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Investigation on Industrial by-products as a Highway Material for Sustainable Development

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ABSTRACT

In roads and highway construction conventionally soil, stone aggregates, sand, bitumen, cement etc. are used in construction after enhancing its strength, stability and durability. Very large amount of soil and aggregates are required and they are also not available. So we started to use alternative materials. The researchers are also searching for various option materials for thruway development, and modern waste item is one such class. In continuation various industrial waste products are used and some enhancements are also done with those alternative materials. Stabilization method highlighted in this project mainly to enhance the inherent strength of wastes like fly ash and crushed blast furnace slag (cbfs). Fly ash and blast furnace slag was collected from Rourkela steel plant (rsp). The characteristics, strength properties of different mixes are determined. The strength parameters that are the unconfined compressive strength and California bearing ratio value for different mixes compacted were evaluated. Further these mixes are blended with lime varying as 0%, 2%, 4%, and 8% and the unconfined compressive strength values are determined after a curing period of 0, 7 and 28 days. Similarly, the soaked cbr values of lime stabilized mixes at 0%, 2%, 4%, and 8% are determined after a curing period of 0 and 28 days. The effects were studied with that combination. The mix with 80% slag shows higher value as compared to 100% slag in the mix. Further the desired strength required for different components of road can be achieved by stabilizing the mix with appropriate lime.

Key words : *Pondash, Flyash, Stability, Durability, Stabilization, California bearing ratio*

Introduction

Conventionally road pavements are constructed using soil, aggregates and binder. Aggregates form the major portion of the total volume of pavement structure and are the primary mineral material used in road construction. A high quantity of aggregates is consumed by the road-building program and similar quantities also used in maintenance works. It is estimated that construction of one cubic meter of Water Bound Macadam (WBM) involves the use of about 1.2 to 1.4 cubic meter of aggregates, and laying of bituminous pavements involve even higher quantities. The aggregate extraction from natural rocks results into a lot of noise, dust, impacting vibrations, hazards, etc.

From the beginning of the industrial revolution, the major issue in front of the industries is the disposal of industrial waste. Industrial wastes are generally harmful to health and have an environmental impact. Therefore, the disposal of these wastes also plays a role in the current scenario. The solution to the above problem is to use these industrial wastes to a maximum level for various purposes like road

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construction, highways and embankments. Moreover, by using these materials the environmental issues especially pollution can be reduced to a great extent.

Developmental studies and fruitful field exhibit ventures have demonstrated that industrial waste like fly ash, iron and steel industry slags, rice husk, marble slurry dust also can be utilized in roadway construction. While using such materials, the construction procedure would be broadly similar to highway constructions using conventional materials.

The geotechnical properties of fly ash and blast furnace slag were then evaluated by conducting various laboratory experiments such as Specific gravity test, Proctor test and dry density of fly ash-slag mixes. Lime stabilized samples were obtained for slag- fly ash mixes by enhancing the lime percentage (0%, 2%, 4%, and 8%). These stabilized samples were then subjected to unconfined compressive strength test following 0, 7 and 28 days of curing and California bearing ratio test for soaked and unsoaked conditions following 0 and 28 days of curing.

Introduction- Waste Products

Fly ash is a byproduct generated from thermal power plants. The main issue with fly ash is its disposal which possesses huge economic loss to the power plants. Thus, special consideration is required for the utilization of fly ash in highway, embankment constructions as a replacement to conventional natural materials. Blast furnace slag is formed as a co-product in the process of iron production. The utilization of blast furnace slag in geotechnical constructions needs a study. Lime is produced by calcination of limestone in a lime kiln at temperatures above 1000 °C.

An Overview of a Pavement Layer

The various layers in a pavement generally consist of sub-grade, sub-base course, base course, and surface course. The subgrade consists of existing soil, which should be clean and free from organic matter. Moreover, the CBR value should not be less than 25%. The sub-base course layer is made up of granular material and is an optional layer if the subgrade is of good quality. The CBR value for this layer lies between 20-30%. The base course lies just below the wearing course, hence the quality of the material used should be highlighted. The CBR values of this layer between 80-100 %. However, depending upon the expected traffic the strength of these layers may vary.

Industrial Waste Products: An Overview

The industrial waste can effectively replace the soil, stone aggregate which are non- replenishing source. **Table 1** shows the possible usage of industrial waste products in highway construction.

Fly Ash: An Overview

Fly ash is a fine structured and mainly consists of silica, alumina and iron. Fly ash when mixed with lime and water forms a cementitious compound. With this unique property fly ash can be used as a replacement to cement in various fields. According to ASTM C 618 (AASHTO M 295) Class F and Class C fly ashes are commonly used as pozzolanic admixtures. Class C materials are often high-calcium between 10-30% with carbon contents less than 2%. Fly ash has a scope to be used in roadway constructions, including pavement structural layers such as base/ sub- sub-base to have a longer lasting and sustainable infrastructure.

Fly Ash for Road Construction

Presently around 205 million tons of fly ash is pro-

Table 1. Possible usage of industrial waste products in highway construction

SI. No.	Waste product	Source	Possible usage
1	Fly ash	Thermal power station	Bulk fill, filler in bituminous mix
2	Blast furnace slag	Steel industry	Base/ Sub-base material, Binder in soil stabilization
3	Construction and Waste demolition	Construction industry	Base/Sub-base material, bulk-fill, recycling
4	Spent oil shale	Petrochemical industry	Bulk-fill
5	Cement kiln dust	Cement industry	Stabilization of base, binder in bituminous mix
6	Marble dust	Marble industry	Filler in bituminous mix

duced per annum. Thus the major challenge is to use this fly ash for roadway construction.

Design and Construction of Fly Ash Embankments

The design of fly ash embankments is similar to the design of soil embankments. Fly ash embankments of height up to 3 m can be constructed adopting a side slope of 1:1.5 (V:H). A flatter slope of 1:2 may be adopted at places where weak subsoil conditions exist or the embankment is constructed in flood-prone areas. Regardless of the height of the embankment, fly ash embankments should always be constructed with soil cover. For the construction of embankments of height more than 3 m, the design process for embankments involves the following steps:

- Site investigations.
- Characterization of materials.
- Detailed design.

In case of high embankment construction, the site investigations are carried out as per IRC:75. The design of the embankment is an iterative process. It involves developing conceptual plans, which satisfy site needs, design requirements on slope stability, bearing capacity, settlement and drainage.

Factors Affecting Properties of Fly Ash

The various properties of fly ash are a function of several variables such as Source of the coal used, Degree of pulverization of the coal, Boiler unit design, Loading and firing Condition, various storages and handling process.

Environmental Impact of Fly ash

The environmental impact of the fly ash can be listed below.

- Due to the construction of large ash disposal areas, there is a huge loss of agricultural production, land for grazing, habitat. Moreover, the design of these areas is inefficient in terms of economy.
- Due to the disposal of fly ash water sources are also get polluted. The pollution of the groundwater occurs mainly through contamination of groundwater from leachate and of surface water from discharge of fly ash effluent.
- The emission of dust from the fly ash also leads to air pollution.
- Failure of the earthen dam causes a threat to life.

Problem Using Fly Ash

Fly ash generally shows minimum strength under saturated condition. Moreover, the shear strength parameters, unit cohesion and angle of internal friction on ageing and degree of saturation.

Uses of Fly Ash

Fly ash can be used for numerous applications. Some of the application areas are the following:

- In landfill and as structural fill in retrieving low areas.
- In the manufacture of cement.
- For stabilizing the soil in various pavement layers.
- For brick manufacturing.
- As a replacement in mortar and concrete.

Blast Furnace Slag (Bfs): An Overview

Blast furnace slag (BFS) is formed as a co-product in the process of iron production. It primarily consists of silicates, alumino-silicates, and calcium-alumina-silicates.

Chemical and Mineralogical Composition of Blast Furnace Slag

Factors Affecting Properties of Blast Furnace Slag

The chemical and physical composition of a blast furnace slag is a function of numerous variables like Composition of iron ores and available flux stones and fuels. Proportions required for efficient furnace operations.

Uses of Blast Furnace Slag

Some of the relevant application areas are as follows:

- In road base and in structural fill.
- As railroad ballast.
- Primarily used in base courses, with trace amounts used in base stabilized with cement or lime-fly ash mixes.
- As aggregate in asphalt concrete.

Lime: An Overview

Lime in form of calcium oxide (CaO), commonly known as quicklime, is a white, caustic and alkaline crystalline solid at room temperature. Lime also contains magnesium oxide, silicon oxide and smaller amounts of aluminum oxide and iron oxide.

i. Production of Lime

Lime is produced by calcination of limestone in a lime kiln at temperatures above 1000 °C. First of all,

Table 2. Chemical Constituents in Blast Furnace Slag

Constituent	Weight percentage
Lime (CaO)	32 to 45
Magnesia (MgO)	5 to 15
Silica (SiO_2)	32 to 42
Alumina(Al_20_3)	7 to 16
Sulphur (S)	1 to 2
Iron Oxide (Fe_20_3)	0.1 to 1.5
Manganese Oxide (MnO)	0.2 to 1

calcium carbonate ($CaCO_3$) is converted into calcium oxide (CaO) and carbon dioxide (CO_2). Active calcium oxide is highly reactive.

ii. Different forms of lime and usage

The various forms of lime which include quicklime, hydrated lime or lime slurry can be utilized to treat the soil. Quicklime is manufactured chemically from calcium carbonate to form calcium oxide. Hydrated lime is generally formed when quicklime chemically reacts with water. Lime can be used to treat a range of soil types which can be used alone or in combination with other materials. The properties of the soils will determine their degree of reactivity with lime and therefore the ultimate strength that the stabilized layers will develop.

Uses of Lime

Some of the relevant application areas are as follows:

- In soil stabilization for road, earthen dams. It is supplementary to low-quality soils to yield a working base and sub-base.
- Used to treat soils in order to develop their workability and load-bearing characteristics.
- Excellent choice for short term modification of soil properties includes a reduction in plasticity, moisture-holding capacity and improved stability.

Table 3. Minerals Constituents of air-cooled Blast Furnace Slag

Mineral	Formula
Akermanite	2CaO-MgO-2SiO2
Gehlenite	2CaO-Al2O3-SiO2
Wollastonite	CaO-SiO2
Dicalcium silicate	2CaO-SiO2
Merwinite	2CaO-Mgo-2SiO2
Anorthite	CaO-Al2O3-2SiO2
Monticellite	CaO-MgO-SiO2

Engineering Properties on Stabilized Flyash

Lav (2000) carried out an analysis considering the microstructural, chemical, mineralogical, and thermal properties of fly ash, to use as a pavement base material. For this work, the fly ash was stabilized separately for cement and lime. The effects of lime and cement stabilization were studied. The results obtained from the lime and cement stabilized samples showed that for both types of stabilizing agents the hydration products are the same that accounts for strength gain.

Pandian and Krishna (2002) made a study on the CBR behaviour of cement stabilized soil fly ash mixes and obtained the suitability for use as a road sub-base. The CBRs corresponding to the two optimum levels are 24.7% and 33% after 28 days of curing with 3% cement, which was significant for field application. A minimum CBR of 20% was recommended for use in the sub-base layer for road pavement. Hence in the present work the cement content has been restricted to 3%.

Fernandez *et al.* (2004) conducted a microscopic study on a set of fly ash samples which are activated by alkali and thermally cured. The morphology of fly ash particles was studied that can be applied to a physical life situation. The fly ash was thoroughly mixed with alkaline activators and the paste was allowed to solidify by curing. The results show that with time the degree of reaction is increasing continuously.

Lav *et al.* (2005) studied on the utilization of class F fly ash as a base material in road pavements. In this work only aggregate, fly ash and cement was used as the main motive is to use the waste material. In this study, cement content was varied (2%, 4%, 8%, 10%) to prepare samples. The test results obtained from the tests were then incorporated into the pavement study.

Ghosh and Subbarao (2006) investigated the suitability of lime/gypsum stabilized fly ash as a roadway material. In this study unconfined compressive strength, bearing ratio, tensile strength and slake durability test was conducted. The effect of lime content, gypsum content and curing period on the above characteristics was highlighted. From this study, it can be said that stabilized class F fly ash has the potential for providing a strong road base.

Bera *et al.* (2008) carried out an unconfined compressive strength test on both unreinforced fly ash and reinforced fly ash with jute geotextiles. The effect of degree of saturation, size of the sample, number of jute geotextile layers and age of the sample on UCS has been investigated.

Pal and Rajak (2015) investigated the CBR values of soil mixed with fly ash and lime in different percentages. The soil was mixed with lime at 5%, 8%, 10% and 12% and with fly ash at 10%, 20%, 30% and 40% to enhance its CBR values. The optimum water content increases and dry density decreases with an increase in fly ash and lime percentage. The addition of fly ash and lime enhanced the Un-soaked CBR value of the soil.

Engineering Properties on Stabilized Slag

Behiry (2012) evaluated the effect of quality of steel slag on mechanical properties of mixes with crushed limestone aggregates, which was used as a sub-base material. The results show that increasing the steel slag percentage to the limestone in the blended mix increases the mechanical properties such as maximum dry density, California Bearing Ratio and resilient modulus. The best density and strength for the layer with the least construction costs obtained at a blended mix of 70% steel slag percentage to 30%limestone.

Bhattacharyya (2012) made a study on the use of Blast Furnace Slag in the sub-base/base layer of pavement. The test was conducted for the suitability of slag in pavement layers. Various field studies of BFS layers after laying and after compaction were made analyzed. From the analysis, it was obtained that cumulative % retained decreases. It was concluded that the material was a very useful alternative of stone material in the GSB layer.

Sinha et al. (2013) focused on the geotechnical characteristics of slag design. The stability analysis of embankment, sub-grade and sub-base layers and suitability of slag in bituminous layers were highlighted. In this study the utilization of slag in a different layer of roads was carried out. From the study it was observed that slag can be used for embankment construction and for sub grade, but not suitable for bituminous layers.

Experimental Setup

The pavement to be constructed using fly ash should be assessed in terms of safety and stability. The industrial waste fly ash and blast furnace slag was collected from the Rourkela steel plant. Specific gravity, grain size distribution, compaction characteristics were performed for various fly ash- slag mixes. Lime stabilized samples of slag- fly ash mixes were prepared at an increasing percentage of 0%, 2%, 4% and 8%. Unconfined compressive strength was performed for the lime stabilized fly ash- slag mixes after 0, 7 and 28 days of curing. Similarly, the California bearing ratio test was conducted for soaked and un-soaked conditions after 0 and 28 days of curing.

Fly ash used in this study was collected from the Rourkela steel plant. Fly ash samples were dried at a temperature of around 105-110 °C. In order to separate the vegetative matter or some foreign matter, the fly ash was screened through a 2 mm sieve and then mixed thoroughly to bring homogeneity.

Physical Properties of Fly ash

Table 4 Physical properties of Fly ash

Properties	Value
Colour	Light grey
Specific gravity, G	2.44
Maximum dry density (g/cc)	1.36
OMC (%)	32.4
Shape	Rounded/sub-rounded
Uniformity coefficient, (Cu)	7.755
Coefficient of curvature, (Cc)	1.939
Plasticity Index	Non-plastic

Blast Furnace Slag (BFS)

The blast furnace slag was collected from the slag crusher unit of the Rourkela steel plant. The finer portion of the crusher unit that is portion passing through the 20mm sieve was collected traffic up to 2 million standard axles (MSA), the CBR value for sub-base course should be between 20-30 %, for a base course it lies between 80-100% and for subgrade course, the CBR value should not be less than 25%. The CBR value of un-stabilized fly ash – slag mixes ranges from 6 -30%, which will fail to satisfy the CBR requirement of different pavement layers. And the combination of fly ash and slag alone will also not be able to cope with the CBR requirement. Hence the CBR test of lime stabilized slag- fly ash mixes were conducted. It is seen that CBR value ranges from 6- 278.8% for fly ash- slag mixes stabilized with lime. But depending upon the traffic load and pavement layer, particular fly ash- slag mixes stabilized with lime is designed which can be successfully utilized in base and sub-base courses of highway pavement. The desired lime stabilized fly ash- slag mix will be a promising material in reducing the use of natural soil, in addition, to mitigate the disposal problems of industrial solid wastes in a greater way.

Conclusion

- Fly ash is mostly well-graded material within its size range having a specific gravity lower than that of slag. The low specific gravity of fly ash is because of the presence of cenospheres.
- The addition of blast furnace slag to fly ash- slag mixes increases the MDD and decreases its OMC value linearly. This is since fly ash having more surface area and more fines are present, which require more water for lubrication and thus OMC values on increasing with the increase in fly ash content.
- The UCS value of the fly ash- slag mixes increases with the addition of slag. The mix with 80% slag shows a higher value as compared to 100% slag. Moreover, the UCS value is maximum for 8% lime in the fly ash - slag mixes subjected to 28 days of curing. This is because, in the presence of lime, the reaction is accelerated forming CSH gel responsible for strength in the mixture.
- The maximum strength observed at 0 days curing is about 235.38 kN/m^2 at a lime content of 8%. After 28 days of curing for the same slag – fly ash mix, the maximum UCS value is around 10 times higher than 0 days curing and the value is 2311.30 kN/m^2.
- The CBR value of the fly ash- slag mixes increase with the addition of slag. As that of UCS, a similar pattern was observed for CBR values, with 80 % slag the CBR values reported were higher having lime content 8% subjected to 28 days of curing. The increase of CBR values can be attributed to an increase in the mechanical strength of fly ash, slag mixes.
- The desired lime stabilized fly ash- slag mix will be a promising material in reducing the use of natural soil in addition to mitigating the disposal problems of industrial solid wastes in a greater way and can be successfully utilized in base and sub-base courses of highway pavement.

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