Approach to fly in roadbed construction

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Received 9/8/2022, Accepted, 17/12/2022, Published 15/1/2023

Nowadays, filling sand is mainly used for roadbed construction. However, this material resource is gradually depleting. At the same time, sand has loose grain structure and small elastic modulus (E ≤ 40Mpa) therefore it fails to meet the technical requirements of roadbed construction. Consequently, roadbed is often embanked with alternative materials such as soil reinforced with inorganic binders, natural aggregates, and macadam. leading to high cost and environmental pollution. Therefore, it is important to determine a new type of roadbed material. This study presents several laboratory tests on the mechanical and physical properties of sand mixed with fly ash in order to find an appropriate mixture for roadbed construction. The test results show that the mixture of sand and fly ash, which contains an optimal ratio of sand/fly ash of 70%/30% with a dry volume value of 1.821g/cm³, not only meets the requirements for roadbed materials, but also utilizes more fly ash. When adopting Geopolymer technology where alkaline solution is added to reinforce sand-fly ash mixture with the ratio of sand/fly ash of 70%/30%, fly ash will be activated by the alkaline solution to produce gelatinous material through a series of reactions. The gelatinous material is characterized by the high-strength and the tightly-linked molecules. Apart from being a suitable material for roadbed construction, sand fly ash material can also be used as a foundation layer for pavement structure.

Keywords: Roadbed, fly ash, sand, laboratory test, aggregate
1. INTRODUCTION

Fly ash is a waste that is discharged from fuel burning operation of thermal power plants. It accounts for about 80% of unburned inorganic matter volume during coal burning [1]. Fly ash flies out, and is collected at a static dust filter. Fly ash production is linked with the continuous development of coal-fired thermal power plants. According to recent research on fly ash, this material is normally found with spherical particles which are very fine and light. The material can be pyrolyzed into some substances with hydraulic activity. The characteristics of fly ash are as follows: 1) The size of particle usually ranges from 1µm to 15µm, 2) The dry mass density is about 0.95g/cm$^3$ to 1.44g/cm$^3$, and 3) The particle volume mass is about 2.4g/cm$^3$ [2]. Fly ash normally contains a certain amount of coal particles that have not been fully burned. This consequently reduces the activation of fly ash during reuse. Fly ash is lighter than sand (e.g. particle mass density of sand is about 26.5kN/m$^3$) [2]. In addition, fly ash is small in size and uniform in shape so it is easy to be tightly compacted. Thus, fly ash can be used for construction on soft ground in order to reduce the applied load on the ground. Fly ash contains more than 30 oxide elements: SiO$_2$, Al$_2$O$_3$, CaO, MgO, Fe$_2$O$_3$, FeO, SO$_3$, Na$_2$O, K$_2$O, etc. Among above oxides, SiO$_2$, Al$_2$O$_3$, CaO, MgO are the components that determine the basic properties of fly ash. Na$_2$O, K$_2$O, SO$_3$ and residual coal are harmful components in the activation reaction of fly ash. Fly ash can be classified into two main categories: 1) Type C and 2) Type F. Type C fly ash is better than Type F due to its low level of impurity. Type C fly ash contains a CaO content of greater than 5%. The CaO content typically stays in the range of 15 ÷ 35% and has a low unburned impurity content smaller than 2%. Type F fly ash has a CaO content of smaller than 5% and an impurity content of greater than 2%. Fly ash in Vietnam is mostly considered as Type F with the unburned carbon content of 25 ÷ 30%. [3].

There have been many researches on both the fly ash and by-products of coal firing in thermal power industry. Researchers have been attempting at investigating the advantages of these by-products as well as solving the environmental problems caused by the by-products. Many studies have adopted Geopolymer technology with alkaline activators that react with fly ash to enhance the strength of a material. The enhanced material can then be used as a replacement for traditional binders such as cement, lime, etc. [4,5]. Fernandez-Jimenez and Palomo studied the characteristics of fly ash and its potential reactions such as alkalinized cement [6-8]. This study provides an insight into the concept of fly ash materials. The results for the characteristics of fly ash are released as follows: 1) Percentage of completely unburned particles is less than 5%, 2) About 80-90% of particles with sizes less than 45 µm, 3) Fe$_2$O$_3$ content (Iron (III) oxide) is less than 10%, 4) CaO (calcium oxide) content is almost negligible, and 5) About 40-50% of SiO$_2$ (silicate) in fly ash reacts with alkaline activator. Ma et al. studied the effect of the activating solution on the durability of fly ash material [9]. A new mechanism is introduced to indicate an increase in alkaline content, which produces a material with a denser structure and a higher strength. Water does not participate in the activation reaction of fly ash. It only helps to improve the workability of the material as a lubricant; however, it will reduce the strength of the material if the water rate is too high. Dan, D.Q. et al [2] investigated the application of ash and slag in filling to determine the physical and mechanical properties of ash and slag and evaluate the durability of the ash-cement mixture with various cement contents. For the physical and mechanical features, the authors conducted compression, tensile strength and shear strength tests to evaluate the strength development over time for the samples whose ratios of ash/cement are:100%/0%, 95%/5%, 90%/10%, 85%/15%, and 80%/20%. The results show that the physical and
mechanical properties of the materials combined with ash and slag are superior compared to those combined with inorganic binders. Ash and slag contain geotechnical characteristics which allow them to be used as filling materials. Davidovits [10-14] carried out studies on the ratios of molecules constituting fly ash cement material to introduce products that contain sufficient durability and strength. Pradip Nath and Prabir Kumar Sarker [15] studied the use of fly ash as a binder in concrete. Zhang et al. [16] ’s research on environment-friendly materials to reduce the greenhouse effect due to CO2 emissions from Portland cement production. Kien, T.T. et al. [17] evaluated the chemical properties, elemental composition, benefits and applications of fly ash material. They came into conclusion that geopolymer concrete provides many advantages such as high strength, excellent corrosion resistance and low CO2 emission. In addition, the authors mentioned the limitations of geopolymer concrete. According to Kien et al, the use of alkaline activators in the production process could pollute soil and water, contributing to greenhouse effects Geopolymer technology is the best way for manufacturing non-fired and precast components. This paper investigates the properties of sand fly ash mixture and adopts the use of alkaline solution (with geopolymer technology) to determine a new mixture that can be used for roadbed construction as well as foundation bottom layer (which is located at least 30 cm below the pavement structure).

2. MATERIALS AND METHOD

Fly ash is generated in the process of firing finely crushed coal in thermal power plants. During the combustion process, minerals in coal are melted, suspended and blown out of the combustion chamber along with flue gas. When they are cooled down, spherical particles, called fly ash, are produced. The fly ash used in this study comes from Vinh Tan thermal power plant, Vietnam (please see Fig. 1). The chemical composition of this fly ash is determined by X-ray fluorescence (XRF) and the results are summarized in Table 1. From the test results, the total content of the components are as follows: (SiO2 + Al2O3 + Fe2O3) > 70%, CaO < 30%, and Na2O < 1.5%. The results meet the standard requirements for ASTM C618-94a regarding fly ash. [18].
Table 1 Analysis result of chemical composition and content (%) of fly ash.

<table>
<thead>
<tr>
<th>Components</th>
<th>SiO$_2$</th>
<th>Al$_2$O$_3$</th>
<th>Fe$_2$O$_3$</th>
<th>K$_2$O</th>
<th>MgO</th>
<th>TiO$_2$</th>
<th>CaO</th>
<th>SO$_3$</th>
<th>Na$_2$O</th>
<th>MKN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content %</td>
<td>56.27</td>
<td>27.52</td>
<td>6.48</td>
<td>5.36</td>
<td>1.22</td>
<td>1.01</td>
<td>0.96</td>
<td>0.41</td>
<td>0.21</td>
<td>20.81</td>
</tr>
</tbody>
</table>

The physical criteria of fly ash are summarized in Table 2.

Table 2 Physical criteria of fly ash.

<table>
<thead>
<tr>
<th>Physical criteria</th>
<th>Specific weight (kN/m$^3$)</th>
<th>Percent passing 0.05mm sieve (%)</th>
<th>Strength index after 28 days (%)</th>
<th>Strength index after 7 days (%)</th>
<th>Loss after burning (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applicable standards</td>
<td>[21] [19] [22]</td>
<td>[19] [22]</td>
<td>[19] [22]</td>
<td>[19] [20]</td>
<td></td>
</tr>
<tr>
<td>Result</td>
<td>2.4</td>
<td>93.5</td>
<td>92.7</td>
<td>79.2</td>
<td>1.1</td>
</tr>
</tbody>
</table>

The 0.05 mm sieve passing ratio is more than 66% which indicates that the fly ash is very fine. Filling sand is used for preparing foundation or cushion for soft ground in saturated state (e.g. clay ground, pasty clay ground, sandy ground, muddy ground, and coal mud ground). Filling sand ensures that the road base reaches the designed elevation (please see Fig. 2).

Figure 2 Filling sand.

The physical and mechanical properties of filling sand are shown in Table 3. The relationship between dry unit weight and optimal moisture content of the filling sand is shown in Fig. 3.
In this test, filling sand and fly ash are mixed with various proportions. The ratio of filling sand/fly ash is selected as 90/10; 80/20; 70/30; 60/40; 50/50 by weight percentage. After mixing, the mixture is poured into a mold to determine standard density, optimal moisture, and CBR. The codes of samples are shown in the Table 4.

3. RESULTS AND DISCUSSION

This test was performed in accordance with the standard 22TCN 333: 2006 (method II-A) [23]. The instruments are innovated proctor mortar with the dimension of D x H = 101.6mm x 116.43mm and pestle of 4.54 kg and 457mm-high drop. The sample is compressed in 5 layers, each of which carries 25 times the weight of the pestle. After the compaction process is completed, dry weight densities corresponding to various moistures are calculated. The max dry weight is determined from the chart of relationship between moisture and dry unit weight. The results are shown in Figs. 4-8.

Figure 3 The chart of relationship between dry unit weight and optimal moisture.

Figure 4 Chart of standard compression of CP90/10 mixture.

Figure 5 Chart of standard compression of CP80/20 mixture.
When the fly ash content in the mixture is increased from 10% to 20%, the dry unit weight rises from 17.58 kN/m$^3$ to 18.61 kN/m$^3$. However, if the content of fly ash in the mixture continues to increase, the standard density will gradually decrease. When the fly ash content in the mixture is 50%, the dry unit weight is found to be with the minimum value of 17.4 kN/m$^3$ among the samples. When the fly ash content in the mixture is between 20% and 30%, the dry unit weight is greater than 18 kN/m$^3$. This value is acceptable for the use of filling sand-fly ash mixture for the foundation bottom layer of the pavement structure.

The test sample for determining CBR index in laboratory is cast with the respective filling sand/fly ash ratio of CP80/20, CP70/30, CP60/40, and CP50/50. This test was conducted according to the standard 22TCN 332: 2006 [24]. The sample is made in a CBR mold with the dimension of D x H = 152.4mm x 177.8mm. Each ratio of sand/ash is used for three samples: 1) Sample 1 is applied with 65 times of pestle per layer, 2) Sample 2 is applied with 30 times of pestle per layer, and 3) Sample 3 is applied with 10 times of pestle per layer. The samples are then cured by immersing in water for 96 hours. When conducting the CBR test, the compression tip penetrates the sample with the specified speed of 1.27 mm/min. Compression forces are recorded at the time when the compression tip penetrates the sample at 0.64mm; 1.27mm; 1.91mm, 2.54mm; 3.75mm; 5.08 mm and 7.62 mm. Appropriate
calculations are used to determine the CBR index of the tested samples. CBR test results are summarized in Table 5 and illustrated in the Figure 9(a, b, c, d).

![Chart of CBR and dry unit weight corresponding to each mixture: (a) Ratio 80/20; (b) Ratio 70/30; (c) Ratio 60/40; (d) Ratio 50/50.](image)

The CBR indexes of the samples, which correspond to the various mixtures of filling sand-fly ash, are smaller than those of filling sand. The reason is that when being immersed in water for 96 hours, fly ash with high expansion properties will reduce the density of the mixture and increase the porosity. Therefore, the larger the fly ash content is, the smaller the CBR of the mixture is. The mixing of filling sand-fly ash increases the density of the mixture to a greater degree compared to that of the filling sand. The appropriate fly ash content that can be used to increase density is 20-30% of the total volume of the mixture. However, the CBR of the filling sand-fly ash mixture is lower than that of the filling sand. Therefore, the use of filling sand-fly ash mixture for road pavement layers is not guaranteed. In order to improve the efficiency of using filling sand-fly ash mixture in roadbed construction, this study combines the mixture of filling sand-fly ash with alkaline activator solution (ASS) with AAS-over-solid ratios of 4%, 6% and 8% of the weight of the mixture. The mixture of filling sand-fly ash is selected with 70% filling sand and 30% fly ash. The alkaline activator (AAS) used in this study is the combination of NaOH solution and liquid glass solution (Na$_2$SiO$_3$) at the ratio of 1/2.5 by weight. The test samples for elastic modulus and confined compressive strength are prepared in the molds, which have the size D x H = 101.6mm x 116.43mm. Material sample is a mixture of 70% filling sand and 30% fly ash mixed with
water and alkali activator at appropriate proportions. The material mixture is compressed in a way that is similar to standard compression test. After casting, the molds are removed, and the samples are cured under moisture condition for 7 days and 28 days. Total number of calculated cast samples corresponding to two curing periods and three types of AAS ratios is 28. Elastic modulus and confined compressive strength are determined by performing laboratory tests. The test results are summarized in Tables 6-8. The chart of the relationship between AAS ratio and confined compressive strength $R_n$, 7-day and 28-day elastic modulus is shown in the Figs. 11-14.

![7-day compressive strength](image1)

**Figure 10** Relation between AAS ratio and 7-day confined compressive strength.

![28-day compressive strength](image2)

**Figure 11** Relation between AAS ratio and 28-day confined compressive strength.

![7-day elastic modulus](image3)

**Figure 12** Relation between AAS ratio and 7-day elastic modulus.
1) The increase of confined compressive strength of the tested sample is directly proportional to the alkaline activator content. The confined compressive strength of the sample increases significantly when the active substance content in the mixture is increased from 4% to 6%. Specifically, at the age of 7 days, the compressive strength increases from 0.7 Mpa to 1.80 Mpa corresponding to an increase by 154.6%. Similarly, at the age of 28 days, the compressive strength rises from 0.92Mpa to 2.31Mpa, corresponding to an increase by 151.3%.

However, when the content of alkaline activator is increased from 6% to 8%, the compressive strength of the tested sample rises slowly. Specifically, at the age of 7 days, the compressive strength rises from 1.80 Mpa to 2.47 Mpa corresponding to an increase by 37.7%. Similarly, at the age of 28 days, the compressive strength rises from 2.31 Mpa to 3.27 Mpa corresponding to an increase by 41.7%.

2) Based on the technical requirements of the soil consolidated with inorganic, chemical and synthetic binders for roadbed or pavement [25], it can be found that the test sample with AAS content below 4% does not meet the technical requirements of consolidation material on compressive strength according to TCVN 10379: 2014 [26].

The results show that the confined compressive strength of the test sample with AAS content above 6% reaches level II and that of the test sample with AAS content above 8% reaches level I according to TCVN 10379: 2014 [26].

3) The elastic modulus of the test samples increases proportionally with the alkaline activator content. The elastic modulus of the sample rises dramatically when the content of the activator in the mixture is increased from 4% to 6%. Specifically, at the age of 7 days, the elastic modulus rises from 160 MPa to 368 MPa corresponding to an increase by 129.1%. Similarly, at the age of 28 days, elastic modulus rises from 189 MPa to 417 MPa corresponding to an increase by 121.2%.

However, when the content of alkaline activator is increased from 6% to 8%, the elastic modulus of the test sample does not rise significantly. Specifically, at the age of 7 days, elastic module rises from 368 Mpa to 401 MPa corresponding to an increase by 9.1%. Similarly, at the age of 28 days, the elastic modulus rises from 417 MPa to 444 MPa corresponding to an increase by 6.5%.

4. CONCLUSIONS

1) If the ratio of sand/fly ash in the mixture is 70%/30%, the dry mass density is over 1.8 g/cm³. This value is acceptable for the preparation of foundation bottom layer (first 30 cm of the roadbed).
2) When the non-alkaline fly ash-sand material is used, the material has a lower CBR than that of the filling sand due to the small fly ash particles, which can in theory penetrate into the voids between the sand particles, making the material become tighter. However, when being soaked in water, fly ash will expand, leading to a reduction in density and an increase in porosity. As a result, the non-alkaline fly ash-sand material is not suitable for foundation bottom layer as well as active areas of road pavement.

3) When Geopolymer technology is adopted with alkali solution being used for the mixture of sand and fly ash (ratio of sand/fly ash is 70/30), fly ash will be activated by alkali solution with a series of reactions to form a gelatinous and high strength material whose molecules are tightly linked together. The ratio of alkali in the mixture is 4% with the elastic modulus of 189 MPa after 28 days, which is suitable for building the foundation bottom layer or the entire active area of pavement. The ratio of alkali in the mixture is 6% or more with the elastic modulus of over 400 MPa, and the confined compressive strength of over 2 MPa after 28 days. This mixture can therefore be used for road foundation. However, it is necessary to learn more about other material properties such as splitting tensile strength and bending tensile strength in order to obtain the most accurate conclusion for the potential application of the material to the foundation layer of the pavement structure.

4) When the 4% alkali-reinforced fly ash-sand material is applied to the foundation, the strength of the roadbed increases from 76.4 MPa to 85.2 MPa corresponding to an increase of 11.5%. This results in a reduction of approximately 34% in the thickness of the pavement structure, and approximately 17.5% reduction in the consolidation settlement of the ground.

5) Research on the use of alkali-reinforced fly ash materials gives great environmental benefits. The most obvious one is that it is possible to find consumption sources for thermal power plant fly ash and reduce air pollution caused by light ash particles flying in the air, which can seriously affect the lives of people around dumping sites. In addition, the areas which are occupied by the fly ash will be reduced to reserve more land for economic development or growing trees, helping to prevent pollution from affecting people around dumping sites. Efficient treatment of waste fly ash minimizes water pollution and limits its hardening due to Ca+, Al+, Fe+ ions, etc.,

6) The application of this new material allows for a reduction in the amount of conventional materials such as sand, natural aggregate, and macadam, which are being indiscriminately utilized, leading to the risk of their extinction. The new material also minimizes environmental impacts resulted from exploitation of such conventional materials. The use of the new material will contribute to a decrease of about 30% of the filling sand during road foundation preparation. In addition, the area below the load-bearing part of the roadbed may use non-alkali sand-fly ash material as a back-filling material. This significantly reduces the exploited sand volume, illegal sand extraction, and risk of exhaustion of sand resources in rivers and lakes. This type of back-filling material also mitigates negative impacts on river ecosystems and minimizes the agitation of sediments, which causes an increase in turbidity and a decrease in light penetration.

References
