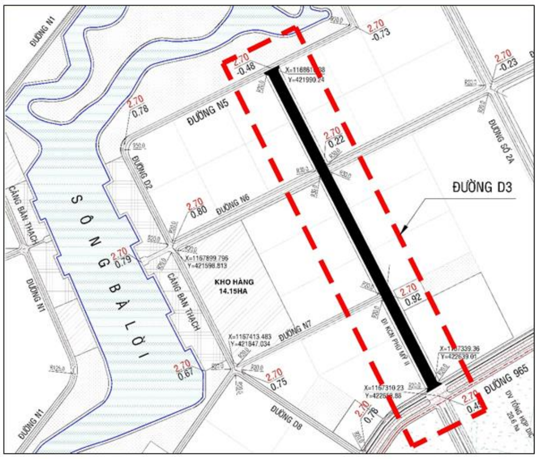

Figure 1. Location of D3 road

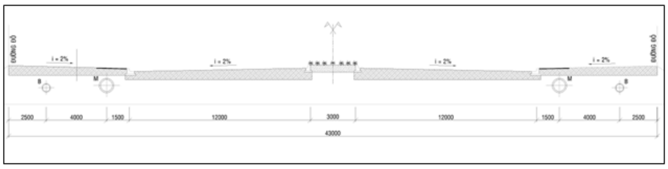

Figure 2. Typical cross-section of D3 road

C. Typical cross-section of D3 road

The natural geology of the D3 road is assessed through the geological survey report:

- Layer 1: clay mud mixed with organic matter, clay mud mixed with gravel in blue-gray and dark gray colors and flowing state. This layer has a thickness of 9.3m

The main characteristics of the layer are as follows:

+ Natural unit weight : γ w = 1.56 g/cm³;
+ Cohesion : C= 0.07kG/cm²;
+ Friction angle : φ= 3° 32'.

This is a weak layer that directly causes instability to the roadbed, which requires appropriate measures.

- Layer 2: clay loam, clay mixed with gravel, in gray white, and yellow colors and soft plastic state. This layer is 6.2m thick

The main characteristics of this layer are as follows:

+ Natural unit weight : γ w = 1.99 g/cm³;
+ Cohesion : C= 0.237kG/cm²;
+ Friction angle : φ= 17° 09'.

- Layer 3: Sand mixed with gravel, light yellow color, medium dense. This layer is 4.5m thick

The main characteristics of this layer are as follows:

+ Natural unit weight : γ w = 2.05 g/cm³;
+ Cohesion : γ w = 2.05 g/cm³;
+ Friction angle : γ w = 2.05 g/cm³;

D. Hydrological conditions:

Hydrological conditions of river: Canals and streams in Phu My area are directly influenced by the Thi Vai River.

The highest water level of the day : +1, 67m;
The lowest water level of the day : -3.27m .
Groundwater is not detected.

E. Design options:

- Pavement structure:
  + Fine-grained hot asphalt concrete 4cm thick;
  + Tack coat of 0.5kG/m²;
  + Coarse-grained hot asphalt concrete 6cm thick;
  + Tack coat of 1.0 kG/m²;
  + Grade 1 crushed stone aggregate, 20cm thick, K ≥0.98;
  + Grade 2 crushed stone aggregate, 20cm thick, K ≥0.98;
  + The natural aggregate subbase is 30cm thick, K ≥0.98; Subgrade of sand, K ≥0.98 (Eo = 40MPa);
- Construction elevation:
  + Sand backfill elevation: 2.90m;
  + Subbase of natural aggregate: 0.30m;
  + Pavement structure height: 0.50m;

Construction elevation: 3.70m.

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F. Comparing the settlement of the mixture of sand, fly ash, and alkali with conventional materials:

Calculate the ground settlement according to the industry standard 22TCN262-2000 [22 through the following equation:

- Consolidation settlement Sc:

$$S_c = \sum_{i=1}^{n} \frac{Hi}{1+eo}\left[C_r^i \lg(\sigma_{pz}^i / \sigma_{vz}^i) + C_c^i \lg \frac{\sigma_z^i + \sigma_{vz}^i}{\sigma_{pz}^i} \right] \quad (1)$$

- Hi is the thickness of the ith soil layer to calculate settlement, i ranges from 1 to n; Hi ≤ 2.0 m;
- eo is the void ratio of the soil layer i in its initial natural state;
- Cc is the compression index or slope of the curve within the range σi > σpzi of soil layer i;
- Cr is the compression index or slope of the above curve within the range σi;
- σ_{vz}^i, σ_{pz}^i, and σ_z^i are the pressure (vertical compressive stress) due to the self-weight of the natural soil layers acting on the layer i, the pre-consolidation pressure acting on the layer i and the embankment load acting on layer i (determine these pressure values corresponding to the depth z in the middle of the soft soil layer i)

- Total settlement S:

$$S = m.S_c \quad (2)$$

With m = 1.1 ÷ 1.4; If measures to limit soft soil from being floated under the embankment load are available.

Instant settlement Si:

$$Si = (m-1).Sc \quad (3)$$

G. The settlement of the soft ground under the embankment layers with sand and natural aggregate:

The settlement is determined by the design document of the D3 road in Phu My II Industrial Park, Tan Thanh District, Ba Ria - Vung Tau Province [23].

TABLE I. PARAMETERS OF STRUCTURAL LAYERS ABOVE THE NATURAL GROUND

Material	γ **(T/m³)**	**h (m)**
Fine-grained asphalt concrete	2,30	0,04
Coarse-grained asphalt concrete	2,30	0,06
Grade 1 crushed stone aggregate	2,00	0,20
Grade 2 crushed stone aggregate	2,00	0,20
Natural aggregate	2,20	0,30 (m)
Sand backfilling	2,00	2,90

Total load inducing settlement: P= 7.58 T/m²

TABLE II. PARAMETERS OF STRUCTURAL LAYERS ABOVE THE NATURAL GROUND

Material	**γ(T/m³)**	**Cc**	**Cr**	**Cv (x10-4 cm²/s)**	**e_o**	**σ_{pz} (kg/cm²)**	**h (m)**
L1: clay mud mixed with organic matter, clay mud mixed with gravel in blue-gray and dark gray colors and flowing state	1,560	0,52	0,2	23,9	1,88	1,24	9,3
L1: clay mud mixed with organic matter, clay mud mixed with gravel in blue-gray and dark gray colors and flowing state	1,990	0,38	0,12	15,46	0,66	2,539	6,2
L3: Sand mixed with gravel, light yellow color, medium dense	2,050	0,030	0,010	-	0,530	3,528	4,5

We calculate the consolidation settlement of the ground under the load of the embankment with the subbase of natural aggregate and the subgrade of sand backfill.

We calculate the consolidation settlement of the ground under the load of the embankment with the subbase of natural aggregate and the subgrade of sand backfill.

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TABLE III. PARAMETERS OF STRUCTURAL LAYERS ABOVE THE NATURAL GROUND

STT No	Thickness (m)	Depth z(m)	e_o	C_r	C_c	σ_{pz} (T/m²)	σ_{vz} (T/m²)	σ_z (T/m²)	Sc(m)
1	0,5	0,5	1,88	0,2	0,520	12,4	0,780	7,490	0,0356
2	0,5	1	1,88	0,2	0,520	12,4	1,560	7,490	0,0265
3	0,5	1,5	1,88	0,2	0,520	12,4	2,340	7,490	0,0216
4	0,5	2	1,88	0,2	0,520	12,4	3,120	7,490	0,0185
5	0,5	2,5	1,88	0,2	0,520	12,4	3,900	7,490	0,0162
6	0,5	3	1,88	0,2	0,520	12,4	4,680	7,468	0,0144
7	0,5	3,5	1,88	0,2	0,520	12,4	5,460	7,431	0,0139
8	0,5	4	1,88	0,2	0,520	12,4	6,240	7,394	0,0141
9	0,5	4,5	1,88	0,2	0,520	12,4	7,020	7,357	0,0144
10	0,5	5	1,88	0,2	0,520	12,4	7,800	7,320	0,0148
11	0,5	5,5	1,88	0,2	0,520	12,4	8,580	7,283	0,0152
12	0,5	6	1,88	0,2	0,520	12,4	9,360	7,246	0,0157
13	0,5	6,5	1,88	0,2	0,520	12,4	10,140	7,209	0,0162
14	0,5	7	1,88	0,2	0,520	12,4	10,920	7,156	0,0167
15	0,5	7,5	1,88	0,2	0,520	12,4	11,700	7,086	0,0172
16	0,5	8	1,88	0,2	0,520	12,4	12,480	7,017	0,0175
17	0,5	8,5	1,88	0,2	0,520	12,4	13,260	6,948	0,0165
18	0,5	9	1,88	0,2	0,520	12,4	14,040	6,878	0,0156
19	0,5	9,5	0,66	0,12	0,380	25,39	15,035	6,808	0,0059
20	0,5	10	0,66	0,12	0,380	25,39	16,030	6,724	0,0055
21	0,5	10,5	0,66	0,12	0,380	25,39	17,025	6,641	0,0052
22	0,5	11	0,66	0,12	0,380	25,39	18,020	6,558	0,0049
23	0,5	11,5	0,66	0,12	0,380	25,39	19,015	6,475	0,0047
24	0,5	12	0,66	0,12	0,380	25,39	20,010	6,391	0,0057
25	0,5	12,5	0,66	0,12	0,380	25,39	21,005	6,308	0,0066
26	0,5	13	0,66	0,12	0,380	25,39	22,000	6,225	0,0075
27	0,5	13,5	0,66	0,12	0,380	25,39	22,995	6,142	0,0084
28	0,5	14	0,66	0,12	0,380	25,39	23,990	6,059	0,0093
29	0,5	14,5	0,66	0,12	0,380	25,39	24,985	5,975	0,0101
30	0,5	15	0,66	0,12	0,380	25,39	25,980	5,892	0,0102
31	0,5	15,5	0,66	0,12	0,380	25,39	26,975	5,809	0,0097
32	0,5	16	0,53	0,01	0,030	35,28	28,000	5,726	0,0003
33	0,5	16,5	0,53	0,01	0,030	35,28	29,025	5,642	0,0003
34	0,5	17	0,53	0,01	0,030	35,28	30,050	5,559	0,0003
35	0,5	17,5	0,53	0,01	0,030	35,28	31,075	5,476	0,0003
36	0,5	18	0,53	0,01	0,030	35,28	32,100	5,393	0,0004
37	0,5	18,5	0,53	0,01	0,030	35,28	33,125	5,310	0,0005
38	0,5	19	0,53	0,01	0,030	35,28	34,150	5,226	0,0005
39	0,5	19,5	0,53	0,01	0,030	35,28	35,175	5,143	0,0006
								ΣS_c =	0,417

- Consolidation settlement Sc: 0.417m;
- Total settlement S: S=1.2x0.417= 0.500m;
- Instant settlement Si: Si= (1.2-1) x 0.417= 0.08m.

H. Settlement of the soft ground under the embankment with the mixture of sand and fly ash reinforced with 4% alkali

To compare the settlement when using new materials and conventional ones, we replace the first 30cm of the roadbed with new materials. The specifications of the road are shown in Table 4.

TABLE IV. PARAMETERS OF STRUCTURAL LAYERS ABOVE THE NATURAL GROUND

Material	γ (T/m³)	h (m)
Fine-grained asphalt concrete	2,3	0,04
Coarse-grained asphalt concrete	2,3	0,06
Grade 1 crushed stone aggregate	2,0	0,2
Grade 2 crushed stone aggregate	2,0	0,2
The mixture of sand and fly ash with 4% alkali	2,075	0,3 (m)
Backfill sand	2,0	2,9

Data of the natural ground from Table 3.2.

Via equation (1), we get the consolidation settlement of the ground under the load of the embankment with the mixture of sand and fly ash reinforced with 4% alkali.

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TABLE V. RESULTS OF CONSOLIDATION SETTLEMENT WHEN USING NEW MATERIALS

STT No	Thickness (m)	Depth z(m)	e_o	C_r	C_c	σ_{pz} (T/m²)	σ_{vz} (T/m²)	σ_z (T/m²)	Sc(m)
1	0,5	0,5	1,88	0,2	0,520	12,4	0,780	7,453	0,0355
2	0,5	1	1,88	0,2	0,520	12,4	1,560	7,453	0,0264
3	0,5	1,5	1,88	0,2	0,520	12,4	2,340	7,453	0,0216
4	0,5	2	1,88	0,2	0,520	12,4	3,120	7,453	0,0184
5	0,5	2,5	1,88	0,2	0,520	12,4	3,900	7,453	0,0161
6	0,5	3	1,88	0,2	0,520	12,4	4,680	7,430	0,0143
7	0,5	3,5	1,88	0,2	0,520	12,4	5,460	7,394	0,0138
8	0,5	4	1,88	0,2	0,520	12,4	6,240	7,357	0,0140
9	0,5	4,5	1,88	0,2	0,520	12,4	7,020	7,320	0,0143
10	0,5	5	1,88	0,2	0,520	12,4	7,800	7,283	0,0147
11	0,5	5,5	1,88	0,2	0,520	12,4	8,580	7,246	0,0151
12	0,5	6	1,88	0,2	0,520	12,4	9,360	7,210	0,0156
13	0,5	6,5	1,88	0,2	0,520	12,4	10,140	7,173	0,0161
14	0,5	7	1,88	0,2	0,520	12,4	10,920	7,120	0,0166
15	0,5	7,5	1,88	0,2	0,520	12,4	11,700	7,051	0,0171
16	0,5	8	1,88	0,2	0,520	12,4	12,480	6,982	0,0174
17	0,5	8,5	1,88	0,2	0,520	12,4	13,260	6,913	0,0165
18	0,5	9	1,88	0,2	0,520	12,4	14,040	6,844	0,0156
19	0,5	9,5	0,66	0,12	0,380	25,39	15,035	6,773	0,0058
20	0,5	10	0,66	0,12	0,380	25,39	16,030	6,691	0,0055
21	0,5	10,5	0,66	0,12	0,380	25,39	17,025	6,608	0,0051
22	0,5	11	0,66	0,12	0,380	25,39	18,020	6,525	0,0049
23	0,5	11,5	0,66	0,12	0,380	25,39	19,015	6,442	0,0047
24	0,5	12	0,66	0,12	0,380	25,39	20,010	6,359	0,0056
25	0,5	12,5	0,66	0,12	0,380	25,39	21,005	6,277	0,0065
26	0,5	13	0,66	0,12	0,380	25,39	22,000	6,194	0,0075
27	0,5	13,5	0,66	0,12	0,380	25,39	22,995	6,111	0,0083
28	0,5	14	0,66	0,12	0,380	25,39	23,990	6,028	0,0092
29	0,5	14,5	0,66	0,12	0,380	25,39	24,985	5,945	0,0101
30	0,5	15	0,66	0,12	0,380	25,39	25,980	5,863	0,0101
31	0,5	15,5	0,66	0,12	0,380	25,39	26,975	5,780	0,0097
32	0,5	16	0,53	0,01	0,030	35,28	28,000	5,697	0,0003
33	0,5	16,5	0,53	0,01	0,030	35,28	29,025	5,614	0,0003
34	0,5	17	0,53	0,01	0,030	35,28	30,050	5,531	0,0003
35	0,5	17,5	0,53	0,01	0,030	35,28	31,075	5,449	0,0003
36	0,5	18	0,53	0,01	0,030	35,28	32,100	5,366	0,0004
37	0,5	18,5	0,53	0,01	0,030	35,28	33,125	5,283	0,0005
38	0,5	19	0,53	0,01	0,030	35,28	34,150	5,200	0,0005
39	0,5	19,5	0,53	0,01	0,030	35,28	35,175	5,117	0,0006
								ΣS_c =	**0,415**

- Consolidation settlement Sc: 0.415m;
- Total settlement S: S=1.2x0.417= 0.498m;
- Instant settlement Si: Si= (1.2-1) x 0.415= 0.08m.

I. Comment

The consolidation settlement of the natural ground when using the mixture of sand and fly ash with 4% alkali to replace the first 30cm of the roadbed is almost not improved compared to that of the natural aggregate on the sand backfill (reduced by 0.49%), because the volumetric mass of the new material is almost similar to sand. This states that if you want to improve ground settlement in road construction, it is required to further study materials to find an aggregate with lower density.

J. Improvement of the pavement structure when using the mixture of sand and fly ash with alkali

The elastic modulus of the mixture of sand and fly ash with 4% alkali is quite high (189Mpa) compared to backfill sand (40Mpa) and natural aggregate (150Mpa), so it may help reduce the thickness of the structural pavement layer, thereby increasing economic benefits for the project.

Pavement structure is calculated according to 22TCN 211-06 [24].

K. Pavement structure is calculated according to 22TCN 211-06 [24].

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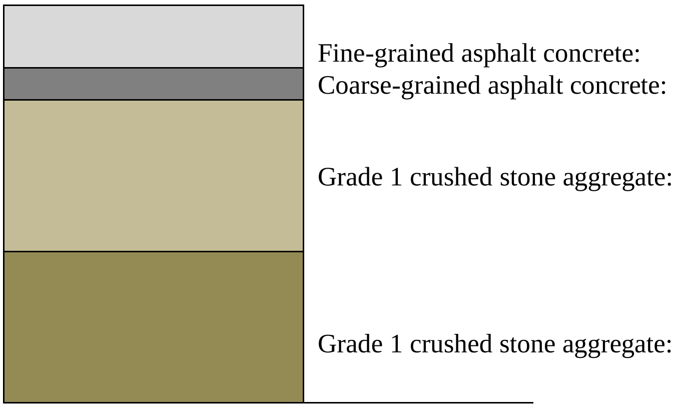


Subgrade of sand + subbase of natural aggregate, density k=0.98

Figure 3. Pavement structure of the project

General elastic modulus of sand and natural aggregate embankment: E_{chm}= 76.4 Mpa.

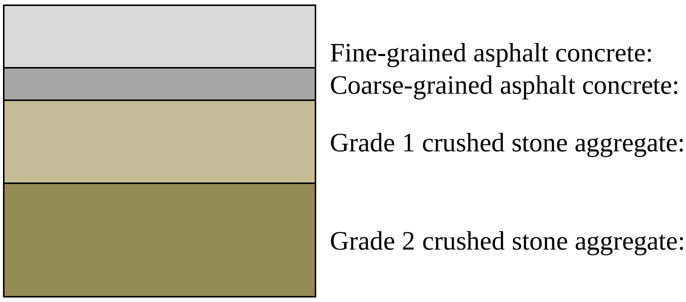
The equation to convert two layers into one is as below:

$$E_{tb}' = E_1 \left[\frac{1 + k.t^{1/3}}{1 + k} \right]^3 \quad (4).$$

- Modified elastic modulus of the structure: E^{dc}_{tb} = 339.66 Mpa;
- Modified elastic modulus of the structure: E^{dc}_{tb} = 339.66 Mpa;
- Required elastic modulus: Eyc= 155Mpa → K^{dv}_{cd} x Eyc = 170.5 Mpa;

Because Ech >Kdvcd x Eyc, the structure meets the requirements for elastic deflection

L. Improved pavement structure :



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Subgrade of sand + 30cm thick subbase of the mixture of sand and fly ash with 4% alkali, density k=0.98

Figure 4. Expected pavement structure with new materials

Audit the expected pavement structure:

Input data:

TABLE VI. RESULTS OF CONSOLIDATION SETTLEMENT WHEN USING NEW MATERIALS

Standard axle load P=	120	*kN*
Diameter of compression plate D=	36	cm
Diameter of compression plate D=	0,6	MPa
Required elastic modulus E yc =	155	MPa

Determine the general elastic modulus of the roadbed:

TABLE VII. ROAD STRUCTURE WITH NEW MATERIALS

No	Material layer	Ei (MPa)	hi (cm)
1	The mixture of sand and fly ash + alkali	189	30
2	Natural ground	40	

Wheel track: D=36cm;

Use graph 3-1 (22TCN211-06) [24] to determine the general elastic modulus of the road foundation:

Ratio: H/D = 0.917 ;

E0/E1 = 0,212.

Look up the math chart: Ech / E1 =0.451

The elastic modulus of the road surface is: Ech = E 1 x 0.451 =85.2 Mpa

Technical specifications of the pavement.

TABLE VIII. TECHNICAL SPECIFICATIONS OF ROAD CONSTRUCTION MATERIALS

Các lớp kết cấu (tính từ dưới lên) Structural layers (from bottom to top)	**Bề dày lớp (cm) Layer thickness**	**Mô đun đàn hồi E (MPa) Elastic modulus E (MPa)**			**Cường độ kéo uốn Rku (MPa) Bending strength Rku (MPa)**
		Tính độ võng Deflection	**Tính trượt Slip**	**Tính k.uốn Bending c**	
Nền đất Ground		85,2			
Cấp phối đá dăm loại 2 Grade 2 crushed stone aggregate	15	250	250	250	
Cấp phối đá dăm loại 1 Grade 1 crushed stone aggregate	8	300	300	300	
Bê tông nhựa hạt thô Coarse-grained asphalt concrete	6	350	250	1600	2,00
Bê tông nhựa hạt mịn Fine-grained asphalt concrete	4	420	300	1800	2,80

- Equivalent structural layers:

TABLE IX. CONVERSION TABLE OF 2 STRUCTURAL LAYERS TO CALCULATE E_{TB}'

Texture layer	Ei (MPa)	t = E_2/E_1	hi (cm)	k= h_2/h_1	H_{tb} (cm)	Etb' (MPa)
Grade 2 crushed stone aggregate	250		15		15	250,0
Grade 2 crushed stone aggregate	300	1,200	8	0,533	23	266,7
Coarse-grained asphalt concrete	350	1,312	6	0,261	29	282,7
Fine-grained asphalt concrete	420	1,486	4	0,138	33	297,5

- Modified average elastic modulus:

$E^{dc}_{tb} = \beta \times E_{tb}' = 329.75x\ 1{,}159 = 344.76$ (Mpa)

(With β = 1.159 according to table 3.6 in 22TCN 211-06 [3])

Use nomogram 3-1 (22TCN211-06) [2] to determine the general elastic modulus of the pavement structure:

Ratio: E_0/ E^{dc}_{tb} = 0,247.

Look up the nomogram: E_{ch} / E^{dc}_{tb} =0.512.

Look up the nomogram: E_{ch} / E^{dc}_{tb} =0.512.

Required elastic modulus: Eyc= 155Mpa → K^{dv}_{cd} x Eyc = 170.5 Mpa;

Because $E_{ch} > K^{dv}_{cd}$ x Eyc, the structure meets the requirements for elastic deflection.

M. Comment:

When applying the mixture of sand and fly ash with 4% alkali to the subbase of the road, the pavement strength will increase from 76.4 Mpa to 85.2 Mpa, i.e. by 11.5%. This will help reduce the thickness of the pavement structural layers to a minimum. Specifically, the thickness of the grade 1 crushed stone aggregate layer is reduced to a minimum of 8cm and the grade 2 crushed stone aggregate layer to 15cm. This reduces the structural layer thickness from 50cm to 33cm, i.e. 34%.

So using new materials to build the roadbed will significantly reduce the thickness of the pavement structural layer above.

N. Environmental benefits in road construction with the mixture of sand and fly ash with alkali 4%

The application of fly ash has great environmental significance. The most obvious benefit of this material is finding a consumption source for waste fly ash from thermal power plants with the following benefits:

Reduced air pollution due to fly ash in the air, which seriously affects the lives of people around the dumping area.

Reduced area of waste dumps will help increase land funds for economic development or tree landscape, helping to reduce pollution from waste dumps.

Reduced water pollution and limited hardening of water due to Ca +, Al +, Fe + ions,... in fly ash disposed into water sources.

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The application of new materials helps reduce the amount of conventional materials such as sand, natural aggregate, and crushed stone aggregate that are being extracted indiscriminately and are at risk of exhaustion, as well as minimize the impact on the environment due to the extraction of traditional materials.

Using new materials will reduce the amount of backfilling sand by about 30% for roadbeds. In addition, we can utilize sand mixed with fly ash without alkali as a leveling material for load-bearing points of the roadbed. This significantly reduces the amount of extracted sand and limits illegal sand mining. The environmental benefits of reducing river sand use are as follows:

Reduced risk of sand exhaustion in rivers and lakes. Currently, many dams upstream of the Mekong River are being built. This causes the amount of sand to become stuck and unable to move downstream, so the amount of sand in the river is gradually depleted.

Reduced risk of landslides in river beds, sea beds, and coastal areas. The cause of this problem is that sand mining activities create holes in the river bed, and then natural flow is broken with a deficit of riverbed sediment to create deep holes and steep slopes with enough whirlpools to cause riverbed erosion. Changing the structure of the river bed leads to instability of both banks, resulting in landslides. Besides, reducing the amount of sand in the river bed prevents sand from reaching the coast and causes coastal erosion.

Sand mining also affects river ecosystems, which results in sediment disturbance and increased turbidity, reduces light penetration and food sources for organisms, and causes the extinction of some sensitive organisms.

Using the mixture of sand and fly ash with an alkali solution can replace natural aggregates and crushed stone aggregates under the pavement structure. Therefore, the use of new materials will reduce the negative effects of resource extraction on the soil, water, and air environment:

For the land environment, extraction of stone and natural aggregate with explosives will cause loss of surrounding vegetation, affect the ecosystem, and cause extinction of many types of organisms. In addition, the explosive residue can contaminate the soil, cause loss of fertility, reduce cultivability and crop productivity. Then, heavy motor vehicles used in mining activities can cause subsidence of geological layers in the surrounding area.

For the water environment, stone mining can pollute groundwater sources due to toxic chemicals from explosives seeping into the ground. They cause hardening and poisoning of water sources, which seriously affects the health and lives of people. In addition, sand dust and toxic substances washed into rivers and lakes will pollute surface water sources, and destroy the habitat of aquatic organisms,...

For the air, stone mining will pollute the air due to dust discharged from stone explosions, motor vehicles, etc. Local people often face serious air pollution, which results in respiratory diseases, etc.

Additionally, noise pollution, risks of rock collapse, and illegal stone mining are also current problems.

The application of fly ash has great benefits to the environment, so it needs to be utilized to reduce natural resource extraction and overcome the negative impacts of using traditional materials on the environment.

IV. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

To develop new materials from industrial waste sources, research on these materials, specifically fly ash, is currently noted. In addition, the authors have studied the characteristics of ground settlement, the improvement of pavement structural thickness, economic efficiency, and environmental benefits in specific projects. After considering the above conditions, they found that the application of the mixture of sand and fly ash with 4% alkali has great environmental benefits and contributes to improving the pavement structure with the ability to reduce by 34% of the thickness of the upper pavement structure, while the economic benefits and potential for application on soft ground are not clear. Therefore, it is necessary to further research the application of materials: apply the mixture with high alkali content to the base of pavement structures and apply the mixture without alkali for ground leveling,... to take maximum advantage of waste fly ash, thereby reducing construction costs.

B. Recommendations

Under environmental pollution conditions and risks of natural resource depletion, construction activities associated with environmental protection are increasing concern. This study on using fly ash in roadbed construction also contributes to the above environmental protection. However, for future research to be better, we would like to make the following recommendations:

It is required to focus on construction methods to prepare a great quantity of material with a low content of liquid compared to the content of solid.

Attention should be paid to researching the mixture with higher fly ash content to fully utilize waste resources;

It is required to pay attention to the application of new materials on field construction to reach the most accurate conclusions about their quality and feasibility.

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