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Activation of Low Calcium Fly Ash with Cementitious Material for Utilization in Subbase Layer of Flexible Pavement

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ABSTRACT

Fly ash and ground granulated blast-furnace slag (GGBS) are by-products of thermal power plants and steel industries, respectively, which are produced in large quantities throughout the world. These materials frequently cause disposal issues as well as pollution of the environment. One of the most effective ways is the utilization of these waste materials in roadways after altering their geotechnical properties. Class F fly ash must be activated by cementitious materials such as lime, cement, and GGBS to achieve sufficient strength due to its lack of self-cementing properties. The goal of this research is to investigate the feasibility of fly ash amended with lime, cement, and GGBS as subbase material for road pavement. Extensive laboratory studies were carried out to determine the compaction properties, unconfined compressive strength, and CBR values of different fly ash-additives mixes. Based on the test results, it is found that fly ash stabilized with a minimum of 3% lime and 3% GGBS satisfies the criteria recommended by the Indian Road Congress for utilization in the subbase layer of flexible pavement. Additionally, a four-layer flexible pavement system was modelled using IIT PAVE to compute strains at the critical locations under standard axle loading. The service life and construction cost of the pavement with stabilized fly ash in the subbase layer was compared with that of conventional pavement. This study confirms that fly ash stabilized with lime and GGBS can be used in roadwork applications with significant economical and environmental benefits.

Keywords: Fly ash; Compressive strength; Service life ratio

1 INTRODUCTION

The socio-economic development of a country like India is dependent on roadways to a large extent. With the development of diverse road construction activities, there is a pressing need to reduce construction costs and improve the quality of pavements. This can be accomplished by utilizing certain industrial by-products, such as fly ash, ground granulated blast furnace slag (GGBS), and steel slag, which are commonly disposed of in landfills after being produced by steel production industries and thermal power plants. Furthermore, there is significant concern over the depletion of traditional materials, such as natural aggregates, which are widely used in road construction. As a result, substituting waste materials for natural resources would be beneficial for environmental stability (Pai et al., 2020). Keeping this in mind, various studies have been undertaken to utilize fly ash and GGBS for soil stabilization purposes and pavement construction.

(Wild et al., 1998) conducted laboratory tests to evaluate the strength development of expansive soils using GGBS in replacement of lime. (Mandal & Singh, 2007) intended to minimize the use of cement and lime by stabilizing soil with fly ash-GGBS admixtures. (Singh et al., 2012) conducted a thorough investigation of the feasibility of cement-stabilized fly ash-GGBS mixes for road embankments. The addition of such waste by-products increased CBR by 105 % which indicated that this mix satisfies the CBR criteria for use as highway subbase course. In a study by (Kumar Sharma & Sivapullaiah, 2012), researchers stabilized expansive soil using various proportions of GGBS, and the results showed an increase in UCS after 28 days of curing, proportional to the amount of GGBS mixed in to the soil. (Oormila T R & Preethi, 2014) evaluated the UCS and CBR of poor expansive soil with fly ash and GGBS amendments. Out of all the combinations evaluated, a 20% addition of GGBS resulted in the highest CBR value.

Apart from this, the bulk utilization of industrial waste materials to completely replace conventional subbase materials for pavement construction has also been demonstrated in previous studies. (Patel & Shahu, 2015; Shahu et al., 2013) tested the strength and stiffness of fly ash – dolime – copper slag mixes for use as a flexible pavement base course. Based on their UCS results, a base course consisting of 20% fly ash and 80% copper slag stabilized with 15% dolime was recommended. (Saravanan et al., 2017) demonstrated the improvement in load bearing capacity of sand and clay soils by the addition of lime-activated GGBS. According to (Sharma & Sivapullaiah, 2016), an appropriate mix of fly ash -GGBS mixtures can be used as construction materials or subgrade and sub-base courses in pavements without requiring substantial amounts of lime. (Neeraja, n.d.) inferred that the cost of the pavement layer was reduced by 21% with the use of waste materials like GGBS and fly ash compared to conventional materials.

Modeling of pavement design has been carried out in various research works to compute the strains at critical locations of pavement and to determine its service life. (A N, 2020) analyzed a flexible pavement design through IIT PAVE software to check for the specifications recommended by IRC: 37-2012 (IRC:37-2018, 2018) and compare the results with experimental data. (Sagar, 2017) designed a pavement using IIT PAVE and including cementitious and reclaimed asphalt materials in the design. (Gonawala et al., 2021) assessed the suitability of an EAF slag and GGBFS mix as a cementitious base/subbase layer for low-volume road construction. Using the IIT PAVE software, the strain values were also reported and found to be below the allowable limit. Nonetheless, attempts to use a mix of industrial wastes have been found to be limited in the field of pavements.

Thus, this study includes a laboratory investigation of fly ash, lime, and GGBS mixtures for the application of the subbase layer of road pavement along with modeling of four-layer flexible pavement using IIT PAVE to compute strains at the critical locations under standard axle loading.

2 MATERIALS AND METHODOLOGY

The additives used in this study were Class-F fly ash (F) and binders including 53 grade Ordinary Portland Cement (C), GGBS (G), and 90% pure commercial grade hydrated lime (L) and btained locally. 90% pure commercial-grade hydrated lime was used in this study. These additives were sieved through a 300-micron sieve and kept in an airtight container until required. Table 1 presents the properties of the industrial by-products and Table 2 presents the trial subbase material mix proportions (in percentage) and were selected based on literature review.

Table 1. *Physical Properties of industrial waste*

Property	Fly ash	GGBS
Color	Gray	Gray
Specific Gravity	2.33	2.38
Grain Size Distribution (%)		
Medium sand size (0.425-2.0mm)	--	4.4%
Fine sand size (0.075-0.425mm)	24.5%	38.4%
Silt size (less than 0.002mm0.075mm)	68.5%	54.2%
Clay size (<0.002mm)	7%	3%

Table 2. *Mix proportions (in percentages)*

Designation	Proportion
Mix 1	100F
Mix 2	93F+1L+6G
Mix 3	94F+3L+3G
Mix 4	94F+3C+3G
Mix 5	91F+3L+6G
Mix 6	91F+3C+6G

The raw fly ash was oven-dried at 105°C before blended with binders. The modified compaction curves of the fly ash-lime-GGBS/ fly ash-cement-GGBS mixes were determined using (2483 kJ/m3) heavy compaction energy according to the procedure specified by IS 2720 (Bureau of Indian Standards, 2015). The optimum moisture content (OMC) and maximum dry density (MDD) values are shown in Table 3.

Cylindrical specimen 50mm in diameter and 100mm in height were prepared at the OMC and MDD and cured for 7 and 28 days for the unconfined compressive strength tests (IS 2720-10-1991). These specimen were sheared at 1.25 mm/min axial strain until the sample failed, and the average value of three identical specimens tested was reported as the UCS value for the specified condition.

In the CBR test (IS: 2720-16- 1987) (BIS (Bureau of Indian Standards), 2015), both soaked and unsoaked conditions were tested in a rigid metallic cylindrical mold of 150 mm diameter and 175 mm high. Prior to testing, the soaked CBR specimen were soaked in water for four days. After the specified curing periods, the specimen were tested in a mechanical loading machine equipped with a movable base plate that provides a uniform strain rate of 1.2 mm/min. Stresses and strains in flexible pavements were calculated using the IIT PAVE stress analysis software. A flexible pavement was modeled using an elastic four-layer structure. Stresses and strains at critical locations were calculated using a linear layered elastic model.

3 RESULTS AND DISCUSSION

3.1 Compaction characteristics

Table 3 displays the compaction characteristics including maximum dry density and optimum moisture content of the mixes containing different percentages of fly ash, lime, GGBS, and cement. Due to the higher specific gravity of cement, the maximum dry unit weights of the fly ash-cement mixes were greater than those of the fly ash-lime mix. Furthermore, the higher the percentage of fines, the finer the mix, which increases the lime-blend mix's water-holding capacity and results in higher optimum moisture content.

Table 3. *Different proportions along with compaction characteristics*

	Mix Proportion by the percentage of Weight				**OMC (%)**	**MDD (gm/cc)**
	Fly Ash (%)	**Lime (%)**	**Cement (%)**	**GGBS (%)**		
Mix 1	100	0	0	0	1.34	19
Mix 2	93	1	0	6	1.37	18.9
Mix 3	94	3	0	3	1.38	18.9
Mix 4	94	3	3	0	1.4	18.5
Mix 5	91	3	0	6	1.4	18
Mix 6	91	3	6	0	1.42	18

Note*: OMC – Optimum moisture Content; MDD – Maximum Dry density

3.2 Unconfined compressive strength test

The minimum UCS value of the stabilized fly ash–lime mixture after 28 days of curing is1.5 MPa for use in the subbase layer of road pavement, according to IRC SP.20.2002 (IRC:SP:20, 2002). Table 4 shows the unconfined compressive strength values for different trial mixes at the curing period of 7 and 28 days. It is worth noting that when combined with lime and GGBS, fly ash demonstrated greater strength compared to mix 1. This indicates that mix 2- mix 6 satisfy the UCS criteria as per IRC SP.20.2002 (IRC:SP:20, 2002). The pozzolanic reaction was inhibited in the individual materials due to a lack of lime and silica. However, as the percentage of GGBS in the mixture increased, both materials provided sufficient lime and silica for the reaction and achieved relatively good strength. The main reason for an increase in UCS of various mixes is the formation of strong hydration products in the presence of cementitious materials.

Table 4. *Unconfined compressive strength and CBR values for the different trial mix.*

	Mix-1	**Mix-2**	**Mix-3**	**Mix-4**	**Mix-5**	**Mix-6**
UCS – 7 Days (MPa)	0.12	1.99	2.02	1.86	3.93	2.85
UCS – 28 Days (MPa)	0.15	4.35	3.37	2.95	5.04	4.06
CBR (%)	8.15	64.5	98	75	120	97

3.3 California bearing ratio test

The results presented in Table 5 show that the CBR value increases for fly ash-lime- GGBS and fly ash-cement-GGBS mixtures with GGBS partial replacement at 3% and 6%, respectively. For the fly ash-cement-GGBS mix, a 6% addition of GGBS increased the CBR value to 29.33% for the same cement content of 3% in both fly ash mixes. IRC 37(IRC:37-2018, 2018) establishes a minimum CBR value requirement of 30% for flexible pavement subbase courses. Fly ash stabilized with lime, cement, and GGBS at various percentages met the aforementioned criteria in this study.

3.4 Service life ratio (SLR) of stabilized material

Pavement SLR is an important tool for controlling the economics of pavement maintenance and rehabilitation. The horizontal tensile strain at the bottom of the bituminous layer (ε_{xx}) and vertical compressive strain on top of the subgrade (ε_{zz}) are both critical parameters in pavement design to limit bituminous layer fatigue failure and rutting failure of other unbound layers. The UCS value for stabilized cementitious material 94F+ 3L+ 3G after 28 days of curing was 3.38 MPa in our study, and the resilient modulus was 3380 MPa. As a result, 94F+ 3L+ 3G CTSB can be used in place of the traditional subbase material. As the calculated resilient modulus of fly ash stabilized with lime-GGBS is too high, 600 MPa is used for the analysis in accordance with IRC 37 (IRC:37-2018, 2018). In this study, 4% CBR of the subgrade is used for analysis, so the resilient modulus of the subgrade is 40MPa according to equation (a):

$$MR\ (MPa) = 10 * CBR \ldots \text{ for } CBR < 5 \ldots\ldots\ldots\ldots\ldots..(a)$$

The fatigue and rutting-based SLR equations were directly derived from the equations of the fatigue and rutting models given in IRC 37, 2018. The following is the fatigue and rutting SLR of pavement with fly ash-lime subbase in relation to GSB:

$$SLR\ Fatigue = (\varepsilon_{xx1} / \varepsilon_{xx2})^{3.89}$$

$$SLR\ rutting = (\varepsilon_{zz1} / \varepsilon_{zz2})^{4.5337}$$

Where ε_{zz1} and ε_{zz2} are the maximum vertical compressive strains developed on top of the subgrade. The calculated horizontal tensile (εt) and vertical compressive (εv) strain using the IIT PAVE software were found to be less than those of conventional pavement material after the modeling.

Table 6. *Parameters used for finite element analyses of flexible pavement*

PARAMETERS	E(MPa)	Poisson's Ratio	t(mm)
Subgrade	40	0.35	500
GSB	140	0.35	200
Stabilized subbase Material	600	0.35	330
WMM	150	0.35	250
DBM	3000	0.35	140
BC	3000	0.35	40

Table 7. *Service life ratio for subbase course of optimum mixes*

Material	Rutting Failure Criteria		Fatigue Failure Criteria	
	εv1or εv2 (micron)	**SLR**	**εt1 or εt2 (micron)**	**SLR**
GSB	138.2	1	271.6	1
94FA+3L+3G	93.67	4.54	137.9	21.84

*All values taken and calculated as per IRC37 (IRC:37-2018, 2018)

4 CONCLUSION

This study examines the use of industrial waste materials like fly ash and GGBS as an alternative to conventional natural aggregates as subbase layers in pavement construction. The following conclusions are drawn from the research work:

- It is concluded from the compaction results that the addition of cement in fly ash causes an increase in MDD and decreases the OMC value. There were no significant changes after adding GGBS to MDD and OMC values up to 12% GGBS.
- From the UCS results, it is observed that the combined effect with Lime-GGBS-fly ash demonstrated greater strength than either fly ash, lime, or GGBS alone.
- Mix 3 is the best subbase layer option for flexible pavement, according to UCS data, because they meet IRC requirements while being less expensive. In addition to this, the CBR value requirements of IRC 37-2018 are also met by Mix 3, making it best suitable for subbase layer.

According to the SLR results, the pavement with soil–binder subbase is more prone to rutting than fatigue. The horizontal tensile (t) and vertical compressive (v) strain calculated with the IIT PAVE software was found to be less than those of conventional pavement material. The study findings encourage the use of various composition pavement materials, which improves not only pavement life and performance but also economic considerations.

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