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Effects of stabilization on resilient characteristics of fly ash as pavement material

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HIGHLIGHTS

- The effect of stabilization on resilient modulus of a Class F fly ash by the means of cyclic triaxial testing.
- Although the confining pressure supplied by air was practical to use, it was difficult to maintain exact target pressure.
- Under the same stress paths samples having higher cement or lime contents exhibited lower strains.
- The rate of axial strains under corresponding stress paths decreased with increasing cement or lime content.
- There was a nonlinear relationship between axial strain and deviator stress.

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ABSTRACT

The disposal of industrial by-products constitutes a mounting problem of global dimensions. Among these, the disposal of fly ash is very problematic, for the increasing demand for electricity from coal burning power stations has been resulting in growing amounts of stockpiled fly ash, inevitably causing environmental problems. The use of this fly ash in road pavements provides an opportunity to use high volumes of this material, however, the ash needs to be stabilized to improve its performance when utilized in upper pavement layers. Because the principal input in mechanistic-empirical analyses is resilient modulus, the aim of this study is to investigate the effect of stabilization on resilient modulus of a Class F fly ash.

1. Introduction

One of the most significant detriments for the modern world is waste production, with billions of tons of waste being generated each year around the world. As a result of this, considerable attention has been given to the utilization of waste materials and other by-products from different production processes. In the recent past these materials were simply stockpiled and dumped as waste. In the last few decades, however, the increasing amount of waste production and the diminishing availability of land fill sites have restrained the dumping of waste products. Therefore, the industries producing waste materials now face an increasing financial burden (cost of disposal) and community concern regarding the potential risk to the environment.

Increasing demand for electricity has rendered coal fired power stations indispensable for many countries. In these stations, the coal is used to provide the steam that drives turbines to generate electricity. Before combustion, the coal is pulverized in coal mills and injected into the furnace by compressed hot air. During the combustion process coal minerals undergo some physical and chemical changes. About 15% of the burned coal falls through open grids into the furnace floor where it sinters to form bottom ash which is a coarser material. The majority (about 80–85%) is carried out of the furnace by means of the flue gases, where it hardens into a fine grained material known as fly ash.

As the demand for energy increases, so does the amount of fly ash that have the potential of being utilized in various applications. Construction of road base, subbase and subgrade provides an opportunity to use high volumes of this material. There is a growing demand for road materials in every country, yet the supply of the classical base and subbase materials such as crushed rock and gravel is diminishing as government regulations restrict

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quarry operations. As a result, natural materials are becoming ever more scarce and expensive. The consumption of high quality natural quarry materials in pavement building continues, however, to be the standard practice. If our goal, however, is to support an environmentally sustainable world, it makes more sense to use these valuable natural materials in structural concretes (high rise building, bridge, pre-stressed concrete structures, etc.), where high strength and good quality material are essential. Furthermore, utilizing materials that are already produced results in less energy and emission in total highway construction, resulting in a "Green Highway" *(A generic for a highway that is produced with minimum or even no harm to the environment in terms of protection of natural materials and reduction of greenhouse gas emissions).* Hence, fly ash has the potential of replacing classical road building materials when circumstances permit.

2. Structure of highways

In general, highways consist of two parts: the pavements and foundation. The pavements are engineering structures that separate the traffic loading (the tires of vehicles) from the foundation (which is usually natural soil, also called subgrade) of roads. Subgrades are generally weak materials and may not be able to bear the stresses induced by wheel loads. Therefore, pavements are needed to decrease the stress to a tolerable level in the subgrade. As an engineering structure, pavements should not fail during their design life. Unlike most civil engineering structures, pavement failure does not happen unexpectedly like the collapse of a bridge or building, but gradually deteriorates over time. That means that the emergence of cracks and the accumulation of plastic deformation up to an unallowable level are considered as design failures. This pavement failure eventually decreases or totally eliminates the function of the structure. Pavement design aims to prevent the failure of the pavement over its design life which is usually 20–30 years.

Regarding the design of fly ash pavements, mechanistic-empirical methods are preferred as empirical design methods are restricted to the range of classical pavement materials. In the mechanistic-empirical method, the stress induced by wheel loading is calculated in order to identify the mechanical responses in the structure (pavement analysis), usually by means of purpose built computer programs. The mechanical responses are basically deflections, stresses, strains and displacements. In order to perform a pavement analysis, the fundamental properties of the fly ash (along with other pavement materials used) should be measured. Stiffness is the most important fundamental property of a pavement materials and it is expressed by resilient modulus, which can be obtained by advanced laboratory tests explained below.

3. Properties of fly ash and stabilizing agents used in the study

The fly ash used in this study is a Class F [1] material with low calcium content (1.61%) and very low loss on ignition (LOI) of 1.28, which is related to the grinding method used to pulverize the coal in power station. Grain size distribution of the material was determined with a laser operated particle size analyzer as the hydrometer test is unsuitable due to its pozzolanic reactivity. A Horiba LA-500 analyzer was utilized by a professional laboratory and the results were presented. The fly ash was found to be smoothly graded, being the maximum and the minimum particle sizes were 174 and 0.15 μm. A total of 83% of the material is finer than 45 μm; therefore, it could be considered as a fine graded fly ash. The stabilizing agents, namely, cement and lime, were also tested to determine their particle size distribution. The maximum and the minimum particle sizes were 116 and 0.13 μm for cement, and 152 and 0.2 μm for lime.

As mentioned previously, fly ash should be stabilized to improve its performance when utilized in upper layers of pavements since stress and strains due to vehicle loadings are significant at the top layers of pavements. In addition, Class F ashes exhibit lower stiffness than Class C ashes due to their low calcium content. However, an uncommon application of 100% fly ash base with no additive or aggregate was attempted in 1988 at Fulshear, Texas, USA. After placement and compaction, the average compressive strength increased only 255 kPa, with between 7 days and 28 days of curing. Also, in four months time it was seen that the asphalt layer at the top became corrugated in some sections. The trial was considered to be a failure [2] and, henceforth, that kind of testing was not again attempted.

In our study, cement and lime were used separately to stabilize the fly ash. These were mixed as percentages by total weight (e.g. 10% lime or cement stabilized fly ash means that 10 g stabilizing agent was mixed with 90 g of fly ash). All of the stabilized samples that required curing before testing were wrapped in plastic bags and cured in a room with controlled humidity and temperature (23 °C and 50% humidity) until the test date.

4. Repeated load indirect tensile test of stabilized fly ash

The repeated load indirect tensile test is based on Frocht's equation [3] for the stress distribution due to a point load. The point load on a fictitious disk is extended to line loading to create a cylinder. In practice, the load is distributed over a loading strip. The strip reduces the vertical compressive stresses and prevents failure under the line load. The load results in a uniform tensile stress (along the vertical diametric plane) and a corresponding horizontal strain that is used to calculate the properties of the material tested. The test is carried out by repeated pulse loading the sample to determine resilient characteristics. According to Kennedy and Hudson [4,5], indirect tensile test can be used to evaluate all pavement materials including stabilized materials. The only exception is unbounded granular materials. Moreover, AUSTROADS [6] has ranked the method as the fourth preferred procedure for testing the resilient characteristics of stabilized materials. Since the test is relatively easy to conduct and sample preparation is easy as well, it was therefore decided to conduct an indirect tensile test to observe the variation of resilient modulus over time and the influence of stabilizing agent content. The Universal Materials Testing Apparatus (UMATTA) manufactured by Industrial Process Control Limited [7] was used. Samples having a diameter of 105 mm and a length of between 51.5 and 70.5 mm were compacted at optimum moisture content and maximum dry density. The lime or cement contents in the samples were 2%, 4%, 8% and 10%. The tests were carried out on samples cured for 7 days, 28 days, 180 days and 300 days. The testing procedure conforms to the ASTM D 4123-82 [8].

Initially, different loading forces up to 700 N (the maximum applicable force was 738 N) were applied to examine the variation in results. Discrepancies due to different load levels were insignificant and it was decided to apply 300 N of loading force throughout the entire test. Testing of samples at a constant tensile strain (constant strain test) was found to be inappropriate for stabilized fly ash, as some samples broke during the trial of constant strain. In the test, five consecutive loading forces having a pulse period of 3000 ms and a rise time of 30 ms were applied in the form of a triangular wave shape. Average modulus was calculated from the recoverable diametric strain. Each sample was then rotated 90° and the same procedure was repeated. The mean value of the average of the moduli at 0° and the average of the moduli at 90°